DIGITAL INDUSTRIES SOFTWARE

Aircraft electromagnetic compatibility

Using a digital twin to design and certify increasingly electrified aircraft for HIRF and IEL compliance

Executive summary

As aircraft become more electrified, there is a corresponding increase in design complexity and required levels of integration. In addition to impacting program cost and time-to-market, this also introduces greater safety challenges. High-intensity radiated fields (HIRF) and indirect effect of lightning (IEL) have the potential to be catastrophic for aircraft. A thorough understanding of HIRF and IEL from the design phase to the certification phase is key to preventing issues and guaranteeing a safe flight. This white paper looks at how simulation can make aircraft design faster and more efficient and provides a technical overview of HIRF and IEL, presenting engineering solutions to overcome them in the most effective way.

Contents

Introduction

Aeronautical platforms are operating in an increasingly complex and more severe electromagnetic environment. There are more external and internal radiating sources than ever before, including: higher power levels of wanted and unwanted emissions, extensive use of materials with reduced shielding effectiveness and electronic devices replacing mechanical and hydraulic flight controls. These electrical and electronic devices that perform safety-critical functions may be damaged by a lightning strike (IEL) or radiation (HIRF) as well as by general electromagnetic compatibility (EMC) issues.

For an engineer, it's key to understand the critical components as early as possible in the design cycle. These are classified as emitters (devices that emit electromagnetic noise through conduction or radiation), transfer paths (structures such as the electrical wire harness or fuselage that transmit electromagnetic noise throughout the entire system) or receptors (avionics systems, radar systems or sensors that are susceptible to electromagnetic interference).

By identifying potential problems early in the design phase, engineers can make better decisions sooner that will enable aircraft to meet regulations and ensure passenger safety.

To reduce expensive and time-consuming testing, aeronautical manufacturers are moving more toward a numerical modeling approach, using simulation to create a digital twin that allows them to address these issues before physical prototypes are built.

Siemens Digital Industries Software makes this possible with the Simcenter™ software portfolio of simulation solutions. Using Simcenter facilitates building a comprehensive twin that allows you to fully understand EMC effects such as IEL and HIRF on an aircraft and front-load the design of critical components in the product development lifecycle.

Simcenter is part of the Siemens Xcelerator portfolio, the comprehensive and integrated portfolio of software, hardware and services.

IDS, part of Fincantieri Group, is Siemens' strategic partner for software and services related to the applications covered in this white paper.

Lightning effects and regulations

When a lightning flash strikes an aircraft, the conduction of the electrical currents can have both direct and indirect effects.

Direct effects of lightning

Direct effects of lightning (DEL) refer to the physical damage to materials caused by thermal effects, spark and magnetic forces:

- Arcing between joints in poorly bonded structural components
- Bending and deformation of metallic components
- Melting or vaporization of cables and external expanded foil protective meshes
- Puncture of carbon ply skin and radomes
- Arcing and formation of hot spots within fuel tanks of fuel vapor zones

Indirect effects of lightning

Indirect effects of lightning refer to electromagnetic interference in electrical or electronic equipment, with a special interest about equipment that belongs to systems or subsystems that perform critical safety functions.

Aperture coupling, structural voltage drops, diffusion and "field-to-wire coupling" are the main physical mechanisms contributing to the interface between the external lightning environment and aircraft equipment.

Bundle current Ibc(t), short circuit currents Isc(t) and open circuit voltage Voc(t) transients at equipment pins level are the main parameters assumed by the certification normatives to verify aircraft robustness for IEL.

IEL certification is designed to demonstrate that equipment performing safety-critical functions can withstand transient current Isc(t), Ibc(t) and voltage Voc(t) levels induced by any possible lightning flash configuration striking the aircraft.

