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)

Voltages and Currents appearing at the interfaces of equipment as a **result of direct attachment of lightning t**o 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 distrbuted

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 E^3 (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 Manufactures 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

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)

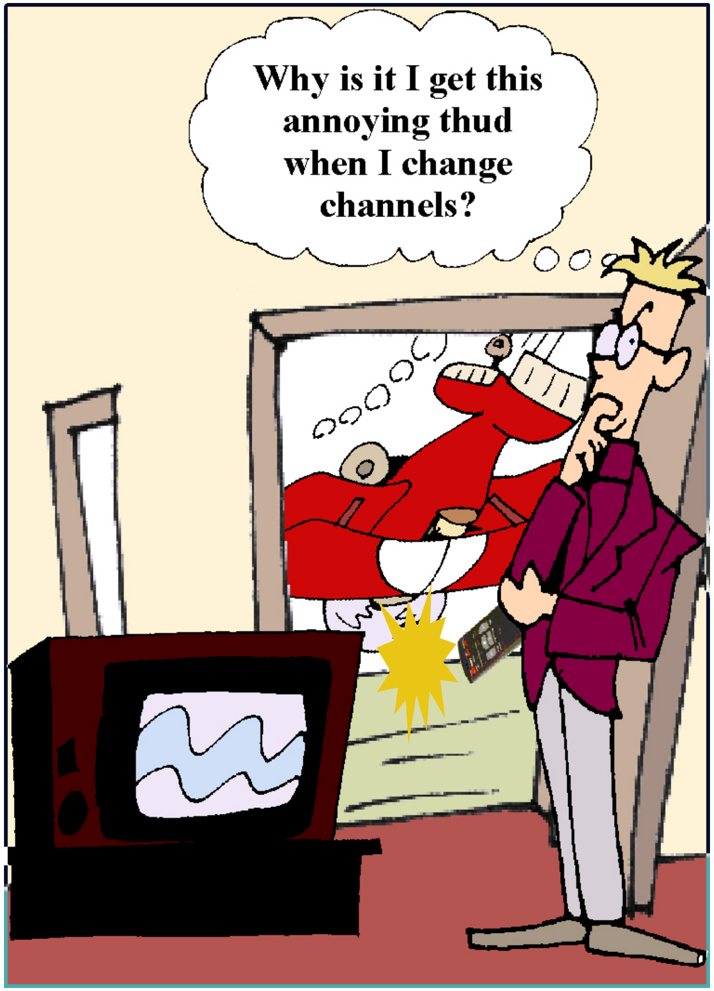
- This applies to the simultaneous operation of equipment on the aircraft and ensuring that one system does not interfere with another system
  - Back Door Coupling – refers to coupling through wire bundles, apertures , power systems, etc.
    - Composite structure can increase these issues via shielding 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

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

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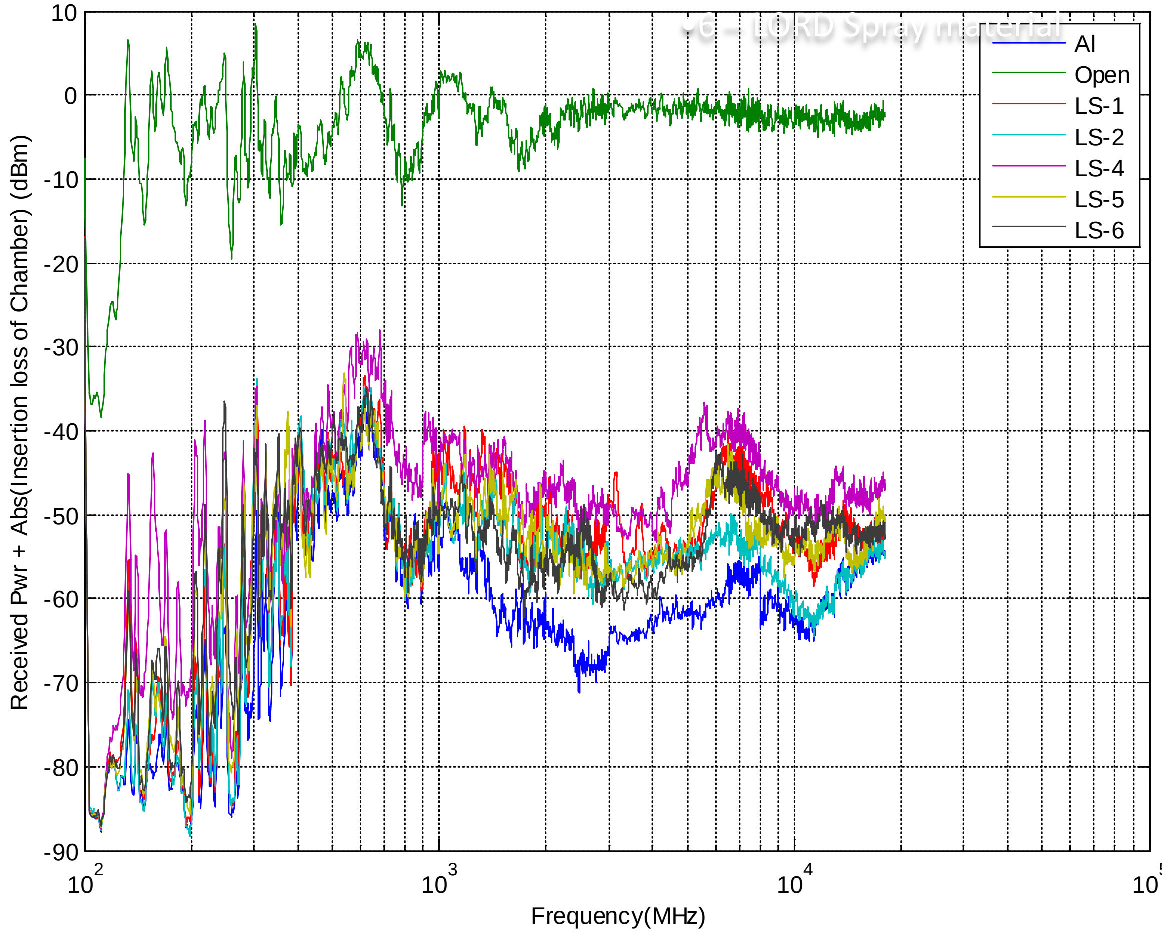
Effect of Lightning Strike Protection

- 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

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Aircraft Interaction with the Lightning Environment

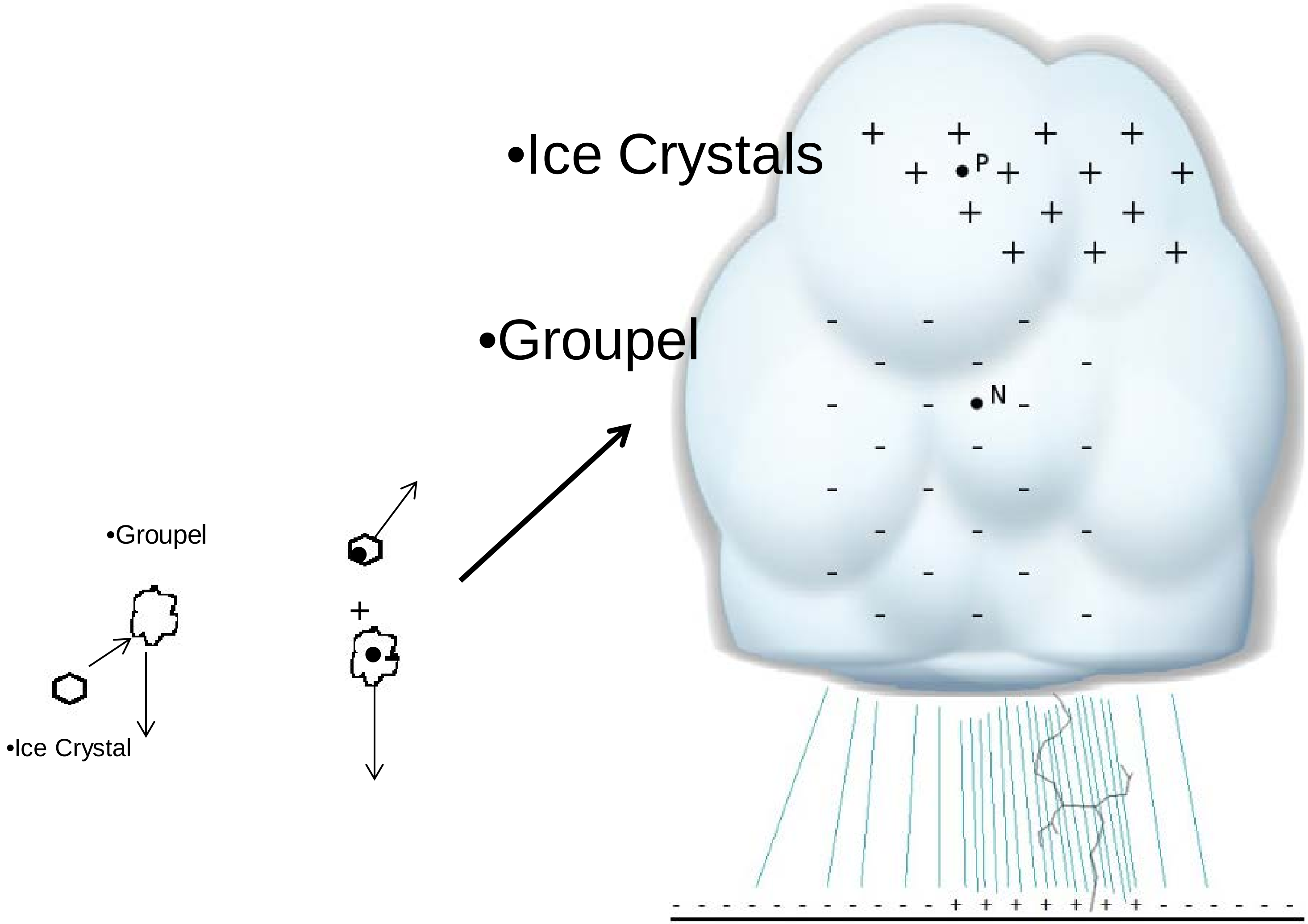
Lightning Phenomenon

- High Voltage
- High Current
- Self Sustaining

Lightning Interaction

- Once within the channel, the aircraft cannot escape and the surfaces at the entry, exit, and the connecting path between them must be capable of carrying extremely large amounts of current (i.e., 200 Kamps).
- A low impedance (resistance) path to the airframe structure is required to allow the metal sections of the aircraft to conduct the electric current without a large voltage build up.

How is lightning generated? (Cloud to Ground)



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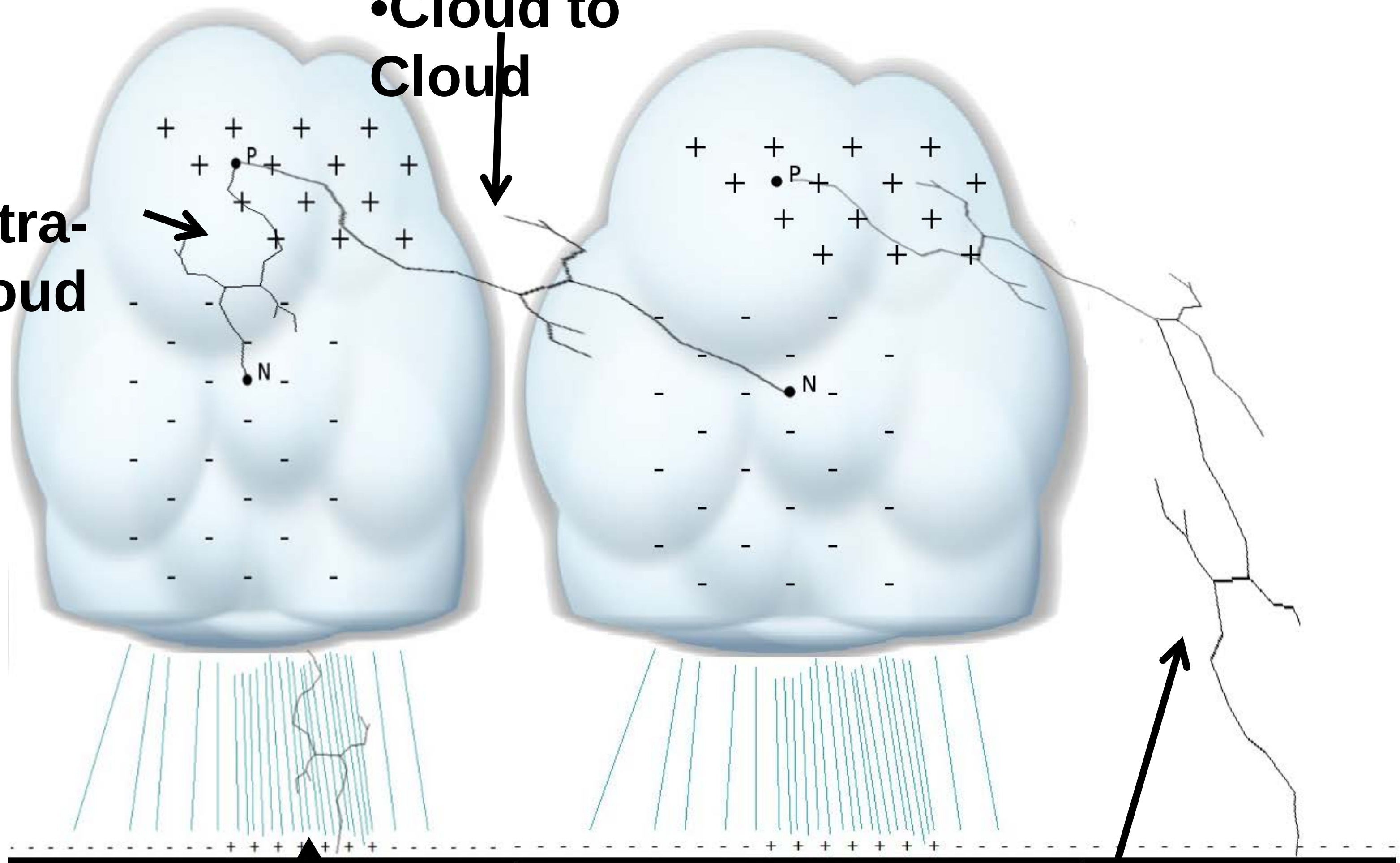
Types of Lightning

