Risk of bird strikes

A discussion of current tools and practices

Ove Njå, Pål Ranestad, Geir Sverre Braut, Rodney Fewings and Espen Kurthi

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Abstract

Bird strike risk assessments have up to now been the responsibility of airport operators establishing risk pictures at the airport and in the close vicinities. The major goals have been to address concerns and identify mitigation measures designed to reduce the risk of conflicts. Criticisms have been raised: 1) the methodologies employed are not risk analysis, 2) there is a decline in the number of safety proposals being put forward; 3) proposed solutions are sub-optimalizations which have served airport operators poorly over time.

This paper reviews the literature on risk assessment and risk management related to the bird strike phenomenon. Bird strike mitigation is special to the air industry because there are no internationally agreed regulations that provide general solutions to the problem. This regulatory deficit should not necessarily be taken as an obstacle to developing safe practices. Rather, it calls upon the practitioners responsible for safe management of airfields to continuously develop and implement procedures based upon best available knowledge. Bird strike regulations can only set out general provisions by virtue of the fact that there are so many variables. Bird strike risk must be based on local conditions, taking into consideration the biological variety in habitats, environmental conditions, air traffic and wildlife patterns in general and the bird stock and migration in particular. This makes the use of risk modelling tools an interesting approach.

However, it is necessary to take into consideration the actors involved, the values exposed to bird strike and the frames of decisions and alterations that might benefit from bird strike risk models. Risk analyses only serve as decision support tools, and our evaluation of different risk assessment methodologies is based on the prerequisites of suggested decision arenas.

Introduction

The IBSC

The International Bird Strike Committee (IBSC) was established in 1966 as the Bird Strike Committee Europe. The aim of the committee was to “improve commercial, military, and private aviation flight safety, by sharing knowledge and understanding

University of Stavanger, N-4036 Stavanger, Norway

concerning the reduction of the frequency and risk of collisions between aircraft, birds and other wildlife" (IBSC web). By enabling all sectors of the civil and military aviation industry to link with biologists and bird behaviour specialists, the IBSC was in a position to publish lists of recommended practices. Papers from 29 meetings have been made available on the Internet and influence has been brought to bear on rule makers and relevant authorities. Over the years, people from outside Europe attended and presented papers at the conferences. In 1996 it was a natural development to change the name of the committee to IBSC (Thorpe, 2012b).

Birds and other wildlife strike aircraft in large numbers globally, but the risk varies with local conditions in and around the specific airfield. The vast majority of reported bird strikes have little or no impact on continued safe flight. However, the risk associated with bird strike collision and bird ingestion by engines has become higher with the increase in flights, the population increase of some species, and an increase in the numbers of larger and quieter modern jet aircraft, with their greater speed. An overview of this topic has previously been given by Raulot (2009). The major concern is collisions with animals that could damage safety critical equipment: engines, wings, radome and windshield. Bird/wildlife incidents are classified under three headings (2006):

Confirmed strikes:

- Any reported collision between a bird or other wildlife and an aircraft for which evidence in the form of a carcass, remains or damage to the aircraft is found.
- Any bird/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.).

Unconfirmed strikes:

- Any reported collision between a bird or other wildlife and an aircraft for which no physical evidence is found.

Serious incidents:

- Incidents where the presence of birds/wildlife on or around the airfield has any effect on a flight whether or not evidence of a strike can be found.

Experience has shown that damage from birds and wildlife collisions has resulted in major change-outs and repairs.

IBIS – an international safety information system

The ICAO Bird Strike Information (IBIS) database encompassed in the period 2001-2007 reporting from 51 nations (Wang, 2011). Bird strikes were reported to have occurred in 145 states or territories, mainly North-America and Europe. Most of these strikes occurred during daylight, and between April and September. Take-off and climb, together with approach and landing/roll out were identified as the flight phases in which the reported bird strikes predominantly occurred. The extent of damage to aircraft was coded for 27 937 bird strikes, comprising approximately 66 per cent of the total number of strikes reported. The resulting records show that three aircraft were destroyed, 753 (3 per cent) of the bird strikes caused substantial damage to the aircraft and 2 120 (8 per cent) caused minor damage. 10 per cent of the bird strikes had an effect on flights, such as aborted take-off and precautionary landings, engine shut downs. The reported damage was related to the front of the aircraft (45 per cent), engine, wings and landing gear (Wang, 2011). Some examples:

