WP 18

EVALUATING THE BIRDSTRIKE THREAT TO AIRCRAFT WINDSHIELD SYSTEMS - A PROBABILISTIC APPROACH[1]

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Figure 1 - The purpose of this report is to briefly describe and illustrate a recent effort to analyze the potential risk of birdstrike damage to an aircraft windshield system.

Figure 2 - This development affords us another weapon for use in our bird war battles. The technique results in predicting the probability of birdstrike damage thru statistical consideration of 4 factors: Number of impacts, bird weight, impact velocity, and impact component strength.

Figure 3 - The approach which will be taken in describing this technique is to briefly describe the statistical model formulation, describe the components of the model, apply the technique and summarize the findings to date.

Figure 4 - The technique was formulated by Dr. John Halpin, USAF, during his efforts to assess the adequacy of windshield system birdstrike protection being designed into a new aircraft. Subsequent model development, analysis and documentation were performed by the University of Dayton Research Institute (UDRI). The effort at UDRI was sponsored by the Air Force Flight Dynamics Laboratory. Principal investigators at UDRI were: A. Berens, B. West, and M. Turella.

Figure 5 - Regardless of preventive measures, birdstrikes will occur. USAF experience is that there are about 35 birdstrikes per 100,000 flight hours. It is obviously unrealistic to protect against all levels of potential birdstrikes, so the general approach, as you all well know, is to pick a protection level which is felt to reasonably represent the risk to be encountered. However, once this desired protection level is established, we must consider two questions: "What happens if I hit a bigger bird at a slower speed or a smaller bird at a higher speed?" and, "How likely is such an occurrence?" The answers to these two questions are, of course, a function of such things as geographical location, aircraft altitude, aircraft mission, and aircraft design. An ability to analytically assess this risk to a transparency system, from birdstrike hazards other than those for which it was designed, is truly needed. It is this need which prompted the work being reported on today.

Figure 6 - What are the factors which influence whether a birdstrike will result in damage to the windshield system? Intuitively, the probability of damage due to a single birdstrike is a function of the bird weight, the

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[1] Oral presentation outline for use at the Birdstrike Committee Europe Meeting in The Hague, Netherlands during 22-26 October 1979.

impact velocity, and the strength of the impact point. Carrying this intuition one step further, the probability of birdstrike damage during a flight is then the probability of damage due to a single birdstrike times the expected number of birdstrikes. It was hypothesized that if each of these factors could be identified in a statistical fashion, there should be some manner of mathematically combining them.

Figure 7 - The model formulated by Dr. Halpin was based on the premise that the expected number of birdstrikes can be predicted and that damage will result when the kinetic energy from a birdstrike is greater than some critical level. It was assumed that a velocity distribution for the aircraft and weight distribution for the birds could be combined to predict a probability distribution for kinetic energy. By assuming that the ability of any given windshield system to defeat a birdstrike is essentially related to impact kinetic energy and impact location, we can identify the proportion of the windshield system which will be damaged as a function of birdstrike kinetic energy level. Mathematically combining the kinetic energy probability distribution with the critical strength level distribution will produce the probability of damage due to a single birdstrike. Combining the expected number with the probability of damage yields the expected number of damaging birdstrikes.

Figure 8 - Let's take a brief examination of how these terms can be quantified. The first one is the expected number of strikes. The equation is not new to those of you who have worked with this problem. D represents the birds per unit volume through which the aircraft is flying and $A\bar{V}T$ represents the volume swept by the component of concern. It is important to note that in computing the values for these terms, there is a necessity to give serious attention to the environment of concern. It must be relevant to the specific problem being addressed and must be common for each of the terms. The expected number of damaging birdstrikes, as opposed to the expected number of strikes, is then the expected number of strikes times the probability that any one strike will result in damage. The probability of a birdstrike causing damage is obtained by an integration which considers the probability that a specific kinetic energy will occur, and the probability that damage will occur at that kinetic energy.

