Configurations for Grounding Plane and Current Return use in Non-metallic Aircraft

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***Abstract* — This paper evaluates metallic grid solutions for aircraft with a composite fuselage to conduct the power return current, and to work as a voltage reference plane. Also, there is concern about the aircraft protection against lightning strikes, as composite tends to be more susceptible to direct effects damage than metal structures. Configurations of metallic current return structures are presented, and the analysis on them stands on the response of the structures to the injection of a standard lightning current, based on electromagnetic effects simulation software. The lightning strike current distribution pattern over the return structure is important for protection of inside installed equipment, and each proposed metallic grids for current return presents different response to lightning discharges.**

***Key words* — Current return, effects of lightning, composite material.**

I. INTRODUCTION

Nowadays, manufacturing technologies are well-known, and composite material is used in several parts of the conventional aircraft – and the trend points to gradual replacement of the aluminum by composite. But besides the manufacture, weight and stiffness advantages of the composite, disadvantages regarding to electrical characteristics are present.

Conventional aircraft made from aluminum, rarely suffer critical damages due to lightning strikes, given their excellent conductivity. This kind of structure has also provided good protection to aircraft susceptible systems and personnel, and very conductive structure, with almost no voltage drop for grounding and bonding the systems. However, current aircraft design has been considering the use of reinforced fibers which present high strength and lower weight, but a lot more electrical resistive than aluminum.

This paper evaluates metallic grid solutions for aircraft with a composite fuselage to conduct the power return current, originated from the power supply to electro-electronic loads and to act as voltage reference for protection, logic and control.

Also, there is concern about the aircraft protection against lightning strikes on a composite aircraft fuselage, as it tends to be more susceptible to direct effects damage than metal structures.

Metallic current return structures, inside a composite fuselage, are then presented, and the analysis on them stands on the response of the structures to the injection of a standard lightning current, based on electromagnetic effects simulation software.

In the occurrence of lightning strike, potential attach of lightning current to metallic structure inside the fuselage is considered, because of the more conductive characteristic of the metal.

The lightning strike current distribution pattern over the return structure is important for protection of inside installed equipment – related to both momentarily voltage rise on ground plane to grounded equipment and the induction of electromagnetic fields inside the cabin. These facts are directly associated to amplitude and time variation of the current on each point of the ground.

II. ELECTRICAL BONDING AND GROUNDING

One of the most important factors in the design and maintenance of aircraft electrical system is proper bonding and grounding. Inadequate bonding or grounding can lead to unreliable operation of systems, e.g., electromagnetic interference (EMI), electrostatic discharge damage to sensitive electronics, personnel shock hazard or damage from lightning strikes [1].

Several requirements are related to electrical bonding in aircraft; they intend to assure safe operation of aircraft systems, based on procedures for electrical bonding and grounding [1].

Electrical grounding is the process of electrically connect conductive objects to either a conductive structure or a conductive return path for the purpose of safely completing a normal or fault circuit.

Electrical bonding is a low-impedance path to aircraft structure, and it is required for electro-electronic equipment that produces or is susceptible to electromagnetic energy. It provides radio frequency return circuits and minimizes EMI. Electrical bonding to aircraft structure is also needed for all conducting objects placed on the exterior of the airframe, in order to conduct static charges and lightning strike currents and also conducting objects placed inside the aircraft to dissipate possible static charges [1].

Hence, electrical bonding and grounding are necessary in aircraft for:

- Bonding: lightning strike protection, static charges, electrical shock prevention, electromagnetic interference control.

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- Grounding: power current return, fault protection, potential reference for all circuits.

A. Definitions

1) Electrical bonding: Electrical bonding is required for lightning protection of aircraft and systems, to safely conduct the lightning currents through a low-impedance path. Damages caused by the impact of the lightning current are called direct effects of lightning (DEL). Discontinuities should not occur on the airframe where the lightning path is expected and electrical resistance of structure shall be minimized in order to control voltage rises of the ground plane caused by lightning currents to levels compatible to system protection design.

2) Electrostatic discharges: Electrostatic discharges (ESD) might be the cause of transitory or permanent damage to some systems, especially sensitive electronic circuits or based on semi-conductors or integrated circuitry. Personnel security is also important, as electric shocks shall be avoided. Adequate bonding of conducting surfaces should always be considered.

