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Abstract: Collisions between birds (and other wildlife) and aircraft are known to cause substantial losses to the aviation industry in terms of damage and delays every year. Techniques exist to control bird numbers on airfields and hence to reduce the number of wildlife strikes, but they are applied at widely different levels from airport to airport. Some of this variation may be due to differing levels of strike-risk at the different sites, but much of it is due to the unwillingness or inability of the airports concerned to invest in bird strike prevention. Part of the reason for this reluctance to invest in airport bird control is a lack of understanding of the true costs to the airlines in terms of direct damage to aircraft and in delays and cancellations. Previous estimates of the cost of bird strikes have concentrated only on measurable repair costs and have not attempted to assign costs to aircraft delays. My paper uses newly available data from major international airlines to provide the first estimate for the total cost of bird strikes to the world's airline fleet. Much of the data are commercially confidential and sources cannot be quoted nor the accuracy of the data verified. The estimates also rely on information from a very small number of airlines to produce extrapolations for the worldwide costs of damage and delays. Although these are major international carriers, and as representative as possible of the world bird strike problem as a whole, the results should be interpreted with a suitable level of caution. A tentative and probably conservative estimate of US\$1.2 billion per year in damage and delays is the outcome of this calculation. The costs of bird damage are evaluated relative to the ability of managers to pay for bird control programs and the derived benefits thereof. Reasons for the industry's failure to invest further to reduce the costs of bird strikes are examined.

Key Words: aircraft, airports, bird strikes, collisions, costs, economics, management, worldwide.

Collisions between birds and aircraft (bird strikes) can have catastrophic consequences and have resulted in the loss of at least 190 lives and 52 aircraft in civil aviation (Thorpe 1996). Military losses are more difficult to estimate, but there have been 283 military aircraft lost and 141 deaths recorded in a limited number of western nations from which data are available between 1959 and 1999 (Richardson and West 2000). The outcome of most bird strikes is far less severe, and the majority (65%) result in no damage to the aircraft at all (Milsom and Horton 1995). Those strikes that do damage aircraft or result in precautionary delays are an important cause of economic loss to the industry. To both preserve public safety and to reduce this loss as far as possible, the International Civil Aviation Authority (ICAO) recommends that airports should take steps to reduce the risk of bird strikes as far as reasonably possible. This recommendation may be reinforced by separate national regulations that require airports to take steps to reduce the bird strike risk (e.g., United Kingdom Civil Aviation Authority 1998).

Bird strike prevention can be expensive and there has been no previous analysis of the costs and benefits it can bring to the aviation industry. Although the costs of bird control are easily determined, the costs of bird strikes to airlines are rarely collated in such a way that they can be separated from other operational costs (e.g., damage due to impacts with other objects such as debris on the runway etc.). Existing estimates of bird strike costs have relied on evaluating all of the bird strikes reported to a given nation; determining the levels of damage on a three-level scale (low, medium, severe); and then using the relatively small number

of cases where damage costs are known to estimate an average cost for a given damage level (Cleary et al. 2000). This technique relies on assumptions being made about the number of unreported strikes and takes no account of the financial costs to the airlines of delays and cancellations resulting from aircraft needing safety checks or repairs following a bird strike incident.

Some airlines are now beginning to collate bird strike costs, and to determine the costs to the company of delays and cancellations. This has enabled an alternative approach to estimating bird strike costs to be undertaken. This technique uses actual costs to airlines of bird strike damage and uses accurately calculated cost data for delays and cancellations applied to the world airline fleet.

This revised approach allows the cost and benefits of additional investment in bird strike prevention to be calculated more accurately than has previously been possible. It also illustrates some of the problems inherent in a system where one commercial company (the airport) is spending money to allow another (the airline) to save on costs.

Many of the data presented throughout this paper are commercially confidential, and to obtain them it was necessary not to identify the companies from which they came. Additionally, it has been necessary to avoid presenting the data in such a way that the identity of the company could be inferred (e.g., by quoting an aircraft movement rate that would identify an airline). Some of the calculations undertaken are thus not presented in full, and none of the sources of previously unpublished information is identified. Although failing to attribute

sources of data is unusual, all data have been obtained from authoritative sources (e.g., company flight safety officers), and this is the only way that this paper could be produced.

