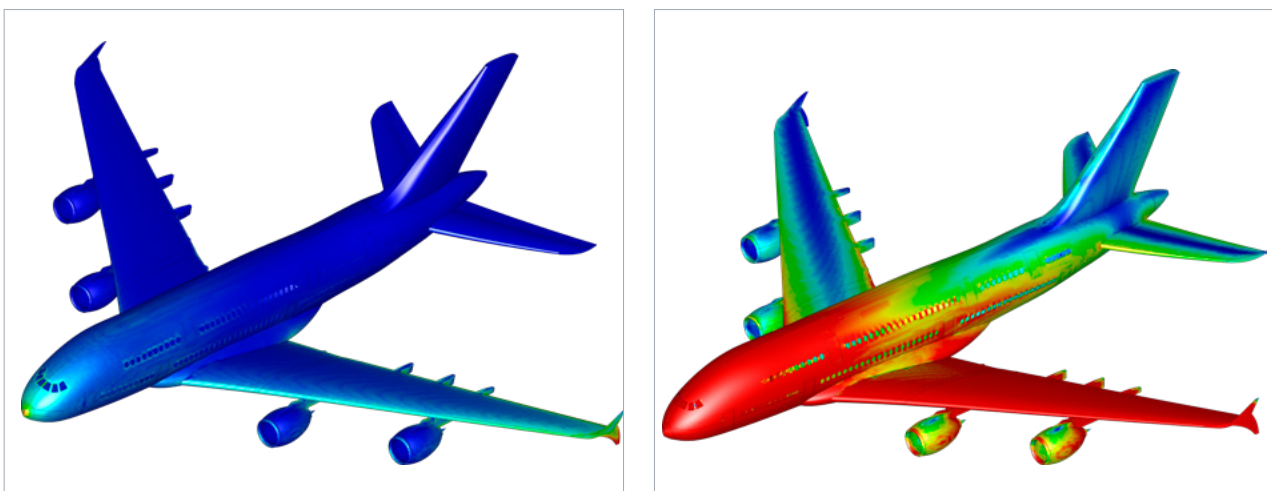


# SIMULATING LIGHTNING ATTACHMENT AND STRIKES ON AIRCRAFT WHITEPAPER

International authorities such as the European Aviation Safety Agency (EASA) and the Federal Aviation Administration (FAA) set the basic requirements for safe aircraft operation in electromagnetic environments, one example of which is lightning. Aircraft testing is used to demonstrate compliance with these regulations but unfortunately aircraft testing is expensive, time-consuming and only possible after a first prototype is built. To solve design issues at this stage of an aircraft development process could become very expensive as major design changes might be required.

To allow lightning testing to be performed earlier and more efficiently, scaled models are often used, but results of such tests have to be treated with care as the response of a scaled model to an electromagnetic field is in general different to that of a full-size aircraft<sup>[1]</sup>. Electromagnetic (EM) simulation offers an alternative approach for analyzing the susceptibility of aircraft to lightning and other electromagnetic environmental effects (E3). This article demonstrates how virtual EM aircraft testing can be performed with CST Studio Suite®, and how simulation can complement physical prototyping in the aerospace industry.



**Figure 1:** Surface power loss  $6\mu s$  after a lightning strike on an aluminium fuselage (left) and a composite material (right).

## THE PRINCIPLE OF VIRTUAL ELECTROMAGNETIC AIRCRAFT TESTING

There are three steps in the virtual EM aircraft testing process: pre-processing, EM simulation and post-processing<sup>[2]</sup>. These steps can all be performed in one common user interface in CST Studio Suite.

Pre-processing means preparing the model for simulation, taking the CAD data and assigning EM relevant properties such as material characteristics and the location of cable harnesses to produce a computational model. The simulation properties are also defined, including the EM sources and boundary conditions, as well as the mesh settings and any monitors and probes needed.

