STASA Birdstrike Special – Wildtierschlag

STASA Birdstrike Special – Wildlife Strike

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Zusammenfassung

Abstrakt: Das Phänomen des Vogelschlags, also der Kollision zwischen Flugzeugen und Vögeln, stellt eine der größten Herausforderungen für die Luftfahrtindustrie dar. Obwohl solche Zwischenfälle relativ selten vorkommen, können die Konsequenzen, wie wir gesehen haben, schwerwiegend sein, sowohl in Bezug auf die Sicherheit als auch die wirtschaftlichen Kosten. Mit dem Anstieg des Luftverkehrs und der zunehmenden Urbanisierung der Gebiete in der Nähe der Flughäfen, wird es immer wichtiger, dieses Risiko zu verstehen und zu bewältigen. In diesem STASA BIRDSTRIKE SOPECIAL untersuchen wir die Ursachen und Statistiken im Zusammenhang mit Vogelschlägen, neuen Technologien zu Ihrer Verhinderung und die weltweit angewandten Strategien zur Eindämmung des Problems und bieten einen umfassenden Überblick über ein Thema, das im Zusammenhang mit der Flugsicherheit Beachtung verdient.

Summary

Abstract: The phenomenon of birdstrike, that is, the collision between aircraft and birds, represents one of the most critical challenges for the aviation industry. Although such incidents are relatively rare, the consequences can be, as we have seen, severe, both in terms of safety and economic costs. With the increase in air traffic and the growing urbanization of areas surrounding airports, understanding and managing this risk is becoming increasingly crucial. In this STASA BIRDSTRIKE SPECIAL, we will explore the causes and statistics related to birdstrikes, emerging technologies to prevent them, and the strategies adopted worldwide to mitigate the problem, providing a comprehensive overview of a topic that deserves attention in the context of aviation safety.

https://centrostudi-stasa.com/wp-content/uploads/2024/11/SPECIALE-BIRDSTRIKE-2024.06-1.pdf

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EASTERN AIRLINES 1960: a lesson learned?

"One of the most spectacular air incidents, which fortunately ended positively, was the ditching on the Hudson River of the Airbus piloted by Captain Sullenberger.
The triggering factor was the impact with large birds, which caused the failure of both engines.

The phenomenon of birdstrike, that is, the collision between aircraft and birds, represents one of the most critical challenges for the aviation industry. Although such incidents are relatively rare, the consequences can be, as we have seen, severe, both in terms of safety and economic costs. With the increase in air traffic and the growing urbanization of areas surrounding airports, understanding and managing this risk is becoming increasingly crucial. In this STASA BIRDSTRIKE SPECIAL, we will explore the causes and statistics related to birdstrikes, emerging technologies to prevent them, and the strategies adopted worldwide to mitigate the problem, providing a comprehensive overview of a topic that deserves attention in the context of aviation safety.

The STASA Research Center thanks Dr. Valter Battistoni, Captain Andrea Bomben, and their colleagues Jeff Follett, Jeff McKee, Phil Shaw, Alessandro Montemaggioni, and Isabel C. Metz for this work, which deserves recognition for being unique in the Italian context, to the benefit of regulators, airlines, pilots, and industry scholars. It is an outstanding work that addresses this phenomenon in its entirety, analyzing causes and consequences while adopting a multidisciplinary perspective.

Enjoy your reading,

Antonio Chialastri

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WILDLIFE STRIKE: WHAT ARE WE TALKING ABOUT?

Valter Battistoni

(This article was originally written in Italian. The English version provided here is the translation performed by an artificial intelligence program. However, lexical and syntactic correctness is not guaranteed as the sole purpose of the translation is to facilitate the understanding of the content.)

INTRODUCTION

Periodically, further to some striking event, the topic of wildlife strike resurfaces, and the media attempts, with varying degrees of success, to describe and explain the phenomenon for those who have not followed or have forgotten the previous explanations.
In September 2023, an aircraft belonging to the National Acrobatic Patrol (PAN) reportedly collided with a bird and, crashing to the ground, struck a vehicle passing by on the road outside Torino airport, resulting in the death of a five-year-old girl.
Naturally, an internal investigation has been launched by the Air Force and another by the Public Prosecutor, the results of which are currently unknown, although the hypothesis of bird ingestion is now losing credibility.

In the recent past, there have been several events that where in the headlines, although fortunately those resulting in human casualties are quite distant in time. Of course, the so-called Miracle on the Hudson (US Airways, 2009) stands out, which also inspired a movie, preceded by the accident at Rome Ciampino (Ryanair, 2008), while the most recent one is the emergency landing in a cornfield by an A320 (Ural Airways, 2019) near Moscow. But practically every day, wildlife strike incidents occur, and all airlines and airports worldwide are potential victims. The most common consequences range from blood stains on the fuselage to the replacement of an engine, but occasionally, a multimillion-dollar aircraft ends its operational life.

The explanations of the phenomenon by media are, by their nature, concise and sometimes imprecise, so STASA has deemed it necessary to dedicate a thematic dossier to this natural phenomenon, composed of seven articles written by professionals, both Italian and foreign, experts in the field.

THE BIG PICTURE

Firstly, it's important to clarify that the term "wildlife strike" is relatively recent; in the past, the term "bird strike" (or "birdstrike") was more commonly used, as the problem primarily involved birds. ICAO preferred the first definition to encompass impacts with other wildlife, predominantly mammals but not exclusively. However, from a quantitative standpoint, bird impacts represent the majority of reported events (approximately 97%), and therefore, for the purposes of this discussion, we will almost exclusively refer to bird strikes.
The formula that describes bird strike is as follows: **E = ½ mv2**, where E is the energy developed, m is the mass of the bird, and v is the relative speed between the two colliding bodies, basically the aircraft speed, which is largely predominant. The formula also highlights that the severity of the impact largely depends on two factors: the speed of the aircraft and the mass of the bird.
Bird strikes can occur in all phases of flight, from taxi before takeoff to after landing, including cruise, although statistically, 90% of impacts occur at an altitude between 0 and 3500 ft. Bird strikes have been reported even when the aircraft is stationary at the parking gate, with birds being ingested into the engine during startup, as well as at high altitudes up to about 35,000 ft, with some species of vultures in African skies.
While the issue of bird/wildlife strike (B/W strike) is as old as aviation itself (the first was reported in 1905 by the Wright brothers), the matter began to assume significance and show its hazard in conjunction with at least four specific circumstances:

1) The introduction of jet aircraft with drastic increases in speed;
2) The proliferation of mass air transportation;
3) The initiation of protective measures for wildlife with the creation of reserves and natural sanctuaries, along with progressive hunting bans;
4) The introduction of increasingly quieter engines.

Given that by their nature, animals, whether flying or not, instinctively tend to avoid impacts, and that these occur due to the impossibility for the animal to avoid the collision, there arose the need to study the phenomenon and find possible solutions. However, the problem was long confined within the realm of chance, a misconception that largely persists to this day. It is rightly noted, though, that for other chance occurrences or natural events (such as ice, wind shear, volcanic ash), the aviation system has eventually found effective countermeasures, which seem to be somewhat lacking for this particular natural issue.

One of the initial issues that researchers faced was the quantification: ascertaining the extent of the problem and its characteristics; first and foremost, it was necessary to define what should be categorized and reported as a bird strike. According to Italian regulations (Circ. ENAC APT 01B), the following events are subject to mandatory reporting:
• Impact (or presumed impact) directly confirmed by flight crew personnel;
• Report of impact (or presumed impact) received by ATS service operators.
• Aircraft damage reported by aircraft maintenance personnel as objectively resulting from impact with birds or other fauna (e.g., traces of blood, feathers, etc.);
• Discovery of carcasses and/or remains of birds or other fauna on the runway or within the area within 60 meters of the center-line;
• Effects on flight operation (go-around, aborted takeoff, etc.) due to the presence of animals, such as evasive maneuvering, but without an impact occurring.

The next step involves the recording of data and their communication to the organization responsible for studying them and suggesting countermeasures. However, since the issue has global implications, the ICAO had long established the IBIS system (ICAO Bird Strike Information System). This system is intended to collect all strike data within the countries adhering to the organization into a dedicated database.

Actually, not all countries worldwide have an organized system for data collection, resulting in data not being transmitted to the ICAO. Even in more virtuous countries, deficiencies are often reported, especially regarding pilot and airport reports. It is worth noting that in the USA, unlike in Europe, reporting an impact is voluntary. In general, it is estimated that reported impacts account for approximately 20-30% of those actually occurring.

From a practical standpoint, ICAO had developed a model for reporting impacts (BSRF, Bird Strike Reporting Form) to be completed by pilots or other relevant personnel, adopted almost globally. However, even then, there was a complaint about the lack of general and specific regulations regarding the obligation to record data. This seemed to be due to the fact that ICAO had long considered bird strike prevention as a recommended practice rather than a legally binding obligation for member states. This obligation for prevention was only definitively established in 2003 when part of the recommendations was elevated to the status of "standards" in Annex 14 - Aerodromes.

In the third millennium, however, paper reports are becoming extinct, replaced by digital and computerized communications. Thus, the BSRF is now being replaced in Europe by ECCAIRS (European Coordination Center for Aircraft Incident Reporting System), which flow to a central European hub under EASA.
The ICAO is also adapting, with the update of DOC 9332 regarding the IBIS system currently in progress and soon to be published.
With regard to Italy, ENAC through the BSCI (Bird Strike Committee Italy), annually compiles and disseminates an analytical report on impacts at airports, together with information on the species involved and recently also including the risk index for each individual airport, called BRI_2 (Birdstrike Risk Index vers. 2). Therefore, we refer to that document (latest data related to 2022).

To explain the function of the BRI_2 index, it is important to consider that the number of impacts recorded annually by itself means little if not compared with a) the number of movements, i.e., landings and take-offs, b) the biomass of the impacted species, meaning the size and weight of the birds, and c) their number. In practice, a single multiple impact with herons at a smaller airport is significantly more serious than 30 or 40 impacts of individual passerines at a busy airport. Furthermore, the number of reported impacts usually also depends on the attention that the airport operator devotes to data collection and monitoring procedures, so it could also be argued that a high number of impacts might be synonymous with strong prevention, and vice versa. For this reason, risk matrices (such as the BRI_2) have long been used, which are based on the aforementioned aspects and provide a more accurate picture of the airport situation.

In the past, much simpler calculation methods were used, such as the number of impacts out of 10,000 movements, which provided only an approximate overview of an airport's situation.

MITIGATION METHODS

A complete examination of containment and mitigation methods of wildlife strikes would require a much broader treatment than that afforded by the present circumstance; in brief, three salient aspects can be mentioned, linked to the classic tripartition in aviation, human, mechanics and environment: a) information and awareness-raising on the issue and the risks associated with it, at all levels, from flight personnel to ground staff, from regulatory bodies to airlines; b) compliance with design requirements concerning structures and the propulsion system, for aircraft certification purposes, requiring greater structural resistance and engine operability even in the event of bird strikes; c) perhaps the most important aspect concerns the environment, both from the moment of choosing the site for the construction of a new airport, to its ecological management (i.e., making it unattractive to birds), and finally to the removal of birds potentially hazardous to air navigation, if present.

As for the matter a), there is a need of implementing at various levels all necessary actions so that the bird/ wildlife strike risk is carefully perceived, awareness is spread among operators, and appropriate measures are taken when risk conditions occur. Furthermore, there is also a need for training and updating on this topic all personnel involved in various forms.

With regard to the matter b), there were two worldwide regulations concerning the strength of structures and propulsion systems in the event of bird strikes, namely the U.S. FAR (Federal Aviation Requirements) and the European JAR (Joint Aviation Requirements). Both, albeit with different prescriptions, required certain parameters of strength, operational duration, and other peculiarities that the aircraft had to possess in order to be certified for public passenger transport. Today, the EASA (European Union Aviation Safety Agency) has replaced JAA and JAR in European technical regulations. This topic will be specifically addressed in the article "Wildlife Strike Risk Management."

Lastly, the matter c) essentially involves airport management with ecological criteria (habitat management) in order to transform it into an undesirable and unattractive place for birds (e.g., by eliminating waste dumps, bodies of water, and water pools, ensuring that grass height does not fall below certain predetermined limits, deploying deterrents where feasible such as nets, cables, spikes, limiting architectural elements that offer nesting opportunities, eliminating agricultural crops, etc.). When these systems are insufficient, means and procedures for bird removal will be necessary, provided they are in accordance with current regulations.

PREVENTION AND DISSUASION

Certainly, this document is not the ideal place to thoroughly discuss the most widespread prevention and deterrent measures worldwide; however, a brief summary may prove useful for better understanding.
A first point concerns the distinction between prevention and deterrence methods. The adoption of prevention methods begins from the moment of selecting the site for a future airport: a thorough naturalistic study of the environment is therefore essential to avoid later being forced to coexist with invasive wildlife, as in the case of coastal airports or those near natural reserves or restocking areas. The careful site selections and studies carried out for the new airports in Mexico City, Lisbon, and Athens are evidence of this. Naturally, in some cases, choices are constrained. Then, significant importance lies in external attractants such as waste dumps, food processing plants, livestock farms, areas of intensive agriculture, etc. Finally, internal elements such as canals, reservoirs, water pools, swamps, canteens, internal dumps, old abandoned structures (e.g., hangars), trees, bushes, all serve as formidable attractions for avian fauna, as does the possible lack of suitable fencing or their bad condition allowing intrusions of stray animals, livestock, etc. A particular form of environmental intervention is the so-called tall grass policy: starting from the premise that some bird species (e.g., seagulls) do not like to perch in tall grass both due to their webbed feet being unsuitable for the purpose and due to the imperfect surrounding visibility, it is suggested to let the grass grow so that its height never falls below 15/25 cm. However, taller grass would instead provide a good habitat for small reptiles and rodents, which in turn would attract other bird species (e.g., small raptors) potentially hazardous.
The American FAA and the US Department of Agriculture in their manual "Wildlife Hazard Management at Airports" summarized wildlife control strategies into four groups: 1) Flight schedule modification (when at certain times of the day there is no other solution, the best option is to leave the sky to the birds) 2) Habitat modification and exclusion of birds 3) Disturbance techniques, 4) Removal of fauna.
As for the harassment techniques, the most common ones generally include acoustic, pyrotechnic, optical devices, and the use of birds of prey (falconry). Among the former, propane gas cannons, with programmed or randomized explosions, have been widely used in the past, while currently distress calls are popular and widely used (i.e., the emission of recorded sounds containing alarm calls of animals in distress, or even synthetic sounds). The latest addition is represented by the LRAD (Long Range Acoustic Device), a directional emitter of high-intensity sounds, whose use remains highly debated as it is considered a weapon although non-lethal.
Pyrotechnic devices include various types of fireworks, typically launched from a rocket gun, with both immediate and delayed detonation.
Optical devices, starting from the old "scarecrows," have been practically abandoned as they are unable to overcome the habituation by birds. Birds quickly "learn" that when the potential predator does not cause any harm, it is not a danger. Therefore, it is suggested to occasionally accompany any non-lethal disturbance action with lethal techniques, such as shooting down some individuals during distress calls, to strengthen their effectiveness over time.
Falconry probably enjoys an undeserved reputation as there have been no independent studies so far to confirm its real effectiveness. It is based on the innate primal fear that birds generally have of raptors but is often limited by employment conditions (meteorological or biological conditions of the bird) as well as high costs. It is obvious that such a system, erroneously labeled as "natural," does not work when the birds to be deterred are larger than the predator (e.g., herons). Recently, a remotely controlled model aircraft resembling a raptor has been experimented with, showing great versatility and undeniable effectiveness.

Regardless of the means employed, airport patrolling with specialized vehicles and human presence remains the most effective deterrent. A separate chapter is dedicated to remote sensing systems, which are discussed in another article in this journal.
This limited analysis primarily confirms that the battle against bird strikes is not an exact science. There are too many variables for any deterrent to be considered effective outright. The trend is to use multiple disturbance methods in an integrated manner and with different modalities, aiming to avoid or limit the greatest obstacle, which is habituation. Birds are intelligent animals, and any single method used (often poorly) has a high probability of being ineffective for its intended purpose. Another consideration is that most countries grant a certain degree of freedom to their airports to adopt the tool that local conditions and past experience have shown to yield results, sometimes encouraging the pursuit of new strategies or means. The aforementioned points lead to the further consideration that fighting the bird strike issue, one of the most complex problems, has a substantial dynamic aspect, continuously evolving, and relies on subsequent refinements.

QUANTIFICATION

Simply examining the statistics of bird strikes that have occurred in Italy, compiled from 2002 onwards, reveals a steady and continuous growth in the phenomenon: the total number of reported strikes increased from 348 in 2002 to 2168 in 2022. Although the initial attempts at quantification were somewhat experimental, with airports not taking data requests too seriously or lacking an autonomous and efficient detection system, there is no doubt about the evident rise in the number of strikes.
Furthermore, a glance at the statistics of other countries allows us to observe a similar trend worldwide. In the USA, reported strikes increased from 1851 in 1990 to 15,556 in 2021; in the UK, from 1481 in 2004 to 5460 in 2019; in France, from 719 in 1994 to 759 in 2019, and so on.
Some argue that the increase in reported strikes (data obtained from reporting models) largely stems from the improved accuracy of inspections and increased awareness among staff. Therefore, the overall number wouldn't be significantly rising but rather remaining relatively constant. This viewpoint suggests a gradual realization of the extent of the phenomenon, which was already present at these levels ten or twenty years ago but went unnoticed. However, this hypothesis can only be partially accepted, particularly regarding the early years of data collection. Today, thanks to heightened attention from operators, European regulations, and even legal action, one can state that at least in major airports, monitoring and reporting of strikes have reached a somewhat acceptable level.

The increase in reported strikes seems primarily due to a greater presence of birds on airports and in their immediate vicinity.
What are the reasons?
Undoubtedly, a contributing factor is the established colonization of cities and human settlements by many species of birds, especially seagulls and pigeons, which find shelter and abundant food there. Additionally, the airport itself represents an attractive element, being comprised of vast, obstacle-free surfaces that allow for full visibility of any natural predators, paved surfaces that warm up more than surrounding ground in winter, favoring resting, decent chances of finding food (snails, seeds, small reptiles, rodents), and practically no lethal reaction from humans. Furthermore, some events can also contribute, such as an abnormal seasonal proliferation of certain insects that attract specific species, like Common swifts (*Apus apus*).

However, the key role in this increase is certainly played by the action of external attractions to the airport, such as landfills, human settlements, agricultural crops, livestock farming, etc. In addressing this issue, the Italian legislation has implemented a legal tool that is theorically highly effective. We are talking about the Articles 711 and 714 of the Navigation Code resulting from the 2005/2006 reform, which allow the National Civil Aviation Authority (ENAC) not only to subject to an authorization all new settlements that may attract birds but also to eliminate hazards and upon payment of compensation if the activity or settlement predates the airport's development plan or zoning plan. Such is the effectiveness of the regulation that some countries around the world have emulated it.

Actually, however, at least the Article 714 has shown little or no application, as public order, hygiene, and general policy interests have so far demonstrated to prevail over those related to safety. It happens, for example, when it comes to close or relocate an urban waste landfill. The continuous resorting to emergency legislation, the invocation of urgencies, in fact, nullify the excellent work done by the legislation.

THE INVOLVED PARTIES

Traditionally, the prevention model against Bird/Wildlife (B/W) strikes has been heavily unbalanced: practically all possible actions, risks, and costs have so far been placed on the airport operator, with other stakeholders in the system acting as almost inert spectators.

