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Dan Parsons *, Steven Leib, Wayne L Martin

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A Review of Wildlife Strike Reporting in Aviation: Systems, Uses & Standards

Dan Parsons *, Steven Leib and Wayne Martin

Central Queensland University, 13 G-14 University Drive, Bundaberg, Queensland 4670, Australia

* Correspondence: daniel.parsons@cqumail.com

Simple Summary: Collisions between aircraft and animals are among the most reported safety events in aviation. While a significant amount of research and effort is undertaken to reduce the risk posed by wildlife, there are challenges associated with capturing data on strikes and other safety-related events. This literature review examines the question of whether wildlife strike reporting systems are meeting the needs of academics and industry in managing the conflict between wildlife and aircraft. The paper concludes that while academics and industry have adopted systemized safety and hazard management concepts and that international guidance material has been keeping pace, international standards, the foundation for many national reporting systems, remains decades behind.

Abstract: Wildlife strikes in aviation are among the most reported safety incidents. As such, strikes have become the fundamental unit of understanding of the risk posed by wildlife. However, with the management of wildlife strike risk shifting to a hazard management philosophy, this literature review considers the contention that current wildlife strike reporting systems are not suited to modern wildlife hazard management techniques. This review sourced academic literature from Web of Science (n=684) and, using bibliometric analysis software, identified relevant papers (n=257). Additional industry material completed the final catalogue (n=542). These papers were reviewed for their treatment and use of wildlife strikes with respect to modern risk and hazard management approaches. This analysis noted three potential challenges with current wildlife strike reporting systems, including the focus on collision events, the potential to introduce other adverse effects and the skewing of risk assessment results. The paper's analysis was supplemented with a review of international standards and relevant national requirements and concludes that while academics and industry have adopted systemized safety and hazard management concepts and that international guidance material has been keeping pace, international standards, the foundation for many national reporting systems, remains decades behind.

Keywords: airport; air traffic management; aviation; bird strike; incident reporting; risk; safety; safety reporting; wildlife management; wildlife strike

1. Introduction

While aviation is considered "ultra-safe", with accidents and incidents relatively rare [1], collisions between aircraft and animals are one of the most commonly reported safety incidents [2]. Known today as wildlife strikes, the Australian Transport Safety Bureau's (ATSB) national aviation occurrence database shows that, in the ten years to 2023 (inclusive), events involving wildlife accounted for 33% of safety reports in Australia [3]. As Dolbeer et al. [4] noted in their regular report on wildlife strikes in the United States, wildlife strikes "have become an increasing concern for aviation safety" (p. v).

The outcome of any single wildlife strike event will vary from negligible to catastrophic. Where a wildlife strike leads to some form of adverse outcome, the consequences may be limited to the impact area or trigger a "critical sequence of a rapidly occurring chain of events" [5] (p. 12) that leads to a serious accident. The preceding quote is from the 1960 accident report of Eastern Air Lines Flight

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375, a Lockheed Electra L-188 that struck multiple birds on departure, resulting in an accident in which 62 passengers and crew were killed.

Research into the costs of wildlife strikes and associated events has recognized the economic impact on aviation. One of the most cited works on wildlife strikes in aviation is Allan [6], later followed up by Allan and Orosz [7], in which the annual worldwide costs of wildlife strikes in aviation were estimated at US$1.2 billion. Adjusted for inflation, this would equal more than US$2.2 billion in 2025. This figure, which includes direct and indirect components, will also likely underestimate the actual cost [7].

Wildlife strikes as a safety issue have been the focus of international standards [8] and national regulations [9–11] that require or otherwise influence aerodrome operators to implement wildlife hazard management programs or similar systems.

As noted in this paper, the wildlife strike event is currently the fundamental unit of understanding across nearly all facets of wildlife hazard management. Wildlife strike events are used in various ways to describe the impact of wildlife on aviation as well as form regulatory triggers for study, review, and action. However, issues with international and national wildlife strike reporting systems continue to be noted in academic literature [12,13] and at industry conferences [14].

