Electromagnetic Effects and Composite Structure

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What are Electromagnetic Environmental Effects (EME) ?

Precipitation Static (P-Static)

The *triboelectric* effect (also known as triboelectric charging) is a type of contact electrification in which certain materials become electrically charged after they come into **frictional contact** with a different material.

Electromagnetic Compatibility (EMC)

Interference caused by “on-Board” systems

High Intensity Radiated Fields (HIRF)

External **Man Made** RF Environment

Indirect Effects of Lightning (IEL)

Voltagess and Currents appearing at the interfaces of equipment as a **result of direct attachment of lightning** to the aircraft

Direct Effects of Lightning

Effects due to the **actual attachment** of the lightning channel to the aircraft structure (or component attached to aircraft structure), both local and distributed
Background

As a result of technology expansion, as well as desire to fly in all types of weather, the FAA have throughout the years issued rules dealing with Electromagnetic Environmental Effects Protection.
Background

Rules Applicable to E³ (Part 25)

25.581
Direct Effects of Lightning Protection Of Structures

25.954
Fuel System Lightning Protection

25.899
Electrical Bonding and P-Static

25.1316
System Lightning Protection

25.1317
System HIRF Protection

25.1431
System compatibility (EMC)
Background

These rules have forced Aircraft Manufacturers to pay much closer attention to design aspects required to provide protection against these threats.

In order to ensure continued airworthiness, the people maintaining these aircraft must also pay much closer attention to these issues.

Composite Structures bring a different set of problems when addressing these environments and compliance to the rules.
P-Static

Precipitation Static occurs when particles such as dry snow, rain, sand, etc., collide with an aircraft and create a high electric field.

If this field is not bled-off the nonconductive surfaces, then corona can occur, which in turn causes static on aircraft communication and navigation equipment.

In the case of P-Static, the threat is high voltage and relatively low of amount of current, and therefore, power is very small (I^2 R). Since the power behind the voltage build up is very small (uamps), a high resistance path to airframe structure is sufficient to protect against P-static.

*However there must be an on purpose electrical bond to ensure bleed off. This true, regardless of metal or composite*
Electromagnetic Compatibility (EMC)

This applies to the simultaneous operation of equipment on the aircraft and ensuring that one system does not interfere with another system.

Back Door Coupling – refers to coupling through wire bundles, apertures, power systems, etc.

- Composite structure can increase these issues via shielding effectiveness reduction, ground plane/power return issues, etc.

Front Door Coupling – refers to coupling through the antenna into the receiver

- Composite structure can increase these issues via shielding effectiveness reduction

Electrical Bonding
High Intensity Radiated Fields (HIRF)
WHAT IS HIRF?

HIRF = High Intensity Radiated Fields

The electromagnetic environment created by high powered ground and air based transmitters.
Shielding Effectiveness Testing

Metal is better but Carbon isn't bad……...

Engineering evaluation tests:

- Baseline with Al panel and open aperture
- Compared with carbon fiber composite panels with and without any lightning strike protection

Bottom Line

- 15-20 db less effective than metal
- Care must be taken during repair
Effect of Lightning Strike Protection

- 1 - 0.016 psf expanded Al
- 2 – 0.029 psf expanded Copper foil
- 4 – LDS 50-01 0.007 psf Al
- 5 – Integument with integrated LSP and PSA
- 6 – LORD Spray material

- Different lightning strike protections about the same shielding effectiveness
Aircraft Interaction with the Lightning Environment
Triggered Lightning (most common)

- Lightning triggered by the presence of the aircraft
  - lightning would otherwise have not naturally occurred, i.e. cloud is electrified but not yet a thundercloud

- Air breakdown (point at which leaders develop)
  - 3000kV/m at sea level
  - reduces with pressure and hence altitude
  - 1500kV/m at 8000m (26,250 ft)

- Ambient field in electrified clouds less than this
  - peak field ~1000kV/m, generally lower ~100kV/m
  - breakdown requires a much higher field strength

- Aircraft must concentrate field locally
  - produce field large enough for breakdown
Conditions for Triggered Lightning

- Volumes within arrowed contours (dashed lines) are where aircraft can trigger lightning
  - i.e. The ambient field is large enough for the field enhancement effect to create leaders
Triggered Lightning Observations

- Electrical activity before strike
  - St. Elmo’s fire (corona) and radio interference
- Radar signature
  - Symmetrical development from aircraft (lightning channels are conductors so show up on radar)
- Can occur in non thunderstorm clouds
- Constitutes ~90% of recorded strikes
E-Field - Triggered Lightning

- Large electric field before attachment
  - field changes principally due to motion of aircraft in cloud
  - slow rise time (seconds)

- $\sim 100$ kV/m

- Time (seconds)
Electrical Field suppression and Charge Separation

The compression of the electrical field and separation of charges, within the aircraft structure occurs, regardless of the “type of lightning”
Fig. 3.13 Compression of electric field around an aircraft.
Charge Separation in E-field

- Conducting body in Electric Field
  - charges migrate in response to E-field
  - charge separation produced

- Charge distribution modifies E-field around body
  - E-field concentrated and strength enhanced
  - large enhancement around pointed structures/extremities where field is more concentrated
Aircraft Field Enhancement

Note: 2D model, indicative only
Threat to Aircraft

- The threat to aircraft systems comes in two parts:
  - electric fields associated with attachment process
  - lightning currents (in particular the return stroke)
- Electric field and $\frac{dE}{dt}$
  - during attachment process large E-fields and rapid changes in strength
  - E-field determines initial attachment locations
  - results in puncture of dielectrics e.g. antennas and radomes
- Current
  - direct and indirect effects
  - material destruction
  - disruption of electronic systems
- Consider threats to
  - Fuels
  - Structure
  - Systems
Indirect Effects of Lightning (IEL)

