THREE DIMENSIONAL BIRD FLOCK STRUCTURE AND ITS IMPLICATIONS FOR BIRDSTRIKE TOLERENCE IN AIRCRAFT

Richard Budgey
Central Science Laboratory
Sand Hutton
York Y041 1LZ
UK

Summary

The number of birds currently used in multiple impact certification is based on data from the historical birdstrike record. As bird populations and engine designs change, new test criteria are periodically required. In order to measure future risks from species rarely struck at present, and confirm the level of risk from species that have been struck frequently, it is necessary to supplement the historical record with direct measurement of the threat posed by flocking birds. We describe a method for filming bird flocks using a stereo pair of video cameras and determining the three dimensional structure of the. flock. By modeling the flocks and plotting the path of an aircraft component through them, it is possible to determine the probability of striking a given number of birds and we include some initial results from running the model. These data can then be used by regulators to inform the choice of bird numbers and weights in future certification testing requirements. We also try to describe a relationship between bird flock density and a biometric factor such as wingspan. If this relationship holds as more data are gathered, the model can then be extended to any species of bird.

Keywords: Flock density, Certification standards, Mathematical models

Introduction

Before entering service, a new aircraft component such as an engine or windshield must pass stringent airworthiness tests, one of which is its ability to withstand bird impacts. The authorities which formulate these tests recognise that in a collision with a flock of birds, more than one wilt be struck, so they require components to be tested against a of number birds simultaneously. At present the requirements of the JAA regulation which relates to engine bird ingestions, JAR-E 800, are the ingestion of one or more birds of between 4oz and 1.5Ib, depending on engine inlet diameter, after which the engine must continue to produce at least 75% of full power and one 41b bird, after which the engine may be shut down, but must not fail hazardously.

The number of birds used in these tests is derived from information from previous birdstrikes where the number of birds recovered after an incident or seen by air or ground crew has been recorded. These reports are not always reliable (Allan and Hammershock, 1994). The species and hence weight of the birds involved may not be identified, and the number is often not recorded precisely. Another drawback of the historical record is that it cannot reflect current or future chances in bird populations. If the species and flocking behaviours commonly encountered in multiple birdstrikes change, such as is the case with the Canada Goose which is rapidly increasing in number (Allan et al, 1995, Seubert 1996), birdstrike testing may not fully represent the threat actually faced by aircraft. By directly measuring bird flock densities and modeling bird flock / aircraft interactions, we can predict the probability of striking given numbers of birds in a flock of any species. The findings from this work can be used to inform the design process when new bird impact regulations are being formulated.

There have been previous attempts to estimate the threat posed by bird flocks through analysing flock structure. Dill and Major (1977) used stereoscopic pairs of photographs to calculate the distance in space between a bird and its nearest neighbour in the flock, known as the "nearest neighbour distance" (NND) and interbird angles. van Tets (1966) and Sugg (1965) used single photographs for two-dimensional estimates of densities of bird flocks in flight. Pomeroy and Hepner (1992) used a perpendicular pair of cameras to find three dimensional NNDs but without any particular interest in birdstrikes.

In this study, we have chosen to adapt the method used by Dill and Major and use a stereoscopic camera pair. The other methods described above, while having some advantages, are not entirely suitable for assessing the birdstrike hazard of flocks. van Tets' method was simple and could be applied to any photograph but it made the assumptions that a group of birds occupied a spherical airspace of the same diameter as the smallest circle enclosing them on the photograph and that the distance between birds could be estimated by measuring their lengths or wingspans on the photograph. From a single image there is no way of checking whether either assumption is reasonable. Sugg was only interested a two dimensional analysis of flock structure and made the assumption that flocks would be struck head on. Pomeroy and Hepner measured three-dimensional data but their equipment had to be set up in a permanent location as they wanted to study turning behaviour in a flock of Rock Doves which were trained to fly past the camera.