Figure 9 - It is this computation of the probability of damage which represents Dr. Halpin's major contribution. Mathematically, this term relates the probability that a specific KE will occur and the probability that damage will result at this KE. It combines the bird weight distribution, f(w), the impact velocity distribution, f(v), and determines the probability that the resulting kinetic energy will exceed the critical value necessary to result in damage.

Figure 10 - Let's now take a look at how this technique was applied to a situation which would seem representative of the necessity to assess the risk of birdstrike damage. We have an existing aircraft where mission profiles are being revised to improve low-altitude proficiency. Those responsible for flight safety were concerned with the increase in birdstrike risk due to the increased low-altitude flying time. Information was needed which they could use in considering both the effects of additional flight time in the birdstrike environment and the effects of improving

windshield system birdstrike resistance. In short, what is the birdstrike risk to the crew and the aircraft due to increased low-altitude flight time, and what modifications of the windshield system would be required to reduce this risk.

<u>Figure 11</u> - We know that there are four factors required to use the probablistic approach: the expected number of birdstrikes, the bird weight distribution, the velocity of impact distribution and the windshield system strength distribution. Let's take a brief look at how values were computed for these four parameters.

<u>Figure 12</u> - Factor 1, Expected Number of Birdstrikes. Birdstrike records for this specific aircraft were on hand so these were used along with operational records of velocity by altitude band to establish the expected number of birdstrikes per 100,000 flight hours. The equation was left in terms of average velocity and percentage of flight time below 5,000 feet so that it could be used to consider the effects of increased low-altitude missions.

<u>Figure 13</u> - Factor 2, Bird Weight Distribution. Birdstrike records for this specific aircraft were again used in establishing the bird weight distribution characteristics. The records show a specific quantity of birdstrikes occurring over a period of time. A certain percentage of this quantity was identifiable as to type of bird. This ratio of identifiable types was then assumed to exist for the entire quantity. Bird weight reference data was used to establish the weight distribution. The resulting cumulative distribution curve for this bird weight is as shown in the figure.

<u>Figure 14</u> - Factor 3, Velocity Distribution. Operational records for this specific aircraft were used to establish the representative cumulative velocity distribution profile shown in the figure. The equation for the curve allows consideration of the effects on the overall distribution through increasing the quantity of low-altitude flights.

<u>Figure 15</u> - Factor 4, Strength Distribution. Based on prior birdstrike testing of this aircraft windshield system, a strength distribution profile was computed by assuming that failures were representative of failure at a kinetic energy level. Based on current windshield system state-of-the-art, including operational considerations such as cost, weight, and visibility, a series of possible design modifications were established. Strength distribution profiles for these system modifications were estimated as shown. Now that all four factors are mathematically defined, let's see what the technique predicted.

<u>Figure 16</u> - Predicted windshield system birdstrike penetrations for a ten-year period are shown. Note that there are four different versions of missions; the existing mission, and the existing mission with multiple increments of low-altitude flights. Note also that there are 4 different versions of the windshield system; the existing system and then 3 modifications of that existing system. Since I haven't presented you with the exact numbers which were used in applying the technique the specific numbers have little meaning to you other than that they show trends and the significant

improvements attainable through any one of the system modifications. Design options which will allow implementation of any one of the modifications are currently being pursued. Final selection will be made by about mid-1980.

Figure 17 - But how realistic are these predictions? A prediction technique such as this produces results which are only as realistic as are the inputs. Examining model sensitivity to inputs revealed that results can vary quite significantly. The approach used to get a measure of how realistic were the predictions, was to take a backward glance at how well this model would have predicted losses over a ten-year period ending with the current period. These loss predictions could then be compared with the actual losses and hopefully the results would indicate some degree of realism between model and actual results. Flight records for the ten-year period for this specific aircraft revealed that the canopy experienced 17 birdstrikes with roughly 6-8 of these being recorded as "failures." The windshield experienced 29 birdstrikes with roughly 1-2 of these being recorded as "failures." The "failures" were representative of penetration or significant fracture and partial loss of a portion of the canopy. Resulting probabilities of failure were as shown on the figure. Applying the probabilistic technique for the same time period resulted in a predicted probability of failure as shown. The correlation between the actual and the predicted was rather reassuring.