This situation mainly derived from a simple statistical consideration: over 90% of bird strikes occur at altitudes between 0 and 3500 feet, with the vast majority occurring within 300/500 feet. Therefore, we are talking about impacts that happen above airport area or in the immediate vicinity. Naturally, the responsibility for mitigating the problem has been practically delegated entirely to the airport operator.

However, this perspective, even though provided for and legally codified, is no longer entirely satisfactory. Despite the efforts made by the operator to keep the airspace above its airport sterile, external elements, natural or artificial, will always play a fundamental and unavoidable role, and the technical and even legal tools available to the operator are entirely ineffective on these external factors. Therefore other parties must be considered, which necessarily have to be involved in terms of assigning their respective responsibilities.

The topic is thoroughly addressed in the aforementioned article "Risk Management of Wildlife Strikes." We add to that comprehensive discussion some "new" stakeholders, many of which are not even aware of their involvement.

Among the key players in the prevention strategy mentioned in the referenced article, aviation investigation authorities play a fundamental role, not only because they analyze and reveal the causes of an already occurred incident but also because they issue recommendations that in some way become binding for the parties they are addressed to. They have the power to change things, a power that unfortunately is often not used or is misused. Unfortunately, in the field of B/W strikes, our country does not shine in terms of promptness: at least two significant investigations concluded after an unreasonable number of years. We refer to the event involving aircraft I-ERJC, Milan Linate 2003, which caused the loss of two pilots, whose final report was issued 17 years later, and to the Ryanair accident at Rome Ciampino in 2008, ten years later. The first one, moreover, without any recommendations.

Unfortunately, even internationally, many investigation reports regarding incidents of B/W strikes are entirely unsatisfactory. In some cases, there is too much inclination towards chance circumstance, while in too many others, there is a reluctance to issue any recommendations. More than one suspicion arises that even investigators need training.

Essential elements of prevention also include territorial authorities, in Italy, municipalities, provinces, and regions. These entities govern and determine the layout of areas surrounding airports. In a large part, these entities are completely unaware of ICAO and national regulations and sometimes authorize settlements or activities incompatible with safe air operations. These are classic cases of those who are unaware of their responsibility. Landfills, intensive farming, natural parks, wildlife repopulation areas, and hunting reserves are indeed elements that attract birdlife, and when located near an airport, they pose high-risk factors.
Additionally, there are other seemingly distant stakeholders from the aviation world that can play an important role in prevention. In this regard, we would like to mention the insurance sector. We know that insurers are the ones who bear the economic damage in the first (and often only) instance and therefore should be particularly interested in risk mitigation. The action of insurers could manifest by drastically increasing insurance costs in the absence of adequate prevention measures and conversely reducing them when the operator takes appropriate measures, even up to denial as *extrema ratio*.

THE COSTS OF BIRD STRIKES

The problem of costs resulting from bird strikes largely eludes statistical analysis because it is considered part of the most intimate and secret area of a company's activities. Airlines are generally reluctant to provide this data, except in court and on a case-by-case basis, so there may be suspicion that in some cases, there is not even a differentiation of costs by type of cause, or at least for this cause. Worldwide, only estimates have been attempted, albeit likely underestimated.
The costs borne by airlines are divided into direct costs, which include damage repair, and indirect costs, such as aircraft grounding, lost revenue, cancelled flights, passenger assistance and re-protection, etc. Instead of attempting an evaluation of overall costs, some researchers have preferred to estimate the cost of a single event, also thanks to the contributions provided by some airlines.
In the United States, with regard to the direct costs of maintenance and repair, an average of around $160,000 per event has been estimated. The indirect costs alone would amount to about $25,000, thus bringing the total average per event to approximately $185,000. However, these data refer to the period between 1990 and 2018, so costs may have increased since then.
The costs borne by airlines are divided into direct costs, which include damage repair, and indirect costs, such as aircraft grounding, lost revenue, cancelled flights, passenger assistance and re-protection, etc. It is a matter of fact that the evaluation of costs resulting from wildlife strikes is highly variable but nevertheless substantial.

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WILDLIFE STRIKE MITIGATION: DECADES OF EFFORT AND NOW IS THE TIME TO STRIKE

Jeff Follett, Jeff McKee & Phil Shaw

Introduction

Aviation stakeholder use a range of wildlife hazard management (WHM) practices to mitigate wildlife strike risk including habitat management, active wildlife management, and staff training. However, after decades of aviation WHM, the industry has not seen substantial reductions in wildlife strikes nor improvements in aviation safety or wildlife conservation outcomes. Wildlife are still harmed, aircraft are still damaged, and occasionally, hull loss and human fatalities still occur. The purpose of this review is to outline the current state of aviation WHM including discussions around how management success is measured and issues that prevent progress. We summarize wildlife strike history and trends, outline the existing aerodrome-centric approach to aviation WHM and provide an alternative approach that accurately identifies the issue as a dynamic airspace collision avoidance problem. We advocate for an airspace collision avoidance management model that will help industry achieve the aviation safety and wildlife outcomes it has sought for decades.

The history of wildlife strikes since 1905 has been documented extensively (McKee et al, 2016; Thorpe, 2016; Metz et al., 2020). Wildlife strikes have caused at least 804 human fatalities and 739 aircraft losses since the beginning of aviation (Shaw and Dolbeer, 2024). The severity of strikes is demonstrated by three serious accidents in recent years. On 15 January 2009, US Airways Flight 1549 (Airbus 320) with 155 persons aboard made a forced landing in the Hudson River after ingesting Canada geese (*Branta canadensis*) into both engines at 2900 ft after departure from LaGuardia Airport, New York (National Transportation Safety Board, 2010). In September 2012, 19 people were killed and the aircraft was destroyed when a Dornier 228 crashed after striking a black kite (*Milvus migrans*) on take-off from Kathmandu, Nepal (Aviation Herald, 2013). On 15 August 2019, Ural Airlines Flight 178 (Airbus 321) with 234 persons aboard made a forced landing in a corn field three miles from Zhukovsky International Airport, Moscow, Russia after ingesting gulls (*Larus sp.*) into both engines during take-off (Aviation Herald, 2019). None of the 389 people were killed in the “Miracle on the Hudson” and “Miracle in the Corn Field” bird-strike events even though both aircraft were damaged beyond repair. Although rare, such serious wildlife strikes continue to occur with at least one human fatality due to wildlife strikes every year since 1952. A sample of recent accidents from Shaw and Dolbeer (2024) includes:

• In 2015, a vulture struck an AS 350B3 Ecureuil (AS50) in India, resulting in seven human fatalities

• In 2019, an unidentified species struck a B737-MAX8 (B38M) in Ethiopia, resulting in 157 human fatalities (National Transportation Safety Board 2023a). The US investigation team found that the erroneous angle of attack (AOA) sensor output was caused by the separation of the AOA sensor vane due to impact with a foreign object, which was most likely a bird.

• In 2022, gulls were ingested into the engine of a Sukhoi Su-34 (SU27) on take-off in Russia resulting in 15 human fatalities.
• In 2023, an Aermacchi MB-339 (M339) crashed in Italy, resulting in one human fatality. Investigations into the accident continue and the examination includes the possibility that a wildlife strike may have triggered the crash. Photographic evidence prior to the accident indicates birds were in proximity to the aircraft prior to the accident.

The main factors determining the consequences of a strike are the number and size of animals struck, the combined closing speed at which the strike occurred, the phase of flight when struck, and the part of the aircraft hit (MacKinnon, 2004). Generally, the larger the animal and the faster the impact speed, the greater the damage. The relationship between body mass and damaging strikes is concerning as there is evidence that some large-mass wildlife populations are increasing in urban areas where they could conflict with terminal traffic (Dolbeer, 2020). Dolbeer (2020) notes that there are 20 large (≥ 1.8 kg) and 16 medium (1.1-1.7 kg) bird species in North America with ≥20 strikes reported for civil aircraft. He reports that the population for the large species had a net gain of 27.8 million birds and the medium bird population had a net gain of 6.7 million from 1990 to 2018.

Worldwide, tens of thousands of wildlife strikes are reported annually for civil and military aircraft. The most recent International Civil Aviation Organization (ICAO) Electronic Bulletin (International Civil Aviation Organization, 2023), which summarizes the reports of all reporting ICAO countries, recorded 273,343 wildlife strike reports for 2016-2021. Wildlife strikes for 2016-2021 were reported from 136 States and reported strikes occurred in 194 States and territories around the world. Due to differences amongst States in strike definitions and due to incomplete strike reports, it can be challenging to confirm the worldwide trends in wildlife strikes; however, based on reviews of wildlife strike databases and wildlife strike summaries from Australia, and the United Kingdom (UK), New Zealand, and the United State (US), the rate of wildlife strikes is not decreasing, and is likely increasing.

In Australia the number of strike reports is increasing with 2017 having the highest number of wildlife strike reports on record with 1,921 records (Australian Transport Safety Bureau, 2019). In the United Kingdom (UK) the wildlife strike rate increased from 2017 to 2021 with a slight decrease in 2022 to rates similar to 2014 to 2016 (United Kingdom Civil Aviation Authority, 2017; United Kingdom Civil Aviation Authority, 2022; United Kingdom Civil Aviation Authority, 2023). In the UK, the number of damaging wildlife strikes has ranged from 45 in 2022 to 86 in 2016. The Civil Aviation Authority of New Zealand (CAANZ) (2023) provides quarterly bird incident rate reports with the October to December 2022 report indicating a static strike rate from 2020 to 2022 although 13 aerodromes trended upwards, and nine aerodromes were categorized as medium- or high-risk. The trend did not improve in 2023 with 11 aerodromes trending upwards, an overall country-wide static trend, and 13 aerodromes categorized as medium- or high-risk (Civil Aviation Authority of New Zealand, 2024).

While each civil aviation authority provides data summaries, the reports differ slightly in their analyses and level of details which can make it difficult to extrapolate to the overall wildlife strike rate, particularly without access to the raw data. In addition, the aviation impacts of COVID-19 make trend analysis from 2020 through 2022 challenging. At a minimum, from this sample of reports, one can assess that the wildlife strike rate is relatively static to increasing and the number of damaging strikes is relatively static.

The US Federal Aviation Administration (FAA) provides public access to the wildlife strike raw data which allows individuals to perform analyses and the FAA also releases an annual report providing the current state of affairs for US wildlife strike data (Dolbeer et al., 2023). During the period 2000-2022 there were substantial increases in reported strikes per 10,000 movements which may indicate increased strike rates and/ or improved reporting (Figure 1). The damaging strike rate to commercial aircraft operating at Part 139-certificated airports has increased since 2000, with most of that increase due to strikes beyond the aerodrome fence, i.e. at greater than 1,500 ft Above Ground Level (AGL) (Figures 2 and 3). General Aviation damaging strike rate continues to increase at all altitudes (Figure 4). Based on the US data, there remains a strong correlation between body mass and the likelihood of a strike causing damage to aircraft.

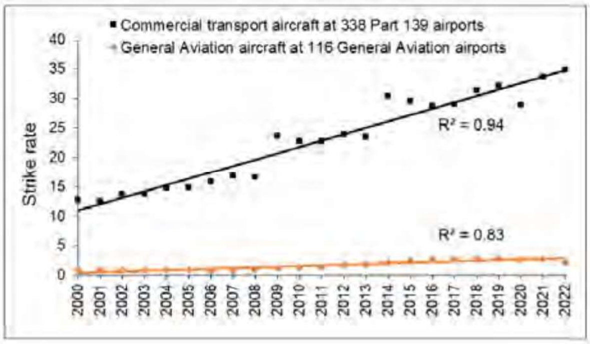

Figure 1 Wildlife strike rate based on reported strikes by aircraft type. Source: Dolbeer et al., 2023.

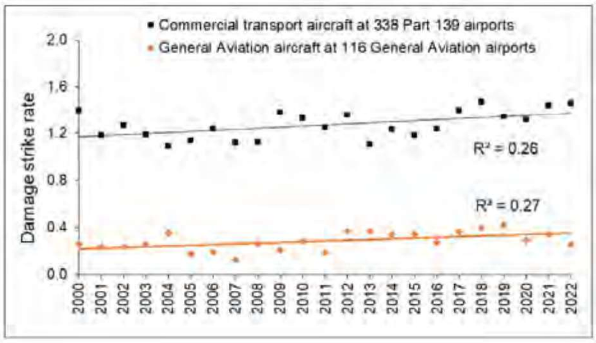

Figure 2 Damaging strike rate for commercial and general aviation aircraft. Source: Dolbeer et al., 2023.

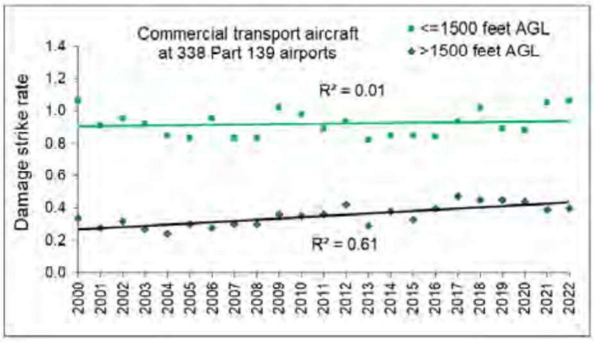

Figure 3 Number of damaging strikes for commercial transport aircraft by altitude and year. Source: Dolbeer et al., 2023.

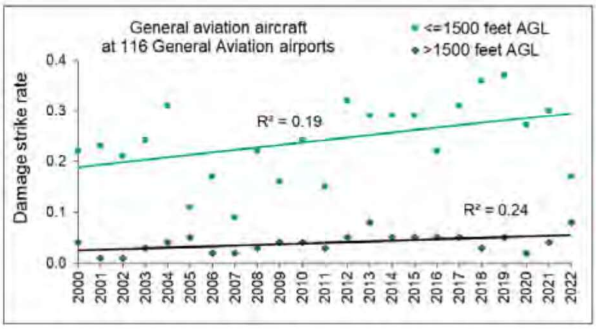

Figure 4 Number of damaging strikes for general aviation aircraft by altitude and year. Source: Dolbeer et al., 2023.

The National Transportation Safety Board (NTSB) US Civil Aviation Dashboard 2008 to 2022 identifies 32 known *Defining Events* responsible for a total of 20,458 fatal and non-fatal accidents (National Transportation Safety Board, 2023b). Four *Defining Events* categories with greater than 100 accidents in the 15-year period have an increasing trend (Figure 5). The number of accidents due to wildlife encounters and bird strikes doubled from 2008 to 2022. In comparison, the other three *Defining Events* with greater than 100 accidents with increasing trends have only increased slightly since 2008.

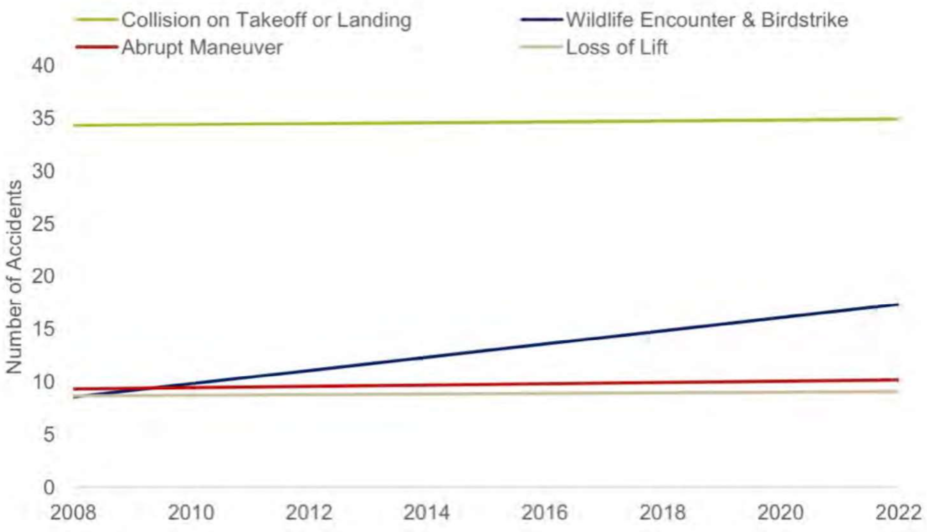

Figure 5 Accident trends for Defining Events with greater than 100 accidents and increasing trends 2008 to 2022. The Defining Events 'Wildlife Encounters' and 'Bird Strikes' are reported separately to the NTSB; however, for this analysis the categories are combined, having a total of 146 reports. Source: Trendlines adapted from National Transportation Safety Board https://www.ntsb.gov/safety/StatisticalReviews/Pages/CivilAviationDashboard.aspx.

Wildlife strikes cost the worldwide commercial civil aviation industry an estimated US$1.2 billion per year (Allan, 2000) and involve more than just the repair of damaged engines and airframes. Even apparently minor strikes which result in no damage can reduce engine performance, cause concern among aircrew and add to airline operating costs. The annual cost of wildlife strikes to the US civil aviation industry in 2022 was projected to be 67,848 hours of aircraft downtime and $385 million in direct and other monetary losses (Dolbeer et al, 2023). Altringer et al. (2021) estimate the annual cost of wildlife strikes to US civil aviation to be USD $54.3 million with an additional annual cost of USD $25 million in spillover delay costs for damaging strikes (Altringer et al., 2022). Parsons et al. (2023) estimate that wildlife strikes cost the Australian aviation industry approximately AUD$7.9 million in repair costs and approximately AUD$4.8 million in other costs each year.

Measuring Wildlife Strikes and Monitoring Wildlife Strike Mitigation

The aviation WHM community has developed guidance documents for data collection, data analysis, risk assessments, hazard communication, and wildlife strike reporting (MacKinnon, 2004; World Birdstrike Association, 2006; International Civil Aviation Organization, 2020; Australian Aviation Wildlife Hazard Group, 2024; International Civil Aviation Organization, 2024). These documents help industry professionals to ensure data is consistent, understand best practices, improve wildlife management practices, and evaluate programs.

While the guidance documents are helpful, some terms are not defined or are inconsistently used which inhibits the analysis of wildlife strike events. Below are proposed definitions that, if universally applied, provide consistency for key performance indicators, inform performance metrics for aviation WHM programs, and help stakeholders to refine where management should focus to best mitigate wildlife strike risk (Table 1).