The major adaptation on the Dill and Major method is the use of video rather than still cameras. This means that the position of birds in a series of video frames, only 2-1 of a second apart, can be averaged to reduce errors due to camera resolution or incorrect identification of the center of the bird on the video image, etc. A long sequence of video footage can be recorded, capturing a number of flocks as they fly past the cameras.

This method uses the degree of parallax shift between the cameras in the stereoscopic pair to measure the distance and angle from camera to object and returns the three-dimensional position of each bird in a flock. The flock is modeled on a computer and a series of random trajectories can be projected through it to represent aircraft or aircraft components. The number of birds struck on each pass of a component gives a measure of the threat posed by flocks of each species.

Methods

Field system

A stereo pair of digital video cameras was used to film flocks of a number of bird species in the UK in locations where their behaviour was likely to be similar to that found on airfields. Species filmed were Starling, Rock Dove (Feral Pigeon), Lapwing, mixed gull flocks and Canada Goose. The cameras were mounted, with identical film planes, at a distance of 2.54m apart on a section of optical beam with a cross-sectional shape that prevented bowing. The beam was mounted on two standard photographic tripods. Provision was made to allow the cameras to be adjusted so that the axes of the lenses were parallel, or so that any degree of divergence from parallel could be measured, by filming a calibration beam with two chequerboard images, also 2.54m apart. The cameras were Pulnix TM-765 black and white digital video cameras with a resolution of 756 by 581 pixels. Lenses of three focal lengths - 28mm, 50mm and 75mm were used. The images were recorded on professional quality U-matic video cassettes using two Sony VO-8800P VCRs that each had a time code unit, one slaved to the other so that frames on both VCRs were recorded at exactly the same time and could be matched for analysis. The images were monitored in the field using a video monitor with an input that could be switched between the two cameras.

The equipment could be transported in a vehicle to suitable field sites. The VCRs and cameras were battery powered and the monitor was powered by a take-off from the vehicle battery. On arrival at the field site, a calibration image was filmed as described above.

Limits of the systems

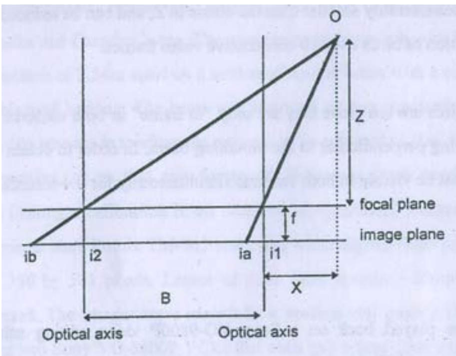
Due to the limits to resolution of the cameras, the maximum distance at which birds can be filmed is about 300m. A calibration trial was conducted which tested both the field and laboratory based systems. The distance to an object placed at 300m, as measured by tape measure, was measured with an error of 2.3% by the system. Errors in X and Y are considerably smaller than the errors in Z, and can be reduced by taking the average position of birds over 10 consecutive video frames. Conversely, if birds are too close they are only "in frame" in both cameras for a very short time, if flying perpendicular to the mounting beam. In order to obtain 10 frames of film, birds must be visible in both cameras simultaneously for 0.4 seconds.

Image analysis

The videos were played. back on a Sony VO-9800P video editing suite with a jog/shuttle facility and individual frames were transferred on to a PC using a Snapper video frame grabber extension card and software that also allowed image contrast, brightness, etc to be altered. Matched frames from each video could be identified by comparing time codes. It is essential that the images from each camera are recorded simultaneously to calculate three dimensional positions.

Once stored as computer image files, the X, Y coordinates of individual birds on each image were measured using the object detecting routines available in Optimas, an image analysis software program. It was obviously important that one could identify the same bird in both images of a pair and this was possible using Optimas by placing them side-by-side on the screen. The pairs of XY image coordinates of each bird were exported to spreadsheet software that automatically returned the real-world XYZ coordinates and nearest neighbour distance for each bird.

