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Key words

Introduction

The number of birds of a flocking species likely to be ingested into an aircraft engine in a multiple birdstrike is of profound interest to engineers when they consider birdstrike tolerance in engine design. Of even more importance than the number of birds which may enter a single engine, when power can still be supplied by the remaining engines, is the probability of more than one engine suffering an ingestion.

The historical birdstrike record can provide such information but is sometimes unreliable as it may be, of necessity, based upon unreliable data; the species of the birds involved may not be accurately identified and the number of birds ingested is often impossible to verify because of the nature of the remains (Allan and Hammershock, 1994). In addition, a historical record cannot reflect current or future trends in bird populations or behaviours.

Some migratory populations of the Canada Goose (*Branta canadensis*) are thought to be in decline, but numbers are increasing in urban areas throughout Northern America and Europe (Allan et al, 1995, Seubert 1996, USDA, 1998). These introduced, non-migratory populations have adapted very well to man-made environments such as ornamental parks and reservoirs which are often near airports. In the absence of satisfactory control techniques becoming widely used, the probability of striking a Canada Goose will rise as its numbers increase. As it is a flock-forming species the risk of a multiple ingestion becomes particularly serious.

The bird flock ingestion model

A method has been developed for determining the probabilities of multiple ingestions by directly analysing the structure of Canada Goose flocks. From stereo images of flocks, the positions of birds within the flock can be derived using the parallax principle. The passage of aircraft engines, in single and twin configurations, through these flocks can then be modelled and a table of probabilities for ingesting any given number of birds produced. These data can be used in conjunction with historical birdstrike records to inform design processes for new aircraft components and birdstrike resistance regulations.

The probabilities thus produced are only of relevance to flocks similar in size and structure to those that have been analysed. However, it is possible to alter the sizes of model flocks so that the outcome of a strike with any desired number of birds could be investigated. In this way, the model can simulate collisions with flocks of average size, as deduced by field observations of Canada Goose flocks.

The probability of an aircraft encountering a flock of Canada Geese is beyond the scope of this study. It is only concerned with the outcome of such an event, but given the increase in the numbers of these birds in critical locations, it is likely that flocks will be struck more often.

There have been previous attempts to measure the three dimensional structure of bird flocks, though none looked at the Canada Goose and none attempted to model aircraft / flock collisions. Several of these methods used a two camera system (Dill and Major, 1977, Pomeroy and Hepner, 1992), while others examined single photographs of flocks and made assumptions about their three dimensional structure (van Tets, 1966, Sugg, 1965).

The major adaptation made in this study compared to earlier methods is the use of video rather than still cameras. This means that the position of birds in a series of video frames, only 1/24 of a second apart, can be averaged to reduce errors due to camera resolution, etc. A long sequence of video footage can be recorded, capturing a number of flocks as they fly past the cameras. In fact, any suitable data containing three dimensional bird co-ordinates can be used with the model.

Methods

Field system

For a full account of the methods used in this procedure, see Budgey (1998).

A stereo pair of digital video cameras was used to film 14 flocks of Canada Geese in locations in the UK where their behaviour was similar to that found on and around airfields, especially low-level transiting flights between feeding and resting areas which may, for instance, cross the paths of approaching and departing aircraft. The images were recorded onto two video cassettes and a time code added to the tape so that individual frames could be matched for later analysis.

Image analysis

The video frames were converted to computer images using a video frame grabber card. Once in computer format, the XY co-ordinates of individual birds on each image were measured using object detecting routines available in a proprietary image analysis software package. The pairs of XY image co-ordinates of each bird were then converted to real-world XYZ co-ordinates for each bird in the flock. Errors in the positions of birds, caused by insufficient resolution in the camera system, or incorrect calculation of the position of the bird on the computer image can be reduced by taking the average position of the bird over 10 consecutive video frames.

