ALISDAR: AN AUTOMATIC LIGHTNING SYSTEM DETECTION AND RECORDING

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ABSTRACT: In the framework of the EC (European Community) project EM-HAZ (Electromagnetic Hazard), an Automatic Lightning System Detection And Recording (ALISDAR) has been developed. The characterization of the lightning strike to an aircraft is done by electrical and magnetic field measurements. A prototype of ALISDAR sensors have been installed on metallic dummy windows. The system was in operation during an in-flight campaign for the icing certification of the Airbus A340-600. Two events of lightning strikes have been recorded. For these two events, the electric field measurements show that the aircraft triggered the lightning strike.

INTRODUCTION

The EC project FULMEN [Zaglauer et al., 1999], completed in 1999, provides a study of external and internal threat on aircraft due to lightning. One of the results of the FULMEN program is a database on natural lightning strike to aircraft. During the building of this database, several problems have been pointed out. (1) Most of the lightning scenarios and waveforms used in the regulatory document and aircraft certification are based on data from natural cloud to ground flashes. Even if this approach were satisfactory from a safety standpoint, it would be very beneficial for the most common in-flight strike scenario to be characterized more accurately. Indeed, in-flight experiments have shown that strikes occur at about 3 km, in the vicinity of the 0°C level, and generally result from intra/inter cloud flashes. (2) The data, collected by the airline companies, on lightning strikes to airliners do not contain information on the severity of the strike unless damages were observed. (3) The data from in-flight lightning experiments are not numerous enough to provide a representative statistical distribution of the lightning strike to aircraft. This lack of knowledge prevents improvement of regulatory documents (adequacy of laboratory test, lightning pulse sequences, ...) and optimization of the lightning protection.

In the framework of the EC project EM-HAZ, a system was developed to realize in flight lightning detection and to characterize the lightning strikes to aircraft onboard commercial airliner. In a first part of this paper, we describe ALISDAR system and in a second part, the two events measured during the icing campaign of the Airbus A340-600 are presented.

DESCRIPTION OF THE SENSOR

In the 80’s, joint programs were performed to investigate the interaction between lightning and aircraft. Instrumented aircraft were flown into thunderstorms. For these campaigns, specific sensors were developed to measure the lightning characteristics. The design of the sensors of ALISDAR is mainly based on this instrumentation and the background acquired during these experiments.

The main challenge for the ALISDAR instrument was to find possible locations for the sensor on an airliner. The investigations, performed by Airbus team, show that it seems extremely difficult to localize, on an airliner, a sensor outside the fuselage sections (wing, tail plane, fin, engines). The easiest way is to use a dummy window made of the same metallic material as the plane on which the sensors will be bonded.

ALISDAR has been designed to characterize the lightning strike through indirect measurements. The sensors of ALISDAR are composed of electric field (E-field) and magnetic field (H-field). In flight campaigns have shown that the E-field variations are produced by the variation of the aircraft electrical potential; the waveforms of the E-field variations are then similar on all the aircraft fuselage and their levels depend on the enhancement factor of the E-field. This implies that the location of the E-field sensor is not too much critical. Our investigations have shown that it is difficult to directly rely the magnitude of the E-field variation to the magnitude of the current flowing through the aircraft. So, in addition to the E-field sensor, a H-field sensor is used in order to have an estimation of the current of the lightning strike. The H-field variation is directly related to the current flowing in the vicinity of the sensor.

The E-field sensor, which specifications are summed up on Table 1, is a flush plate connected to an electronic circuit which integrates the signal and delivers two output with a decay time of 2 s (0.5 Hz) and of 10 ms (100 Hz). The H field sensor, which specifications are summed up on Table 2, is based on a double Moebius loop. The low dynamic range of the sensor is composed of 5 loops which are designed to measure H-field associated with pulse current lower than 3 kA while the high dynamic range (1 loop) is designed for pulse
currents lower than 150 kA. The loops are oriented in order to measure magnetic field component produced by a current component along the fuselage axis.

