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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 numbers 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 birdstrike prevention. Part of the reason for this reluctance to invest in airport bird control is a lack of understanding of the true costs involved to the airlines in terms of direct damage to aircraft and in delays and cancellations. Previous estimates of the cost of birdstrikes have concentrated on measurable repair costs and have not been able to assign costs to aircraft delays. This paper uses newly available data from major international airlines to provide the first estimate for the total cost of birdstrikes to the world's commercial airline fleet. Some of the data are commercially confidential and some of the sources cannot, therefore, 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 world wide costs of damage and delays. Although the data sources are major international carriers, and as representative as possible of the world birdstrike problem as a whole, the results should be interpreted with a suitable level of caution. A tentative estimate of US$1.2 billion in damage and delays to commercial airlines for 1999 has been produced using this calculation. This does not include damage to general aviation aircraft or helicopters. This paper refines that estimation based on a more complete data set for 1999 plus the full data set for 2000. The revised figure of US$ 1.28 billion (range US$ 1.21 – US$ 1.36 billion) per year is also presented as cost per flight and cost per strike to allow other carriers to estimate the costs to their operation. These costs are compared with examples of the costs of bird control programmes from various parts of the world. Clear cases of the ability to invest money in bird control and save a greater sum in reduced birdstrike costs are identified. Reasons for the industry's failure to invest further to reduce the costs of birdstrikes are examined.

Key Words: birds, aircraft, collisions, costs, management, birdstrikes, airports, world wide, economics.

INTRODUCTION

Collisions between birds and aircraft (birdstrikes) 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 the limited number of western nations from which data are available, between 1959 and 1999 (Richardson & West 2000). The outcome of most birdstrikes is far less severe, and the majority (65%) result in no damage to the aircraft at all (Milsom & Horton 1995). Those strikes that do damage aircraft, or result in precautionary delays for safety checks, are an important cause of economic loss to the industry. In order both to 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 birdstrikes as far as reasonably possible. This recommendation may be reinforced by separate national regulations that require airports to take steps to reduce the birdstrike risk (e.g. UK Civil Aviation Authority 1998).

Birdstrike prevention can be an expensive operation and there have been few previous analyses of the costs and benefits that investing in better bird control can bring to the aviation industry. This is partly because, although the costs of bird control are easily determined, the costs of birdstrikes 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.). Most estimates of birdstrike costs have relied on evaluating all of the birdstrikes 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 (e.g. 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 birdstrike incident.

United Airlines are now beginning to collate birdstrike costs separately from other causes of damage and delays to their aircraft, and another major carrier has undertaken calculations to determine the costs to the company of delays and cancellations. This has enabled an alternative approach to estimating birdstrike costs to be undertaken. This technique uses actual costs to airlines of birdstrike damage and uses accurately calculated cost data for delays and cancellations to determine the cost per flight to the airline, which can then be applied to the world airline fleet. Using this method, Allan (in press) arrived at a figure of US$1.2 billion per year as an estimate of the total cost of birdstrikes to commercial airlines around the world. He also produced calculations for the average costs to an airline of each birdstrike incident and for the average cost per flight of birdstrike damage and delays. These figures allow any airline, airport or national regulator to determine how much birdstrikes are costing their operation and to compare this with the costs of and additional bird control measures that could be put in place.

The original estimate produced by Allan (in press) relied on only one year's data from United Airlines and was thus potentially inaccurate if the year in question was untypical. This paper refines that estimate using a more complete dataset for the year in question plus a second year of data.

Many of the data presented throughout this paper are commercially confidential, and in order to obtain them it was necessary to undertake not to identify some of the companies from which they came. As well as not naming the companies directly, 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 some of the sources of previously unpublished information are not 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 BIRDSTRIKE DAMAGE

Reliable estimates of the cost of birdstrikes to civil aviation are difficult to obtain, partly because of the failure of most commercial airlines to collate birdstrike damage data separately from other costs, and partly because of the poor standard of reporting of birdstrike incidents around the world. For example, Cleary et al. (2000) estimate that only 1 in 5 of all birdstrikes that occur in the USA is reported, but 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 down time in the USA. These range from 94,373 hours down time and US$78.2 million in repair costs assuming that all damaging strikes are reported, to 471,867 hours down time and US$391.4 million 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 US Air force suffers around US$33 million per year in damage to aircraft (including aircraft losses) (USAF Bird Aircraft Strike Hazard Team pers. comm.) whilst the UK Royal Air Force suffers around US$23.3 million in birdstrike damage (excluding costs of lost aircraft) annually (RAF Inspectorate of Flight Safety pers. comm.).