In the simulation step, EM solvers are used to calculate the fields around the device. Depending on the test, these may be high-frequency or low-frequency solvers, and can be chained together. Parameter sweeps allow multiple scenarios – for instance, different geometries or attachment points – to be analyzed in one simulation run.

The final stage, post-processing, sees the field results from the simulation converted into a format that can either be directly compared to measured data, or can undergo further analysis.

## CREATING THE VIRTUAL AIRCRAFT

The first step in creating the computational model is to import the CAD data. In this case, the aircraft model was supplied in IGES format. The cable geometries can then be imported separately or modeled in the software using the CST Cable Studio solver.

The choice of material is important for assessing the susceptibility of the aircraft. For conventional metals such as aluminium, an aircraft skin is still a good shield for the electric field at low frequencies but a poor one for the magnetic field<sup>[5]</sup>. However, manufacturers are increasingly turning to composites such as carbon-fiber reinforced polymer (CFRP), which has a layered structure consisting of several ply of carbon fiber woven in different directions. Compared to traditional metal skins, these have more complex frequency-dependent conduction and transmission characteristics and tend to provide less shielding to interior avionics (Figure 1). Composite materials can be efficiently modeled using thin panel material, which describe the electrical behavior of the layer stackup analytically.

Field probes and current monitors are essential to calculate the progression of the lightning strike at different points on the aircraft. Current monitors can be defined around the fuselage and wings, and they integrate all current passing through their surface. Field probes inside the aircraft are useful to characterize the field coupling into the aircraft, while probes outside are useful for detecting airframe resonances. Time-domain volumetric field monitors can be used to visualize the lightning strike in 3D.

