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In-flight measurement of high-energy lightning-related atmospheric phenomena.

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Abstract

The results of lightning interaction with an aircraft are shown in this paper. An in-flight lightning strike damage assessment system has been developed, installed and tested. The data obtained from it was then compared to the worldwide and European ground-based lightning detection networks. High-energy radiation bursts were detected inside the cabin synchronously with lightning current pulses. Their origin and possible threat are unknown and need further investigation.

1 Introduction

High-Energy Atmospheric Physics is a newly emerging branch of physics actively developing at the edge of particle physics, optics, electrodynamics and engineering [1]. Although the thundercloud generation process involves electrostatic charging, a multitude of very dynamic lightning-related discharge processes have been identified recently in and above thunderclouds. They are Terrestrial Gamma-Ray Flashes (TGFs) and Terrestrial Electron Beams (TEBs), a number of Transient Luminous Events (TLEs), and Thundercloud Ground Enhancements (TGEs). The TGFs have immediately after discovery been recognized as the most energetic electromagnetic events in terrestrial atmosphere. Besides it, due to significant advance in optical and electrical registration techniques, lightning initiation, propagation and attachment processes have been only recently better understood.

During the same period the number of passengers carried by air transport rose by more than 1000% from 0.3 to 3.4 billion in 1970 – 2015 [2]. Aircraft themselves greatly progressed in using new materials and sophisticated electronic systems. However, the last public research campaign dedicated to lightning interaction with aircraft was ended in the 1980's. None of the above-mentioned phenomena were even known by then.

2 Results

An aircraft is hit by lightning on the average once a year. In order to collect reliable statistics on severity of lightning strikes, a large number of aircraft should be investigated. The

most interesting information is entry and exit points, and caused damage.

2.1 In-Flight Lightning Damage Assessment System (ILDAS)

The In-flight Lightning Damage Assessment System, or ILDAS for short, has been developed for this purpose. It contains 8 magnetic field window sensors [3,4] and one electric field sensors to determine the current distribution over the aircraft (figure 1). The trigger is provided by the characteristic electric field variation with time caused by the lightning attachment or, more often, initiation process.

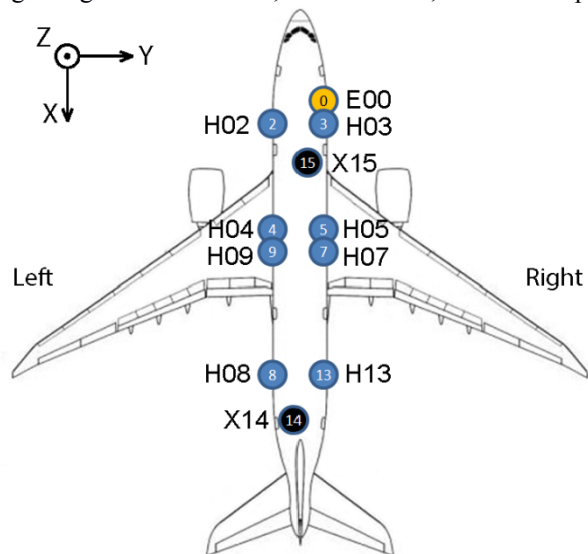


Figure 1. Top view of the A350 aircraft. The E-field, H-field window sensors, and two X-ray detectors are indicated as positioned in the cabin.

Recently the system was extended with two LaBr3 scintillating x-ray detectors. This allows radiation measurements inside the cabin with perfect time synchronization (10 ns) with the H and E sensors.

Data from all detectors are sampled with 100 MHz rate over 1 second, with 0.2 seconds pre-trigger interval. The required dynamic range is better than 90 dB, which allows to capture small and large signal. The provided accuracy of H-field data is 10% or better with 10 MHz bandwidth. Data stored in-flight by laptops in the prototype system; data transfer, and further analysis is performed later on the ground.

2.2 Ground-based lightning location networks

Many of the lightning strikes triggered or intercepted by the aircraft were also recorded by ground-based lightning location networks. In this work we present data from three networks, WWLLN, LINET and Météorage.