- A herring gull (Larus Argentatus) was ingested by a B737 engine during take-off at Tromsø airport in October 2008, which resulted in engine shut down and a precautionary landing, after circling in mountainous terrain. The consequences were costly: engine replacement, aircraft out of service and passengers delayed.
- A hull loss was experienced when a US Airways A320 landed in Hudson River after a bird strike during climb after departure from LaGuardia Airport in January 2009 (Marra et al., 2009).
- During take-off from runway 18L at Amsterdam Schiphol Airport a Boeing 737-4B6 heading for Morocco collided with a flock of geese, which resulted in serious damage to the left engine. The aircraft had limited climbing capability and the crew decided immediately to return to the airport. The aircraft flew low over the built-up area of Vijfhuizen, Haarlem and the western harbour area of Amsterdam and passed a number of high obstacles. It eventually landed safely, and no passenger sustained any injuries (TDSB, 2011).
- Seven minutes after take-off from Amelia, Louisiana, a Sikorsky S76C ferrying oilfield workers to an oil platform in the Gulf of Mexico hit a red-tailed hawk. Both left and right sections of the windshield had shattered after the hawk had struck the canopy just above the top edge of the windshield. The helicopter crashed and was partly submerged in marshy ground, eight people were killed and one sustained serious injuries (Thorpe, 2010, 2012a).

A bird strike reported during landing at a remote airport may result in an aircraft inspection, delayed by the unavailability of a qualified aircraft inspector. An example is the small but important Stokkmarknes Airport which was closed for almost a week during a snow bunting invasion at the airport. Bird strikes cost, whether the physical damage to aircraft is minor or major. In addition, the risk of human loss is always present and is the most important motivating factor for developing mitigating measures.

Major issue for the study

Every airport with its surroundings is unique and there is thus a need to understand the role of local conditions in the safety management of wildlife. Types of birds present at airports will vary with the environment and time of year. Manmade attractants to birds are present at some airports (fish industry, landfills, farms etc). Migrating birds follow different routes, which may conflict with aircraft routes. There are major migration routes from east Europe to Africa, passing the Middle East, resulting in huge numbers of birds northbound or southbound twice a year. All these hazards call for tailor-made risk assessment procedures to adapt risk mitigation activities to the actual needs and challenges identified. Over the last decade or so there have been various approaches to risk management in this area, but not necessarily systematically conducted:

> "Formal risk assessment is now routinely used in almost all aspects of health and safety work. Bird/wildlife strike prevention has tended to lag behind in this field because the involvement of birds and other wildlife (creatures whose behaviour can vary hourly, daily and seasonally, and whose populations can fluctuate over longer periods) as a key component of the system being assessed makes it difficult to accurately predict risk levels. Techniques are now available that make use of the frequency that each species is struck, combined with probability of aircraft damage for that species, to calculate risk levels for a particular airport. These allow risk assessment matrices to be constructed and updated annually in order to evaluate how the risk level is changing in response to the bird management measures in place." (IBSC, 2006, p. 16)

Over the past 10 years risk analysis tools have been developed for bird strike assessment, generally on a commercial basis and common to all safety and risk management practices in various sectors. However, this area is new and the needs and conditions throughout the global population of airfields are rather unclear. We therefore raise two questions related to observed practices, which we address in this article:

1. Are today's bird strike risk assessment approaches efficient tools as a basis for the safety management of air traffic close to airports?
2. How can credibility be increased in a framework of sound scientific theory?

The paper is organised as follows: Firstly we elaborate on the most important concepts applied in risk assessments. Secondly, we discuss the premises for adopting risk assessment methodologies. Thirdly, an analysis of relevant documents is provided in order to reveal trends and basic assumptions. Finally, the concluding discussion outlines future risk-informed strategies in the control of wildlife and bird-strike hazards.

The concept of risk and associated decisions

Accident and incident statistics can be used to monitor risk and safety levels, give input to risk analyses, identify hazards, analyze accident causes, evaluate the effect of risk-reducing measures and compare alternative areas of work and measures. We have seen useful applications of accident statistics to all of these items, but we have also seen many examples of poor use and misuse. There are many pitfalls when dealing with accident statistics, and there is often a higher ambition for using such statistics than is realizable. One main challenge is related to the understanding of historical data when the *future*, that is the *risk*, is the point in focus.

Risk – foundational issues

Risk is often interpreted as an inherent property of the world (the air transport system including airport, aircraft, ATC, wildlife, surroundings and other relevant attributes). Matrices, aggregations and non-dimensional quantifications are usually employed to express the risk results. Traditionally, risk analysis produces risk estimates $P^*(A|K)$, where A could be a bird strike event or an outcome quantity of interest and K is the background information. The tendency seen in the research is that the background knowledge K rests on wildlife observations (airport characteristics, population, environment etc.) and accident/incident statistics. Other sources of information, such as expert judgements, specially designed studies, local knowledge, deficiency reports etc. are to a large degree omitted as background data and recommended considerations. Thus, very little is left to the analysts themselves. This is a traditional risk perspective, which is vital for how risk is understood and applied in risk management.

The traditional approach to risk and risk analysis is based on the idea that risk exists objectively, and risk analysts see the analysis as a tool for producing estimates of this objective risk. Objective risk is expressed by probabilities and expected values. A probability is interpreted in the classical statistical sense as the relative fraction of times the events occur if the situation analyzed were hypothetically "repeated" an infinite number of times. To estimate the risk, models are often introduced.