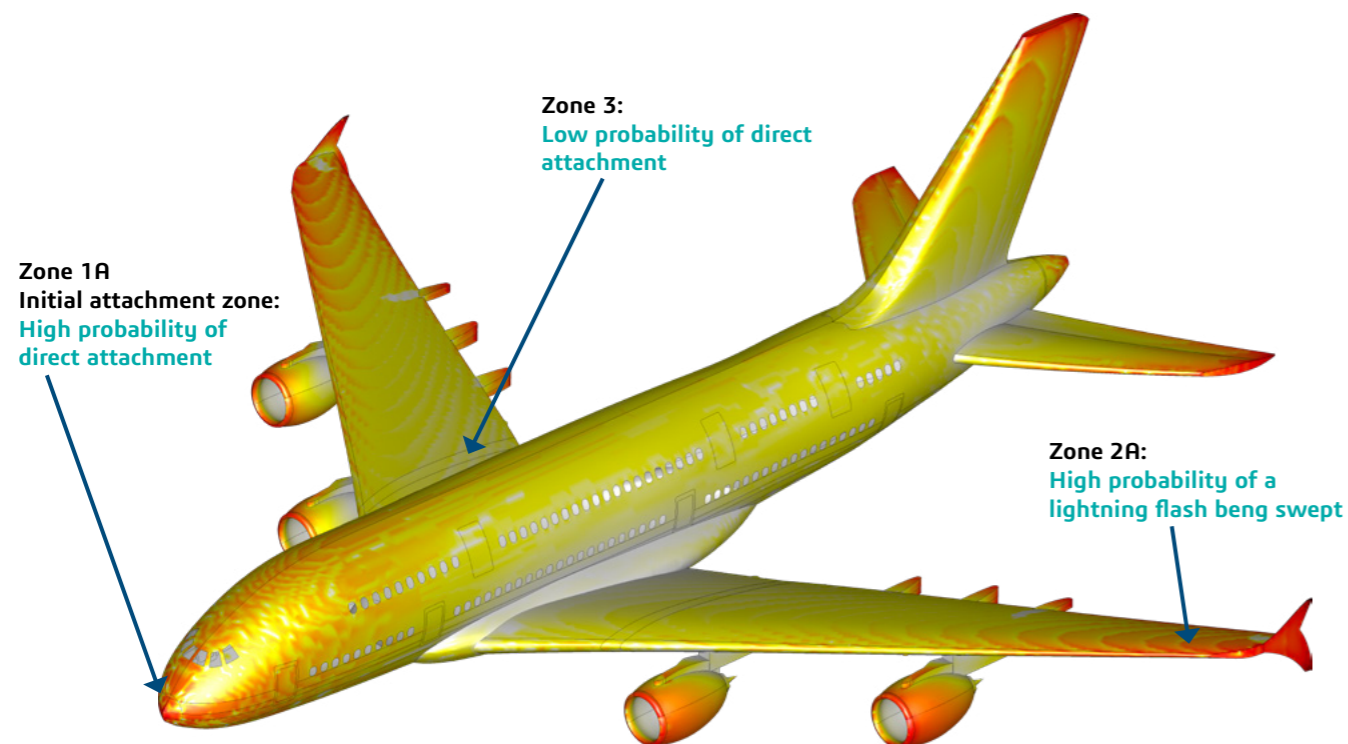


Figure 2: Lightning attachment zones according to SAE/EUROCAE, superimposed on an electrostatic field simulation.

## ZONING ANALYSIS

As explained in [3, 6, 8], lightning attachment to an aircraft generally starts at aircraft extremities with small curvature radii such as nose and wing tips (Figure 2). It's in these initial attachment zones of an aircraft that an ambient electrostatic field originating from thundercloud charges will be locally enhanced, enabling corona breakdowns<sup>[3]</sup>.

Electrostatic field simulations can be used to characterize the initial attachment zones of an aircraft. There are two approaches that can be taken – a boundary value problem (BVP) approach, where two boundaries of the simulation domain are assigned fixed potentials, and an initial value problem (IVP) approach, where a fixed potential is assigned to the skin of the aircraft.

It's well known that the electric field tends to be very large at aircraft extremities with a small curvature radius<sup>[7]</sup>. This field enhancement only depends on the three-dimensional shape of the aircraft extremity and not on the ambient field. Therefore it's sufficient to solve the IVP in Figure 3 with a fixed potential assigned to the aircraft skin in open space. This means that in general, the IVP is a more efficient approach, as all attachment zones can be found in one simulation run, while the BVP requires three simulations to consider ambient E-fields in the X, Y and Z directions.

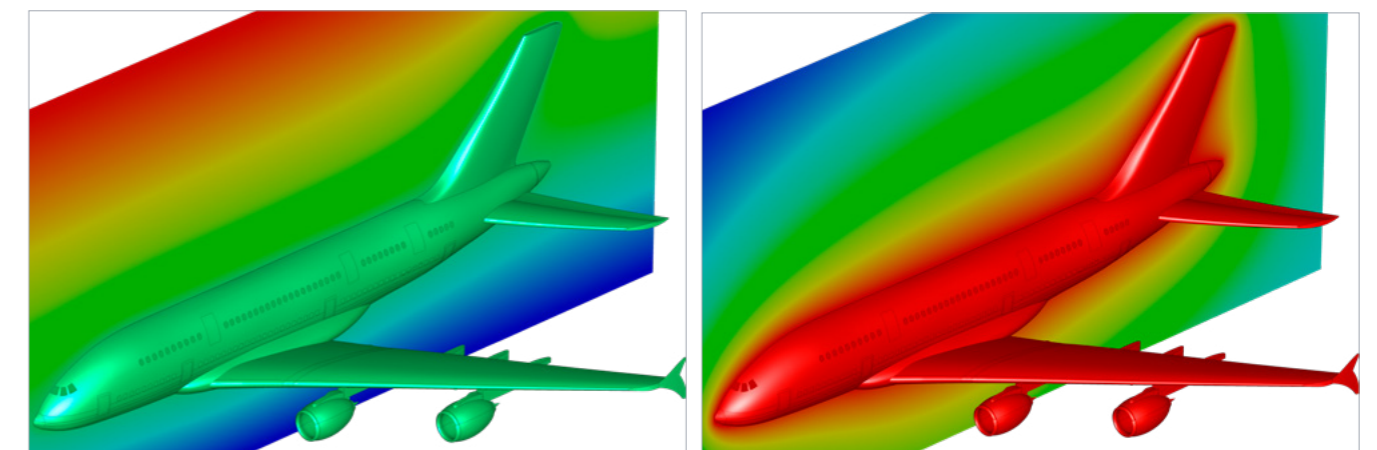


Figure 3: Electronic potential in a BVP (left) and an IVP (right).

