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# ESTABLISHING AND VALIDATING AIRCRAFT BIRDSTRIKE RESISTANCE REQUIREMENTS

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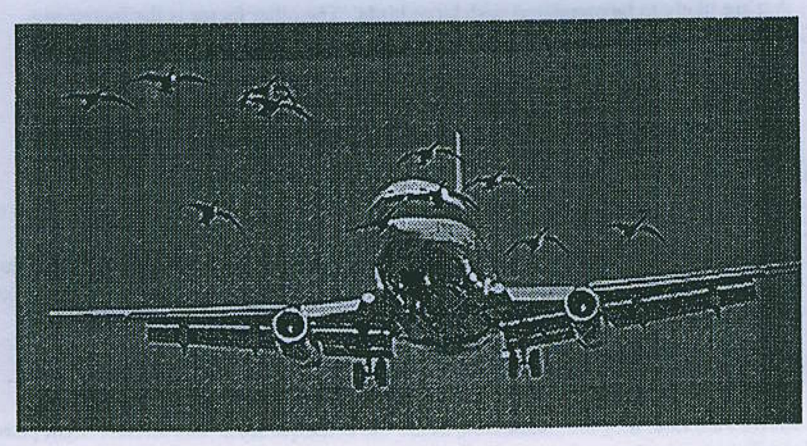
## ABSTRACT*

Aircraft repeatedly prove that birds and aircraft cannot occupy the same airspace at the same time; over 3000 birdstrikes per year cause 50-80 million US dollars in damage to USAF aircraft. To the worldwide aviation fleet this problem is estimated to cost more than one billion US dollars per year. Factors for consideration in establishing birdstrike resistance requirements, and in validating compliance with these requirements are presented. Also presented are some emerging technologies that show promise in combining aero-science and bio-science for reducing the frequency of birdstrikes.

(Key Words: Transparencies, Engines, Avoidance, Engineering, Testing, Control Methods, Microwaves, Infrasound, Ultrasound, Bird Impact, Artificial Birds)



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## INTRODUCTION

Collisions between birds and aircraft demonstrate a consequence of sharing-the-air. This realization is usually followed by a desire to reduce the frequency and the consequences of such mid-air collisions. A series of words can be used to summarize these collisions: Rare, costly, predictable, reducible and tolerable. The intent of this paper is to establish a basis for conversations about establishing and validating birdstrike resistance requirements. A brief discussion about each of these descriptive terms will place the complexity of this task in perspective. The authors stand ready to participate in these conversations and to point the way toward specific technical references for additional in-depth information.

## BIRDSTRIKES

### Rare

Birdstrikes are rare occurrences. Most pilots will pursue their career without encountering a significant birdstrike event. Serious birdstrike are measured in occurrences per million flight hours. Historical records accumulated in the 1970's showed that about 95% of all birdstrikes encountered were at bird weights of less than 4 pounds (1.8Kg). So, the probability of encountering a bird of significant size is rather small. More recent analyses of operational statistics show an increase in this weight to about 4.5 to 5 pounds (2.0 to 2.3 Kg). Two factors are believed to be contributing to this. One is a trend to conduct low-altitude flying in corridors where noise will be less objectionable to local civilian populations. This results in increased use of corridors that are likely to be populated with large birds. The other factor is the increasing populations of these large birds.

### Costly

A significant birdstrike, while rare, can be very costly. The USAF experiences about 3000 birdstrikes per year. These birdstrikes result in a loss of about 1-2 aircraft per year and a loss of about 1-2 aircrew members every 3-5 years. USAF costs for birdstrike damage are about 50 million US dollars per year. Costs for birdstrike damage encountered by the worldwide aviation fleet are estimated at over one billion US dollars per year. Damage costs are a function of three primary variables: Bird weight, impact speed, and impact location on the aircraft.

### Predictable

While birdstrikes are rare, they are predictable as are the consequences. The aircraft flight path sweeps through a given volume of airspace. Birds have seasonal as well as daytime and nighttime population distributions within this airspace. Birds also have a probability distribution by weight. The probability of collision with a given weight bird is therefore predictable. The aircraft time and speed in various altitude bands can be predicted for a more precise estimate of the range of probable impact weight and speed conditions.