In the following literature review, we will examine the contention that wildlife strike reporting systems are not currently meeting the needs of academics and industry in managing the conflict between wildlife and aircraft. As a first step, we provide a broad survey of academic research articles using bibliometric techniques to identify significant sections of research activity and acknowledge the role of industry research. From here, the literature review is divided into two parts. In part one, we use the collected literature to review the nature of wildlife hazard management in terms of harm and risk and then dive deeper into key areas where we believe the industry's focus on strikes, to the exclusion of other wildlife-related events, may be limiting the industry's hazard mitigation efforts. In part two, we explore how wildlife strike events are used in research and the role of international standards and national legislation. Our final discussion outlines the interplay between academic research, industry practice and the international standards development process, and how future research may address the issues identified in the literature.

2. Survey of Relevant Literature

A broad search of academic research relating to wildlife strikes in aviation shows that it spans a diverse range of disciplines. To help identify relationships between related, complementary and seemingly disparate sources, we used software-based bibliometric analysis to survey the academic literature landscape. Using bibliometric analysis software, such as VOSviewer, researchers can visualize and interpret patterns in literature. These patterns are based on relationships between authors, keywords and [15]. When used in cross-disciplinary research, its capability to cluster items and present visual maps provides a method for identifying relationships within a field of research.

Using a relative board search query, we obtained a library of relevant research from the Web of Science database. The query searched for a combination of wildlife or bird strike with aviation-related terms across all database fields. Throughout this paper, the term wildlife is used to refer to the hazard at the center of research. However, for much of its history, the term "bird strike" has been more common, with over 95% of reported wildlife strikes in 2023 attributed to birds [4]. The resulting search provided 684 documents.

Using VOSviewer, we produced a visualization of the relationships between the documents downloaded from the database using citations. The resulting visualization, shown in Figure 1, shows three groups of documents. The first group, shown as a grey ring, indicate unconnected documents covering a variety of topics, including general biology and ecology [16,17], and unrelated aviation and aerospace topics [18,19].

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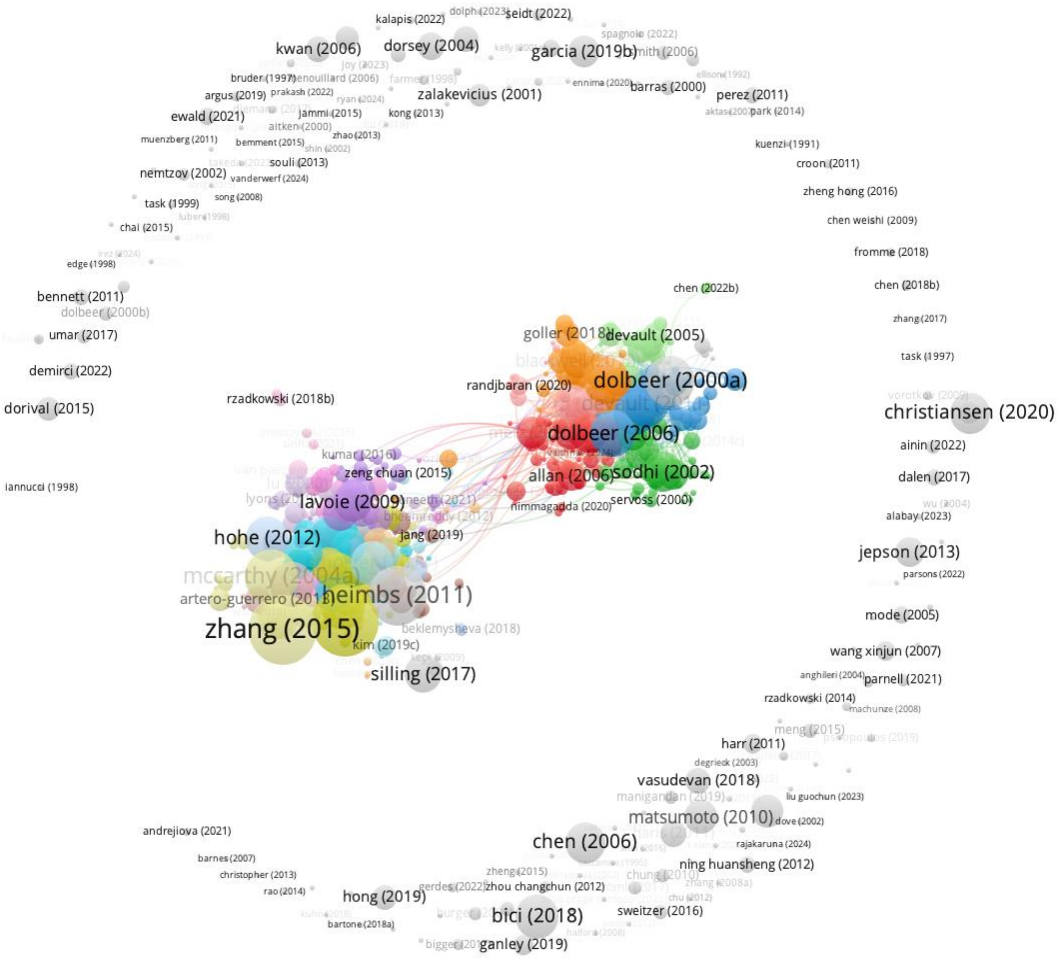