The sensors have been installed on two dummy windows of an Airbus A340-600 (Figure 1). The sensor 1 has been installed in the front of the aircraft while the sensor 2 is put in the middle of fuselage. The windows were bonded to the fuselage with metallic braid. An electrostatic electric field computation has been also performed from an A340 mesh file in order to compute the enhancement factors at the sensor location (Table 3) of the atmospheric field $\vec{E}_o$ and of the net charge $Q_{net}$. The E-field $E$ at the sensor is given by the following expression: $E = \vec{K} \cdot \vec{E}_o + K_q Q_{net}$ (Eq. 1)

The signals of the sensors are recorded with a data acquisition system, performed by Airbus, and based on fast 12 bit A/D converter boards, compatible with a record of 1s length at a sample rate of 1MS/s.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Dynamic Range</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor 1</td>
<td>±1000 kV/m</td>
<td>0.5Hz - 10MHz</td>
</tr>
<tr>
<td>Sensor 2</td>
<td>±1000 kV/m</td>
<td>100Hz - 10MHz</td>
</tr>
</tbody>
</table>

**Table 1: Specifications of the E-field sensor**

<table>
<thead>
<tr>
<th>Sensors 1 &amp; 2</th>
<th>Dynamic Range</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low dynamic</td>
<td>±300 A/m</td>
<td>100 Hz-10 MHz</td>
</tr>
<tr>
<td>High dynamic</td>
<td>±10 kA/m</td>
<td>100 Hz - 10 MHz</td>
</tr>
</tbody>
</table>

**Table 2: Specifications for the H-field sensor.**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>$K_x$</th>
<th>$K_y$</th>
<th>$K_z$</th>
<th>$K_q$ (V/m/µC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor 1</td>
<td>-3</td>
<td>1.5</td>
<td>1.8</td>
<td>55</td>
</tr>
<tr>
<td>Sensor 2</td>
<td>-0.3</td>
<td>0.57</td>
<td>1.6</td>
<td>37</td>
</tr>
</tbody>
</table>

**Table 3: Enhancement factors $\vec{K}$ ($K_x, K_y, K_z$) of the atmospheric field $\vec{E}_o$ and $K_q$ of the net charge $Q_{net}$.**

**GENERAL INTERPRETATION OF THE LIGHTNING STRIKE TO AN AIRCRAFT**

In the framework of the A340-600 icing campaign for certification, Airbus France has proposed to test ALISDAR sensors because during this kind of campaign, many lightning usually strikes the aircraft. The campaign was performed from the end of April to the first weeks of May 2002. During this campaign, the ALISDAR system was in operation only at the end of the campaign which explains why among all the lightning strikes to the aircraft observed by the crew, only two events (the last lightning strikes) were recorded.

These events occurred the 7 of May 2002 respectively at 10H55 et 10H56 (UTC). The aircraft was flying above Atlantic ocean at few hundred kilometers of the west coast of the Portugal (-10°42';38°54'). The altitudes of the flight was from 11600 to 12000 ft (3600 m) and the velocity was in the range of 260 to 274 kts (482 – 508 km/h). The Sferics system, which detects and locates the lightning flashes at ground level, shows (Figure 2) that the aircraft was flying inside a stormy region coming from an East front. The number of strikes at 11H00 was in the range of 16 to 24 flashes per 30 min.

**Figure 1 : Locations of the ALISDAR sensors on the fuselage of the A340-600.**

**Figure 2: Location and intensity of number of flashes detected by the Sferics system (http://www.wetterzentrale.de). The color scale is associated with time evolution of the storm activity and the size of the dot with the number of flashes per 30 minutes.**
The main chronological sequence of events can be investigated by using the E-field variation measured on E-field sensors. In this part, we only investigate the event 10h55 (Figure 3) because the event 10h56 is quite similar. Note that the variation of sensor 2 is different of the sensor 1 because of the difference of decay times used in the integrator (see Table 1). The sensor 1 cuts off low E-field variation such as observed just before the lightning strike (Time < 0 ms). The E-field variations show that there are two phases in the lightning strike to aircraft (Lalande et al. 1999):