Table 1 Some wildlife collision terms used to help define, localize and understand wildlife strike risk

Category	Term	Definition
Location	On-aerodrome Strike	A strike that occurs while the aircraft is still inside the aerodrome boundary, or ≤200' AGL on approach, or ≤500'AGL on departure
	Airport Vicinity Strike	A strike that occurs while the aircraft is outside the area defined as 'on aerodrome' but within an area of 13 km radius from the aerodrome reference point (ARP) or ≤1,000 ft AGL
	Remote Strike	A strike that occurs while the aircraft is more than 13 km from an aerodrome or ≤1,000 ft AGL
Strike Definitions	Non-strike	A reported wildlife collision for which, after investigation, no evidence is found
	Unconfirmed strike	A reported collision between wildlife and an aircraft for which no physical evidence is found and which cannot through investigation be designated as a non-strike or confirmed strike
	Confirmed strike	A reported collision between wildlife and an aircraft for which evidence in the form of a carcass, remains or damage to the aircraft is found -or- Wildlife found dead on an airfield where there is no other obvious cause of death (e.g. struck by a car, flew into a window etc.)
	Serious strike	A strike resulting in adverse effect on planned flight and/or damage to the aircraft
	Near-miss	An occurrence report where wildlife in the airspace of an aircraft posed a risk of collision, but resulted in a non-strike
	Adverse Effect on Planned Flight (AEPF)	Strikes or near misses that result in aborted or non-standard procedure, precautionary or forced landing, delay/cancellation, diversion, accident and/or affects the serviceability of the aircraft or aerodrome
	Damaging Strike	A wildlife strike that causes damage to an aircraft component irrespective of whether that damage has AEPF
Other Terms/Metrics	Strike/near-miss Rate (Number)	Number of strikes/near misses per 10,000 aircraft movements
	Mass Struck Rate (Mass)	Total mass (kg) of wildlife struck per 10,000 movements
	AEPF Rate	Number of strikes causing AEPF per 100,000 movements
	Wildlife Attrition Rate	Total number of wildlife killed directly from strikes plus any killed as a result of control programs per year
	Conservation Attrition Rate	Total number of conservation-listed species killed directly from strikes plus any killed as a result of control programs per year
	Critical Area	Areas within or in proximity to the runway strip, approach and landing paths, and movement areas of an aerodrome
	Critical Airspace	The airspace volume defined by an aircraft flight path surrounded by a 100 m radius. Includes any published standard or commonly used flight path
	Critical Airspace Mass Infringement Rate (CAMIR)	The mass flux of wildlife (kg) through critical airspace per unit time
	Aircraft Movement Rate (ACMR)	The number of aircraft movements (take-off or landing) per unit time

Aviation stakeholders should evaluate their WHM program success using a scorecard system which consists of metrics that are considered most suited to the air operational and biological context of the aerodrome (or fleet) in question. Table 2 provides a non-exhaustive list of metrics to assess aviation WHM programs. Scorecard metrics may change over time in response to dynamic changes in aircraft and wildlife behavior and management initiatives. Ideally, the metrics include leading and lagging indicators which allow stakeholders to review events that have happened (lagging) and to predict how program activities could contribute to mitigating strike risks (leading). Table 2 proposes targets or acceptable threshold values for some of the metrics.

Table 2 Examples of scorecard metrics with proposed targets or acceptable threshold values.

Metric	Indicator type	Target Threshold Value	Reference
Strike/near-miss Rate – Number of strikes/near misses / 10,000 aircraft movements	Lagging	5 / 10,000	Adapted from Metz et al. (2020)
AEPF strike rate – AEPF strikes / 100,000 movements for on-aerodrome and airport vicinity strikes	Lagging	0.09 / 100,000	Dolbeer and Begier (2012)
Damaging strike rate – damaging strikes / 100,000 movements	Lagging	0.96 / 100,000	Dolbeer and Wright (2009)
Total mass struck / 10,000 aircraft movements – kg / 10,000 movements	Lagging	1.7 kg / 10,000	Shaw and McKee (2016)
Conflict Index (CI) - CAMIR x ACMR	Leading	Insufficient data	Not available
Mass of wildlife surveyed airside within critical area – kg in critical area/survey	Leading	Insufficient data	Not available
Number of high and moderate risk species surveyed within critical area – number / survey	Leading	Site specific	Not available
Wildlife hazard management training completed – person hours/year	Leading	16 hrs / yr	Not available
Competency checks completed – Checks / person / year	Leading	1 / yr	Not available
Review of plans completed in previous year	Leading	1 / year	International Civil Aviation Organization (2020)
Strike incident investigations completed – Number of investigations/total number of strikes	Leading	10%	Not available
New WHM techniques or equipment formally trialed in the previous year	Leading	1 / year	Not available

Strikes are a tangible metric to assess wildlife management programs. However, using strikes alone is a retrospective approach which can inform future decision-making, but cannot easily be used for proactive management. In addition, the sample size for wildlife strikes, adverse effect strikes, and mass struck are quite small, often resulting in low signal-to-noise-ratio data that is difficult to interpret (Figure 6).

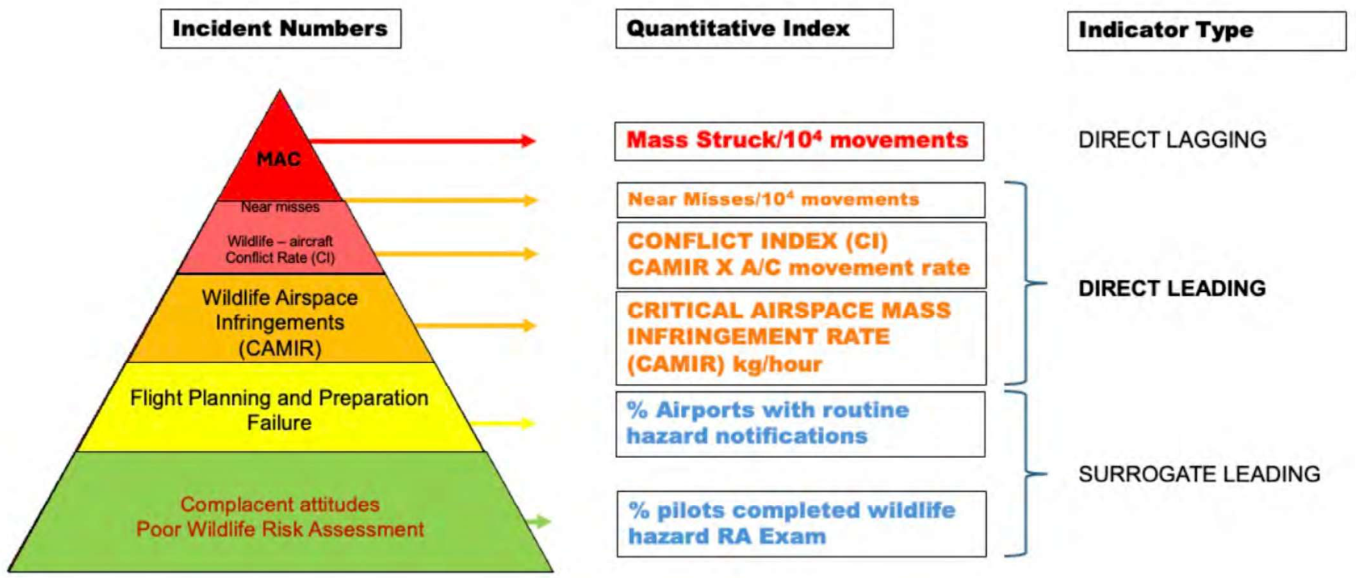

Figure 6 *Example of some indices used for aviation WHM program evaluation. The direct, leading indicators (orange group) are the most informative metrics to monitor but quantifying these accurately may require sophisticated remote sensing techniques.* ***MAC*** *= Mid-Air Collisions. Source: adapted from Shaw and McKee, 2016.*

Focusing on the top of the safety pyramid and relying on strike information alone can be misleading. Often, robust correlative information can be extracted from the data sets lower on the pyramid which have a greater number of data points. Evaluation of aviation WHM programs needs to include measures lower in the pyramid as the low numbers of incidents at the top of the safety pyramid do not necessarily reflect the future risk of serious wildlife strike events.

It is important that scorecards include multi-dimensional metrics and that they attempt to address the broad objectives of an integrated management program including: air safety; air operational; cost-benefit; wildlife and land conservation; and animal welfare. These objectives need to be clearly articulated in any program and in the case where objectives conflict, they should be ethically prioritized with bias towards air safety and animal welfare.

The decision of appropriate program metrics is context-dependent, and in general, the metrics used to assess program efficacy are most effective if they are at least partially redundant and cross-correlative. Various agencies and regulators release reports that attempt to provide a current 'state of affairs' for aviation WHM and wildlife strike mitigation. However, the complexity involved in evaluating wildlife strike mitigation success from these reports is demonstrated by examples from the US, provided in Figures 1 to 4. Between 2000 and 2022, reported strike rates to commercial aviation aircraft in the US has been steadily increasing (Figure 1), as have damage rates (Figure 2). Further analysis shows that damage rates are steady for commercial aircraft below 1500 ft (when aircraft are operating at or near the aerodrome) but are increasing above 1500 ft (where aerodrome operators have less control) (Figure 3).

When this same analysis is extended to general aviation, the trends are consistently increasing for all altitudes (Figure 4). So, is the overall aviation WHM program in the US effective? The answer, unfortunately, is that it depends on which aerodrome you are evaluating and the quality of the data going into the analysis. Reporting culture and the quality of wildlife strike data may differ amongst reporting organizations and trends in reporting may change over time. An aviation stakeholder with increasing strikes may reflect an improved reporting culture and comparing strike rates amongst aerodromes may reflect varied criteria for reportable strikes. Trends across all ports are interesting, but in the end, it is each individual aerodrome's wildlife program that needs to be assessed. The nature of averaged statistics likely makes assessment of any one program inaccurate when using the averages

Even when assessing an individual aviation WHM program, evaluation requires analysis of multiple datasets and assessment against various criteria. Figure 7 demonstrates a situation where strike rate is increasing; however, adverse effect strike rate is decreasing which is consistent with decreased mass struck per 10,000 aircraft movements. Using multiple performance criteria, despite an increasing strike rate, a stakeholder may determine that management is effectively prioritizing high-risk species. Alternatively, a stakeholder assessing the program in Figure 8, may determine that the runway strip and critical areas are not being monitored and cleared effectively based on an increased critical area infringement rate resulting an increased mass struck rate.

While the industry has guidance material for strike reporting and data collection, scenarios such as those above continue to make aviation WHM program evaluation difficult. Additional measures beyond the industry standard of strikes per 10,000 aircraft movements are required to accurately assess wildlife strike risk because strikes per 10,000 aircraft movements only considers the probability/likelihood part of the risk equation. A low strike rate may be a high risk because the wildlife being struck are large flocking species, and conversely, a high strike rate may be a relatively low risk because only small birds are being struck. For this reason, evaluation should focus on metrics which measure the probability and the consequence of wildlife and aircraft occupying the same space, such as the conflict index (mass of wildlife and aircraft movements) and mass struck per 10,000 aircraft movimenta.

Impediments to Aviation Wildlife Hazard Management Progress

Because most wildlife strikes occur during take-off and landing when aircraft are at low altitudes and where wildlife mostly operate, the aerodrome operator has traditionally been primarily responsible for aviation WHM programs. This aerodrome-centric model for WHM is reinforced by industry: ICAO (Annex 14, Document 9137), the World Birdstrike Association (WBA) (Standards for Aerodrome Bird/Wildlife Control), the FAA (14 Code of Federal Regulations (CFR) Part 139.337, Advisory Circular (AC) 150/5200-38 and Wildlife Management at Airports: A Manual for Airport Personnel), and the Australian government's National Airports Safeguarding Framework (McKee et al., 2016). At every level of regulation, standard, and guidance, the issue remains an aerodrome problem because it is perceived that the operator can control the wildlife within their fence. Unfortunately, aerodromes do not control airspace, and many animal groups can fly or find ways around fences. Aerodromes only control the land area within their boundaries and both wildlife and aircraft do not restrict their movements to those areas.

Wildlife/aircraft collision has traditionally been considered unimportant, boxed as unmanageable, and assessed as a "cost of doing business." An example of this "too hard to manage" approach to wildlife strikes is a quote from an international airline spokesperson after a B747 was forced to turn around after birds were ingested in one of its engines, "It's bad luck for the flight and bad luck for the birds" (ABC News, 2010). This quote is from an airline that has a stellar safety record. In some circumstances, this fatalistic attitude may be an accurate assessment of our inability to predict and manage random events but in many arenas, it has been applied to all wildlife strikes and consequently has left the civil aviation industry locked in a conviction of learned helplessness.

When inevitably an aircraft and wildlife collide, parties often resort to litigation to resolve culpability. Courts often focus on whether due diligence was exercised, particularly on behalf of the aerodrome. In some cases, liability is extended to multiple stakeholders such as the aerodrome operator, Air Traffic Control (ATC), and the airline (Shaw & McKee, 2018). Unfortunately, stakeholders often rely on regulations or standards to display that they have acted in good faith and fulfilled their duty of care. Regulations and standards should be treated as the minimum or the starting point when it comes to aviation WHM and stakeholders should focus on best practice (Follett et al., 2019).

An alternative to adversarial litigation is collaborative investigation which aims to identify the root causes of serious strikes and to provide recommendations to prevent similar incidents. However, to date, few if any large post incident investigations into serious wildlife strikes have included detailed wildlife biological or behavioral examinations and thus have failed to capture up to 50% of the relevant reasons for the collision. Shaw and McKee (2018 and 2019) reviewed 10 incident reports for aviation accidents resulting from wildlife strikes and found only 19% of the words in the reports and 9% of the photos, illustrations, tables, and appendices related to biology or wildlife behavior and management. They also noted that most of the biological information included in these reports was generic summaries of aerodrome wildlife management that included no incident or aerodrome specific observations or analysis (Shaw & McKee, 2018).

After reviewing 70 investigative reports from 24 countries, Battistoni (2023) found that only 24 of the reports provided recommendations that specifically address the prevention of wildlife strikes. If the purpose of the investigations was to prevent similar incidents from occurring in the future, then the investigations should have answered the question of why an aircraft and wildlife were occupying the same airspace at the same time. To answer that question requires a thorough understanding of the aircraft and its site-specific operation and a detailed analysis of site-specific wildlife behavior and motivation. Only when the aircraft and the wildlife components are included can one successfully hope to prevent similar incidents in the future (Battistoni 2023). All the investigations cited above included specialist investigators conversant with aircraft type, operation and performance. None of them included investigators conversant with wildlife biology and behavior, consequently the investigations could not resolve biologically relevant analyses or derive specific wildlife management or air operational recommendations to prevent recurrence (Shaw & McKee, 2019; Battistoni, 2023). In what is a perfect analogy for "putting the ambulance at the bottom of the cliff", the NTSB investigation into the Flight 1549 Hudson River ditching made recommendations including "Equipping aircraft with flotation seat cushions." There is, however, little mention of bird avoidance models nor a detailed analysis of the biological evidence (NTSB 2010).

Aviation safety is predicated on implementing prescriptive controls to reduce risk. Wildlife hazards and their management do not fit cleanly within this approach as wildlife hazards are dynamic, often difficult to predict, and the associated risk is constantly changing over various time scales. This means that static risk assessment will not suffice, and that effective management requires clever, low latency means of assessing the constantly changing threat levels which requires a thorough understanding of wildlife behavior.

The impediments to successful aviation WHM are a positive feedback loop. The industry considers wildlife strikes to be a part of doing business. Airline insurers tend to pay for damages caused by wildlife strikes thus creating a disconnect between the entities that bear the costs of wildlife strikes and the entities that must pay for the solutions that prevent wildlife strikes. Then, the status quo leads to continuing wildlife strikes, damage to aircraft, and human and wildlife fatalities which then proves to cynics that it is an intractable problem. Few ecological or biological professionals are engaged in wildlife strike investigations which then lead to investigative recommendations that focus on human factors and manufacturing solutions which do not parse the biological data to truly determine where best to invest in aviation WHM. These investigations focus on data that points to an aerodrome-focused fix to aviation WHM (e.g., shoot all the animals) and completely disregard the data that points to an airspace conflict and separation issue between aircraft and wildlife. In the end, these failures result in a poor or non-existent cost-benefit assessment of investments in aviation WHM and exclude key stakeholders from participating in solutions.

Aviation Wildlife Hazard Management as an Airspace Problem

Aerodrome-centric programs that focus on high-risk wildlife species can reduce serious strikes in some circumstances, particularly if the target species is local. However, strike prevention with transient and migratory species can be difficult, and a broader, regional airspace approach is required to understand and manage the collision risk associated with these species. Dolbeer et al. (2023) note that on-ground WHM activities out to 8 km can only reduce risk for 82% of all wildlife strikes, with the remaining strikes occurring at flight speeds which increase the potential consequence of serious strikes. In many situations, managing wildlife out to 8 km is contingent on contributions from land users in the vicinity of an aerodrome who may not be obligated to take actions to reduce wildlife strike risk and, justifiably, do not understand how they fit in an aerodrome-centric model of aviation WHM. However, there has been progress toward an airspace approach to aviation WHM as evidenced by additional stakeholders involved in solutions and increased awareness of wildlife strikes.

Information regarding wildlife strikes is collected and reported upon more regularly now than in previous decades. Although there are some issues outstanding regarding the consistency of data inputs, data sharing and wildlife strike data availability has increased which results in greater awareness of the issue. Evidence for this is provided by the latest ICAO report which had a total of 273,343 wildlife strike records for 2016 to 2021 compared to 97,751 for 2008 to 2015, and 42,508 for 2001 to 2007. It is likely that this increase is due largely to better reporting rather than an increasing number of strikes. In addition, information is publicly available through websites such as the FAA Wildlife Strike Database (https://wildlife.faa.gov/home) and the Serious Accident Database (https://avisure.com/serious-accident-database/)

Manufacturers such as Rolls-Royce and Airbus are going beyond minimum regulatory requirements by researching airframe and engine standards and designs to make aircraft more resilient to wildlife strikes (Angulo-Ibanez and Pilon, 2023; Macdougall and Pilon, 2023). After Wizz Air identified intolerable wildlife strike rates in 2009 and 2010, the airline implemented an internal approach to aviation WHM. The airline took a safety management system approach to the issue, advocated for wildlife strike reduction standards from the European Union Aviation Safety Agency, adopted standards in their operations manual, provided wildlife hazard information guidance to aerodromes, and conducted safety audits of WHM programs (Pekk, 2012). The program recorded a 20% reduction in strike rate, a 10% reduction in damaging strike rate, and a 40% reduction in total delay time to the Wizz Air fleet in the first program year (Pekk, 2012).

Historically, if a wildlife management program wanted information on bird movements, it would require expensive tracking devices that only provided information for a small sample of a population. Wildlife biologists now have tools such as eBird (https://ebird.org/home) which rely on citizen science to provide information on species presence and abundance. The detailed information from eBird can be combined with BirdCast (https://birdcast.info/about/weather-surveillance-radar-and-bird-migration-primer/) which uses weather radar data to provide information on the numbers and flight directions of birds in order to expand the understanding of migratory bird movement. Nilsson et al. (2021) demonstrated that weather data and citizen science can predict the probability of wildlife strikes, can predict when most damaging strikes occur, and could be used to standardize wildlife strike warnings.

The potential for multi-stakeholder, data-rich approaches to aviation WHM is evidenced by military approaches from around the world. The Israeli Air Force (IAF) suffered several incidents that prompted an aviation WHM approach that incorporated bird migration routes to develop a Bird Avoidance Model (BAM) (McKee et al., 2016). The IAF built upon the initial model by implementing remote sensing systems that assist pilots to avoid high-risk areas (Ovadia, 2012). The European Space Agency (ESA) built upon Israel's success and the work of the Dutch, Belgian, French and German Air Forces in developing the FlySafe program. The system uses information from satellites, air defense, and weather radar networks to create Bird Notice to Airmen (BIRDTAM) which predict short-term movements of birds for use by military personnel in flight planning (Dekker et al., 2008; FlySafe, 2014). The US Air Force (USAF) developed a similar BAM based on historical bird migratory data and weather radar networks called the Avian Hazard Advisory System (AHAS). The system is available to military and civil pilots for flight planning purposes (United State Air Force, 2024). Each of these systems contributed substantially to positive aviation safety outcomes in the form of reduced collisions with wildlife, reduced cost due to wildlife strikes, and reduced wildlife and human fatalities (McKee et al., 2016; van Gasteren et al., 2018).