Figure 18 - We have a risk assessment technique which is available for use in the continuing bird war battle. The technique is sensitive to bird density, bird weight, impact velocity, and impact area strength distributions. This sensitivity has both negative and positive implications. On the negative side it permits either accidental or intentional bias to distort the results. On the positive side it permits consideration of specific alterations to the input data and thus, allows recognition of the overall problem complexity. The ability to derive the prerequisite distributions from operational data improves confidence in the resulting risk assessment as these distributions, if selected with care, can truly represent the specific operational environment of concern. Applications where all four distributions must be hypothesized, such as for a new aircraft in a new role, thus involve the highest risk of improper interpretation of results. Applications involving lower risk in interpreting the results are those where fewer distributions must be hypothesized, as opposed to derived from operational data. For example, changing operating locations with a given aircraft and mission profile or changing mission profile without changing aircraft or operating location. Investigations have shown that the sensitivity of the technique can be reduced, if desired, through future model developments. Until such development is accomplished, however, it is felt that the technique does have current application providing realistic distributions for the four factors are established representing a common operational environment of concern.

BACKUP FIGURES

A. Characteristic distribution shapes. Weight and velocity distribution are of the Weibull type; strength distribution is of linear segments.

B. Computation of probability density function of impacting kinetic energies.

EVALUATING THE BIRDSTRIKE THREAT TO AIRCRAFT CREW ENCLOSURES - A PROBABILISTIC APPROACH

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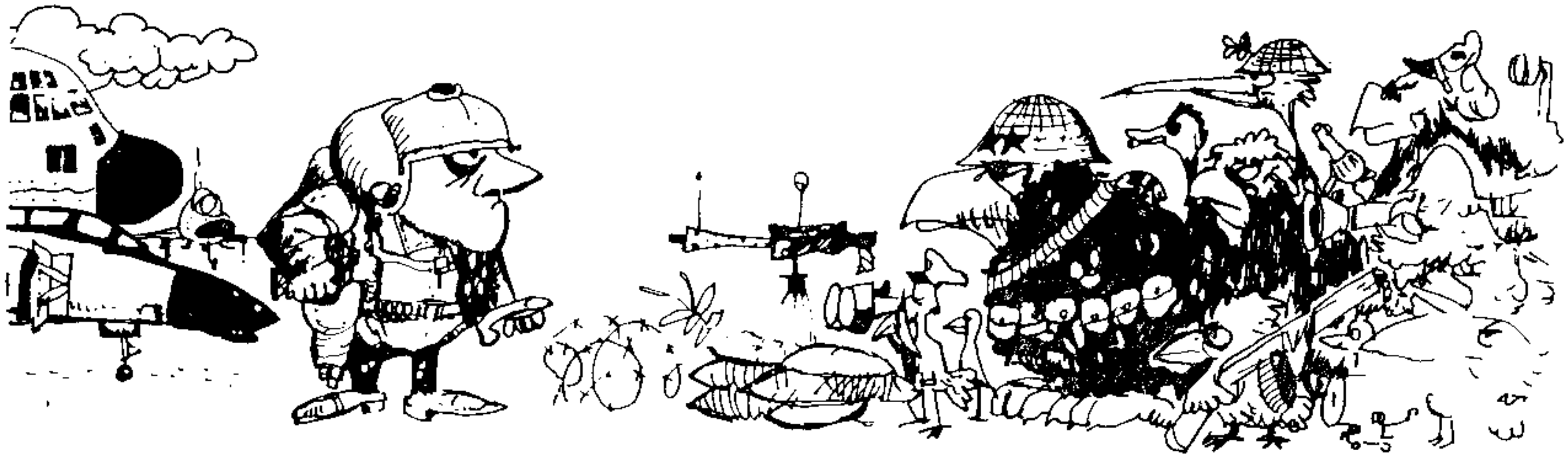
FIGURE 1