3) Electromagnetic protection: Shielding of conductors, electronic bays and equipment enclosures are often used to protect susceptible systems from electromagnetic fields caused by lightning – they are called indirect effects of lightning (IEL) – or other sources, as emissive equipment or high intensity radiated fields (HIRF). Bonding of the shields is an important factor to be assured, to prevent capacitive currents through the shields – they could affect other systems. The shielding is also considered for preventing lightning currents from entering the airframe through electric cabling of navigation lights, antennas, air data probes etc. Electric bonding of the shielding to the airframe allows the current to return to the structure, protecting internal systems.

4) Current return: Current return path is a very important part of the circuits, as other circuit leads. A requirement for proper ground connections is that they should maintain essentially constant ground impedance. They shall be designed for adequate current rating and voltage drop for proper operation of electrical and electronic equipment connected to them.

5) Voltage reference: Potential reference plane is necessary for the proper response of connecting systems from an input received. Besides, the fault protection and voltage regulation control of an electrical system based on grounded neutral requires a "common" point of ground.

In metallic aircraft, the compliance to bonding and grounding related requirements is accomplished with no effort, because of its high conductive characteristic. Systems, external mounted equipment, shielding etc. are easily electrically bonded to the aircraft structures.

However, if the structure is fabricated of a material such as carbon fiber composite (CFC), which has a higher resistance than aluminum or copper, it will be necessary to provide alternative ground path for ground return current. Materials with low-conductive characteristics should not be used in power return paths, because of voltage drop, resistive loss and damage to the material.

Additionally, if composite material is used, the inherent protection from direct and indirect effects of lightning provided by metallic fuselage is shortened, and systems inside will be more susceptible to lightning strike currents and electromagnetic fields.

III. NON-METALLIC AIRCRAFT NEEDS

The mechanical and manufacture advantages of the use of CFC in aircraft have been shortly presented. However, some characteristics of the composite material are not best for electrical conductivity of power return currents, protection from DEL, or attenuation of electromagnetic fields inside the airframe.

As a conductive path for lightning currents, the composite material by itself is not adequate, as the presence of high currents results in heating of the point of attach and possibly in irreversible damage to the CFC structure – entrance and exit points of the current shall be especially treated. Additionally, externally mounted cables, hydraulic lines and ventilation tubes are exposed to lightning current conduction, and aircraft systems might be affected by it. Therefore, CFC structures require external protection against lightning strikes.

Despite the attenuation ability of the CFC material, it is not the intent of a CFC fuselage to protect the systems inside airframe from electromagnetic fields originated from lightning strikes or other sources, as a metallic airframe naturally provides. Without the important shielding of metallic fuselage, electro-electronic systems will be more susceptible to electromagnetic hazards, and they shall follow a more restrictive spec regarding to susceptibility to radio-frequency.

For a return current, the low-conductive CFC material should not be used, in order to avoid voltage drop and power loss along the return path and heating of the grounding points. Its resistive characteristic may also prevent proper function of electrical system fault protection and voltage regulation.

This paper presents some configurations for alternative return path and potential reference for non-metallic airframes. They consist of metallic structure of cylindrical bars, placed inside a CFC fuselage. This structure shall be available for electrical bonding and grounding of internal systems and equipment enclosures, as a metallic fuselage would be. It shall also provide route for return current to generation system with very low impedance, and uniform current distribution, in order not to result in high voltage differences between distinct points in the return structure [2].

Referring to direct and indirect effects of lightning, the structure proposed for return path and potential reference is not at first intended to protect the airframe from them; some extra features shall be implemented for this purpose. However, the attachment of a lightning strike to this metallic structure inside a CFC fuselage is possible, considering that the CFC material electrical resistance is a lot higher than metal's – and the return structure will conduct major part of the lightning current. Therefore, the return paths proposed will be evaluated by attaching a full lightning current to them, as a conservative approach, and verifying how the current is distributed from the entrance to exit point in each configuration.

