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ANALYSIS OF THE IMPACT OF LIGHTNING STRIKES ON FLIGHT SAFETY

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Abstract: The lightning effects in aircraft have been known since the early days of aviation, and still they are a subject of active research. Lightning or atmospheric electric discharge is a natural phenomenon that cannot be affected by man. The goal of this paper is to analyze the impact of atmospheric electrical discharges on flight safety by providing risk assessment techniques. The effects that occur as a result of lightning strikes are presented, and it is explained how lightning strikes can be reported. All relevant events recorded in the database Aviation Safety Network - Database are shown in the tables and there are a total of 29 events caused by lightning strikes in the aircraft during the summer. The main part of this paper is the analysis of aircraft accidents caused by lightning. This analysis involves defining the hazards, assessing the safety and assessing each risk individually. By providing this analysis, safety and mitigating measures could be defined for future lightning strikes occurrences.

Keywords: aircraft, safety, risk, lightning strikes.

1. Introduction

Aviation safety is a key priority in all aircraft operations. Air traffic is influenced by many negative factors where some cannot be controlled due their nature. Lightning strikes or atmospheric electrical discharges are a natural phenomenon that humans cannot control. Scientific understanding of the impact of atmospheric electrical discharges on flight safety is an essential basis for analyzing accidents resulting from lightning strikes in the aircraft.

The aim of this paper is to analyze the impact of atmospheric electrical discharges on flight safety, to show how atmospheric electrical discharges affect flight safety, whether there are consequences and adverse effects that may occur during the normal operations and how this occurrence can be avoided or mitigated.

The motivation for analyzing the impact of lightening on flight safety is based on the fact that each airplane during its normal operations is struck by lightning on average once per year (Larsson, 2002). Many authors performed risk analysis of lightning hazardous effects in aircraft at a system level to assess and mitigate the lightning risks (Lee and Colins, 2017). Lighting standards concerning treat levels and zoning for lighting achievements (Karch *et al.,* 2021; Cheon *et al.,* 2014) are of high importance for airworthiness certification provided by civil aviation authorities worldwide (Jones *et al.,* 2001).

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2. Impact of Lightning on Flight Safety

Fig. 1 shows entry and exit points on the aircraft caused by lightning strikes during the normal operations.

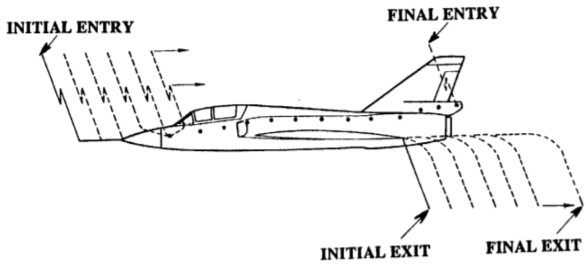

Fig. 1.
Entry and Exit Points on the Aircraft caused by Lightning Strikes
Source: (AGATE, 2002)

Lightning the aircraft usually occurs within 5,000ft of the freezing level. Lightning is accompanied by a bright flash of light and often the smell of arson, as well as noise. The presence of airplanes near the Cumulonimbus cloud causes disruption to the electrical field and lightning formation, whether the airplane is electrified or not.

The highest number of lightning strikes in flight occur between -5°C and +3°C, with a maximum on around 0°C (Lazić, 2012).

On Fig. 2 can be seen as the charge approaches the aircraft, followed by a lightning strike on the aircraft (AGATE, 2002).

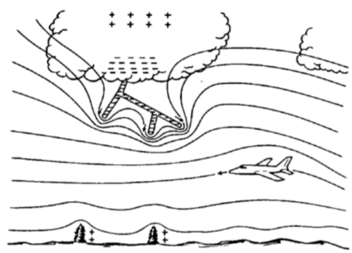

Fig. 2.
Approaching Electrification to the Aircraft
Source: (AGATE, 2002)

A lightning strike can be very distressing to passengers and crew, but significant damage to an aircraft is very rare and flight safety is usually not compromised. These damages are one of the three main causes of structural damage and weakening, namely accidental damage (AD). The assessment of the structure's sensitivity to these damages is made based on the size of the initial damage and the ability of the structure to prevent further penetration of the damage through the aircraft structure (Skybrary, 2022).

