Lightning Damage Prediction of Carbon Fiber Composite Materials

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Introduction

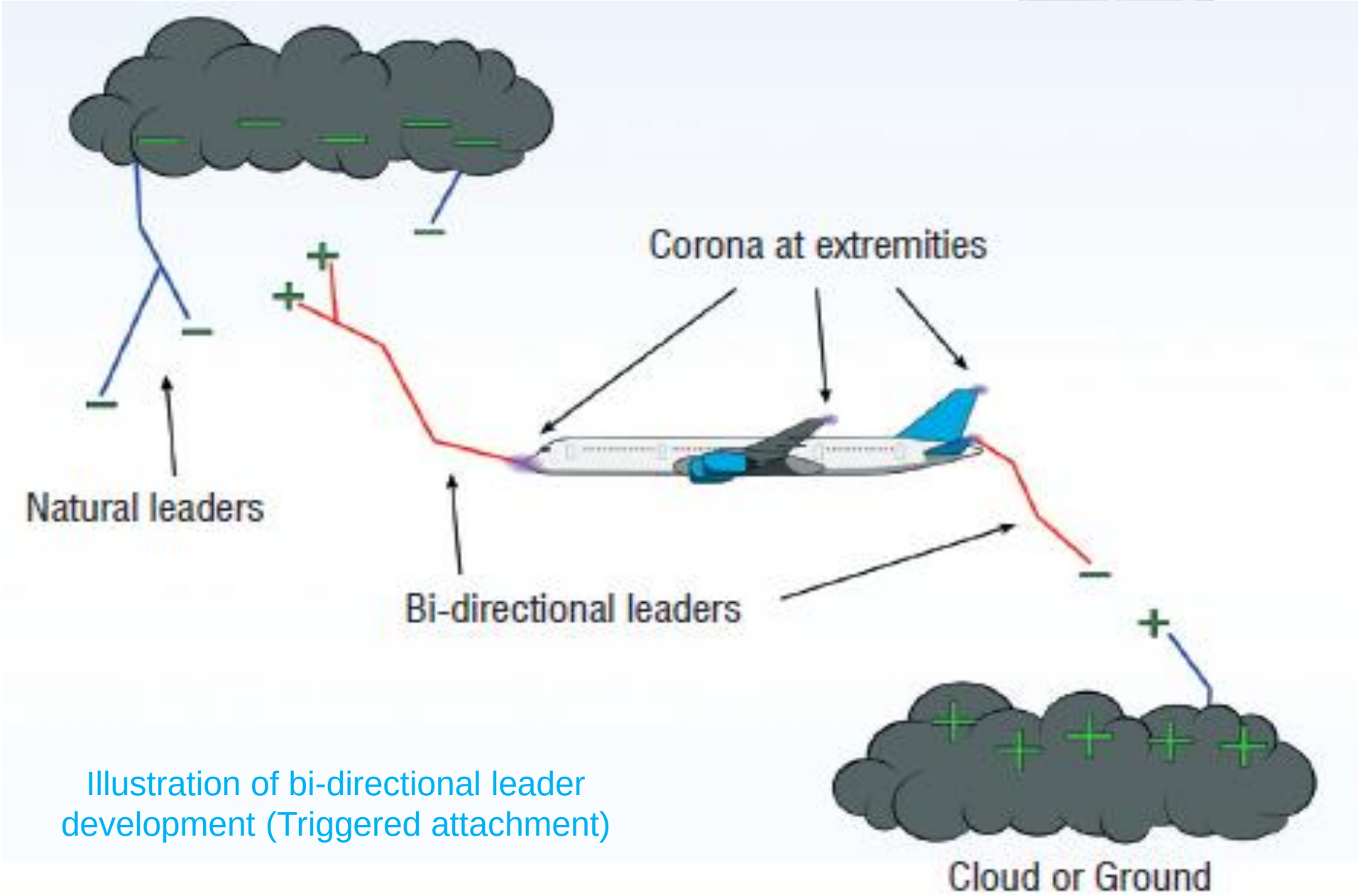


Illustration of bi-directional leader development (Triggered attachment)