Although the composite frame and metallic mesh are capable of attenuating fields caused by IEL, they cannot replace a metallic fuselage, and their effect is not considered in this paper for simulation of resultant electric and magnetic fields. This last feature of verifying the resultant fields inside the airframe is very important to foresee the threat that the aircraft systems will be susceptible to during a strike.

IV. ENVIRONMENT AND MODEL DEVELOPMENT

In order to comply with requirements for a return path and potential reference plane for electrical system, four structures composed of metallic bars and rings are presented. Electrical current return structures shall comply with operational needs of electrical system and they are also evaluated regarding to DEL and IEL.

The proposed configurations response to lightning strike will be simulated on Microwave Studio (MWS), Computer Simulation Technology's (CST) electromagnetic field simulation software for high frequency range [3]. It provides a solid modeling and graphic feedback for electromagnetic analysis and design. The Finite Integration Technique is used, where Maxwell's equations on integral form are discretized in space and calculated.

A lightning strike current is injected to one discrete point forward at the return structure, and other point is chosen to be the output of the attachment, at a rear discrete point. The composite fuselage is not considered in the simulation.

The current waveform attached to the return structure is the component D of the lightning environment, according to [4]. The waveform was selected based on the zone of the aircraft that the ground and return plane is placed: center fuselage, which represents zone 2A, according to [5]. 2A zone is a direct impact zone, where secondary strike currents attach, as a sweep area, and hang on effect is not probable. On that zone, components B, C and D are used for lightning effects analyses according to [4], and component D was considered the most conservative waveform to assess current distribution as DEL and field induction as IEL, since it presents the highest peak value and highest derivative. The waveform is presented in Fig. 1.

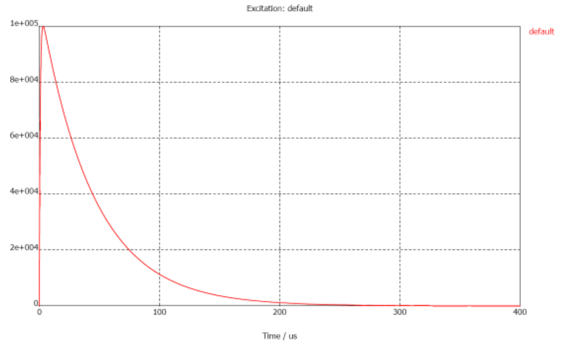


Fig. 1. Component D current waveform applied to the model.

V. GROUNDING PLANE AND CURRENT RETURN CONFIGURATIONS

Four configurations are proposed for current return, ground plane and voltage reference. They represent half of a center fuselage, composed of cylindrical bars, 20mm diameter. Bars are set along the half fuselage, connected by two or three rings also formed by 20mm diameter bars.

The metal structures are 8.2m long, 1.14m radius. D component current waveform is injected on discrete point at top forward, and exit discrete point is at rear bottom, as shown in Fig. 2.

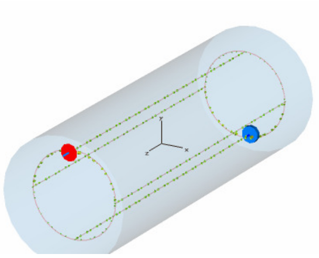
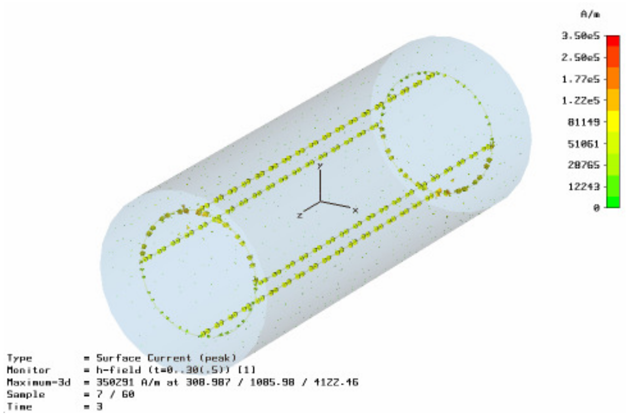


Fig. 2. Red area fwd represents current entrance point, while blue area at rear structure represents exit point.

The intent of the simulation is to evaluate the contribution of the bars and the connecting rings for current distribution and field attenuation inside.

