

## Quantitative analysis of aviation incidents: A comprehensive study on bird strikes and safety improvement opportunities

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**Abstract:** Safety in aviation has various connotations. According to the International Civil Aviation Organization (ICAO), it is a state in which the possibility of harm to people and property is minimised and maintained within a continuous process of identifying threats and managing safety risks at an acceptable level or below an acceptable level. Actions related to threat identification can be reactive, proactive, or predictive. Reactive actions aim to verify what happened, why, and how to prevent it from recurring. For this purpose, incidents that occurred in the past are analysed. By Polish law, the Commission for Investigating Aviation Accidents investigates accidents and serious incidents, while incidents mostly fall under the responsibility of the aviation organisation in which the incident occurred. Therefore, this article aims to identify threats causing incidents. Three thousand two hundred aviation incidents reported between 2017 and 2022 to the Civil Aviation Office as part of the mandatory and voluntary event reporting system were analysed. The identified causes, due to the diversity of their description, were divided into four groups. The first group consists of human factors, representing inadequate actions by pilots, crews, or individuals who caused a situation of danger. The second group comprises errors in the operation of technical objects, including aircraft. This group also includes situations where foreign objects violate airspace or minimum conditions are breached. The next group includes environmental causes such as wild animals, birds, and weather conditions. The last group consists of procedures related to flight phases.

**Keywords:** incidents, safety management systems, identify threats, human factor, procedures



## 1. Introduction

Correction 30 to Annex 6 of ICAO (International Civil Aviation Organization) requires aviation organisations to establish Safety Management Systems (SMS) that, at a minimum, fulfil the following (Maragakis et al., 2009):

- identification of safety threats,
- risk assessment,
- assurance that necessary corrective actions to maintain an acceptable level of safety are implemented,
- continuous monitoring and regular evaluation of the achieved level of safety,
- ongoing enhancement of the overall safety level.

The risk assessment process consists of eight components (Maragakis et al., 2009): system or operation description, threat identification process, consequence analysis, cause analysis, risk assessment, risk mitigation, residual risk approval, and safety assessment documentation. Internal and external information sources can be utilised to identify threat sources, a prerequisite for further actions. Internal information sources for the threat identification process include mandatory and voluntary reporting systems and findings and recommendations from incident investigations in post-investigation reports. Audit and safety review reports, flight plans and parameters analysis, and analysis of trends in internal safety indicators are also helpful. External information sources mainly encompass statistics and reports on aviation accidents and serious incidents and the national mandatory incident and accident reporting system (currently ECCAIRS 2.0). In accordance with European Union regulations, aviation organisations are obligated to report aviation events to the State Aviation Accident Investigation Commission and the Civil Aviation Authority. An aviation event, as defined in (UE, 996/2010), is any safety-related occurrence that poses a danger or, if corrective actions are not taken or not addressed, could endanger the aircraft, persons on board, or any other persons.

Aviation organisations are bound by the Mandatory Occurrence Reporting System (MORS) and the Voluntary Occurrence Reporting System (VORS). According to the provisions of Annex 19 to the Convention on International Civil Aviation in Chapter V on the Collection, Analysis, Protection, Sharing, and Exchange of State Safety Data, safety data collection and processing systems (SDCPS) are established at the state level to acquire, store, aggregate, and analyse safety-related data and information. This includes a mandatory system for reporting safety events, encompassing incident reporting (Piwek, 2022). At the European level, the reporting of aviation events is regulated by the European Parliament and Council Regulation (EU) No. 376/2014 on the reporting and analysis of occurrences in civil aviation. Another European document addressing the reporting of aviation events is Regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on investigating and preventing accidents and incidents in civil aviation. Additionally, based on Article 19, the European Union Aviation Safety Agency (EASA) and the relevant authorities of member states regularly cooperate, participating in the exchange and analysis of information covered by Directive 2003/42/EC. The Act of 3 July 2002 – Aviation Law specifies national regulations regarding the reporting of aviation events.