McKee et al. (2016) provide a conceptual model summarizing the components of a dynamic wildlife separation system which approaches aviation WHM as an airspace problem (Figure 9). The model outlines an approach similar to successful programs such as BAM, FlySafe, and AHAS. The main outputs are a series of interlocked hazard forecasts and real-time situation reports that are relayed to aircrew for flight planning and flight execution. In this model, aerodrome operators are a contributing stakeholder as are ATC, pilots, and airlines. In addition, aeroecologists and ornithologists are engaged to detect wildlife movements that can assist the model in predicting potential airspace conflicts. The system continually updates to provide real-time information for flight planning

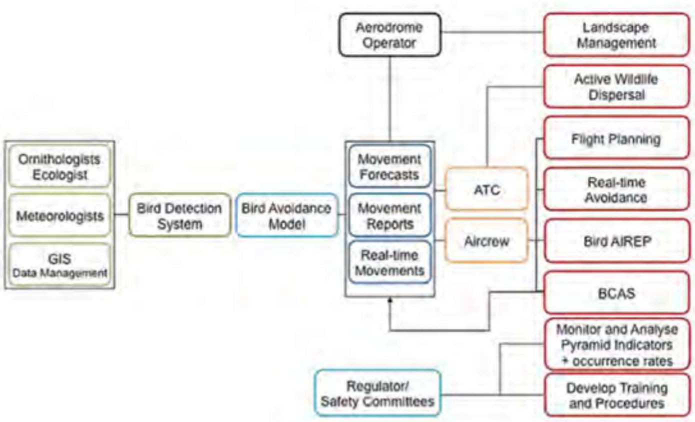

Figure 9 Conceptual model of airspace approach to aviation WHM. AIREP (Airborne Report); ATC (Air Traffic control); BCAS (Bird Collision Avoidance System); GIS (Geographic Information System). Source: McKee et al., 2016

Although the IAF, ESA, and USAF examples focus on military applications, Vancouver International Airport (CYVR) and King Shaka International Airport (FALE) have applied approaches similar to McKee et al.'s (2016) conceptual model. At these airports, birds originating from off-airport locations resulted in conflicted airspace and substantial wildlife strike risk.

Snow geese (*Anser caerulescens*) from Wrangel Island winter on the Fraser River estuary adjacent to CYVR. As the population increased from successful breeding on Wrangel Island, the number of snow geese conflicting with aircraft at CYVR increased. Although the airport could successfully manage geese within the aerodrome boundary, the geese would consistently return and would conflict with aircraft on arrival and departure. CYVR trialed the use of avian radar to inform wildlife management decisions. Key stakeholders including airlines, airside operations staff, and ATC engaged in the program and contributed to the program's results. By studying hour-long blocks of radar data and using in-vehicle radar displays, the wildlife management team could predict when and where geese would conflict with aircraft and used that information to proactively manage geese and communicate potential hazards to ATC (Bradbeer and Follett, 2023). By tasking the avian radar system with specific questions, the CYVR wildlife management team created the wildlife movement forecasts and reports at the core of McKee et al.'s (2016) conceptual model. The system resulted in the absence of snow goose in areas adjacent to the CYVR runways due to proactive management activities, and provided actionable information which was used to hold aircraft departures based on goose movements.

In the first year of the program, there were no recorded damaging snow goose strikes (Bradbeer and Follett, 2023). Bradbeer and Follett's study supports the conclusions of Colón and Long (2023) which state that bird detection radars best complement early-warning systems such as AHAS at aerodromes with large numbers of hazardous birds flying at low altitudes during daylight hours, especially in late afternoon.

Avian radar was similarly applied to prevent aircraft from FALE conflicting with barn swallows (*Hirundo rustica*) (Merrit et al. 2012; BizCommunity, 2013). These small birds congregate in the late afternoon and early morning when arriving at and departing from their overnight roost. The airport used a bird detecting radar to provide actionable information to arriving and departing aircraft. The radar system informed the movement forecasts used to slow arriving aircraft or hold departing aircraft which allowed the swallows to settle in their roost and deconflict airspace. Although recent data is limited, the system achieved zero swallow strikes in 2013 (BizCommunity, 2013).

Metz et al. (2020) accurately note that ATC involvement is required for the success of systems such as CYVR and FALE. ATC is the conduit for information from on-ground wildlife management teams, remote sensing systems, and pilots. They note that developments in technology allow aviation WHM to move from static warnings about peak bird movement avoidance to real-time warnings for high-risk situations which inform aircraft movements to avoid airspace that has dynamically changing wildlife hazards. Organizations are using fast-time simulation to determine the reduction in wildlife strike risk (Metz et al., 2019) and using real-time human-in-the-loop simulations to determine that a wildlife hazard advisory system can be used to reduce strikes by using take-off delays for high-risk strikes based on accurate bird movement predictions (Metz, 2023).

The success of aviation WHM programs that treat the issue as an airspace problem should be no surprise to those who are familiar with the history of windshear in commercial aviation. After windshear-caused commercial aviation accidents resulted in over 400 human fatalities in the 1970s, the US FAA worked with stakeholders to develop and regulate an effective warning system based on on-ground and aircraft-mounted Doppler-radar detection systems (Hollowell and Cho, 2010). By implementing these systems and investing in training programs, the aviation industry reduced windshear related accidents by 93% from 1985 to 2010 and the total cost of accidents by 97% (Hollowell and Cho, 2010). In addition, the most recent human fatality in commercial aviation related to windshear was in 1994 (Figure 10) (Golding, 2005; Smith, 2014; National Transportation Safety Board, 2023b).

Although aviation WHM requires a transition to an airspace approach, the requirement will soon become even more essential. In the US, the National Aeronautics and Space Administration (NASA) expects Advanced Air Mobility (AAM) to operate predominantly from 0 to 4,000 ft AGL with cruise heights between 1,500 and 4,000 ft AGL (Patterson et al., 2018; Deloitte, 2020). Of all strikes reported to the FAA between 1990 and 2022 for commercial transport aircraft, 94% occurred below 4,500 ft AGL (Dolbeer et al., 2023). Consequently, while conventional fixed-wing aircraft are mostly exposed during departure and arrival (97% of strikes), AAM aircraft will be vulnerable throughout their entire operations. The predominant flight altitude for AAM is expected to lead to similar strike statistics as for helicopters, which experience 67% of strikes while in cruise phase (Rotorcraft Bird Strike Working Group, 2019). As millions of AAM aircraft are incorporated into airspace, focusing on aerodromes for aviation WHM will not address the ever-growing wildlife strike risk.

Conclusion

Worldwide, tens of thousands of wildlife strikes are reported annually for civil and military aircraft. Aviation occurrence data from ICAO, ATSB, UK CAA, CAANZ, FAA, and NTSB indicate static to increasing trends in wildlife strikes, wildlife strike reporting, serious off-aerodrome wildlife strikes, and accidents related to wildlife. While some aerodromes have successfully reduced wildlife strikes within their perimeter fences, the aerodrome-centric approach to aviation WHM is predicated on mature wildlife management programs reliant on substantial investments in local management activities which have not reduced the overall wildlife strike and damage rate trends and cannot address increasing strike rates beyond the aerodrome fence.

The aerodrome-centric approach to aviation WHM is solidified by international and national guidance focused on the aerodrome operator as the party responsible for solving wildlife strike issues. Because guidance is focused on aerodromes, when wildlife and aircraft collide, the result is often litigation and finger-pointing. If an incident is investigated, rarely does the investigation include a biological or ecological professional who would seek to answer the question of why an aircraft and wildlife were attempting to occupy the same airspace at the same time. To prevent accidents in the future, one must focus on indices that assess the likelihood of large mass species and/or flocks of wildlife occupying the same space as aircraft at the same time. Only then can stakeholders track progress against leading and lagging indicators on an aviation WHM scorecard.

A multi-stakeholder, data-rich approach to aviation WHM is not just a conceptual model. It has been effectively implemented by the IAF, ESA, and USAF in their BAM, FlySafe, and AHAS programs. Each of these organizations implemented an airspace collision avoidance approach to aviation WHM and the result was decreased wildlife strikes. In each case, the model focused on interlocked hazard forecasts and real-time situation reports that were relayed to aircrew for flight planning and flight execution. The wildlife forecasts successfully brought together ATC, pilots, airlines, aerodrome operators, aeroecologists, and ornithologists to detect wildlife movements to predict potential airspace conflicts and inform operational decisions to reduce airspace conflict. The success of the collision avoidance model is not limited to military aviation. Civil airports in Canada and South Africa have effectively used similar systems to mitigate wildlife strike risk. The success of a collision avoidance approach in the military and civil aviation WHM programs is similar to the success recorded in addressing windshear-related accidents.

Wildlife strikes are not a completely unpredictable issue that is simply part of aviation. Instead, the issue is the lack of industry commitment to address the root cause of wildlife strikes, airspace conflict, and to apply the airspace model's separation-based procedures. After decades of aerodrome-centric aviation, the industry must finally implement an airspace approach to substantially reduce wildlife strikes, improve aviation safety, and conserve wildlife

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STATISTICAL ANALYSIS AND WILDLIFE STRIKE RISK ASSESSMENT

Alessandro Montemaggiori

Data and timely information are the basis of any scientific research and/or analysis and promote the advancement of knowledge. This, of course, also applies in the field of wildlife strikes. For this reason, international and national regulations on the subject impose a rigorous collection of information regarding the phenomenon, on the basis of which risk mitigation strategies and policies can be set up (ICAO, 2018, 2020; EASA, 2014; ENAC, 2011).

There are now numerous databases, more or less accessible, both at international and national level, which offer a wealth of information for those who wish to analyse and study the wildlife strike problem (e.g. FAA, 2024; Avisure, 2024). Impact data, more often than not, are aggregated by the various aviation authorities and analysed at various levels to provide information and guidance to contain and mitigate wildlise strike risk (e.g. ICAO, 2023; Dolbeer et al., 2023; Montemaggiori, 2023a).

An up-to-date detailed overview of the wildlife strike phenomenon from the above analyses is as follows (Montemaggiori, 2023c): Birds make up 95-98% of all wildlife strikes (Dolbeer, 2021; ICAO, 2023; ATSB, 2019). Depending on the country, average wildlife strike rates between 2.33 and 10.30 per 10,000 aircraft movements in civil aviation have been reported in recent years (Montemaggiori, 2023a; Dolbeer et al., 2023).

While collisions between wildlife and aircraft usually have lethal consequences for animals, damage to aircraft or effects on flight are rare. In the US, 7% of all wildlife strikes recorded between 1990 and 2022 (272,016) resulted in aircraft damage, but less than 3% were impacts with substantial damage or catastrophic effects. Also in the US, with regard to operational effects on flight, 5% of incidents resulted in an adverse effect on flight, but less than 1% resulted in the shutdown of the struck engine (Dolbeer et al., 2023).

However, the outcome of a wildlife strike can also have catastrophic consequences. Globally, wildlife strikes, including those involving military aircraft, killed 804 people and caused the loss of over 739 aircraft from 1905 to 2023 (Avisure, 2024).

From an economic perspective, wildlife strikes result in an estimated annual cost of approximately USD 1.2 billion to the global commercial aviation industry (Allan, 2002). Due to incomplete reporting, these figures must be interpreted as conservative estimates; in the United States alone, the 2022 estimate of direct and indirect bird strike costs is around 67,848 hours of downtime and USD 385 million in repairs for commercial aviation alone (Dolbeer et al., 2023). In Italy, a cost of EUR 2.4 million/year in commercial aviation alone, including repairs and flight delays, is estimated through comparisons with the US (Montemaggiori, 2022).

Approximately 70-74% of reported civil aviation impacts worldwide are found to occur in or near airports, mainly during take-off and landing. However, more than 90% of impacts occur below 3,500 ft altitude (1,067 m) (Dolbeer et al., 2023; ICAO, 2023).

In Italy, 81% of accidents occur below an altitude of 300 ft (91.4 m) and 97% below 3,000 ft (914.4 m) (Fig. 1), while as far as flight phases are concerned, 63% of accidents occur during landing and 36% during take-off. Only 1% of accidents occur in the cruise phase (Fig. 2).

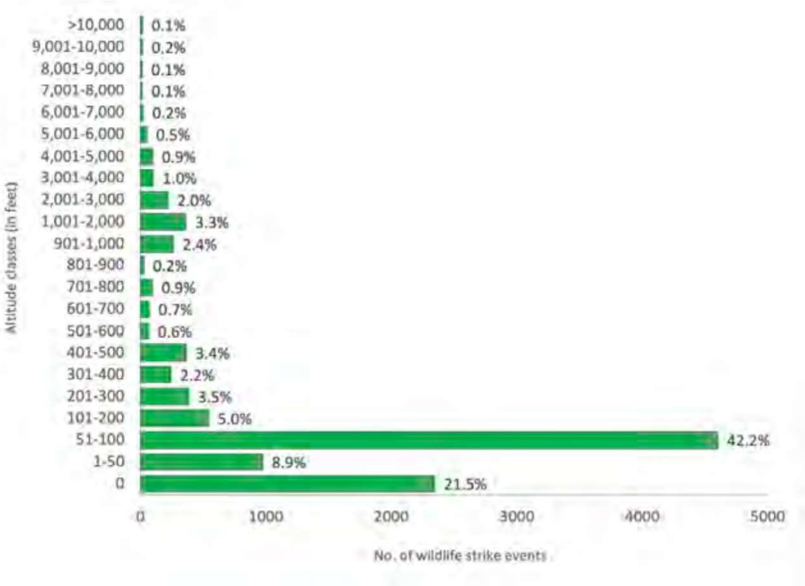


Figure 1 Percentage of wildlife strikes in commercial aviation per flight altitude (ft) in Italy (2006-2022). N = 10,899. (elaboration from ENAC - Ente Nazionale Aviazione Civile data).

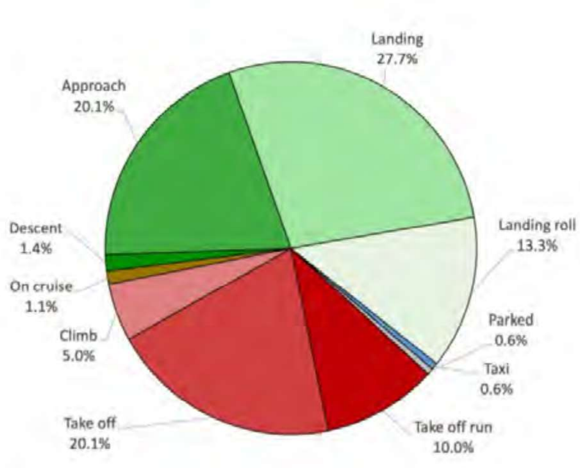
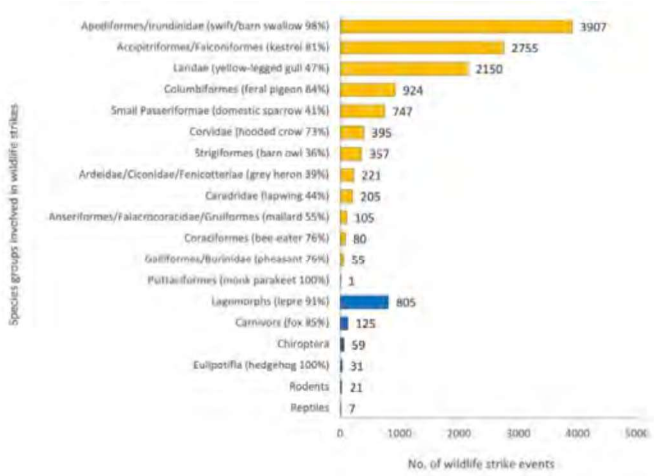


Figure 2. Percentage of wildlife strikes in commercial aviation per flight phase in Italy (2006-2022). N =15,749. (elaboration from ENAC - Ente Nazionale Aviazione Civile data).

The species groups most involved in wildlife strikes worldwide in the period 2016-2021 were Falconiformes (28%), Passeriformes (27%), Charadriiformes (18%), Columbiformes (8%) and Mammals (5%) (ICAO, 2023).



"In Italy in 61.15% of the events (those in which it was possible to identify the species involved), the species most involved in accidents for the period 2006-2022 were the Common swift (Apus apus) and the Barn swallow (Hirundo rustica), treated as a single taxon due to the impossibility of distinguishing the two species on the basis of the reports analysed, the Eurasian kestrel (Falco tinnunculus) and the Yellow-legged gull (Larus michahellis). Among the most representative birds involved in bird strikes we also find the Feral pigeon (Columba livia domestica), the Italian domestic sparrow (Passer italiae), the Hooded crow (Corvus cornix), the Barn owl (Tyto alba) the Grey heron (Ardea cinerea), the Northern lapwing (Vanellus vanellus), the mallard (Anas platyrhynchos), the Bee-eater (Merops apiaster), the Pheasant (Phasianus colchicus) and the Monk parakeet (Myiopsitta monachus). The mammals that are most impacted are the Hare (Lepus europaeus), the Red fox (Vulpes vulpes), bats and the Hedgehog (Erinaceus europaeus) (Fig. 3).

Figure 3. Number of wildlife strikes in commercial aviation in Italy by species groups (2006-2022). In orange Birds, in blue Mammals and in grey Reptiles. N = 12,950. (elaboration from ENAC - Ente Nazionale Aviazione Civile data).

Sixty-eight per cent of the world's impacts occur during the daytime, while the season when most impacts occur is summer (June-September) (ICAO, 2023). In Italy, the percentage of impacts occurring during the day is 78%, mainly in the early morning hours, while the months in which most impacts occur are those between May and August (Fig. 4).

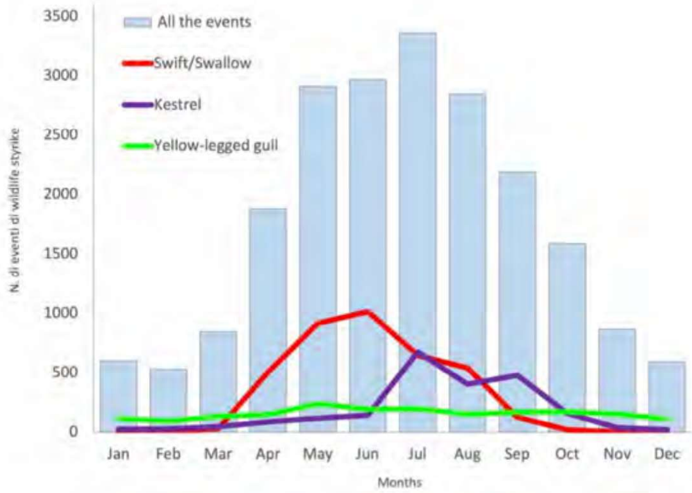


Figure 4. Seasonal trend of wildlife strikes in commercial aviation (2006-2022). In addition to the overall monthly data, seasonal trends are also shown for the three taxa most represented in wildlife strikes in Italy. N = 21,174. (elaboration from ENAC - Ente Nazionale Aviazione Civile data)

Finally, the parts of the aircraft most affected globally by this type of accident are the engines, which are damaged in 34% of cases (ICAO, 2023), while in Italy the 'nose' of the aircraft (nose and radome) is the most affected part (33% of cases), while the most damaged are the engines (17% of cases).

Another important fact that emerges from the analysis of the time series is that the phenomenon of wildlife strikes is constantly growing in all countries of the world (ICAO, 2023). In the USA, in civil aviation alone, from 2,000 incidents in 1990 to almost 17,190 in 2022 (Dolbeer et al., 2023). In Italy, 348 impacts between aircraft and wildlife were recorded in 2002, while 2,168 events were recorded in 2022 (Montemaggiori, 2023a) (Fig. 5).