A. *Direct Effects of Lightning*

Fig. 3 through Fig. 6 show the simulation results for surface current density ***j*** on each structure, represented by smaller or greater arrows.



```
Type         = Surface Current (peak)
Monitor      = h-field (t=0..30(.5)) [1]
Maximum-3d   = 350291 A/m at 308.987 / 1085.98 / 4122.46
Sample       = 7 / 60
Time         = 3
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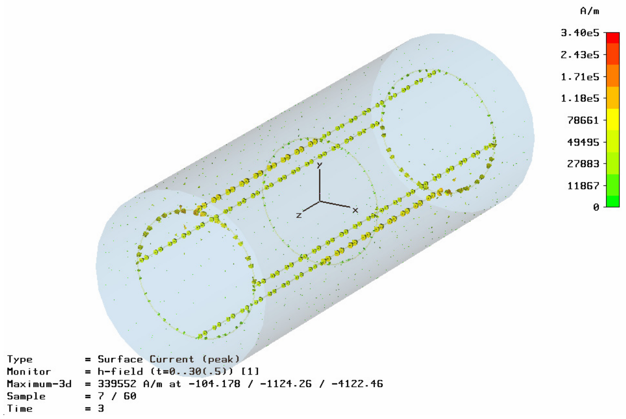
Fig. 3. Return structure I: four bars, two rings, aluminum.