WWLLN is the World Wide Lightning Location Network. It is operated by the University of Washington in Seattle with lightning location sensors at VLF (3-30 kHz). Ground-based observations in the VLF band are impulsive signals from lightning discharges called “sferics”. Significant radiated electromagnetic power exists from a few hertz to several hundred megahertz, with the bulk of the energy radiated at VLF [5].

LINET and Météorage are European lightning detection networks with peak current estimation ability. They use VLF/LF band to detect cloud-to-ground (CG) strikes and VHF for intra-cloud (IC) and clout-to-cloud (CC) discharges.

2.2 Case study

Figure 2 shows an aircraft-triggered lightning as was recorded by ILDAS system. Five most intense strokes are numbered. They all belong to one lightning flash. Top panel shows signal from H02 window sensor. The bottom panel shows X-ray signal from X14 detector.

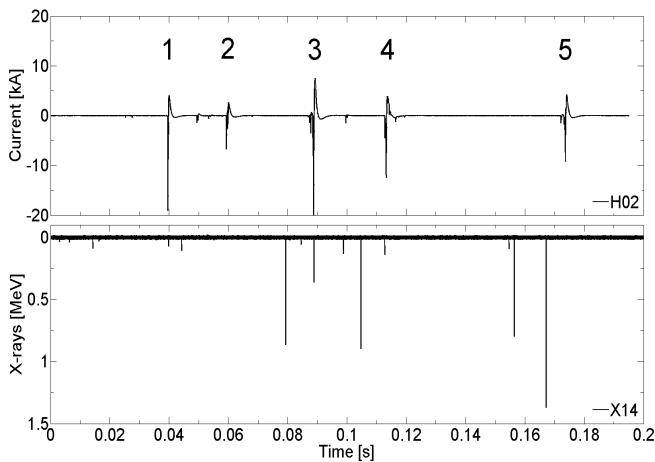


Figure 2. The aircraft-triggered lightning flash recorded by ILDAS. Top panel shows current signal from H02 window sensor. Bottom panel shows X-ray signal from X14 detector.

The same flash was detected from the ground by WWLLN, LINET and Météorage networks. The precise flash identification is possible by comparing inter-stroke intervals.

Figure 3 maps locations of the strokes as reported by the networks. The flash was triggered oven Southern Italy at 4 km altitude. WWLLN reported 6 strokes but two of them were reported simultaneously within WWLLN time uncertainty. LINET and Météorage reported 5 strokes each in close proximity.

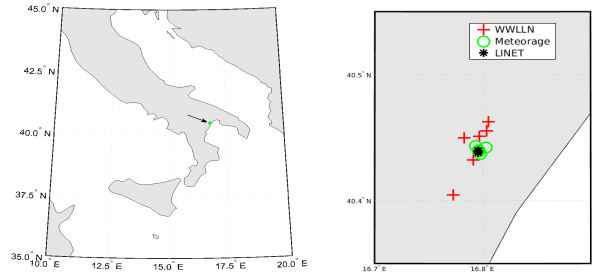


Figure 3. The aircraft-triggered lightning mapped by three ground-based lightning location networks over Southern Italy.

Strokes #1, 3 and 4 are recorded synchronously with X-ray bursts. Similar X-ray bursts were reported in [6].

LINET and Météorage networks report estimated peak current that can be compared to one measured by ILDAS. Figure 4 shows the current comparison as provided by LINET and Météorage networks and measured by ILDAS.