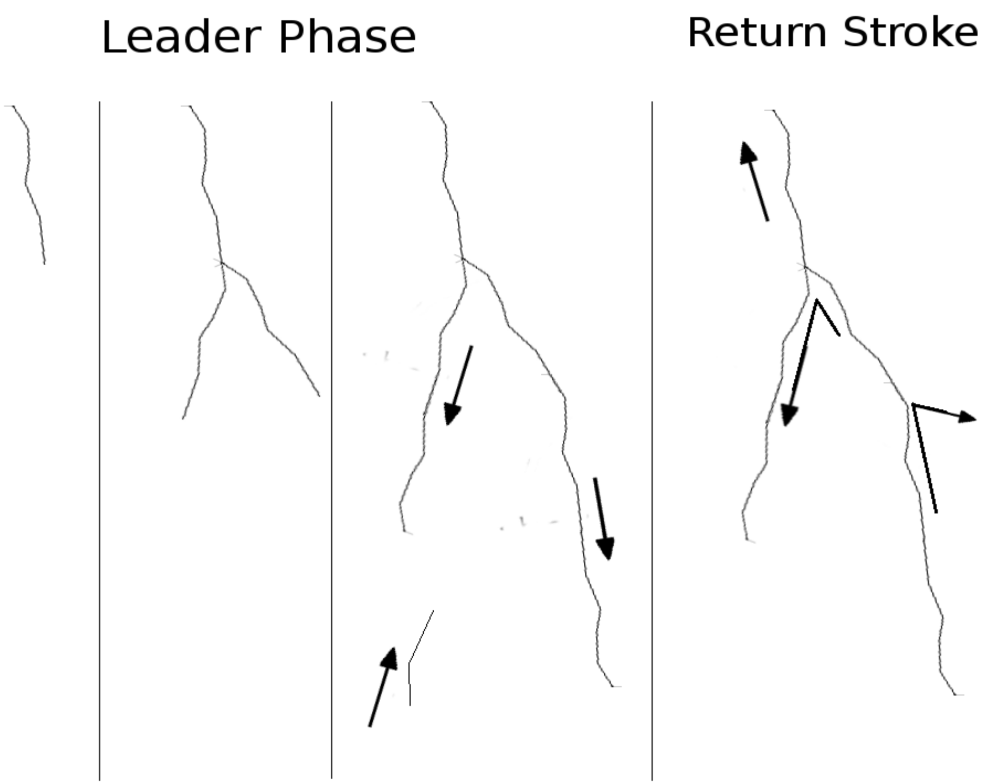
- Cloud to Cloud
- Intra-Cloud



- Cloud to Ground
- (-ve)

- Cloud to Ground
- (+ve)

Elements of a lightning strike (Cloud to Ground)



Lightning Interaction

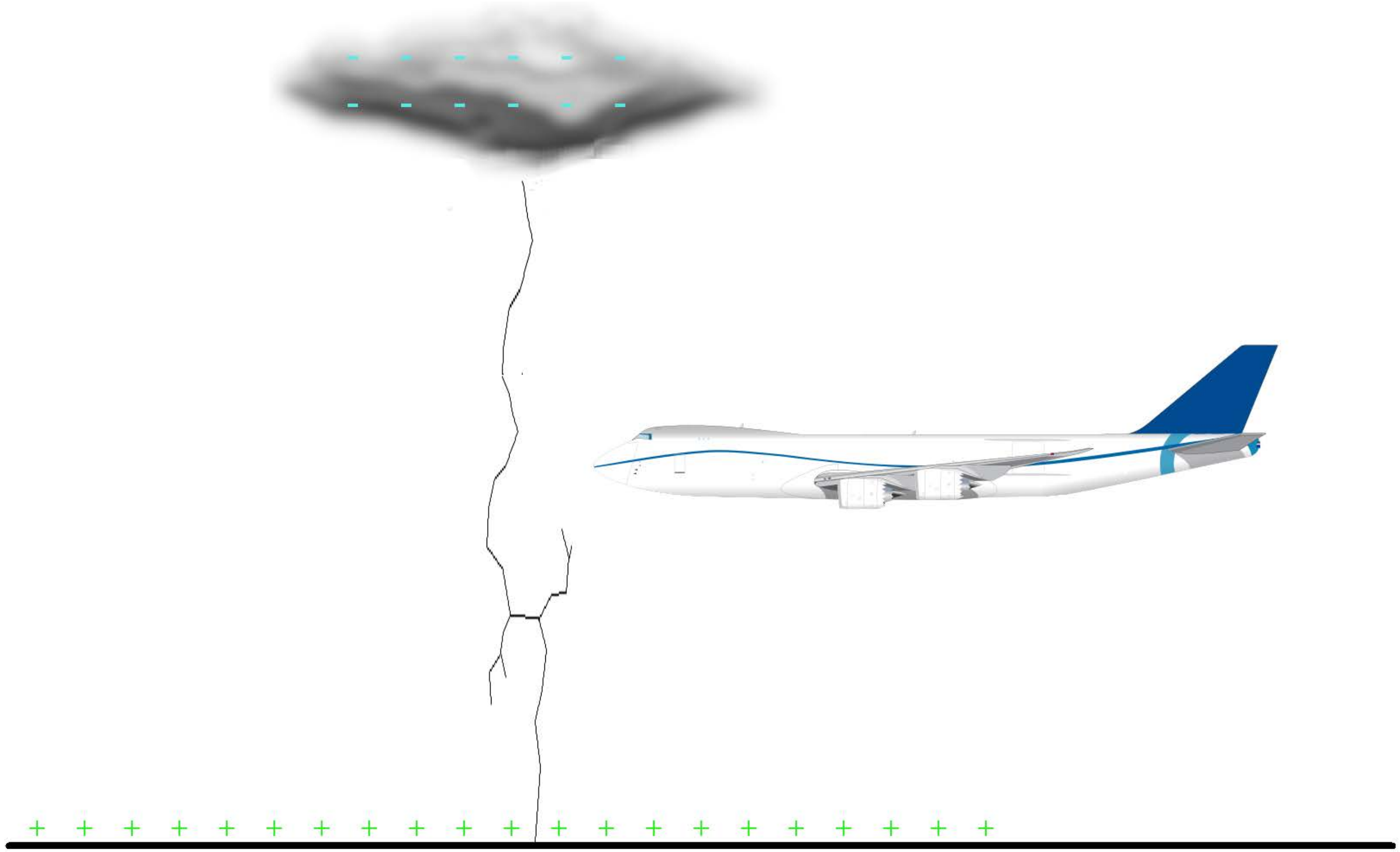
- Lightning interaction with an aircraft occurs when the aircraft is surrounded by an electrical field and the air around the extremities (i.e., wing tips, radome, etc.) begins to ionize.
- If sufficiently intense, streamers may also form and propagate outward from the aircraft toward the lightning stroke or charge center.
- When the streamers from the aircraft contact the lightning stroke, the aircraft becomes a link in the conducting channel from the cloud to the ground or another cloud.

Lightning-Aircraft Interaction Scenarios

- 3 Primary types of interaction
  - Natural Lightning
  - Aircraft Triggered Lightning
  - Hybrid Lightning

Natural Lightning – Intercepted

- Aircraft flies into existing/forming lightning channel



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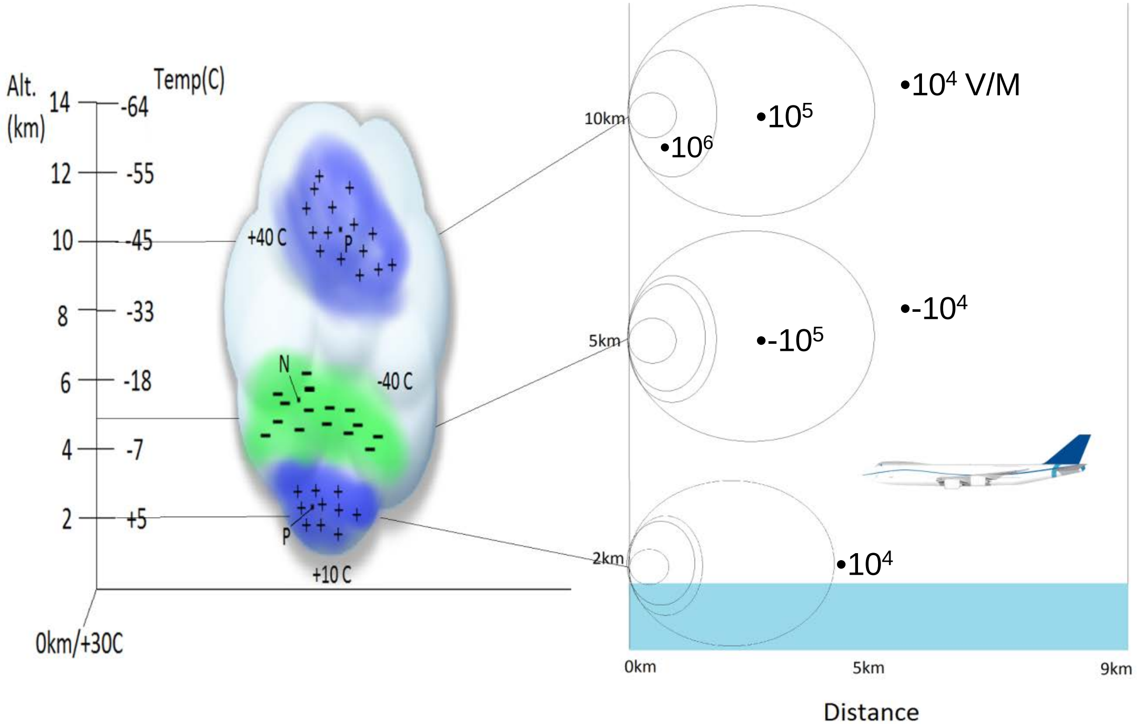
Triggered Lightning (most common)

- 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



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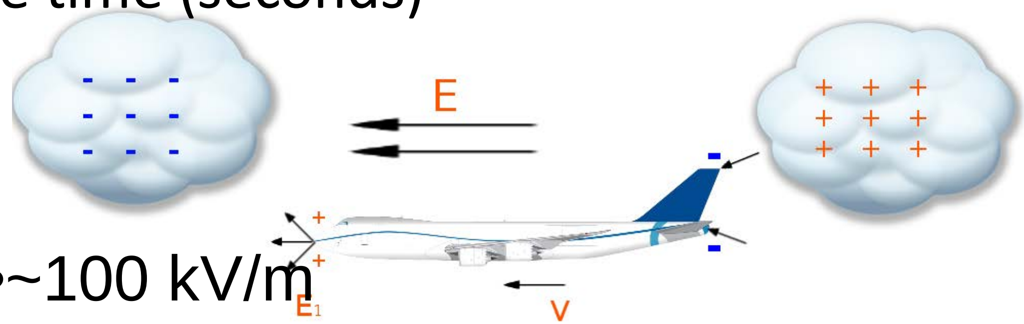
Triggered Lightning Observations

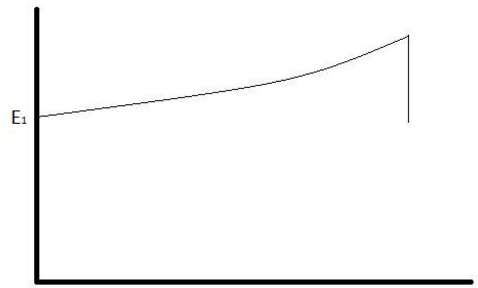
- Electrical activity before strike
  - St. Elmo's fire (corona) and radio interference
- Radar signature
  - symmetrical development from aircraft (lightning channels are conductors so show up on radar)
- Can occur in non thunderstorm clouds
- Constitutes ~90% of recorded strikes