An alternative approach to interpreting risk is by considering observable quantities such as the occurrence of bird strike events, the number of bird strikes, the movements of geese etc. In this approach it is "the world" that comes first, then uncertainties about what the world might be and finally our uncertainty about these quantities, whereof parts could be expressed by probabilities. The traditional approach puts probability first. Say that we study the risk of bird strike at Stavanger airport. Should we then focus on the future performance of the airfield, expressed for example by the occurrence or not of selected bird strike events, or should we seek to estimate the average performance of an infinite population of similar airports to the one studied? If you choose the latter approach, you will have a hard time specifying what you mean by this population of similar airports. Does it mean the same design specifications, the same traffic regulations, the same topography, the same air traffic management, the same type of personnel positions at airport ground level, the same influence of exogenous factors, etc? Something must be different, because otherwise we would get exactly the same output result. So we should allow for variations in airport maintenance quality, air traffic loads, human behaviour, etc. But the question is to what extent we should allow for such variations. For example, in human behaviour, do we specify the safety culture or the standard of the private lives of the personnel involved in the airport management, or are these to be considered as factors creating the variations from one airport to another? It is clear that we will have problems specifying the framework conditions for the "experiment" and the stochastic variation. In practice we seldom see such a specification, the framework conditions of the "experiment" being tacitly understood. It is not obvious how to make a proper definition of the population. We recognise that the concept "similar" is intuitively appealing, although it can be hard to define precisely. The main problem with the classical approach is however not this concept but, as stated above, the fact that risk is a constructed quantity that focuses on the wrong area, on measuring fictional quantities.

The essential feature of the Bayesian approach (the alternative) to risk analysis is that probability is a measure expressing uncertainty about the world (i.e. how a system or activity performs) seen through the eyes of the assessor and based on some background information and knowledge. Complete knowledge about the world does not exist, and the analysis provides a tool for dealing with these uncertainties based on coherent use of the rules of probability. If sufficient data become available, consensus on probability assignment may be achieved but not necessarily, because there are always subjective elements involved in the assessment process. Statements concerning risk should be seen as judgemental, not factual. Professional risk analysts do not have the exclusive right to describe risk.

As presented above, we consider the predictive approach to risk analysis, focusing on observable quantities such as the number of bird strikes, and we sometimes use probabilities to express our (the analyst's) uncertainty about what values the quantities will take. Fictional probabilities are not introduced. Accordingly we do not introduce a thought-constructed population of similar airports, but assign a probability distribution of numbers of bird strikes at Stavanger airport next year, using all relevant information. In some cases we could also develop models, such as fault trees, to assign the probabilities. The models are tools for expressing the uncertainties about the observable quantities. They are a part of the background information that the probabilities are conditioned on.

Closely related to the discussion above is the interpretation of performance related to bird strike risk-reducing measures. How shall we express and interpret performance? Again we need to identify observables, such as: will the measure be there when it is needed, what is its capacity, how long will it last and finally will it continue to deter with time? These measures are uncertain and they will depend on the different contexts (wildlife and environmental exposure, manmade activities, etc.) and the assessors' knowledge included in the assessments.

Risk results to support decision making

Of course risk and performance analyses are not carried out for their own sake but because the tools are thought to be important contributors to critical decisions. Such decisions may be closely linked to the concrete mitigation of bird strike risk at existing airports or they could be part of planning processes for the development of the airport and surrounding areas. Today bird strike is considered to involve influence areas in a radius of 13 km around the airport borders. We begin here by addressing risk assessments as part of airports' risk management strategies. Then we distinguish between two major decision categories: strategic decision making and operational decision making. Even though these categories are closely related there are also fundamental differences. We elaborate on some decision typologies as well as inherent prerequisites from normative decision theories.

Strategic decision making

Strategic decision making can be seen as the overall management of bird strike risk, encompassing the design and location of the aerodrome, development of aerodrome, the redesigning and optimization of surroundings with respect to hazardous species, choice of permanent preventive mitigation measures, training programmes, choice of bird control management plan (BCMP), and the prioritizing and provision of necessary resources to maintain bird strike risk awareness. The decisions would involve the aerodrome manager and his/her institutional system. Under current aerodrome licensing conditions, the paperwork chain requires the preparation of a safety management manual (SMM) to cover all aspects of aerodrome operations. This would be based on the templates described in the ICAO manual but the latter is not specific about bird strikes except for noting that it is one of a number of operational areas to be considered. Therefore, the safety management of bird strike would be spelt out in the aerodrome SMM. The SMM would be the responsibility of the Operations Director who would report to the Aerodrome Manager / Board of Directors / CEO. The Operations Director would probably be responsible for negotiating the budget for bird strike mitigation and would therefore be responsible for deploying the appropriate resources and discussions with third parties. The aerodrome insurers might also have an impact on discussions on mitigation, especially if there is a known problem.