Reports are submitted by the following individuals (Article 4(6) of Regulation No. 376/2014/EU) using the mandatory reporting system established by the organisation:

- The pilot-in-command or, in cases where the pilot-in-command is unable to report the event, another crew member in the aircraft's command structure,
- An individual under the supervision of a member state or the Agency involved in the design, production, continuous airworthiness monitoring, technical maintenance, or modification of an aircraft or any equipment or its parts,
- An individual under the supervision of a member state or the Agency signing the airworthiness review certificate or granting the aircraft or any equipment or its parts operational approval,
- An individual performing a function requiring authorisation by a member state as a member of air traffic services personnel tasked with air navigation services or an employee of aeronautical information services,
- An individual performing a function related to the safety management of the airport covered by Regulation (EC) No. 1008/2008,

- An individual involved in installing, modifying, technically servicing, repairing, overhauling, controlling in-flight, or inspecting aeronautical navigation installations, with oversight provided by a member state,
- An individual under the supervision of a member state or the Agency involved in the design, production, continuous airworthiness monitoring, technical maintenance, or modification of an aircraft or any equipment or its parts,
- An individual performing a function related to ground handling of aircraft, including fueling, preparing load sheets, loading, de-icing, and towing, at an airport covered by Regulation (EC) No. 1008/2008.

Events subject to mandatory reporting are listed in the sample event list – Annex 1 to the Regulation of the Minister of Transport of 18 January 2007 on aviation accidents and incidents and categorised (CAA, 2007).

Not only events subject to mandatory reporting are reported, but also all other events (or information) that, from the reporter's perspective, pose a real or potential threat to aviation safety. The reporter should share this information within the aviation system with the relevant entity, i.e., the organisation or the competent authority. The voluntary reporting system (VORS) aims to collect:

- Detailed data on events that may not have been captured in the mandatory reporting system,
- Other safety-related information that, according to the reporter, poses a real or potential threat to aviation safety.

Reporting within the organisation is carried out by employed individuals, those performing activities based on a civil law contract, and those providing services to the organisation. Upon receiving a report on an aviation event, the Chairman of the State Commission for Aircraft Accident Investigation classifies it as an aviation accident, serious aviation incident, aviation incident, or other event. Each aviation accident or serious incident involving an aircraft subject to the obligation of entry into the national register of civil aircraft is subject to investigation by the Commission. Other aviation incidents involving these aircraft are investigated by the aircraft operator, air navigation services, or airport management institutions under the supervision of the Commission unless the Chairman of the Commission decides to conduct such an investigation. An aviation accident is defined as an event related to the operation of an aircraft that occurred from the moment any person entered its cockpit to make a flight until all persons on board left the aircraft and during which any person suffered at least serious bodily injury, or the aircraft was damaged, or its structure was destroyed, or the aircraft is missing and has not been located. Official search efforts have been terminated, or the aircraft is in a place where access is impossible (Aviation Law, 2002). A serious incident is an incident whose circumstances indicate that an aviation accident almost occurred. This concept is included in Annex 13 of ICAO. Therefore, the difference between an aviation accident and a serious aviation incident lies in their consequences. Serious aviation incidents should be investigated in the same way as aviation accidents. Because the PKBL always investigates aviation accidents and serious incidents, and thus, after the investigations, their causes are made public, this article decided to analyse the causes of aviation incidents. The analysis is based on data from 2017-2022 for Poland's eight most important airports, obtained from the Civil Aviation Authority (CAA).

## **2. Research methods**

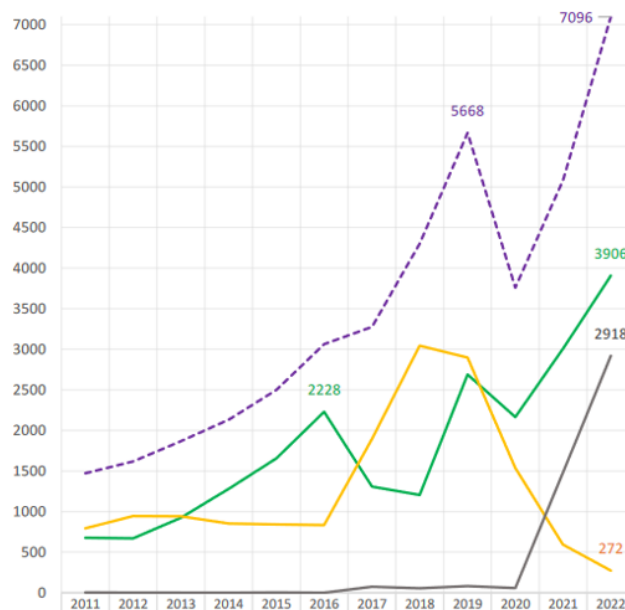
The research methods used in this article are based on analysing aviation incidents reported to the Civil Aviation Authority (CAA) of Poland from 2017 to 2022. The data were obtained from the mandatory and voluntary occurrence reporting systems established by the aviation organisations. The incidents were classified into four groups according to their causes: human, technical, environmental, and procedural. The analysis focused on the eight main airports in Poland, which account for the majority of air traffic in the country. The aim of the analysis was to identify the most common and recurring threats to aviation safety and to propose possible preventive measures. The research methods involved descriptive statistics, frequency analysis, and graphical presentation of the results. The research methods were chosen to provide a comprehensive overview of aviation incidents and their causes in Poland.