E-Field - Triggered Lightning

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



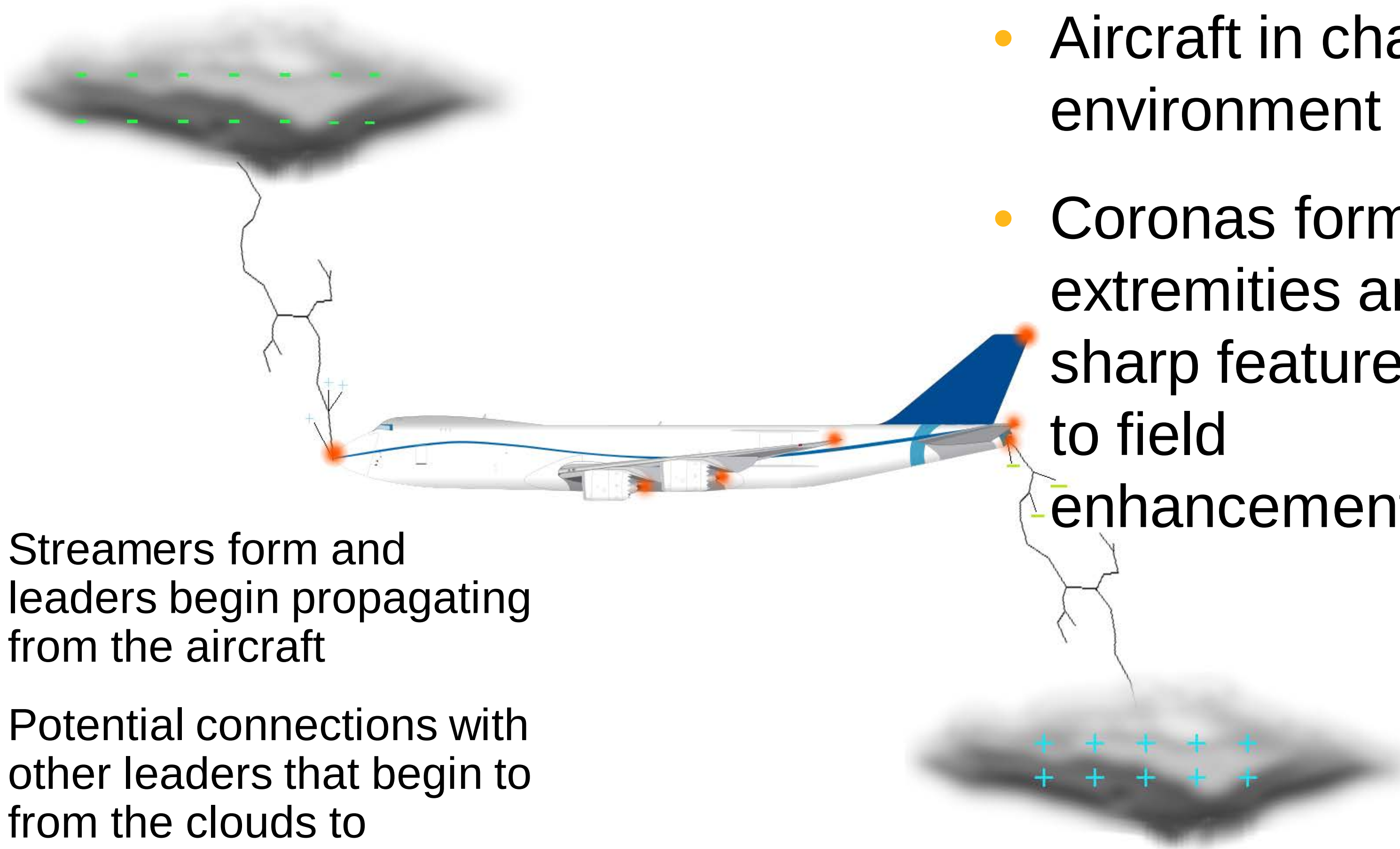
•~100 kV/m



•Time (seconds)

Scenario 3 – Hybrid Lightning

- Aircraft in charged environment
- Coronas form on extremities and sharp features due to field enhancement

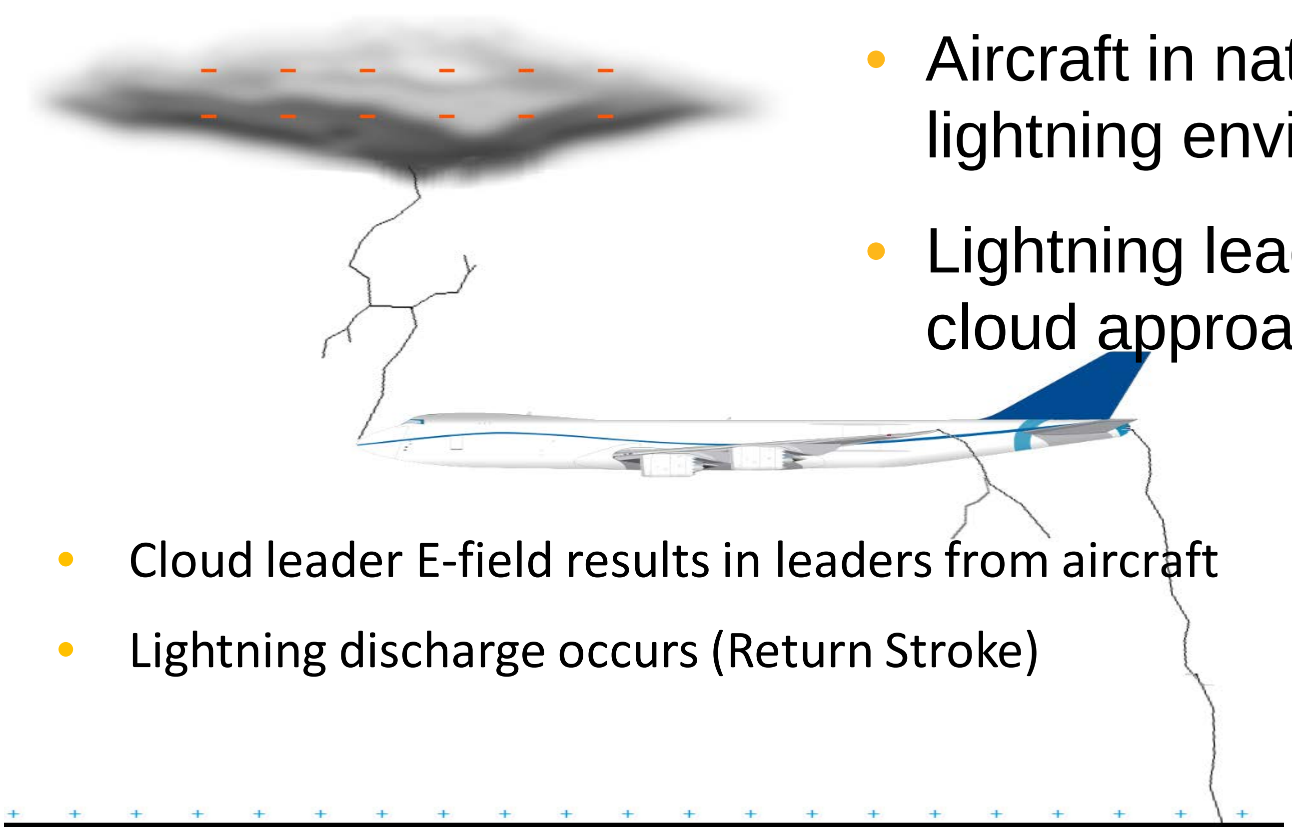


- Streamers form and leaders begin propagating from the aircraft
- Potential connections with other leaders that begin to from the clouds to complete current path
- Lightning discharge occurs (Return Stroke)

•(Cloud or Ground)

Hybrid Lightning

- Aircraft in natural lightning environment
- Lightning leader from cloud approaches aircraft



- Cloud leader E-field results in leaders from aircraft
- Lightning discharge occurs (Return Stroke)

•(Cloud or Ground)

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Hybrid Lightning Observations

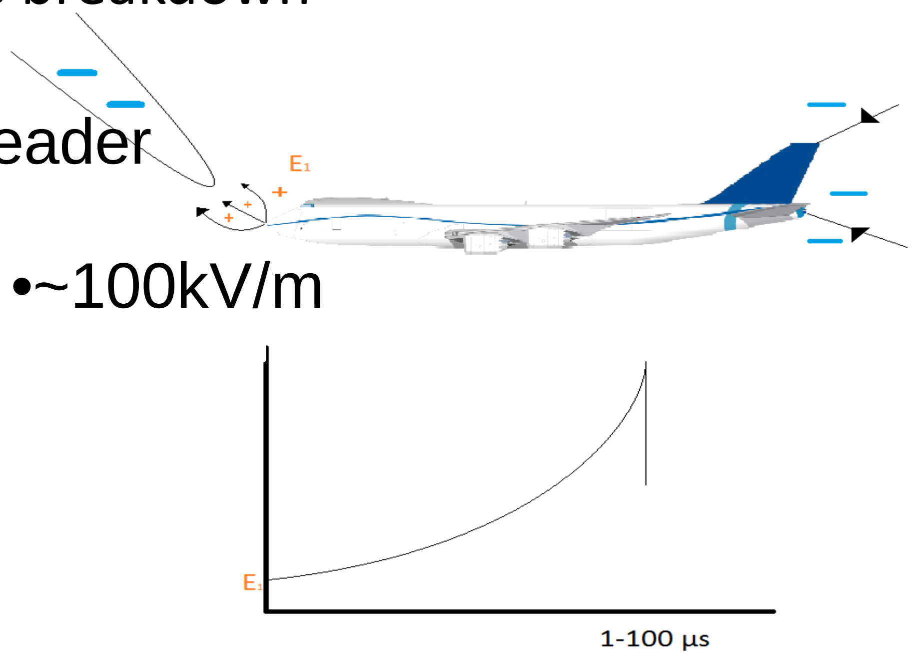
- No electrical activity before strike
  - no corona or radio interference observed
- Radar signature
  - natural and aircraft leader signals seen to coalesce
- Only occurs in thunderclouds
- Constitutes ~10% of recorded strikes
  - Mainly as aircraft try to avoid thunder clouds

E-Field - Hybrid Lightning

- Large electric field before attachment
  - fast field changes due to rapid propagation of leader (microsecond rise)
  - dielectric breakdown

•Leader

•~100kV/m



Electrical Field suppression and Charge Seperation

The compression of the electrical field and separation of charges, within the aircraft structure occurs, regardless of the "type of lightning"

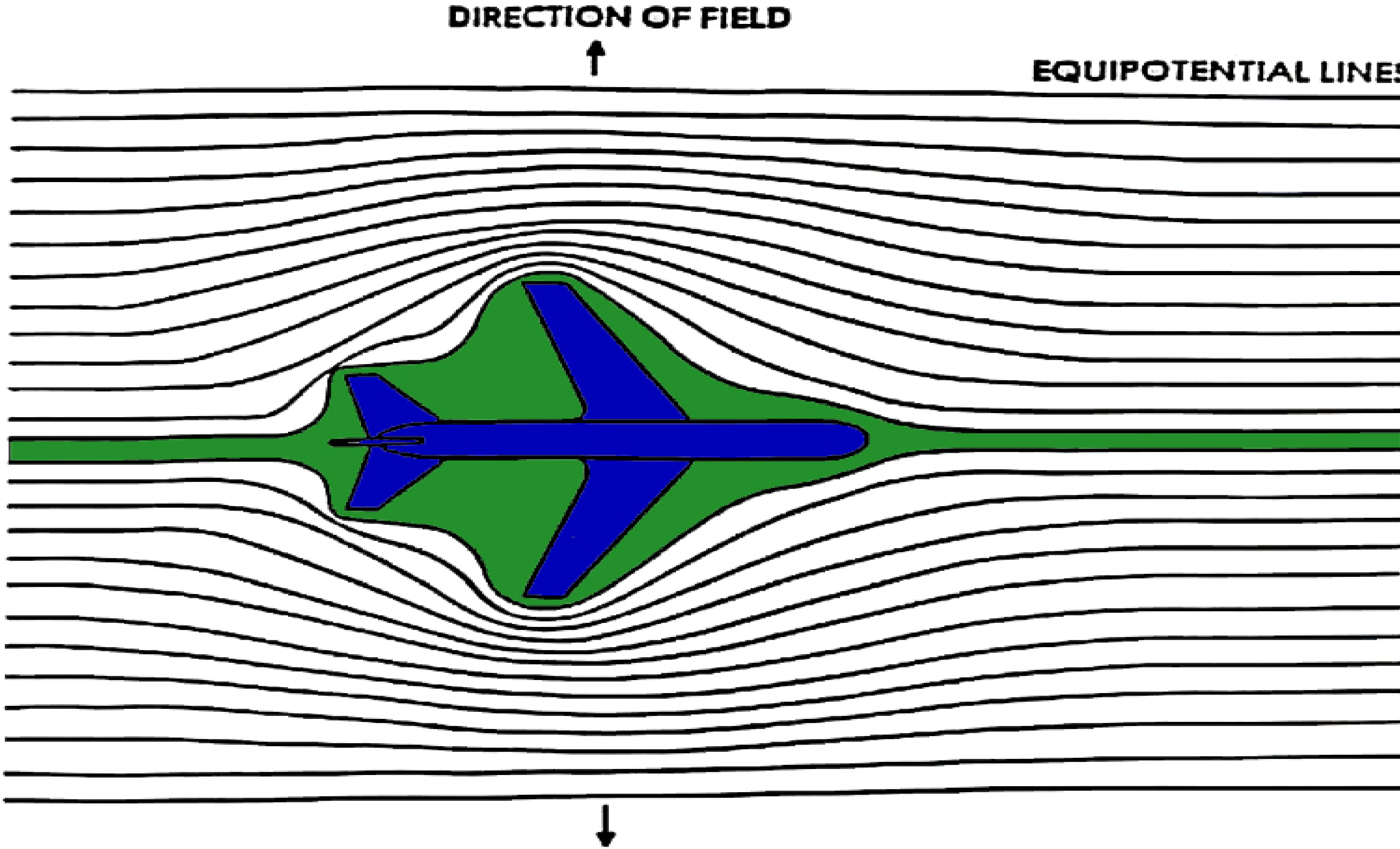
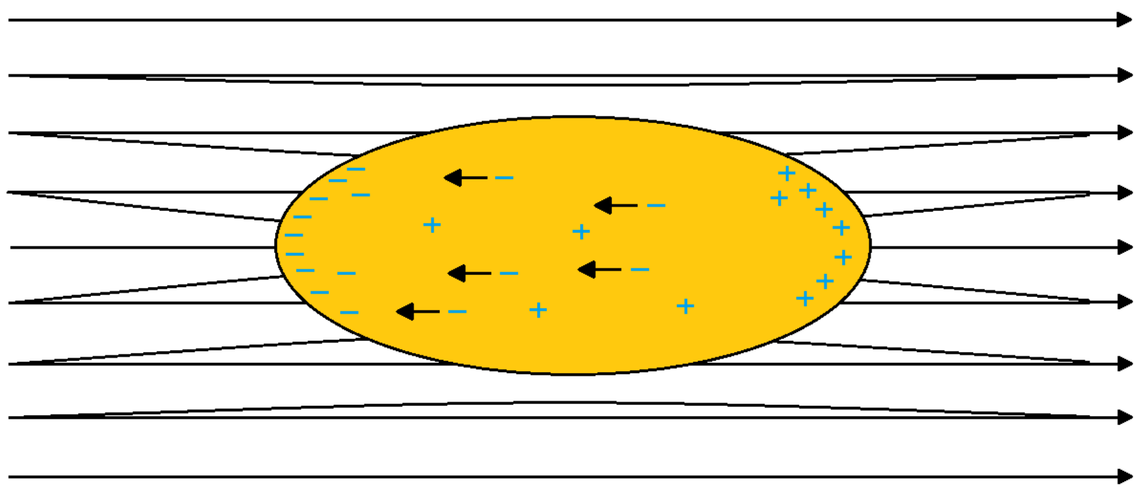


