Electrical Characterizations of Lightning Strike Protection Techniques for Composite Materials

George N. Szatkowski, Truong X. Nguyen, Sandra V. Koppen, Jay. J. Ely
NASA, Langley Research Center, Hampton, Virginia

John J. Mielnik
Lockheed Martin, Hampton, Virginia

Abstract

The growing application of composite materials in commercial aircraft manufacturing has significantly increased the risk of aircraft damage from lightning strikes. Composite aircraft designs require new mitigation strategies and engineering practices to maintain the same level of safety and protection as achieved by conductive aluminum skinned aircraft. Researchers working under the NASA Aviation Safety Program's Integrated Vehicle Health Management (IVHM) Project are investigating lightning damage on composite materials to support the development of new mitigation, diagnosis & prognosis techniques to overcome the increased challenges associated with lightning protection on composite aircraft. This paper provides an overview of the electrical characterizations being performed to support IVHM lightning damage diagnosis research on composite materials at the NASA Langley Research Center.

Introduction

NASA's work in advanced aeronautics includes growing interest in environmentally responsive aircraft, one component of which involves the use of composite materials to significantly reduce weight, and hence fuel consumption. The aircraft industry shares this interest and is utilizing more composite materials in each new generation of aircraft being manufactured for general aviation, business jet and jumbo jet aircraft applications. Boeing's 787 aircraft is just one example of the growing use of composites being incorporated in the construction of the next generation fleet. With this growth in composite usage, new technical challenges arise. Composite skinned aircraft are far more vulnerable to lightning strikes than their aluminum skinned predecessors. The electrical current incident on an aircraft from a typical lightning strike can exceed 200,000 amperes [1], occurring in less than a fraction of a second.

Without proper lightning strike protection, the carbon fiber/epoxy composites can be significantly damaged, particularly at the entry and exit points of the strike. Approaches have been developed to protect the composite structures from lightning direct effects to reduce damage to acceptable levels by using conductive foils or meshes in the outer layer of the composite system. When a known lightning strike occurs, the points of attachment and detachment on the aircraft surface are visually inspected and checked for damage to ensure continued flight safety. Repairs may be required to replace damaged composite sections per FAA procedures [2].

Even though lightning damage can occur on a composite aircraft, the damage level and associated risk to flight safety is deemed acceptable by the FAA and does not compromise flight safety. However, existing lightning strike protection techniques in composite systems are not always sufficient to adequately protect avionic installations from potential upset due to induced electromagnetic fields coupled into the aircraft and require additional protections to improve avionic shielding to meet standards for aircraft certification. These additional protections reduce the overall weight savings the composites provide.

NASA's IVHM project is interested in supporting research to help the aircraft industry improve shielding effectiveness performance on composite lightning strike protection designs. Identifying the most promising technologies which are expected to emerge for future composite fuselage designs is an important component to IVHM research. The stated goal of the IVHM lightning research is to diagnose lightning damage based on a measurement of the lightning current transferred to the aircraft to estimate potential damage in flight. To accomplish this goal, identifying the appropriate composite lightning strike protection technique expected to be fielded in future aircraft designs is essential to develop representative lightning damage at different levels of lightning current. This will allow meaningful fatigue to failure analysis to be performed to support damage diagnosis and failure prognosis.

Electrical characterizations will be conducted to evaluate RF shielding effectiveness, current propagation and surface conductivity on various composite lightning strike protection techniques both before and after lightning direct effect testing. This paper provides a description of the ongoing electrical characterizations and presents example test results.

RF Shielding Effectiveness Measurements

Efforts are under way in the NASA Langley High Intensity Radiated Fields Laboratory (HIRF Lab) to establish test methodologies to conduct RF shielding effectiveness (SE) measurements on composite panels with integrated lightning strike protection in the outer layer. Facility modifications completed in the summer of 2007 included the addition of a 4 foot square aperture in the adjacent wall between two faraday enclosures to provide the capability to perform nested reverberation shielding effectiveness measurements. A test fixture plate was fabricated to go over the large aperture to reduce the size of the opening to 12" x 12" to accommodate 14" x14" composite panels allowing 1" overlap on each side to ensure adequate electrical contact. The test fixture can accept panels up to a half inch thick. Figure 1 presents a photograph of a composite panel mounted in the test fixture.