### 3. Data analysis

#### 3.1. Incidents

An aviation incident is an occurrence related to the operation of an aircraft, other than an aviation accident, that has or could have an adverse impact on operational safety. From the definition, it is evident that this event is closely tied to the performance of a flight. Therefore, one could assume that its definition is similar to that of an aviation accident, which is stated as follows: "An aviation incident is an aviation occurrence that arises in connection with the operation of an aircraft from the moment at least one person boards an aircraft to make a flight until the last person leaves the aircraft, causing potential threats to flight safety" and in which no one from the crew or passengers is injured, and the aircraft is not damaged. Aviation incidents do not negatively impact the safety assessment of an organisational unit's flights and do not provide grounds for consequences against aviation personnel. On the contrary, the more aviation incidents detected and analysed in a given unit, the greater the assurance that the unit's activities in accident prevention are correct and successful. An essential aspect of flight safety prevention is detecting (searching) and recording aviation incidents and emergency factors, thorough examination, determining the circumstances and causes of occurrence, developing conclusions aimed at their identification and elimination, and thus, preventing aviation accidents (CAA, 2003). According to Civil Aviation Authority data (Figure 1), the number of incidents and events without impacting safety is increasing. In 2022, 7,096 such events were recorded; in 2019 (comparable traffic volume), there were almost 1,500 fewer. This is likely due to an increasing awareness of safety culture. Signatories to the safety culture commitment since 2017 pledge to implement a fair treatment culture and promote the improvement of aviation transport safety.

**Figure 1: Incidents and occurrences without safety effects in Poland 2011 – 2022**



Source: Civil Aviation Authority

(green – incident, yellow – occurrence, grey – undefined, purple – together)

In the literature, various classifications of aviation incidents can be found. In (Skorupski, 2018), the author proposes a classification that quantifies the probability of transforming an incident into an accident and determines the effectiveness of existing safety barriers. The author distinguishes three groups of incidents. The first significant group of serious aviation incidents consists of incidents where the transformation into an accident depends only on the occurrence of a certain sequence of events – incidents with logical dependencies. The second group consists of incidents where the transformation of an incident into an accident depends on favourable or unfavourable temporal sequences. In contrast,

all partial events necessary for the occurrence of an accident have taken place. The third group includes incidents of a hybrid nature, where the transformation of an incident into an accident requires both the occurrence of a certain sequence of additional events and specific temporal dependencies between events. These are the most general cases (Skorupski, 2018). From the SMS (Safety Management System) perspective, it would be essential to determine the probability of transforming an incident into an accident and, more importantly, identify the cause so that appropriate barriers can be applied. Understanding the circumstances in which aviation incidents occur is crucial for preventing their transformation into accidents. Authors divide causes into those related to humans, aircraft and technology, the environment, and procedures. These factors interact, creating elements of the H-A-T (Human - Aircraft - Technology) system. These factors should be understood broadly as actions, cases, or situations whose occurrence or non-occurrence increases the probability of an event.