The bird control co-ordinator is an example of a role that the aerodrome manager might turn to regarding information and communication of bird strike risk assessments. The decision arenas employing bird strike risk assessments would in general be:

- Boardroom decisions
- Management meeting decisions
- Decisions in meetings with liaisons and land owners in the vicinity of the aerodrome

The prevailing basic assumption in risk management strategy is a rational expert-oriented process that employs risk analysis to measure safety levels (ISO, 2009). This strategy could be denoted instrumental rationality, based on the classical article of Edward Banfield (1959). We do not intend to elaborate on this strategy here, but will scrutinize bird strike risk approaches and how they relate to decision making.

Tactical decision making

Tactical decision making encompasses prioritized periodical events with a view to making plans based on risk assessments. It is about transferring risk models and assessments into the practical management of the aerodrome, and the bird strike control co-ordinator must therefore be able to comprehend the risk information and apply it to aerodrome operations. In this respect these tactical decisions must be based on communication with both the strategic and the operational level. Decision-making on this level includes the management/staff that surrounds the bird strike control co-ordinator. The decision arenas employing bird strike risk assessments would in general be:

- Airport flight safety committee
- Airport coordination meetings
- Airport operation meetings
- Meetings of the different working teams

These meetings could make decisions on seasonal precautions, targets for risk mitigation measures related to hazardous species, provision of information and warnings to ATC (pilots and airport staff) conditioned on ability to alert, situational awareness, collective mindfulness, etc.

Operational decision making

Operational decision making is the front line level for determining actions for implementing mitigation activities comprising monitoring, reporting, habitat management and site modifications, repellent techniques, etc. At this level too there is a need to be on alert, be aware of situations, interact with other operators and so on. The decisions are skill-based, day-to-day and hour-to-hour assessments, knowing when to transform a “blink” into a “wink”, meaning how to interpret signs and act to mitigate hazards. The decision making situation could be structured on the field, but mostly it will be non-structured and occasional and dependent on personal and organizational skills, cf. for example recognition-primed decisions (Klein, 1993), situation awareness and collective mindfulness (Weick, Sutcliffe, & Obstfeld, 1999).

Analysis of frameworks for bird strike risk management

Birds offer a variable level of risk to aircraft safety because they fly in large flocks or because of their individual size. For example, seagulls feed on small invertebrates found on farmland, aerodromes and landfill sites. Starlings usually fly in dense flocks of up to 100 000 birds. Large birds like ducks, geese and raptors are a risk because of their size. In Europe, Canadian Geese pose a high risk because they usually fly in flocks. In addition, their large size (2-7 kg) and their 3 to 4 metres in-flight separation increase the possibility of multiple engine strikes.

Below we analyze the regulation principles and risk assessment approaches found in a sample of articles and reports. The literature is analyzed in three aspects: the conceptualizations used, the analytical prerequisites, and the intended use. We have broken these aspects further down:

Conceptualization:

- Risk
- Performance
- Decision

Analyses:

- Models
- Data
- Assumptions

Use (analyses as decision support):

- Risk acceptance criteria
- Risk mitigation measures
- Decision making

We also describe our practical experience of using some of the tools available.

Regulation principles

At present it seems reasonable to claim that there are two different strategies used when approaching bird strikes in aviation from the regulatory side. The first strategy relates to the design of aircraft and technical components so that they become resilient and less vulnerable to such incidents. The second strategy is to reduce aircraft exposure to bird strikes. As the problem is mainly connected with take-offs and landings, this latter strategy concentrates on the particular conditions at specific airports.

The first strategy will only be briefly mentioned here. This strategy is built upon a fairly traditional approach to managing technical safety challenges and appears to be highly uniform at an international level. Regulators have had to consider engine and airframe certification standards to meet this risk. Manufacturers and engine builders have had to design their aircraft so as to make them more resilient to bird strike and engines more resilient to bird ingestion.

The aircraft certification process is intended to demonstrate that the aircraft and engines comply with the main criteria forming the resistance of the aircraft structure to the kinetic energy of a bird, a function of the mass of the bird and the square of the aircraft speed. For example, a 6.8 kg goose striking an aircraft flying at a closing speed of 200 knots may result in a force of 16 tonnes (cf. EASA and FAA). Current standards exist for both multiple and single bird engine ingestions into a single fixed wing aircraft engine. The criteria relate to fire, shut down aspects, thrust or power, and uncontained failure.

The second strategy is at present not so standardized as the first and will therefore be given more detailed comment here.

International requirements

The 5th edition of ICAO Annex 14 Aerodromes was published in 2009. Bird strike is included as a topic. It stipulates that the wildlife strike hazard shall be assessed and the annex describes, briefly, appropriate methodologies. Wildlife reports are to be collected and forwarded to ICAO for inclusion in the IBIS database. Furthermore, action should be taken to decrease the risk to aircraft operations, including the prevention or elimination of garbage disposal dumps in the vicinity of an airport. Lastly, States should give due consideration to aviation safety concerns related to land developments in the vicinity of the aerodrome that may attract wildlife (ICAO, 2011).