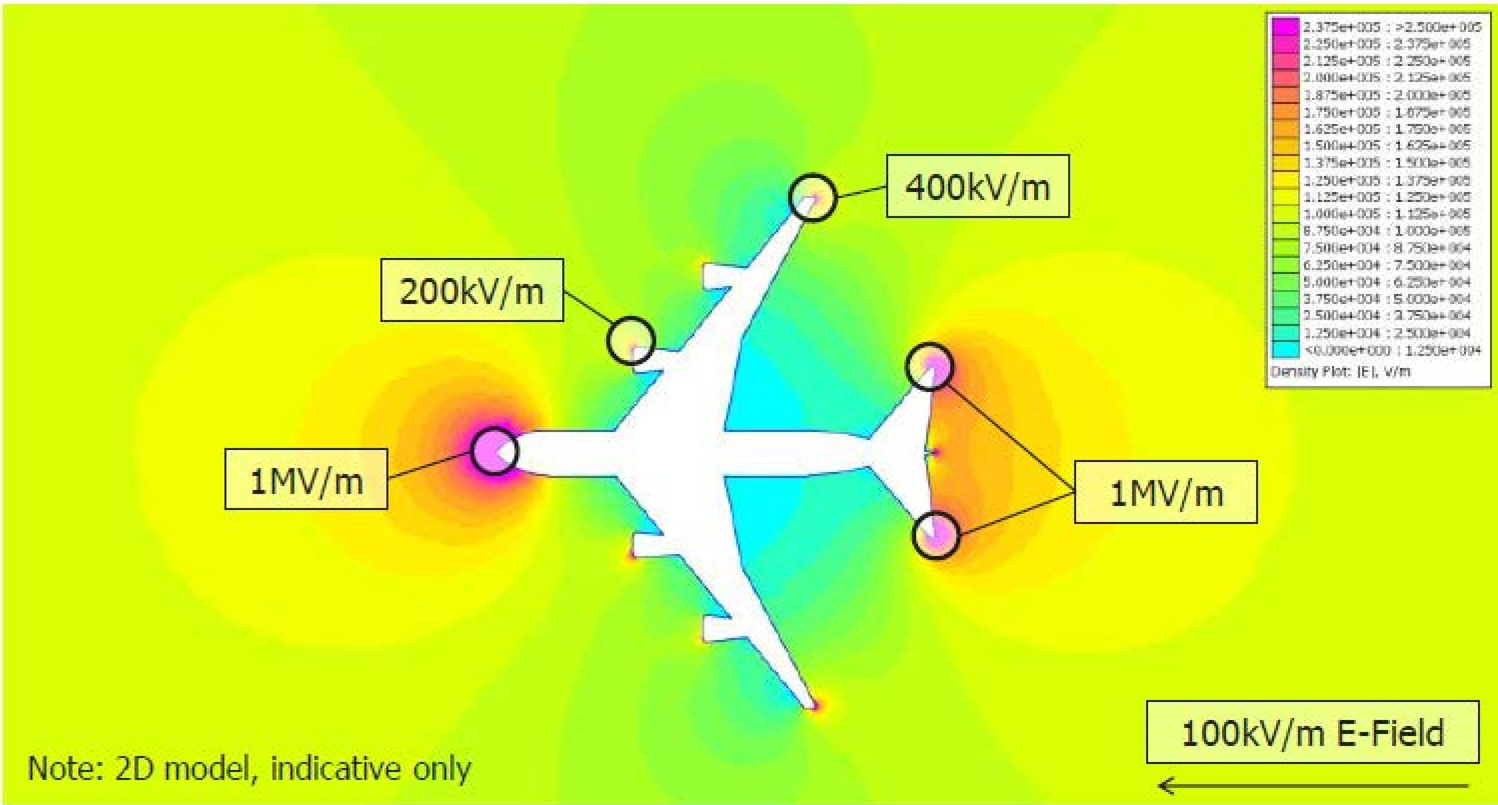
Fig. 3.13 Compression of electric field around an aircraft.

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



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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 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)

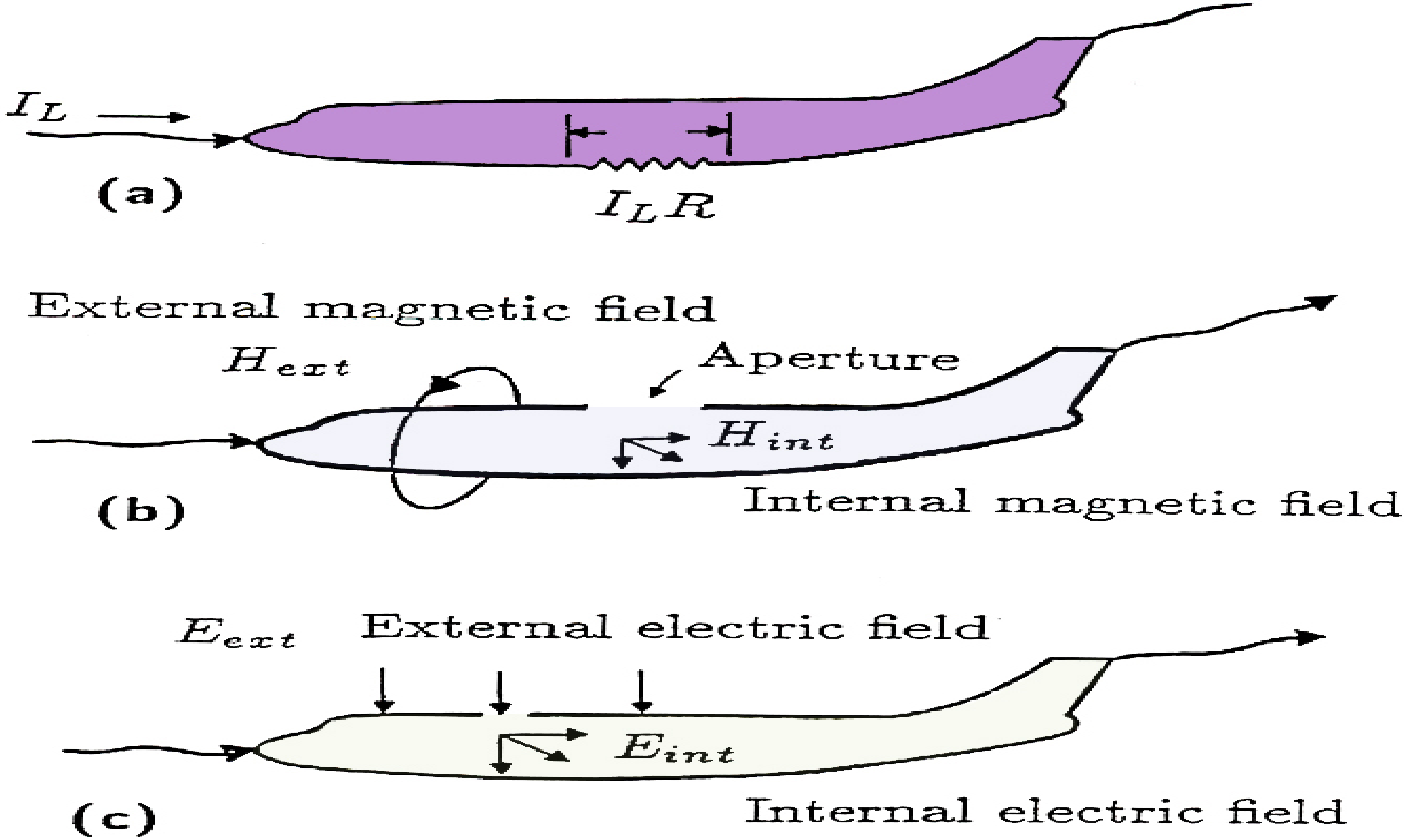

Fig. 8.4 Coupling mechanisms.
(a) Resistive
(b) Magnetic fields
(c) Electric fields

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

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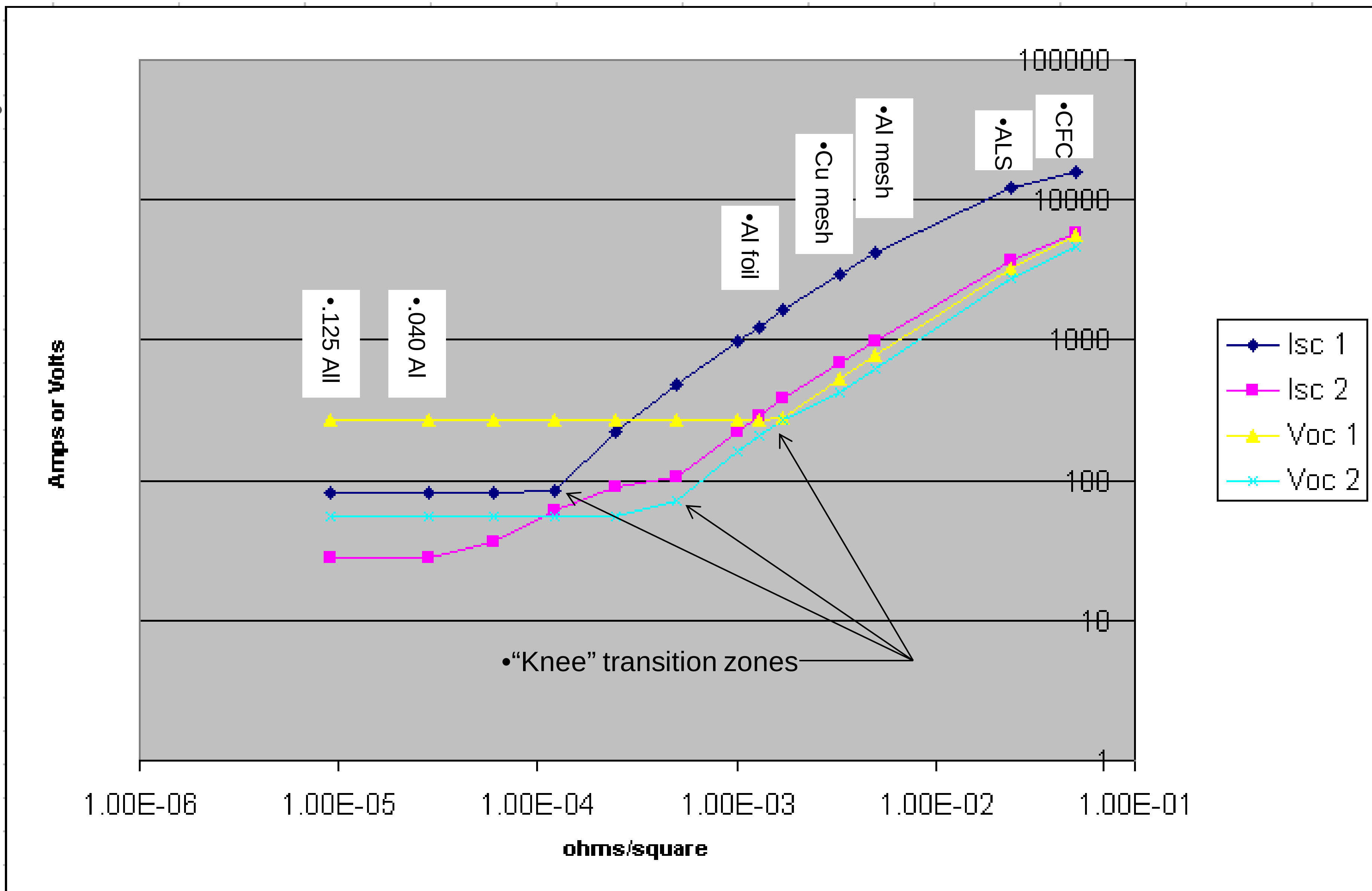
Conductivity of Material

- Effect of DEL Protection Schemes

	ohms/square
.125 Al	9.00E-06
.040 Al	2.81E-05
	6.05E-05
	1.22E-04
	2.46E-04
	4.96E-04
Al mesh lower limit	1.00E-03
Thick Al Foil	1.30E-03
Thin Al Foil	1.70E-03
Cu mesh	3.30E-03
Al mesh upper limit	5.00E-03
ALS	2.40E-02
8 plies of CFC	5.00E-02



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IEL Coupling

- Bottom Line
  - The closer the protection scheme reflexes 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

FAR 25.581

- (a) The airplane must be protected against catastrophic effects from lightning
- (b) For metallic components, compliance with paragraph (a) of this section may be shown by-
  - (1) Bonding the components properly to the airframe; or
  - (2) Designing the components so that a strike will not endanger the airplane.