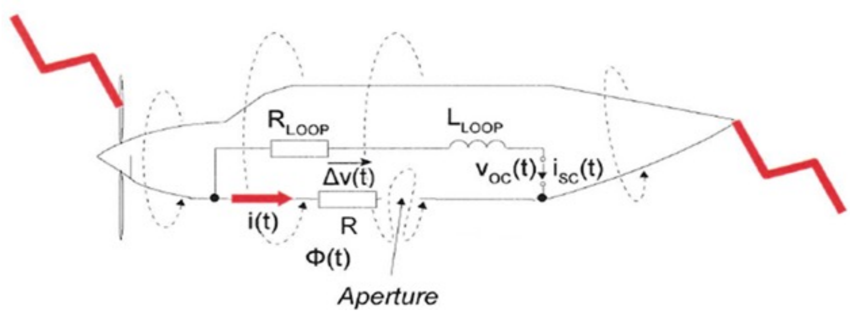

Figure 1. Physical mechanisms responsible for indirect effects of lightning on safety critical equipment.

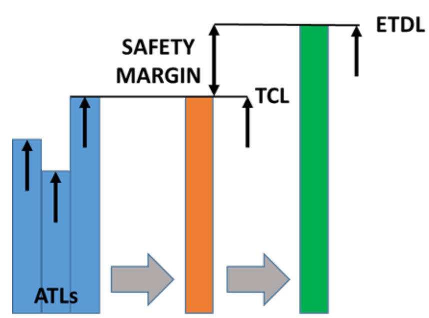

Figure 2. ATLs, TCL, ETDL and safety margin.

A workflow must be followed that proves the equipment transient design levels (ETDLs) exceed the maximum of the actual transient levels (ATLs) by a safety margin established in the certification plan agreed to with certification authorities.

Figure 3 shows the clearly defined route leading to full IEL certification compliance:

- IEL certification compliance: AC 20-136B, SAE ARP5415, STANAG AECTP 500
- Lightning environment and related test waveforms: SAE ARP 5412B, MIL-STD-464C, STANAG AECTP 250
- Aircraft lightning zoning identification procedure: SAE ARP5414B
- Equipment test methods: DO160G, MIL-STD-461G, STANAG AECTP 500
- Aircraft/system lightning test methods: SAE ARP5416A, STANAG AECTP 500

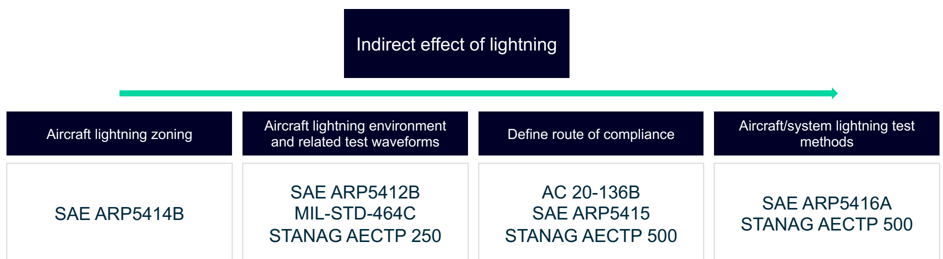

Figure 3. IEL regulations and route to certification compliance.

High-intensity radiated field effects and regulations

External electromagnetic radio frequency (RF) fields can penetrate an aircraft structure through specific points of entry (apertures, gaskets, materials with low-shielding effectiveness) and may couple with a cable harness or directly interfere with equipment.

HIRF immunity is the ability of the aircraft systems and equipment to correctly perform their functions in the presence of any electromagnetic environment generated from external RF sources such as radio, television or radar emitters.

RF currents induced in each cable bundle (Ibc) and RF electric fields (Ei) impinging on installed equipment are assumed by the certification to be as normative as the parameters to be controlled to ensure aircraft systems are immune from HIRF.

The ability of the airframe to attenuate the external RF fields (and therefore to reduce Ibc and Ei to sustainable levels) is related to the electromagnetic shielding properties of the structure:

- Capability of airframe structural material to reflect or absorb electromagnetic energy
- Dimensions and orientation of apertures and gaps in the structure
- Presence of bonding impedance among interconnected surfaces such as panels
- Secondary shielding of wiring and equipment