The ICAO Airport Services Manual (ICAO, 2011) gives guidance towards implementation of Annex 14. The document includes (a) organization of a national committee; (b) roles and responsibilities of a control programme; (c) how to organize an airport bird strike control programme; (d) classification of birds as a potential hazard; (e) environment management; (f) dispersal methods; and (g) staffing and land-use.

National requirements

The Norwegian situation will be used as a case to show how the bird strike challenge is dealt with by the national regulator and the governmental airport manager. The Norwegian situation we believe to be quite typical for several European countries.

Norwegian bird and wildlife management is briefly described by the Norwegian CAA (NCAA) in the "Bestemmelser for sivil luftfart" (Civil Aviation Regulations), BSL E 4-1 section 10 (based on Annex 14 9.4):

- The airport manager is responsible for collecting data on the occurrence of birds and wildlife, including conflicts between aircraft and birds/wildlife.
- The data shall be submitted to whoever the CAA decides appropriate.
- The airport manager is responsible for implementing measures, both operative and strategic, to reduce the risk of conflicts between aircraft and birds/wildlife, at the airport and in the approach and departure area.
- Strategic and operative measures shall be implemented in cooperation with the ATM, and the ATM shall be informed of any hazards introduced by birds and wildlife.

Restriction regulations with basis in the legislation have been developed for each airport, describing the responsibility of local airport managers to take into account the bird strike hazard in the area regulation processes.

The Aeronautical Information Circular, AIC-N 19/05 describes some further details, including references to the legislation relevant for airport operators, ATM and aircraft operators. This refers to ICAO and JAR-OPS.

Risk assessments are not explicitly described in the parts of the legislation describing the airports' responsibilities related to wildlife and bird hazard to aircraft. In addition, the regulations do not cover en route requirements related to bird strike risk.

On the other hand, the NCAA describes the use of risk assessments in another document, BSL A 1-9 section 10: The service provider (airport manager or ATC) is required to plan and execute the necessary risk assessments, to identify hazards. How to assess the hazard related to bird/wildlife-strikes is not described.

Risk assessment approaches

In this review we have selected the following resources: (Allan, 2000, 2006; Allan, Orosz, Badham, & Bell, 2003; Anagnostopoulos, 2003; Both, van Gasteren, & Dekker, 2010; DeVault, Belant, Blackwell, & Seamans, 2011; Ditlevsen, Christensen, & Hansen, 2010; Paton, 2010; Portland International Airport, 2009; Shaw & McKee, 2008; Sowden, Kelly, & Dudley, 2007; Witter, 2008), IBSC and Avinor experiences (Kurthi & Ranestad, 2011a, 2011b). A literature search in the data bases at the University of Stavanger suggests that the list could have been greatly extended. However, the resource list has been tested within the IBSC and found representative for the current thinking.

Conceptualizations

Risk

A variety of understandings of the term risk seem to have been employed in the bird strike community. Anagnostopoulos (2003) defines $Risk = Exposure \times Probability \times Severity$, but these quantities have not been further explored. The Geographical Information System (GIS) tool he presents applies the categories “Bird attributes”, “Surface Analysis”, “Attractants”, “Weather Conditions”, “Airport area” and “Airport Use”, with which no connection to the risk formula has been shown. Sowden, Kelly & Dudley (2007) also present a spatial framework for categorizing Risk Elements into “Aircraft Related”, Bird-species Related and “Land-use Related by Hazardous Species”, but they do not make clear either what to be understood by risk. Ditlevsen, Chistensen & Hansen (2010) advocate a simple risk assessment tool composed of three quantities; “Bird Species”, “Mobility” and “Distance to the aerodrome”. Their proposed scale for risk (-4,4) has not been substantiated in practice, and they advocate the use of comprehensive qualitative assessments of “other factors” as well. Paton (2010) recommends a semi-quantitative risk assessment tool in which probabilities are assigned to different sources related to “Abundance”, “Strikes” and “Other Bird Behaviours”. The consequence categories are developed from “Body Mass”, Flock Size” and “Flight Behaviour”. Again the intention is to provide airport and aerodrome operators with a simple method of documenting risk assessment. The Bird Hazard Index (BHI) presented by Both, van Gasteren & Dekker (2010) does not relate to any risk definition. The indicator is developed from historical data over a 15-year period on seven different military airbases. Similarly, Shaw & McKee (2008) have developed the Species Susceptibility to Strike (SSS) index, which is also a product of historical data and observations.