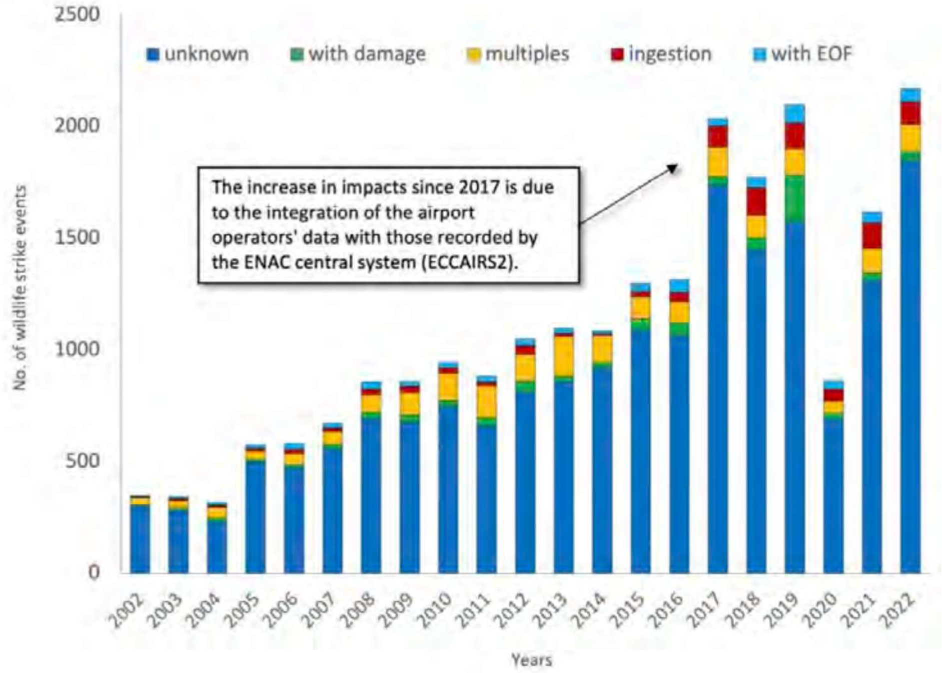


Figure 5. Number and type of wildlife strikes in commercial aviation in Italy per year (2002-2022). Multiple events if with more than 1 animal, with ingestion if in engines, with EOF if they generated flight consequences. N = 23,705. (Montemaggiori, 2023a modified).

In 2020-2021, there was an overall decrease in incidents, due to the lockdown imposed by the Covid emergency, which drastically reduced aviation activity, however, over the same period, the impact/flight rate increased greatly (Parsons et al., 2022; Metz et al. 2022).

The increase in wildlife strike events worldwide is due to a multitude of factors, including the decreasing noise of engines, the consumption-driven reduction in the number of aircraft engines and the progressive increase in air traffic (Dolbeer et al., 2023).

In fact, the ICAO, until 2019, recorded an average growth rate of global air traffic of around +5% each year. Long-term air traffic forecasts predicted that the 4.5 billion scheduled passengers carriedin 2019 would grow to around 10 billion by 2040 and that the number of departures would increase to around 90 million in 2040 (ICAO 2019). The COVID-19 pandemic brought this trend to an abrupt halt, with flights dropping by as much as 70 per cent in 2020 in many countries. However, already today traffic is practically back to pre pandemic levels, and the 2019 growth forecast seems to be confirmed

There is also another factor that has led and continues to lead to the steady increase in impacts between aircraft and wildlife, and that is the increasing population of many taxa. In the USA, many species that are large, and therefore more dangerous to aviation, have seen a significant population increase over the last 30 years.

To give a specific example, the resident population of Canada geese (Branta canadensis), the species that caused the Hudson River incident in 2009, has increased more than fourfold, from 1 million individuals in 1990 to 4.5 million in 2021 (Dolbeer, 2020; U.S. Fish and Wildlife Service,2022). In the same period, the population of Canadian cranes (Antigone canadensis) also quadrupled, from 200,000 individuals to 800,000 (Dubovsky, 2019; Dolbeer, 2020; Sauer et al., 2022).

In Italy, the breeding population of Yellow-legged gull has more than doubled from the 1980s to the first decade of the 21st century, now exceeding 65,000 pairs (Brichetti and Fracasso, 2018).

As we have seen, the majority of wildlife strikes occur at or near airports, so the current regulations mentioned above require that each airport regularly conduct a local and timely assessment of its wildlife strike risk; these analyses are then extended to a national and/or international scale by the different aviation authorities.

To do this, various risk estimation procedures have been created and implemented, each of which has advantages and disadvantages. In fact, no single method has been used to carry out this analysis, also because the phenomenon presents different characteristics and specificities from time to time, and it is very difficult to establish objective standards that are valid in the same way for every part of the world. Each airport is a case in itself, where the risk depends on an infinite number of variables that change from time to time: the species and number of animals present, their seasonality, their behaviour, which may vary depending on local environmental conditions, the airport's operating procedures, its geographical location, the presence in the airport's surroundings of sources capable of attracting fauna that is dangerous to air navigation, such as urban waste dumps, whose dangerousness in terms of air safety has been widely documented (Montemaggiori, 2023b).

Much also depends on what data are collected, when, and how they are interpreted, and the lack of fixed parameters and definitions (taxonomy) accepted by all countries, which persists even for the simple definition of “wildlife strike”, does not help (van Eekeren, 2021).

Many countries use a traditional risk assessment matrix to judge risk based on the number of wildlife strikes that have occurred in recent years (Allan, 2006; Coccon et al., 2015). In the United Kingdom, Allan (2006) used both national and airport-specific data on the degree of damage to aircraft to evaluate bird risk, creating a simple probability-times-severity matrix. Coccon et al. (2015) used Generalized Linear Models (GLMs) with binomial distributions to estimate the contribution of habitats to wildlife use of the study area, as a function of the season.

In China, Ning (2014) proposed a real-time birdstrike risk evaluation method based on the bird information collected by the airport-based avian radar system and the flight phase of the aircraft provided by the air-traffic control system, while Hu and colleagues (2020) proposed the use of empirical data on the presence of birds at the airport and in a surrounding 8-km buffer along with the assessment of each species through a risk assessment matrix that takes into account bird number, weight, flight altitude, tendency to grouping and range of activity. In the USA, methods have been proposed that emphasise the importance of the physical characteristics of individual airports (Wilke et al., 2015).

In Italy, Soldatini et al. (2011), in a joint project between the University of Venice Ca' Foscari and ENAC, the Italian Civil Aviation Authority, established the Birdstrike Risk index (BRI) using an ecological approach, incorporating time scales that allow for appropriate management planning.

The BRI takes into account the ecological characteristics of the bird communities present in the airport area, the local history of wildlife strikes, their effect on flight and the number of aircraft movements, so that the measure is comparable from airport to airport. The index was conceived as a tool capable of describing an airport-specific wildlife hazard, based on the historical trend of wildlife observations, in order to identify critical periods during the year. Therefore, the index is not intended as a prognoistic index, as the distribution of birds over the years is difficult to predict, but it can be applied to assess specific theoretical risk scenarios.

The BRI algorithm has been adopted as a standard by ENAC to carry out wildlife risk assessment (ENAC, 2011) at a national level, and its value for each airport is regularly reported in the national report that ENAC produces each year (Montemaggiori, 2023a),

Recently, a study conducted in Mexico compared some of the most widespread risk assessment systems in a series of Central American airports. Of these, only the BRI identifies the highest-risk species, and relates it to spatial and temporal scales if necessary, and provides faster results than heuristic risk assessment based on species impact history. Variables such as the species strike history and the number of individuals within the airport environment are crucial when calculating hazard and risk values. (Gutiérrez Serralde et al., 2023)

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WILDLIFE STRIKE RISK MANAGEMENT

by Cpt Andrea Bomben

Wildlife Strikes are a risk to flight safety, the management of which, therefore, cannot ignore a 360-degree approach, which should involve all stakeholders systematically and proactively, as happens for all other aspects of the aeronautical system.

For this to be achieved, it is essential to manage three fundamental components effectively:

1. **Reduce hazard exposure:** this strategic result is obtained by physically separating aircraft from wildlife, on the one hand by operating at altitudes where birds seldom fly and, on the other, by creating inhospitable airport grounds and discouraging the presence of animals (reducing attraction sources such as food and nesting sites).

2. **Reduce impact probability:** this tactical result is obtained - after identification by airport operators and/or pilots and/or flight controllers - through fauna dispersal by BCU intervention and pilot intervention through avoidance actions (runway change, change of SIDS [1] (Standard Istruments Departure) and STARS [2] (Standard Instruments Arrival), use of aircraft lights to be more visible to birds, etc.). From this point of view, an essential aspect is a well-timed and accurate communication.

3. **Reduce impact probability:** this tactical result is obtained - after identification by airport operators and/ results, wildlife strikes will still occur because, among other things, intervention capabilities progressively diminish as we depart the airport area. For this reason, it is necessary to reduce damage following an impact and therefore, it is essential to:

- verify and, if necessary, modify airframe and engine certifications, to better absorb impacts with one or more birds;
- ensure that interventions on wildlife by airport operators are constantly updated and proportioned to risk levels obtained from the related matrixes;
- make sure pilots obtain the knowledge and the competencies necessary to reduce damage following an impact. Once adequately trained, they will be able to use various defensive measures, such as staying informed on local wildlife activity, increasing their attention during more risky flight profiles and staying up to date on emergency procedures.

[1] SIDS: Standar Instruments Departure
[2] STARS: Standard Instruments Arrival

The management of these three components is assigned, to a different extent, to the stakeholders as summarised in the following Table.

	Exposure	Probability	Severity
Regulatory Bodies	X	X	X
Airports	X	X	X
Air Traffic Service Providers		X	
Pilots	X	X	X
Airlines		X	X
Aircraft and Engine Manufacturers			X

Regulatory authorities

International and national regulatory bodies play a primary role and are paramount in reducing the wildlife strike risk. International regulators are the ICAO (EASA, on an intermediate level in Europe) and the national CAAs (Civil Aviation Authority) of single countries, using local bird strike committees.

The duties of International regulators, according also to recommendations emitted by expert organisations such as IBSC/WBA and by aeronautical investigation bodies[1] (e.g. the NTSB for USA), are:

- to define the problem;
- to define and impose standardised data collection and elaboration;
- to issue regulations to member States.

ICAO takes care of data collection and statistical elaboration through the IBIS database and takes care of regulation with the continuous revision of Annexes and DOCs. For wildlife strikes, the reference regulations are in Annex 14 (Aerodromes) and partly Annex 11 (Air Traffic Services). The explanatory documents for the related Annexes are DOC 9137[1], DOC 9332/AN909[2] DOC 4444[3], DOC 9426[4], DOC 9184[5].

At a European level, the EU has issued Regulation 1108 of 2009, which implements the EASA indications to regulate the various sectors of airport activities, included those of airport managers, to prevent and combat the phenomenon of Wildlife Strikes

[1] Airport Services Manual, third part, “Wildlife Control reduction”.
[2] *Manual on the ICAO Bird Strike Information System (IBIS)*.
[3] Air Traffic Management, Chapter 7, “PROCEDURES FOR AERODROME CONTROL SERVICE”.
[4] ATS, Planning Manual, Part 1, “PLANNING FACTORS”.
[5]Airport Planning Manual, first part, concerning new airports construction and expansion of existing ones.

The duties of National Aeronautical Authorities (CAA) are:

- to arrange and monitor the implementation of regulations on the subject;
- to use standardised wildlife control data for better risk management processes (currently, no national body collects this data);
- to collect, elaborate and send wildlife strike statistics to ICAO;
- to create and/or support appropriate bodies (Bird Strike Committee) able to develop and exchange information concerning research and development regarding the control of wildlife inside airports;
- to involve local authorities and maintain international relations, participating in regional and international committees (IBSC/WBA) and ICAO meetings;
- to promote cultural initiatives and information tools for the benefit of organisations and involved personnel.

For further information on the legislation, please refer to the documentation in the bibliography; here, we will limit ourselves to underlining that in terms of wildlife strike prevention, no initiatives have yet been taken, at any level, aimed at including the mitigation actions suggested by decades of experience in the SOPs for use by pilots and air traffic controllers.

Airport Manager

The main airport manager's duty consists of maintaining a safe airport, acknowledging the Regulator directives, and developing policies and practices that identify and solve the problems associated with wildlife strikes. Everything revolves around creating a wildlife study and the subsequent implementation, by the local BCU, of a wildlife strike management and control plan (WSMP).

Effective problem management is achieved with a balanced, systematic, and scientifically supported integration of passive and active initiatives, with continuous monitoring of the airport grounds and collecting and analysing data relating to wildlife activity. Passive initiatives are referred to habitat management to reduce sources of attraction for wildlife, represented by food and shelter (exposure reduction)[1]. It is worth specifying that effective habitat management would be unrealistic if confined within the airport grounds because it is well known that the airport fence is meaningless to wildlife. Therefore, it is of fundamental importance that this management is extended to areas up to a radius of 13 km from the airport (obviously with different types and intensities of measures), as established by ICAO and recalled by the IBSC (IBSC, 2006).

Active initiatives, instead, aim to detect, disturb and disperse the wildlife still present by moving it away from the airport area or, as a final resort, by removing it using the most humane means (reduction of impact probability). They are fundamental when habitat management does not entirely solve the problem due to its known complexity. Active initiatives must be effective over time (preventing wildlife habits) and in space (preventing dangerous animal species from accessing the airport perimeter). These are put into practice by specific teams called BCU (Bird Control Unit), generally equipped with radios (to communicate with ATS units) and involved in wildlife monitoring activity. Worldwide, the training of these personnel is highly heterogeneous, and they often use non-certified instruments with little or no scientific basis.

[1] Canals, basins, pools of water, marshes, canteens and internal landfills, old abandoned buildings (e.g. hangars), trees and bushes are all formidable attractive elements for birds, as well as the possible lack of suitable fences, or their dilapidation, allow the intrusions of stray and non-stray animals, livestock etc.

The table below shows some examples of tools currently in use:

Not Recommended	Limited Recommendation	Highly Recommended
- High-intensity sound - Microwaves - Lasers - Ultrasound - Aircraft hazing - Smoke - Magnets - Lights - Dyes - Aircraft engine noise - Infrasound	- Gas cannons - Phoenix Wailer® - AV-Alarm® - Bird Gard ABC® - Scarecrows - Reflecting tape - Predator models - Hawk kites and balloons - Gull models - Chemical repellents - Foam - Predator calls - Lure areas - Model aircraft - Poisons - Dogs (Border Collies)	- Pyrotechnics - Falconry - Distress and alarm calls - Shooting - Trapping & remote release

It's a partial classification, not exhaustive and subject to continuous modifications and re-elaborations due to new scientific evidence and the peculiarities of each area where they are applied).

Air Traffic Controllers

- While in continuous contact with all airport personnel inside and outside the airport perimeter, these professionals:
- identify wildlife activity on specific radar screens (Avian radar, when installed, available, accepted and operating);
- visually identify birds and mammals from control towers;
- forward critical information regarding wildlife to ground personnel, wildlife management personnel (BCU) and pilots (by radio or ATIS);
- assist flight crews after a wildlife strike event;
- assist the activity of the BCU, ensuring that it does not interfere with aircraft.

Generally, information passed from controllers to pilots helps raise their situational awareness, allowing better management of flight profiles and reducing the chance and seriousness of wildlife strikes. It is, therefore, clear that constant surveillance by ATS (Air Traffic Service) personnel is of primary importance in the daily prevention of wildlife strikes. This indispensable contribution must come with proper and punctual training on the wildlife strike issue, which is currently insufficient or absent. Nevertheless, with the recent revision of DOC 9137 Part III (2012)[1], ICAO has established that the training of controllers must go from recommended to mandatory, a decision that represents a fundamental step forward in flight safety.

One of the most important aspects in the training of controllers is the awareness of the effects of a wildlife strike on the crew and the conduct of the aircraft; adequate training in this regard can make a difference in the positive management of an impact.

Regarding safety, not all countries clearly define and recognize the role and responsibilities of air traffic controllers. This discrepancy is due to, in part, the limited clarity of norms contained in the already mentioned ICAO Annex 11, DOC 9137, DOC 4444 and DOC 9426, which give birth to

[1] 12.3.4 Clear and precise procedures should be developed for air traffic control, and controllers should be trained such that they are able to give specific and timely information to pilots and wildlife control crews to avoid identified hazards),

different interpretations when one has to incorporate these rules in the ATM (Air Traffic Management) manuals of ATS providers. There is no doubt that air traffic controllers must inform pilots of wildlife. Still, interpretations diverge on their requirement to forward reports from others (BCU, pilots or other sources) or actively and directly locate wildlife (as they must with fixed or moving obstacles).

For example, in some countries (United States, Great Britain, South Africa and Canada) ATM manuals report this obligation; in others, such as Japan and Italy, they do not. It becomes clear that, while waiting for the revision of DOC 4444 -but in light of the fifth edition of DOC 9137 (2020)[1]- the present interpretation of international rules by some ATS suppliers needs an urgent update. Besides mortifying a whole category of professionals, these differences seriously de-powers a fundamental component of flight safety without protecting air traffic controllers from eventual criminal proceedings[2].

Pilots

Pilots are on the frontline in tackling the risk of wildlife strikes; they are the last helpful barrier in reducing exposure, probability and severity of impacts.

To achieve this, knowledge and technical expertise are of paramount importance and are obtainable mainly through training. Unfortunately, formation is currently not supplied by anyone, nor is it required by any regulatory body and is not available in any form. For this reason, the problem of wildlife strikes is continually underestimated by pilots - even though lives and hulls have been lost and the risk of future events is genuine - exactly like pilots in the 50s underestimated the danger of flying through cumulonimbus.

Pilot training should allow them, on the one hand, to deal with the wildlife strikes and, on the other, to apply the measures envisaged to reduce the risk of impact. In general, this involves limiting the stay at altitudes where the danger is greater, avoiding concentrations of observed or reported fauna, requesting the intervention of the staff proposed to remove the fauna (BCU) and applying all precautionary measures for every single phase of the flight, from pre-flight planning until reaching the parking area. All of this without forgetting the fundamental and irreplaceable duty of accurately reporting any event, sighting, near-collision or strike.

Since it is impossible here to go into detail about all the recommendations and strategies that are the responsibility of pilots, we will limit mentioning the general operating principles, referring to the attached bibliography for further information.

1. Plan the flight by reducing as much as possible the time spent at heights below 3.000 ft, where the risk of collision is higher, and a potential failure would result in an increased workload.
2. Below 10.000 ft reduce IAS at or below 250 kts and below 3.000 ft AGL operate at further reduced speeds to minimise the severity of the impacts (the magnitude of the forces developed is proportional to the square of the speed).
3. Although many bird species are active mainly during the daytime, many other birds, such as owls, long-eared owls and migratory waterfowl, regularly fly at night.
4. Despite widespread belief, some birds also fly in low visibility conditions (clouds, fog, rain or snow).

[1] 5.2.1: (…)Additionally, ATC and other personnel should inform wildlife controllers when they observe wildlife;
[2] "In case a court finds that an aviation accident was caused by the failure to report a sighting or the failure to directly and actively search for wildlife"

5. Most birds tend to be more active at dawn and dusk, such as species that move to food sources at dawn and return to their nests at dusk.

6. In the northern hemisphere, there are three bird strike risk peaks throughout the year:

   a. spring migration (March – April);
   b. July and August, when many young and inexperienced birds are present and the flying abilities of adults are impaired because of the change of feathers;
   c. the autumn migration (September – October).

7. Many birds, such as raptors and gulls, take advantage of thermals to climb to very high altitudes during hot summer days.

8. Bird size is inversely proportional to the wing flapping frequency: the lower the frequency, the larger the size and the greater the damage in an impact. Large birds and flocks pose a considerable risk to aircraft; a mass of large birds is extremely dangerous.