Figure 1. VOSviewer produced Network Visualization showing two main groups of connected and interconnected papers surrounded by a third group of unconnected papers.

At least one relevant paper [20] was identified in this group. However, its record did not include citations to other documents, so it was not connected to the central clusters. A paper of a similar name was located in the proceedings of the 1994 International Bird Strike Committee (IBSC) meeting [21]. This paper's absence from the Web of Science results suggests that industry resources are not treated like academic literature and could have been missed in our analysis.

The second group is the super-cluster located in the lower-left quadrant. We identified this group as relating to aircraft-engineering-related topics. We analyzed the six largest clusters in this group (each n > 20) using VOSviewer's clustering algorithm [22]. These clusters covered topics like impact assessments and simulation on aircraft structures [23–25], involving jet engines [26–28], and involving laminate materials [29–31],.

The last group, located in the upper-right quadrant of the diagram and the focus of this literature review, could be described as the wildlife hazard management super-cluster. We also identified six clusters within this group with more than 20 documents each. There appeared to be greater overlap between clusters, but some of the more significant papers explored risk management [32–34], wildlife biology and behaviors and their impact on wildlife strikes [35,36], wildlife strike statistical analysis [37], habitat management [38], intervention strategies [13,39] and wildlife strike outcomes [40–42]. This super-cluster consisted of 257 articles and other documents.

As noted above, industry papers were absent from the Web of Science results. To complete our literature review, we searched the proceedings of foremost industry conferences and fora for relevant

 doi:10.20944/preprints202504.1888.v1

material. After reviewing the indexes of the IBSC/World Birdstrike Association (WBA), the North American Bird Strike Conference, and the Australian Aviation Wildlife Hazard Group (AAWHG) Forum, we collated a catalogue of 542 documents.

3. The Evolution of Wildlife Hazard Management

The management of wildlife strikes tends to fall under the business activity of wildlife hazard management, a systemized business activity often undertaken by but not necessarily exclusive to an airport operator [43]. While wildlife hazard management could be considered broader than just the impact on aviation from wildlife strikes, the literature tends to equivocate and define these terms in a one-to-one relationship or to use them interchangeably.

For example, the Airport Services Manual, the International Civil Aviation Organisation's (ICAO) primary source of guidance on the subject, defines wildlife hazard, in general terms, as "the presence of wildlife (i.e. birds and other animals, both wild and domestic) that could result in damage to aircraft" [44] (p. 1-1). Yet, the subsequent discussion focuses on historical wildlife strike events before explicitly tying together the two concepts with the statement that the "objective of wildlife hazard management at aerodromes is to reduce the risk of a wildlife strike" [44] (p. 1-2).

Wildlife, as a term for all animals, including feral and domesticated specimens, can impact aviation in various ways. Therefore, we began by reviewing the definitions of important terms. Scheer et al. [45] noted a significant issue in risk communication regarding distinctions between hazard and risk. They outlined research examining how the use of each word impacted the management approach taken by different organizations and how they communicated, often depending on the circumstances. As an example, regulatory bodies would use the terms interchangeably when talking to the public but distinctly when communicating with professionals. Scheer et al. [45] also noted that the term used when describing the management strategy also influences the approach aims.

When hazard management is used, the management strategy leans towards "rigorous limiting" [45] (p. 1272) of the hazard without considering exposure to or severity of harm. It is easier to understand and communicate these concepts over a risk-based approach. Risk management requires a deeper analysis of exposure and impact stemming from the hazard. Scheer et al. [45] posited that "the large majority of people do not fully understand the process and results of risk assessment" (p. 1272).