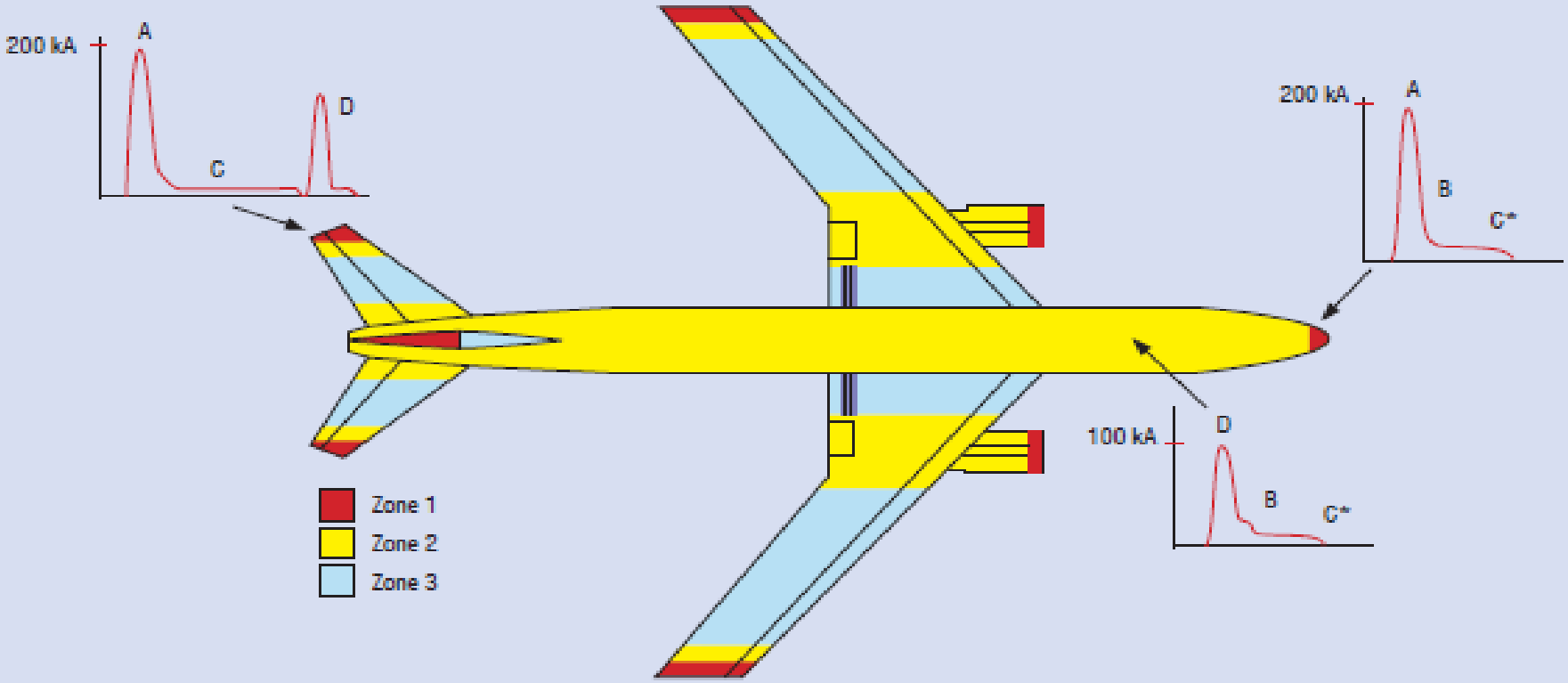
Introduction

Lightning protection

- Lightning strike to aircraft represents a possible safety hazard
- Goal: Prevent accidents and increase the reliability of aircraft.
- The protection of aircraft is based on standards and certification steps :
  - Zoning : consists in highlighting the most probable locations of attachment and sweeping zones on the aircraft
  - Structures tested in the laboratory, under controlled lightning conditions

Introduction

Box - Simplified aircraft zoning



Zone 1 - High probability of initial lightning flash attachment (entry or exit).

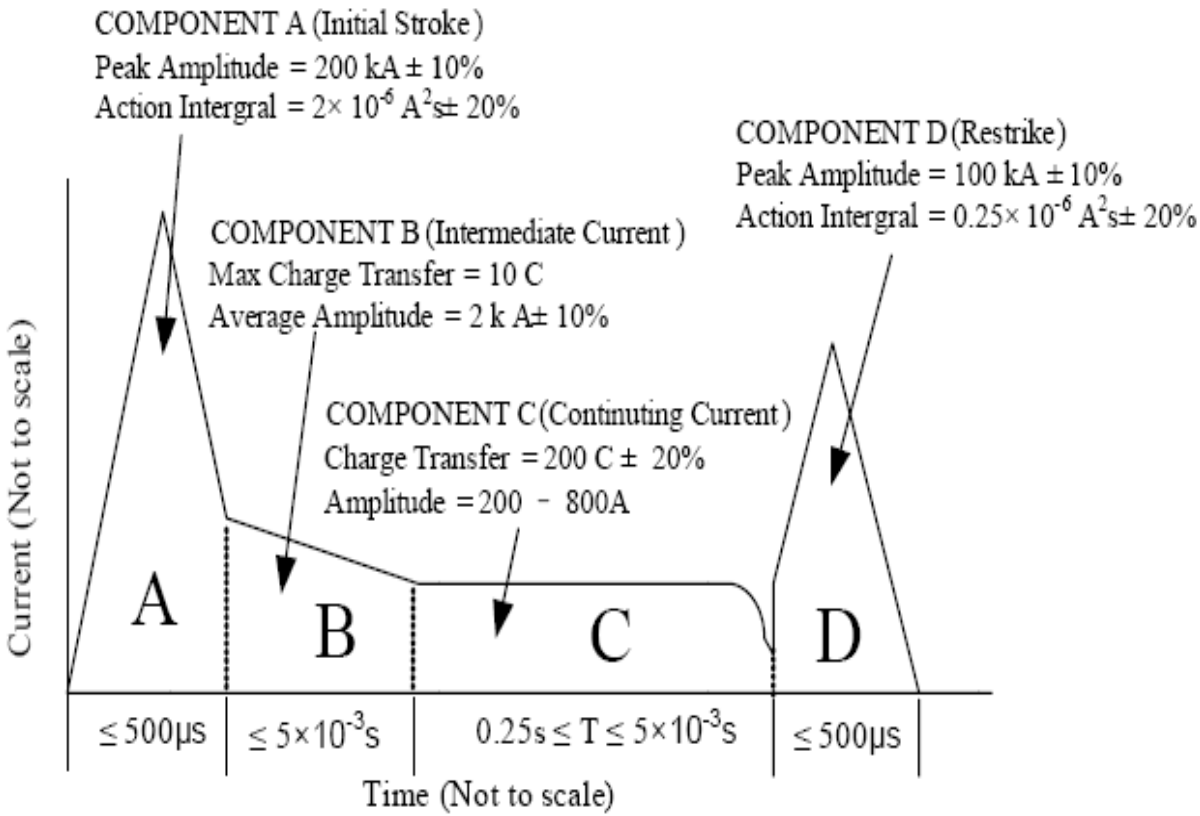
Zone 2 - High probability of a lightning flash being swept from a point of initial attachment.