Figure 1. Composite Panel Mounted in Test Fixture

SE measurements in the HIRF Lab [3] will follow a NIST developed test technique [4] which requires mode stirring in the chamber to expose the composite panel with varied polarizations and angles of incidence to determine the average SE. Unlike other reverberation techniques, the NIST approach accounts for the aperture shape, cavity size and chamber loading effects to improve measurement accuracy. Basic SE is determined by the ratio of two independent measurements, with and without the panels, with the transmit antenna in one chamber and the receiver antenna in another chamber. The NIST developed first-order corrections account for the change due to the presence of the panels to the chambers' Q, which can be measured with both transmit and receive antenna in the same chamber. Rather than measuring average receive power as theorized, peak receive power was measured to improve measurement sensitivity by about 10 dB. The receive power ratios used should be equal for peak and average values, however, the use of peak values can result in slightly larger variability and uncertainties.

Initial test results show very good dynamic range performance can be achieved in the HIRF facility up to about 4 GHz. Above 4 GHz, chamber losses begin to impact system performance and reduce the overall dynamic range of the measurement. Methods to improve measurement performance above 4 GHz will be investigated. Figure 2 presents the shielding effectiveness data of a 7 layer carbon fiber weave composite panel with aluminum mesh lightning strike protection. The vertical axis is calibrated SE in dB. The horizontal axis represents frequency in megahertz. The top trace is the calibrated shielding effectiveness of the composite panel. The bottom trace is the calibrated noise floor of the measurement. The tested panel is shown to posses about 120 dB of isolation below 1.5 GHz. The composite panel edges were not prepared in any way to improve surface conductivity between the panel and the test fixture. Techniques to increase the surface conductivity at the composite panel edges to reduce RF leakage around the panel will be explored and are expected to further improve the measured performance of the composite panels.

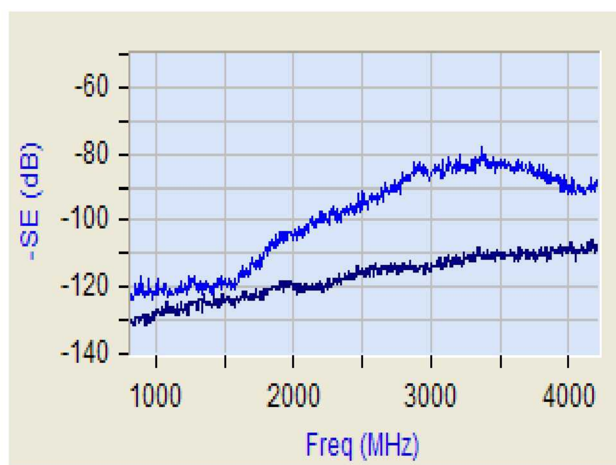

Figure 2. SE Measurement of Composite Panel

Shielding effectiveness testing will be conducted on various composite panels with lightning strike protection techniques both before and after lightning direct effect testing.

Eddy Current Measurements

Eddy current measurements were performed on an initial set of composite panels with lightning strike protection at Langley's Non Destructive Evaluations Lab to evaluate surface conductivity on the upper and lower surfaces. Eddy current measurements have been shown to be an effective test to find defects in reinforced carbon-carbon materials [5]. The initial measurements will serve as a baseline for repeat measurements after the panels are exposed to direct effect lightning exposure.

The Jentek Meandering Winding Magnetometer system was used to conduct the measurements and is shown in Figure 3. The flexible array coil is positioned on the underside of the wheeled cart. The cart position is recorded by an encoder wheel as it is translated across the composite panel under test and the data is processed to generate a C-scan image over the surface of the sample.