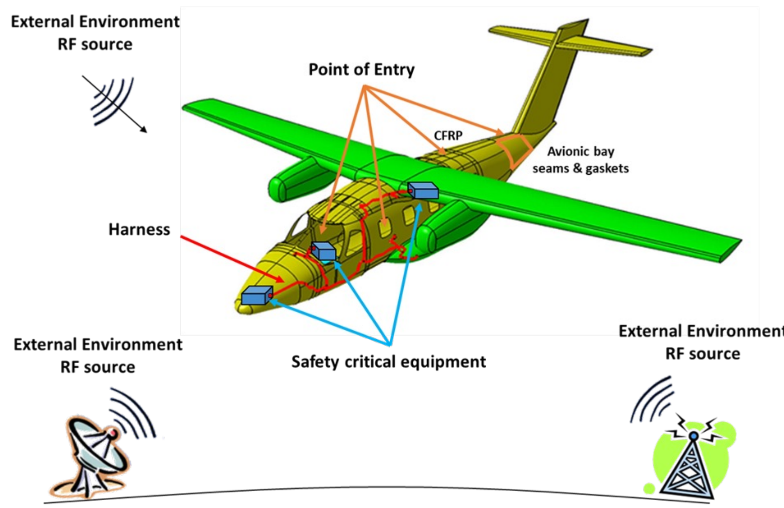

Figure 4. HIRF scenario.

HIRF certification is designed to demonstrate that equipment and systems performing safety-critical functions can withstand the internal electromagnetic environment (in terms of Ibc and Ei) induced by a given external electromagnetic environment.

Different verification approaches are defined in the certification normative, varying in terms of observables and frequency ranges:

- Low level direct drive (LLDD), applied from 10 kilohertz (kHz) to first airframe resonance, considering the transfer function of the currents induced on bundles (Ibc) by the currents excited on the airframe skin
- Low level swept current (LLSC), used from 500 kHz to 400 MHz, considering the transfer function of the currents induced on bundles (Ibc) by the external electromagnetic environment illuminating the aircraft
- Low level swept field (LLSF), applied from 100 MHz to 18 gigahertz (40 GHz), for the transfer function of the e-fields Ei induced in selected internal areas of the aircraft (for example, at safety critical equipment locations) considering the external electromagnetic environment illuminating the aircraft

Figure 5 shows the clearly defined route leading to full HIRF certification compliance:

- HIRF certification compliance (AC 20-158, ED107A/SAE ARP5583A, STANAG AECTP 500)
- External electromagnetic environment (AC 20-158, MIL-STD-464C, STANAG AECTP 250)
- Equipment test methods (DO160G, MIL-STD-461G, STANAG AECTP 500)
- Aircraft/system test methods (ED107A\SAE ARP, STANAG AECTP 500)

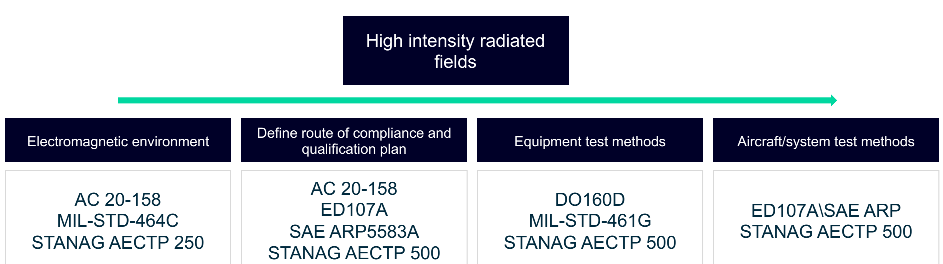

Figure 5. HIRF regulations and routes to certification compliance.

Using modeling to support HIRF and IEL design and certification

Certification authorities have recognized numerical analysis as an option to support IEL and HIRF compliance. Detailed guidelines for the use of analysis in the certification process have been included in regulations (HIRF: AC 20-158 and IEL: AC 20-136B).