9. To help make the most appropriate decision following a wildlife strike during takeoff or landing, it is helpful to introduce the distinction between suspected and confirmed impact:

   Suspected impact:
   When the crew sees the wildlife very close and believes that it may have struck the aircraft, but there is no confirmation of the impact (i.e. see below).
   Confirmed impact:
   when the crew sees the wildlife very close, and

   a. observes the impact on the airframe/windshield and/or sees the remains of the wildlife on the airframe/windshield and/or observes damage to the airframe/windshield, or
   b. hears the noise of the impact or damage caused by it (e.g. engine stall/surge, damaged radome, penetrated airframe, loss of pressurization) or
   c. hears or observes a temporary or permanent variation in sound and/or engine parameters (EPR, N1, N2, EGT, FF, compressor stall/surge, N1 and/or N2 vibrations), or
   d. perceives aerodynamic vibrations or abnormal manoeuvrability of the aircraft, or
   e. observes a loss or a significant change in flight instrument parameters due to damage to speed or angle of attack sensors, or
   f. observes or perceives smoke, smells burnt meat, or
   g. finds damage to communication and/or navigation antennas, exposed cables, hydraulic pipes landing lights, or;
   h. ground personnel reports witnessing a wildlife strike;
   i. after takeoff or landing, wildlife remains are found on the runway or in its vicinity (200 ft or less from its centerline).

10. Following a confirmed impact:

a. Maintain aircraft control. Remember that the noise of the impact could be much more than the actual damage.

b. Monitor flight instruments and engine parameters.

c. In the event of suspected or confirmed airframe and/or engine damage, maintain or reduce speed and do not accelerate unless necessary for flight safety or to maintain control of the flight path.

d. Follow the checklists and complete the required abnormal/emergency procedures:

- in case of failure or loss of thrust to one or more engines, try to restart;
- in case of damage, shut down the engine according to abnormal/emergency procedures;
- reducing engine thrust often reduces the intensity of N1/N2 vibrations; if vibrations persist, apply the necessary abnormal or emergency procedures (consider engine shut

e. Determine the damage and the effects on the aircraft's landing performance.

f. Land at the nearest suitable airport.

g. Request the assistance of ATS and emergency ground personnel.

h. In the event of suspected structural damage and damage to control surfaces, consider a check of the aircraft controllability before landing.

i. On fly-by-wire aircraft, where there is no direct connection between flight controls and their corresponding surfaces, there is no feedback to the pilots. Consequently, any damage to and vibration of the control surfaces may not be evident, also due to the lack of fidelity of the cockpit Display Units' representation of the position/behaviour of the flight surfaces.

j. In case of windshield breakage or cracking, apply procedures in manufacturer and/or operator manuals. In addition, in case of windshield breakthrough, reduce speed and consider using glasses or smoke goggles to protect the eyes from wind, debris and precipitation.

11. Before resuming the flight, the aircraft must undergo a thorough inspection by the competent maintenance personnel to ensure that:

a. the impact did not damage or obstruct the air intakes, engine exhaust and ventilation and cooling ducts;

b. the landing gear, hydraulic brake lines, down blocks, and all electrical landing gear components are intact;

c. in the event of suspected airframe or flight control surface damage, a thorough inspection is carried out to check their integrity; in fact, apparent minor damage could hide serious structural damage;

d. turbine engines that have ingested wildlife are subjected to accurate checks. In many accidents, the visual inspection could not reveal damage that emerged in later flights.

Pilots have an essential share of the responsibility in reducing the risk of wildlife strikes, a commitment that they can fulfil through four crucial tasks:

1. Plan and operate all flights minimising exposure, probability and severity of impacts with wildlife.
2. Stay "ahead of the aeroplane" in the lookout for birds and mammals.
3. Report wildlife activity to ATS authorities and other pilots.
4. Fill in an ASR and deliver it to the airline/regulatory body/flight safety or other competent agency.

Experience tells us that wildlife strikes are such a common phenomenon that it is estimated that an airline pilot will face this problem two to five times in his career; knowledge and competence are the basis of the correct management of it.

Aircraft Operators

Impacts with wildlife have significant repercussions on airlines, starting from a safety perspective, continuing with the economic image and legal consequences. Therefore, aircraft operators should be interested

in reducing both the probability and severity of impacts.

To affect these two components, Operators should:

· implement suitable SOPs for the concerned personnel (pilots, flight dispatchers, maintenance personnel and ramp agents).;

· constantly inform the concerned personnel (see the previous point) and provide them with regular and structured training;

· develop their risk matrix or index for their airport network, using data collected by their pilots and data published annually by the authorities, to critically analyse the official risk matrixes or indexes and, if necessary, request the necessary interventions by regulatory bodies and airport managers to bring the risk back to an acceptable level;

· set up a suitable reporting system (ASR) of wildlife strike events (usability, immediacy, clarity, completeness and ease of use), highlighting its importance among employees for an adequate statistical analysis at local, national and international level. Ensure that the wildlife strike reports received from employees are promptly sent to the appropriate national regulators, not before having checked them and possibly integrated them with additional information from other corporate entities, sources and employees;

· interact with Regulators at all levels to exchange valuable information for implementing and continuouslyupdating SOPs and training programmes.

Aircraft and engine manufacturers

As already mentioned, the certification of airframes and engines is of fundamental importance to reduce the severity of damage following an impact since it is impossible to eliminate exposure to wildlife strikes. The components vulnerable to collisions with wildlife are all those placed in the front of the aircraft and therefore: radome, windshield and windows, speed and angle of attack sensors, wing leading edge, tailplane, engines and landing gear.

Historically, the authority involved in certifying these components in the world is the US FAA, followed later by the European EASA (former JAA – Joint Aviation Authorities). Based on new data produced by the aeronautical industry (accidents and safety reports, technological progress and experience), the certification criteria are continuously revised, to reflect the new operational realities. However, it is necessary to underline that in order not to become too penalizing, the new standards are not applied retroactively (Grandfather Rights).

In the case of engines, regulations are FAR 33 for the FAA and CS-E 800 for EASA. In case of airframe and windshield, certification standards are FAR 25 for FAA and CS 25 for EASA.
Below are two tables that illustrate FAR25 and FAR 33 in detail

Airframe Bird Strike Airworthiness Requirements (FAR 25)	
Airframe Component	**Bird Impact Requirements**
Entire aeroplane	Able to safely complete a flight after: • striking, at designated cruising speed (Vc) at sea level and 0,85 Vc at 8.000 ft, with a bird weighing 1,81 kg (4 lbs) or • the strike with the engine fan blades or • an uncontrolled engine failure or • the failure of high-energy rotating components.
Empennage	Able, at designated cruising speed (Vc) at sea level, to complete flight after strike with a bird weighing 3,64 kg (8 lbs).
Windshield	Able, at designated cruising speed (Vc) at sea level, to withstanding impact without penetration with a bird weighing 1,81 kg (4 lbs). The internal panels must be made of material which, if damaged, does not project splinters.
Airspeed indicator system	The pitot tubes must be far enough apart to avoid damage to both in a collision with a single bird.

Turbine Engine Bird Strike Airworthiness Requirements (FAR 33)				
Mass of ingested birds	**Number of ingested birds**	**Strike speed**	**Thrust**	**Bird impact requirements**
85 g (3 oz)	Maximum of 16 birds in rapid succession	Takeoff	Takeoff	Impacts may not cause more than 25% power or thrust loss, require engine to be shut down within 5 minutes, or result in a hazardous situation
0,68 Kg (1.5 lbs)	Maximum of 8 birds in rapid succession	Initial climb (V2)	Takeoff	
1,81 Kg (4 lbs)	1	Maximum climb speed if the engine is equipped with inlet guide vanes. Takeoff speed if the engine is not equipped with inlet guide vanes.	Takeoff	Engine is not to catch fire, burst, or lose the capability to be shut down

Regarding the airframe and windshield certification standards, the requirements have remained virtually unchanged compared to those existing in the early 1970s; in the case of engines, in the year 2000 there was a revision of FAR 33, which led to more stringent certification in terms of weight and number of birds that the engines must be able to ingest, guaranteeing specific operating standards.

In any case, and despite the improvements above concerning engine certification, the current certification standards are still not satisfactory from many points of view:

- The engine certification considers that the ingestion of one or more birds concerns only one engine when the data shows a significant increase in cases of simultaneous bird ingestion (even of large size) in more than one engine.
- None of the current jet engines are built and certified to survive and continue to operate following the ingestion of a goose (3,5-7,0 kg), a pelican, a stork, a vulture or a swan (11 kg).
- The need for more stringent certification standards is urgent, also in consideration of the continuous increase in the frontal area of new jet engines, introduced starting from 2014 (see the CFM "LEAP" and the Pratt & Whitney "Geared turbofan", which are progressively powering thenarrow-body fleets of the Airbus family, Boeing B737, Mitsubishi and Bombardier).
- EASA and FAA certification standards regarding airframe and windshield components consider these aircraft parts single, separate, and independent. Therefore, in the case of encounters with a flock of birds, the cumulative effects of multiple damages to the aircraft are not adequately considered.
  Numerous accidents of this type demonstrate that the old “one component failure” principle must be abandoned.
- Current regulations require windshields to withstand an impact with a 1,81 kg bird at the expected cruising speed (Vc): the windshield must not yield or disintegrate, projecting glass shards.
  Unfortunately, numerous cases of damage and collapses suggest that the regulations need to be improved.
- All modern fuselages have been penetrated by birds, mainly in the radome area. The current certification criteria do not provide that the airframe resists penetration following an impact with wildlife.
- The certification of the various components of the airframe (FAR 25) is issued using the VC speed as reference (designated cruising speed), from sea level up to an altitude of 8.000 ft. Numerous cases of airframe penetration and destruction of windshields suggest extending the certification requirements to an altitude of 10.000 ft and replacing the VC with the VMO would be appropriate.
- Although the landing gear is part of the aircraft structure, the current regulations do not require the same certification standards as the airframe. Unfortunately, failures to the landing gear, its sensors and its hydraulic pipes have occurred following impacts with wildlife, with difficulties in lowering it or confirming its effective extension, hydraulic leaks, locked brakes, damage to the actuators and loss of steering.

Conclusions

All the data provided by the aviation industry, growth projections and certification standards tell us that:

- air travel is constantly growing;
- world fleets will continue to grow; this trend will be higher than average for regional and single-aisle medium-haul aircraft, both performing many takeoffs and landings a day;
- growth will be higher in developing countries, where wildlife management programmes are non-existent or at an embryonic level;
- populations of many large bird species are increasing throughout the world;
- the weight of many large bird species exceeds that established in today's airframe and engine certification standards.

Therefore, the exposure, probability, and severity of impacts with wildlife are expected to increase in the future; the qualified contribution of all stakeholders is essential to take a decisive step forward in managing this risk.

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Is Avian Radar the Silver Bullet in Wildlife Strike Prevention

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In civil aviation, most collisions between aircraft and wildlife take place during the low-level flight phases of take-off, climb, approach and landing due to the abundance of wildlife at low altitudes (e.g McKee, et al., 2016). This situation has led to an airport-centric view on wildlife strike prevention, seeing airport operators as the responsible party to mitigate wildlife strike risks. This perspective is reflected in the regulations by the International Civil Aviation Organization (ICAO) which place all Wildlife Hazard Management (WHM) measures in the Airport Services Manual (ICAO 2020) under Annex 14 – Aerodromes (ICAO, 2018). While it is agreed that traditional airport-centric efforts such as habitat management, exclusion, harassment, capture and relocation of critical wildlife or even lethal measures are necessary and helpful (DeFusco, et al., 2015; Dolbeer 2011), there is a rising awareness that they are not enough.

In fact, especially damaging strikes outside the airport boundaries have increased, which is claimed, in parts, due to the inexistence of mitigating efforts in these areas (Dolbeer, 2011). Critical wildlife species have increased due to conservation efforts, rising the likelihood of collisions with aircraft (Dolbeer 2020; Staneva & Burfield, 2017). Reduced air traffic and limited WHM activities during the COVID-19 period resulted in peaking wildlife strike rates (collisions per movements), as reported for the USA and Europe (Altringer, et al., 2023; Metz, et al., 2022; Parsons, Malouf & Martin, 2022). The rates have stayed above pre-pandemic levels ever since (e.g. Dolbeer, et al., 2023; DAVVL, 2024). This trend is especially worrying, since the intentions to introduce Urban Air Mobility (UAM) operations – air taxi services within and between urban areas performed at low altitudes – are close to realization in many countries (Metz, Henshaw & Harmon, 2024). While the call for action beyond the airport fence is not new (e.g. MacKinnon, 2004; McKee, et al., 2016), the implementation of measures to separate flight tracks of wildlife and aircraft irrespective of their location have never been more urgent. This requires the involvement of the parties actually controlling the aircraft, namely air traffic control (ATC) and aircrew (McKee, et al., 2016; Metz, et al., 2020).

In a sense, this can be interpreted as taking the surveillance and control of airspace to a next level, taking into account feathered and furry opponents in addition to the ones made of metal or, more recently, composite materials, somewhat repeating history.

After an increasing amount of mid-air collisions between aircraft due to rising air traffic levels in the 1930s, the need for surveillance and control of the airspace was identified. Following military developments during World War II, radar was increasingly used for this task by civil ATC as well. (Nolan, 2010). Next to aircraft, the radar screens of air traffic controllers also showed dot-like echoes which at first could not be identified. Investigations revealed that these “angels” were caused by weather phenomena as well as by airborne animals, namely bats and birds (Eastwood, 1967).
At the time, these echoes were considered as distracting by air traffic controllers and efforts were taken to filter them out. However, ornithologists soon realized the tremendous opportunities to study airborne wildlife movement by using information from ATC as well as weather radars (e.g. Gauthreaux, 1970). Over the decades, the understanding of large-scale movement of airborne birds, bats and even insects has grown immensely. Migratory flyways across continents were detected and natural as well as artificial hurdles identified.

For example, the threat to avian life by high-rise buildings and wind farms as well as disorienting effects of strongly illuminated cities at night were demonstrated, building the foundation to call for, if not initiate counteracting measures. Bauer, et al. (2017) as well as Nilsson, et al. (2024) provide in-depth reviews of the power of long-range (weather) radar networks for the understanding and preservation of avian wildlife and to mitigate airborne human-wildlife conflicts.

In the aviation context, it was the military forces who identified the value of radar to protect animals and aircraft from encountering each other. After suffering substantial losses of aircraft due to wildlife strikes, the Israeli Air Force (IAF) developed the first Bird Avoidance Model (BAM) to provide their fleet – at first – with strategic measures to optimize flight planning around critical wildlife movement based on information obtained, among others, from air defense and weather radars (McKee, et al., 2016). Many air forces followed, and today, systems providing real-time risk-assessments as well as broad-scale forecasts to support military low-level aircraft operations in the prevention of wildlife strikes are in place across the globe. Some of them, such as the American Avian Hazard Advisory System (AHAS) provided by the US Air Force (USAF, Detect Inc., n.d.) and the European FlySafe Bird Avoidance Model by a group of European Air Forces (van Gasteren, et al., 2019) are also accessible by civil users. On the AHAS homepage (<https://usahas.com/>), risk profiles for low-level flight routes can be visualized and used for flight planning. The FlySafe homepage (<https://www.flysafe-birdtam.eu/>) provides real-time and forecasted bird density profiles as a function of altitude for weather radars in the Netherlands, Belgium and Germany. Moreover, these values are translated into warning levels used for military training flight planning, with high warning levels resulting in flight restrictions in time and/or space. A long-term analysis comparing strike occurrences between air forces found a 45 % reduction in damaging strikes for air forces applying BAMs (van Gasteren et al., 2019).

In civil aviation, large-scale rerouting or long-term postponement of flights in case of high bird or bat activity is not feasible with tight flight schedules. However, the power of surveillance tools and hereby especially radar, has been identified to provide an increased situation awareness of the wildlife situation at and around airports (Beason, et al., 2013; McKee, et al., 2016).

Dedicated avian radar systems have been developed and continuously been improved for higher resolution and larger covering ranges. Their benefits in the surveillance of airborne wildlife is the continuous tracking independent of lighting situations. In the beginning, there were mostly two-dimensional-applications, providing lateral information only. By now, there are systems which deliver a full three-dimensional view. (Beason, et al., 2013). This supports operators with situation awareness about the location and movement patterns of avian life.

Avian radar systems automatically detect targets and label them into different groups such as aircraft, vehicles, birds or insects, filtering out unwanted groups on demand. Bird targets can further be classified into different size groups or flocks. However, no species information is available and the number or size of birds within a flock cannot be identified. (Beason, et al., 2013). Hence, especially for flocks, it is difficult to determine the risk they pose to air traffic, if there is no means for a visual observation and identification by the operator. Studies of detecting abilities of large individual birds have revealed a reliable performance of up to 1.5 km (Dokter, et al., 2013; Gerringer, et al., 2016), which is a limiting factor when intending to observe larger areas.

In most of the cases where avian radar is installed at civil airfields, as per personal observation of the author, local wildlife control units (WCUs) rather than ATC are provided with the derived information. It is often used to identify wildlife hotspots, movement patterns, and trends of critical animal movement depending on daytime, weather or season. Hence, WCUs can tailor their activities, which certainly supports avian and aviation safety. However, there is still a missing link to provide ATC and pilots with real-time information about potential wildlife threats for their risk assessments.

To close this gap and to prevent aircraft and wildlife meeting at the same point in time and space, a clear commitment by the aviation stakeholders is of utmost importance. In contrast to military air forces, where all parties involved in the aviation process are part of the same organization, this is different in civil aviation. There, the stakeholders such as airport operators, aircraft operators and ATC origin from different organizations with different priorities and performance indicators. These might counteract the introduction of a more extended WHM. For example, airports and airlines strive for undisturbed traffic flow and maximized capacity, while ATC needs to ensure manageable workload to maintain an efficient and safe traffic flow. Moreover, following the decision of at least one court case (Battistoni, 20XX), legal liability in case of wildlife strikes may play a role.

Therefore, the involvement of all stakeholders in the definition of goals and procedures as well as the consideration of operational and legal requirements are necessary. With regard to goals, it should be decided whether real-time wildlife movement information is to serve the enhancement of situation awareness and individual risk assessment of pilots or measures such as short-term departure delays or advisement of different climb rates imposed by ATC (Metz, et al., 2020).

Thereby, scientific evidence of the efficacy of the agreed concept is required to achieve confidence and stakeholder commitment. For example, it could be demonstrated in large-scale fast-time simulations that the impact on airport capacity is negligible when delaying departing aircraft in case of reliably predicted critical wildlife activity (Metz, 2021). In initial Human-in-the-Loop (HIL) studies with five controllers performed by the FAA, controllers reported that they appreciated the increased situation awareness and even identified an innovation that could reduce workload (Hale and Stanley, 2017). A second set of HIL simulations with ten controllers met their expectations by identifying a hazard communication design that provided information that was simple to interpret and that did not take too much attention from other tasks. All controllers reported that they preferred to forward information, leaving the risk-assessment and decision to take evasive action with the pilot in command. Through the use of clearly defined procedures and limiting controller liability for wildlife strikes, the controllers all could imagine working with such a system in their towers (Metz and Schier, 2024).

Prior to any actual installation, the local situation and daily as well as seasonal wildlife occurrence needs to be fully understood to be able to tailor any program for the individual needs and depending on the environmental conditions. Based on these findings as well as the set goals, the discussed technological limitations have to be accounted if not be compensated for. For example, installing a network of radars may overcome the range limitations while the combination with other sensor technology may allow a species identification of tracked targets. Since airports are unlikely to bear the sole financial responsibility to install highly sophisticated network of sensors, especially if they are to not only cover the extended airport areas but also low-altitude flight networks, collaborative solution for the financing of such projects have to be found.

Considering all these prerequisites, successful implementations of systems extending the horizon of wildlife strike prevention to beyond the airport boundaries and taking ATC and aircrew in the loop are possible, as shown by two international examples.