CURRENT ESTIMATES OF THE COST OF BIRD STRIKE DAMAGE

Reliable estimates of the cost of bird strikes to civil aviation are difficult to obtain, because of the failure of commercial airlines to collate bird strike damage data separately from other costs and because of the poor standard of reporting of bird strike incidents around the world. For example, Cleary et al. (2000) estimate that only 1 in 5 bird strikes in the United States is reported. It is impossible to determine whether the unreported strikes are those that result in no damage or whether damaging, and therefore costly, strikes are also unreported, and if so at what rate. Cleary et al. (2000) therefore provide minimum and maximum estimates for cost of damage and aircraft downtime in the United States. These range from 94,373 hours downtime and US\$78.2 million in repair costs assuming that all damaging strikes are reported, to 471,867 hours downtime and US\$391.4 million in repairs if only 1 in 5 damaging strikes is reported each year.

Accurate estimates of damage costs are easier to obtain from military aviation. The U.S. Air Force (USAF) suffers around US\$33 million per year in damage to aircraft (including aircraft losses) (USAF Bird Aircraft Strike Hazard Team personal communication) while the United Kingdom Royal Air Force (RAF) suffers around US\$23.3 million in bird strike damage (excluding costs of lost aircraft) annually (RAF Inspectorate of Flight Safety personal communication).

AN ALTERNATIVE APPROACH TO ESTIMATING COSTS

The cost calculation used here takes advantage of the fact that one major U.S. airline has a system that accurately tracks repair costs and flight delays due to bird strikes. The company is confident that its staff reports all bird strikes and the direct costs can thus be determined without concerns about failure to report. The disadvantage of this method is that it relies on a single company for a cost estimation, and, at present, data are only available for a single year. Thus, if the company concerned was fortunate enough to avoid any major bird strikes in that year then the estimate of damage costs will be artificially low. For example, a single incident that results in a total engine loss could incur a bill of US\$5 million for a replacement engine. The presence or absence of 1 or 2 incidents of this nature could easily double or halve the total cost estimate for repairs. It would be preferable, therefore, to

use data from several airlines for a period of several years, but this information is not yet available.

The U.S. airline that supplied the cost figures for bird strikes assumes that, on average, each primary delay or cancellation (the delay or cancellation to the aircraft that was actually struck) results in 4 secondary delays or cancellations, either to subsequent flights to be made by that aircraft or to connecting flights that need to be held for passengers. The average costs of these delays and cancellations were obtained from another major U.S. carrier that has gathered the information in order to determine how both bird strikes and other sources of delay (e.g., failure of aircrew to report on time, air traffic control delays etc.) affect its business (Table 1). These figures are rounded estimates calculated for business planning purposes. Errors in these estimations may significantly affect the estimates of total cost (see below).

Table 1. Estimated costs of primary and secondary delays and cancellations to commercial transport aircraft (source major US airline).

Primary Delay	US\$75,000
Primary Cancellation	US\$75,000
Secondary Delay	US\$35,000
Secondary Cancellation	US\$75,000

Data for damage repair costs that do not require assumptions about reporting rates are therefore now available. By combining these with cost and frequency estimates for primary and secondary delays and cancellations, and dividing the total cost by the number of flights flown by the airline concerned, it is possible to calculate a cost per flight for bird strike damage. This cost can be extrapolated to any other airline, country, etc. where the air traffic movement rate is known. The one major assumption involved is that the rate of damaging bird strikes per flight is the same for the airline from which the cost data were obtained as it is for other airlines or countries around the world. The airline involved is one of the world's largest and, although the majority of its operations are in the United States, it operates substantial numbers of flights around the world. It is thus one of the most representative samples of the world aviation business. The accuracy of the calculation would be improved if data from airlines that operate predominately outside the United States becomes available in the future.