```
Type         = Surface Current (peak)
Monitor      = h-field (t=0..30(.5)) [1]
Maximum-3d   = 339552 A/m at -104.178 / -1124.26 / -4122.46
Sample       = 7 / 60
Time         = 3
```

Fig. 4. Return structure II: four bars, three rings, aluminum.

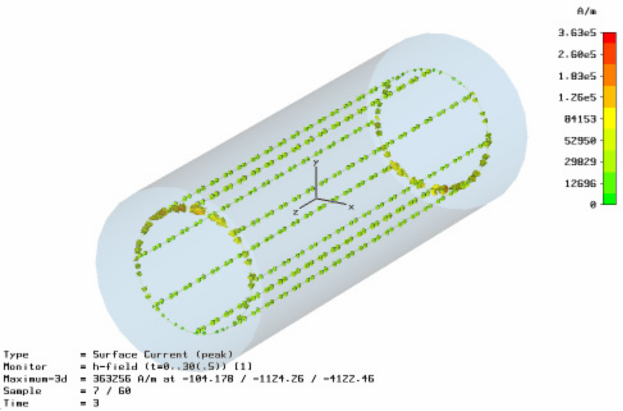


Fig. 5. Return current III: eight bars, two rings, aluminum.

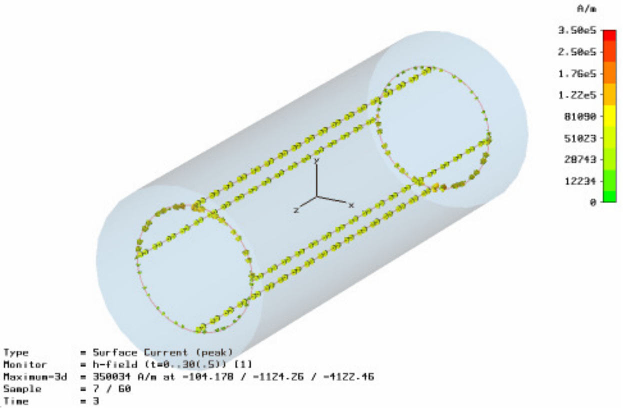


Fig. 6. Return structure IV: four bars, two rings, copper.

It is noted a homogeneous current distribution along return structures. When an intermediate ring is present, as in Fig. 4, it is noted that very short part of the current is drained by it, and most of it routes through the first ring, where the current has been injected.

Fig. 5 shows the third mode, where there are eight bars along the structure. With greater cross section, it is expected the better current distribution on the bars.

The last structure is made of copper, a more conductive material than aluminum. Despite the better electrically conductive characteristic, it was not observed differences in current density along the structure when comparing the aluminum and copper ones, mainly because of the high cross section used: low loss is verified on aluminum structure, so small difference is observed on these situations.

B. *Indirect Effects of Lightning*

Referring to the Indirect Effects of Lightning for systems placed inside the fuselage, they are also assessed on simulation. Fig. 7 to Fig. 10 represent magnetic field ***H*** of a section of each structure and environment inside, while Fig. 11 through Fig. 14 represent electric field ***E***.

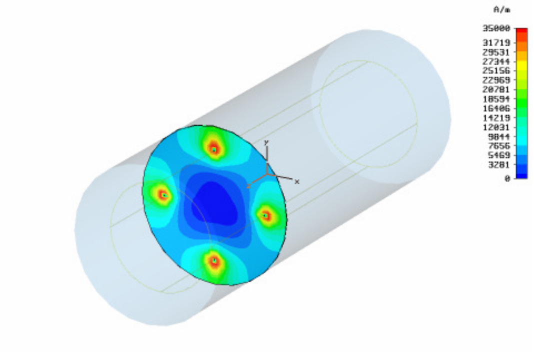


Fig. 7. *H* field environment inside the cabin for return structure I.

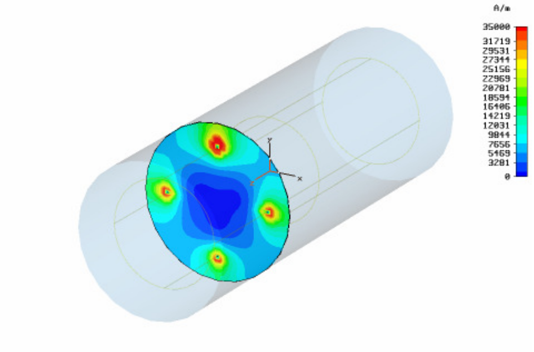


Fig. 8. *H* field environment inside the cabin for return structure II.

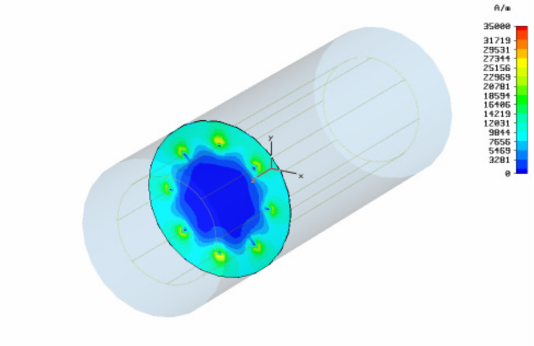


Fig. 9. *H* field environment inside the cabin for return structure III.

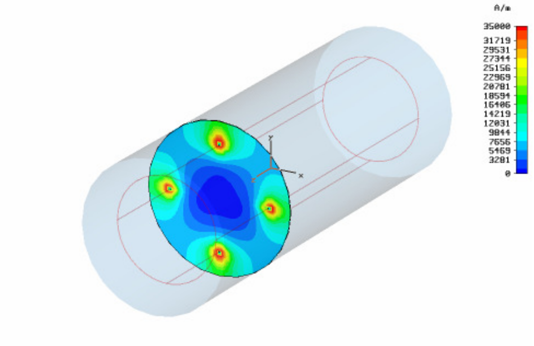


Fig. 10. *H* field environment inside the cabin for return structure IV.

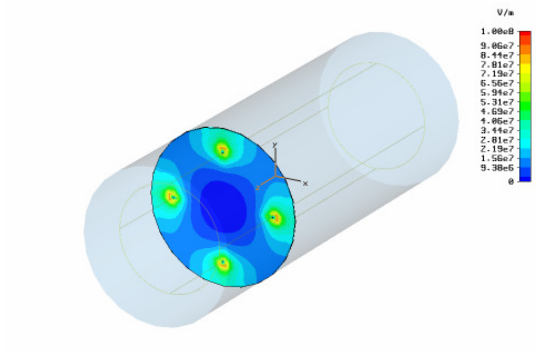


Fig. 11. *E* field environment inside the cabin for return structure I.

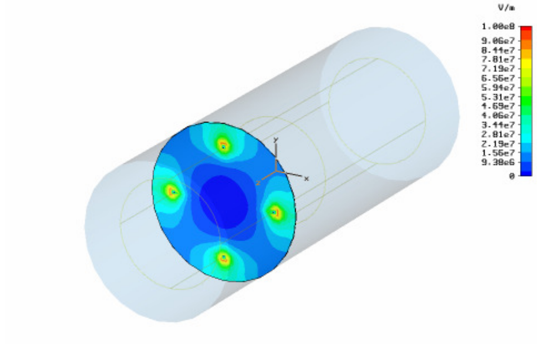


Fig. 12. *E* field environment inside the cabin for return structure II.

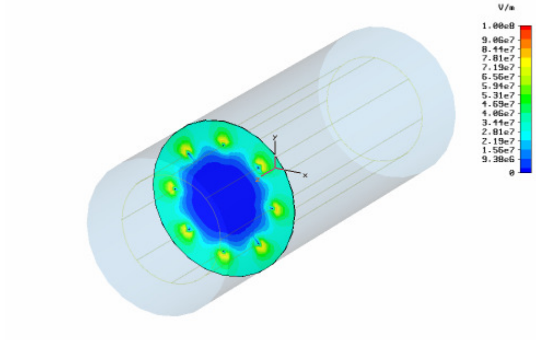


Fig. 13. *E* field environment inside the cabin for return structure III.

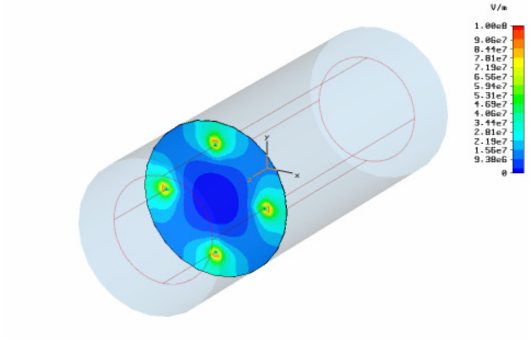


Fig. 14. *E* field environment inside the cabin for return structure IV.