At King Shaka International Airport in Durban, South Africa, millions of wintering swallows cross the extended runway center line twice a day. An avian radar covers the critical area and both ATC as well as the WCU are presented with a radar display. Once the birds' take-off towards the extended runway center line is visible, airport operations are ceased until the massive swarm has crossed the critical corridor (Marshall, L., 2010).

Another, more recent example concerns Vancouver International Airport in Canada. The airport lies adjacent to the Fraser River estuary, with its two main runways being laid out perpendicular to the shore. During the winter months, thousands of wintering snow geese cross the extended runway center lines during dawn and dusk to move between roosting and feeding areas. The evening movement is especially critical since, with decreasing daylight, the birds are difficult to detect optically. After studying radar data on the goose movement patterns and behavior, the airport implemented a system to harass the geese on their feeding grounds to move the birds in one flock rather than transiting the airfield in multiple small flocks. Their movement is observed on the radar and communicated to the tower which imposes departure delays until the birds pass (Bradbeer and Follett, 2023).

It is hoped that these examples serve as motivation for other use cases, especially for locations, where there is a well-understood and timely defined movement pattern of critical birds such as in the cases of the airports of Durban and Vancouver.

A next step forward would then be to not only visualize current local wildlife movement but also to predict its future tracks to also allow an extension of the timely horizon for taking strike reducing measures. Studies to develop such predictive models have been conducted, but they have yet to prove their operational feasibility (Metz, 2021; Krenc, et al., 2022; Sabziyan Varnousfaderani, E., & Shihab, S. A. M., 2023; Xu, et al. 2023). With several research groups working on the topic, the increasing number of avian radars at airports and consequently the rising data availability to serve as inputs for such models, it may be anticipated that the time for sophisticated prediction algorithms useful to be integrated into wildlife strike warning systems is coming.

To conclude, rising awareness and improving technology are supporting the pathway to an integrated WHM, extending the horizon to beyond the airport boundaries and involving all aviation stakeholders. The prerequisites for successful implementation include a strong commitment by the parties involved, a clearly defined goal and the understanding of the ecological and environmental situation as well as the consideration of operational and legal requirements. Carefully integrated, sensing technology such as avian radar, while certainly not being the silver bullet, will contribute these efforts to create a safer sky for aircraft and animals.

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LEGAL ASPECTS RELATED TO WILDLIFE STRIKES

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(This article was originally written in Italian. The English version provided here is the translation performed by an artificial intelligence program. However, lexical and syntactic correctness is not guaranteed as the sole purpose of the translation is to facilitate the understanding of the content.)

For decades, the aviation world, both civilian and military, has regarded wildlife strikes as something unpredictable and somewhat inevitable. Thus, there was no perceived necessity to frame the phenomenon within a legal framework of rules aimed at prevention. There were certainly recommendations, best practices and suggestions on the use of various bird dispersal and removal systems, but none of these best practices had any legal or binding force. Even the ICAO (International Civil Aviation Organization) allocated a few lines to the issue in Annex 14, albeit in the form of recommendations rather than standards. The same applied at the DOC level: the first edition of Doc 9137 part 3 (Bird Control and Reduction) was published in 1975, following the recommendation in the fifth edition of Annex 14 in 1969, which highlighted the need to reduce the number of birds in airports. (1)

The first legislative action on the subject, unless mistaken or omitted, occurred in Italy in 1992 with the enactment of Law 157, which, however, was essentially a law to regulate hunting. However, at the end of Article 2, paragraph 3), it stated: "*The control of the bird population level in airports, for the purpose of aviation safety, is entrusted to the Minister of Transport*." By entrusting an administrative body of the State, and therefore its peripheral airport detachments, with the task of controlling - and reducing - the presence of birdlife, there immediately arose the need to establish how to do so, thereby referring to the aforementioned international recommendations. Thus, the first embryo of the BSCI (Bird Strike Committee Italy) was born in 1993, established by Ministerial Decree 1/BSCI. Its initial activities were to inform airports, mostly under total public management at that time, of the need to address this new requirement, also suggesting operational methods recommended by ICAO.

Meanwhile, in other countries, especially in Canada, the USA and Great Britain, a system of preventive actions was also taking shape, yet always and only of a non-binding nature. Significant in this regard is the manual "Sharing the Sky" published by Transport Canada in 2001, later updated in 2004, which still provides a comprehensive overview of prevention and dispersal methods.

Following ENAC's (Italian Civil Aviation Authority) takeover in 1997 in the direct management of public airports, replacing the General Directorate of Civil Aviation (DGAC) of the Ministry of Transport, it is noteworthy to recall that the first circular of the new body (APT01) in the APT (Airports) series was indeed intended to provide directives on procedures to prevent the risks of bird strikes at airports.

Leaving aside the complex issues regarding ENAC's regulatory power, this circular nevertheless represented a significant step forward, positioning itself halfway between recommendation and regulatory provision. Over the years, the circular has undergone subsequent updates with versions 01A and 01B. The wildlife topic was then included in the ENAC Regulation (1st edition in 2002) for the Construction and Operation of Airports (RCEA), which essentially incorporates, integrates, and modifies Annex 14 ICAO.

However, the step we would define as "revolutionary" from the perspective of national regulation was the reform of the part related to air navigation in the Navigation Code of 1942, implemented through two legislative decrees in 2005 and 2006.

With it, after Law 157, some very important provisions regarding prevention rose to the rank of primary law. For example, the ENAC (Italian Civil Aviation Authority) gains the possibility to deny authorization for the establishment of human activities capable of attracting wildlife outside airports and even to order their elimination (Articles 707, 711, and 714).

This entirely original legislation on the global stage then served as inspiration for other countries, such as Brazil (Law 12,725 of 2012), for the issuance of similar norms. It's worth noting that wherever the Italian regulations were presented worldwide, they garnered extreme interest and requests for further insights.

Starting from the early 2000s, as awareness of the risks posed by wildlife increased, several regulatory provisions emerged, especially at the European level. These include EU Regulation 1108 of 2009, 139 of 2014, and European Directive 2003/42/CE on reporting, among many others issued by ENAC with an explanatory character. Similarly, ICAO also considered the issue of wildlife strikes from other perspectives, for instance, with DOC 9184 (Airport Planning Manual and Land Use and Environmental Control).

As positions became less fatalistic regarding wildlife strikes, implying that within certain limits they could be predicted and even reduced or eliminated, issues of liability for the events started emerging. Despite the initial ICAO regulations being based on recommendations, they left room to identify, after a damaging event, who should have taken the mitigation measures suggested but not adopted or insufficiently adopted. Initially, those called upon tended to cling to the non-binding value of a recommendation, immediately followed, at least in Italy, by the old argument that the ICAO Annexes (and let alone the DOCs!) had not been incorporated into our legal system: as per legal Latin jargon, they were "*tamquam non essent*," as if they did not exist.

However, this situation, even though legally founded, risked being quite weak in a courtroom, where other considerations grounded in domestic law and extensive interpretations of "best practices" were at risk of prevailing instead.

By the late 1990s, articles dedicated to this problem began to appear in some specialized magazines (2). During those years, the state of the art regarding wildlife strikes was far from excellent, not just in Italy: there were even difficulties in determining the number of impacts, the criteria for assessing their hazard were rudimentary, as were the methods of prevention and dispersal of wildlife, especially avian species. Some experts believed that the threat of having to compensate airlines for damages caused by bird strikes (the most frequent events) might prompt airports to adopt preventive and mitigation measures. The threat of legal action was therefore seen as an "useful tool" to stir the stagnant waters of prevention and enhance flight safety. Indeed, compensations in aviation matters reach extremely high amounts, calculated in millions of Euros, sufficient to potentially bankrupt a small airport.

Setting aside, for the moment, the commission of any offences related to a wildlife strike, falling under criminal law, from a civil law perspective the risk of conviction for airport management in Italy is essentially based on two articles of the Civil Code, namely Article 2043 (*Any intentional or negligent act causing unjust harm to others obliges the one who committed the act to compensate for the damage*) and Article 2050 (*Anyone causing harm to others while engaged in a dangerous activity, either by its nature or the means used, is liable for compensation unless they prove to have adopted all suitable measures to avoid the damage).*

The latter article is mentioned because, despite the widespread global civil aviation system enabling mass air transport, there was a case when a judge considered the management of a coastal airport a hazardous activity due to the risk of bird strikes. The peculiarity of this latter article lies in the fact that the airport managers absolve themselves of all responsibility if they prove to have adopted "all" suitable measures to avoid the damage. Literally interpreted, this article constitutes a kind of impossible burden of proof, as there are indeed numerous possible and imaginable measures to prevent or avoid a bird strike, making it almost impossible to adopt them all, regardless of their effectiveness. These are arguments that would be the subject of intense debates among experts and lawyers in a courtroom.

Regarding trials and sentences, it's interesting to observe the judges' stance concerning the harmful events caused by wildlife strikes and the claims for compensation from the affected parties. At this juncture, we will limit ourselves to summarizing two concluded civil proceedings in Italy with finalized judgments, while providing an appendix summarizing the outcomes of major civil proceedings in other countries.

The first case refers to an incident that occurred in 1989 at Genoa Airport. Seven years later, in 1996, the cargo airline TNT started a lawsuit against Genoa Airport, the Autonomous Consortium of the Port, the Ministry of Transport, and ENAV seeking compensation for damages suffered by one of their aircraft following the ingestion of seagulls into the engines of the Bae 146 during takeoff. Fortunately, the aircraft managed to return and land with only one of its four engines running, reaching the parking area. The compensation claims involved the airport for the failure to implement security measures, the Ministry of Transport for the omission of control and oversight action by the Airport Director, and ENAV only if the seagull flock was visible from the Control Tower.

After a lengthy and detailed debate, the single judge of first instance attributed 50% of the responsibility for the event to the Ministry of Transport, 30% to the airport operator, and 20% to the Port Consortium. ENAV was not held responsible solely because the seagull flock was not deemed visible by the controller, as the incident occurred at night. The amounts to be compensated ranged from a minimum of $400,000 (attributed to the Consortium) to a maximum of $1 million (attributed to the Ministry).

On appeal, the overall accusatory framework stood, with differing assessments regarding the compensatory amounts to be determined in a separate judgment. Even in the Supreme Court, the first-instance judgment was not overturned, except once again for the need for a separate judgment regarding the sums. However, as it appears, such a judgment was never activated by the affected parties, and in effect, no compensation was made.

The judgment caused a stir in Italy and beyond. The substantial compensation amounts that the Court mandated the Italian government and the airport operator to pay resulted in a sudden surge of interest at various levels regarding the issue of bird strikes. Several airports immediately initiated projects for naturalistic studies related to bird presence, while others began implementing regulations issued by Civil Aviation authorities.

Of particular interest is the issue of ENAV's competence and responsibility, which are still not recognized by that body. The fact that they were excluded from compensation was solely linked to the lack of visibility of the flock; perhaps a different assessment might have been made if the event had occurred during the day.

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The second case instead concerns a Ukrainian aircraft, an Antonov AN124, again at Genoa Airport, in June 1997. During the takeoff roll, it struck a flock of seagulls, some of which were ingested into two of its four engines. One engine immediately shut down, while another experienced a power loss. The Antonov was loaded, as later determined, beyond the maximum takeoff weight, and the manoeuvre to return for a reverse runway departure was particularly challenging, especially during braking. However, the event concluded successfully aside from the damage caused to the aircraft by the seagulls, estimated at 2.5 million dollars.

Following the pattern of the TNT case, in 2001, the insurance company filed damages claim against the airport operator, the Ministry of Transport, ENAC, and ENAV. The compensation claims were based more or less on the same grounds as the previous case: the lack of application or improper use of prevention measures (for the airport), non-compliance with control and oversight obligations by public authorities (for the Ministry and ENAC), and omission of information to the pilots (for ENAV).

The debate initially unfolded at the consultant level, appointed by the parties, and then proceeded to court with their respective legal representatives. In a nutshell, as it would be too lengthy and not even relevant to narrate the various stages of the proceedings here, the positions clashed over a fundamental aspect—the position of the seagull flock. According to the injured party, the birds settled on the runway or in the immediate vicinity, whereas for the other parties, the flock came from outside in a swift, low-level flight, making the impact with the aircraft during takeoff unpredictable and unavoidable. If the first hypothesis had been accepted, the responsibility of the operator would have emerged as highly probable if not certain. Otherwise, it would have been deemed a classic case of force majeure in which no one would have been at fault.

The Court's Consultant, in his expertise, opted for this second hypothesis. However, the single judge, curiously the same as in the TNT case, decided differently with a debatable rationale, claiming that the event was foreseeable and avoidable. The judge argued that too much emphasis had been placed on the technical provisions implemented by the operator while underestimating the human factor. The judge affirmed that the management of a coastal airport constituted a hazardous activity under Article 2050 and added that in such cases, normal diligence was not sufficient. Consequently, responsibility was attributed: 35% to the airport operator, 35% to ENAV, 22.5% to the Ministry of Transport, and the remaining 7.5% to the Port Consortium.
Of course, the convicted parties appealed, and this time the trial was entrusted to a board of judges that appointed two experts, different from that of the first instance.

The two Court-appointed Experts confirmed the assessment of the previous consultant, which had been disregarded by the first-instance judge. They argued that "*due to their origin and lighting conditions, the seagulls were only 'visible' in the last few seconds immediately preceding the impact, i.e., when the aircraft was at V1 or had just passed it. Under those conditions, no intervention would have prevented the collision*," thus supporting the hypothesis of a fortuitous event.
Consequently, the Court of Appeals completely overturned the first-instance judgment, accepting the appeal.

The preceding description is a highly condensed summary since the appeal process, in which the author participated as a technical consultant for one of the parties, covered many other interesting points. However, it appears that the decisive argument was indeed the flight path of the seagulls originating from outside the airport premises and the impossibility of detection by both ground operators and the Control Tower.

Fortunately, cases in which harmful events caused by wildlife strikes are evaluated as criminal offences and subject to investigation by a criminal judge are exceedingly rare. Regarding the very recent incident in Turin, where an out-of-control aircraft of the acrobatic patrol (PAN) caused the death of a five-year-old girl outside the airport, there is no further information available so far, except that the Public Prosecutor's Office competent authority initiated an investigation.

The issue of the criminal liability of air traffic controllers was addressed in the lengthy process following an incident in Georgia, USA, at the Dekalb-Peachtree Airport in 1973, resulting in the death of eight people. Ultimately, no evidence was found that the controllers had seen the birds, and therefore, they were acquitted. The case continued in civil court.

Another case that came to light involved an event in 1995 at Paris Le Bourget Airport when a Falcon 20 during takeoff ingested lapwings into an engine, causing it to fail. The aircraft became uncontrollable and crashed, resulting in the death of ten people. The investigation identified several shortcomings on the part of the airport, and two individuals were charged with manslaughter. However, in the initial trial, the two were acquitted, and the verdict was upheld in the subsequent appeal, deferring compensation issues to another Court.

A brief examination of judgments globally (see Appendix) highlights some common elements. The presence of adequate preventive measures serves as a mitigating, if not exclusionary, factor in terms of liability. Even in cases where specific internal regulations are absent, judgments refer to various recommendations issued by ICAO (effectively recognized as good practices in legal systems).

Equally crucial is the communication to pilots about the potential risk due to the presence of wildlife, in all its forms prescribed by aviation regulations (AIP, NOTAM, ATIS, etc.). However, this can be debated as a form of exoneration of responsibility, considering that a general note in AIP or a NOTAM does not provide the pilot with substantial real assistance and cannot significantly influence their manoeuvres.

Essential (and substantial) is the factual determination of the impact dynamics. If it appears to be an unforeseeable and unavoidable event, it absolves all potential parties involved in the incident. This is considered a fortuitous event, although this declaration might hastily overshadow other probable aspects of responsibility.
It is intended to allude here, as previously mentioned, to the possible involvement of other parties, more or less unaware of being responsible for something. We have mentioned air traffic controllers, but even the pilots themselves could potentially be implicated, as well as their Flight Operations Departments and the authors of their manuals. There was even a case of a municipal administration that had correctly published on its institutional website the constraint maps around an airport, but then disregarded them by giving a favorable opinion for the installation of a structure highly attractive to certain types of birds in an area where it was not permitted.

"Below is a summary overview of the outcomes of the main (known) legal disputes following wildlife strikes (data covering the period 1960–2015). In some cases these are first-instance judgments, in others final rulings. A complete list of legal proceedings and the related judgments can be found on the STASA Research Center website (centrostudi-stasa.com) and on www.birdstrike.it
."

Paese	Sentenza in favore degli attori	Sentenza in favore dei convenuti	Totale	Note
Argentina		1	1	
Australia		1	1	
Croazia	3		3	
Francia	1	1	2	
Germania	1/2	1/2	1	Responsabilità condivisa
Italia	1	1	2	(*) (§)
Malta	1		1	
Olanda		1	1	
Regno Unito	1	1	2	
Russia	2		2	
Spagna	1	2	3	
Sud Africa	1		1	
USA	7	7	14	(°)
TOTALE	18 1/2	15 1/2	34	

TOTALE 18 1/2 15 1/2 34

(*) There were two other summons to trial, one for an event that occurred in Pescara and one in Parma but, as far as is known, they ended with out-of-court settlements.

(§) There was another serious case of bird strike at Milan Linate in 2003 that caused two deaths. This was followed by a criminal trial for matters connected to the main event (attempted bribery of an expert witness). There is no information about a possible civil trial for compensation.

(°) One of these cases ended in favor of the plaintiffs but with an out-of-court settlement. This is the famous case of the Air France Concorde that struck Canadian geese at JFK Airport in New York in 1995.

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The accident of the Eastern Airlines 375: a lesson learned?

by Cpt Andrea Bomben

In a monograph concerning the problem of wildlife strikes, an example of a lesson learned could not be missing; on the one hand, to frame a problem a specific event is often much more useful and effective than a thousand theoretical disquisitions, on the other, it allows to evaluate whether the industry has understood the lesson or not.

There would be many examples, but the one proposed is obligatory, not only because the Lockheed Electra accident is the most serious in world history caused by an impact on wildlife, but above all because, comparing the photograph of 1960 with that of today, doubts about the effectiveness of the lesson remain many.

If it is true that after the Boston accident, the world aeronautical authorities took note of the need to test and certify airframes and engines to make them suitable to face the Wildlife Strike danger, it is also true that despite the further tightening of the regulations, aircraft impacts with wildlife remain firmly in second place in the causes of death in the aeronautical world (and are constantly increasing).

The reasons for this situation have been analysed in previous articles; what Eastern Airlines flight 375 does not seem to have taught us, however, mainly revolves around the fact that today's engine redundancy has been drastically reduced compared to the sixties and, above all, the knowledge and skills of pilots and air traffic controllers on the problem have remained the same as then, i.e. zero.

In order to confirm this, it would be enough to read the documentation used in pilot training courses, in the manufacturer and airline manuals and the reference texts of Air Traffic Service suppliers; what they all have in common is the substantial absence of cultural contributions and guidelines that allow a fundamental part of frontline professionals to do their part to reduce the risks caused by wildlife.

Moreover, if two weeks after having destroyed the aircraft following the impact with the birds and the subsequent ditching, a Commander of the calibre of Chesley B. Sullenberger went so far as to state before the American Congress that "Birds are not a problem for modern jet planes", probably the most danger is not wildlife, but human beings.

E. L. Logan Airport in Boston, Massachusetts, United States of America.
It's 15:33 on a sunny and warm afternoon on October 4, 1960.

Eastern Airlines Flight 444 (registration N5533) from New York has just landed and is heading towards the parking area.