Damage is usually limited to antennas, compasses and causing small holes in the fuselage. Of greater concern is the possibility that a transient disruption of air flow associated with a thunderstorm will probably cause engine shutdown, especially for engines that have full authority digital engine control (FADEC), but also for engines that do not have FADEC (Skybrary, 2022).

Lightning strikes can also occur in volcanic ash clouds formed in close proximity to eruptions because the vertical movement and collision between solid particles within the cloud creates static charges. Sometimes an aircraft can be hit by ball lightning. This lightning, which is still an insufficiently investigated phenomenon, has a diameter, usually between 10 and 30 cm, lasts from 5 to 10 seconds and occurs with a strong flash and bang, although there are also cases of silent disappearance. It is assumed that it has a temperature of 500 - 700 K. It most often occurs in red, orange, yellow or white, but it can also be gray, blue, purple and green (Lazić, 2012).

The following map (Fig. 3) shows the uneven distribution of lightning around the world. The data was obtained using space sensors. It can be observed that phenomena such as lightning occur most often in Africa, specifically in Central Africa (Democratic Republic of Congo and Central African Republic) (Skybrary, 2022).

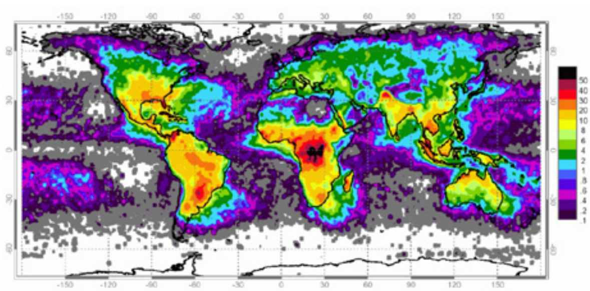

Fig. 3.
Distribution of Lightning around the World
Source: (Skybrary, 2022)

2.1. The Consequences of a Lightning Strike on an Aircraft

Lightning strikes are a phenomenon that happens very often during the flight. The effects that occur as a result of a lightning strike are (Vasov, 2021):

- Aircraft damage: Structural damage to aircraft from lightning strikes is rare and even less likely to threaten the aircraft safety during the normal operations. Nevertheless, there have been many cases of lightning strikes leaving holes in the aircraft's radar, rudder and elevator, and damage to flight control surfaces;
- Impossibility of the crew to provide tasks on duty: the consequence that occurs is blindness in people from lightning flashes, which can occur especially at night. This phenomenon is common;

- Damage to aircraft parts: a lightning strike can affect aircraft systems, especially compasses;
- Difficulties in providing a radio communication - a very common occurrence during a lightning strike;
- Engine shutdown: a transient airflow disturbance associated with a thunderstorm can cause engine shutdown on both FADEC and non-FADEC engines in aircraft with closely located engines.

2.2. Measures to avoid Lightning Strikes

Standard advice to pilots is to fly at least 20NM away from any cumulonimbus cloud. The turbulence, wind shear, and in-flight icing hazards associated with cumulonimbus are far greater threats that can occur than the threat of lightning.

If flying in the vicinity of cumulonimbus clouds, or lightning is seen near the aircraft, it is necessary to review the manufacturer's instructions for the measures to be taken in the event of a lightning strike. If the aircraft is equipped with gyro-magnetic compasses, it is recommended that one of the compasses be selected for the gyroscope if there is a risk of lightning (Vasov, 2021).

3. Examples of Aircraft Accidents Caused by Lightning Strikes

In the Aviation Safety Network - Database (ASN, 2022), a total of 29 events (from 1940 to 2017) can be found, the cause of which was a lightning strike on an aircraft during the normal operations.

Looking at the above data (ASN, 2022), it can be concluded that in most cases, the consequences caused by a lightning strike in the airframe of the aircraft are: damage to the fuselage, nose, tail, wings of the aircraft, damage to the aircraft system and fatalities. From 1940 to 2002, 20 events resulting in deaths were recorded.