So, do these observations apply to the concept of wildlife hazard management? Our answer is no. A significant amount of wildlife hazard management research is devoted to risk assessment methodologies, including Allan [46], Dolbeer et al. [47], Zakrajsek and Bissonette [32], Shaw [48], Paton [49], Pfeiffer et al. [50], and DeVault et al. [51]. These risk assessment techniques provide structures for wildlife hazard managers to undertake that deeper analysis involving severity of harm, exposure and probability. As such, wildlife hazard management is generally approached from a risk-based perspective. We then explored the natural follow-up question: are impact assessments limited to wildlife strikes?

As with any hazard, wildlife, as a "source of potential harm" [52] (p. 3), can realize that harm in more ways than just wildlife strikes. We found the following examples of non-strike-related harm in the literature. House et al. [53] detailed their research on the impact of keyhole wasps on aircraft through blockages to pitot tubes. Their analysis described a 2013 incident involving an Airbus A330 that declared a Mayday due to airspeed discrepancies. An investigation found sand and mud deposited by wasps blocking a pitot tube. Bridgman [54] observed bird nesting activities during his career in the Royal Air Force. He discussed the difficulty in removing found nests and noted that some nests could impact flight safety. However, he reported that he could not find any records of accidents attributed to this hazard. Solman and Thurlow [55] detailed aerodrome damage by mammals, including flooding caused by beavers and noted that "failure at a critical phase of landing could cause a serious hazard" (p. 109). Finally, Marcus [56] reported on the impact on aviation from wildlife infiltrating aircraft with the diversion of an AirAsia flight due to a stowaway snake in

 doi:10.20944/preprints202504.1888.v1

Malaysia. The airline cited safety as its top priority when deciding to divert. The report also referenced other snake-related events, including a smuggled cobra biting the hand of the smuggler in 2012 and a stowaway python in 2016.

To identify research that discussed wildlife hazard management without a focus on wildlife strikes, the literature catalogue was filtered for titles that included the words hazard and management. The resulting list contained 67 documents (including one podcast). Nine documents that related to the general topics of risk management, safety management systems, and land use management were excluded, as was one document on wildlife research that merely occurred on an airport.

Of those documents left to be examined, sixteen referenced wildlife strikes in the title. Further analysis found that, when discussing the hazard posed by wildlife to aviation, all but one of the 41 remaining documents referred to wildlife strikes as the primary focus of the problem. These documents covered a range of research topics and purposes, including wildlife hazard management [57,58], wildlife risk assessment [34,47,50,59], habitat management [60–62], case studies [63–65], avian radar technologies [66–68], and regulatory guidance [69–73].

The close relationship between wildlife hazard and wildlife strike can be exemplified by a quote from Davis et al. [59], who, in reviewing the wildlife hazard extant at a proposed airport site, state that "the final goal of the exercise is to reduce the risk of bird-strikes to aircraft" (p. 5). However, to explore this paper's contention further, we examined the one paper that bucked this trend with a view to identifying key issues with the current approach to wildlife hazard management and research.

4. Challenges Associated with Wildlife Strike Reporting

As a summary of issues resulting from not having a set of standard requirements for wildlife hazard event reporting, Eekeren [14] made a strong call to action on the need for common definitions of wildlife hazard events. He identified confusion regarding regulatory triggers following wildlife strikes, legal liability disputes and miscalculation of wildlife risk, as potential issues with incomplete and inconsistent definitions. Discussions between conference participants highlighted frustrations with previous industry-based attempts to address this issue.

Unfortunately, these were not new issues. Dekker and Buurma [74] raised the importance of definitions and conventions in their discussion on mandatory reporting. Their concerns included whether non-avian strikes would be included and if there would be a minimal impact threshold for reporting. They suggest an expectation that agreement on these issues would be reached as a matter of course. Eekeren [14] indicated that little progress has been made.

The following sections will discuss some of these issues as they appear in academic and industry literature.

4.1. More than Just Wildlife Strikes

The sole exceptional document referred to above as taking a broader approach to wildlife hazard is Mendonca [75]. In their analysis of safety management system principles, as they applied to wildlife hazard management, they consistently used the word "hazard", which, while defined with significant reference to wildlife strike scenarios, also included "incidents where the presence of birds on or around the airfield has any effect on a flight whether or not evidence of a strike can be found" [75] (p. 8). Here, Mendonca [75] combined the definitions for three categories of wildlife incidents established by the IBSC [76], which noted that such incidents are also "potentially dangerous" (p. 14) and do not necessarily involve a wildlife strike.