BIRD WAR

OUTLINE

- PROBLEM = NEED
- STATISTICAL MODEL FORMULATION
- MODEL COMPONENTS
- MODEL APPLICATION
- SUMMARY

FIGURE 3

ACKNOWLEDGEMENT

BASED ON AN INITIAL MODEL FORMULATED BY DR. J. HALPIN, USAF, W-PAFB, OHIO. SUBSEQUENT MODEL DEVELOPMENT, ANALYSIS AND DOCUMENTATION PERFORMED BY UNIVERSITY OF DAYTON RESEARCH INSTITUTE (UDRI), DAYTON, OHIO. UDRI EFFORT SPONSORED BY USAF FLIGHT DYNAMICS LABORATORY, W-PAFB, OHIO.

UDRI PRINCIPAL INVESTIGATORS:

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B. WEST
M. TURELLA

FIGURE 4

BIRDSTRIKES -

-DO OCCUR

- PROTECTION LEVEL CAN
  BE SPECIFIED AND VERIFIED

- NEED RISK ASSESSMENT CAPABILITY

FIGURE 5

FACTORS OF INFLUENCE
-INTUITIVE-

- PROBABILITY OF BIRDSTRIKE DAMAGE DUE TO A SINGLE BIRDSTRIKE = P(D)
    - BIRD WEIGHT
    - IMPACT VELOCITY
    - STRENGTH OF IMPACT POINT
- PROBABILITY OF BIRDSTRIKE DAMAGE DURING A FLIGHT
    - P(D) × (EXPECTED NUMBER OF STRIKES)

FIGURE 6

STATISTICAL MODEL FORMULATION

ASSUMPTIONS

- EXPECTED NUMBER OF BIRDSTRIKES CAN BE PREDICTED
- DAMAGE WILL RESULT WHEN :
  KINETIC ENERGY $\geq$ CRITICAL LEVEL
  - KE IS PREDICTABLE:
    - VELOCITY DISTRIBUTION
    - BIRD WEIGHT DISTRIBUTION
  - CL IS PREDICTABLE:
    - AREA OF "DAMAGE" KNOWN AS FUNCTION OF KE

FIGURE 7

EXPECTED NUMBER OF STRIKES:

$E_{(n)} = D\ A\ \overline{V}\ T$

D = OPERATIONAL BIRD DENSITY WITHIN ENVIRONMENT OF CONCERN

A = FRONTAL AREA OF CONCERN

$\overline{V}$ = AVERAGE VELOCITY WITHIN ENVIRONMENT OF CONCERN

T = TIME WITHIN ENVIRONMENT OF CONCERN

EXPECTED NUMBER OF DAMAGING BIRDSTRIKE:

$E_{(N)} = E_{(n)}\ P(D)$

$P(D)$ = PROBABILITY OF A BIRDSTRIKE CAUSING DAMAGE

FIGURE 8

PROBABILITY OF A BIRDSTRIKE CAUSING DAMAGE

$$P(D) = \int_{0}^{\infty} P(KE)\ P\ (D/KE)\ dKE$$

P(KE) = PROBABILITY DENSITY FUNCTION OF IMPACTING KINETIC ENERGIES.
CALCULATED FROM f(W), BIRDWEIGHT DISTR, AND f(V), VELOCITY DISTR.

P(D/KE) = PROBABILITY OF DAMAGE AT AN IMPACT KE LEVEL.