The model

The model is a statistical one. It uses a 'Monte Carlo' analysis to determine the probability of a component striking a given number of birds as it passes through a flock. One thousand random trajectories, representative of aircraft climb and descent angles are generated through the flock and the number of birds that would be struck on each pass is recorded in the form of a frequency histogram. A broad cross-sectional area can be applied to each trajectory so that for say, a 100 inch diameter engine, any birds within 50 inches of the centre line of the trajectory will count as having been struck. The engines modelled, at 100 inches in diameter, are similar in size to the Trent 800 engine, manufactured by Rolls-Royce.

For a twin engine configuration, 1000 parallel trajectories are generated for pairs of engines at the desired separation, in this case 15.63m, the engine separation found on the Boeing 737, and the number of birds ingested into each engine is recorded.

Single engine parameters

The frequency histogram produced from running the model provides the data needed to determine the maximum number of birds that may be ingested in, for example, 95% of encounters. In this way the most serious 5% of passes are disregarded as being unlikely to happen in operation.

Twin engine parameters

When considering the probability of ingesting birds into more than one engine, the situation is more straightforward. It is then simply a case of determining the proportion of the total number of cases where both of the engines struck a bird.

One thousand is the recommended number of randomisations for estimating 5% significance (Manly 1991) which is analogous to estimating 95th percentiles, so we model 1,000 passes of a component. If a more extreme percentile figure is required, say 99%, a greater number of passes would be required

Comparison with historical records

As stated above, it is difficult to make accurate determinations from birdstrike remains of the number of birds ingested into a single engine. No attempt therefore has been made to compare the number of ingestions obtained from the single engine model with the historical record. Data for the proportion of flock encounters that resulted in ingestions into more than one engine is however available (CAA, unpub.). Where records indicate that a flock of Canada Geese was involved in a birdstrike we have made a simple comparison between the number of events where more than one engine was struck and the results of the twin engine configuration model.

A direct comparison of the twin engine configuration model with historical data must be interpreted with care as the size of the flocks encountered in operation is unknown. The separation and diameter of the engines involved in these events may also be different to that used in the model.

Results

Table 1. Frequency of ingesting a given number of Canada Geese from the single engine flock ingestion model. (1000 passes of a single 100 inch diameter engine through 14 Canada Goose flocks. The size of the flocks is also shown)

Number of birds in flock	Number of birds ingested										
	0	1	2	3	4	5	6	7	8	9	10
8	129	304	312	151	52	24	19	9	0	0	0
9	522	288	130	30	16	11	2	1	0	0	0
9	411	214	157	144	42	19	10	3	0	0	0
9	173	244	206	154	130	72	17	4	0	0	0
10	331	421	203	35	9	1	0	0	0	0	0
10	303	393	206	64	23	10	1	0	0	0	0
11	801	172	23	4	0	0	0	0	0	0	0

11	489	241	167	53	28	11	5	6	0	0	0
18	703	209	64	20	4	0	0	0	0	0	0
18	80	144	222	202	181	82	35	30	13	9	2
24	687	237	51	17	8	0	0	0	0	0	0
27	795	147	38	17	2	1	0	0	0	0	0
29	435	296	163	55	29	14	7	1	0	0	0
30	539	261	127	48	15	6	4	0	0	0	0
Mean	457	255	148	71	39	18	7.1	3.9	0.9	0.6	0.1

Table 2. Mean percentage probability and mean cumulative percentage probability of ingesting given number of birds, derived from table 1.

	Number of birds ingested										
	0	1	2	3	4	5	6	7	8	9	10
% probability	46	26	15	7.1	3.9	1.8	0.7	0.4	0.1	0.1	0
cumulative % probability	46	71	86	93	97	99	99	100	100	100	100

There is a 26% probability of ingesting one bird and a 71% probability of ingesting a maximum of one bird. The 95th percentile falls within the category of four ingestions, thus on 95% of passes through similar flocks a maximum of four birds will be ingested and more than four birds will only be ingested on 5% of passes.

Table 3. Frequency with which a given number of Canada Geese was ingested into each engine of a hypothetical aircraft from the twin engine flock ingestion model. (1000 passes through a flock of 29 Canada Geese of two engines with a separation of 15.63m and diameters of 100 inches).