Zone 3 - Any aircraft surface other than those covered by zones 1 and 2. In zone 3 there is a low probability of a direct attachment, however, zone 3 areas may carry substantial lightning currents by direct conduction between two attachment points.

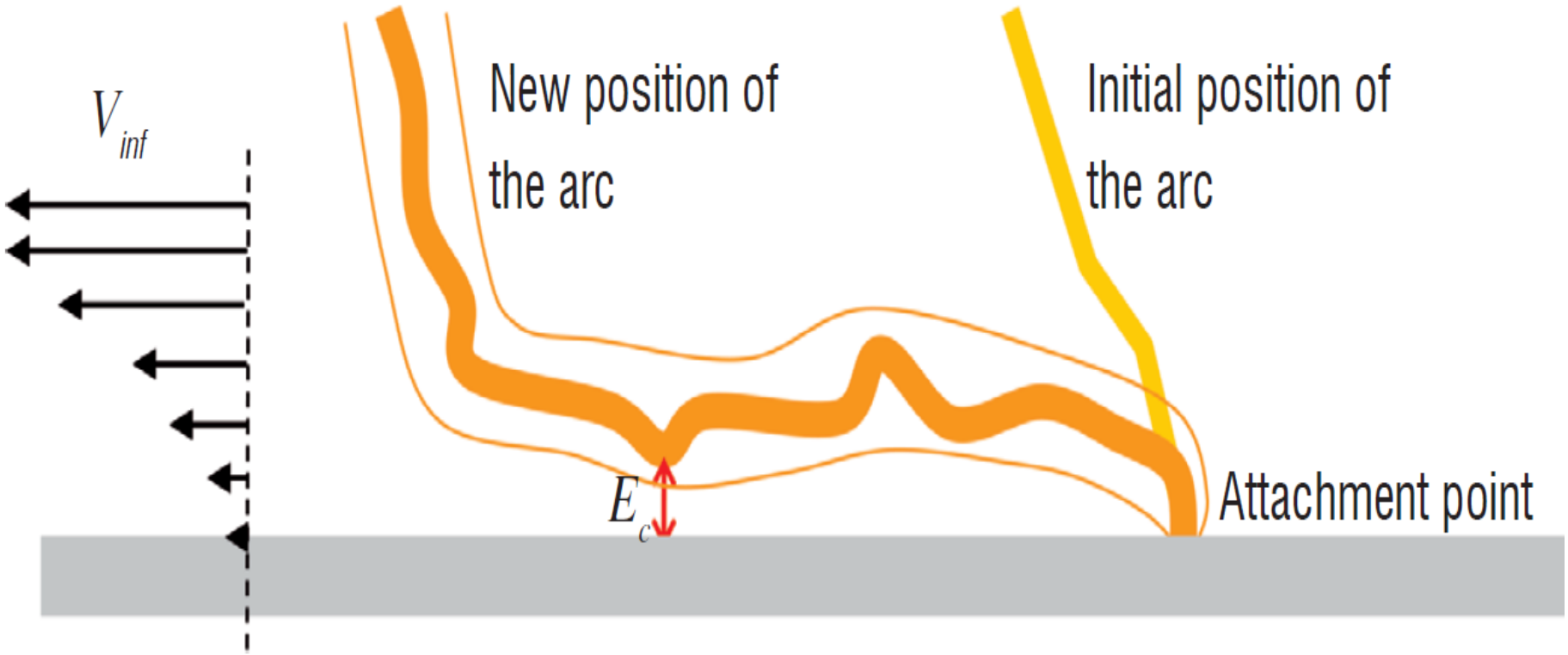
Zones 1 and 2 are further subdivided into A and B regions, depending on the probability that the flash will hang on for a protracted period of time. An A region is one in which there is a low probability that the arc will remain attached (*e.g.*, at the leading edge of a wing) and a B region is one in which there is high probability that the arc will remain attached (e.g., at the trailing edge of a wing).