John Allans’s works (2000, 2006) have been influential on the current thinking about bird strike risk (Allan et al., 2003; Portland International Airport, 2009; Witter, 2008). He defines risks as “The probability that an adverse event will occur within a specified time period or as a result of a particular event or series of events” (Allan, 2000, p. 32). Allan thus clearly has a futuristic perspective. However, his view on risk management is purely pragmatic advocation of some kind of ALARP principle. Allan further claims that his protocol “allows them (airport managers) to objectively assess the current risk at their airports, …” (Allan, 2006, p. 2). This view is based on a traditional (classical) approach to risk, assuming a true underlying probability or probability distribution revealed by the risk analysis. In general it is fair to say that the risk elaborations rest heavily on historical data, either local (Anagnostopoulos, 2003; Paton, 2010), national (Allan, 2006) or continental (DeVault et al., 2011). The literature does not reflect much over the basic assumptions of the risk concept. Developing methods and protocols for risk analysis, including framing of risk factors, has been the major concern.

Performance

Performance measures other than risk could be applied to different kinds of bird strike risk mitigation actions. Close reading of the literature does not indicate that assessing mitigation effects has been part of the protocols or risk assessment methodologies conducted. Witter (2008) reports on a positive trend in bird strike frequencies regarding the medium and high risk species accounted for in the BAA, which he partly attributes to risk assessment procedures. However none of the documents discusses the connection between the risk assessment processes and the wildlife management plan and performances. Risk management has been focused more on the species with the highest risks (Allan et al., 2003; Paton, 2010; Shaw & McKee, 2008; Witter, 2008).

Area classification schemes have been an outcome of some of the risk assessment tools (Anagnostopoulos, 2003; Ditlevsen et al., 2010; Sowden et al., 2007). Anagnostopoulus introduced GIS in order to develop a tool for real time risk assessment. This initiative stranded.

Decision

None of the works reviewed have reflected over the decisions that were meant to be supported by the risk assessments. Indirectly one could infer that the expectations made of the assessors as well as the decision makers are not very high, since the need for tools to be simple and easy to use is emphasized in many cases. The aerodromes and their surroundings could be regarded as linear and simple systems with regard to bird strike risks, but then we would expect that this to be substantiated. We find the wildlife, fauna and the airport traffic to be complex and tightly coupled systems, which imposes heavy demands on the bird strike control co-ordinator and other involved parties.

Indirectly, the articles and reports reviewed constitute a self-appointed decision-making authority on risk reducing measures by deployment of the various proposed criteria; red, yellow and green zones, area classifications, targets. Nothing seems to be left to the decision makers themselves.

Analyses

Models

The general approach to risk analyses is semi-quantitative, addressing quantities to be considered in the process. The aggregation of the assessments of quantities leading to placement in a risk matrix is rarely argued for, but it follows some kind of reasonable judgement, see for example (Ditlevsen et al., 2010; Paton, 2010; Sowden et al., 2007). Sowden, Kelly & Dudley (2007) presents the most standardized risk assessment approach (ABRAP), in which Bird Hazard Zones are developed on standardized assessments of aircraft flight paths, high-risk bird species and hazardous land uses. This Canadian approach is fully deterministic and gives no possibility for local knowledge and adaptations to influence the assessments apart from the observation of physical quantities. Probabilities are not part of the game. The models, i.e. relationship between risk element factors and risk of bird strike, have not been substantiated. Ditlevsen, Christensen & Hansen (2010) have developed a similar approach aimed at Danish airports.

Damage-inducing factors have been approached in the research literature. Both Allan (2006) and De Vault et al. (2011) have found a relationship between proportion of damage and bird weight. De Vault et al. used a construct of “Relative Hazard Score” in which the levels of damage and interruption were screened. They did not find any regression for birds above 1.125 kg, but the general damage level for these kinds of birds was usually high. In contrast, Allan predicts a linear relationship for all valid bird weights.

Both, van Gasteren & Dekker (2010) developed the Bird Hazard Index as a risk measure on which to base the development of a bird control system without relying on bird strike statistics, which they claim are inconsistent and based on low numbers.

The omission from risk assessment approaches of risk models as an aid to understanding wildlife behaviour in conflict with air traffic, may be attributable to the very limited research on the topic.

Data

All the authors employ hard data, either from observations or recorded events. This seems to be the only acceptable routine for assessing risk, the corollary being that nothing else matters. The data selected for risk assessments could be contextual and event oriented (either local or national). Portland International Airport (2009) gathers data on location, behaviour, wildlife numbers and airport operations variables, which are fed into a database. These data are meant to be assessed in conjunction with the summary of registered wildlife strike data, which for the period of 1999-2003 was an average of 65 strikes. The computer model based on contextual observations depicts an influence diagram. The models have not been validated through evidence or theories.

Paton (2010) addresses data on relative abundance, frequency of occurrence and or area of occurrence as background knowledge for the probability assignments. Since such data are probably not available at airports, a qualitative assessment is recommended in a model of ranking hazards relative to species.