Mendonca [75] supported the addition of non-strike events with reference to Heinrich and Granniss' safety triangle and the benefits of investigating near-miss events [77,78]. These considerations often conjure the image of an iceberg with the visible portion above the water representing the reports we receive but the bulk of the "problem", near-miss events and hazard reports, sits below the surface and hidden.

 doi:10.20944/preprints202504.1888.v1

Swissair were capturing near miss event reports as early as 1978 but were not using them in their statistical analysis [79]. Klope et al. [80] examined the role of near-miss wildlife event reports further and highlights that, on any given airport, wildlife strikes are underreported and de-coupled from management actions. This makes them insensitive to changes in the environment that may precede wildlife strike events. The authors propose the "augmentation" [80] (p. 213) of wildlife strike data to provide the granularity required to manage wildlife hazards.

Despite this research and guidance for US operators to report near-misses that have a negative effect on flight, the latest report analyzing the data contained in the US National Wildlife Strike Database only discusses negative effect on flight in relation to wildlife strikes [81]. Likewise, Smallie and Froneman [82] described the approach taken at South African airports as incorporating the non-collision negative effect on flight concept in their definition of bird strike, but subsequent discussion appears to omit these reports as such reports are not even assign a bird strike level.

This suggests further work is required to define and support the reporting of non-collision wildlife hazard events.

4.2. Potential Tunnel Vision on Success

While wildlife hazard mitigation is a multi-pronged endeavor, McKee et al. [58] explain that the prevailing airport-centric approach of attempting to establish a wildlife exclusion zone around airport is flawed. They advocate for separation of aircraft and wildlife, and they recommend greater involvement of Air Traffic Control (ATC) in this strategy.

Such a strategy was developed by Metz [83] as an air traffic control advisory system designed to prevent wildlife strikes (bird strikes, in particular). Through fast-time simulation, they showed that the introduction of an advisory system could prevent a significant percentage of wildlife strikes [84]. In the real-world, such a positive impact would likely register in existing systems as they focus on wildlife strike events.

Metz [83] acknowledges that the safety benefit must be weighed against airport capacity, delays and, eventually, costs. Their analysis, again through simulations, shows that delays would fall within acceptable limits and that the costs would be outweighed by the costs saved from prevented wildlife strikes.

These results are encouraging from a feasibility point of view, but real-world tracking of these factors would not be possible under the current system. Instead, aerodrome operators may identify the reduction in wildlife strikes and curtail wildlife control measures as the advisory system carries the weight of the wildlife hazard management program. Aircraft operators would register an increase in costs after the changes have come into effect, and much like tracking wildlife strike events, this would be too late. This scenario further supports the need for consistent and standardized reporting of non-collision or wildlife avoidance events.

4.3. Impact on Wildlife Risk Assessment

Eekeren [14] specifically mentioned that differences in definitions can the impact on risk assessment techniques used by wildlife hazard managers. At least two of the most prominent risk assessment methods utilize percentage of damaging and/or negative effect on flight strikes as indicators for the potential risk severity for specific wildlife species. Allan's [33,46] model and the Dolbeer et al. [47] Relative Hazard Score (RHS) approach both consider the portions of total strikes resulting in an adverse outcome and, through different methods, calculate a severity/impact score to be used in further risk assessment.

If the basis of reporting changes, the results from these techniques will also change. Allan et al. [12] found this when they revisited the Allan [33] risk assessment matrix after the introduction of mandatory bird strike reporting in the United Kingdom. The data showed that increases in reporting rates of non-damaging strikes had caused an apparent increase in risk which could cause airport-based wildlife hazard managers to invest resources into managing unnecessary species.

 doi:10.20944/preprints202504.1888.v1

Allan et al. [12] also noted that reporting culture, differing reporting requirements, and varying application of existing requirements meant that risk analysis using similar techniques needs to be undertaken on a national basis using its own data. This would pose a challenge for smaller countries with limited data and those looking to benchmark against other countries.

5. The Use of Wildlife Strike Data in Research

When outlining the impact of wildlife on aviation and to justify the research being reported, most authors will employ wildlife strike report data in one of the following ways.