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.

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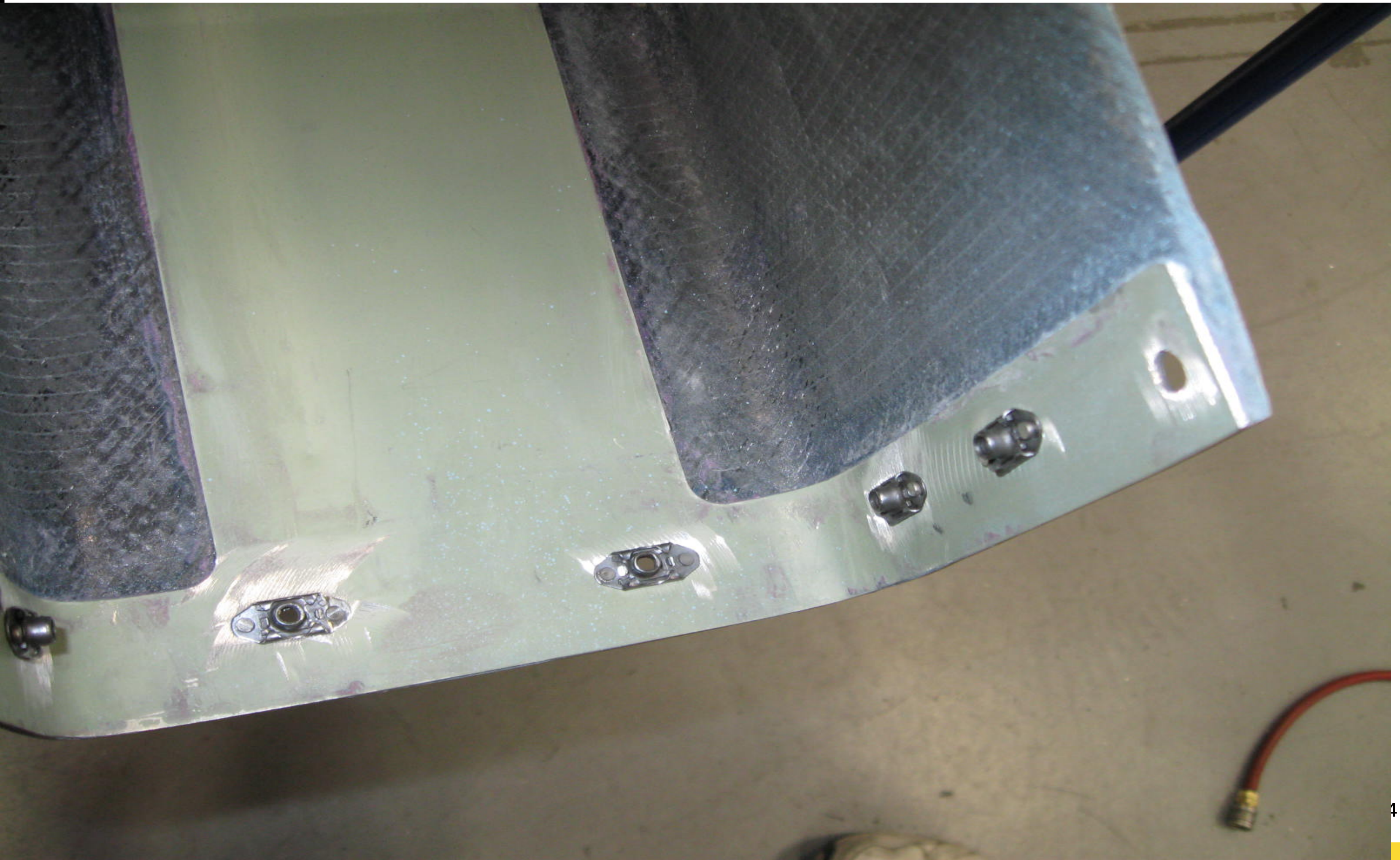
Ensure sufficient Current Paths for external equipment

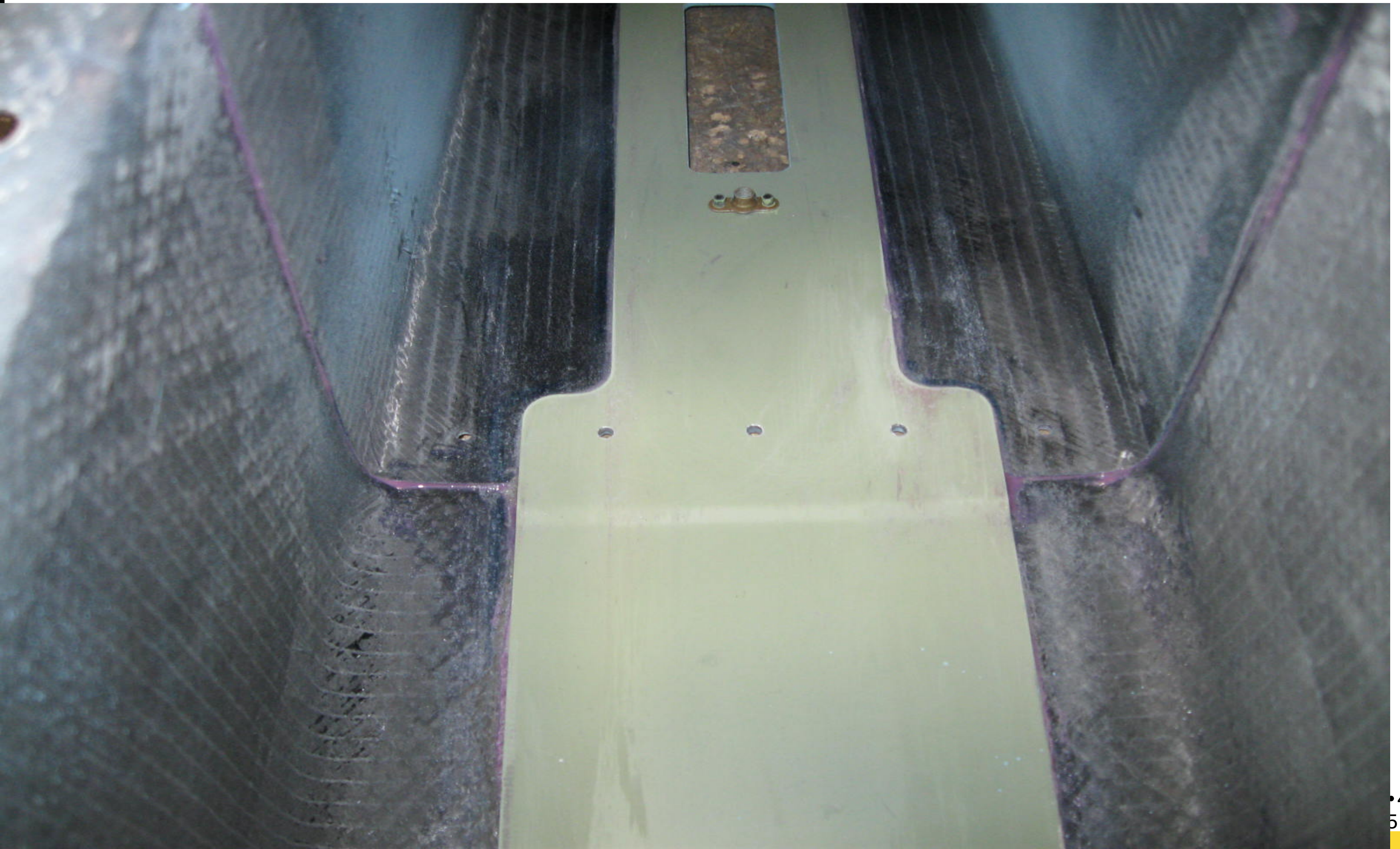
Anytime you install electrical equipment (e.g. lights, probes, etc) on the external surface of the aircraft, it is critical to ensure that there is a sufficient path to ground.

- In the case of composite structure, this must be designed into the structure

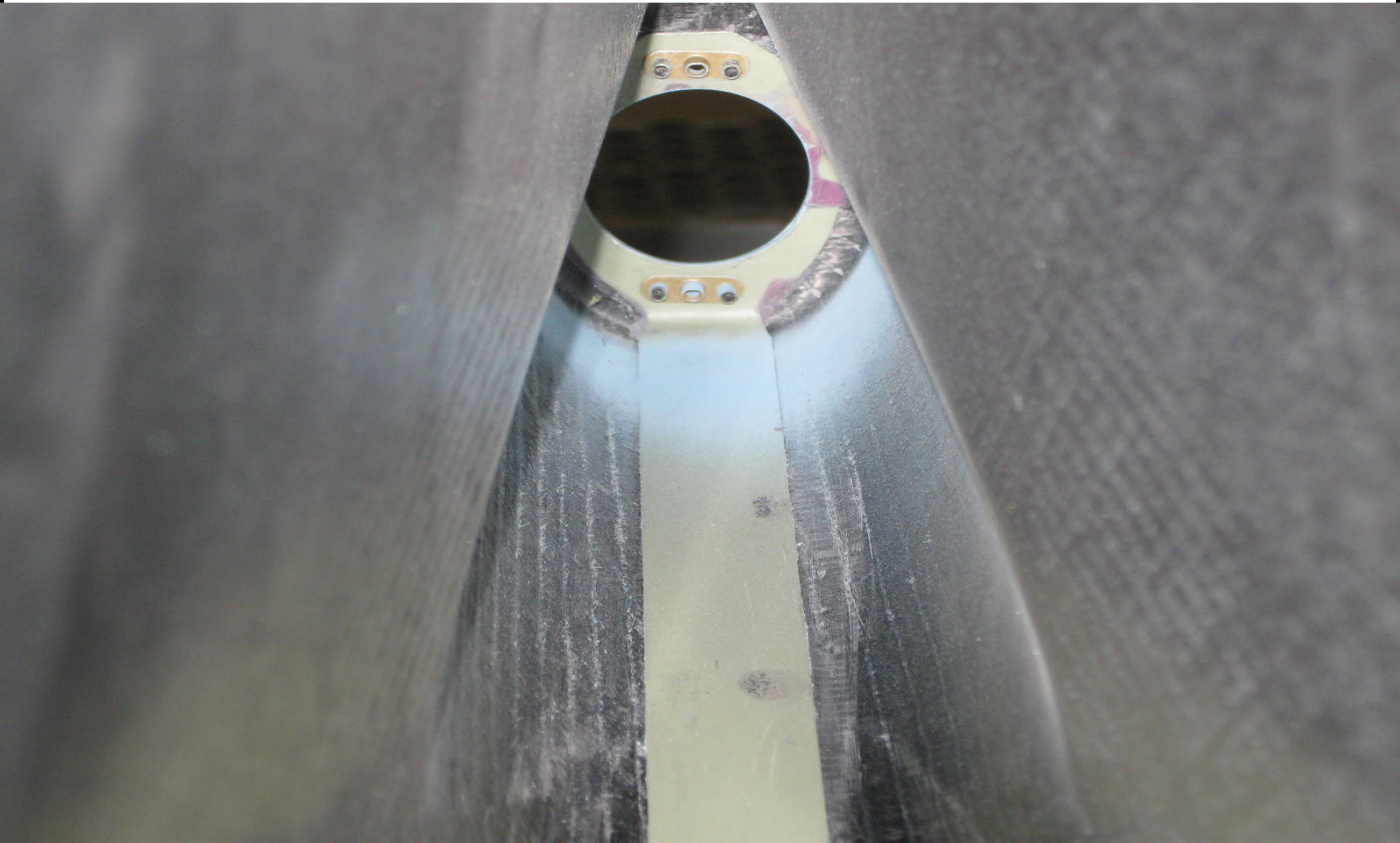
Composite Fairing Current Path Construction