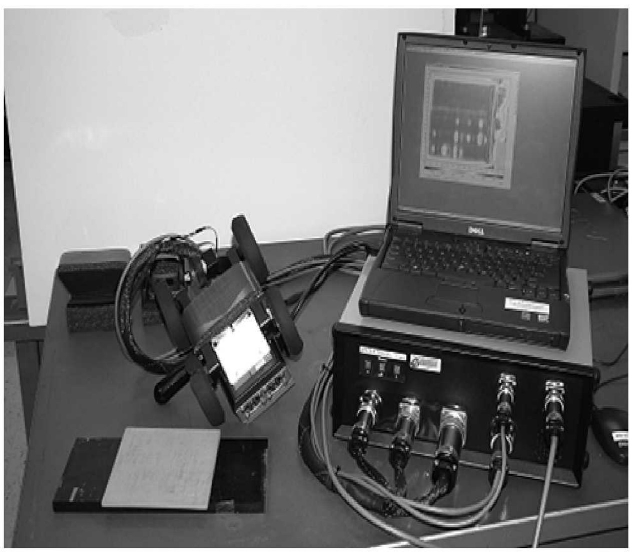

Figure 3. Jentek Meandering Winding Magnetometer

The eddy current measurements were conducted at 10 MHz to provide the best surface flaw detection. Both the composite panel upper surface with the lightning protection layer and the bottom surface were independently scanned.

Figure 4 presents an example eddy current C-scan image collected on the upper surface of a 7 layer carbon fiber weave composite panel with aluminum mesh lightning strike protection. The horizontal and vertical axis are surface dimensions of the panel in inches and the image depicts the center 12" x 12" area. The color intensity depicts the surface conductivity of the panel and ranges in intensity from 1.95×10^4 (ohm*m)$^{-1}$ to 2.45×10^4 (ohm*m)$^{-1}$

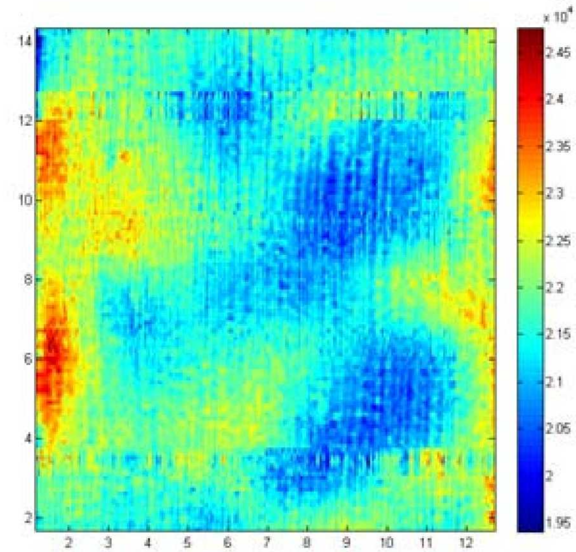

Figure 4. Eddy Current C-scan Image of Composite Panel Top Surface with Aluminum Mesh

Figure 5 presents the eddy current measurement data collected from the bottom surface on the same panel showing the difference in conductivity. The conductively intensity scale for the back side of the panel is 1×10^5 (ohm*m)$^{-1}$ to 1.3×10^5 (ohm*m)$^{-1}$