The first phase is characterized by the « bi-directional leader » inception and development. This phase begins when the aircraft flies into a region of the thunderstorm where the atmospheric field \(E_o\) reaches a critical value in the range of 50-100 kV/m. Then, an electrical discharge, a « positive leader », is initiated from the aircraft and propagates according to the orientation of the atmospheric field \(E_o\). During the development of this leader (from \(t_a\) to \(t_b\) Figure 3) a negative charge is injected in the aircraft. It produces a positive variation of the E-field on the aircraft surface (ab phase). Consequently 15 milliseconds later, the electrical conditions for the inception of a stable negative stepped leader are reached. It develops from the aircraft and propagates in the opposite direction of the ambient field vector \(E_o\) and of the positive discharge. The negative leader development injects positive charge which reduces the negative net charge of the aircraft and leads to a negative variation of the E-field from \(t_b\) to \(t_c\) (bc phase). Consequently to the negative leader development, the positive leader accelerates and branches which produces from \(t_c\) a positive increase of the E-field.

The second phase starts 100 milliseconds of propagation of the bi-directional leader by the development of recoil streamers. It is characterized by large E-field variations in the range of 600 to 1200 kV/m separated by few tens of milliseconds (Times \(T_{rs1}, T_{rs2}, T_{rs3}\)). These large E-field variations are associated with large pulse current not measured here.

![Figure 3: E-field variation during the lightning strike for the event which occurred at 10h55.](image)

**LIGHTNING CHARACTERISTICS**

*Electrostatic configuration before the lightning strike*

Measurements performed during the 80’s with a Convair CV580 and a Transall C160, have usually shown that the aircraft has a negative net charge just before the lightning strike. The E-field variation on the sensor is composed of two components (Eq. 1), one due to the atmospheric field \(E_o\) and one due to the net charge. If we assume that the atmospheric field, which triggers the two events, is 63 kV/m, similar as the one measured during the in-flight campaign of the 80’s and if we take into account the maximum enhancement factor of the sensor (1.6 see Table 3), the component on the sensor due to \(E_o\) can be estimated of 100 kV/m. From this estimation, the component of field due to the net charge can be inferred by making the difference between the estimated component due to the atmospheric field (100 kV/m) and the E-field measured Table 4. By using the enhancement factor (37 V/m/µC) of Table 3, the net charge just before the lightning strike can be estimated from \(-1\) mC to \(-5\) mC.
Leader properties

The charge $Q$ produced by the positive leader during its development can be inferred from the E-field variation between the time $t_a$ and $t_b$. On the assumption that this charge mainly contributes to the aircraft potential variation, we have the following relation:

$$Q = \frac{E(t_b) - E(t_a)}{K_q}$$

By dividing this charge by the time $t_b - t_a$, the average positive leader current flowing through the aircraft is inferred and is of several amperes ($1.3 - 2.8$ A see Table 5). For these two events, the time between $t_b$ and $t_a$ is in the range of 12 to 15 ms. This duration is much larger than the one measured during the Convair and Transall campaign (4-5 ms). It is due to the difference in the capacitance between the aircraft. In one case, the capacitance of the Airbus A340-600 is 1.67 nF while in the other case, the capacitance for a Transall or a Convair is in the range of 0.74 to 1 nF. It means that it is much easier for a positive discharge to develop from a large aircraft (large capacitance) than from a smaller one.

Between $t_b$ and $t_c$, the E-field variation is mainly associated with the negative stepped leader development. The time between the first steps is 200 µs. Each step can be associated with a charge of $2 mC$. As the negative leader elongates, the steps progressively decrease due to the filtering effect of the leader channel.

<table>
<thead>
<tr>
<th>Time</th>
<th>E-field sensor 2</th>
<th>Q</th>
<th>$I_{mean}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10h55</td>
<td>710 kV/m</td>
<td>19 mC</td>
<td>1.3 A</td>
</tr>
<tr>
<td>10h56</td>
<td>740 kV/m</td>
<td>20 mC</td>
<td>2.8 A</td>
</tr>
</tbody>
</table>

Table 5: Main characteristics of the positive leader

CONCLUSION

The ALISDAR system is a useful instrument to remotely characterize the lightning strike to an airliner. Data reduction for the two lightning events observed with ALISDAR shows that in both cases, the aircraft triggered the lightning strike. The next step is to design a more compact system of ALISDAR and to develop an automatic treatment of the signal in order to extract the main characteristics of the lightning. Some further investigations have to be performed to rely the field variation to the current.

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REFERENCES
