

Aircraft Structure Paint Thickness and Lightning Swept Stroke Damages

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ABSTRACT

During its flight an aircraft can be struck by lightning and the induced high current will require a highly conductive airframe skin structure in order for it to propagate through with minimum damage. However an aircraft skin is generally coated with paint and the airframer does not always have control on the paint thickness. Paint thickness generates heightened concerns for lightning strike on aircraft, mainly because most of coatings dedicated to that purpose are non-conductive. Using insulating material or non-conductive coating with certain thickness may contribute to or increase damage inflicted by the swept stroke lightning energy, even on metallic structures

Due to its high relative permittivity, a non-conductive paint or coating on a fuselage skin surface will contribute to slow down the lightning current propagation through structure. With this comes the risk of increasing heat that will favor structural damage and possible melt through. The correlation between paint thickness, lightning dwell time, and aircraft skin thickness are all contributing factors in lightning swept stroke damage in aircraft lightning Zone 2A. Paint thickness is not always under direct control of the manufacturer and the maximum paint thickness that could safely be applied on an aircraft skin with very low risk of puncture due to lightning is still a controversial matter. This paper introduces the analysis and investigation performed by the Bombardier Aerospace Core Engineering Electromagnetics team through several test campaigns.

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INTRODUCTION

During its flight, a commercial aircraft can be exposed to different electromagnetic threats, among which lightning appears to be the most spectacular, mainly because of the physical damages that can occur on an airframe.

Lightning current requires a highly conductive aircraft structure in order for it to propagate on the skin. This last requirement, coupled with the fact that there is normally a non-conductive coating, brings great concerns. As for the thickness of non-conductive paint used on aircraft skin surfaces being variable introduces an additional factor. Actually, low conductivity surfaces tend to slow down lightning current propagation, and as such, even a metallic aircraft skin can be badly damaged by the increased dwell of swept stroke lightning energy if the paint thickness is not well controlled.

Despite the knowledge available today about lightning effects there is a lack of data in the literature related to the

maximum paint thickness that could be applied on aircraft structure with minimum risk of puncture.

In order to quantify lightning swept stroke effects on a metallic aircraft skin, Bombardier core Electromagnetic Engineering has performed investigation via testing of several aluminum panels with different paint thickness. The testing was performed at the former Lightning Technologies in Pittsfield) (USA).

This paper highlights the interaction between lightning dwell time, paint thickness, variation of charge transfer and the magnitude of damage on the panels tested.

DESCRIPTION OF THE MECHANISM RELATED TO LIGHTNING DAMAGES

Insulating aircraft skin with a certain thickness of non-conductive paint may cause not only electrostatic problems, but also lightning damage in swept stroke Zones. For lightning, the dwell time at the point of attachment on a

painted metallic panel is dependent on the electrical characteristics of the paint which are: the relative permittivity ϵ_r , the relative permeability μ_r and the relative conductivity σ_r . ϵ_r contributes to slow down the lightning energy propagation within non-conductive paint with a velocity V such as :

$$V = \frac{C}{\sqrt{\epsilon_r}} \quad (1)$$

with C as the speed of the light

Any aluminum panel is characterized by its electrical conductivity $\sigma(\sigma_{\perp}, \sigma_{\parallel})$, with components $\sigma_{\perp}$ and $\sigma_{\parallel}$ as described on [Figure 1](#). Within the horizontal plane of the panel, the conductivity is $\sigma_{\parallel}$ and perpendicularly to that (on the radial axis $\vec{OZ}$) the conductivity becomes $\sigma_{\perp}$ with:

$$\sigma_{\perp} \ll \sigma_{\parallel} \quad (2)$$

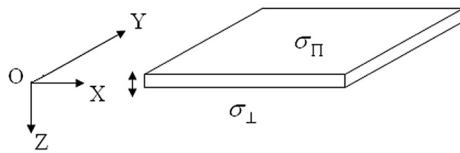


Figure 1. Conductivity distribution on square metallic painted panel

During a lightning strike, an Electric field $E(E_x, E_y, E_z)$ will be developed at the injection point and in the surrounding zone, with E_x and E_y on the upper surface of the skin, and E_z as the radial component. Through the panel, we may assume that:

