ANALYSIS OF STANDARDS REQUIREMENT FOR AIRCRAFT EQUIPMENT LIGHTNING PROTECTION

M. Georgiev, S. Nikolova

Abstract: Analysis the problems caused by lightning strikes affecting aircraft and avionics, various lightning strike protection (LSP) solutions have been developed for inspection, maintenance, and testing. The main industrial standards recommendations are SAE ARP 5412A [1], SAE ARP 5414A [2] and U.S. Federal Aviation Administration Regulations applicable worldwide are described below.

Keywords: Lightning strikes, Environmental Conditions and Test Procedures for Airborne (LSP) Equipment protection, lightning damage.

1. Introduction
Many airplane manufacturers specify DO-160G Section 22, lightning induced transient susceptibility, as a requirement for critical systems, like guidance, radars, communications, engine control, and heat and air controls. As you see in the following Figure 1, she presents the most susceptible parts like: aircraft fuselage, wing and tail flight controls, wing tips, fin tips, engine nacelles, and landing gear are the areas most likely to be hit by lightning strikes [1,2]

Fig.1. Lightning Strike Susceptible Locations on a Commercial Aircraft

On modern aircraft, the structure is increasingly constructed from composite materials, in particular carbon-fiber composite. There is also an increasing reliance on electronic avionics systems for primary control of the aircraft. Both of these aspects have made aircraft manufacturers pay greater attention to lightning protection and its certification through testing and analysis. Aircraft modifies the electric fields in its vicinity, which acts as a catalyst for lightning attachments: an uncharged aircraft located in an electric field will become polarized and the local electric field values at the aircraft surface will be magnified at those extremities aligned with the field, especially where the radius of curvature of the conducting structure is small, such as on wing tips, the tail tips, random protection strips, etc. [5,6]
2. Scenarios of lightning strike in flight

Scenarios of lightning strike in flight: corona breakdown can result in the development of bi-directional leaders extending from the aircraft extremities, which may eventually connect with oppositely charged regions in the cloud. In the classic cloud to ground scenario, one of the charged regions would be ground. Through this process, the aircraft triggers a lightning strike, with itself being the direct path of the return stroke current flowing between the two attachment locations. Only about 1 in 10 strikes are intercepted attachments, which explain the reason for the relatively high strike rate of airborne aircraft compared to that of those on the ground [3].

This idealized current waveform is divided into four components, A to D (fig.3):

Component A is associated with the initial return stroke attachment location, for instance, near the nose and tail of the aircraft. Component D is associated with a re-strike, as the arc is swept along the aircraft. The peak current of the D is half that of the component A, but its Action Integral, the energy associated with the waveform, is an 8th (2 MJ/Ω for the A and 0.25 MJ/Ω for the D). This is due to this difference in the rise and fall times of the two components [4].

Components B and C form the long duration slow components, also known as the intermediate and continuing currents respectively. A long component C will only be injected at trailing edges where the lightning arc hangs on and cannot sweep to a further aft location.

Fast component damage (A and D):
- Joule heating, proportional to the action integral of the lightning waveform can cause thin conductors to fuse explosively, leading to damaging overpressures. In carbon-fiber materials, this heating can melt and vaporize the epoxy, leading to delaminating damage of the carbon fiber;
- Magnetic forces arising from the high currents can crush, or drive together/pull apart conductors;
- The acoustic shock caused by flash heating of the air by the lightning channel (thunder) can cause damaging overpressures, particularly inside radomes;
- Current flow within the structure can cause arcing and sparking across interfaces potentially igniting fuel vapor/air mixtures;
- Changing magnetic fields, created by the current flowing in the airframe, generate induced transient voltages in the wiring, which can cause damage or interruptions to the aircraft avionics systems.

Slow component damage (B and C)
Metals, particularly aluminum alloys, are not significantly damaged by the fast components; however, the charge transfer associated with the slow component can create local melting and puncture. Similarly, carbon-fiber composite can be damaged by the heating process of an attached arc. This is especially important for fuel tank skins.
The methods used to protect against this potential damage are assessed during High Current and Induced Effects testing. Knowing that these different components can cause different types and severity of damage, and therefore require different types of protection to be installed and tested [4, 5].

3. Test standards and certification

Regulations and test standards define procedures for the certification of aircraft structures and systems against lightning damage and also define the lightning characteristics to be considered [4,5].

![Box - Simplified aircraft zoning](image)

**Fig.5. The guidance for zoning gives a series of templates for different aircraft geometries**

There is a limited amount of data publicly available and there is also the question of data reliability, as it is not easy on a large metallic aircraft to find arc attachment points, and especially to determine the sequence of events behind the observed attachment points. Aircraft equipment are divided into zones, and each zone has an associated electromagnetic compatibility (EMC) environment [3].