The XYZ coordinates of a bird are derived from stereoscopic pairs of XY coordinates by the method of similar triangles. If the separation of the two cameras, the focal length of the lenses, the total extent of the image and the position of the bird on the image are all known, the position of the bird in space can be deduced, viz:



Where:

O = object
Z = distance to *object* along the optical axis of the right hand camera
X= perpendicular horizontal distance to *object* from optical axis of right hand camera
Y = perpendicular vertical distance to object from optical axis of right hand camera
B = camera separation
f= focal plane to image plane distance = focal length of the lens
ia = image position in right hand camera
ib = image position in left hand camera

From similar triangles:
X=(iai 1 z) / f Y = (ydisp z) / f Z=(f B) / (ibi2-iai 1)
Where ydisp is the y displacement from the optical axis.

The camera image position is calculated by scaling down the computer image XY coordinates returned by the Optimas image analysis software.

The Model

The modeling process is carried out using spreadsheet software. The XYZ coordinates of the flock are normalised, that is to say the origin of the coordinates system is moved from the camera to a corner of the flock. A set of random trajectories are generated for aircraft components through the flock and the number of strikes in each pass is recorded as 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 center line of the trajectory will be counted as being struck. More complex shapes such as windshields can also be modeled. The trajectories are limited so that they are never steeper than the maximum climb out angle of an aircraft.

In order to use the model predictively, it would be desirable to relate flock density to a biometric factor such as wingspan. To this end it is convenient to use a single figure to categorise flock structure. One such term is the flock's mean NND, alternatively one could use a term obtained from the histogram described above, such as the mean number of birds struck or the 95th percentile (ie the maximum number of birds struck from all passes through the flock, excluding the most severe 5% of cases). This is a useful term for aero-engineers as it describes the flock in terms of its birdstrike hazard. if the 95th percentile of a species is found to be proportional to its wingspan, it would be possible to predict the birdstrike risk of any species from its wingspan alone. Taking the value of the 95th percentile as the number of birds used in a multiple impact test ensures that the test is stringent enough to describe 95% of likely multiple ingestions. Other values such as the 90th or 99th percentiles could be used if a more or less stringent test were required. 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.

Results

Charts 1 to 5 show the positions in three dimenstions of birds in an example flock of each species.