A typical approach to this is:

- Build a high-fidelity simulation model of the aircraft
- Validate the model with a defined set of tests, providing a scientific foundation for the next certification phases
- Prepare and agree on a compliance analysis plan with certification authorities
- Execute the plan and provide a compliance report

Using a digital twin in this way has many benefits:

- It can also be used in design, from feasibility to detailed phase, thus sharing the costs and risks between design and certification
- It allows for the evaluation of HIRF and IEL problems before the creation of a physical prototype, reducing the risk of wasted time and resources
- Once validated, the digital twin can be used to manage the design and certification of updated configurations of the aircraft, reducing the time and cost of development
- It allows preliminary computation of physical parameters to drive testing at equipment and aircraft levels
- It enables full configuration control to be part of the certification documentation with traceability to official computer-aided design (CAD) drawings

Challenges in creating a high-quality digital twin

Wide frequency range of analysis
Simulations must be performed on a wide frequency range – from direct current (DC) to 10MHz for IEL and from 10KHz to 18/40GHz for HIRF.

Therefore, several physical regimes must be managed from simply conductive (DC), skin-effect, resonance regime, to high-frequency scattering. This requires a multi-method approach – full-wave, asymptotic and power balance modeling tools.

As very low frequencies need to be analyzed, common low-frequency breakdown and ill-conditioning problems must be addressed.

At high frequencies where the platform is electrically large the huge number of mesh elements requires efficient computation methods to reduce random access memory (RAM) usage and overall computational time.

High level of accuracy
Resistance and admittance values, especially at very low frequencies, can be of the order of a fraction of ohm. So, for the simulation to be effective, it must create an extremely accurate high-fidelity model. This means modeling small details (for instance, geometries that have dimensions on the order of a centimeter), bonding and grounding contact

resistances, apertures, seams and gaskets together with the entire aircraft structure.

As these elements do not have homogenous dimensions, it presents a multi-scale problem that poses significant challenges for CAD preprocessing capabilities (generation and management of meshes composed of millions of elements), management of numerical ill-conditioning and software and hardware acceleration methods (based on iterative solvers, preconditioners and parallel coding).

Additionally, materials must be accurately characterized (in terms of physical parameters like resistivity or equivalent parameters like transfer and surface impedance Zt, Zs) and managed to model both current conduction and electromagnetic field penetration.

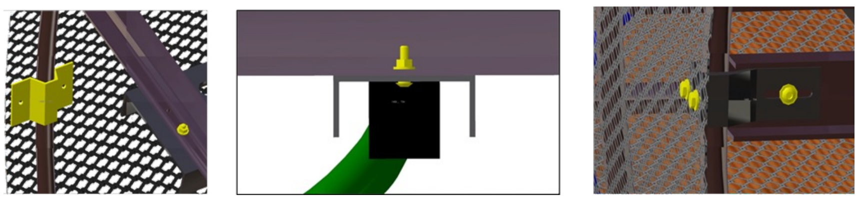

Figure 6. Examples of the level of detail to be properly managed to achieve the required accuracy.

Wide range of physical observables to be computed

Methods are required for computing observables such as bundle currents, electric field levels and Voc(t) and Isc(t) transients at equipment pins.

To facilitate this, a field-to-transmission line coupling approach is applied consisting of a hybrid 3D wave solver and a multiconductor transmission line network (MTLN) procedure. The full-wave solver resolves the 3D problem and evaluates the electromagnetic field along the cable harness pathways, while the MTLN tool resolves the field propagation along the cables, up to voltage and currents on terminal loads.

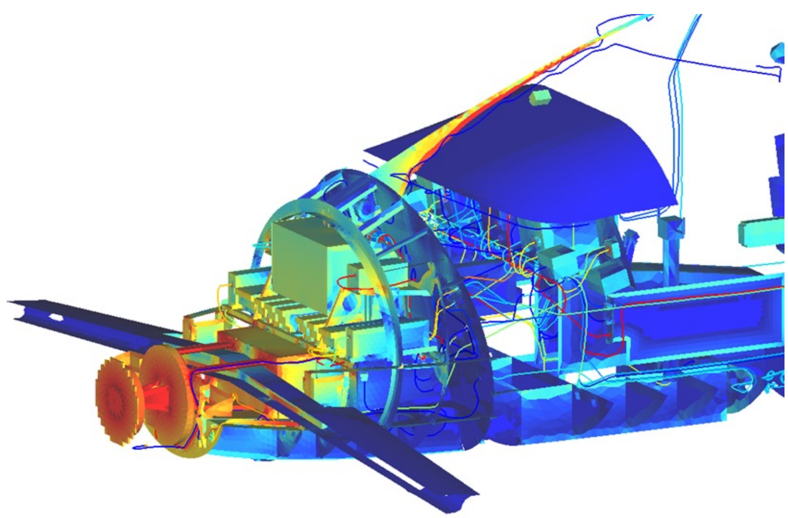

Figure 7. Currents induced by a lightning strike in internal parts and cables. (courtesy: HIRF-SE project)

