

Parameters of Cloud to Cloud and Intra-cloud Lightning Strikes to CFC and Metallic Aircraft Structures

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Abstract—This paper presents for the first time an assessment of the impact of direct cloud-to-cloud (CC) and intra-cloud (IC) lightning flash on a commercial and a military aircraft. In contrast to cloud-to-ground (CG) lightning strikes to aircraft, where measurements of CG flash measurements may be extended to aircraft strikes, CC and IC flashes are not so accessible. The effects of CC and IC flashes differ from CG flash largely owing to the earth resistance present in CG flashes which imposes limits on the lightning return stroke. It applies the experimentally-attested transmission line model which was reviewed in a previous companion paper to assess the impact on metallic and carbon fiber composite (CFC) structures of modern aircraft. It compares the electrical impact of CC lightning flash on aircraft made of CFC and metallic structures. The simulations and analysis of voltages and the first return stroke current waveforms demonstrate the important distinctions in the characteristics of direct CC lightning effects on metallic and non-metallic airframes. Among the significant results observed are large differences in current time derivatives on the surface of the carbon fiber composites and metallic airframes. Further observations show that there are rise times for the voltage and currents which fall within the subnano and submicro seconds yielding large time derivatives for both the voltages and the currents. This can have important implications for the shielding and protection of the aircraft electrical and electronics systems.

Index Terms—lightning-aircraft electrodynamics, transmission line modeling, lightning attachments, lightning direct effects.

I. INTRODUCTION

The future of commercial and military aviation will depend on composite material and fly-by-wire electronic technologies. For commercial aircraft the trend in going composite has been for economical reason while for military the demand for fast maneuvering aircraft that has motivated the need for carbon fiber composites (CFC) airframe structures. However, composite material presents difficulties in lightning protection to effectively dissipate electrical charges and currents from the airframe structures due to its

low electrical conductivity (7.3×10^4 S/m for polyacrylonitrile based CFC) compared to aluminum (3.77×10^7 S/m aluminum) [1]. Metallic coatings are embedded into the CFC to improve the conductivity of the material. Despite the improvement in using conductive fillers or microgrid or nanostrand conductive meshes integrated into the carbon composite materials and even conductive paints, it does not completely shield off electromagnetic interference (EMI) due to lightning radiated electromagnetic pulses (LEMPs). That is, when lightning generated electromagnetic waves strike the surface of an aircraft, free electrons are generated, resulting in generation of surface currents [2]. The currents transmit electromagnetic energy, which for a CFC airframe, the energy is temporarily entrapped on the surface. The slower decay of the aircraft surface current is influenced by the CR time constant with the CFC aircraft having a large R . Note, C and R are the respective capacitance and resistance of the aircraft per unit length. Thus, airframes of carbon fiber/ epoxy composites can be damaged, particularly at the entry and or exit points of a lightning direct strike, since they absorb the lightning induced voltage and currents instead of conducting and dissipating it. Further, the magnitudes of peak current and voltage induced is capable of inducing a higher electric fields along the surface since the rise time of the transient is short. This can have severe effects on the aircraft electrical and electronics systems [3, 4].

In this paper, we apply the self-contained transmission line model [5] to study the direct impact of lightning strike on commercial and military aircraft of both CFC and metallic (aluminum) structures and compare effects of the return stroke current parameters and the voltage induced. The four specific effects of lightning current considered paramount in producing damage [3, 4] are: (1) the peak current, (2) the maximum rate of change of current, (3) the integral of the current over time (i.e., the electric charge transferred) which is responsible for the mechanical force and the heating effects, and (4) the integral of the current squared over time, the "action integral," which is responsible for the melting effects. Current is the primary source of thermal and mechanical damages caused by lightning. The high rate of change of current di/dt (where i is current) through an electrical system will give rise to high voltage drops ($v=Ldi/dt$) where L is the inductance of the aircraft). For aircraft electrical components with inductive impedance, such as cabling in electronics systems or electrical connections on printed circuit boards, the

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