It is observed that where the current is better distributed on the elements – at structure model III, represented on Fig. 5, Fig. 9 and Fig. 13, the electric and magnetic fields inside the fuselage are lower and more uniform – very important characteristics for installed systems inside the composite fuselage.

The differences between field distributions on structures I and IV along and in a section of them are minor. Structure with the ring joining the bars (Fig. 8 and Fig 12) presented the highest magnetic field on first half of upper bar and second half of lower bar, due to contribution of middle ring on inducted fields.

VI. CONCLUSION

By the simulation models, it is concluded that the more bars on the return structure, the more protected is the aircraft – both against DEL and IEL.

The ideal grid is to have as much bars as a whole metal fuselage; however, the weight requirements involve the use of as less metal as possible, without compromising electrical systems, DEL and IEL protection, and general grounding and bonding requirements. This quantitative analysis is to be performed in next works.

The middle joining ring of structure II is important for current distribution, especially if a strike occurs in bars between two rings [2].

Regarding to IEL, the best condition for systems is the one with more bars routing on fuselage length. In this case, design installation of equipment and wiring is easier to place because of the more uniform area inside the cabin.

In order to compare fields expected on a metal grid and fields expected on a metal fuselage, Fig. 15 shows electrical and magnetic field densities on a metal fuselage.

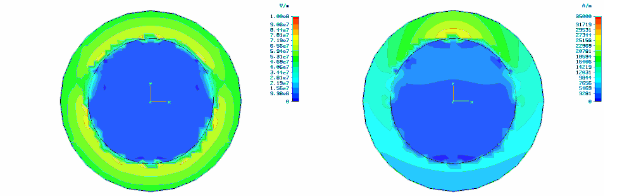


Fig. 15. *E* and *H* fields result of D component injection on a metal fuselage with windows, respectively.

Attenuation and uniformity of electromagnetic fields on the metal fuselage is notable when compared to the metal grid only. Composite material, when used on the surface will contribute for IEL protection of the interior, but not as much as the metal fuselage does.

The systems inside are qualified by industry to stand the HIRF and IEL threat environments attenuated by the aircraft structures. The composite structure use will imply in more robust – and more expensive – electro-electronic equipment.

A compromise between electrical and weight means shall be performed on metallic grid design for current return and potential reference. The number of bars is shown very important for both current density distribution and induced fields inside.

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