Introduction

- *Lightning direct effect test：*
  - *Lightning injection test（SAEARP5416）*
    - ***Zone 1A （A+B+C*）***
    - ***Zone 1B（A+B+C +D）***
    - ***Zone 1C（A_h+B+C*）***
    - ***Zone 2A（D+B+C*）***
    - ***Zone 2B（D+B+C）***
  - *Lightning conduction test（SAE ARP 5416）*
    - ***Zone 3 （A+B+C +D）***

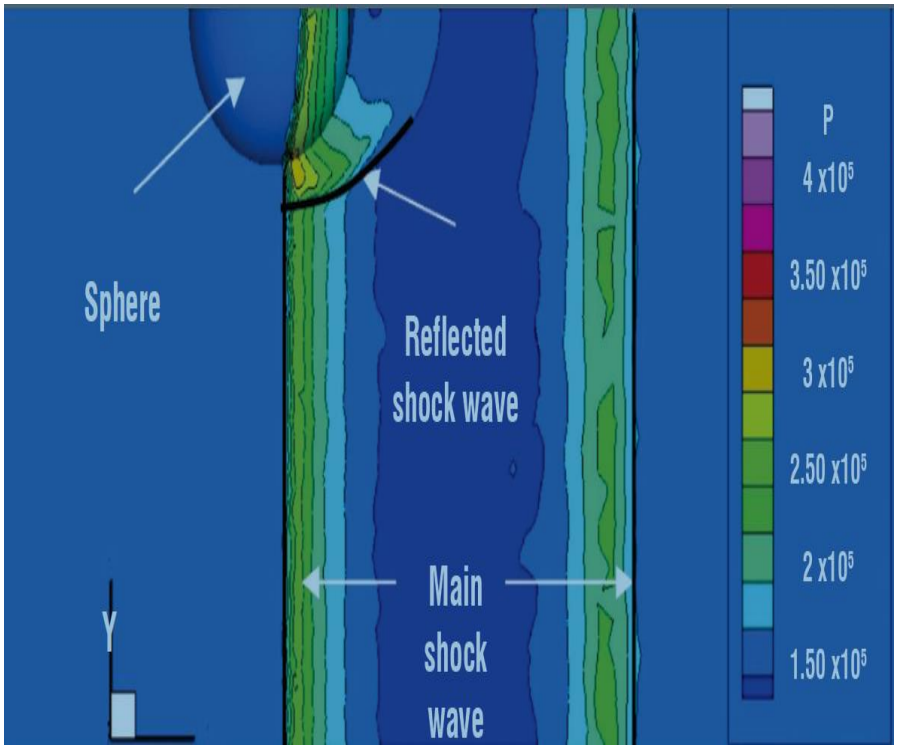


Lightning direct effect on CFRP

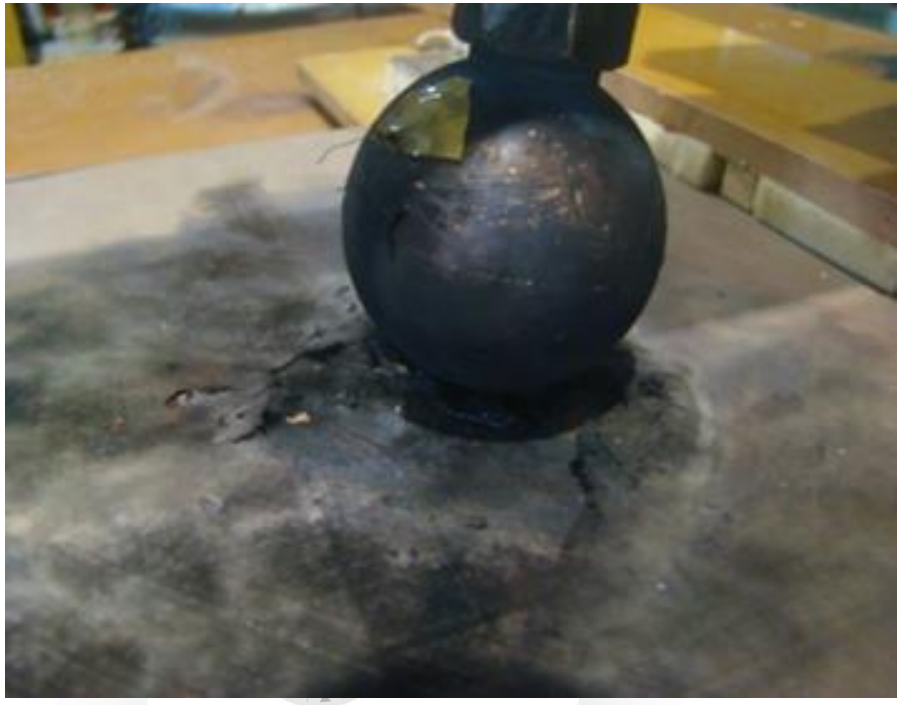


Schematic drawing of the swept stroke