AN ALTERNATIVE APPROACH TO ESTIMATING COSTS

Allan (in press) has taken advantage of the fact that United Airlines has set up a system that allows repair costs and flight delays due to birdstrikes to be accurately tracked throughout the company. The company is confident that its staff report all birdstrikes 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 the time, data were only available for a single year. Thus, if United was fortunate enough to avoid any major birdstrike incidents in that year then the estimate of damage costs would be artificially low. For example, a single incident that results in a total engine loss could incur a bill of $5million for a replacement engine. The presence or absence of one or two incidents of this nature could easily double or halve the total cost estimate for repairs. This paper uses a second year of data from United to refine the estimate, but a longer data run, preferably including data from other companies would produce a more reliable figure.

United Airlines estimate that, on average, each primary delay or cancellation (the delay or cancellation to the aircraft that was actually struck) results in a further 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 delayed passengers. In determining the costs of these delays and cancellations Allan (in press) quotes another major US carrier who has gathered that information in order to determine how birdstrikes and other sources of delay (e.g. failure of aircrew to report on time, air traffic control delays etc.) affect its business (see 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) (after Allan (in press))

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

Data for damage repair costs that do not require assumptions about reporting rates are now, therefore 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 United in the year concerned, Allan (in press) calculated a cost per flight for birdstrike 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 birdstrikes or delays per flight is the same for United as it is for other airlines or countries around the world. United is one of the world's largest airlines and, although the majority of its operations are in the USA, 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, especially ones which operate predominately outside the USA, becomes available in the future.

The cost calculation presented here is restricted to the costs described above. There are other costs of birdstrikes, 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 birdstrike damage, and the additional fuel costs and global pollution that results from stronger and heavier aircraft being developed to give additional birdstrike resistance.

COST CALCULATION

The worldwide cost of birdstrikes 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 United Airlines summed for the n incidents suffered in a year.

b is the number of primary cancellations suffered in a year as a result of birdstrikes by United

c is the number of primary delays suffered in a year as a result of birdstrikes by United.

d is the number of air transport movements for United in the year

e is the number of air transport movements for the world fleet in the year (ICAO data)

Substituting the new data for 1999 and information for 2000 supplied by United, and using world Air Transport Movement (ATM) data from ICAO, the following revised estimates for birdstrike costs are obtained.

Table 2 Estimated costs of birdstrike damage and delays to the world airline fleet in 1999 and 2000

	1999	**2000**	**Mean**
Total number strikes per 10,000 flights	16.2	19.2	17.7
Total cost per strike	US$ 42,947	US$ 33,020	US$ 37,983
Total cost per flight	US$ 69.7	US$ 62.2	US$ 66.0
Total cost to world commercial aviation	US$ 1.36 billion	US$ 1.21 billion	US$ 1.28 billion

The estimates show a difference between the two years of US$ 0.15 billion or 12%. United suffered a total of 1,325 wildlife events in 1999 compared to 1,538 in 2000. Despite the increase in the number of events, the cost of damage fell by US$ 2.1 million, from US$ 7.5 million to US$ 5.4 million. Primary delays and cancellations remained broadly stable at 167 delays and 36 cancellations in 1999 compared to 164 delays and 27 cancellations in 2000. It is unclear whether these year on year differences are typical of the variation in birdstrike cost data that will be seen in the longer term as more data are collected. The lower cost per strike in 2000, a reduction of 23% compared to the 1999 figure, suggests that the estimate for the world wide figure should be interpreted with caution until a better estimate of the variability in the data is obtained.

Assuming that the birdstrike costs incurred by United are typical of companies operating fixed wing transport aircraft, then any airline can estimate the costs incurred for its organisation simply by multiplying the total number of strikes experienced by $37,983. Similarly, a national regulator can estimate the costs of birdstrikes 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 birdstrikes that have been reported. An alternative approach where reporting is thought to be unreliable would be to multiply the total number of ATM's for the country concerned by $66.0 to arrive at a cost estimate independent of reporting rates. Any difference in the two estimates may give an indication of the level of non-reporting of birdstrikes in the country or organisation concerned.

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 birdstrike. 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 USA (Cleary et al 2000), lapwings (*Vanellus vanellus*) in the UK (Bell 1999) and a variety of species of birds over 2 kg in weight (Allan et al. 1999). At the airport level behaviour of local populations of birds may have profound effects on the birdstrike risk. For example, a change in the feeding location of one group of Canada Geese which 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 programme 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 behaviour 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 two main elements; habitat management to reduce the availability of resources such as food and water to the birds, and active bird deterrents, 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 & Bridgman (1980) found that cultivating a dense grass sward 15 to 20cm 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 (5-10cm) swards. In contrast, 15-20cm 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 pers. com., Barras *et al.* in press). 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 on-going cost to the airport operator.