FIGURE 9

APPLICATION

SITUATION

- EXISTING AIRCRAFT
- LOW ALTITUDE MISSION QUANTITY BEING INCREASED
- NEED BIRDSTRIKE HAZARD ASSESSMENT AS FUNCTION OF
  - LOW ALTITUDE MISSION QUANTITY
  - WINDSHIELD SYSTEM BIRDSTRIKE PROTECTION LEVEL

FIGURE 10

INFORMATION REQUIRED
TO USE THE PROBABILISTIC APPROACH

1. EXPECTED NUMBER OF BIRDSTRIKES

2. BIRDWEIGHT DISTRIBUTION

3. VELOCITY DISTRIBUTION

4. WINDSHIELD SYSTEM STRENGTH DISTRIBUTION

FIGURE 11

1. EXPECTED NUMBER OF BIRDSTRIKES

$$E(n) = DA\bar{V}T$$

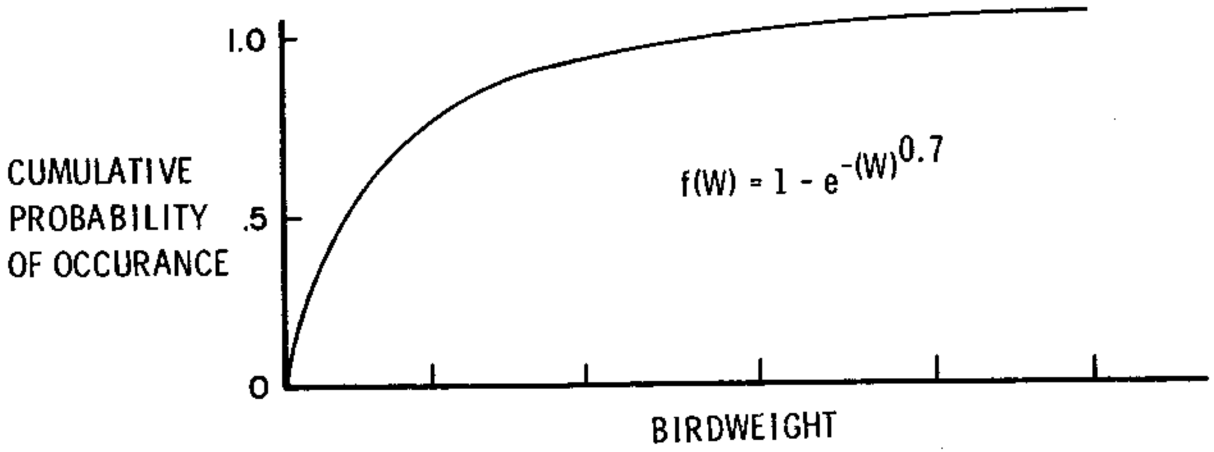
- BIRDSTRIKE RECORDS FOR SPECIFIC AIRCRAFT
- OPERATIONAL RECORDS OF VELOCITY BY ALTITUDE BAND

$$\frac{E_{(n)}}{100{,}000 \text{ flight hours}} = \left[\bar{V}\ (.012)\right]\left[\%T \text{ at ALT.} < 5{,}000 \text{ ft.}\right]$$