Lightning direct effect on CFRP

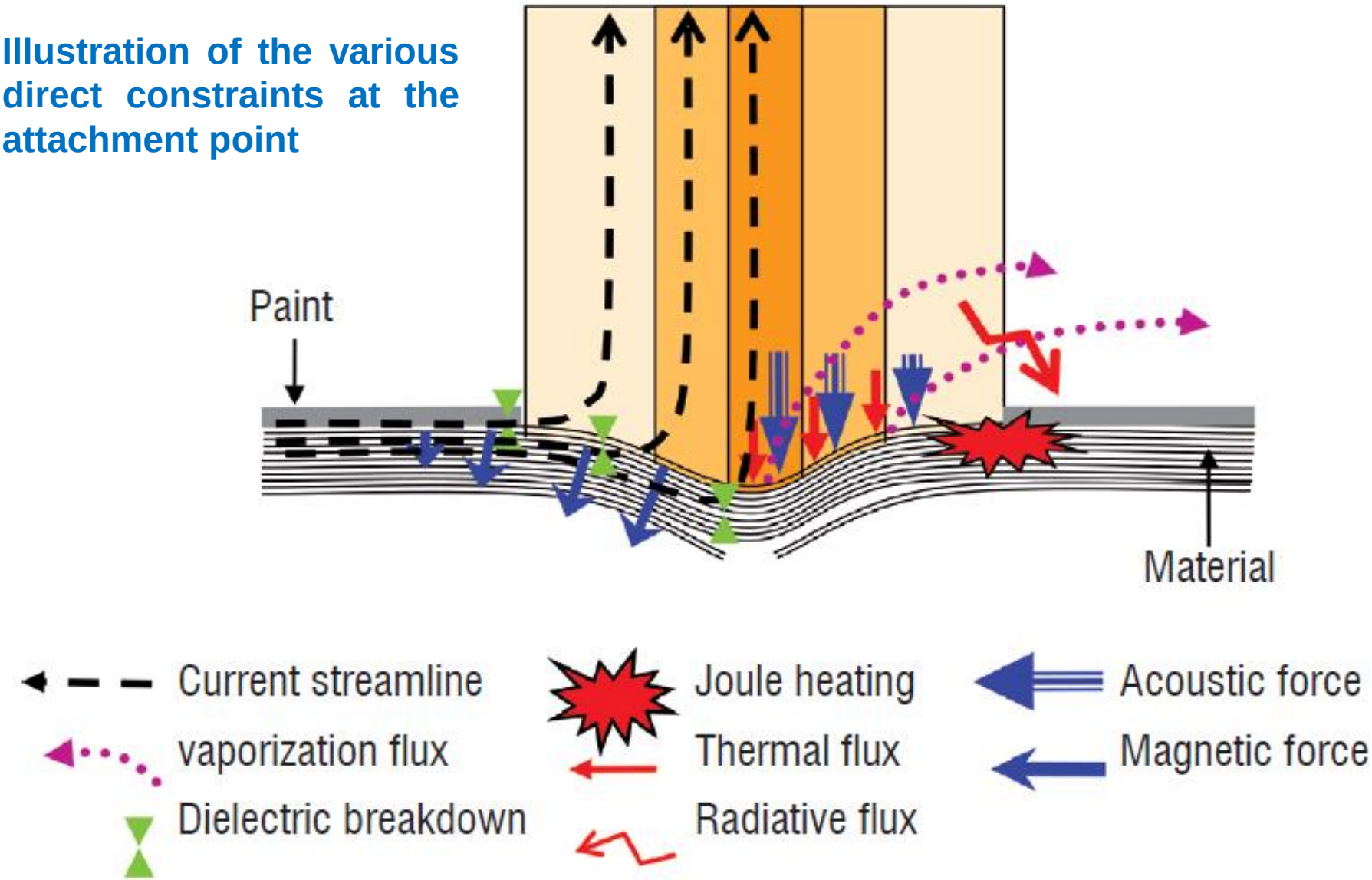


Formation of shock waves 23µs after ignition with the test set-up advised in the SAE ARP 5416



Lightning direct effect on CFRP

Illustration of the various direct constraints at the attachment point



Lightning damage prediction

Energy conservation

$$\int_S \left(\int E_c J_c \, dt\right) dx dy + \int_V \left(\int \rho J_c^2 dt\right) dx dy dz = \int_V H_0 dx dy dz$$