How to create a high-quality digital twin

Simcenter offers predictive simulation and testing solutions to enable the creation of a digital twin.

CAD and meshing tools for high-fidelity modeling

Meshed models are directly derived from detailed CAD models, minimizing the need for simplifying electromagnetic analysis. This leads to rapidly and efficiently generating and managing multiscale meshes composed of millions of elements. The fundamental technology of Simcenter applied to this use case is based on boundary elements (the method of moments) and hence only requires surface meshes. This substantially reduces mesh sizes compared to other methods like the finite element method (FEM).

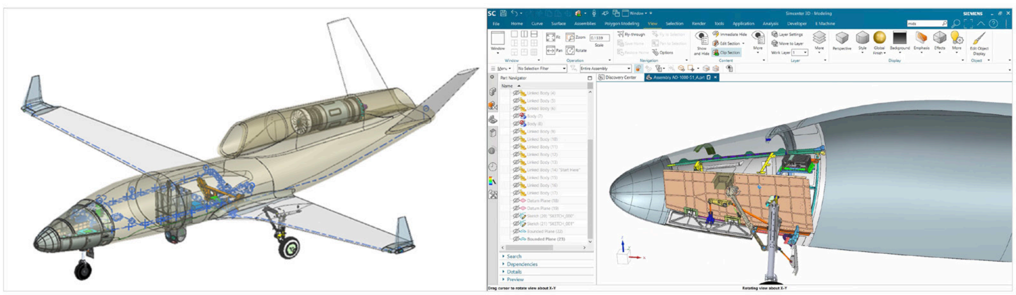

Figure 8. Efficient meshing from a complex CAD assembly.

Seamless and streamlined interface to electrical CAD tools

Using Simcenter enables you to automatically import cable harness models from electrical CAD tools such as Capital™ software, Siemens' harness engineering software. This includes harness architecture and 3D routing, bundle composition, cables cross-sections, cable jackets and braids, junctions, loading terminations and much more. They are then translated into models suitable for hybrid 3D electromagnetic MTLN simulation.

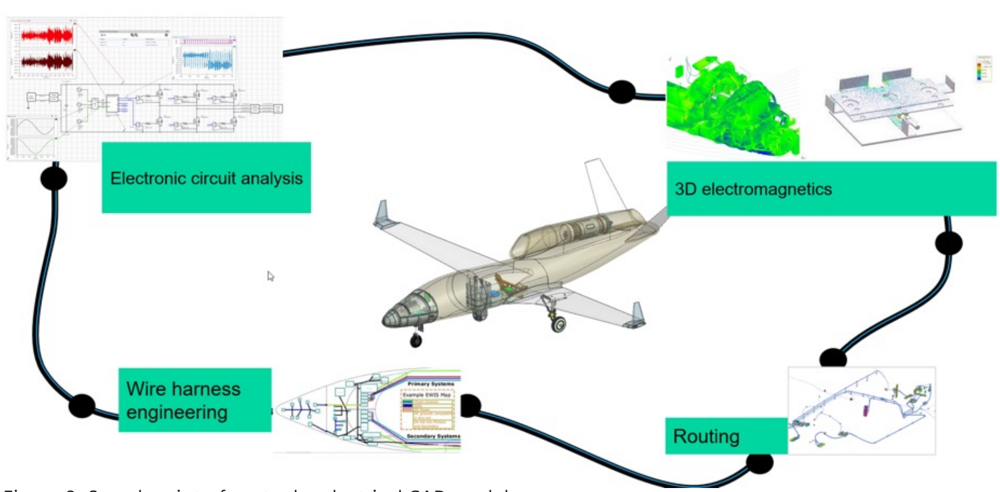

Figure 9. Seamless interface to the electrical CAD model.