FIGURE 12

2. BIRDWEIGHT DISTRIBUTION

- BIRDSTRIKE RECORDS FOR SPECIFIC AIRCRAFT
- BIRDWEIGHT CHARACTERISTICS REFERENCE DATA *

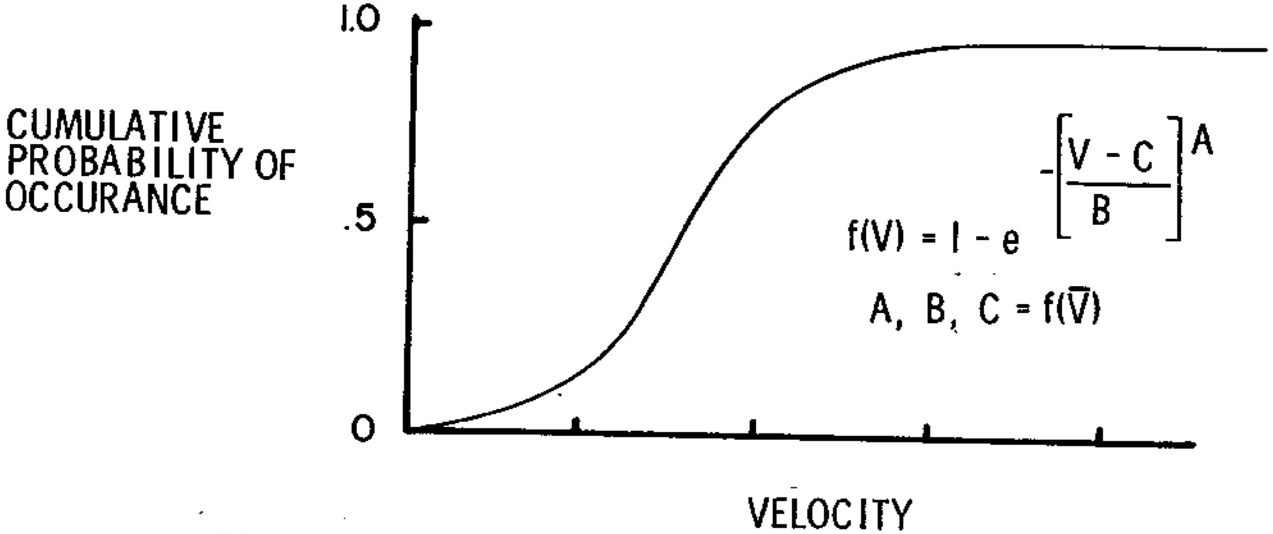


* AFFDL-TR-73-103 'WINDSHIELD BIRD STRIKE STRUCTURE DESIGN CRITERIA' J. H. LAWRENCE AND M. J. COKER

FIGURE 13

3. VELOCITY DISTRIBUTION

- OPERATIONAL RECORDS
- ADDITIONAL LOW ALTITUDE MISSIONS



$$f(V) = 1 - e^{-\left[\frac{V - C}{B}\right]^{A}}$$

$$A,\ B,\ C = f(\overline{V})$$

FIGURE 14

4. STRENGTH DISTRIBUTION

- PRIOR BIRDSTRIKE TEST RESULTS
- BIRDSTRIKE RESISTANCE STATE OF THE ART
- OPERATIONAL CONSIDERATIONS,
  COST, WEIGHT, VISIBILITY, ETC.