Aft Bullet Fairing Construction



Aft Bullet Fairing Construction



FAR's
25.581 Lightning Protection

For Non-metallic Components

Airplane Must be Protected Against Catastrophic Effects

Minimize the Effect of Strike

Divert Current So As Not to Endanger the Airplane

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

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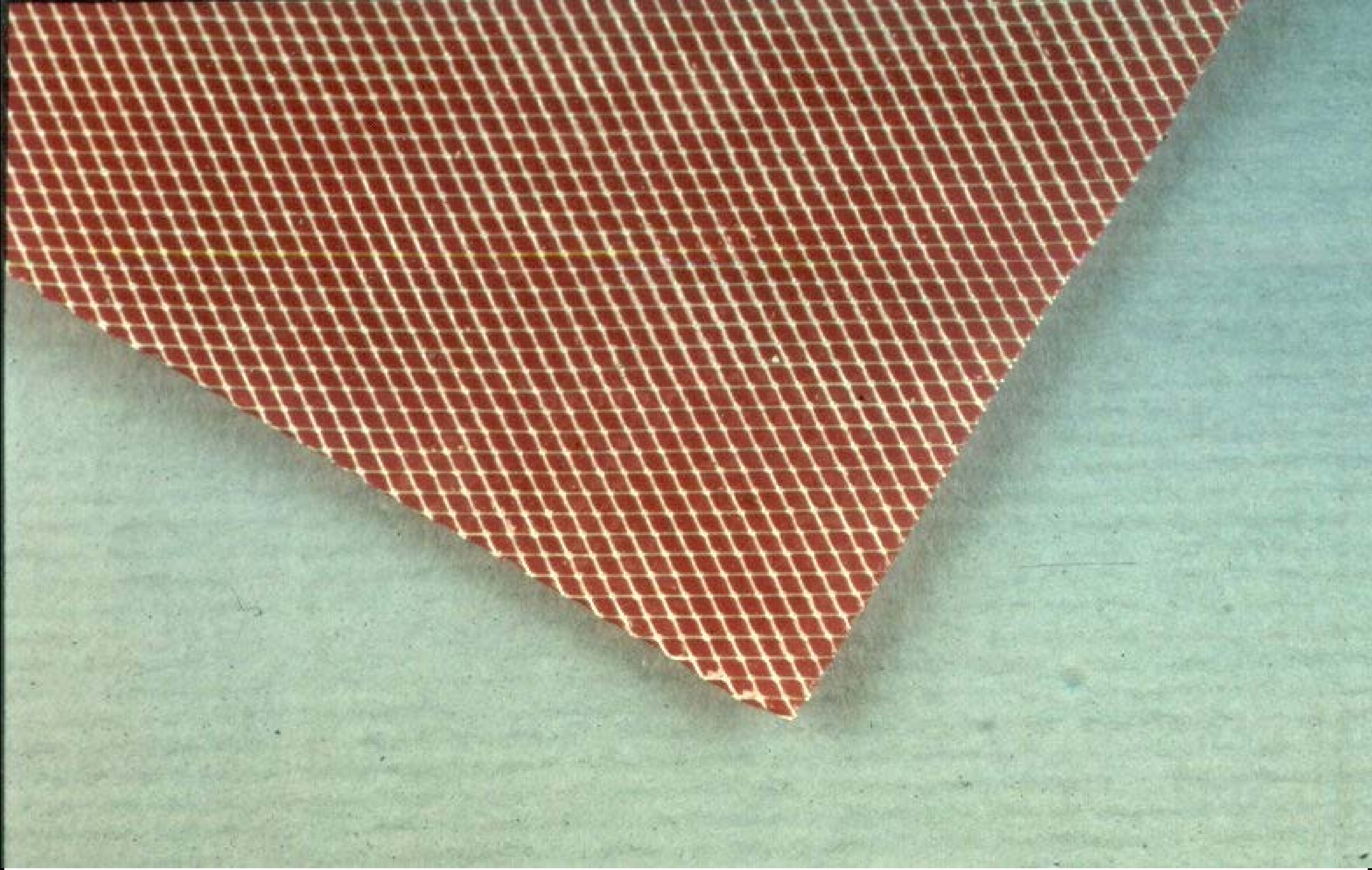
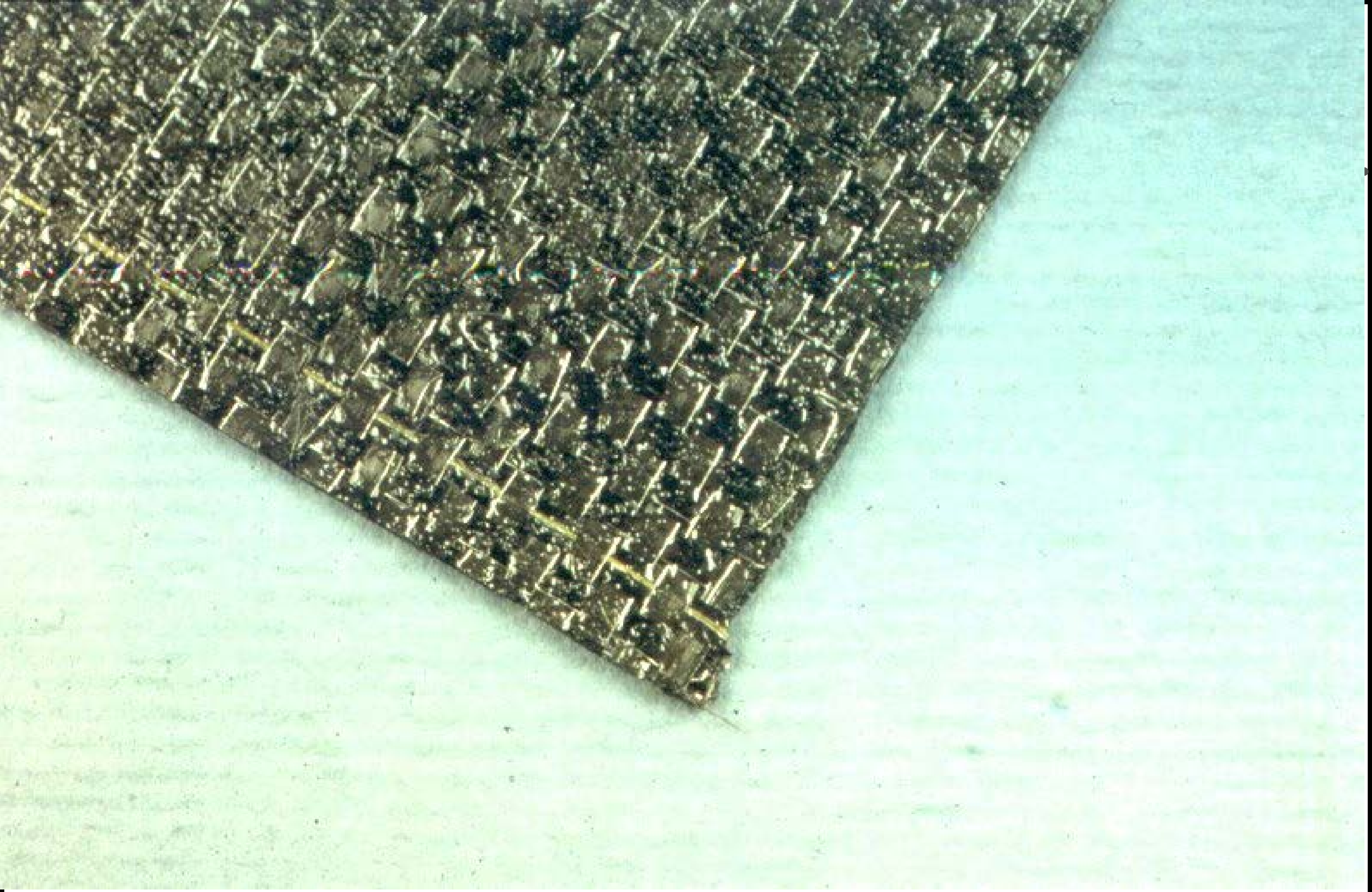
Protection Techniques Structures

Conductive Coatings

Arc or Flame-Sprayed Metals

- Woven-Wire Fabrics
- Aluminized Fiberglass
- Metal-Loaded Paints
- Explanded 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

Conductive Composites

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

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Conductive Composites

Arc Root Dispersion

Determined by:

Conductivity of Outer Layer

Surface Coating

(Paint and Sanding Surfacer)

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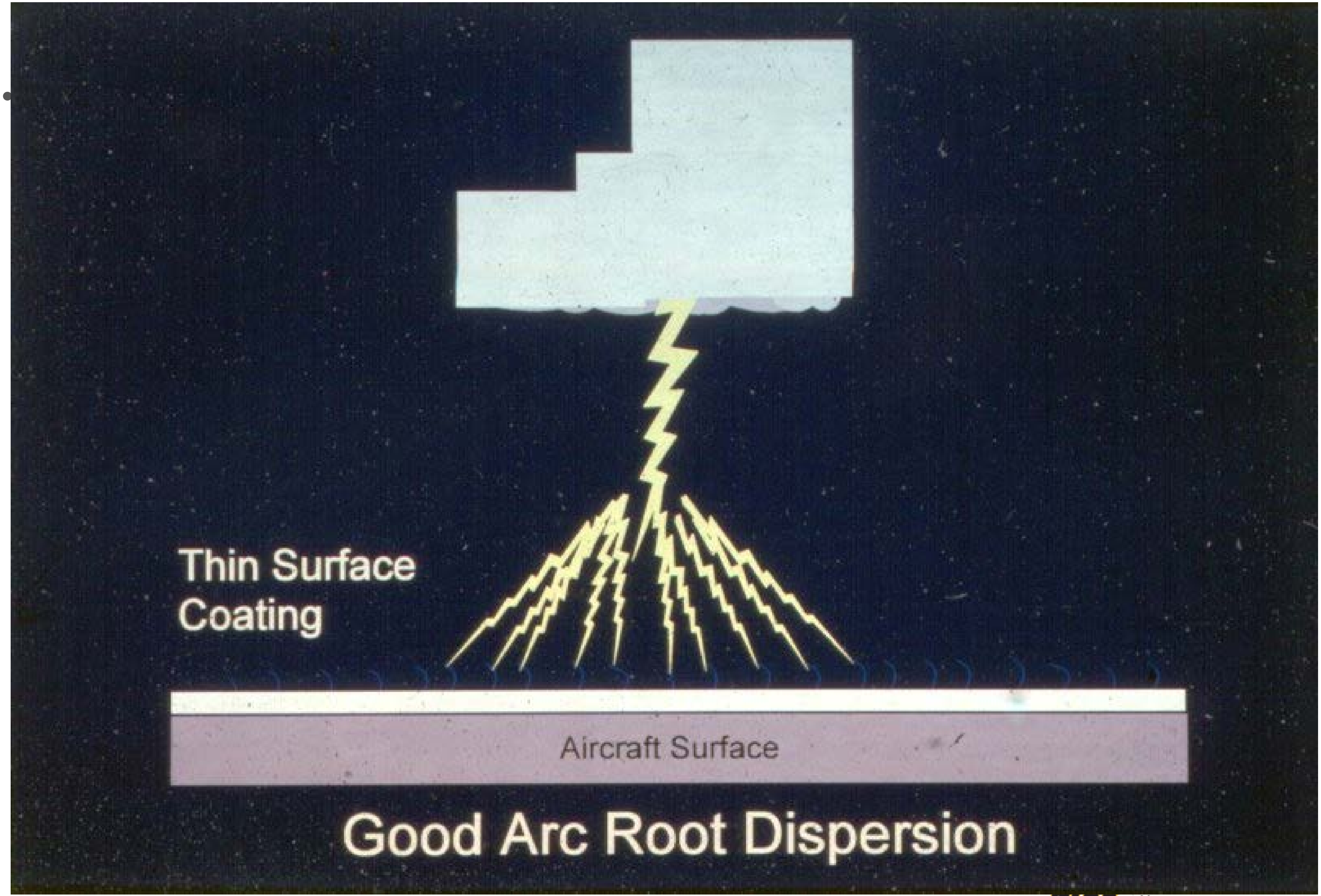
Conductive Composites