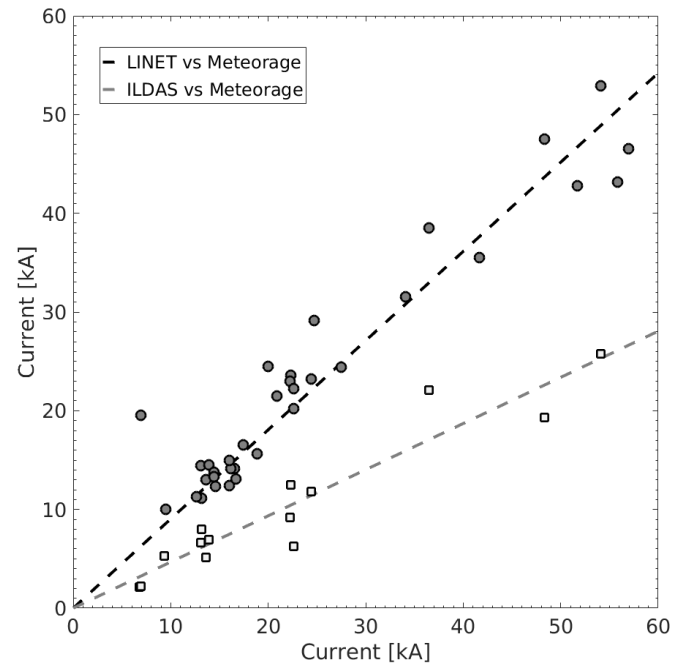


Figure 4. Peak current comparison between ground-based lightning location networks and ILDAS. LINET and ILDAS currents are plotted on Y axis.

While LINET and Météorage networks show good relative conformity, ILDAS systemically reports twice lower peak current. However, more sophisticated current reconstruction techniques are desirable. A full-scale electrostatic model of the A350 aircraft is needed to simulate lightning interaction with it.

3 Lightning-related phenomena

As seen from figure 2, lightning strokes associated with X-ray radiation. In this particular flash, strokes #1, 3 and 4 were

detected synchronously with X-ray bursts. Since the detector area is relatively small (11 cm²), X-rays from other strokes could have been missed due to large distance and/or lower intensity.

Figure 5 zooms on stroke #3. A two microsecond X-ray burst was detected preceding the rapid current jump. Individual photons can be seen on the bottom panel. The most energetic photon has 350 keV energy.

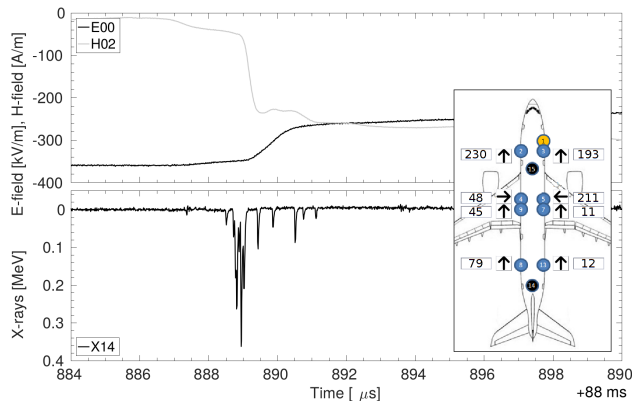


Figure 5. Zoom on stroke #3 of the lightning flash shown in figure 2. Burst of X-ray radiation was detected preceding the rapid current change. Inset shows the current pattern through the aircraft after the moment of X-ray detection. Numbers are in A/m.

The inset in figure 5 shows the current pattern that was reconstructed using the information from all window sensors. It corresponds to a scenario, when electrons are coming from nose and both wings and leaving the aircraft from the tail. Number near each arrows is current sheet density in A/m.

4 Conclusions

In this work we showed new results on lightning interaction with an A350 aircraft with major carbon-composite parts. Three independent ground-based lightning detection networks were synchronized with on-board ILDAS system with sub-millisecond precision. This allowed to identify and localize an aircraft-triggered lightning flash. Further analysis showed that ILDAS measures half of the current reported by ground-based networks.

It was shown that lightning flashes are associated with microsecond-long bursts of X-ray radiation. The precise mechanism of their generation is unknown. It is likely related to formation of high electric field regions near or inside the aircraft during stroke attachment. The location, spectral information and spatial distribution of the X-rays can shed more light on the mechanism and possible threat of this radiation to humans and on-board electronics.

Long-lasting gamma-ray flux enhancements were also detected during some of the test flights. They belong to the class of events called Long Gamma-Ray Glows [7], or subclass of Thunderstorm Ground Enhancements (TGEs) [8]. They are both usually explained by Relativistic Runaway Electron Avalanche (RREA) mechanism [9,10]. However recently, another mechanism was proposed by Chilingarian et

al. [11]. Modification Of the energy Spectra (MOS) process responsible for much frequent but small and modest (less than 10%) Thunderstorm Ground Enhancements. The observed by the aircraft gamma-ray flux enhancements lasted much longer than commonly accepted sub-millisecond duration of Terrestrial Gamma-Ray Flashes (TGFs). Their spectrum is also much softer than such of TGFs. Further data analyses required to identify the underlying mechanism of these glows.

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