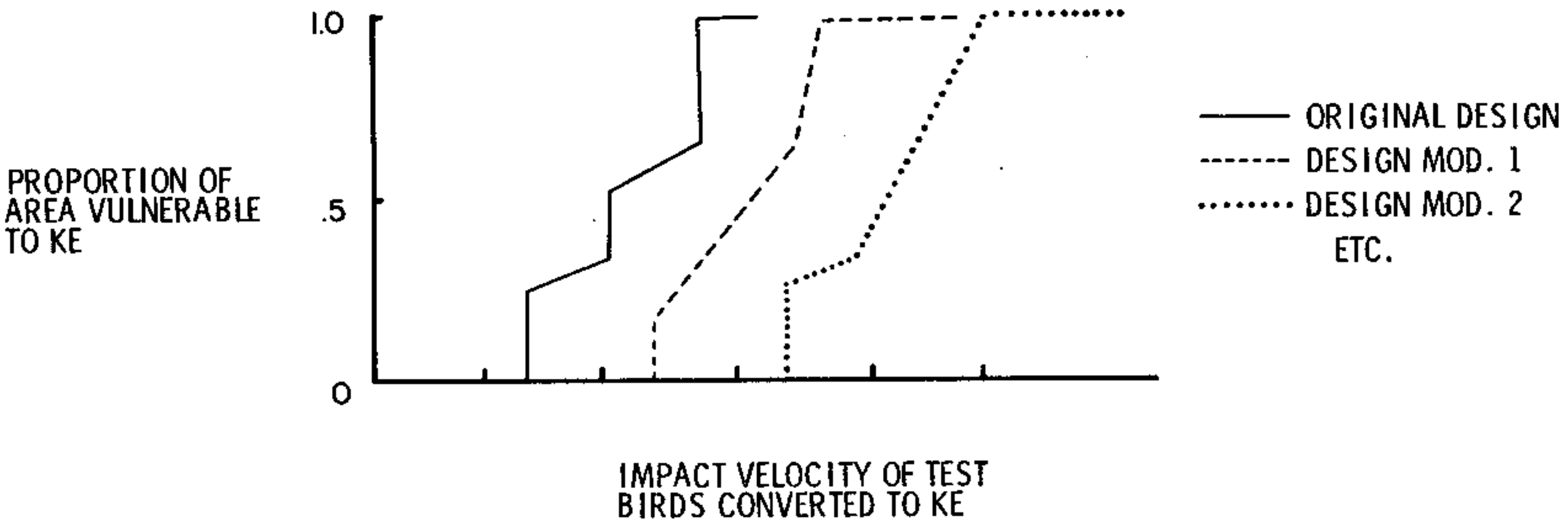


FIGURE 15

RESULTS

PREDICTED PENETRATIONS

(10 YEAR PERIOD)

MISSIONS	**WINDSHIELD**	**SYSTEM**		
	EXISTING	MOD. 1	MOD. 2	MOD. 3
EXISTING	7.1	0.9	0.6	0.4
EXISTING WITH X LOW ALTITUDE FLIGHTS	8.3	1.3	0.9	0.7
EXISTING WITH 2X LOW ALTITUDE FLIGHTS	9.6	1.7	1.2	1.0
EXISTING WITH 3X LOW ALTITUDE FLIGHTS	11.3	2.3	1.7	1.4

FIGURE 16

MODEL ASSESSMENT

	CANOPY	WINDSHIELD
FLIGHT RECORDS (1968-1978)		
BIRDSTRIKES RECORDED	17	29
SYSTEM 'FAILURES'	6-8	1-2
ACTUAL PROBABILITY OF FAILURE	.35-.47	.035-.068
USE OF PROBABILISTIC MODEL		
PREDICTED PROBABILITY OF FAILURE	.31	.047

FIGURE 17

SUMMARY

- RISK ASSESSMENT TECHNIQUE AVAILABLE
- TECHNIQUE SENSITIVE TO:
    - BIRD DENSITY DISTRIBUTION
    - BIRD WEIGHT DISTRIBUTION
    - IMPACT VELOCITY DISTRIBUTION
    - IMPACT AREA STRENGTH DISTRIBUTION
- DEGREE OF SENSITIVITY REFLECTS PROBLEM COMPLEXITY:
    - NEW AIRCRAFT
    - AIRCRAFT OPERATING LOCATION CHANGE
    - AIRCRAFT MISSION CHANGE
    - HARDWARE MODIFICATION
- DEGREE OF SENSITIVITY CAN BE REDUCED