- Lightning Indirect Effects May Result When the Electromagnetic Fields Produced by a Direct Strike to the Aircraft Induce Voltage and Current Transients Into the Electrical/Electronic Equipment or Components
- These Transients can be Produced by Electromagnetic Field Penetration Into the Aircraft Interior or by Structural IR (Current Times Resistance Voltage Rises Due to Current Flow on the Aircraft)
Fig. 8.4 Coupling mechanisms.
(a) Resistive
(b) Magnetic fields
(c) Electric fields
Conductive Composites

Carbon-Fiber Composites (CFC)

- Approximately 1/1000 Times as Conductive as Aluminum
- Protective material must be placed on the outer surface of CFC (or non-conductive composite) to help protect them from DEL
- These different “protection schemes” also effect the magnitude of the IEL coupling
Conductivity of Material

- Effect of DEL Protection Schemes

<table>
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<tr>
<th>Material</th>
<th>ohms/square</th>
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<tr>
<td>.125 Al</td>
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<tr>
<td>.040 Al</td>
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<td>Al mesh lower limit</td>
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<td>Thick Al Foil</td>
<td>1.30E-03</td>
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<tr>
<td>Thin Al Foil</td>
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<tr>
<td>Cu mesh</td>
<td>3.30E-03</td>
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<td>Al mesh upper limit</td>
<td>5.00E-03</td>
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<tr>
<td>ALS</td>
<td>2.40E-02</td>
</tr>
<tr>
<td>8 plies of CFC</td>
<td>5.00E-02</td>
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</table>
IEL Coupling

• Bottom Line
  – The closer the protection scheme reflects the metal structure, the better shielding effectiveness
  – Example
    • Protection schemes, such as ALS work very well for DEL but dramatically increase (order of magnitude) the IEL coupling vs. Cooper expanded metal
Lightning Protection of Structures

The primary concern in regard to lightning protection of structures is safety:

If there is no safety hazard then it is an economic concern and a cost trade off between repair/replace.
Metal Structures

Metal Structures are naturally resistance to lightning strikes due to the conductivity of the material

The main danger to metal structures is the long duration dwell time

- If the material is not thick enough then the lightning can burn though the material and if fuel is presentation – BOOM
- Long duration current can also damage bonding straps, weld joints, couple to wiring an create explosion, etc.
Ensure sufficient Current Paths for external equipment

Anytime you install electrical equipment (e.g. lights, probes, etc) on the external surface of the aircraft, it is critical to ensure that there is a sufficient path to ground.

In the case of composite structure, this must be designed into the structure.
Composite Fairing Current Path Construction
Composite Structure

Unlike Metal Structure, Composite is Not Inherently Resistant to Lightning and Therefore Lightning Protection of Composite Structures Must be Considered From the Start of Design. Will Result in:

- Costs
- Materials
- Weight
Composites

Two Types

Conductive

Non Conductive
Non-conductive Composites are Electrical Insulators

Cannot Carry the Lightning Current

Will be Punctures by the High Electrical Field and the Flash Attach to a Metal Object Beneath the Skin
Non-Conductive Composites

Lightning produces damage to a non-conducting skin by two mechanisms...

Puncture

Surface Flashover
Protection Techniques
Structures

Conductive Coatings

Arc or Flame-Sprayed Metals

Woven-Wire Fabrics
Aluminized Fiberglass
Metal-Loaded Paints
Expanded Metal Foils
Carbon-Fiber Composites (ALS)
Conductive Composites

Conductive Composites Are Electrical Conductors

Carbon-Fiber Composites (CFC)

Approximately 1/1000 Times as Conductive as Aluminum
Conductive Composites

Lightning produces damage to a conducting skin by two different mechanisms

   Electrical Current
   Resulting in Heat Transfer

Shockwave and Pressure Effects
Resulting in Puncture due to Resin/Fiber Failure

Protection Techniques Basically the Same as Non-conductive

   Improve Electrical Conductivity
   Majority of Current Flows in Outer Protective Layer
   Arc Root Dispersion
Conductive Composites

Majority of the electrical current will remain in outer layer if...

Good Electrical Bonding

Arc Root Dispersion

Determined by:

Conductivity of Outer Layer

Surface Coating

(Paint and Sanding Surfacer)
Conductive Composites

Surface Coating Degrades Protection by:

Insulating the Outer Layer
Concentrate the Arc
Current under Pressure
Thin Surface Coating

Aircraft Surface

Good Arc Root Dispersion
Thick Surface Coating

Aircraft Surface

Poor Arc Root Dispersion
Engineering Tests

• Various Representative Ply Stacks
• Various Surface Coating Thickness
  • 5, 10, 15 and 20 mils
• Requirements
  • 1A and 2A
  • Limited 1B and 2B
There are composites in ALL Zones on the aircraft.

Some are CRITICAL due to the system present beneath the surface (i.e. FADEC, Fuel System, electrical wiring, etc.)

Some are CRITICAL due to the function the surface performs (i.e. Rudder and Horizon Stabilizer)
If the Paint Thickness on these surfaces is not controlled.....

- Protection CANNOT be certified
- Protection CANNOT be maintained
Lightning Protection of Composites

Conclusion

Composite Structure Must Be Protected From Lightning If There Is A Safety Concern
Protection Must Consider Both Direct and Indirect Effects of Lightning
Protection Must Be Maintained Throughout The Life Of The Aircraft Both In General Maintenance And Standard Repair
Consider all aspects of protection or bad things happen

Questions?