## LIGHTNING EM PULSE SIMULATION

Once the attachment zones have been identified, the lightning strike itself can be analyzed. Lightning EM pulse (LEMP) simulations are best performed in time domain, and the Transmission Line Matrix (TLM) solver in CST Studio Suite is especially efficient for these scenarios. It offers octree meshing, conformal meshing, compact models such as vents and seams, thin panel materials (including layered materials for composites) and uni- and bi-directional coupling with the cable solver, CST Cable Studio.

As the frequency band of a lightning signal only extends to a few MHz, the smallest mesh size is defined by the smallest structural details of an aircraft. Therefore, avoiding structural details in the model not relevant from an electromagnetic point of view reduces simulation time. Otherwise, thin panel materials and compact models allow the consideration of geometrical details (e.g. multilayer laminates and seams) relevant for the EM response of an aircraft in an EM environment without resolving the structural details in the mesh.

A typical lightning pulse extends up to 0.5 ms, which is comparatively long for a transient EM simulation. However, the high-performance computing (HPC) options in CST Studio Suite, including multithreading, GPU, MPI cluster computing and cloud computing, allow large-scale lightning problems to be solved in a reasonable time frame.

The lightning channel is modeled as a wire, allowing the current to enter the aircraft at one attachment zone and leave at another. In the example shown here, the lightning channel sees the current injected into the left wing tip and leaving via the nose.

Carrying out two simulations, one with aluminium skin and one with CFC skin, shows that the aluminium offers much more effective shielding. For this reason, a wire mesh is typically used as an additional layer of the CFC. In case of the aluminium skin, the power loss is confined to the wing edges and the nose but, in case of the CFC skin, the power loss is distributed across the left wing and the front part of the fuselage where the current is flowing from the wing tip to the nose.

The power loss distribution can be exported to the thermal solver in CST Studio Suite to allow a multiphysics simulation. This can calculate how the skin of the aircraft heats up during the lightning strike, allowing the integrity of the materials to be checked.

The effect of cable shielding can also be assessed through the simulation. A cable trace is laid through the aircraft, and two simulations are performed – one with the cable shield bonded to the aircraft skin, and one in which the cable shield is left open at both ends.

As can be seen from the result in Figure 4, the wire current at a probe in the left wing is higher in the unshielded wire by a factor of about 6 after 50  $\mu\text{s}$  compared to the shielded case. This demonstrates the importance of a cable shield. Further coupled EM/cable simulations can be used to optimize the cable shielding in terms of shielding effectiveness, weight and cost.

## CONCLUSIONS

Virtual electromagnetic aircraft testing complements the testing of physical prototypes in the aircraft development and certification process. Advanced EM simulation technology, such as high-performance computing, thin panel materials and compact models, allows critical structures and materials to be simulated efficiently and helps engineers to handle the large multi-scale problem of lightning and other electromagnetic environmental effects on aircraft. In addition, 3D visualization of fields and currents offers a unique insight into the precise EM behavior of the aircraft body – one which is not available from measurements – and helps engineers to understand early in the design process how aircraft will react to lightning strikes.