Human factors constitute the weakest link in the flight safety system and are the primary source of accidents. According to J. Lewitowicz (2006), "human error occurs when there is a general agreement (consensus) that a person should have done something different from what they did". Human error in aviation handling is "an action or its absence by personnel that leads to problems on board an aircraft" (Truszczyński, 2003). Error is a natural side effect of any human activity and should be perceived as a normal component of interacting systems: human-technology-environment. Due to the specific relationships in the aviation system, the number of errors committed there is significant. Most often, they result from the so-called "dirty dozen," which includes (Dąbrowska, 2011):

1. Lack of communication – errors and disruptions in the flow of information.
2. Routine – certainty resulting from prolonged practice combined with a loss of awareness of existing threats, often caused by repetitive tasks and monotonous work.
3. Lack of knowledge – lack of clarity or certainty in understanding something.
4. Distraction – caused by diverting attention, confusion, and mental chaos.
5. Lack of teamwork – inconsistent effort of a group of people caused by a lack of common purpose, fear of pointing out errors made by others, inappropriate leadership style, or inadequate communication.
6. Fatigue – often ignored because, as long as it is not excessive, a person may not be aware of it.
7. Lack of resources – tools, materials, outdated documentation, inappropriate working conditions.
8. Pressure – caused by pressure from superiors or colleagues, lack of time, improper task assignment.
9. Lack of assertiveness – lack of the ability to refuse a task resulting from lack of self-confidence, fear, or complexes.
10. Stress – nervousness caused by time pressure, new methodologies, changes in task scope, competition, or private factors.
11. Carelessness – incorrect assessment of possible consequences of actions caused by pressure, lack of experience, or lack of knowledge.
12. Facilitations – accepting deviations from instructions as standards facilitating work.

Another significant factor influencing the safety of flight execution is the reliability of the aircraft. Its operation is influenced by many components, including tactical-technical characteristics, standardisation, automation, and protective and duplicate systems (Dzik, 2013). In aviation, aircraft designers and constructors focus on the cockpit, i.e., creating the most ergonomic arrangements of instruments and indicators. Analysing the results of air accident commission studies, it can be observed that typical errors caused by lack of ergonomics in the cockpit were incorrect reading of indications from improperly located instruments, incorrect readings from poorly described or double-scaled instruments, and using a faulty instrument mistakenly perceived as correct (Dzik, 2013). The factors above contributing to aircraft damage also include the impact of natural and artificial environments, known as the surroundings. The natural environment includes weather conditions, earthquakes, volcanic dust, terrain features, landing conditions, and bird collisions. The artificial environment includes objects built by humans, such as air traffic control devices, navigational aids, landing systems, runways, and other aircraft. The most significant threats to the aircraft come from hazardous weather phenomena and bird collisions. Hazardous weather phenomena are those that make takeoff and landing difficult or impossible, regardless of the pilot's level of training or the type of aircraft, or those that can

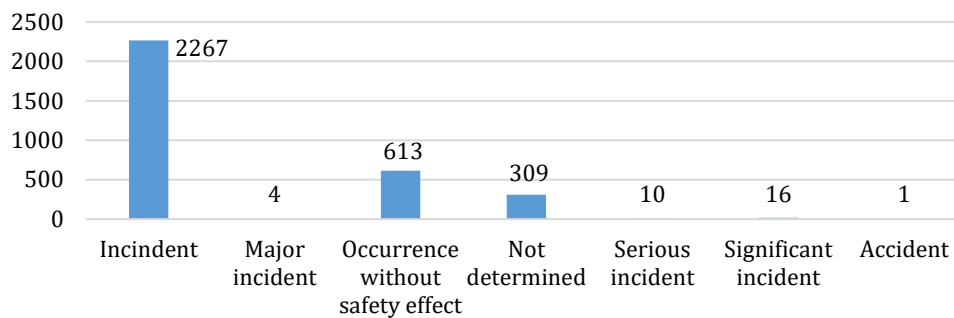


cause destruction (damage) of aviation technology and equipment at the airport (MON, 2004), These phenomena include storms, fog, intense icing, strong turbulence, squalls, wind shear, tornadoes, hail, and visibility-reducing precipitation.

### 3.2. Incident analysis

In the eight main airports in Poland, 3220 incidents were reported, of which 2267 were incidents (Fig. 2).

**Figure 2: Number of aviation events in the years 2017-2022**



Source: Author's computation of AAC data

The explanation of the events specified in Figure 1 is as follows (Eccairs, 2010):

– Accident. An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until all such persons have disembarked, in which:

a) a person is fatally or seriously injured as a result of: - being in the aircraft, or - direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or - direct exposure to jet blast, except when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew; or

b) the aircraft sustains damage or structural failure which: - adversely affects the structural strength, performance or flight characteristics of the aircraft and - would usually require significant repair or replacement of the affected component, except for engine failure or damage, when the damage is limited to the engine, its cowlings or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, minor dents or puncture holes in the aircraft skin; or

c) the aircraft is missing or is completely inaccessible.

