Lightning Protection of Aircraft

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Abstract - this paper concerns lightning phenomenon and methods of aircraft protection against the lightning effects .

I. INTRODUCTION

It is estimated that on average, each airplane in the U.S. commercial fleet is struck lightly by lightning more than once each year. In fact, aircraft often trigger lightning when flying through a heavily charged region of a cloud. In these instances, the lightning flash originates at the airplane and extends away in opposite directions. Although record keeping is poor, smaller business and private airplanes are thought to be struck less frequently because of their small size and because they often can avoid weather that is conducive to lightning strikes. The last confirmed commercial plane crash in the U.S. directly attributed to lightning occurred in 1967, when lightning caused a catastrophic fuel tank explosion. Since then, much has been learned about how lightning can affect airplanes. As a result, protection techniques have improved. Today, airplanes receive a rigorous set of lightning certification tests to verify the safety of their designs. Although passengers and crew may see a flash and hear a loud noise if lightning strikes their plane, nothing serious should happen because of the careful lightning protection engineered into the aircraft and its sensitive components.[6]

II. LIGHTNING PROTECTION REQUIREMENTS

For modern transport aircraft, the ANAC (Civil Aviation National Agency), FAA (Federal Aviation Administration) and EASA (European Aviation Safety Agency) include the Requirements:

- 25.581 for structural parts lightning protection,
- 25.901 and 25.903 for engines,
- 25.954 for fuel system lightning protection,

Also SAE's (Society of Automotive Engineers) Aerospace Recommended Practices 5412, 5413 and 5414 are extensively used as the basis for the current aircraft lightning environment definition and for compliance demonstration. SAE has emitted ARP 5412 regarding lightning environment and waveforms, and ARP 5413 that provides guidance for compliance with indirect effects of lightning regulations. In addition to the 25.1301 and 25.1309 current airworthiness requirements, the ANAC, FAA and EASA have emitted 25.1316 requirement, which define operation condition for electrical-electronic system level A (critical system) and level B /C (essential system).

The requirements of EMI (Electromagnetic Interference) and lightning direct and indirect effects are complied by incorporating, since the early design phases, special electrical bonding and EMI shielding protection devices and techniques:

- Metal parts electrical bonding is extensively used;
- Composite materials parts include embedded expanded copper foil and specially developed electrical bonding interfaces to metal structure;
- Wiring harnesses are segregated by separately routing the different EMI categories of signal and power leads and shield termination make extensive use of 360 degrees termination and bonding to connector backshells.

The use of the composite material in fuel tanks and fuel system are in development, where special attention will be given to protection against lightning direct effects.[1,3]

III. LIGHTNING PHENOMENON

Lightning is an atmospheric discharge of electricity, which typically occurs during thunderstorms, and sometimes during volcanic eruptions or dust storms. In the atmospheric electrical discharge, a leader of a bolt of lightning can travel at speeds of 60,000 m/s (220,000 km/h), and can reach temperatures approaching 30000 °C. There are some 16 million lightning storms in the world every year. An average bolt of lightning carries an electric current of 40 kA, and transfers a charge of five coulombs and 500 MJ. Large bolts of lightning can carry up to 120 kA and 350 coulombs. The voltage depends on the length of the bolt, with the dielectric breakdown of air being three million volts per metre; this works out to approximately 1GV for a 300 m lightning bolt. With an electric current of 100 kA, this gives a power of 100 terawatts.[7]

The lightning current consists of 4 components (Fig. 1):

- Component A appears during initial stroke. The peak amplitude of this component is equal 200kA ±10% with time duration $\leq 500\mu s$.
- Component B is an intermediate current with average amplitude about 2kA. The maximum charge transfer for this component is 10 coulombs.
- Component C is a continuing current with amplitude in the range 200-800A. Charge transfer is equal 200 coulombs ±20%.
- Component D appears during restrike. The peak amplitude of this component is equal 100kA ±10% with time duration $\leq 500\mu s$.

Those current components described above may be utilized for analyses or test purposes, or for combinations thereof to assess the potential lightning effects on the aircraft structure or system, and verify adequacy of protection designs.