$$E_z \leq E_x \text{ and } E_z \leq E_y \quad (3)$$

Coming back to the painted panel under lightning swept stroke test, the current density J will be developed such as:

$$J = \sigma E \quad (4-a)$$

Or else

$$J = \begin{pmatrix} \sigma_{\parallel} & 0 & 0 \\ 0 & \sigma_{\parallel} & 0 \\ 0 & 0 & \sigma_{\perp} \end{pmatrix} \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix} \quad (4-b)$$

Thus:

$$\vec{J} = \sigma_{\parallel} \vec{E}_x + \sigma_{\parallel} \vec{E}_y + \sigma_{\perp} \vec{E}_z \quad (4-c)$$

From [equations \(2\), \(3\) and \(4\)](#) one has:

$$\sigma_{\perp} \vec{E}_z \ll \sigma_{\parallel} \vec{E}_x + \sigma_{\parallel} \vec{E}_y = \sigma_{\parallel} (\vec{E}_x + \vec{E}_y) \quad (4-d)$$

Then using [equations \(4-c\) and \(4-d\)](#), we may approximate the current density developed in the panel of concern such as:

$$\vec{J} \approx \sigma_{\parallel} (\vec{E}_x + \vec{E}_y) \quad (5)$$

[Equation \(5\)](#) shows that the majority of lightning current stays on the metallic panel surface. That current moves faster on the outer layer of the skin structure (because of the high conductivity of the horizontal plane) than within the cross section. The cross section of the panel that is conducting less, will then rely only on the thickness of the metal to withstand charge transfer energy that may lead to a puncture. The heat generated by lightning on the aircraft structure is inversely proportional to the electrical conductivity; therefore the cross section of the panel will face more heat during lightning swept stroke than the horizontal plane of the panel. Finally, if that heat is not dissipated and reaches the aluminum melting temperature, then there will be a puncture in the panel at the point of lightning attachment.

LIGHTNING DIRECT STRIKE EFFECTS TESTS ON PAINTED ALUMINUM PANELS

To study this problem, Bombardier Core Electromagnetic Engineering has performed multiple tests on several aluminum panels, representative of aircraft skin, coated on the external surface with different paint thicknesses (of the same type of paint) ranging from 5mils (0.005 inches or 0.127mm) to 20mils (0.02 inches or 0.51mm). The internal surface of each panel was coated with one layer of a specific protective coating. The tests were performed on panels that are designed to be implemented on aircraft lightning zone 1A and 2A according to SAE ARP 5416. An ignitable mixture was used during those tests to detect any presence of puncture or hot spot in the panel that could cause ignition. [Fig.2](#) depicts lightning energy used to test the panels.

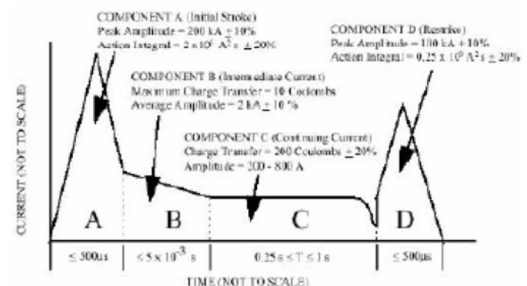


Figure 2. Lightning energy used for painted panels

Component D- subsequent stroke current

Action Integral (AI) $0.25 \times 10^6 \text{ A}^2 \text{ s}$ ($\pm 20\%$) with 500 μs ,
Peak (Ip) 100 KA ($\pm 10\%$)

Current component B -subsequent stroke current

- Charge transfer Q_c of 10 ($\pm 10\%$) coulombs in 5($\pm 10\%$) ms
- Average amplitude of 2kA ($\pm 10\%$)
- Current component C, continuing current
- Average (IA) 400 A ($\pm 10\%$) Dwell time of 5,10,15,35, and 45 ms

