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PERSPECTIVES IN ORNITHOLOGY

COMPETITION IN THE AIR: BIRDS VERSUS AIRCRAFT

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THE FIRST KNOWN aircraft fatality that was directly attributable to a bird occurred in 1912, when a gull (*Larus* sp.) was caught in the control cables of an aircraft, causing it to crash. Since that time, aircraft have generally increased in size to carry more passengers. Bird–aircraft conflicts are becoming more common recently, which is possibly due to increased numbers of both aircraft (e.g. an estimated 28 million jets now take off in the United States as compared to 18 million in 1980) and some kinds of bird species (e.g. Canada Geese [*Branta canadensis*], in the United States have quadrupled to 2 million since 1985). Between 1990 and 1998, there were an estimated 22,000 bird–aircraft collisions in the United States, which cost an annual $400 million in aircraft repairs. This bird–aircraft conflict takes place around the world, although the species, situations, and severity differ. It is estimated that at least 350 people have been killed in bird–aircraft collisions worldwide.

Understanding bird–aircraft conflict is critical due to monetary reasons and the potential threat to human life. Despite the severity of the situation, bird–aircraft conflict has largely remained on the fringes of rigorous ornithological investigations, and sound ornithological understanding is still required to find long-term management solutions for that conflict. I hope that this review will stimulate ornithologists to show more interest in this crucial issue.

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HUMAN SAFETY AND ECONOMICS

Incidents.—On average, the aircraft of the U.S. Air Force incur 2,500 bird strikes annually (Lovell 1997). Out of those, one human death occurs per 2,000 strikes (Neubauer 1990). Most air crashes occur when a bird hits the windshield or is inducted into the engine. In terms of civilian aircraft, over 5,000 bird strikes were reported in the United States during 1999 alone. Between 1950 and 1999, 286 serious bird-related accidents of military aircraft (in which the aircraft were destroyed or there were fatalities) occurred in 32 countries. Of those accidents, 63 were fatal, which resulted in 141 deaths (Richardson and West 2000). These bird-strike incidents, at least in some cases, are minimum estimates because pilots only report 20 to 30% of actual strikes (Burger 1985). Pilots are thought to underreport bird strikes either because they are unaware of the strikes or because of the inconvenience of filing reports (Solman 1978, Linnell et al. 1999, Brown and Hickling 2000). Sometimes, strikes by large bird species (>350 g) such as Brahminy Kites (*Haliastur indus*) and Cattle Egrets (*Bubulcus ibis*) go unreported by pilots (N. Sodhi pers. obs.). Therefore, runway carcass searches must supplement pilot reports to correctly evaluate the bird threat at airports.

Economic losses.—The cost of repairing an aircraft damaged by a bird strike can vary from very little to millions of dollars when an aircraft is lost. The aircraft component that is most frequently damaged by bird strikes is the engine. International Civil Aviation Organization's (ICAO) analysis shows that bird strikes damaged 200 engines on or near airports around the world in 1996. The cost of repair due to bird ingestion can range from $250,000 to $1 million, depending on the type of engine. However, there have been cases in which the cost of aircraft repair has been as high as $6 million, as was the case for an Air France Concord that was struck by a number of Canada Geese in 1995 on approach to the John F. Kennedy International Airport in New York City. It is predicted that bird–aircraft conflict will become costlier due to the plans for increased numbers of wide-bodied jets in the air (Robinson 2000).

The cost of the bird management program at the Christchurch International Airport in New Zealand is about twice that of repairs to aircraft that are damaged by bird strikes. However, that does not include the costs of lost flight time, passenger disruption, and passenger safety (Chilvers et al. 1997). Annually, aircraft spend 461,000 h on ground in the United States due to bird strikes (Cleary et al. 1999). The cost of bird strikes in terms of human morbidity and mortality has not been rigorously investigated (Neubauer 1990). One human fatality can cost up to $2.5 million. Other studies show that bird management actions have halved the cost of repairs to aircraft that are damaged by birds (e.g. Solman 1973).