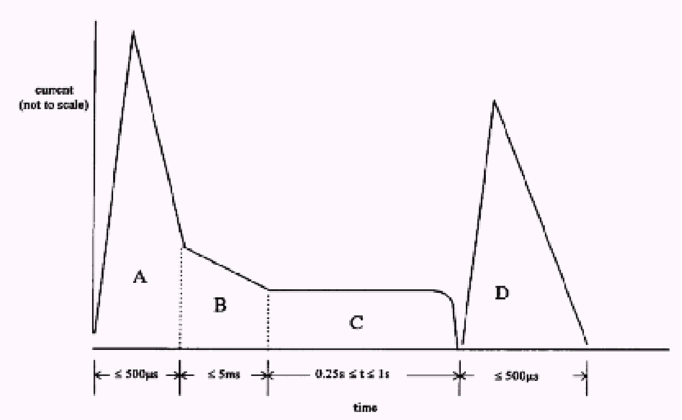

Figure 1. Lightning current components [1].

The lightning effects to which aircraft are exposed are divided into direct effects and indirect effects. Direct effects are physical effects to the aircraft and/or equipment due to the direct attachment of the lightning channel and/or conduction of lightning current and its high power and short time transient. This includes dielectric puncture, blasting, bending, melting, burning and vaporization of surfaces and structures. It also includes directly injected voltages and currents in associated wiring, plumbing, and other conductive components. The thermal effects at the arc attachment and the high current flowing in adjacent structures can produce direct damage. For example, the heating and mechanical effects of the strike could result in the puncture of thin fuel tank skins or damage to control wires. Shock waves may shatter thin panels and the huge magnetic forces derived from the lightning currents may buckle metalwork and snap bonding braids. In addition, the radome, which is a non-conducting aerodynamic fairing over the weather radar, might be punctured and shattered by a lightning strike. A further effect resulting from a strike is the occurrence of sparks which might be generated on the inside of a fuel tank by the passage of the current. These sparks could ignite the fuel/air vapour present resulting in fires and explosions. Indirect effects are resulting predominantly from the interaction of the electromagnetic fields accompanying lightning with electrical apparatus in the aircraft. When the aircraft is struck by lightning, it becomes part of the lightning channel. Lightning could flow into an attachment point such as a wing tip and out from another such as a tail fin. A large current pulse is thus driven through the aircraft enveloping it in a large and changing magnetic field which can induce voltages in the long wire and cable runs which are routed throughout the aircraft. the field penetrates the aircraft by "electromagnetic windows" such as the cockpit windshield. Unless protective measures are taken, induced voltages and currents can easily be large enough to destroy electrical components or disrupt electronic and computer systems. It is the same changing fields which generate the clicks heard on the radio even hundreds of miles from the lightning source. [1][2]

To analyze of the lightning effect is necessary to determine the aircraft surfaces, or zones, where lightning strike attachment to the aircraft is more or less probable.