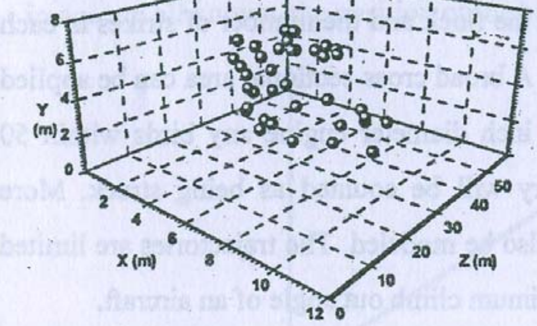


Chart 1. Starling

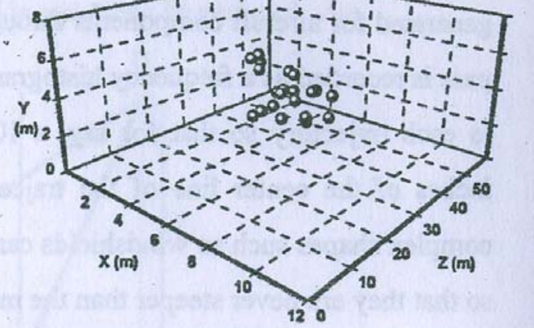


Chart 2. Rock Dove

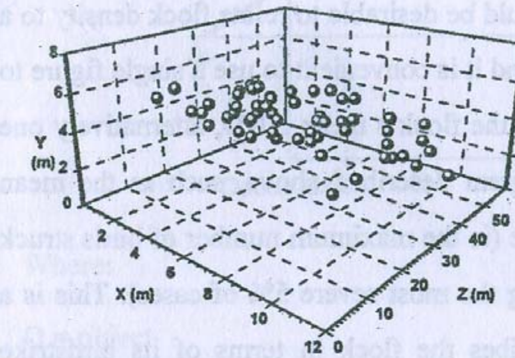


Chart 3. Lapwing

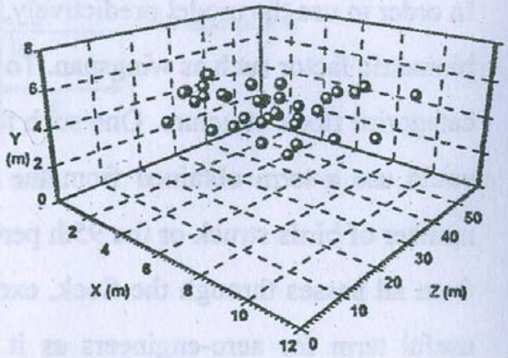


Chart 4. Mixed Gulls

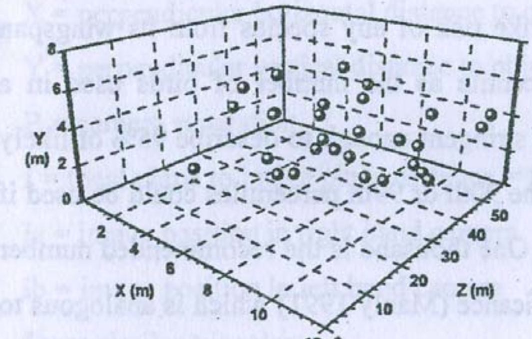
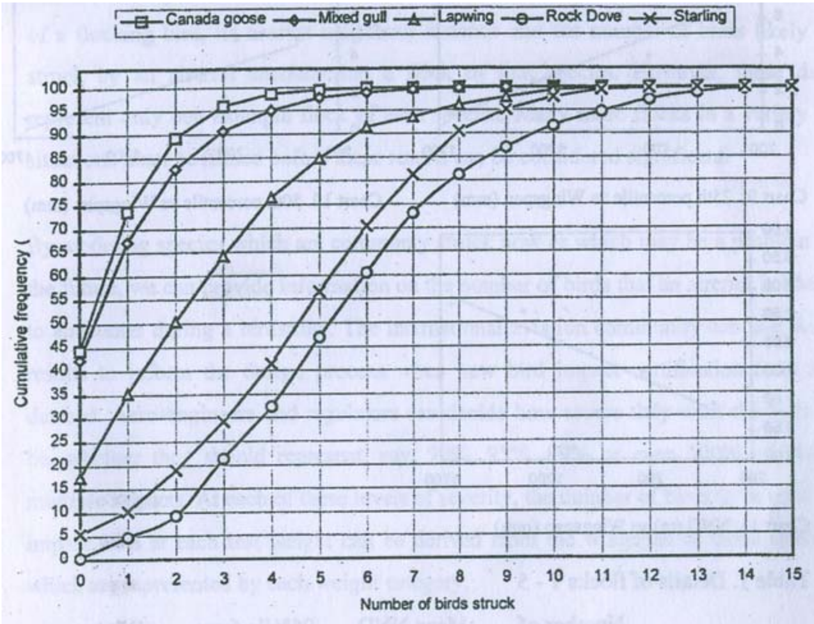


Chart 5. Canada Goose

Chart 6. Results from running the model – the cumulative frequency of striking a given number of birds for 1,000 passes of a 100 inch diameter jet engine through each of the flocks shown in charts 1 to 5.



From this chart it is possible to choose a value of cumulative frequency, say 90% or 95% and investigate the relationship between that value and the wingspan of each species, as shown in charts 7 to 10. Chart 11 shows the relationship between wingspan and NND for the five flocks described here.