Military versus civil aircrafts.—Military aircraft are usually more vulnerable to bird strikes than civil aircraft because they typically travel at high speeds at low altitudes (30 to 300 m), where most birds fly. Approximately 54% of the bird strikes on military aircraft and 90% of those to civil aircraft around the world occur in or near to airfields (e.g. during take off) (Smith 1986, Neubauer 1990, Cleary et al. 1999). However, those figures should be viewed with caution because bird strikes *en route* can go unreported. Military aircraft are also vulnerable at bombing ranges where pilots do not always adequately detect approaching birds (Neubauer 1990). The number of reported bird strikes on military aircraft in the United States increased steadily between 1974 and 1987. However, that could have been due to heightened pilot awareness of the need to report collisions. Thus, bird–aircraft collisions are not uncommon and can result in loss of life and high costs.

Why do Birds Collide with Aircraft?

Airfields can provide good resources (e.g. foraging and nesting sites) for some bird species (e.g. Kershner and Bollinger 1998). However, they can be hazardous habitats due to the danger of getting hit by an aircraft. The ability to avoid an aircraft may involve learning to judge the threat and flying in a manner to evade it successfully. As bird strikes typically occur four to six times per 10,000 aircraft movements, it is possible that most individual birds succeed in evading an aircraft. However, it is critical to understand why evasive behavior does not always work. Birds should typically be good at sound and color signal detection. Those abilities, however, can vary with species and individuals. How nutritional stress, parental duties, disease, and ecotoxins (e.g. neurotoxins) affect a bird's ability to evade an aircraft remains poorly understood (Kelly et al. 2000). For example, carcasses versus live individuals in airports can be compared to determine whether dead individuals have disproportionately more parasites. Therefore, exciting research avenues remain open to understand which characteristics may make individuals more likely to collide with aircraft.

It is also possible that due to a lack of previous near-fatal encounters, most birds do not perceive an aircraft as a threat or potential predator. Limited evidence suggests that the amount of air traffic affects birds' evading abilities. The chance of bird strikes increases with the reduction of air traffic on a runway (Burger 1985). Birds probably get acclimatized to the lack of traffic and become less vigilant. Therefore, airport mangers must take specific action (e.g. disperse birds before resuming aircraft activity) when a runway has been inactive for several hours.

Recent design improvements might have made aircraft more vulnerable to bird collisions. Due to public and economic pressure, quieter, larger, and faster aircraft have been developed. Faster and wider-bodied aircraft are struck more often by birds than are the older, narrower-bodied jets (Burger 1983). For example, birds strike 737 passenger jets less frequently than the larger 767 jets (Chilvers et al.

1997). With the wider bodied aircraft, birds have to fly twice as far to escape than they do for the older small-bodied aircraft. Perhaps birds are also unable to hear the newer, larger-bodied quieter aircraft. Engine recording playbacks have shown that the escape distance from third generation quieter jet engines is much less than older, noisier engines (Solman 1981). At least for some species, aircraft noise may have little affect on daily activities (Conomy et al. 1998a). Furthermore, it may be hard for birds to distinguish aircraft noise from background noise at airports.

Species respond differently to aircraft characteristics (e.g. visual and auditory cues; Conomy et al. 1998b), suggesting that some bird species might be better at learning to avoid aircraft, but the evidence remains anecdotal. For example, American Crows (*Corvus brachyrhynchos*), Northern Harriers (*Circus cyaneus*), and American Kestrels (*Falco sparverius*) were not reported to strike aircraft, despite being common at the John F. Kennedy International Airport in New York City (Burger 1985).

Numerous questions remain unanswered as to why some birds do not or cannot perceive the aircraft as threat. Modifications to the newer aircraft might have made them less detectable and difficult to evade.

Which Birds are Hitting Aircraft?

Around the world, gulls (*Larus* spp.) account for a majority of strikes on civilian as well as military aircraft (e.g. Van Tets 1969, de Jong 1970, Solman 1978, Burger 1985, Smith 1986, Dolbeer et al. 2000). At the Lihue Airport in Kauai, Hawaii, the body mass of birds that hit the aircraft ranges from 13 to 1,300 g (Linnell et al. 1996). Individuals of heavier bird species are more hazardous to aircraft (Dolbeer et al. 2000). The average body mass of the bird species that caused fatalities or injuries to aircraft occupants is 5.1 kg (Neubauer 1990).