Multiple modeling formulations for aeronautical materials

Typical aeronautical materials (metallic, composite, engineered) are managed with modeling formulations such as impedance boundary condition (IBC), thin sheet and neighboorhood impedance boundary condition (NIBC). Complexity is reduced by basing them on equivalent parameters such as shielding effectiveness for penetration problems, or surface impedance or transfer impedance for scattering/induced current problems.

Aircraft component modeling based on equivalent representations

Where detailed electrical and geometrical information is not yet available in the early stages of development (because of supplier proprietary data or because of a preliminary development phase when only the requirements of the components have been decided), components can be modeled based on the defined requirements and equivalent representations.

Mathematical formulations based on state-of-the-art algorithms

Complex mathematical formulations are required to eliminate low-frequency breakdown, carry out high-fidelity modeling and accurately represent the skin-effect while maintaining low-numerical complexity models.

Simcenter is used to manage this by employing a combination of state-of-the-art algorithms:

- **S-PEEC formulation** to extend the standard method of moments to very low frequencies (from MHz down to DC)
- **Multiresolution (MR) preconditioners** to analyze dense, multi-scale meshes (typical ill-conditioned problems)
- **Adaptive cross approximation (ACA) and multi-level fast multipole acceleration algorithms (MLFMAs)** to compress memory occupancy and computational time, suited to both low-frequency and high-frequency problems **(NlogN complexity)**
- **Field-to-wire coupling** hybrid procedure interfacing 3D full-wave methods to multi conductor transmission line network solver
- **Adaptive frequency sampling** algorithm to reduce the number of frequencies to be evaluated
- **Asymptotic algorithms (current-based and ray-based)** to overcome the limitations of full-wave methods in the very high-frequency range, also allowing evaluation of complex scattering phenomena like multiple-diffraction, creeping waves, etc.
- **Statistical methods (power-balance)** based on the oversized cavity theory for high frequencies "quasi-cavity problems" where deterministic simulation approaches are not effective

Application and validation examples

Below typical modeling applications and validation examples are shown with respect measurements, which come from acitivities performed by IDS, the strategic partner of Siemens Digital Industries Software.

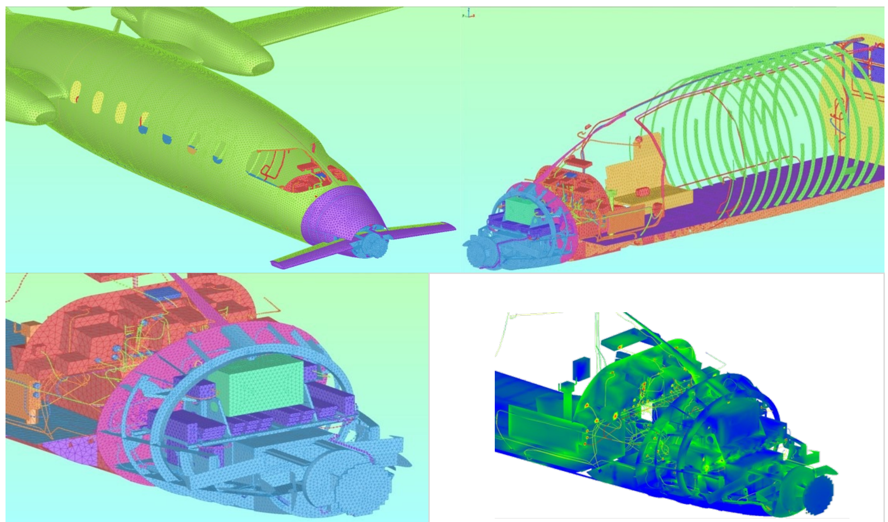

Figure 10. Modeling activities: external structure, internal structure, cables and equipment and induced current. (courtesy: HIRF-SE project)