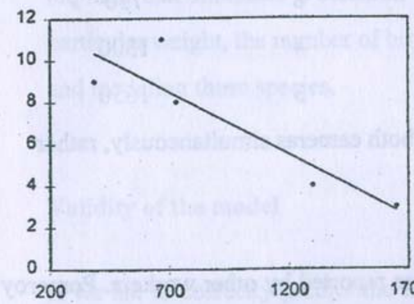


Chart 7. 95th percentile vs Wingspan (mm)

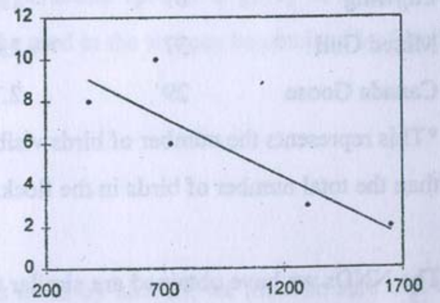


Chart 8. 90th percentile vs Wingspan (mm)

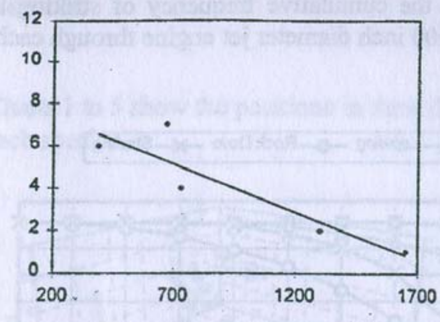


Chart 9. 75th percentile vs Wingspan (mm)

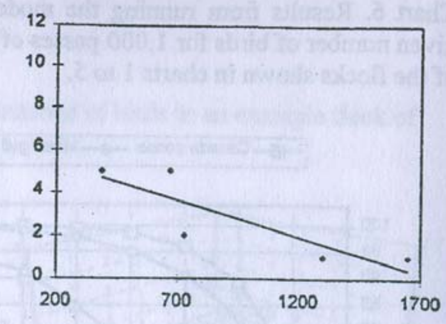


Chart 10. 50th percentile vs Wingspan (mm)

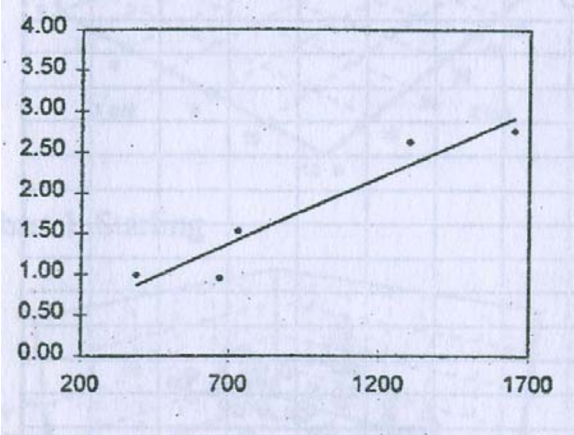


Chart 11. NND (m) vs Wingspan (mm)

Table 1. Details of flocks 1- 5

	Number of birds in flock*	Mean NND (m)	95%ile from model	Wingspan (mm)
Starling	38	0.99	9	387
Rock Dove	21	0.95	11	670
Lapwing	61	1.53	8	730
Mixed Gull	37	2.62	4	1300
Canada Goose	29	2.76	3	1650

*This represents the number of birds visible to both cameras simultaneously, rather than the total number of birds in the flock.

The NNDs we have obtained are similar to those reported by other workers. Pomeroy and Hepner recorded Mean NNDs of about 1.2 meters for Rock Dove and Dill and Major found NNDs of 0.63 meters for Dunlin and 1.33 meters for Starling.

Discussion

From the data presented above, there is an apparent relationship between the wingspan of a flocking bird, its nearest neighbour distance and the number of birds likely to struck by an aircraft encountering a flock of that species. However, these data represent only one example flock of each species. Many more flocks in a variety of situations must be filmed before these results can be considered significant.