Several authors have suggested that disproportionately more immature individuals may be involved in aircraft strikes. Significantly more young than adult individuals of Herring (*L. argentatus*), Ring-billed (*L. delawarensis*), and Laughing (*L. atricilla*) gulls strike aircraft at the John F. Kennedy International Airport (Burger 1985). However, such is not the case for the Great Black-backed Gull (*L. marinus*). The reason for these species differences is not clear, but young individuals are probably either less capable of perceiving an approaching aircraft as a threat or less successful at evading it.

All things being equal, a solitary individual will cause less damage to an aircraft than will a flock. The number of birds that strike aircraft varies with species. Usually, ducks, geese, herons, owls, and doves collide with aircraft as individuals. However, shorebirds and starlings usually hit aircraft in flocks.

Is There a Dangerous Time?

Numerous factors can affect bird strikes on aircraft. Below, I discuss some of the more important factors.

Timing of bird strikes.—At the Christchurch International Airport in New Zealand, bird strikes peak at midmorning (0900), and there is another, smaller peak at night (2000) (Chilvers et al. 1997). However, strikes by sparrows peak at about 0800, whereas those by gulls peak at midday. At the John F. Kennedy International Airport, most gull strikes occur between 0500 and 0900 (Burger 1985), but non-gull strikes do not show any diurnal peak time. Although approximately 10 to 17% of bird strikes can occur during night (Neubauer 1990, Satheesan and Grubh 1992), nocturnal birds are generally ignored in bird strike monitoring and control. That may be partly due to difficulty in sampling nocturnal birds and, in some cases, difficulty in accurately assigning the timing of strikes to bird carcasses that are found at airports.

Effects of weather.—For the U.S. Air Force aircraft, 61% of bird strikes occur during clear weather, when both birds and aircraft are more active (Neubauer 1990). To save energy, migratory birds usually use tail wind to fly. However, wind speed does not significantly affect bird strikes (Manktelow 2000). There is a positive correlation between bird strikes and mean monthly rainfall at Lihue Airport (Linnell et al. 1996). That correlation is probably because of increased seed production along the runways during the rainy months, which attracts granivorous birds. Similar results have been found in the United Kingdom (Manktelow 2000).

Seasonal variation.—The chance of a bird strike is 5× higher during the migratory season than at other times (Jerome 1976). Bird strikes with the U.S. Air Force aircraft usually peak coinciding with the spring and fall migration (Neubauer 1990). Other authors have reported similar results (e.g. Blokpoel 1976). A large number of fatigued birds probably results in more bird strikes during migration. Heightened pilot awareness during the migratory season may also be at least partly responsible for more reporting.

More bird strikes occur in April than at any other time of year at the Christchurch International Airport. That is the time when fledglings are abundant, and they are possibly less successful at evading aircraft (Chilvers et al. 1997).

Can Pilots do Anything?

Approximately 90% of bird strikes occur <1,500 m above ground, but there are records of bird strikes at altitudes >2,000 m (Satheesan 1990). For military aircraft, 56% of bird strikes occur at <300 m above the ground (Neubauer 1990). Jerome (1976) makes a number of recommendations for pilots to minimize bird strikes. They include scanning the skies before take off, avoiding taking off into the sun, switching the aircraft lights on in areas of high bird concentration, keeping the windshield heat on to withstand a greater impact force, and maintaining lower safe airspeeds. Above all, Jerome recommends that pilots should report bird sightings and suspected and actual bird strikes to control towers. Hence, pilot vigilance can prevent some, but not all, bird strikes.

