Chapter 1

Electromagnetic effects

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Abstract

This chapter provides an overview of the various electromagnetic effects design areas involved in design, test, and operation of vehicles and equipment built with composite materials. These design areas determine how well composite materials perform in electromagnetic energy fields and any indirect effects to any systems and equipment on or within. Specifically, the focus will be on the effects that the use of composite materials has on the various electromagnetic effects design areas. The various material properties that contribute to the effects will be addressed from the standpoint of quantification early in a design phase through testing and analysis, design/mitigation choices, and current material and mitigation trends related to these properties. The terminology in this chapter relates the application to aircraft. However, the concepts are also directly applicable to any other complete systems, such as wind turbines and buildings. Note that many of these design areas are interrelated. Be sure to consider all the design areas and their effects in order to get a system-wide view of the interactions.

1.1 Major design areas for electromagnetic effects

The name *electromagnetic effects* (EME) is typically used to describe all the *design areas* related to electromagnetic effects on an aircraft. The use of the acronym EME, as well as others such as EMC and EMI, varies somewhat across the industry. The uses of the terms in this chapter are the most common forms.

For the purpose of this chapter, the following major design areas of EME will be considered. The specific definitions of these terms follow.

- Electromagnetic compatibility (EMC)

- Electromagnetic interference (EMI)
- Electrical bonding and grounding
- Direct effects of lightning (DEL)
- Indirect effects of lightning (IEL)
- Precipitation static (P-Static)
- High intensity radiated field (HIRF)
- Power distribution
- Electrostatic discharge (ESD)
- Nuclear electromagnetic pulse (NEMP)
- Atmospheric radiation
- Antenna performance

1.1.1 Electromagnetic compatibility

The term EMC is typically used to describe a test on a complete aircraft, where one system is operated (as a source) to see if it interferes with the operation of a second system (the victim). This type of testing is called *source/victim testing*.

This testing is usually done on the completed aircraft, near the end of a program. Discovering problems at this stage is costly. Consequently, bench levels testing as well as vehicle level analysis are done earlier in the program in order to reduce the risk.

1.1.2 Electromagnetic interference

The term EMI refers to bench level testing of components or systems. This typically falls into these broad categories:

- Emissions:
  - Conducted (on wiring)
  - Radiated (electromagnetic fields)
- Susceptibility:
  - Conducted (on wiring)
  - Radiated (electromagnetic fields)

Setting emissions and susceptibility requirements so that there is a safety margin between them helps ensure there are no EMC issues at the aircraft level. These bench-level EMI tests are currently the primary area of defense against EMC related issues. The EMC test is usually used as a secondary/cursory check for system level verification.

These bench-level tests are also typically the final means of showing performance related to the *indirect effects of lightning* (IEL). Full-threat IEL testing is seldom done on a complete aircraft.

1.1.3 Electrical bonding and grounding

Electrical bonding and grounding are similar but not the same.

Grounding is connection of a circuit to a common reference point, typically assumed to be zero volts. This common reference is typically the aircraft primary structure, and is called *ground*. Ground is typically used as a power return for electrical power, and sometimes used as a zero-voltage reference for signals.

Bonding is making good, low impedance electrical contact between two conductors. This connection can be to ground, or can be between any two conductors.

In the existing design methods used for systems, both of these items are very important for the control of EMI/EMC. Two very important aspects in electrical bonding include eliminating non-conductive materials from the contact areas, and long term prevention of corrosion in the contact area.

1.1.4 Direct effects of lightning

When a lightning strike attaches directly to an aircraft, the point of attachment experiences extremely high currents and voltages. The energy involved can cause a number of physical/thermal effects:

- Melting
- Blasting
- Burning
- Holes
- Dents
- Magnetic pinching
- Sparks
- Exploding wires
- Welding

These effects are called *direct effects of lightning* (DEL) (see Chapter 2 for more details). Some secondary effects can include ignition of fuels, jammed control surfaces, structural degradation, etc.

Usually, DEL can be distinguished from *indirect effects* by assuming that anything that addresses voltages and currents on wiring is considered indirect effects. However, in the cases where lightning attaches directly to a wire on the exterior of the aircraft, or an arc-over to a wire occurs inside an external antenna/probe/light, it is usually considered direct effects.

1.1.5 Indirect effects of lightning

When a lightning strike attaches directly to an aircraft, the high currents and voltages involved and the rapid rise times generate large magnetic fields (H-fields), electric fields (E-fields), as well as currents and voltages on the structure. All these can induce voltages and currents on internal wiring, which in turn appear at the connected systems/equipment. These are called *indirect effects of lightning* (IEL).

The E-fields and H-fields can penetrate into the interior of the aircraft and induce voltages and currents on aircraft wiring, which is then seen by the equipment attached to the wiring.

The currents on structure and internal conductors can also generate H-fields that couple onto wiring. The current flowing through the resistance of the aircraft structure can also result in voltages ($V = I\ R$) seen on the structure/ground. Since *ground* is then no longer *zero* volts, the equipment grounded to the structure can be affected.

1.1.6 Precipitation static

When two items rub together, they can transfer charge to each other by *rubbing off electrons*. This is what happens when you drag your feet in carpet on a cold or dry day and you get a spark. An aircraft charges in the same way when it flies through any liquid or solid particles (rain, haze, snow, ice, sand, dust, etc.). The particles rubbing on the aircraft transfer electrons between the particles and the aircraft. This effect is called P-static. Another name for it is triboelectric charging. Without proper design, the aircraft can charge to hundreds of thousands of volts and start arcing into the surrounding air (corona), between parts of the aircraft (arcing), or across the surface (streamering). When this discharge is visible, it is sometimes referred to as St. Elmo's Fire. This discharge interferes with aircraft radio receivers, making them unusable. These discharges can also be a hazard to flammable mixtures such as at fuel vents.

Static wicks are placed on the wingtip and tail trailing edges to dissipate this charge without interfering with radio receivers. This typically requires that all external surfaces are conductive and make electrical contact with each other and the static wicks.

Inlets and ducts that are exposed to airflow from outside can also experience static charging and must be properly grounded.