		Number of birds ingested into second engine										
		0	1	2	3	4	5	6	7	8	9	10
Number	0	332										
of birds	1	289	42									
ingested	2	144	37	8								
into	3	50	14	8	5							
first	4	28	6	0	0	0						
engine	5	19	3	1	0	0	0					
	6	5	0	0	0	0	0	0				
	7	5	0	0	0	0	0	0	0			
	8	2	0	0	0	0	0	0	0	0		
	9	2	0	0	0	0	0	0	0	0	0	
	10	0	0	0	0	0	0	0	0	0	0	0

Table 4. Proportion of total number of passes on which birds were ingested where one or two engines experienced ingestions, derived from table 3.

One engine	82%
Two engines	18%

Thirty three percent of encounters with the flock resulted in neither engine ingesting a bird in this simulation.

Table 7. Data from historical Canada Goose birdstrike record, showing proportion of total flock encounters where one or more than one engine was struck. This data is taken from a total of 50 incidents where one or more birds were struck and more than one bird was present (seen or struck).

	Canada Goose
One engine	82%
More than one engine	18%

There is a quite remarkable correspondence between the proportion of single to twin engine ingestions that have occurred in operation and that have been found from running the model. The most reliable element of a birdstrike account is probably the degree of damage caused to the aircraft, including the number of engines struck and as such this element of the historical birdstrike record provides a credible validation of the model data. However the caveat mentioned above, that some details concerning flock size, etc. are missing from the operational data should be borne in mind.

Discussion

Results from the model indicate that when even relatively small Canada Goose flocks, of no more than 30 birds, are struck by an aircraft, an ingestion is more likely than not to occur, and multiple ingestions will occur, with an engine of this size - 100 inches in diameter, on nearly a third of encounters.

There would be an ingestion into more than one engine on nearly one fifth of encounters with engines of this size and a separation of 16 metres. A similar ratio of flock encounters to multiple engine ingestion is found in operation.

The numbers of Canada Geese in urban areas are increasing (USDA 1998), and consequently the number of birds around airports is also likely to rise and it is probably safe to assume that the probability of an aircraft encountering a flock of them in operation is similarly rising. If the size of flocks typically encountered is similar to or larger than those we have studied here, there is the potential for a serious incident to occur. To combat the increasing threat from these birds, there are two possible approaches, as there are with any other problem species - reduce the threat or tolerate it.

Reducing the threat requires a reduction in the numbers of Canada Geese, at least around airports. The standard airfield control measures for these birds must be applied rigorously as should a planning policy that ensures no environmental features that may attract them are accepted nearby. On a wider scale, national and international population management programmes would reduce the threat still further but would be logistically and politically difficult to implement.

Tolerating the threat requires a considerable degree of engineering effort. An engine certified to fail safely after the ingestion of a single Canada Goose would ingest more than one bird on nearly a quarter of encounters with a flock such as those analysed here. According to both the model and the operational database, in 18% of cases where birds strike engines, they impact more than one engine. In 2% of cases, our model indicates that more than one bird would be ingested into each of the two engines; in a larger flock this could be more likely. The probability of a bird striking an engine in operation does not necessarily equate to the probability of an ingestion occurring (the bird may impact the engine cowling, etc. and be deflected away from the intake). Thus the model may overestimate the true risk insofar as it regards any impact as an ingestion into the engine.

The analysis of flock structure methods and model described here can be applied to any species of bird, and may be of particular use where populations are increasing or the risk is rising due to behavioural changes or local shifts in populations bringing more birds into the proximity of aircraft.

Validity and refinement of model

When applying a model such as this it is important to ensure that the flocks being modelled are representative, both in structure and size, of those likely to be struck in operation. This can be achieved through field observations and it is possible to change the number of birds within a model flock to reflect this. The behaviour of a flock, especially when an aircraft is approaching has not been considered in this generation of model. Using video footage to study flock structure permits the modelling of flocks through time, and may allow the birds modelled to exhibit "avoidance" behaviour. If the rules governing bird flock structure and movement can be deduced it may be possible to generate entirely artificial flocks which can exhibit any desired behaviour or response to aircraft.

Acknowledgements

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