– Serious incident. An incident involving circumstances indicating that an accident nearly occurred. N.B. Examples of serious incidents can be found in Attachment D of ICAO Annex 13 and the ICAO Accident/Incident Reporting Manual (ICAO Doc 9156).

– Incident. An occurrence other than an accident is associated with the operation of an aircraft, which affects or could affect the safety of the operation. N.B. The types of incidents of main interest to the International Civil Aviation Organization for accident prevention studies are listed in the ICAO Accident/Incident Reporting Manual (ICAO Doc 9156) and ICAO Annex 13.

– Major incident. An incident associated with the operation of an aircraft, in which the safety of the aircraft may have been compromised, having led to a near collision between aircraft with ground or obstacles (i.e. safety margins not respected, which is not the result of an ATC instruction)

– Significant incident. Eurocontrol: An incident involving circumstances indicating that a serious or major accident could have occurred if the risk had not been managed within safety margins or if another aircraft had been in the vicinity.

– Occurrence without safety effect. A possible safety-related occurrence is not meeting the reporting requirements. This could be, e.g. the result of downgrading the incident after review.

– Not determined. The class of the occurrence has not been determined.

The causes of incidents are divided into four groups: human, technical, environmental, and procedures. In the human group, approximately 100 incidents were identified with the following causes:

1. Air Traffic Control: improper communication, incorrect decisions.
2. Air Traffic Management: severe deterioration of the psychophysical condition, staff clearance deviations during LVP procedure (Low Visibility Procedures).
3. Passengers: inappropriate behaviour, health issues, improperly declared items in luggage.
4. Crew and handling: incorrect decisions, communication problems, health issues, improperly filled NOTAM or load sheet.
5. Pilot: incorrect decisions, communication problems.
6. Third parties: blinding pilots of aircraft with lasers.

In the technical group, over 430 incidents were recorded, with the most frequently recurring problem being:

1. Technical problems of the aircraft: including engine problems, landing gear problems, flaps problems, damaged tires, doors problems, and brake issues.
2. Runway (RWY) problems: blocked, checked, or not vacated.
3. Warning systems: TCAS, EGPWS.
4. Ice protection system problems.
5. Foreign Object Damage (FOD).
6. Objects in airspace: balloon, undefined airborne object, UAV.
7. Fire and smoke.

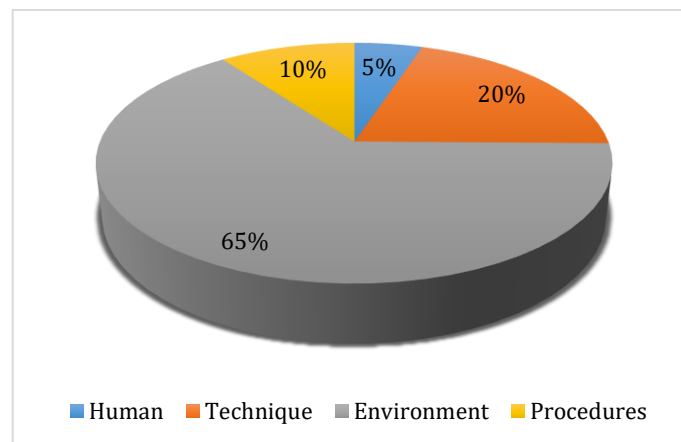
The third group, environment and surroundings, represents over 1440 incidents, with over 90% attributed to bird strikes or interrupted operations due to their activity. Only eight incidents were caused by bad weather and wind shear, and four were due to the activity of wild animals.

The last group consists of procedures (over 200 incidents). In the analysed groups, the following were observed:

1. Bounced landing: behaviour of an aircraft losing contact with the runway during landing.
2. Deep landing: an aircraft landing beyond the aiming point on the runway.
3. Hard landing: occurs when an aircraft hits the ground with more incredible vertical speed and force than in a normal landing.
4. Go-around: procedure for a missed approach.
5. Landing below minima.
6. Separation problem: maintaining minimal distance between aircraft vertically and horizontally.
7. Rejected take-off.