Figure 3 shows examples of damages observed 5.5 mils paint thickness after a lightning swept stroke test with an average of 36 ms of dwell time,; and 22.5 C charge transfer

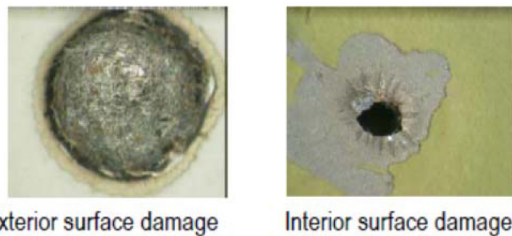


Figure 3. Damages due to swept stroke lightning in zone 2A(magnified 14 times)

The understanding of the structure puncture in Zone 2A following a lightning strike, requires finding a correlation between all the parameters that contribute to that puncture on the aircraft skin. That correlation is governed by the interaction between paint thickness, dwell time, charge transfer variation and the amplitude of damage

TEST RESULTS ANALYSIS AND UNDERSTANDING OF THE PHENOMENON

Tables 1 and 2 summarize some data measured on different panels with 5 mils paint thickness respectively 10 mils. For the same paint thickness, each panel was struck several times, but at different locations. From the measured data it is assumed that there is a melting through in the panel any time the depth of the puncture on the panel reaches 80 mils (0.08 inches or 2.032 mm), that represent the metallic panel thickness. Under that limit, the panel is damaged without melting through

Table 1. Correlation between Total charge transfer and dwell time for 5mils paint thickness

Test panel number /test point number	Damage depth without melt through (inches)	Total charge transfer (Coulomb s)	Equivalent Dwell time (ms)
Test panel 4 / test point 5	0.0364	10.1	5
Test panel 6 / test point 1	0.0384	12.9	12
Test panel 4 / test point 1	0.0508	12.9	12
Test panel 5 / test point 1	0.0521	13	12
Test panel 6 / test point 2	0.0545	15.8	19
Test panel 4/ test point 2	0.0553	15.8	20
Test panel 5 / test point 2	0.0599	16	20
	Damage depth with melt through (inches)	Total charge transfer (Coulomb s)	Equivalent Dwell time (ms)
Test panel 4 / test point 6	0.08	27.8	50
Test panel 5/ test point 5	0.08	29	53

Table 2. Correlation between Total charge transfer and dwell time for 10mils paint thickness

Test panel number /test point number	Damage depth without melt through (inches)	Total charge transfer (Coulombs)	Equivalent Dwell time (ms)
Test panel 7 / test point 1	0.0463	12.7	12
Test panel 9 / test point 1	0.0488	12.9	12
Test panel 8 / test point 2	0.0662	15.9	20
Test panel 8/ test point 3	0.0607	19.2	28
Test panel 7 / test point 2	0.0773	22	35
	Damage depth with puncture (inches)	Total charge transfer (Coulombs)	Equivalent Dwell time (ms)
Test panel 7/ test point 3	0.08	18.7	27
Test panel 9/ test point 4	0.08	22.3	36
Test panel 8/ test point 4	0.08	23	38
Test panel 9/ test point 5	0.08	26.8	47
Test panel 7/ test point 5	0.08	27.2	48
Test panel 8/ test point 5	0.08	28.3	51

The non-exhaustive set of data exposed in table 1 and table 2 shows that the dwell time $t(\text{ms})$ and the charge transfer $Q(c)$ that govern aircraft structure puncture due to a swept stroke following lightning attachment, can be related as follows, provided $t > 0$

$$Q_c(t) = \alpha + \beta t \quad (6)$$

α and β are parameters to be determined in table 3

Tests have been conducted on different aluminum panels with respectively 5mils, 10 mils, 15 mils and finally 20 mils paint thickness.

Table 3 gives values for α and β determined for 5 mils, 10 mils, 15 mils and 20 mils paint thicknesses.