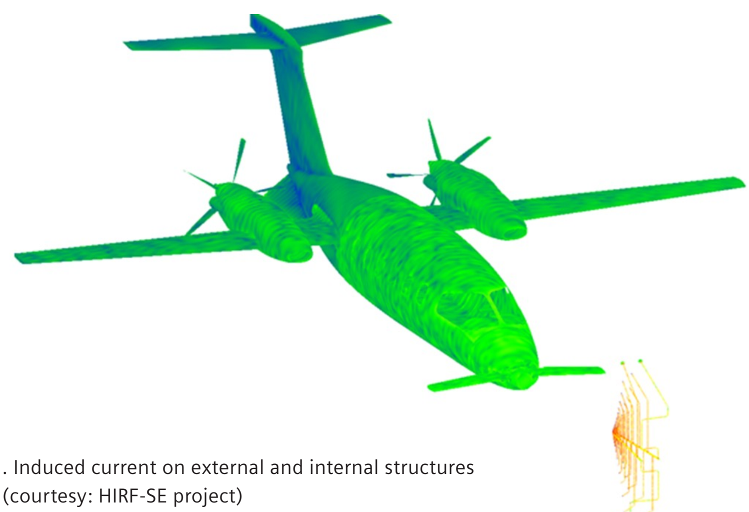

Figure 11. Induced current on external and internal structures at 1GHz. (courtesy: HIRF-SE project)