By modeling species which are commonly struck now or which may be a problem in the future, we can provide information on the number of birds that an aircraft is likely to encounter during a birdstrike. The international aviation community can use these results to inform the design process when new bird impact certification tests are devised. Aero-engineers and regulators can decide how severe they want the tests to be, whether they should represent, say, 90%. 95%, 99% or even 100% of likely multiple impacts. At each of these levels of severity, the number of birds to be used in impact tests at each test weight can be derived from the wingspan of those species which are represented by each weight category.

Even if the relationship between wingspan and flock density that we have suggested does not remain valid as *further* data are collected, we have described a method which can directly measure the birdstrike threat posed by any species of bird; if a test is required that simulates a collision with a particular species or group of species of a particular weight, the number of birds to be used in the test can be obtained by filming and modeling those species.

Validity of the model

If we are to correctly predict the hazards faced by aircraft, we must be sure that the flocks we are modeling are representative of flocks that are likely to be struck throughout the world.
One of the most important factors regulating the number of birds that can be struck is the number in the flock. It is particularly important that impacts are modeled with flocks of a size representative of those found on or close to airports. Further fieldwork or literature study will be required to determine these flock sizes. Even if one were unable to film flocks of the required sizes, the size of the flock used in the model could be adjusted to this level. However this would be to assume that flocks of different sizes are similar in structure - it is possible that bird separation varies as *flock size* increases.

The shape of flocks is also important. If *flocks* tend to extend in only one dimension as numbers increase, ie they become "sausage" shaped, then it is unlikely that increasing size will affect the birdstrike hazard unless an aircraft were to fly down the long axis of the flock. If flocks did exhibit this type of overall shape, it may only be necessary to, obtain data for flocks up to a certain size if the probability of an aircraft flying down the long axis of the flock were sufficiently low.

The structure of bird flocks is of great interest to biologists and several possibilities have been suggested to explain why different flocking strategies are adopted. The 'V' shape typical of long distance migratory goose skeins probably results from an attempt to reduce the energy cost of flying (Speakman and Banks, 1998). When transiting short distances, for instance from roosting site to feeding site, geese f°rm much looser, less structured flocks. The structure of flocks found in species such as Starling, Lapwing, etc is probably an anti-predatory adaptation such as is found in many groups of animals (Bertram, 1978). The large number of possible prey to choose from is bewildering to a predator and the probability of any individual being caught is reduced when in a group. Birds on the periphery of such flocks are at greater risk of predation and continually try to obtain a better position in the flock (Pommery and Heppner, 1992). The structure of this kind of flock may be different when a predator or other threat is actually present compared to when the birds are being normally vigiIant, such as flying to and from a roost site, so flocks exhibiting a wide variety of behavoiurs, especially those common close to airfields, should be filmed for modeling. The reaction of birds to approaching aircraft has been little studied, but it is possible that they have avoidance behaviours which will decrease their likely hood of being struck. This behaviour may be dependent upon their perception of the threat posed by approaching aircraft. Cuthill and Guilford (1990) found that the perception by Starlings of the risk from obstacles placed in the way of their food source was dependent upon hunger level. The reaction of birds to aircraft may depend upon how they perceive the threat at the time. This clearly has implications for aerodrome bird control but it also means that the behaviour and structure of flocks filmed may not be the same as that of flocks in the vicinity of aircraft. Filming of flocks on or close to airfields will therefore be required.

Conclusion

Clearly a great many more flocks have to be modeled. If data obtained by this method are to be used to formulate new impact tests, sufficient species have to be studied so that we can establish whether the wingspan/flock density relationship is valid, or if it is not, to determine which representative species at each test weight category must be modeled. Within each species, it is necessary to collect data on flocks containing wide range of bird numbers to see whether this affects nearest neighbour distance and overall flock shape. Similarly the effect of different behaviours on flock structure should be investigated, preferably close to airfields. The size of flocks likely to be struck by aircraft should be established by field observations or literature study.

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