The cost calculation presented here is restricted to the costs described above. There are other costs of bird strikes, such as increased insurance premiums for airlines and loss of passenger goodwill (and possibly repeat business) following significant delays. Other costs include the design of engines and aircraft to resist bird strike damage and the additional fuel costs and global pollution that result from stronger and heavier

aircraft being developed to give additional bird strike resistance.

COST CALCULATION

The worldwide cost of bird strikes can be expressed mathematically as:

$$((\sum_i^n a + (75,000 * b) + (75,000 * c) + (75,000 * 4b) + (35,000 * 4c)) / d) * e$$

where

a is the cost of damage repairs suffered by the airline supplying the cost data for each individual bird strike summed for the *n* incidents suffered in 1999.

b is the number of primary cancellations suffered in 1999 as a result of bird strikes by the airline supplying data.

c is the number of primary delays suffered in 1999 as a result of bird strikes by the airline supplying data.

d is the number of air transport movements for the airline concerned.

e is the number of air transport movements for the world fleet.

Substituting values supplied by the airline, and using world Air Transport Movement (ATM) data from ICAO, the total cost of bird strikes for the world fleet is estimated at US\$1,255,726,475 per year, which equates to US\$64.50 per flight.

The airline supplying information for this paper suffered a total of 1,326 bird strikes in 1999. The total cost of repairs resulting from bird strike damage was US\$6,200,000 and the estimated total cost of delays and cancellations was US\$46,450,000 making a total annual cost of US\$52,650,000, or US\$39,705 per bird strike event.

These estimates do not include helicopter traffic, nor the private aviation sector where smaller aircraft operating at lower speeds are involved. The costs of bird strikes to these aircraft may be different than costs for commercial airliners. The consequent costs in terms of delays and cancellations will also be substantially lower.

Assuming that the costs incurred by the airline supplying the information are typical of companies operating fixed-wing transport aircraft, then any airline can estimate the costs incurred for its organization simply by multiplying the total number of strikes experienced by US\$39,705. Similarly, a national regulator can estimate the costs of bird strikes to transport aircraft in its territory by the same means. The accuracy of this cost calculation will, of course, depend upon the proportion of the bird strikes that have been reported. An alternative approach where reporting is thought to be unreliable would be to multiply the total number of ATMs for the country concerned by US\$64.50 to arrive at a cost estimate independent of reporting rates. Any difference in the two estimates may give an indica-

tion of the level of non-reporting of bird strikes in the country or organization concerned.

LIMITS TO ACCURACY OF THE COST ESTIMATE

Because the data used to arrive at the cost estimates above are from such a small number of sources and cannot be independently verified, there is considerable scope for bias in the final result caused either by errors in the original data or by the fact that the data may not be representative of the industry as a whole. To better describe this possible bias the cost calculations have been repeated assuming a variation of plus or minus 10% in the annual total for damage costs and in the costs of delays and cancellations. The cost estimate has a range of US\$1.27 to US\$1.24 billion (a range of 2.4% of the original US\$1.25 billion estimate) if the cost of direct damage is varied by plus or minus 10%. If the estimated costs of delays and cancellations are varied by the same amount the cost estimate has a range of US\$1.36 to US\$1.14 billion (17.6%). Similarly, if the number of secondary delays and cancellations resulting from a primary delay or cancellation due to bird strike is varied by plus or minus 10%, i.e., from 3.6 to 4.4, the range in the resulting estimate of costs is US\$1.18 to US\$1.33 billion (12% of the original estimate). This basic sensitivity analysis shows that it is the estimation of numbers of secondary delays and cancellations and the estimated cost of these that has the greatest effect on the final cost estimation. It is also here that the data are less certain, relying on company estimates which are not verifiable. Nevertheless, a world wide cost estimate for bird strike damage and delays of US\$1 billion to US\$1.5 billion per year for large transport aircraft remains the best estimate available.