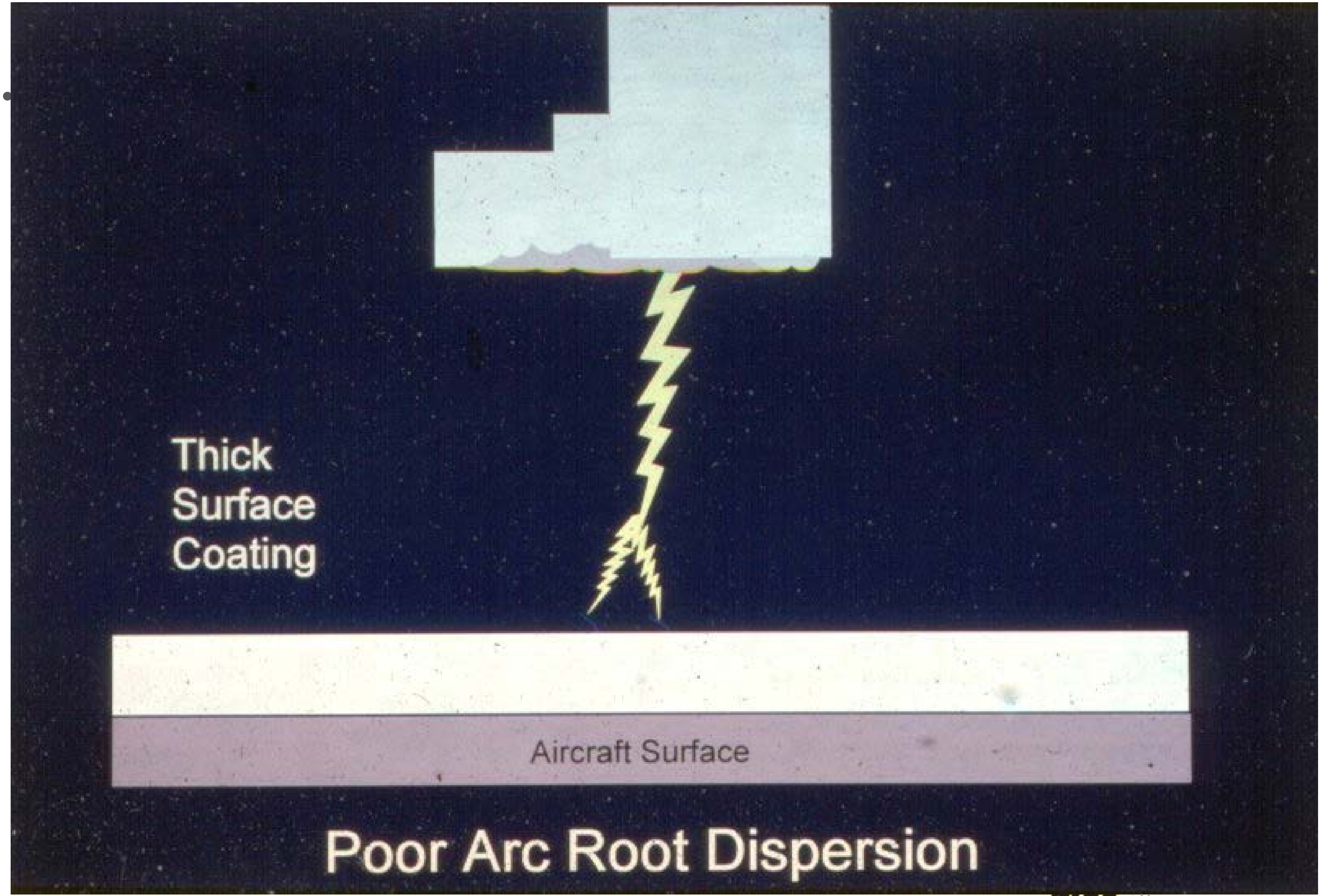
Surface Coating Degrades Protection by:

Insulating the Outer Layer

Concentrate the Arc

Current under Pressure


Thin Surface
Coating
Aircraft Surface
Good Arc Root Dispersion



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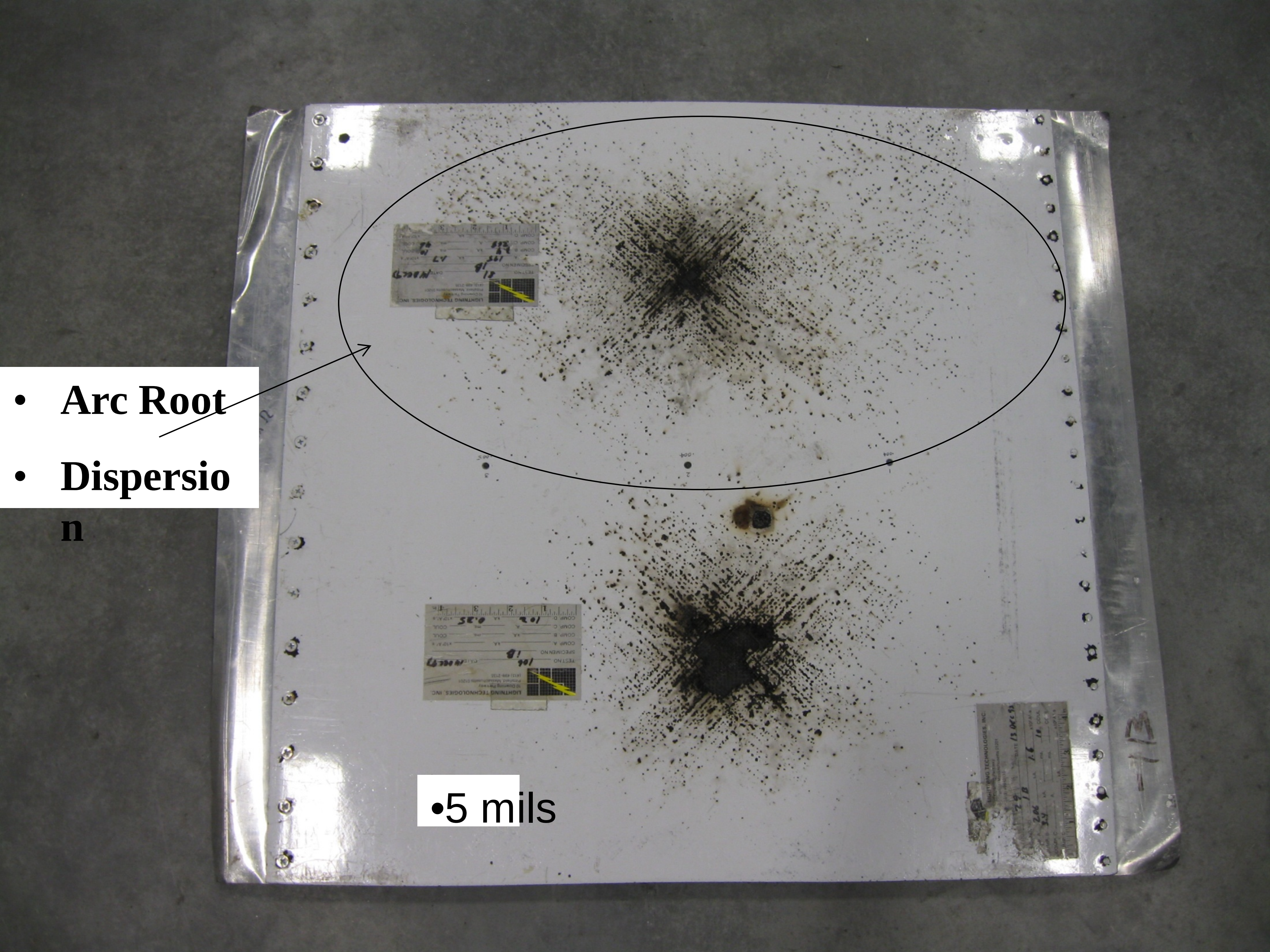
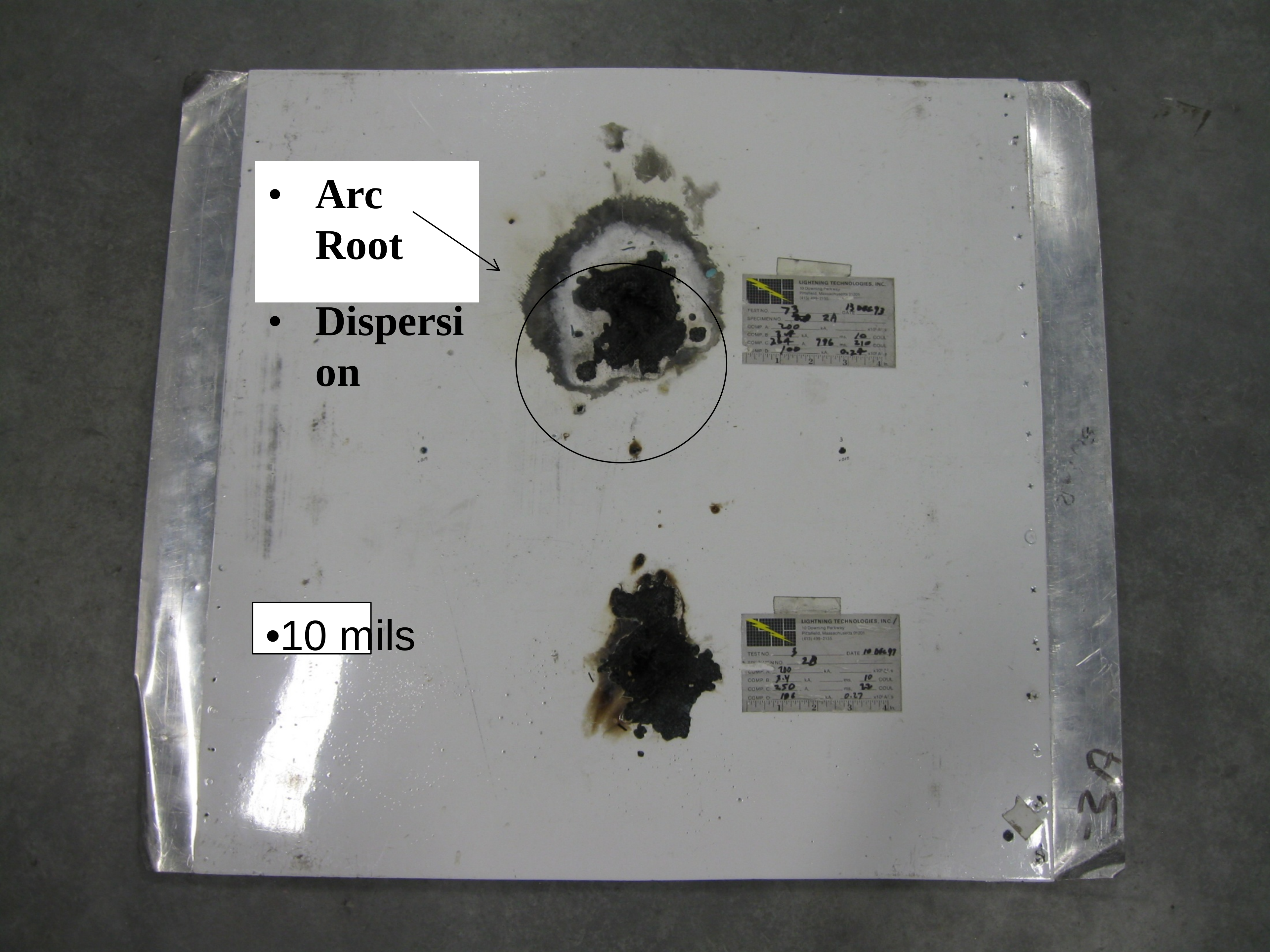
Engineering Tests

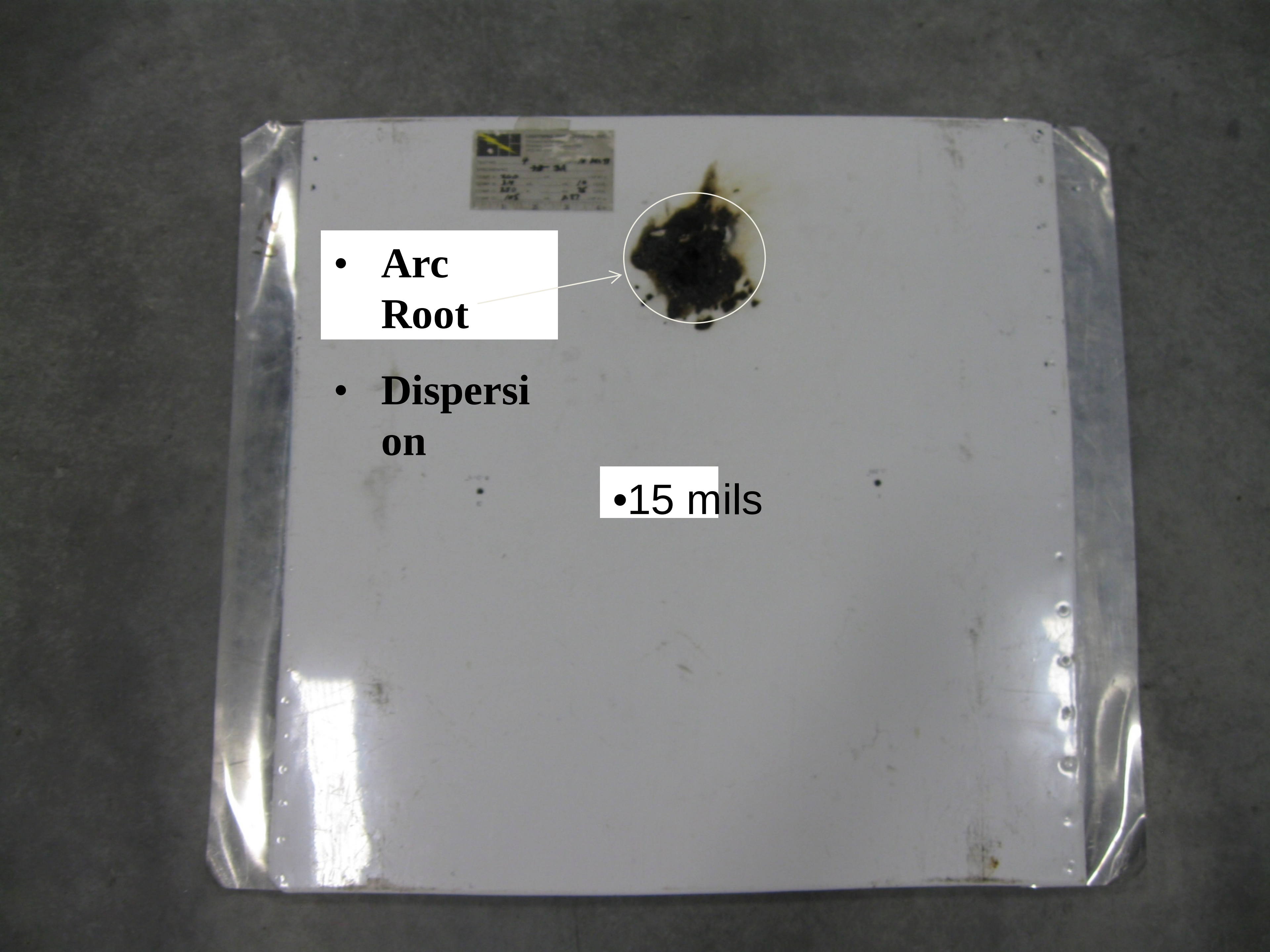
- Various Representative Ply Stacks
- Various Surface Coating Thickness
  - 5, 10, 15 and 20 mils
- Requirements
  - 1A and 2A
  - Limited 1B and 2B