The historical justification involves detailing early and/or significant wildlife strike events using, primarily, the work of Thorpe [85–88], who has provided a detailed account of "all known fatalities and destroyed aircraft" (p. 1). This work has been carried on by Shaw and Dolbeer [89], while Richardson [90,91] and Richardson and West [92] collated similar summaries for military aircraft. Wildlife hazard researchers using this approach, such as MacKinnon [70], Cleary and Dolbeer [71], and Viljoen and Bouwman [93], will mention the first recorded wildlife strike from 1905, which involved Orville Wright, while other researchers, such as Dolbeer [94], McKee et al. [58], and Tatlier and Baran [95] describe the first fatal wildlife strike that took the life of celebrity pilot Cal Rodgers, who was also flying a Wright Flyer.

Historical data from Thorpe [85–88], Shaw and Dolbeer [89], Richardson and West [92] and other sources are also summarized to form a safety-based justification. The safety-based justification is typically constructed as the total number of human fatalities and aircraft destroyed over the period described in the relevant source. Examples include Rochard [69], Swaddle et al. [96], and Jeffery and Buschke [97]. The current total stands at 534 fatalities and 618 destroyed aircraft [89].

A relatively recent variation of the safety-based justification uses a well-known significant event as justification in its own right. An example of this is the January 2009 wildlife-strike-induced ditching of American Airlines flight 1549, known as the "Miracle on the Hudson" [98]. While authors such as Hesse et al. [64], Martin et al. [99], and Chen et al. [66] use this event as justification for research into aerodrome-based management practices, it is important to note that during a public hearing on this accident, a Federal Aviation Administration (FAA) representative advised that the location and altitude of the wildlife strike fell "well outside the area expected to be covered by the LGA (aerodrome's) WHMP (Wildlife Hazard Management Plan)" [100] (p. 26).

As most recorded wildlife strikes do not lead to catastrophe, they have been used in various forms to create statistical justifications. Authors have used the total number of reports [48,101], the percentage of reports indicating damage [102] and the general increasing trend in reporting rates [103] to provide background for their research. With respect to making a statistical justification, research showing that wildlife strikes are generally underreported [104,105] could be considered a positive as the accurate scale of the problem is likely to be larger. However, the phenomenon has a negative effect when wildlife strikes are used in risk analysis.

Also born out of non-catastrophic wildlife strike events, costs associated with wildlife strikes have also been used as an economic justification. For worldwide civilian aviation, the most quoted figure is a conservative US$1.2B calculated by Allan [106] and used by authors like Allan et al. [107], Dolbeer and Wright [108] and Metz et al. [13]. Research focusing on United States civilian air traffic tends to use annual FAA/US Department of Agriculture - Wildlife Services (USDA-WS) reports [81,109] and can be seen in the work of DeFusco [110], Barras and Seamans [111], and DeVault et al. [102]. More recent research into estimating costs has focused on barriers to capturing such information [112] and machine learning analysis of existing wildlife strike data [41,42].

6. International/National Standards & Guidance

As an international endeavor, the regulatory system surrounding aviation is substantial and complex. In the aftermath of World War II, the international community understood that aviation was essential to global harmony and a threat to security. They sought to cooperate in the development

 doi:10.20944/preprints202504.1888.v1

of standards and recommended practices that promote safety, order, equality, and sound economics [113]. Wildlife hazard management has been included in these standards and recommended practices and guidance material for over five decades.

Despite the expectation that ongoing obligations on states should be published in annexes to the Convention on International Civil Aviation [113], as early as 1965, ICAO, via various State Letters, requested bird strikes involving aircraft be reported [114]. This expectation has since been incorporated into Annex 14 – Aerodromes [8] along with several other wildlife strike hazard reduction specifications. Initially, as a recommendation and now as a standard, signatory states are required to establish a reporting system for wildlife strikes as a means of assessing the wildlife hazards on and around the aerodrome [44,115]. States must also collect and forward wildlife strike reports to ICAO for inclusion in the ICAO Bird Strike Information System (IBIS) and to take action to decrease the risk of collisions between wildlife and aircraft [44].

These provisions firmly place the emphasis of hazard management and reporting on wildlife strikes as actual collisions. The IBIS Manual [116], being of a similar era to these specifications, aligns closely with this approach, stating that "reports should be submitted only when a bird strike has actually taken place" (p. 4) and that "occurrences of birds flying near aircraft should not be reported" (p. 4).