EXISTING WILDLIFE MANAGEMENT OPTIONS FOR AIRPORTS AND THEIR COSTS

The basic premise underlying bird management on aerodromes is that reducing the number of birds present on and around the airfield will reduce the probability of a bird strike. The relationship between bird abundance and strike frequency is a complex one, however. At the national level, changes in bird numbers coincide with changes in strike frequency for those species where reliable data are available e.g., Canada geese (*Branta canadensis*) in the United States (Cleary et al. 2000), lapwings (*Vanellus vanellus*) in the United Kingdom (Bell 1999) and a variety of species of birds over 2 kg in weight (Allan et al. 1999). At the airport level, behavior of local populations of birds may have profound effects on the bird strike risk. For example, a change in the feeding location of one group of Canada geese that causes them to fly over the airfield could profoundly increase the strike risk at an airport without any change in total bird abundance. This may allow

an airport bird control program to target particular groups of birds that are increasing risk levels disproportionately, thus obtaining a greater benefit at reduced cost (Cooper 1991).

Bird management on airports usually seeks to modify the behavior of birds to reduce the numbers that come into the operating environment of the aircraft. The techniques used may involve the killing of some birds, but this is normally done to enhance the effectiveness of other techniques rather than to reduce total numbers in a local population. Conventionally, this bird control comprises 2 main elements: 1) habitat management to reduce the availability of resources such as food and water to the birds, and 2) active bird deterrence, either in the form of scaring devices or 'bird patrols' where airport staff or contractors actively deter or remove birds from sensitive areas using techniques such as pyrotechnics, recorded distress calls, or live ammunition. The most effective combination of techniques depends on the environmental conditions that prevail at the airport concerned and on the bird species that are causing the hazard. For example, Brough and Bridgman (1980) found that cultivating a dense grass sward 15 to 20 cm long reduced numbers of gulls (*Larus* sp.) lapwings (*Vanellus vanellus*), golden plovers (*Pluvialis apricaria*), and starlings (*Sturnus vulgaris*) on airfields in Great Britain by up to 75% compared to short grass (5- to 10-cm) swards. In contrast, 15- to 20-cm grass swards in areas where large birds of prey are abundant may cause significant problems because they can support large populations of small mammals, which attract raptors and owls (J-L Briot personal communication, Barras 2000). Whatever the techniques employed, large-scale habitat management on airfields is likely to involve significant costs, and the deployment of staff and/or equipment for bird scaring is a further ongoing cost to the airport operator.

The maintenance of bird-repellent grass swards of the type used in the United Kingdom involves regular cutting of the grass, removal of cuttings once a year and applications of fertilizers, selective herbicides, and occasionally, insecticides (Mead and Carter 1973, UK CAA 1998). The frequency of cutting and the need for chemical treatments varies from site to site, but typical costs range from US\$80,000 to US\$250,000 per year (RAF Strike Command personal communication). In an effort to reduce chemicals and the costs of maintenance, alternative poor, long grass swards have been developed in some countries. These involve reducing the nutrient status of the soil to reduce grass growth and hence lower cutting frequency as well as encouraging a diverse flora by eliminating the use of herbicides and insecticides. Such methods would reduce the cost of maintenance considerably (to around US\$5,000 to US\$10,000 per year) (Dekker 2000), but their effective-

ness compared to the more expensive regime has not been rigorously tested.

Elsewhere in the world, different habitat management regimes are employed. For example, in desert environments, where cultivating grass swards is impossible, the airfield is simply rolled flat and no vegetation is permitted to grow. This results in little or no bird attraction. Airfields situated in swampy habitats rely on drainage or netting of wetland areas to deter shorebirds or fish-eating species that are the main hazards at these sites (Bird Strike Committee Europe 1990). Unfortunately, data on the costs of these activities are rarely available.

As well as managing the airfield habitat, many airports need to manage other features to make them unattractive to birds. Examples include bird-proofing buildings to deny access to birds such as house sparrows (*Passer domesticus*) or feral pigeons (*Columba livia*), or modifying amenity plantings to remove trees or bushes that offer roosting or nesting sites to birds. The costs of these operations vary depending on the nature and scope of the works involved.

In summary, it is likely that an effective habitat management regime (i.e., one which has a significant effect on the numbers of birds using the airfield or its surroundings) might cost an airport in the region US\$75,000 per year to implement in Western Europe. The different management techniques and differences in labor costs in other parts of the world might significantly alter these figures.