FIGURE 18

DISTRIBUTION FUNCTIONS

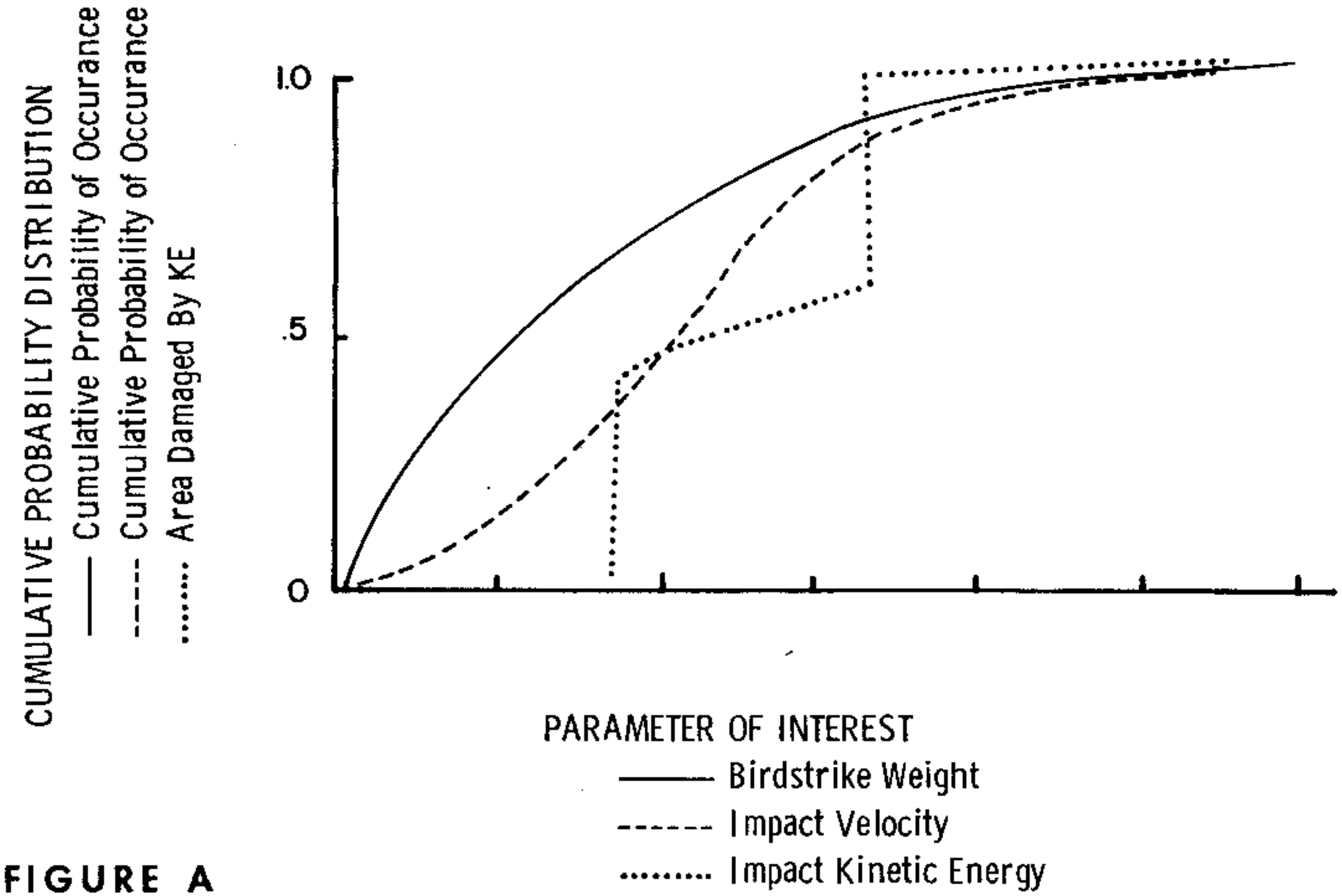


FIGURE A

$P(KE)$ = PROBABILITY DENSITY FUNCTION OF IMPACTING KINETIC ENERGIES

$C(KE)$ = CUMULATIVE DISTRIBUTION OF KE

$$C(KE) = P(KE \leq KE^*)$$

$$= P\left[\frac{WV^2}{2g} \leq KE^*\right]$$

$$= \int_0^\infty \left[\int^{\frac{2gKE^*}{V^2}} f(W)\, dW\right] f(V)\, dV$$

$$P(KE) = \frac{d\, C(KE)}{d\,(KE)}$$

$$= 2g \int_0^\infty \frac{1}{V^2}\, f\left[\frac{2g\, KE^*}{V^2}\right] f(V)\, dV$$

FIGURE B