Improvements to Aircraft Design

Aircraft speed is a major factor in crashes due to bird strikes (Niering 1990). That is because the kinetic energy that is dissipated during a bird strike increases with the aircraft speed. There is probably no jet engine in the world that can ingest as large a bird as a Canada Goose and still fly (Eschenfelder 1990). Based on bird-strike data, efforts are underway to improve aircraft so that they can withstand a greater impact (Niering 1990). Those efforts include new material designs for aircraft engine compressor blades, stronger windshield design, and more damage-resistant wings. For military aircraft, windshields need further strengthening modifications, and some of the older aircraft are probably still vulnerable during bird strikes (Neubauer 1990). Previous lessons are sometimes taken into account when making recommendations to improve aircraft design. When a DC10 remained in the air for 10 min after two of its three engines were hit by birds in 1973, the Bird Strike Committee of Europe recommended that European airbuses should have three engines instead of two (Solman 1978).

The current engine certification standards remain vague and are primarily based on the amount of bird flesh ingestion rates. Artificial birds should be used for such tests because it is a humane course of action, and will probably assist in standardization across different aircraft manufacturers. However, existing bird models use only body mass specifications with little biometric data such as density and shape. Research is now underway to develop a better artificial bird for aircraft engine testing (Budgey and Allan 2000). There still is a need to further educate the aviation industry so that more effective bird-proof aircraft are designed.

Monitoring, Predictability, and Education

Before 1960, bird strikes were not seriously considered. However, in 1960, a departing aircraft at the Logan International Airport in Boston ingested European Starlings (*Sturnus vulgaris*) into three of its four engines. The aircraft crashed, and 62 of the 72 people on board died. A review of bird strike data at that time revealed data deficiency and a lack of coordination in its collection. In 1965, the ICAO started to collect bird-strike reports from participating states. With the introduction of the ICAO's bird strike information system (IBIS) in 1980, bird strike reporting became automated. From 1980 until 1998, data on ~78,000 bird strikes were collected from 190 participating states and territories. In the United Kingdom, each airport is required to report all bird strike incidents that result in damage or danger. However, to my knowledge, bird strike reporting in the United States is voluntary.

Different techniques have been used to warn the pilots and flight schedulers of potential bird threats. Radar has been used to monitor bird movements and warn the relevant personnel (Solman 1981, Short et al. 2000). In the 1980s, the Bird Airplane Strike Hazard Team (BASH) of the U.S. Air Force developed a bird avoidance model (BAM). Using historical data of bird distribution, BAM provides pilots with information on the specific locations and times of high bird activity within the continental United States. BAM has been used by the airline industry since its implementation in 1983. A recent study shows that BAM can be useful in predicting bird threats on low-flight-level routes (Lovell and Dolbeer 1999). BAM information for the continental United States is now available on the Internet, with data arranged in biweekly intervals for different times of the day (e.g. dawn and dusk) (see Acknowledgements). BAM and similar monitoring programs are being used or developed in other areas of the world (Leshem 1994, Oost et al. 2000, Verbeek et al. 2000). However, the models—which are primarily based on bird migration information—may need to be recalibrated if global climate change alters the migratory behavior of birds, as has been predicted (Zalakeuicius 2000).

Not all wildlife species are equally hazardous to aircraft. Dolbeer et al. (2000) ranked the species according to their potential hazard to aircraft in the United States. This ranking was conducted so that managers would not waste money and effort in targeting the wrong species. As expected, heavier bird species such as vultures and geese were more hazardous to aircraft than lighter species such as sparrows and swallows. However, that ranking should be viewed with caution because it did not take behavior such as flocking into consideration. A flock of birds can cause greater damage to an aircraft than can a single individual.

In addition to predicting the bird hazard, the education of the relevant personnel is the key to success in reducing the bird hazard at airports. A three-day course is offered for military and civilian airport personnel in the United Kingdom. The course content includes bird biology, habitat management, dispersal techniques, and data recording and analysis (Deacon 2000). The ICAO sponsors bird hazard workshops with similar objectives.

There has been a concern that inadequate resources are allocated for studying and solving bird–aircraft conflict (Short et al. 2000). Predicting and avoiding the bird threat to aircraft are critical issues, and more research is certainly needed to fine-tune the existing models and techniques. Educating the relevant personnel is equally important so that effective management is implemented.

Management

The ICAO recommends that airports should take steps to both monitor and reduce the bird hazard to aircraft. Each airport has its own specific bird hazard problems that depend on the bird species involved, and the habitat types within and surrounding the airports. Hence, a single management recipe that applies across all airports is not possible.

