BIRD STRIKE AS AN ENGINEERING PROBLEM

Yasushi Takeda, Prof. Dr.[1,2] Yuichi Murai, Prof. Dr.[1]

[1] Graduate School of Engineering, Hokkadio University, Sapporo, Japan
[2] Solution Science Research Laboratory, Tokyo Institute of Technology, Tokyo, Japan
Email : yft@eng.hokudai.ac.jp

ABSTRACT

Two topics in the field of risk assessment of bird strike are revisited and considered as an engineering problem. The two height distributions of the number of bird strike (civilian and military data) are reviewed and the original data was re-casted for equal bin size of statistics. The result indicates that the distribution follows the exponential declination with respect to the altitude, which is represented by two lines with breaking point at 3000 ft for civilian and 5000 ft for military data. This exponential declination is supported by a simple theoretical model of bird population. "Fly slower" principle is discussed based on the concept of bird flux and it is shown that the principle is valid even for lowering the collision probability irrespective of the scale of damage.

Key Words: Height distribution, Exponential declination, Collision probability, Bird density, Bird flux

INTRODUCTION

Aviation is highly technological and its operation relies on engineering of all sorts. Bird strike is a problem where the highly engineering system suffers directly from natural life. The activity of natural life is pretty unpredictable, although some general characteristics are known. Risk assessment of bird strike is important for improving its social acceptance as well as economical configurations.

Basic methodology for assessing the risk of bird strike is said to be too reactive. This is because the statistical analysis only is quantitative and other consideration and discussion are qualitative. Building a BAM system appears to be proactive, but it seems that its reliability is still low, since the nature of the risk is too complex to model and the available technology is still too little powerful to cover a range of risk items and factors. For improving the situation, it is necessary to combine both of these efforts. Namely, usage of the knowledge of natural science such as ornithology and zoology is expected to ease the proactive risk assessment by reducing the number of items and factors to be included in the analysis by using the various models.
In this paper, we revisit two results of analysis on the features of bird strike; height distribution and fly slower principle, and discuss in engineering methodology.

HEIGHT DISTRIBUTION

It is known that a huge dataset of records of bird strike has been accumulated for more than ten years and they have been analysed, but mainly for statistics. According to these statistics, it was clearly shown that the risk of bird strike has been increased in a quite substantial rate for the last ten years. Detail analysis of these statistics has given us, however, little progressive information to help making quantitative evaluation, and it remains only as statistics.

One of the important findings, however, is clear evidence on the height distribution of the bird strike made by Dolbeer (2006). In his paper, as quoted here in Fig.1, "the number of reported strikes declined consistently in height", and it shows an exponential decay with decay constant of -0.3846. He also stated that "exponential decay in height suggests some fundamental relationship to some physical parameters", but did not hint any reasoning for this type of relationship.

Replotting in semilog scale

A detail dataset was digged out and first replotted, as in Fig.2 in the semilog form of plotting. This is quite typical in describing engineering problems. By this type of engineering representation of the result, two findings made by Dolbeer (2006) are better shown; an exponential declining of the strike is clearly shown by its linear tendency with negative slope, and an extremely large portion of the strike occurrs below the AGL of 500 ft. A simple change of the way of representation like this reveals another feature that the line is broken at the AGL of 10k ft, showing a few times larger than that of below this AGL. This was not stated in the original paper.

Fig.1 Height distribution of bird strike (Dolbeer 20[...]   **Fig.2 Same data plotted on semilog scale.**
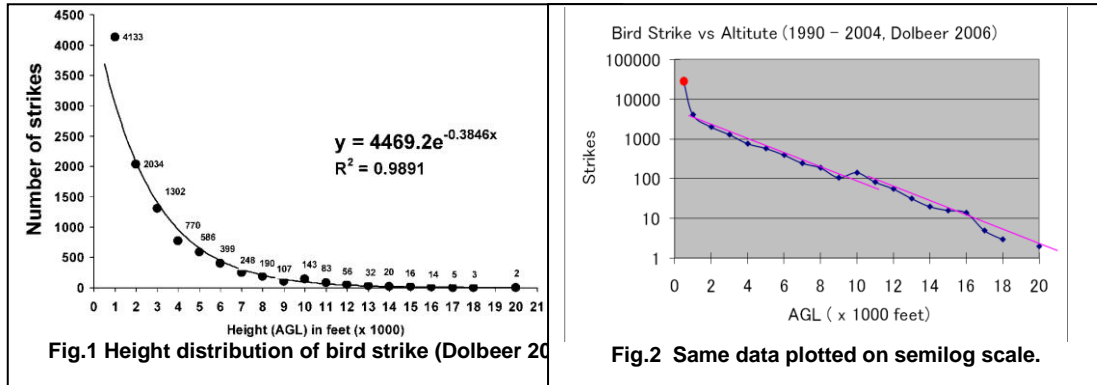
Unequal bin size