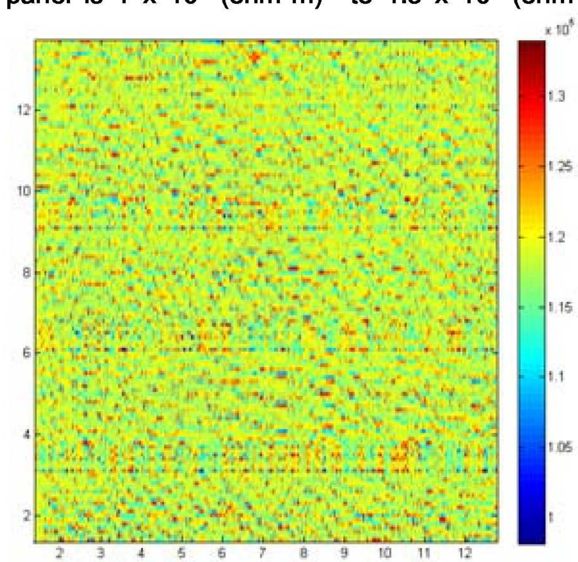

Figure 5. Eddy Current C-scan Image of Composite Panel Bottom Surface

Surface Current Mapping Measurements

Personnel at Old Dominion University (ODU) Research Foundation are working collaboratively under a NASA Research Announcement cooperative agreement to support Langley HIRF Lab researchers to investigate lightning current propagation on composite materials using surface current mapping techniques. The purpose of these investigations is to determine the effects various lighting strike protection techniques have on the overall lightning current propagation. Surface current mapping techniques will also be used to help evaluate and calibrate the performance of lightning current measurement sensors currently under development.

The measurements are conducted by injecting a simulated lightning waveform on one edge of the composite panel. The current flows across the panel to the ground terminal located on the other edge of the panel. The current sensor is moved to various locations on the panel and records the electrical current at its location. Surface current mapping will be conducted on various composite lightning strike protection techniques both before and after lightning direct effect testing. Research at NASA, Langley will begin in this area in the late fall of 2009.

ODU personnel have conducted preliminary surface current mapping measurements using a vector measurement technique incorporating two orthogonal Hall Effect sensors to determine the direction of current flow. Preliminary measurements to demonstrate a proof of concept have been completed and are presented in Figure 6.

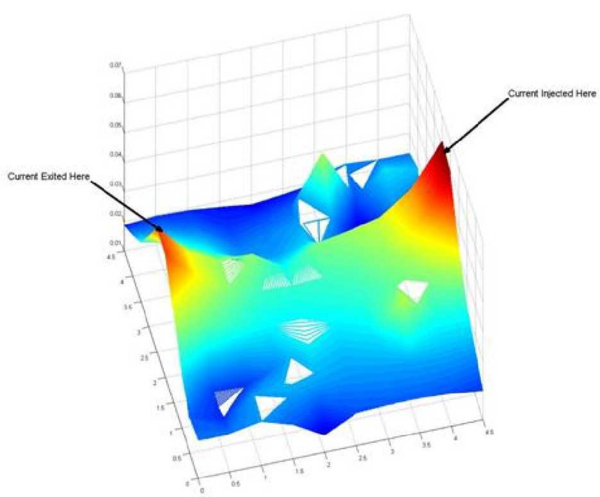

Figure 6. Current Map using Hall Effect Sensors

Distance in inches are shown on the x and y axis. Current density is shown in the z axis. The image clearly shows the current path along the length of the composite surface. Discontinuities in the image are believed to be from improper grid spacing in the measurement procedure.

Conclusions

Researchers working under NASA's Aviation Safety Program's Integrated Vehicle Health Management (IVHM) Project are investigating lightning damage on composite materials to support the development of new mitigation, diagnosis & prognosis techniques to overcome the increased challenges associated with lightning protection on composite aircraft. The stated goal of the IVHM lightning research is to diagnose lightning damage based on a measurement of the lightning current transferred to the aircraft to estimate potential damage in flight. Identifying the appropriate composite lightning strike protection technique expected to be fielded in future aircraft designs is essential to develop representative lightning damage at different levels of lightning current to conduct meaningful fatigue to failure analysis for damage diagnosis and failure prognosis. Electrical characterizations will be conducted to evaluate shielding effectiveness, current propagation and RF surface conductivity on various composite lightning strike protection techniques both before and after lightning direct effect testing.

References

[1] Pitts FL, Fisher BD, Vladislav V, Perala RA. Aircraft jolts from lightning bolts. IEEE Spectrum 1988;25:34–8.

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