The second element of airfield bird control, active bird control, can be similarly difficult to cost. On most civil airports, the bird control staff is part of the operations or fire departments which have duties other than bird control. Few airports separate the costs of their bird management programs from the other functions of the departments concerned and separate costings are thus difficult to obtain. Some airports, however, employ contractors to provide bird control services and in these cases the costs of the services are readily available. In the United Kingdom, the RAF employs contractors at almost all of its airfields. Annual costs vary between US\$130,000 for 24-hour bird control involving continuous patrolling, bird dispersal, and wildlife depredation services on a fast jet station, and US\$65,000 for patrolling between 9 a.m. and 5 p.m. At a training station (RAF Strike Command personal communication). In the United States, costs of bird control programs vary between US\$25,000 for a basic harassment program conducted by military staff to US\$150,000 per year for a full bird control program involving falconry (R. Dolbeer personal communication).

Airports also need to influence the types of development that occur close to their property in case these attract birds. In some countries, the types of develop-

ment that are allowed near airports are restricted (e.g., landfills might be prohibited within a certain distance), while in others, airports are given the opportunity to object to bird-attracting developments close to the site. The costs of evaluating developments close to airports can be considerable, requiring the use of expert consultants, and if a legal dispute results, costs can become very high indeed. Even if the airport is successful in preventing a development without resorting to legal action, there will be opportunity costs to the developer whose application has been denied.

THE COST EFFECTIVENESS OF EXISTING BIRD STRIKE PREVENTION MEASURES

Milsom and Horton (1995) showed that, where a bird control program was already in place at an airport, increased investment was only effective in reducing the number of bird strikes if it resulted in a specified level of bird control efficiency score. The way that this score was derived was not precisely defined, but it required the implementation of standard bird repellent grass, the provision of bird control equipment in the form of pyrotechnics and distress calls, staff who had attended a recognized training course and a specified level of staff presence on the airfield (T.P. Milsom, personal communication). Based on estimates provided by the RAF, this level of bird control and habitat management would cost around US\$200,000 per year per airfield to implement in the United Kingdom. Less expensive programs may have significant benefits in situations where bird control is minimal or absent, or where investment can be made in large-scale reductions in bird populations close to airports. For example, the implementation of even the most basic bird scaring at an airport with large numbers of large birds such as geese on or close to the runway would significantly reduce the risk of a costly strike.

One example of the costs and benefits of a substantial bird control program is available from John F. Kennedy International Airport (JFK) in the United States. Prior to the introduction of improved control techniques, the airport suffered an average of 300 strikes per year (Dolbeer 1998) which based on the calculation above, would have cost the airlines that used the airport a total of around US\$12 million each year. To combat the problem, the airport implemented a habitat management policy, hired a full-time wildlife biologist, employed a team of shooters to kill gulls flying over the property during the main risk period and recruited a bird control company specializing in falconry to assist the airport operations staff who carry out routine bird dispersal duties throughout the year. Although there is some debate about the relative effectiveness of the different components of the new bird management program (Dolbeer 1998), the implementation of shooting

alone reduced the number of strikes from around 170 per year to around 50 per year during the period that the shooting teams were in place (Dolbeer et al. 1993, Dolbeer and Chipman 1999). The 120 strikes thus prevented would have cost the airlines using the airport US\$4,764,600 each year, compared to the cost of the shooting programme which was US\$120,000 per year (R.A. Dolbeer personal communication).

THE POTENTIAL COSTS AND BENEFITS OF FURTHER INVESTMENT IN AIRPORT WILDLIFE MANAGEMENT

To determine whether additional investment in bird management would result in significant savings, the costs of the bird strikes that would be prevented must be determined. If the strikes that are prevented carry the average cost of US\$39,705 calculated above, then it would require only a reduction of 5 strikes to cover the total costs of a program of the sort required to reach Milsom and Horton's bird control efficiency score of 75%. Similarly, the example quoted from JFK airport above resulted in a save:spend ratio of 39:1. Unfortunately, the organizations required to invest in the additional control (the airports) are not those that benefit from the reduced bird strike costs (the airlines).