It was interesting to study the reason for this new finding, but more interesting was found (FAA 2009) that the statistics was made by unequal bin size. The number used here is the count of reported strikes occurring within a certain height interval at that altitude. It is an integral value of the strikes for that height interval and thus the same interval should be used for comparison. It was, however, using the unequal bin size (interval), which indicates an invalidity of the statistics. They collected the counts for the bin size of 100 ft below 1000 ft, 1000 ft from 1000 to 5000 ft and 5000 ft above 5000 ft. By guessing the large uncertainty of the reported altitude of the strikes and the number of occurrence, it is understandable to use the larger bin size for counting, but we have to say it is not appropriate to use the number for comparison.
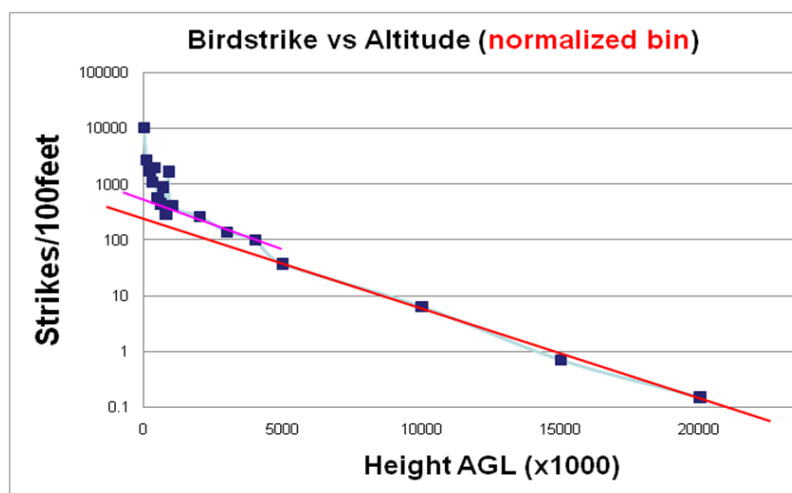

**Fig.3 Height distribution for a normalized bin size**

So, we recalculated the table and the number was evaluated for the normalized bin size of 100 ft. The result is shown in Fig.3. It still shows a clear exponential decrease in height, but it does not show any sign of breaking the line at the AGL of 10k ft. The breaking point is now shifted to the

lower altitude, and the tendency of the strike risk is higher for the lower altitude, in contrast to the earlier finding.

Military dataset

Air Force Safety Center supplies us a good data set "strikes by altitude", which is plotted in Fig.4, and it was used by Le Boeuf (2006) for his briefing. He indicated three main ranges of height having high statistics with corresponding cost – Airfield, Low-Level range and the traffic pattern.

Again, this data set is constructed using the unequal bin size of altitude as by Dolbeer, and we normalized the counts for equal bin size of 100 ft. Like for the Dolbeer's case, the result (Fig.5) shows different features from its original plotting by Le Boeuf, namely, there is no bump in the distribution showing smooth linear relationship as a height distribution. There are two approximated lines in the distribution above 500 ft. This feature is quite similar to the civilian data, although the breaking altitude is different; at 3000 ft for civilian and 5000 ft for military. Below this breaking altitude, the count is two to three times larger.

Fig.4 Height distribution for military bird strike.

Fig.5 Normalized for equal bin size of 100 ft.
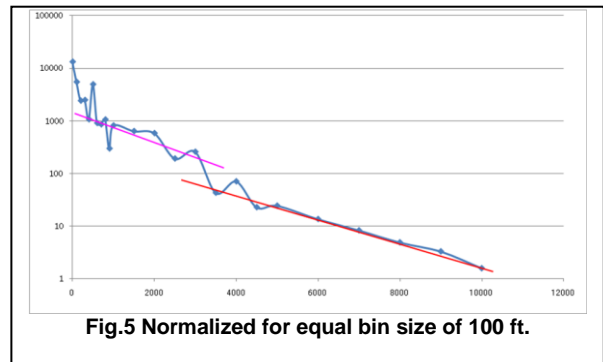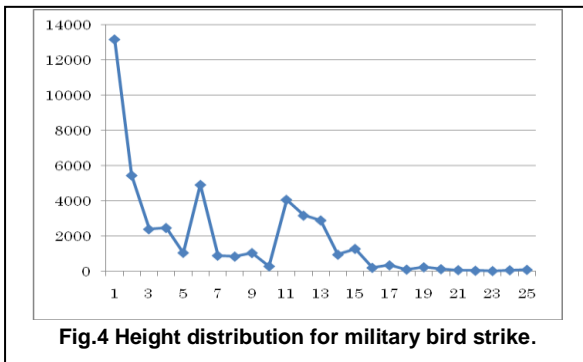
Exponential declination