The maintenance of bird repellent grass swards of the type used in the UK involves regular cutting of the grass to keep it at the required height. It also requires cutting the grass short and removal of cuttings (usually by dumping at a landfill) once a year, plus applications of fertilizers, selective herbicides and, occasionally, insecticides (Mead & 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 (Royal Air Force Strike Command pers. com.). In an effort both to reduce chemical inputs and to reduce 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$5000 to US$10000 per year) (Dekker 2000) but their effectiveness 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 which 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 which are the main hazards at these sites (Birdstrike 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 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 of US$75,000 per year to implement in Western Europe. The different management techniques and differences in labour costs in other parts of the world might significantly alter these figures.

The second element of airfield bird control, active bird control, can be more difficult to cost. On most civil airports, the bird control staff are part of the operations or fire departments, which have duties other than bird control. Few airports separate the costs of their bird management programmes from the other functions of the departments concerned and separate costings are thus difficult to obtain. Some airports, however, employ contractors to provide their bird control services and in these cases the costs of the services are readily available. In the UK, the RAF employ contractors at almost all of their 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 9am and 5pm at a training station (RAF Strike Command pers.com.). In the USA costs of bird control programmes vary between US$25,000 for a basic harassment programme conducted by military staff to US$150,000 per year for a full bird control programme involving falconry (R. Dolbeer pers. com.).

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 development that are allowed near airports are restricted (e.g. landfills might be prohibited within a certain distance), whilst 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 BIRDSTRIKE PREVENTION MEASURES

Milsom & Horton (1995) showed that, where a bird control programme was already in place at an airport, increased investment was only effective in reducing the number of birdstrikes 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 that had attended a recognised training course and a specified level of staff presence on the airfield (T.P. Milsom, pers. com.). Based on estimates provided by the UK RAF, this level of bird control and habitat management would cost around US$200,000 per year per airfield to implement in the UK. Less expensive programmes 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 programme is available from John F. Kennedy Airport in the USA. 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$11.4 million each year. In an effort 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 specialising 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 programme (Dolbeer 1998), the implementation of shooting alone reduced the number of strikes from around 170 to around 50 during the period each year that the shooting teams were in place (Dolbeer et al. 1993, Dolbeer & Chipman 1999). The 120 strikes thus prevented would have cost the airlines using the airport US$4.6 million each year, compared to the cost of the shooting programme which was US$120,000 per year (R.A. Dolbeer pers. com.).

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

In order to determine whether additional investment in bird management would result in significant savings, the costs of the birdstrikes that would be prevented needs to be determined. If the strikes that are prevented carry the average cost of US$37,983 calculated above, then it would require only a reduction of 5 strikes to cover the total costs of a programme of the sort required to reach Milsom & 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 organisations that are required to invest in the additional control (the airports) are not those that benefit from the reduced birdstrike costs (the airlines).

There are a number of options available to link the costs and benefits of investment in birdstrike 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 birdstrikes then 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 provision in the same way that other safety features, such as fire and emergency services, are required to be 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 one, 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 saving in reduced birdstrike damage and delays. Assisting airports in the developing world with the development of even elementary bird control programmes where none existed before could substantially reduce the birdstrike frequency suffered by the airlines that operate there. In countries where labour costs are low, the prevention of one average birdstrike might be sufficient to pay for an entire year's bird control programme. Given that airports with no bird control are likely to suffer from a greater proportion of strikes with large and/or flocking birds (those that would be dispersed first if properly targeted bird control was in place) then the chances are that the strikes prevented by this investment would be even more costly than the average and the potential to save is even greater. The converse of this argument applies to those airports with sophisticated, and expensive, bird control programmes already in place. At these sites the number of strikes with large birds or flocks should be lower and the majority of birdstrikes 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 birdstrike costs to allow this hypothesis to be tested.

COSTS OF DESIGNING AIRCRAFT TO WITHSTAND BIRDSTRIKES

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 (both of which are more likely to cause damage (Milsom & Horton 1995)), the probability of a catastrophic power loss is reduced. If birdstrikes with the most hazardous species can be reduced in frequency to the point where the risk of catastrophy is lower than the 1 in 10^9 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 gasses 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$1.28 billion per year for damage and delays to commercial transport aircraft caused by birdstrikes is probably a conservative one. It 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 birdstrikes 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 in order to better identify the costs and benefits involved in birdstrike prevention. Nevertheless, it is clear that a substantial amount of the annual cost of birdstrikes could be saved if properly targeted investment in birdstrike prevention is made in the future. The difficulty, in an intensely competitive business, is to connect the savings due to reductions in birdstrike costs with the investment in airport bird control. It will also be necessary to develop methods which gather the data needed to evaluate the true cost effectiveness of increasing bird control provision and of the existing birdstrike measures currently in place at airports.

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