But later guidance material developed by ICAO sought to broaden the scope of wildlife hazard event reporting. Doc 9981 – Procedures for Air Navigation Services – Aerodromes [117] uses the phrase "wildlife strike-related events" when outlining accident and serious incident as well as IBIS reporting requirements. This document also establishes expectations for aerodrome operators to have procedures for recording, analyzing and reporting wildlife incidents. It also expects WHMPs to contain procedures for collecting, reporting and recording wildlife strike and observation data and to warn aircraft operating on or nearby the aerodrome of wildlife hazards. However, it should be noted that the wildlife incident reporting criteria established in Appendix 2 to Chapter 6 [117], is focussed on wildlife strike reporting only.

In the newer Doc 9137 – Airport Services Manual – Part 3 – Wildlife Hazard Management [44], the objective of wildlife hazard management is established as wildlife strike risk management and then defines a strike in collision terms. And yet, it then expands the scope of recordable events to include occurrences where the presence of wildlife could have a negative effect on a flight.

There may, however, be a difference between reportable and recordable events. This document describes recordable events as being reported to the aerodrome operator, but whether they are to be reported to the National Aviation Authority (NAA) and/or the IBIS is unclear. It expects wildlife incidents, which may or may not include the events above, to be reported per the aerodrome operator's national incident reporting regulations. Relevant guidance to national aviation authorities merely repeats the requirements of Annex 14.

Given the numerous references to incidents above, it is necessary to consider Annex 13 – Aircraft Accident and Incident Investigation [118], which defines incident in tandem with accident and serious incident as follows:

- An accident is an event involving the operation of an aircraft that results in the death or serious injury of a person, the aircraft sustains significant damage or the aircraft is missing. However, this definition excludes specific types of damage resulting from a bird strike.
- A serious incident is a situation that had a high probability of being an accident.
- An incident is any other type of occurrence that affects or could affect safety.

Finally, we explored the topic of safety reporting within the ICAO Safety Management System (SMS) framework as described in Annex 19 – Safety Management [119]. This model establishes a much broader concept of safety reporting, and yet, the details of these specifications describe a system geared towards incident reporting separate from mandatory reporting requirements to a national aviation authority. They also include the collection and analysis of a wide variety of safety data, which, for aerodrome operators, could include inspection records, risk assessment results and voluntary reports [120].

 doi:10.20944/preprints202504.1888.v1

However, ICAO SARPs and guidance material do not directly impose a legal obligation within any specific state or operator. States, either through their national aviation authorities and/or independent safety bodies, establish national regulations on topics such as wildlife hazard management and event reporting. The following paragraphs will detail the approach taken by the United States, the European Union and Australia.

At a regulatory level, the United States has created the obligation to monitor wildlife strikes as a potential trigger for formal wildlife hazard management processes [9]. Further details on wildlife strike reporting are contained in advisory material with the national reporting system considered voluntary [121]. The FAA [121] did, however, define two aspects of a wildlife strike in detail.

Firstly, a wildlife strike should be reported if it involves a bird, a bat, a terrestrial mammal larger than one kilogram or a reptile larger than one kilogram. Secondly, a strike is deemed to have occurred when:

- someone witnesses a collision between wildlife and an aircraft;
- there is evidence on an aircraft, including damage, of a collision with wildlife;
- the remains of wildlife are found either on or near a runway, on a taxiway or anywhere else near an aerodrome where there is no other explanation for the animal's death, or a collision is suspected; or
- wildlife on or near an aerodrome have had a "significant negative effect on a flight" [121] (p. 3).

Within the European Union aviation regulatory system, aerodrome operators are required to minimize wildlife collision risk, including having procedures to record and report wildlife strikes and to use this data in their wildlife risk assessment [11]. Aircraft operators and air traffic service providers must also report wildlife strikes [122]. There was no specific definition provided for wildlife strike nor any commentary on the reporting of suspected wildlife strikes or other wildlife hazard-related events.

The European air navigation service provider Eurocontrol has defined a wildlife strike as a collision between an animal and an aircraft either in flight, taking off, or in the landing roll [123]. They also suggested that incidents where a collision is "narrowly avoided" should be reported [124].

In Australia, aerodrome operator regulations and standards have established the requirement for a wildlife hazard management system [125] and the monitoring of wildlife strikes on or near the aerodrome [10]. The requirement to report wildlife strikes that do not result in an air accident can be found in a different set of regulations [126] and establishes that collisions with animals involving air transport operations or that occur on certified aerodromes as routine reportable matters.

This analysis shows variations in the specificity and scope of reporting requirements, especially where evidence of a collision is limited or a collision was narrowly averted. This is not surprising given that international standards and guidance span multiple documents written over a thirty-year period.