Simplification

$$\int E_c J_c dt + \int \rho J_c^2 dt Z_{max} = H_0 Z_{max}$$

Max. damage depth

$$Z_{max} = \frac{\int E_c J_c dt}{H_0 - \int \rho J_c^2 dt}$$

Expansion

$$Z_{max} = \frac{E_c \times \sum_{i=0}^{n} a_n \left(\int I dt\right)^n}{H_0 - \rho \times \sum_{i=0}^{n} b_n \left(\int I^2 dt\right)^n} \qquad (n = 1, 2 \ldots.)$$

- $Z_{max} = f(J_c)$
- **Parameters a_n and b_n are to counteract the influence of the composite model, the single layer thickness, the laying mode, the surface protection layer and the paint layer**

ECO COMPASS

Lightning damage prediction

$$Z_{\max} = \frac{E_c \times \sum_{i=0}^{n} a_n \left(\int I \mathrm{d}t\right)^n}{H_0 - \rho \times \sum_{i=0}^{n} b_n \left(\int I^2 \mathrm{d}t\right)^n} \qquad (n = 1, 2 \ldots.)$$

Damage depth prediction model

n=2

$$Z_{\max} = \frac{E_c \times \left(a_1 \times \int I \mathrm{d}t + a_0\right)}{H_0 - \rho \times \left(b_1 \times \int I^2 \mathrm{d}t + b_0\right)}$$

Error function

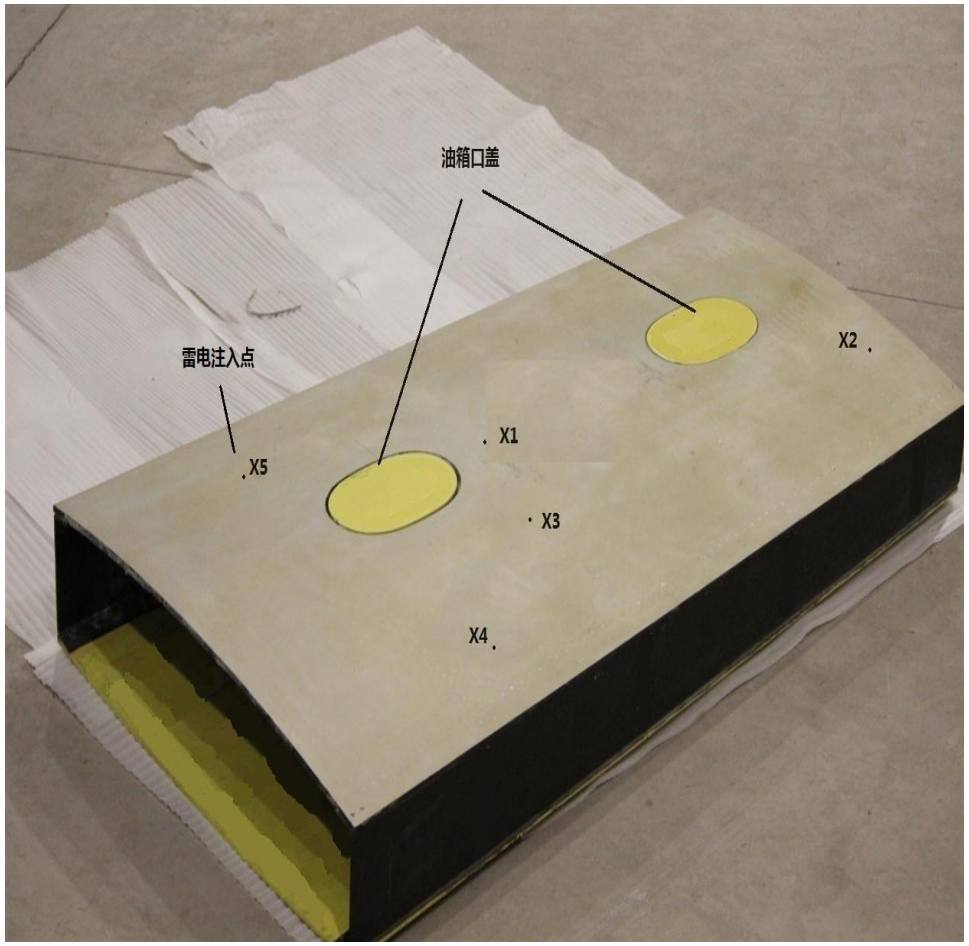
Genetic Algorithm is to adjust the parameters in the model to minimized the error

$$S = \sum_{test=1}^{n} \left(Z_{\max}{}^{test} - Z_{\max}\right)^2$$

$Z_{\max}{}^{test}$ is the maximum damage depth in the test to the number of trails

Lightning Test

Test pieces



- Composites wing box section
- Size: 2000mm*1100mm*300mm
- Aluminum mesh are used on surface， mesh wire in diameter of 0.1mm, covering by the paint layer of 0.2mm
- Lightning current injection point: X1~X5