There are a number of options available to link the costs and benefits of investment in bird strike prevention. One would be for airports to increase the landing fees charged to airlines by a small amount per flight and to invest this money in improved bird control. Providing that data could be gathered to show that the increased investment had paid dividends in terms of a reduction in bird strikes, it may be possible to persuade the airlines that a small increase in landing fees is an acceptable price to pay for improved safety and reduced damage and delays. An alternative approach would be for national regulators to require a certain level of bird control in the same way that other safety features such as fire and emergency services are required at a certain level for a particular category of airport. At present, some nations (e.g., the United States, Canada, Australia, and most European countries) have some level of formal inspection of bird control practices, such as an annual audit by a regulator. Only France has formal requirements for a specified level of bird control provision for airports of different sizes. In the developing world, many airports have no bird control requirement, and hence no bird control. It is at these airports where airlines have the greatest potential to invest money in bird control, which would result in a net benefit by producing a greater savings in reduced bird strike damage and delays. Assisting airports in the developing world with the development of even elementary bird control programs where none existed before could substantially reduce the bird strike frequency suffered by the airlines

that operate there. In countries where labor costs are low, the prevention of 1 average bird strike might be sufficient to pay for an entire year's bird control program. Given that airports with no bird control are likely to suffer from a greater proportion of costly strikes by large and/or flocking birds (those that would be dispersed first if properly targeted bird control was in place), the potential savings provided by this investment would be even greater. The converse of this argument applies to those airports with sophisticated and expensive bird control programs already in place. At these sites, the number of strikes by large birds or flocks should be lower and the majority of bird strikes will be with small non-damaging bird species. The benefits of investing in improved bird control at these sites may thus be lower, but at present there are insufficient airport-specific data on bird strike costs to allow this hypothesis to be tested.

COSTS OF DESIGNING AIRCRAFT TO WITHSTAND BIRD STRIKES

Many aircraft components are required to pass a bird-impact test before being allowed into service. The test is designed so that the probability of a catastrophic accident following the failure of the system or component is less than 1 in every 10^9 flying hours. An engine, for example, might have to demonstrate the ability to provide a certain level of power for a specified period of time following an impact with a given number of birds of a given weight. When these certification tests are designed, a calculation is undertaken which evaluates the frequency of strikes with a particular size and number of birds, the probability of an engine losing power after hitting a bird of this size, and the probability of that power loss leading to a crash. Effective bird control can have a profound effect on that calculation. If airport bird controllers target the large bird species and flocks of birds that are more likely to cause damage (Milsom and Horton 1995), the probability of a catastrophic power loss is reduced. When calculating the need for a particular level of certification test, regulators set a target of no more than 1 catastrophic incident in 10^9 flying hours as an acceptable level of safety. If bird strikes with the most hazardous species can be reduced in frequency to the point where the risk of catastrophe is lower than this threshold, then more stringent certification tests may be avoided and the need to design additional robustness into an engine may be eliminated. The stronger the engine, the heavier and less fuel-efficient it becomes. This not only increases the fuel costs to the operator, but also increases the levels of pollutant gases discharged into the upper atmosphere by aircraft. Such gases are known to contribute to global warming, the costs of which are beyond the scope of this paper to estimate.

CONCLUSION

The estimate of US\$1.2 billion per year for damage and delays to commercial transport aircraft caused by bird strikes is probably conservative and should be interpreted with caution as the data which underlie it are limited, and the assumptions made to arrive at the final figure are considerable. As airlines collect more data and differentiate bird strikes from other foreign-object damage, it will be possible to produce a more refined analysis. This will permit the separation of different bird species, airlines, and airports to better identify the costs and benefits involved in bird strike prevention. Nevertheless, it is clear that a substantial amount of the annual cost of bird strikes could be saved if properly targeted investment in bird strike prevention is made in the future. In the intensely competitive air travel industry, the key is to connect the savings due to reductions in bird strike costs with the investment in airport bird control. It will also be necessary to develop methods to gather the data needed to evaluate the true cost effectiveness of increasing bird control provision and of the existing bird strike measures currently in place at airports.

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