Even beyond the weight and momentum behind wildlife strike reporting as a regulatory and academic standard, the process of amending ICAO standards is complex and time-consuming. While the ICAO development and amendment process offers a range of methods for proposing changes and new material [127], all proposals must be approved by the Air Navigation Commission (ANC). The ANC reviews such proposals in consideration of its Work Programme and judiciously assigns Job Cards to the relevant Panel [129]. The relevant panel, in the case of wildlife hazard management, the Aerodrome Design and Operations Panel (ADOP), then seeks experts to contribute their time to actioning the proposal laid out in the Job Card.

However, the standards development process at ICAO is slow [128]. The International Federation of Air Traffic Controllers' Associations (IFATCA) [127] notes that this process may take up to five years. However, there are examples of Job Cards taking much longer. The review of Obstacle Limitation Surface (OLS) standards commenced in 2013 and was only finalized a decade later [130]. Even after this, the process may take another two years for the final amendment to become applicable [127].

 doi:10.20944/preprints202504.1888.v1

The role of guidance material in this system is to support the application of standards and recommended practices [131]. Yet, where specific provisions of the Chicago Convention obligate contracting States to adopt the standards and recommended practices produced by ICAO, States may not incorporate guidance into their national legislation [132]. Nonetheless, guidance material can be considered easier to produce and amend under the expectation that this material, typically contained in technical manuals, is updated regularly [131]. Although Salih [131] also identifies areas where such material has become obsolete.

Only one of the ICAO documents discussed above, the IBIS Manual, was published or updated more than ten years ago. This document was recently reviewed with an update expected to be delivered by the end of 2023 [133]. But despite the modernization of these supporting documents, do their inconsistencies and stagnant foundation, a standard rooted in a 50-year-old letter, best serve the industry today?

7. Conclusions

Under the broadest view of hazard, wildlife present a complex and continued risk to aviation safety. While wildlife can interact with the aviation system in a variety of ways, collisions between animals and aircraft are the predominant concern for the industry. Previous research has established the nature and, in some cases, quantum of the wildlife strike problem. Yet, a holistic, systemic approach to hazard management calls on safety professionals to look beyond the ultimate manifestation of the hazard. Near-miss and other related events may provide as much actionable context and information to wildlife hazard managers as they do other safety managers.

The literature review above shows a dynamic and diverse sub-industry of professionals of varying stripes and academics working to develop structures that support analysis and intervention. The history of this sub-industry shows its pragmatic approach to managing what has been measured, wildlife strikes. Advances in systemized safety and hazard management have made inroads into the field with the adoption of wildlife hazard management practices becoming the norm.

However, the research and regulations still focus on the occurrence of wildlife strikes as the primary performance measure. The discussion above highlighted three areas where this focus may not lead to optimal outcomes. Near miss events may not be given their due and the avoidance of strikes may lead to unintended adverse effects on operations. These and other effects also impact broad risk assessment methodologies which could mask underlying, latent conditions.

For the most part, ICAO's guidance material has been keeping pace with industry advancements. But the basis for wildlife strike reporting remains the standard established in the 1970s. Standards compliance is the obligation on contracting States and the short analysis above showed variation between major regulatory systems where guidance material provisions were involved.

If these inconsistencies are to be resolved, the industry might have to establish a consensus before approaching ICAO to revise the standard. The resource limitations that drive ICAO to manage their Work Programme closely must be overcome with clear evidence that there is a need for change. Academia has a role to play in supporting efforts to build and show consensus on such issues through robust methods and engagement with the industry.

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Abbreviations

The following abbreviations are used in this manuscript:

AAWHG	Australian Aviation Wildlife Hazard Group
ADOP	Aerodrome Design and Operations Panel
ANC	Air Navigation Commission
ATC	Air Traffic Control
ATSB	Australian Transport Safety Bureau
FAA	Federal Aviation Administration
IBIS	ICAO Bird Strike Information System
IBSC	International Bird Strike Committee
ICAO	International Civil Aviation Organisation
IFATCA	International Federation of Air Traffic Controllers' Associations
NAA	National Aviation Authority
OLS	Obstacle Limitation Surface
RHS	Relative Hazard Score
USDA-WS	US Department of Agriculture – Wildlife Services
WBA	World Birdstrike Association
WHMP	Wildlife Hazard Management Plan

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