To each of the 6 defined zones, a specific lightning current waveform is attributed. The highest current values (up to 200 kA) are attributed only to small areas, namely the nose, wings and stabilizers tips and the front parts of turbine housings, while the most of the fuselage belongs to the second zone, where the current values are much lower (up to 2 kA).

Due to the electrical power limitation of generators in facilities, it is actually impossible to reproduce simultaneously the voltage and the current damages on aircraft [6]. So, it has been decided to divide these tests into two large categories in order to reproduce the effects of lightning: high voltage testing and high current tests.

Their purpose is to:
- Determine the primary attachment points on a structure and permit to calculate the zoning of the aircraft.
- To test the dielectric parts of an aircraft two voltages waveforms are mainly used for these tests: a faster waveform A dedicated to reproduce the reattachment of the arc channel in zone 2 and the slowest waveform D more appropriated for initial attachment regions in zone 1 (see figure 5)
In such tests, the diameter of fused mesh relates closely to specific energy (action integral), but the shock effect (panel splitting) appears to be more a function of the peak current. For military aerospace and defense applications with added robustness that reduces system failures.

At the beginning of the aircraft design, the manufacturer defines a TCL (Transient Control Level): This is a stress lightning level that the equipment could be submitted during a worst-case lightning strike of the aircraft. Then, the aircraft manufacturer applies a margin in order to determine the ETDL (Equipment Transient Design Level) which is the level of certification required to the equipment manufacturer [2].

In this context, two types of tests are performed:
• Damage tolerance tests in order to validate the protections.
• Functional tests following predefined acceptance criteria.

4. Simulation and testing for electronic devices
For aircraft, there are two types of electrostatic charges [4, 5]:
• charges that are on a metal surface and create a potential difference between the surface and the surrounding air;
• charges formed, located and interacting on an isolated surface (glazing, antenna radomes, propeller blades made of composite materials, etc.). In this case, a rather large potential difference may occur not only between the surfaces and the ambient air, but also between two, even very close points of the surface.
On aircraft, static dischargers are used on the trailing edges of wings and other surfaces. To prevent the negative effects of static electricity on aircraft, the following protective measures are installed: Jumpers metallization connecting the individual elements of the design of the aircraft between themselves and the mass of the aircraft.

5. Conclusions

It is important to remember that the aircraft during a thunderstorm cannot be completely protected from discharges. Therefore, systems are used that would compensate or negate all falling charges. In the process of movement the aircraft can get not only under the influence of a natural phenomenon that occurs by itself, but also independently generate or cause such discharges.

Protection of the aircraft from lightning can be done in various ways. Often several types and technologies are used simultaneously on the same machine. It is worth noting that the main task of such systems is as follows: the exception of the occurrence of the slightest spark in the fuel system of the aircraft (this is especially important for fuel tanks located in the wings); compensation of the internal charge, which accumulates as a result of the work of turbines, electronics and the interaction of the aircraft body with the charges of the clouds (own charge can cause lightning discharges when flying through clouds that carry positive charges); protection of electronics, crew and passengers from electric shock; shielding of engines and radar systems; remove corona effect and etc.

Forty years ago solid metal construction of the airframe worked like a camera Faraday with extremely low impedance propagation path. A typical jet built today is as little as 20% pure aluminum. Most of the non-critical structural material – paneling and aesthetic interiors – now consist of even lighter-weight carbon fiber reinforced polymers (CFRPs), honeycomb materials, or ceramic-matrix composites (CMCs). These materials are tested continuously to determine degree of protection from static discharges and lightning protection.

Bibliography:

ИЗИСКВАНИЯ НА СТАНДАРТИТЕ КЪМ КОМПОНЕНТИТЕ НА АВИАЦИОННИТЕ МЪЛНИЕЗАЩИТНИ СИСТЕМИ

М. Георгиев, С. Николова

Резюме: В настоящата статия са разгледани изискванията на авиационните стандарти за начините на защита на въздухоплавателните средства от натрупване на статични заряди и мълнезащита. Направен анализ на изискванията при формиране на отделните защитени зони. Разгледани са характеристиките на тестови модел за изпитания и сертификация на авиационно оборудване, като са обсъдени предимствата и недостатъците на отделните технически решения.

Данни за авторите:
Мартин Василяев Георгиев, Национален Военен Университет „Васил Левски”, Факултет “Авиационен”, Катедра "Електротехника, автоматика и информационни технологии" – Долна Митрополия, Р. България, тел.: +359899153875, e-mail: irritant17@gmail.com
Снежана Стоянова Николова, Национален Военен Университет „Васил Левски”, Факултет “Авиационен”, Катедра "Електротехника, автоматика и информационни технологии" – Долна Митрополия, Р. България, тел.: +359896909219, e-mail: snej98_@abv.bg