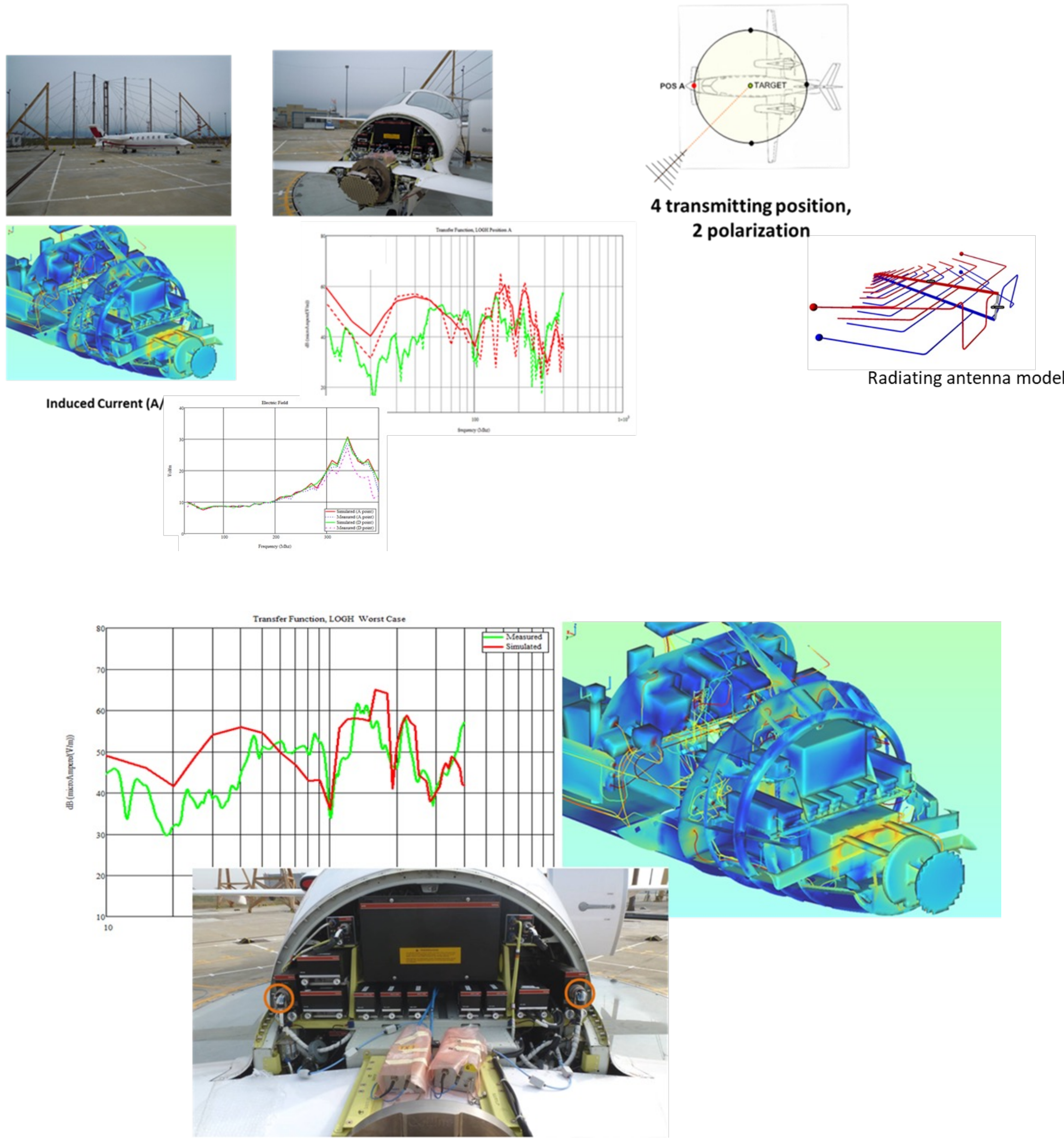

Figure 12. LLSC test, current transfer function measured versus simulated 10MHz to 400MHz.
(courtesy: HIRF-SE project)

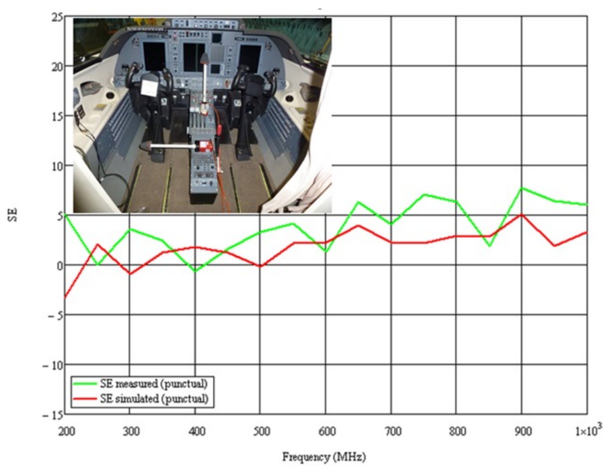

Figure 13. Cockpit SE measured versus simulated, 200 MHz to 1 GHz. (courtesy: HIRF-SE project)

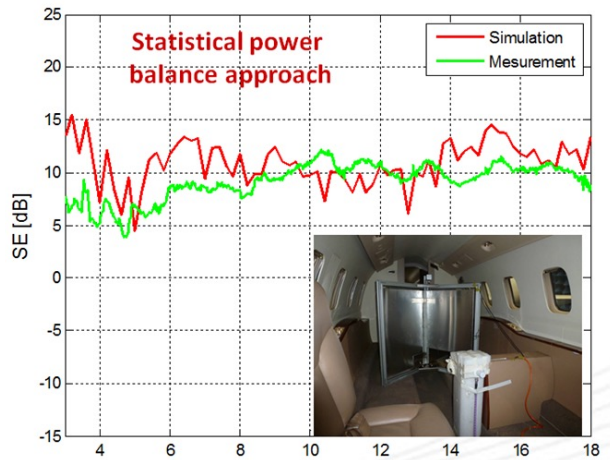

Figure 14. Cabin SE measured versus simulated, frequency band 3 GHz to 18 GHz. (courtesy: HIRF-SE project)

Conclusion

Aircraft electrification gives rise to new requirements for electromagnetic compatibility. Engineers need to implement robust, efficient processes for high-fidelity EMC analysis to deal with IEL and HIRF and ensure that aircraft achieve certification and guarantee passenger safety.

The Simcenter portfolio facilitates the creation of a digital twin through:

- Seamlessly integrated CAD and meshing tools for high-fidelity modeling
- Multiple modeling formulations for aeronautical materials
- Component modeling based on equivalent representations
- Mathematical formulations based on state-of-the-art algorithms

This allows full EMC analysis to be front-loaded in the design process, meaning critical design decisions can be made much earlier to ensure aircraft program execution excellence.

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