The most comprehensive data gathering process was described for Athens Airport (Anagnostopoulos, 2003), where an Airside Monitoring and Inspection team (AMI) and the supervisor for wildlife and landscaping (SWL) provided records on bird control, bird strikes and the avifauna in general. The massive data gathering was part of a programme to develop a systematic approach for mapping and visualizing bird strike hazards across the airport area.

Allan (2006) combines national bird strike with local records in his risk assessment protocol. National data are only used to obtain severity judgments related to bird species, while local recordings are incorporated directly in his protocol.

Of those approaches relying on incident or accident data, no consideration is given to the quality of the data besides that Shaw & Mckee (2008) questioning the reliability of their observations and the high portion of unknown species in their development of species’ susceptibility to strike (SSS) index. The issue of the quality of incident data is on the other hand spelled out as the major problem by those authors advocating indexes based on bird activities (Both et al., 2010).

Assumptions

Most of the approaches presented in the literature presume that the assessments are related to existing aerodromes in operational phases. The Canadian prescriptive approach is deemed applicable for planning and modification purposes within and around the aerodrome as well (Sowden et al., 2007). Furthermore the major goal is to clarify how dangerous the aerodrome area is, and this is assumed to be sufficiently measured by the risk assessment approaches. The risk pictures provided are considered best estimates and no further reflections are spelled out as needed. Many of the authors assume that the risk picture needs to be updated annually.

Use

Risk acceptance criteria

Perhaps the most surprising observation in the review of the various risk assessment approaches was that of those addressing risk (probabilities, consequences) where risk was graded in "red, yellow and green zones", setting out what is acceptable or not. However, the reasoning for these general risk acceptance criteria does not reflect the facility, regulations or other company or authority preferences. Allan (2006, p. 4) points out that the boundaries were "based on a pragmatic approach involving discussion with airport bird control staff and managers, as well as on Central Science Laboratory's years of experience ..".

The works built on Allan's protocol are loyal to the risk acceptance criteria, regardless of the facility analyzed (Allan et al., 2003; Kurthi & Ranestad, 2011a, 2011b; Portland International Airport, 2009; Witter, 2008). Paton (2010) is less rigid about boundaries and only claims that species that fit into the extreme or very high categories should be given priority. The Airport Bird Hazard Zones are classifications of aerodrome areas, but these area classifications have not been related to specific measures or requirements (Sowden et al., 2007). The focus is more on how to determine zones, which could be applied when developing an airport wildlife management programme, design and modifications to airports or the development of land uses in the vicinity of the airport.

The authors of the risk indices have been more concerned about the construction of the index than about cut-off limits, claiming safety to be compromised. These authors recognize that their tools should be used in wildlife hazard control but they do not prescribe how the tools should affect the work (Anagnostopoulos, 2003; Both et al., 2010; Ditlevsen et al., 2010; Shaw & McKee, 2008).

Risk mitigation measures

De Vault et al. (2011) have analyzed the FAA National Wildlife Strike Database and ranked species on a relative hazard score. Their recommendations include measures that reduce wildlife habitat suitability, based on local species and contexts. They address wildlife managers and engine manufacturers as the target for their recommendations. For engine manufacturers they recommend changes to the design criteria, to include multiple birds exceeding 1 kg body mass.

In general the sample of literature that we have reviewed pays little attention to concrete risk reducing measures and their associated performances. This does not mean that risk reducing measures are not considered in papers or other documents, at least in the practical applications of the risk assessment tools. On the contrary, identifying risk reducing measures is often an important goal of the risk assessment. However, it is a trend in research literature and risk analysis reports that the performances of barriers and risk-reducing measures are not very well documented. ICAO's Airport Service Manual (2011) contains numerous measures.

Decision making

The major management tasks are related to wildlife hazard management plans, safety management systems and risk management. These activities may be subject to review by the Civil Authority Safety Inspector (Allan, 2006). Very few of the articles reviewed pay any attention to the decision making processes in which the risk assessments ought to play a role. In general, studies investigating the uses and implementation of risk assessment are scarce and critical reviews of different risk assessment and management approaches are thus seldom seen.

Allan (2006) proposes an ALARP process as the chosen risk management strategy. Recommended assessments of performances versus costs should accordingly be given priority in these approaches. Estimated costs of damage from bird strikes have been presented for the period from 1999-2002 (Allan et al., 2003).

Anagnostopoulos (2003) claims that their effort to develop a GIS-based tool had the aim of providing; 1) decision-making support to the risk assessment process, and 2) a monitoring tool to follow the effectiveness and results of the risk management procedures. These goals have not been described, researched or further elaborated.

None of the works in this review have questioned decision making processes. We find this rather odd because risk assessments are often influenced by risk acceptance criteria, actors' preferences and the outline of planning processes.