Table 1

Occurrences causes by Lightning Strikes during the Aircraft Operations - Examples

Date	04.12.2003.	29.11.2013.	13.03.2015.	20.07.2017.
Type	Dornier 228-202	Bombardier DHC-8-402Q Dash 8	Gulfstream G-IV	de Havilland Canada DHC-8-106
Registration	LN-HTA	JA462A	JA001G	C-FDWO
Total Airframe (hrs)	-	811	9964	-
Country	Norway	Japan	Japan	Canada
Location	Bodø Airport	20 km E from Fukue Airport	over Niggata Airport (KIJ)	74 km N from Val-d'Or
Operator	Kato Air	ANA Wings	Japan Civil Aviation Bureau	Air Creebec
Crew & Passengers	4	41	5	15
Fatalities	0	0	0	0
Investigated Causes	The consequence is damage to the nose and landing gear of the aircraft.	The consequence is damage to the nose of the aircraft and deformation of the internal structure of the nose.	The consequences are damage to the left REAR side of the fuselage, the REAR bottom of the fuselage and the left horizontal stabilizer.	The aircraft sustained significant damage to the right wing and tail.

Source: (ASN, 2022)

The following figures illustrate the damage of aircraft caused by lightning strikes.

Fig. 4.
Aircraft Lockheed L-1011-385-1-14 TriStar 150 after Lightening Strike, July 6th, 2002
Source: (ASN, 2022)

Fig. 5.
Aircraft Dornier 228-202 after Lightening Strike, December 4th, 2003
Source: (ASN, 2022)

4. Analysis of Aircraft Accidents Caused by Lightning Strikes

In this chapter, an aircraft accident in flight caused by a lightning strike will be analyzed, from the Aviation Safety Network - Database (ASN, 2022). This analysis involves defining generic hazards, assessing the risks generated by these hazards and assessing each risk individually.

Using the safety risk probability table (Table 2), it is possible to determine the probability that an unsafe event or condition will occur, as well as their consequences (Čokorilo, 2020).

Table 2

Safety Risk Probability Table

Likelihood	Meaning	Value
Frequent	Likely to occur many times (has occurred frequently)	5
Occasional	Likely to occur sometimes (has occurred infrequently)	4
Remote	Unlikely to occur, but possible (has occurred rarely)	3
Improbable	Very unlikely to occur (not known to have occurred)	2
Extremely Improbable	Almost inconceivable that the event will occur	1

Source: (ICAO, 2018; Čokorilo, 2020)

After determining the probability that a harmed event will occur, it is necessary to assess the nature of the consequences that such an event could issue. The severity of the consequences of the event can be determined using the table of the safety risk severity (Table 3) (Čokorilo, 2020).

Table 3

Safety Risk Severity Table

Severity	Meaning	Value
Catastrophic	• Aircraft / Equipment destroyed • Multiple deaths	A
Hazardous	• A large reduction in safety margins, physical distress or a workload such that the operators cannot be relied upon to perform their tasks accurately or completely • Serious injury • Major equipment damage	B
Major	• A significant reduction in safety margins, a reduction in the ability of the operators to cope with adverse operating conditions as a result of increase in workload, or as a result of conditions impairing their efficiency • Serious incident • Injury to persons	C
Minor	• Nuisance • Operating limitations • Use of emergency procedures • Minor incident	D
Negligible	• Few consequences	E

Source: (ICAO, 2018; Čokorilo, 2020)

The next step is to assess the acceptability of the safety risk. This process consists of two steps. In the first step, it is necessary to fully review and assess the safety risk, and this is achieved when the probability of the occurrence of the safety risk (Table 2) and the severity of the consequences of the safety risk (Table 3) are combined in the matrix for determining the safety risk (Table 4) (Čokorilo, 2020).