Bird management can be broadly grouped into short-term or long-term action. Short-term action includes scare tactics (e.g. the playing of distress calls) and shooting. Long-term management includes habitat modifications so that airfields and their surroundings become less conducive for birds. One of the problems with short-term control action has been habituation. Birds usually become habituated to bird distress calls within four to six weeks, and reach pretrial numbers in eight weeks (Baxter 2000). The other problem is that birds usually stay in an area before and after the use of calls. The removal of birds through trapping and culling has been practiced at various airports (Blokpoel 1976). However, bird removal can also pose problems because more hazardous individuals that are naïve about aircraft might replace experienced residents. That may be counterproductive, but the removal of juveniles can still be effective.

Innovative methods have sometimes been used to counter the bird hazard. For example, border collie dogs (*Canis familiaris*) are being used to chase birds from airfields (e.g. Southwest Florida International Airport at Fort Myers; Ryan 1999). Such an effort at the Vancouver International Airport in Canada resulted in a 40% reduction of bird numbers over a year (Patterson 2000). Similarly, in Canada, trained Peregrine Falcons (*Falco peregrinus*) and Gyrfalcons (*F. rusticolous*) have been used to drive birds away from airports during daylight hours (Solman 1973). However, that technique has limited value for airports that have flights during the night and during adverse weather conditions.

In the United Kingdom, all airports are recommended to maintain grass at 20 cm high (Smith 1986). That is based on the assumption that most birds are reluctant to feed in tall grass areas because of difficulty in effectively scanning for predators. However, such grass can result in a high population of small mammals, which can attract birds of prey. Heathrow Airport in the United Kingdom has recently been experiencing problems due to growing numbers of Canada Geese. Pilots have been warned of these birds, and nearby farmers around this and other British airports are being educated to make their properties less inviting habitats for that species. Canada Geese have also been causing nuisance at British parks, and there is now a program underway to limit their productivity through contraceptive pills and the pricking of eggs. Chemicals have been used to reduce the bird hazard. The Manchester International Airport in the United Kingdom applies lumbricides in the grass on runway edges to prevent earthworms from moving on to the runways and thus attracting birds (Smith 1986). However, the large-scale use of lumbricide is not recommended due to possible harmful effects such as poor grass growth and drainage problems (Allan and Watson 1990).

For increased effectiveness, a combination of both short and long-term management actions is used at some airports. At the John F. Kennedy International Airport, as many as 315 bird strikes occur every year, of which over 80% are caused by gulls (Dolbeer et al. 1993). Bird strikes between 1979 and 1990 increased more than two-fold. The possible reason for that increase was that in the nearby Jamaica Bay Wildlife Refuge during the same period, Laughing Gull numbers increased from 15 pairs to 7,629 pairs. The shooting of gulls in 1991 and 1992 resulted in a 66 to 89% reduction in gull strikes. A study that attempted to understand the environmental factors attracting high number of Laughing Gulls was also conducted at that airport (Buckley and McCarthy 1994). The study concluded that Laughing Gulls were primarily attracted to the oriental beetle (*Anomala orientalis*) in the short grass (≤5 cm) areas of the airport. Management action was recommended to remove ecological features such as short grass areas and standing water, and to reduce beetle populations. Similar approaches have been employed elsewhere, whereby food abundance (e.g. soil fauna) is monitored to recommend minimizing its availability to bird species (Allan and Watson 1990, Yang et al. 1998).

At the John F. Kennedy International Airport, two vehicles patrol the runways between 0600 and 2000. The crews on those vehicles are equipped with devices such as bird distress call tapes to disperse birds (Burger 1985). Moreover, active environmental management action is being taken by removing trees that provide roosts for starlings, and the drainage of water bodies that attract waterbirds. All-round management has also been practiced at Gatwick Airport in the United Kingdom, and at Schipol Airport in The Netherlands (Smith 1986, Van Geuns 1984). Management action cut bird strikes in half at Schipol Airport (Van Geuns 1984). However, that was not the case at the Christchurch International Airport, where agricultural practices outside of the airport hindered successful management (Chilvers et al. 1997).

