SIMULATION OF LIGHTNING STRIKE EFFECTS ON AIRCRAFT SKIN COMPOSITE LAMINATE

By

Muhammad Elsayed Hamza Khalil

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Aerospace Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

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Title of Thesis:

Simulation of Lightning Strike Effects on Aircraft Skin Composite Laminate

Key Words:

Lightning Strike, Electric Arc, Composite Laminates, Thermal Plasmas, Magnetohydrodynamic Modeling (MHD).

Summary:

Aircraft carbon fiber/epoxy composite material is sensitive to lightning strike. Its damage and protection design suffering from lightning strike is becoming increasingly important. A numerical model is proposed to describe an arc and its interaction with a composite material in an anodic configuration. After a validation step with published experimental results in two dimensions (2D), the model is used to quantify the degradation level of the material versus the pulse duration and the current intensity value. A three-dimensional (3D) model is then developed and used to evaluate the degradation of the composite material. This model shows the behaviour of the plasma column representing the lightning strike and quantifies the power transferred to the anode. The contribution of this study is modeling the composite panels' material properties as temperature dependent, which was excluded by other researchers. The order of estimated temperature (of the order of 45,000 K) and pressure (of the order of 0.1-0.2 MPa) suggests that the waveform – C damage is mainly due to thermoelectric effect, while pressure effect is minimum.

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Dedication

To my father for his partnership in every success in my life.

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Nomenclature

Abbreviations

LTE	Local Thermodynamic Equilibrium
MHD	Magnetohydrodynamic
LSP	Lightning Strike Protection system
FEA	Finite Element Analysis
SMF	Solid Metal Foils
ECF	Expanded Metal Foils
CFRP	Carbon Fiber Reinforced Polymers

Symbols

$\vec{H}$	Vector magnetic field intensity
$\vec{D}$	Electric displacement vector
σ	Electrical conductivity
$\vec{J}$	Current density
ε	Dielectric constant (permittivity)
μ_0	Permeability
$\vec{E}$	Electrical field intensity
V	Electrical potential
$\vec{B}$	Magnetic flux density
$\vec{A}$	Magnetic potential
$\vec{v}$	Velocity vector
t	Time
ρ	Density
μ	Viscosity
p	Pressure
k	Thermal conductivity
T	Temperature
T_0	Ambient Temperature
k_B	Stefan-Boltzmann constant
e	Electron charge

ε_N	Net emission coefficient
q_a	Anode heat flux
q_c	Cathode heat flux
q_{pl}	Plasma heat flux
$\vec{n}$	Vector normal to the electrodes surfaces
j_i	Ion current density
j_e	Electron current density
V_i	Air ionization potential
$\emptyset_c$	Cathode work function
$\emptyset_a$	Anode work function
$\emptyset_e$	Effective work function
V_A	Anode fall voltage
A_r	Richardson's constant
j_r	Richardson current density
r_c	Internal volumetric current source per unit volume
P_{ec}	Electrical energy
η_v	Energy conversion factor
$\dot{U}$	Time rate of the internal energy
r	Heat generated within the body
T_b	Boiling temperature
T_{tc}	Critical temperature
m	Atomic mass of the material
L_v	Latent heat of vaporization of the material
x, y, z	Space coordinates
C_P	Specific heat at constant pressure
C_{pb}, C_{pa}	Specific heat of composite and char
f_a, f_b	Volume fraction of composite and char
H_s	Decomposition heat
α	Decomposition degree
M_i	Initial mass of composite
M_e	Final mass of composite