T700/2510 Parameters

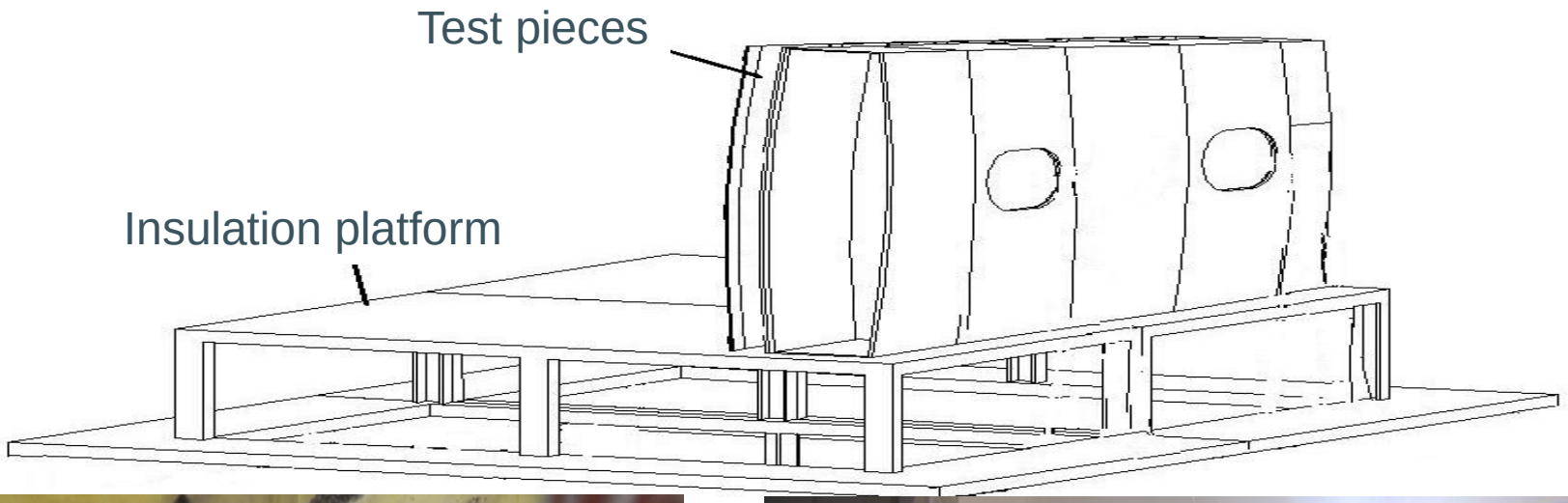
Material	E_C （V）	H_0 （J/m³）	P （Ω．m）
T700/2510	22.5	7.81×10^8	23.5

Lightning Test

Lightning current waveform

Injection point	Peak Current (kA)	Coulomb （C）	Action Integral (A^2s）
1	204.9	9.6	1.75×10^6
2	196.27	219.56	1.65×10^6
3	100.57	31.97	0.28×10^6
4	104.89	219.93	0.31×10^6
5	139.83	34.89	0.66×10^6