Due to large human populations, high species diversity, and poor garbage disposal, the bird hazard at tropical airports is usually high, and its management is difficult. For example, a study that was conducted at the Dar Es Salaam International Airport in Tanzania found that the presence of household as well as aircraft-generated refuse and poultry within the airport and surrounding areas attracted crows and birds of prey (Howell and Msuya 1993). Effective management seemed difficult due to the constant encroachment of local residents into airport compounds for activities such as refuse deposition and goat (*Capra hircus*) grazing. The management of vultures in India shows that effective management can still be possible in developing countries. Annually, $70 million is spent in India to repair aircraft that are damaged by vultures. Vulture numbers can be significantly reduced by removing carcasses within 100 and 200 km radii of civil and military airports, respectively (Satheesan and Satheesan 2000).

Architects and horticulturists can use some of the recommendations at early stages of airport development to attract fewer birds. For example, the building of ledges can be minimized to repel nesting birds such as House Sparrows (*Passer domesticus*). Soil can be seeded within monoculture grass, or trees can be planted widely apart so that they do not become roosts for mynas and starlings. It is much better to evaluate the bird hazard before selecting a site for an airport, as has been done in Portugal

(Pessoa et al. 2000). Similarly, habitat restoration and enhancement projects near airports should consult, during the early stages of development, personnel who are involved in reducing the bird threat at those airports.

As shown above, well-rounded management can reduce the bird hazard at airports. The advances that ornithology has made in understanding bird distribution and habitat associations can be relied upon for effective management.

Conclusion

Airports attract some bird species by providing them with resources such as food and nesting sites. Those birds can be hazardous to landing and departing aircraft. To eliminate or reduce that hazard, airports around the world should have rigorous bird monitoring and management programs. Such programs should also target surrounding areas, because not all hazardous birds are restricted to sites within airports. Different airports may have different problems depending upon species and habitat types. Hence, although a widely applicable management scenario may not be possible, there is a need to develop a rigorous international standard for reducing bird threats to aircraft. There is also a need for better information transfer among airports, particularly in relation to those in developing countries. The Internet can be an excellent tool for such information transfer (see Appendix). Models that predict *en route* bird threats may have to be updated should there be changes in bird distribution and migratory behavior. The aviation industry needs to consult ornithologists more closely in bird proofing its aircraft. Deep ornithological knowledge may be required to eliminate or reduce bird threats to aircraft. Great opportunities for ornithological research exist in the realm of bird–aircraft conflict and hopefully more funding will be channeled into studying that conflict.

With this review, I in no way wish to imply that humans should have air superiority over birds. Birds provided the inspiration for humans to build aircraft, and now a detailed understanding of their biology could be the most effective tool in minimizing bird–aircraft collisions.

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APPENDIX. More information on bird strikes can be found at the addresses below.

International Bird Strike Committee
℅ Royal Netherlands Air Force
P.O. Box 20703
2500 ES Den Haag
The Netherlands
http: / / www.int-birdstrike.com

International Civil Aviation Organization
999 University Street
Montreal, Quebec H3C 5H7
Canada
http: / / www.icao.int /

Civil Aviation Safety Authority Australia
http: / / www.casa.gov.au

Transport Canada
Safety and Security
Aerodrome Safety Branch
330 Sparks St., Place de Ville
Tower C, Ottawa, Ontario K1A ON5
Canada
http: / / www.tc.gc.ca / CivilAviation / menu.htm

Civil Aviation Authority
Kingsway, London
United Kingdom
http: / / www.caa.co.uk /

German Bird Strike Committee
P.O. 1162
D-56831 Traben-Trarbach
Germany
http: / / www.davvl.de /

Bird Strike Committee Italy
http: / / web.tiscali.it / birdstrike /

Bird Strike Committee USA
6100 Columbus Avenue
Sandusky, Ohio 44870, USA
http: / / www.birdstrike.org

The Federal Aviation Administration
Room 810
800 Independence Avenue, SW
Washington, D.C. 20591, USA
http: / / www.faa.gov