Table 4
Safety Risk Assessment Matrix

Risk Probability	Risk Severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
5 - Frequent	5A	5B	5C	5D	5E
4 - Occasional	4A	4B	4C	4D	4E
3 - Remote	3A	3B	3C	3D	3E
2 - Improbable	2A	2B	2C	2D	2E
1 – Extremely Improbable	1A	1B	1C	1D	1E

Source: (ICAO, 2018; Čokorilo, 2020)

In the second step, the acceptability of the safety risk is determined based on the safety risk index estimated in the composite safety risk matrix. Table 5 shows how the acceptability of safety risk is determined based on the safety risk index (Čokorilo, 2020).

Table 5
Safety Risk Tolerability Matrix

Assessment Risk Index	Suggested Criteria	Tolerability Description
5A, 5B, 5C, 4A, 4B, 3A	Unacceptable under existing circumstances	Intolerable
5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C, 1A	Acceptable based on the safety risk mitigation. It may require management decision	Tolerable
3E, 2D, 2E, 1B, 1C, 1D, 1E	Acceptable	Acceptable

Source: (ICAO, 2018; Čokorilo, 2020)

4.3. Case Study: DHC-8-106 Aircraft

Air Creebec flight 236 was en route from Chisasibi to Val-d'Or, Quebec, Canada, at 8000 feet when it suffered a lightning strike. Subsequently the right generator stopped. The crew worked the Quick Reference Manual (QRH) and reset it. The flight continued to the destination without further problems. A post-flight inspection revealed significant damage to the aircraft. The operator's maintenance staff replaced the right aileron, right wing tip, rectifier number 2, and the tail cone. The aircraft was back in service on July 25, 2017.

Table 6
Risk Control/Mitigation

Risk reference	Generic Hazard	Risk(s) description	Current measures to reduce risk(s) and risk index	Further actions to reduce risk(s) and resulting risk index	Responsibility
Example OPS/01	Airport location	Thunderstorms often occur in this area.	1. Use of technology: VOR, radio communications; 2. CRM; 3. Training; 4. AIP. ***Risk index: 3A*** ***Risk tolerability: Unacceptable under the existing circumstances***	1. It is necessary to develop operational procedures; 2. CRM needs to be improved. ***Risk index: 2A*** ***Risk tolerability: Risk Control/ Acceptable after review of operations***	1. Pilot in Command; 2. Flight Training Manager; 3. Head of the documentation department; 4. Director of the Air Traffic Control Center.
Example OPS/02	Low weather conditions	Low weather conditions affect the take-off and landing operations of aircraft. Strong thunderstorms belong to more serious weather phenomena.	1. The crew should study the available aircraft charts; 2. Training; 3. Implementing CRM. ***Risk index: 2A*** ***Risk tolerability: Risk Control/Acceptable after review of operations***	1. Raise pilot awareness of the importance of forecasting; 2. Raise the awareness of the dispatcher that it is necessary to inform the pilots about potential problems at the airport and that it is necessary to review the limitations of landing performance together with the pilots; 3. It is necessary to improve pilot training for performing operations in severe thunderstorm conditions (defining specific procedures that would facilitate the pilot). ***Risk index: 2C*** ***Risk tolerability: Acceptable after review of operations***	1. Pilot in command; 2. Flight Training Manager; 3. Head of the documentation department.

5. Conclusion

According to provided analysis, it is possible to draw the following conclusions:

- A lightning strike on an aircraft in flight can result in death;
- As a result of a lightning strike, damage to the aircraft occurs (damage to the wings, tail, nose of the aircraft, fuselage, aircraft systems, etc.);
- A consequence that also occurs is blindness of crew members from lightning flashes, which can occur especially at night;
- Difficulties in providing a radio communication;
- A lightning strike can cause an aircraft engine to shut down.

Therefore, analyzing how atmospheric electric discharge affects the flight safety and knowing what consequences can arise as a result of such a phenomenon, it is concluded that the occurrence of atmospheric electric discharge is something that happens very often and can threaten flight safety. By analyzing an aircraft accident caused by a lightning strike by defining the hazard, assessing the risk generated by those hazards and assessing each individual risk, it is possible to provide adequate safety measures and mitigation strategies. Therefore, by using proactive approach to this complex problem, the awareness of the importance of the influence of atmospheric electric discharge on flight safety is strengthened.

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