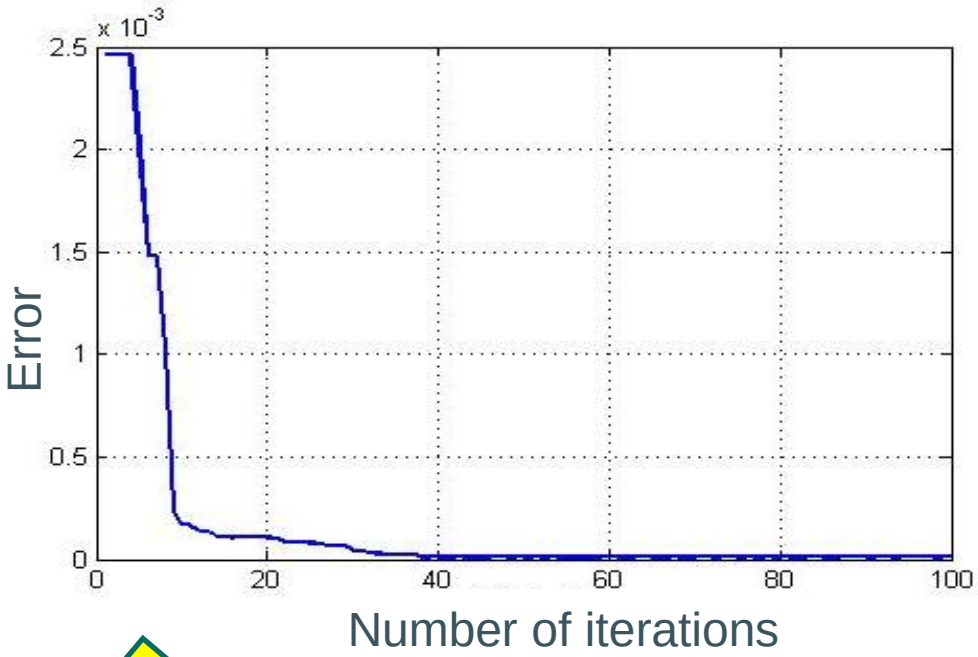
Lightning Test



Lightning Test

Ultrasonic test results

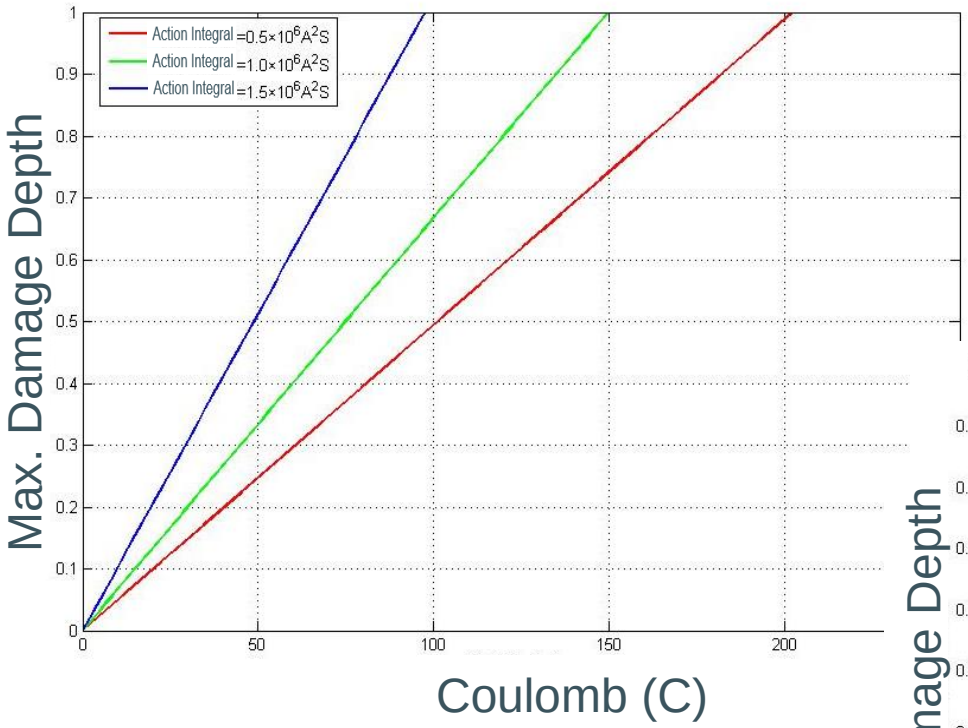
No. Injection points	Max. damage depth
X1	1/7
X2	1
X3	1/7
X4	1
X5	1/8



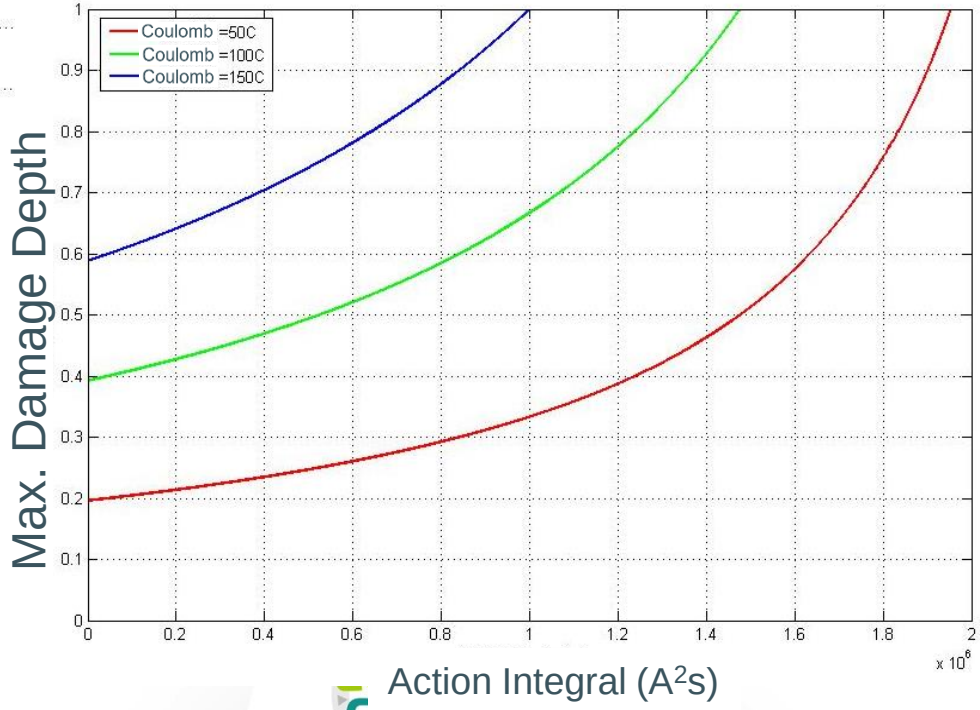
- ✓ 1 for complete breakdown
- ✓ 0 means no significant damage to the test piece

a_0	a_1	b_0	b_1
0	1.2147×10^5	3.5988×10^6	12.1967

Conclusion



A proportional increase!



Thanks!!