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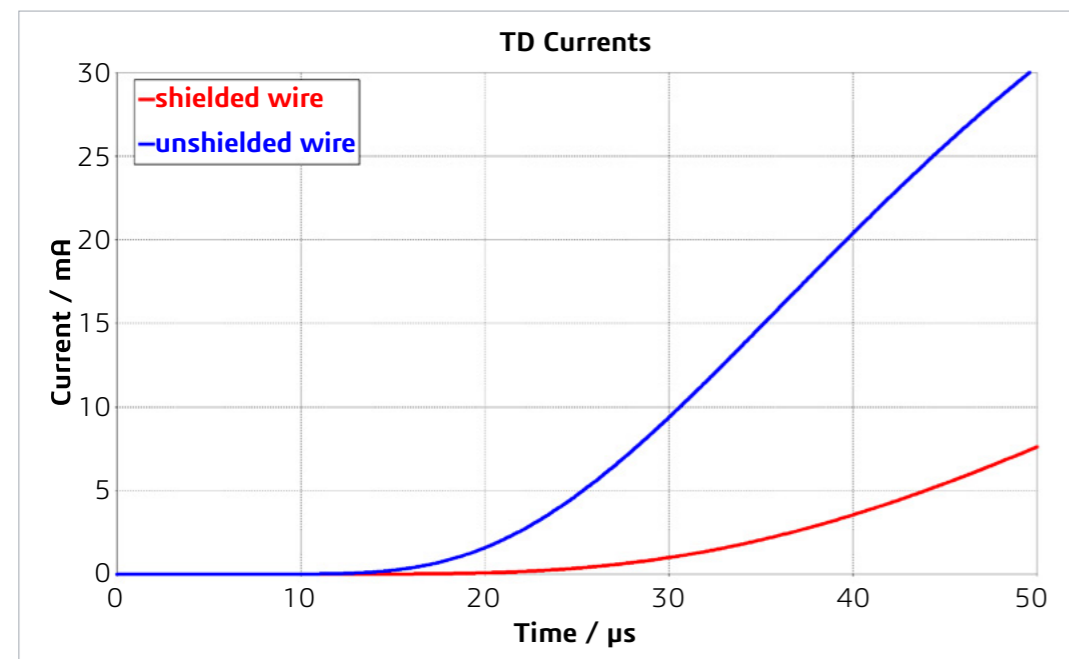
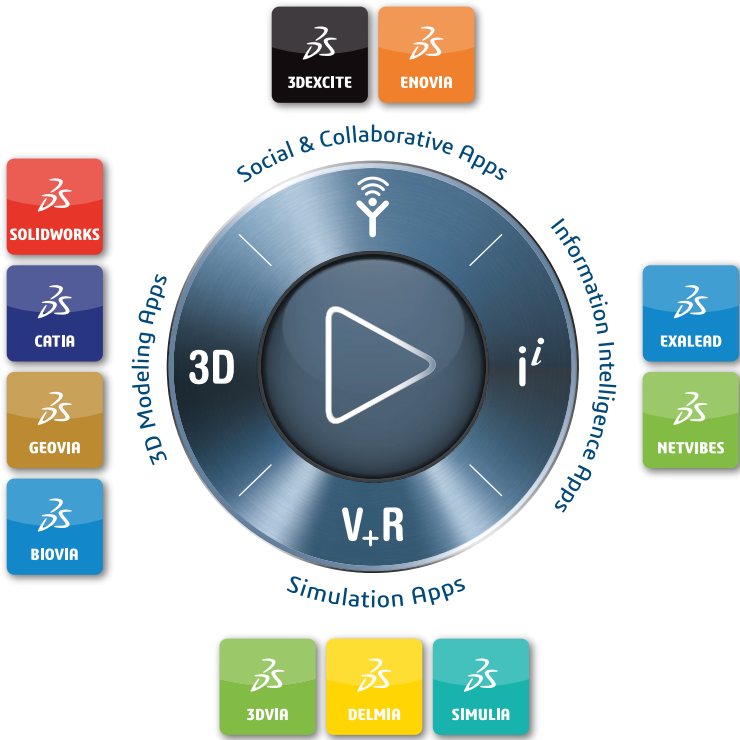


Figure 4: Time domain currents through the cable, for shielded and unshielded wire.



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