For trying to model the height distribution discussed so far, and to explain the finding by Dolbeer, we postulate that the bird strike occurs in proportion to the bird population. That is, the more bird strike occurs where the bird population is larger. The number of birds to be counted (bird population), dN, at altitude x is proportional to the number of birds in the adjacent altitude and the size of the counting volume dx.

$$dN = -\alpha N dx$$

Then the equation and its solution is given as following, with boundary condition being that the population is highest (N_0) at ground level (x=0) and zero at the infinite height ;

$$\frac{dN}{dx} = -\alpha N \qquad\qquad N = N_0 \exp^{-\alpha x}$$

Using this model, it is easily explained why it shows an exponential declination with height. It will be interesting to pursue what the declination constant is and if it agrees with Dolbeer's finding of 32% declination per every 1000 ft.

"FLY SLOWER" PRINCIPLE

It is often stated that the reason for the larger damage in the lower altitude just after take-off and during a climb is its high speed and larger kinetic energy released by collision which is represented by equation of $E=mv^2/2$. It is also emphasized that speed is more important than mass since released energy is proportional to a square of speed (Dolbeer 2007). This reasoning has led to a

discussion on a change of fan blade design (Demers 2009). This problem was investigated related to an engine design in earlier time to study the way how and in what form the total energy is released to become a burden on the engine blade (Frischbier 2002). This might be the case for assessing a degree of damage after an ingestion of birds, but it seems to have nothing with lowering a collision probability, on which we will discuss and we think it most essential.

Collision probability

Obviously there are too many variables which are involved in the quantitative assessment of bird strike risk, but it would be reasonable to assume that the total bird strike hazard rate is determined by a collision probability times damaging factor. Damaging factor may consist of a damage function which determines the scale of damage and an operation function which determines the influence on the operation. The main item we treat here is a collision probability, and we may be able to say that lowering the collision probability is a key issue for lowering the bird strike risk. Then, collision probability is determined by a bird distribution function and aircraft distribution function. Bird distribution function, B, is a function to represent where and when birds exist and a function of space and time as $B(x,t)$. Aircraft function is defined in the same manner as for the bird distribution function as $A(x,t)$. Consequently, we define that collision probability S as

$$S(x,t) \equiv B(x,t) \cdot A(x,t)$$

It should be noted here that both functions are probability function and would not give any absolute magnitude of the risk.

Bird flux

As so defined that function B is a probability function for bird to exist in the field and A for aircraft, at a fixed position in space as aerodrome x_a probability of collision might be represented as

$$S(t) = B(x_a,t) \cdot A(x_a,t) = B(t) \cdot A(t)$$

Since bird function B is a probability of birds to be there and birds are in motion, B is not a simple number density but a flux of birds passing the area of interest with velocity v_B. A bird flux is then defined as a number density multiplied by velocity as $N_B(x_a,t)v_B$ so that it is a vector quantity. The same concept can be applied to aircraft function but with $N_A = 1$ and velocity v_A. Finally, collision probability S is given as

$$S(t) = N_B(x_a,t)v_B \bullet v_A$$

This reads that the larger flock is more problematic since N_B is a number density and S is proportional to it. Namely, if N_B is large, S becomes large and if there is no bird ($N_B=0$), no collision would occur. By a similar consideration on this equation, if v_A is smaller, collision probability is smaller. For instance, if the aircraft stays at rest, there should happen no collision.

The concept of bird flux confirms that the "fly slower" principle is valid even for a collision (irrelevant to a scale of damage); if the flying speed is smaller relative to the motion of birds, collision probability decreases.

Velocity, not speed

The motion of birds and aircraft is directional. They fly/move with their speed to a certain direction so that their motion is represented by vector quantity, v_A and v_B . Collision probability is given by a scalar product of these two vectors since they should produce a scalar quantity and also the orientation of two vectors is relevant. If the flight direction of airplane is perpendicular to the flight path of the bird, collision probability is zero (as the model has no size of the objects.)

Treating the motions in vector form is important and sometime mentioned (e.g Morgenroth 2003). Recently, Illinois group tried to formulate the collision probability and to include the effect of flight direction between two objects (Wang, 2010). In order to construct a theoretical basis for risk assessment, further consideration is needed on the way of viewing the problem as a field value.

CONCLUDING REMARKS

We have revisited two important topics used in the field of risk assessment of bird strike. Height distribution (the number of strike reported with respect to the altitude) was re-evaluated and it was found that the distribution is exponential and the slope of the line breaks at a certain altitude. The result shows that the feature is same for civilian and military flight although the altitude of the line breaking is slightly different. The model of bird population confirms the exponential distribution. "Fly slower" principle was discussed based on the concept of bird flux and it was shown that the principle is valid and effective for lowering the collision probability irrespective of scale of damage. Further study is needed to establish the theoretical basis for quantitative consideration of the risk assessment of bird strike.

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