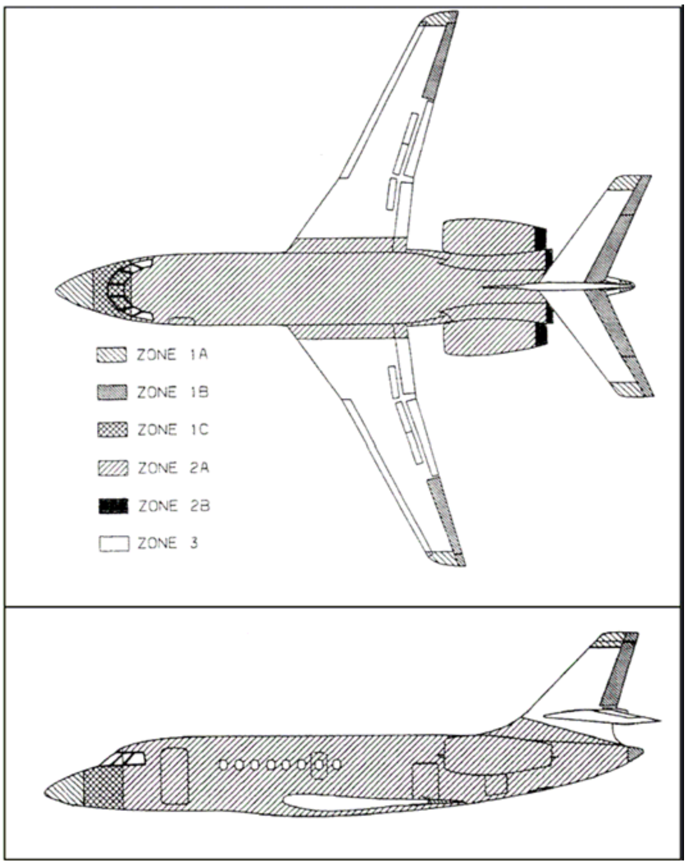

Figure 2. Example of lightning strike zone details for Transport Aircraft [3]

The Federal Aviation Administration has defined the following zones in its Advisory Circular AC 20-53A and in a proposed draft AC 20-53B associated with specific external lightning waveforms.

The specific zones definitions are as follows [3]:

- Zone 1A: Initial attachment point with low possibility of lightning channel hang-on.
- Zone 1B: Initial attachment point with high possibility of lightning channel hang-on.
- Zone 2A: A swept-stroke zone with low possibility of lightning channel hang-on.
- Zone 2B: A swept-stroke zone with high possibility of lightning channel hang-on.
- Zone 3: Portions of the airframe that lie within or between the other zones, which may carry substantial amounts of electrical current by conduction between areas of direct or swept stroke attachment points.

The advisory circulars do not prescribe the actual locations of these zones on a particular aircraft since they depend critically upon the geometry of the aircraft, materials and operational factors. However, they give generic examples for different classes of aircraft (large jets, small single and twin-engine propeller aircraft, helicopters).

IV. LIGHTNING PROTECTION

It is true that some aircraft are less prone to lightning strikes. Size, shape, and speed are all aircraft-specific variables which determine an aircraft's susceptibility to a lightning strike. However, it is also true that all aircraft damage varies with aircraft type. Careful aircraft design can minimize lightning damage. [4]

Some pilots are better at avoiding lightning strikes then others, but all of them have to remember some basic rules about flying. Those rules can help to avoid the lightning strikes.

- The most important thing is to stay clear of thunderstorms. Do not attempt to "pick your way through".
- The higher the aircraft altitude, the farther away from a thunderstorm you should fly. Lightning strikes have been known to occur in the clear air up to 80km downwind from the nearest thunderstorm.
- At low levels, avoid flying close to high surface features (ridge tops, towers, etc.), or between such features and an overhead thunderstorm.
- If you fly above the freezing level in or near thunderstorms, you can trigger an in-cloud or cloud-to-cloud discharge. If you fly below the freezing level, you could be involved with a cloud-to-ground lightning strike. Overall, if you must penetrate or fly close to a thunderstorm system, you can expect more strikes penetrating a thunderstorm area well above the freezing level.
- Lightning damage is usually worse for large total current transfers. At altitudes above the freezing level, you are more likely to experience longer-lasting lightning attachments made up of numerous small pulses and large total current transfer. Below the freezing level, you are more likely to experience shorter lightning attachments with a few strong current pulses; however the total current transfer is usually less then that above the freezing level.
- Electrical activity generated by a thunderstorm may exist even after the thunderstorm cell has destroyed. Therefore, avoid penetrating the cirrus decks that were recently associated with thunderstorms.[4]

The complying of above rules can be treated as a first level of aircraft lightning protection. If the pilots remember above rules the probability of lightning strike to the aircraft will be lower.

Unfortunately, this probability will never be equal zero, therefore we have to apply some protection system or devices against direct and indirect effects of lightning strikes. The most popular protection system against lightning strikes is Lightning Diversion Strips LDS. Lightning Diversion System has developed a new and improved lightning protection device that diverts lightning strokes from aircraft nose radomes and other sensitive areas. The protection system consists of a segmented diverter strip which provides maximum multiple-strike protection.