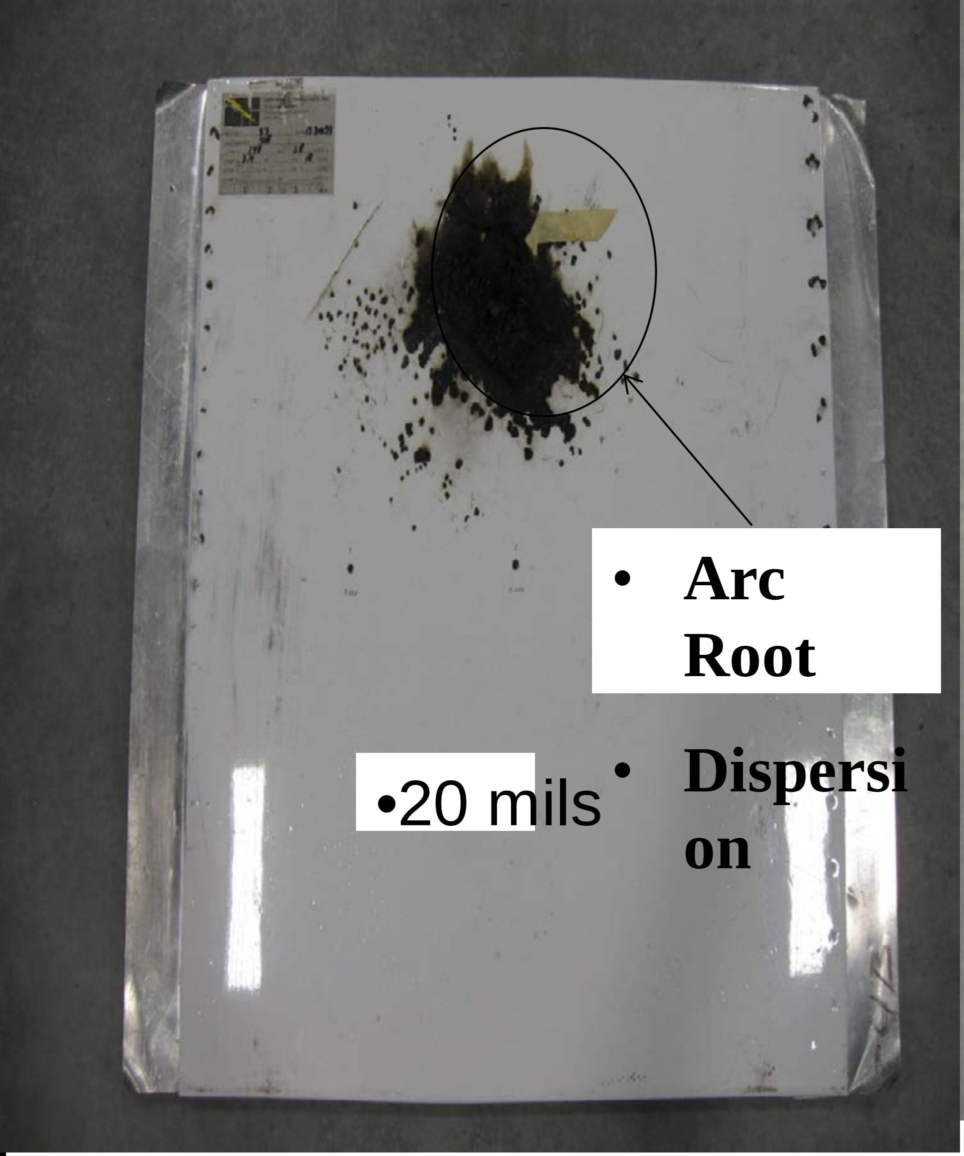


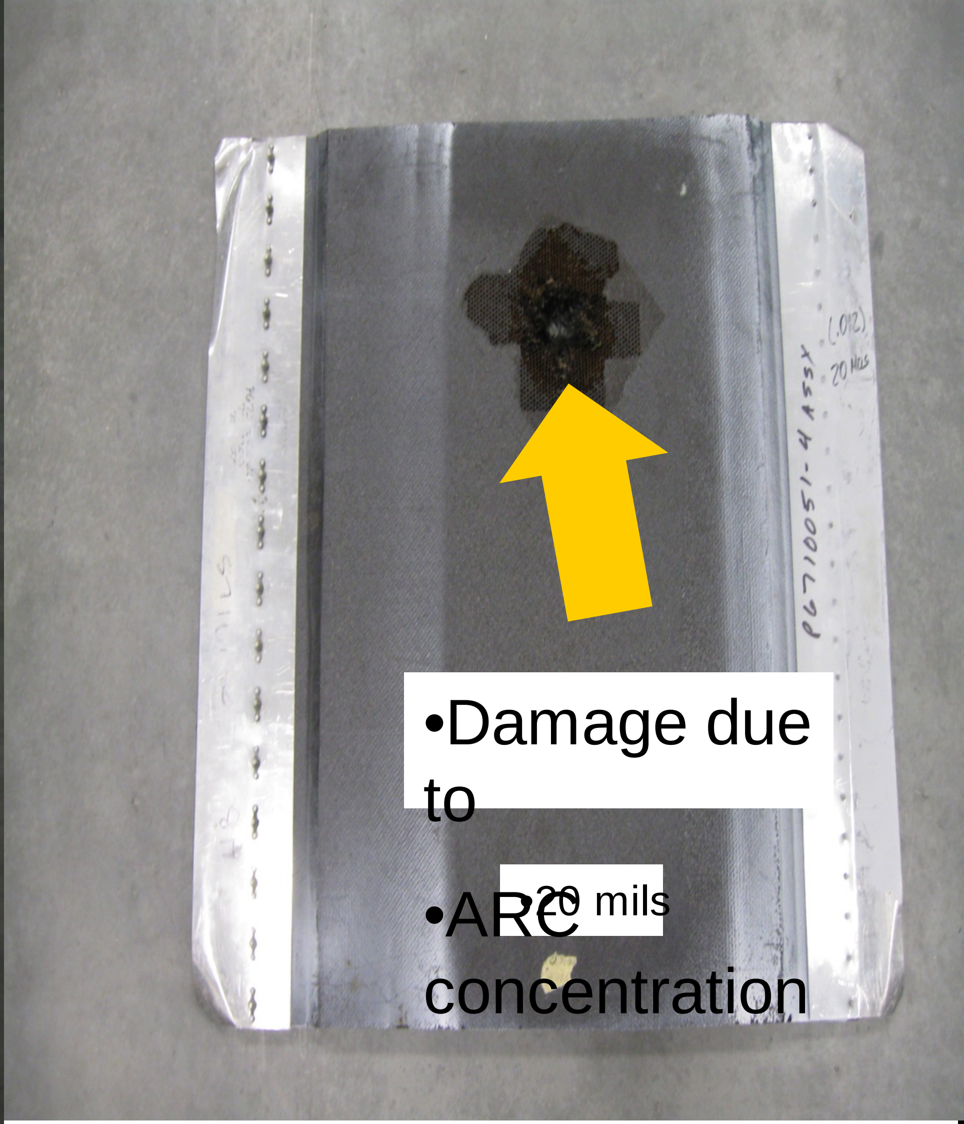
- **Arc Root**
- **Dispersion**

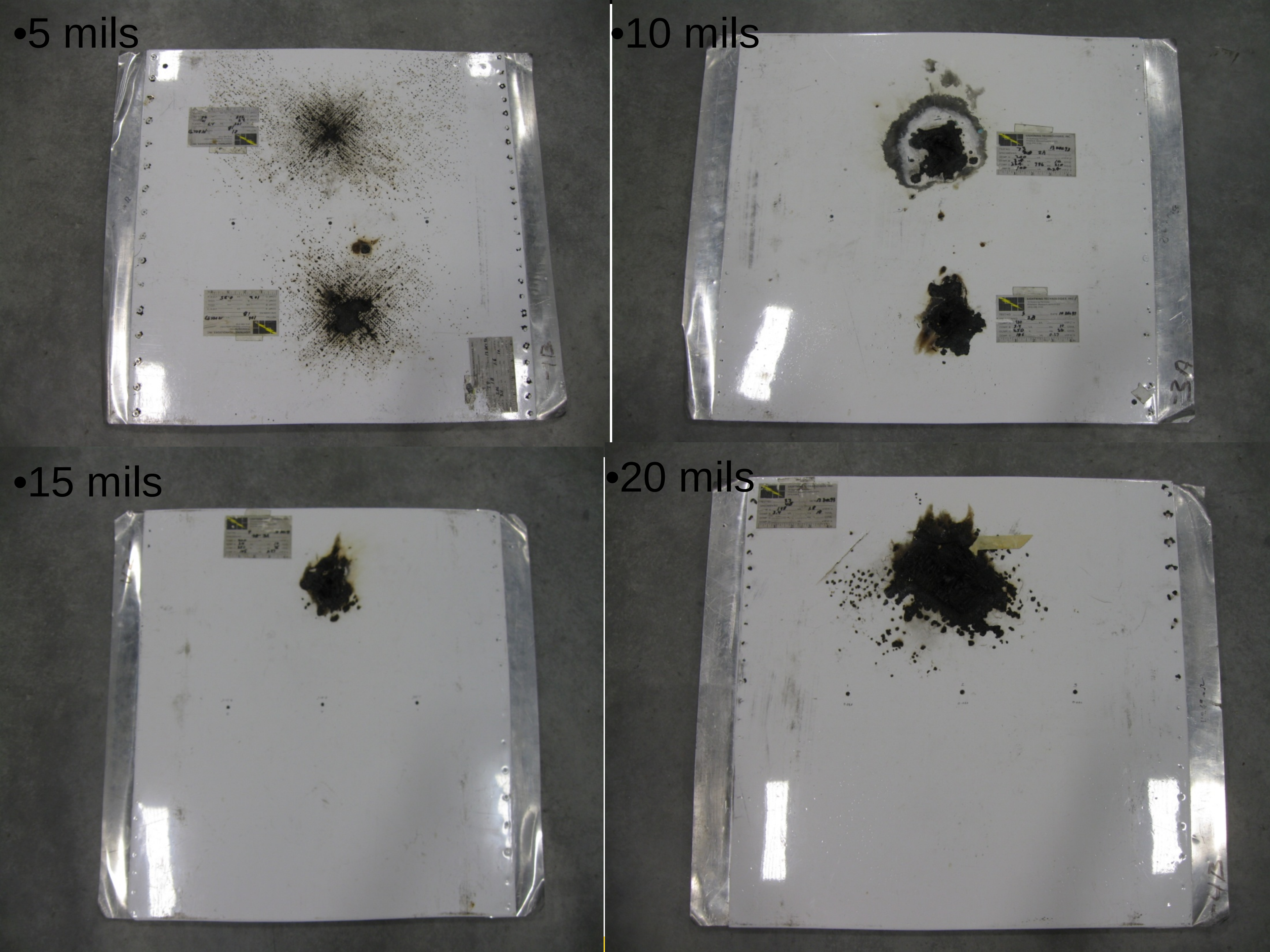
•5 mils


• Arc Root
• Dispersion
•10 mils
LIGHTNING TECHNOLOGIES, INC.
LIGHTNING TECHNOLOGIES, INC.


• Arc Root
• Dispersion
•15 mils


• Arc Root
• Dispersion
•20 mils


•Damage due to
•ARC concentration
•20 mils


•5 mils
•10 mils
•15 mils
•20 mils

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)*

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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

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Consider all aspects of protection or bad things happen

Questions?