The percentage share of each group is presented in Figure 3.

**Figure 3: Percentage of groups in aviation incidents**



Source: Author's computation of AAC data

As the analysis indicates, most incidents are caused by factors classified into the environmental group, specifically birds. They account for 65% of all incidents. Methods to prevent bird strikes can be found in (Skakuj, 2018; Skakuj et al., 2014).

The next group is technical problems. However, it should be noted that despite classifying aircraft failures or problems with warning devices, it may be the indirect or direct fault of humans (operators, designers, or individuals responsible for maintaining technical facilities). Although considered the most unreliable link in aviation, humans generated the most minor threats. This is due to two reasons. One has already been mentioned, namely, that the operation of technology depends largely on humans. The second reason is that humans are flexible. This means they can control an unfavourable situation if they have experience and are adequately trained or if their intuition kicks in.

#### 4. Results

The increased reported aviation events, including incidents, are partially associated with more aviation operations. The introduction of the Central Reporting Database by the Civil Aviation Office in 2018 also increased the number of reported aviation events. The Central Reporting Database, replaced by ECCAIRS 2.0 in 2023, is a tool for submitting reports from any location with network access. Another aspect is the improving culture of reporting. A more significant number of reports of aviation events also means greater threats. Considering threats in aviation, attention should be paid to their evolution. New types of threats emerge. The elimination of aviation incidents is impossible. Nevertheless, it is possible to reduce the probability of incidents transforming into accidents and serious incidents by analysing their causes and implementing appropriate safety barriers. In the article, the causes are divided into four groups: human, technical, environmental, and procedural.

The analysis of 3,200 incidents at eight Polish airports over five years indicated that nature is the greatest threat to aviation safety. Approximately 65% of incidents were caused by bird strikes. Analyses related to the risk of aircraft collisions with birds have been essential to mitigating aviation risks for many years. Although most collisions do not have serious consequences, accidents can occur in the case of collisions with large and flocking bird species. Therefore, efforts should be made to reduce the likelihood of such events by using methods such as the presence of a falconer at the airport, sound signals, observations, or the use of a dog, as is the case at the Łódź airport.

Another group of causes included technical problems. Most frequently, malfunctions concern the aircraft, including landing gear, engine, and tires. Problems with door closure also often occurred. Therefore, special attention should be paid to these elements. These causes can probably be attributed to humans as operators, designers, or mechanics. However, the article's goal was not to point out the direct cause. The aim was to draw attention to the most common and recurring threats.

In terms of quantity, the third-largest group included events resulting from procedures, especially during takeoff and landing. It was identified as a separate group, although in the vast majority, a human factor can also be found in it. This is due to the inability to determine whether, for example, a deep landing was caused by external conditions, lack of training, or human error.

The last group, characterised by the smallest number of incidents, concerns human errors, communication problems, or neglect. This study can serve as an introduction to a quantitative analysis of the causes of aviation incidents and the possibility of incidents transforming into serious incidents or accidents.

#### 5. Conclusions

Based on data from the Civil Aviation Authority, the article analysed the causes of aviation incidents at eight Polish airports from 2017 to 2022. The causes were divided into four groups: human, technical, environmental, and procedural. The analysis showed that the most significant threat to aviation safety was the environmental factor, especially bird strikes, which accounted for 65% of all incidents. The second group was technical problems, mainly related to aircraft malfunctions. The third group was procedural issues, especially during takeoff and landing. The last group was human errors, communication problems, or neglect. The article suggested that identifying and eliminating the causes of incidents could reduce the probability of their transformation into serious incidents or accidents.

*Future research:* The article proposed some directions for further research, such as:

- Quantitative analysis of the probability of transforming incidents into accidents and serious incidents, based on historical data and risk assessment methods.



- Evaluate the effectiveness of safety barriers and mitigation measures for different incidents and identify potential gaps or weaknesses.
- Development of new methods and tools for preventing and detecting incidents, such as bird-repellent systems, warning devices, or training programs.
- Comparison of the causes and trends of incidents in Poland with other countries or regions and identification of best practices or lessons learned.

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## Conflicts of Interest

The author declares no conflict of interest.

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