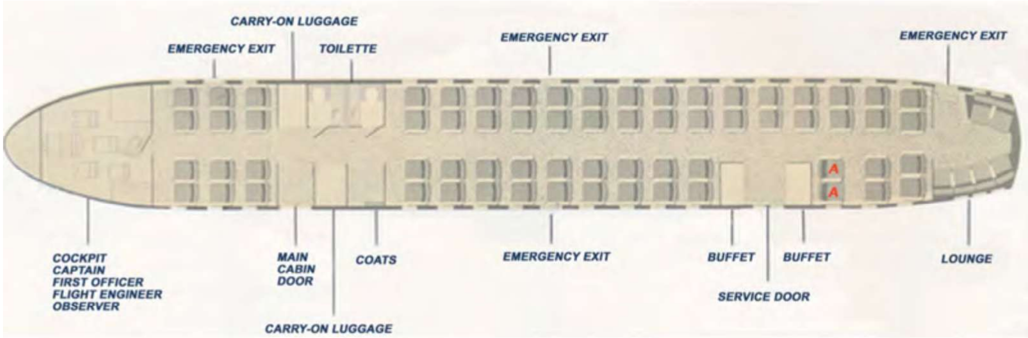
After the disembarkation of the passengers and the usual checks, pilots and hostesses relax; it will be a long and demanding day at work. Two hours later, the next flight 375 is scheduled for Philadelphia (Pennsylvania), followed by three more: Charlotte (North Carolina), Greenville (South Carolina) and Atlanta (Georgia).

The crew consists of five members: Captain Curtis W. Fitts (a 59-year veteran of Bell Meadow, Georgia, with over 23,000 flight hours), First Officer Martin J. Calloway (5800 flight hours, Atlanta, Georgia), flight engineer Malcom M. Hall (7800 flight hours, Memphis, Tennessee) and the two very young flight attendants, 22-year-old Joan Berry, from Prentice (Mississippi) and 23-year-old Patricia Davies, from Jacksonville (Florida).

The aeroplane is a brand new Lockheed L-188A Electra, a short/medium haul four-engine turboprop just over thirty meters long, which left the factory in June of the previous year and cost 2.5 million dollars. It was a revolutionary machine for its time, still dominated by much slower, uncomfortable, noisy and expensive planes with piston engines. Eastern pilots, therefore, jostle to fly it, with the result that invariably those higher up in the seniority list prevail, despite some doubts of reliability starting to peep even among them, after the four mysterious accidents that occurred in the previous nineteen months.

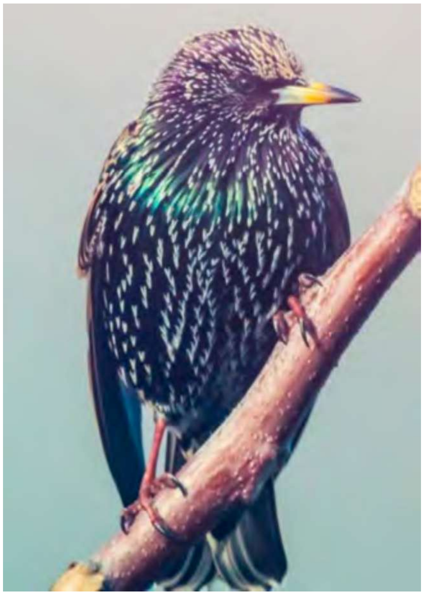
The Lockheed L-188A Electra
(San Diego Air & Space Museum, public domain)

The aircraft is also innovative from the passengers' point of view, with a spacious and comfortable interior, sixty-six seats in rows of four divided by the central aisle, and six seats in a small lounge in the tail. The air conditioning and pressurization quality are comparable to the contemporary long-range jet aircraft, such as the Boeing 707 and Douglas DC-8.



Cabin configuration (From "Lockheed field service digest", December 1958)

As dusk and low tide approaches, Winthrop Bay and the remaining bodies of water surrounding the airport begin to populate with pilots far more seasoned and skilled than even Commander Fitts. The bay is an authentic paradise for birds of all species, who find plenty of food and refreshment. Among them, in terms of number and motor and singing liveliness, small black birds stand out, weighing no more than eighty grams: the *Sturnus vulgaris*, commonly known as starlings.



Sturnus vulgaris Mickey005,

Wikipedia (Share Alike 4.0 International)

Storni in volo Oronbb,

Wikipedia (CC BY-SA 3.0)

After spending the whole day looking for seeds, insects and small vertebrates, they are preparing to reach their night shelters, which in this case are probably the metal structures of the Maurice J. Tobin Memorial Bridge (the former Mystic River Bridge), located northwest of the airport.

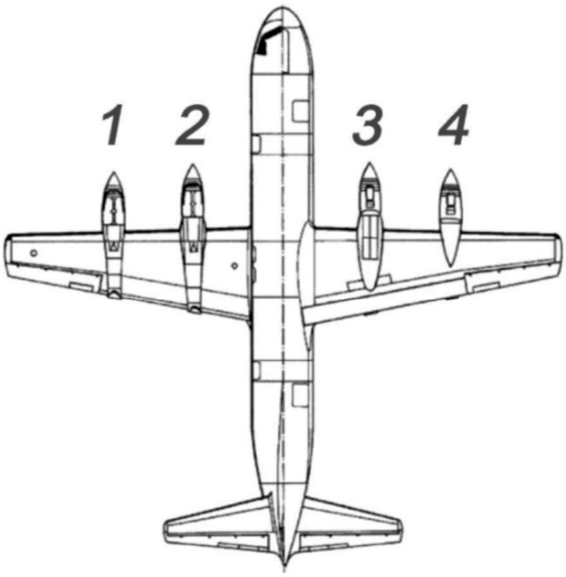
Starlings are gregarious birds that gather in flocks of thousands of individuals, capable of flying at 60 km/h and performing tight and complex evolutions wing to wing, without ever touching.
Unfortunately, these are not the only exceptional qualities they possess: it is also a very adaptable and prolific species, so much it is included in the list of the hundred most harmful invasive species worldwide.

When, in 1890, a New York drug manufacturer, a certain Eugene Schieffelin, released sixty specimens of European starling in Central Park, followed by another fifty the following year, he could not have imagined that, within a century, the starlings, an alien species in North America, would have become two hundred million.

At 17:00, Fitts orders the boarding of the 67 passengers, which are all on board in about twenty minutes; after signing the flight paperwork and saying goodbye to the company agent, he instructs Davies to close the door.

There are few clouds above Logan Airport, the visibility is 30 kilometres, and a light southeasterly breeze blows. The weather is also splendid along the 500-kilometre route; it promises to be a smooth 90-minute flight at an altitude of just over 3,000 metres.

At 17:30, having received the authorization from the tower, the flight crew begins to start the four engines, actually with some difficulty for numbers 1 and 2, those installed in the left wing (the engines are numbered increasing from left to right).



Engine numbers

In any case, after some additional checks by Hall, all engines start, and Calloway asks the controllers for permission to start taxiing.

At 17:35, the Electra moves with its engines at idle towards the take-off runway, which today is number 09 (rotated 90° clockwise from magnetic north, therefore heading east), 2140 meters long.

At 17:39, flight 375 is cleared for take-off, and the acceleration of the 15,000 horsepower Allison engines glues the passengers to their seatbacks. A little more than 20 seconds and 760 meters later, at a speed of 215 km/h, the N5533 gently lifts from the runway its 45 tons and its shadow, which in its rapid lengthening on the ground, seems to announce the next reunion in Philadelphia.

Everything will happen sooner and much faster.

Six seconds after take-off, a black cloud suddenly fills the view of the three "new" aviators on board, who meet a few thousand "old" ones: the starlings. On the way back to the Memorial Bridge, the birds found themselves in the wrong place at the wrong time and although exceptional fliers, they are not equipped to recognize and avoid an unknown object thirty meters wide and ten meters high, travelling at 230 km/h.

The impact is inevitable and very violent and causes a devastating effect in the cockpit; starlings are small and light but have one of the highest body densities in nature, so much so that someone calls them "feathered bullets".

For the crew of the Electra, the surprise and acoustic effect is the same as a machine gun burst. An unknown number of specimens crash all over the plane: the windshields, the nose, the speed sensors, the wing, the engines and the tailplanes. It causes the external visibility to zero, the failure of the onboard speed indicators and severe problems with the engines, which need to absorb considerable quantities of air to work, whatever it contains.

Four birds go into engine 1, six in engine 2 and an unspecified number in engine 4. The consequence is the definitive failure of engine 1, the momentary but violent failure of 2 (which emits a fireball at the exhaust) and a momentary power loss of 4.

It is such a sudden, intermittent, unbalanced, and intense drop in performance that it exceeds the control surfaces' ability to compensate for it. Fitts, while acting immediately on the rudder and ailerons, is unable to counteract progressive yaw to the left, which by increasing drag causes a dangerous decrease in speed, which in turn reduces the effectiveness of the rudder, which in turn increases drag, which further decreases speed (to a rate of 25 km/h per second).
It's the classic dog chasing its tail.

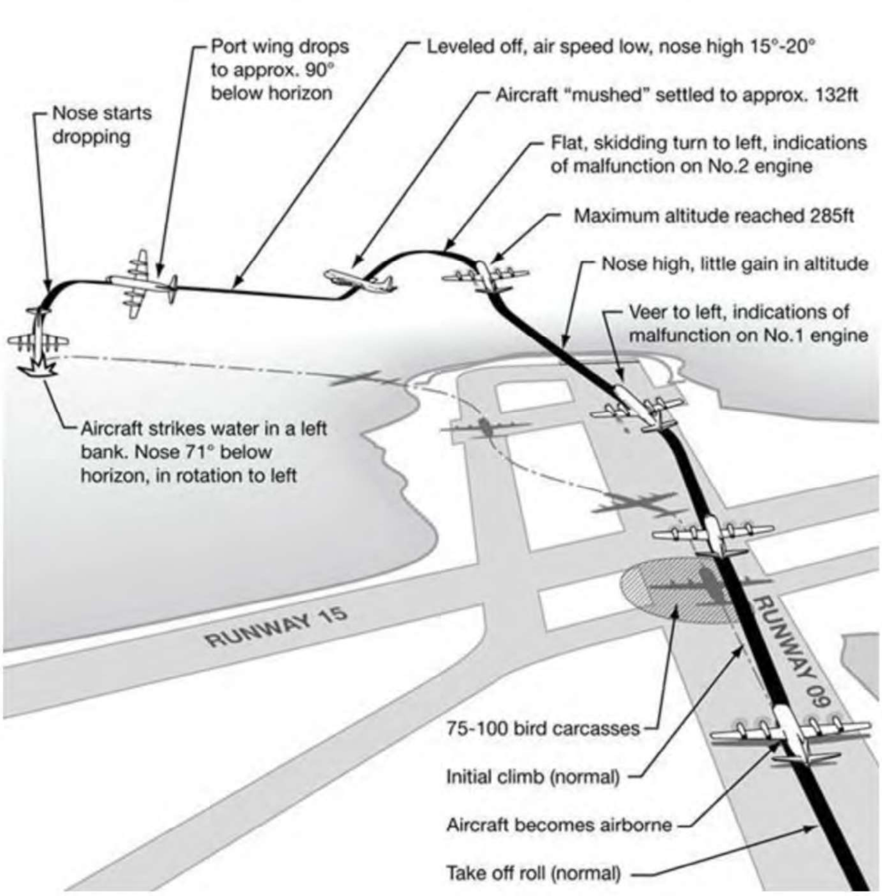
The Electra's heading swings wildly from east to the northeast as airspeed approaches dangerously close to the stall speed, the one that marks the difference between an object flying and one falling.

The only way to regain control would be to reduce the asymmetry between the null power developed by the engines on the left wing and the 7500 horsepower pushing the right one, and simultaneously lower the nose to regain speed. Unfortunately, to do so would require a much higher altitude than the measly 87 meters reached up to that moment.

Despite the crew's great experience, the fate of the Electra is sealed.

The decrease in speed causes the stall of the left wing and the consequent spin of the aircraft, which plunges vertically at 290 km/h into the icy waters of Winthrop Bay, just over two kilometres away from the runway and 200 meters from the shore. 47 seconds have passed since the start of take-off and only 27 of flight, during which the pilots were unable to say a single word on the radio.

One eyewitness watches in disbelief at the crash and subsequent rise of a tall column of water and debris, while another hears an explosion that he initially mistakes for the sonic boom of a military aircraft. Among the witnesses, there is also Myron Williams, a freelance photographer who manages to take two photos of the plane in flight, images that will later be invaluable during the investigation.



Flight envelope (Drawing by Matthew Tesch, from https://daydaynews.cc)

In the impact, the aircraft undergoes a deceleration of one hundred times that of gravity, which causes the fuselage to break into two parts; the front part immediately sinks into ten meters deep water, while the rear one floats for a few minutes. In the collision, all but two of the passenger seats are uprooted from the floor and thrown forward, while 50% of the central anchor points of the seat belts break.

Shortly after, an unreal silence falls like a shroud over the scene and over the inhabitants of Winthrop, who are preparing to sit down to dinner and enjoy the sunset.

However, it is a silence that does not last long: in the following minutes and hours, hundreds of people, many of them teenagers, are catapulted into the sea with the most disparate floats to reach the scene of the accident and provide first aid. In the end, there will be more than 200 boats, including kayaks, canoes, rowboats and motorboats, followed by institutional rescuers, including numerous helicopters and a hundred divers. It is a spontaneous mobilization whose memory in Boston remains alive and unchanged decades later.

As the rescuers approach, everything begins to emerge from the sea: pieces of aluminium, rubber, plastic, luggage and the airplane seats, most of which with their respective passengers still belted up, upside down in the water at 16°C. Meanwhile, the 11 tons of kerosene leaking from the tanks form a highly flammable and toxic patch, which spreads dangerously, soaking everything.

For 62 of the 72 people on board, including the two pilots and the flight engineer, there's nothing they can do: the deceleration suffered on impact is much higher than that bearable by a human being. Most die instantly, others in the arms of rescuers, some in the ambulance and two of them shortly after arriving at the hospital. Ten of them, all seated in the rear part of the plane, are saved because they suffer lower decelerations than the others.

Among the survivors are the two flight attendants, Joan Berry, who breaks her leg, and Patricia Davies, who escapes unhurt (both sitting in the seats marked with a red A).

The birds did not fare better: shortly after the accident, near the take-off point and scattered over an area of 8000 square metres, between 75 and 100 carcasses of starlings were found, which together with those disintegrated by the impact with the plane and from the ingestion of the engines, will lead to hypothesize the death of at least 150 specimens. A thousand and more survivors, not satisfied with the narrow escape, two weeks later will sacrifice themselves on another aeroplane taking off from Boston which, however, will emerge unscathed managing to interrupt take-off before going into flight.

The two sections of the airplane will be recovered the following day.

La coda dell'Electra
By J. Walter Green,
www.bostonmagazine.com

In the following two years, the CAB (the body in charge of the technical investigation, forerunner of the NTSB, the current US National Transport Safety Board) will investigate the causes of the accident with the collaboration of the aircraft and engine manufacturers, making use of testimonies, analysis of the wreck, photographs, etc. The "black boxes" (actually the "orange" ones) had recently been invented and were not installed on the Electra; they began to be so only a few years later.

To reconstruct what happened in the cockpit, the investigators also brought together the best sixteen L-188A captains in the United States: they put them one after the other on board the aircraft's flight simulator and, after take-off and without warning, proposed them the same failures that happened to the unfortunate crew of N5533.

None of them managed to avoid the crash. Only after other attempts, knowing by now what awaited them, someone managed to bring the plane back to the ground, but all came out of the simulator pale and sweaty like freshly centrifuged rags.

Even in relatively calm conditions, nobody had been able to do better than Fitts, Calloway and Hall.

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Acronyms and abbreviations

AAM	Advanced Air Mobility
ACMR	Aircraft Movement Rate
AEPF	Adverse Effect on Planned Flight
AGL	Above Ground Level
AHAS	Avian Hazard Advisory System
AIP	Aeronautical Information Publication
AIREP	Airborne Report
ANSV	Italian civil aviation safety investigation authority
AOA	Angle of Attack
ARP	Aerodrome Reference Point
ASR	Air Safety Report
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATS	Air Traffic Service
ATSB	Australian Transport Safety Bureau
BAM	Bird Avoidance Model
BASH	Bird/wildlife Aircraft Strike Hazard (USAF)
BCAS	Bird Collision Avoidance System
BCU	Bird Control Unit
BIRDTAM	BIRD Notice To Air Man
BPZ	Bird Plagued Zone
BRI2	Birdstrike Risk Index 2 (Italian Risk Index)
BSC	Bird Strike Committee
BSCI	Bird Strike Committee Italy
BSRF	Bird Strike Reporting Form
B/W	Bird/Wildlife
CAA	Civil Aviation Authority
CAANZ	Civil Aviation Authority of New Zealand
CAMIR	Critical Airspace Mass Infringement Rate
CFM A	Joint venture between GE Aviation and Safran Aircraft Engines (formerly known as Snecma) CFR Code of Federal Regulations
DGAC	Direzione Generale Aviazione Civile (Former name of Italian CAA)
DU	Display Unit
EASA	European Union Aviation Safety Agency
ECCAIRS	European Coordination Center for Aircraft Incident Reporting System
EGT	Exhaust Gas Temperature
ENAC	Ente Nazionale per l'Aviazione Civile (The Italian CAA)
ENAV	Ente Nazionale per l'Assistenza al Volo (The Italian air navigation service provider)

EPR	Engine Pressure Ratio
ESA	European Space Agency
EU	European Union
FAA	Federal Aviation Administration (USA)
FAR	Federal Aviation Regulations
FF	Fuel Flow (Engine)
GIS	Geographic Information System
GLMs	Generalized Linear Models
HIL	Human in the Loop
IBIS	ICAO Birdstrike Information System
IBSC	International Bird Strike Committee
ICAO	International Civil Aviation Organisation
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
LEAP	Leading Edge Aviation Propulsion (CFM)
LRAD	Long Range Acoustic Device
MAC	Mid Air Collisions
N1	Rotational speed of the low pressure (low speed) engine spool (in per cent RPM, based on an engine manufacturer defined rotational speed that corresponds to 100%)
N2	Rotational speed of the high pressure (high speed) engine spool (in per cent RPM, based on an engine manufacturer defined rotational speed that corresponds to 100%)
NADP	Noise Abatement Departure Procedure
NASA	National Aeronautics and Space Administration (USA)
NOTAM	NOtice To AirMan
NTSB	National Transportation Safety Board (USA)
PAN	Italian National Acrobatic Team "Frecce tricolori"
RCEA	Regolamento per la Costruzione e l'Esercizio degli Aeroporti (Italian Regulations for the Construction and Operation of Airports)
SOPs	Standard Operating Procedures
STASA	Study Center. Air Transport Advanced Systems – Safety and Environment UAM Urban Air Mobility
UE	European Union
USAF	United States Air Force
VC	Designated cruise speed
VMO	Maximum Operating speed (clean configuration)
WCU	Wildlife Control Unit
WHM	Willdlife Hazard Management

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The manual aims to improve the knowledge and expertize of airline pilots regarding a problem seriously underestimated by the aeronautical industry and national and international regulators. Since 2022 he has been a member of STASA where, with Valter Battistoni, takes care of the Wildlife Strike section of the Association's website, rich- among others - with a large database and a remarkable amount of documentation, regulations, Accident /Incident Reports, press reviews, etc.
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A 20-year member of the Roster of Wildlife Strike Experts of the International Civil Aviation Organization (ICAO), he was the director of the National Marine and Terrestrial Protected Area "Isole di Ventotene e S. Stefano", scientific director of the Rome Zoo, scientific advisor for the Institute of Applied Ecology (IEA), on contract professor at Dept. of Biology and Biotechnologies of Sapienza University of Rome.
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