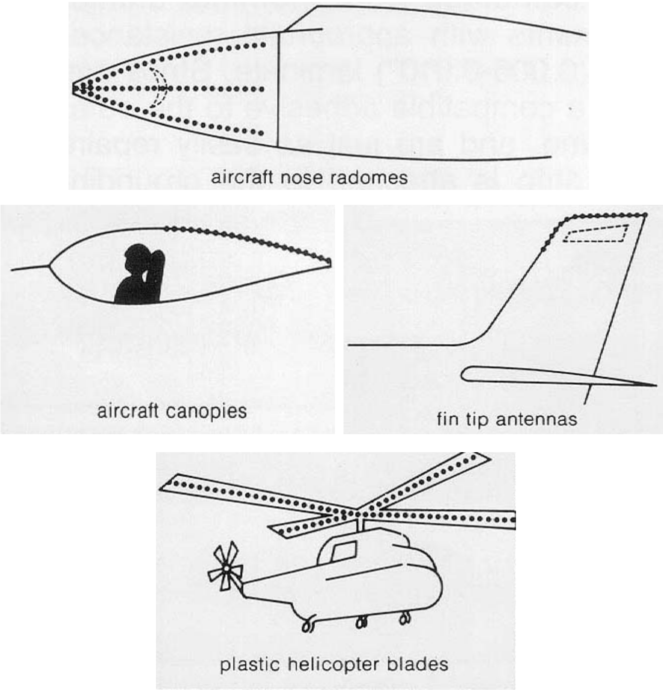

Figure 3. Application of LDS [8]

Attached to an aircraft's radome, the system allows a lightning stoke to travel safely and directly to ground in an ionized channel created in the air above the diverter strip. It combines permanent protection with a low drag aerodynamics and has insignificant effect on radar antenna radiation patterns. The electrostatic shield created by the system provides a new source of streamers outside the radome wall to the fuselage. The small diameter of the disc segments makes the strip compatible with radar system operation. If necessary, disc size can be reduced for optimum antenna patterns at higher frequencies.[8]

To protect an electrical devices we can apply surge suppressors. For example the 115 VAC high energy surge suppressor combines in one unit the low clamping voltage and high surge current capabilities needed to protect solid state power and electronic systems from severe lightning-induced and other over-voltage surges. This suppressor meets the need for low clamping voltage and exceptionally high surge current capability packaged in a single, small size unit. The suppressor is packaged to withstand rugged airborne and ground-based environments and will clamp repetitive high energy transients. The 115 VAC high energy surge suppressor is especially suitable for clamping lightning-induced surges appearing on aircraft 115 volt AC power distribution busses feeding solid-state avionics. The suppressor clamps the high energy surges to levels easily tolerated by most solid state power supply inputs without interruption of power or tripping of circuit breakers. Its surge current capability exceeds that of many spark-gap devices, and its response ("turn on") time is virtually instantaneous. The suppressor meets applicable requirements of most aircraft power quality specifications. [8]

Applications of surge suppressors in aircrafts:

- Primary power distribution busses.
- Secondary power distribution circuits, at utilization equipment.
- Externally mounted electrical apparatus (windshield and air data probe heater circuits, navigation lights, and electrical de-icing systems.)
- AC power and control circuits within advanced composite airframes

V. CONCLUSIONS

According to [5], lightning aircraft incidents most often occur when the air temperature is in the range of -5 to 0ºC. Lightning incidents frequency depend on altitude and season, thus in winter more incidents happen at about 1km above sea level and in summer more incidents occur at about 5km above sea level. Taking into account that pilots know this information and rules from chapter IV, flying by plane should be very safe. And it is. But sometimes thunderstorm can surprise even the best of pilot. Therefore all kinds of airships have to fulfill a lot of lightning protection requirements. But we have to remember, that even the best lightning protection system does not replace the human being. Thus, in my opinion if the pilot sees a thunderstorm he should change flight direction to bypass this hazard.

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