Experience so far

The literature we have reviewed has a positive perspective on risk management processes and the inherent measuring tools. This is in rather sharp contrast to communications within the IBSC, from which actors have questioned both the relevance of risk mitigation measures and the risk assessment approaches. Our review has also not revealed causes of this conflict or how perceptions have been created. This could be a topic for the next conference. However we refer to Witter's (Witter, 2008) experiences with bird strike risk management activities at seven aerodromes in the UK. From 2004 until 2007 reported bird strikes involving high and medium risk species were reduced from 108 to 71. Ian Witter associates the risk assessment processes with positive prevention measures that have contributed to the overall reduction in bird strikes, despite an increment in air traffic of 12%. Avinor (Kurthi & Ranestad, 2011a, 2011b) has carried out risk assessments on the wide scatter of airports in Norway. The analyses have revealed several weak conditions in the airports' systems and targeted risk reducing measures have been developed. However, how the airports and involved actors should relate to the risk acceptance criteria remains unclear. Measures involving external actors are more complicated to implement. According to Avinor's experience, risk assessments contribute to a discussion about bird strike safety and a decision making process. Internal measures are more easily implemented and often subject to a cost benefit assessment process.

Risk images as a continuous safety management praxis in bird strike risk mitigation – concluding remarks

The existing risk assessment approaches in the aviation industry emphasize objectivity as the major value for obtaining a credible approach. Science-based knowledge is thus regarded as very important. Multiple documents reviewed claim that their recommended approaches serve the ideal of objectivity.

They fail on this point. Their approaches are not objective, nor are they tools to help depict the true risk of bird strike. If the risk assessors insist that their risk assignments are estimates of true risk, they must also relate uncertainties both to the data employed and to the inherent models and assumptions made. No one has addressed uncertainties.

We recommend the IBSC conference to accept that risk assessment approaches are tools for addressing risk, which is a measure of uncertainty associated with future realizations, i.e. bird strikes and their consequences. Uncertainties could be partly represented by probabilities, but that involves much more. Uncertainty is a measure of the level of knowledge deemed important to the air traffic system. In this respect the conference, the risk assessments, the wildlife control programmes, etc. are arenas for learning and sharing knowledge. Furthermore the IBSC should create a discussion on what is the recommended level of knowledge. The existing databases should be investigated for their reliability, validity and relevance to address bird strike risk and whether risk indices based on non-incident observations at the aerodrome area are more promising. We argue that airport owners should pay much more attention to local knowledge and employee/third party involvement (experts and local inhabitants) in the assessment processes. There seems to be a professional conflict at this point, where the aerodrome operators have different views from those of ornithologists. Marra et al. (2009) claim that only 43% of reported bird strikes contain information about species, a situation which needs to be improved if effective risk-mitigating programmes are to be implemented. The opposite standpoint is represented by all who recommend simplistic risk assessment approaches that even lay persons can use. We think the latter idea downgrade the professional safety discipline and underestimates the ability of managers and decision makers. Future risk assessments should pay greater heed to the decision making process they are part of and to the actors who should be addressed either for communicating risk or being involved in the analysis.

As risk analyses presume to say something about the future, it is difficult to see that any particular risk analysis can be judged right or wrong. At least it cannot be done on the basis of hindsight alone. That said, risk analyses can still be judged as good or bad.

We contend that a good risk analysis, for either managerial or for learning purposes, must possess the following properties (Braut, Rake, Aanestad, & Njå, 2012):

1. The analysis must *invent* a risk image based on up-to-date knowledge and subsequent attempts to construct valid causal relationships between identified and shared opinions on threats and hazards and connected consequences.

2. The analysis must encourage *sharing* of the risk image among the relevant actors, and give them the opportunity to comment upon identified threats and hazards as well as connected consequences.

3. The analysis must establish a platform for *continuing development* of the risk image so that the risk image depicts the current operational situation in a valid way.

Complacency is the enemy of safety (Thorpe, 2012a). The goal to "predict accurate risk levels" as presented by IBSC should be removed: it is the optimal decisions and level of knowledge that should be emphasized. In a risk management system based on risk acceptance limits, the aerodrome operator needs to demonstrate to the authorities that the limits have been met. This is often achieved by referring to the risk results, and involvement by the authorities is sometimes rather superficial.

With an ALARP approach, this also implies that authorities' involvement needs to be stronger. ALARP requires continuous updating of the risk image. The authorities, as supervisory bodies before a possible accident as well as investigators after an accident, must therefore concentrate on how organizations establish and continuously maintain and make use of a valid risk image. The reflections and discussions on this risk image both among the employees and on managerial level are probably more important than the risk image itself. The ALARP demonstration is more comprehensive than merely inspecting risk results. For authorities to review an ALARP demonstration, an extensive evaluation process will normally be needed to determine if a sufficiently wide search for alternatives (e.g. possible risk-reducing measures) was undertaken, and whether arguments relating to gross disproportion are valid. This means that more effort is required on the part of the authorities.

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