The probable impact location on the aircraft is closely related to the projected frontal area of the components of concern. While these areas vary with different types of aircraft, a nominal distribution of birdstrikes as seen by the USAF from 1989 to 1993 is as follows:

| | |
|---|---|
| Engines | 21% |
| Wings | 19% |
| Windshields | 17% |
| Radome | 16% |
| Fuselage | 11% |
| Multiple | 11% |
| Landing Gear | 5% |

Analytical tools for predicting both the probability and the structural consequences of a birdstrike are available to those pursuing this task. The tools for predicting structural consequences are also becoming sufficient for use in designing components to tolerate such birdstrike energies.

## Reducible

Birdstrikes cannot be eliminated but the probability of occurrence can be modified to the benefit (or the detriment) of the aircraft and crew. Information is available on habitat modifications in the vicinity of the airfield to result in either increasing or decreasing bird populations. For example, controlling vegetation height near the runways can reduce attractiveness to birds, and allowing landfills or standing water near the runways can increase the attractiveness to birds. Falcons, bird distress calls and noise generators such as shell-crackers and explosive gas cannons are available for control of airfield birds. An excellent source of expertise on habitat management is the USAF Bird Aircraft Strike Hazard (BASH) Team. This team, currently led by Dave Arrington, can be contacted at telephone 505-846-0698 (fax 505-846-2710) at the Air Force Flight Safety Agency (HQ AFSA/SEFW) Kirtland AFB, New Mexico, 87117-5671.

The inevitable suggestion for avoidance through pilot maneuvering of the aircraft is not a very practical solution. Aircraft speed, aircrew hazard detection time, and aircrew-aircraft reaction times rapidly consume distances greater than normal visual acuity distances. This quickly translates into the pilot needing to see the bird and begin an evasive maneuver when the bird would appear as a very small object. This also presupposes that the bird will not also go into a natural, or evasive, change of course, which happens to match that of the pilot.

Through integration of aero-science and bio-science, some new technologies are emerging for use in reducing the birdstrike probability. One practical application is to modify the birdstrike prediction model with more accurate distribution mapping of bird populations along specific flight corridors. These mappings include information on seasonal and time-of-day bird activities. These birdstrike probability prediction models have become known as Birdstrike Avoidance Models and are used for comparing alternate flight corridors as to their relative risk for birdstrikes.

As an example, less than 5% of USAF birdstrikes are with Turkey Vultures (Cathartes aura) yet these impacts result in about 40% of the damage. It was felt that if the typical daily and seasonal flight pattern of these birds were known, then this could be taken into account in planning a flight corridor or in comparing alternate corridors. Eight birds were captured and fitted with miniaturized radio transmitters. Data being accumulated will be used to modify the Birdstrike Avoidance Models. With this better understanding of the vulture flight patterns, both the birds and aircraft will be better off and this may result in a USAF damage reduction of about $5M per year.

Two new approaches to birdstrike reduction are being explored. One involves better information for use in real-time avoidance of a particular birdstrike event that is likely to be significant. The other involves active deterrence of bird activity from the aircraft flight path. Both approaches are still in their infancy. A secondary goal underlying this research is for solutions to be beneficial for both the aircraft and the birds and that the research, or the result, not be injurious to the birds, the environment, or people in any way.

Radar tracking of birds has long been a tool used by ornithologists in their studies. Radars, both airborne and ground based, that are used for aircraft flight path information, detect birds. This information is not critical to flight management and is filtered out as unwanted clutter. The technology being explored is to take this bird detection information and process it along with aircraft flight path information through an artificial intelligence network to predict birdstrikes that are about to occur. For those that have a high probability of being a serious incident the aircrew could be given a warning to take evasive action. For impact with single birds this is a fairly straight forward calculation. For collision with a flock of birds, it is not so clear cut as to what will constitute a serious situation. To build this understanding, equipment is being developed for use in the field to measure spatial characteristics of representative bird flocks. This information can be used in the probabilistic birdstrike collision prediction models to determine quantities of hits likely to be encountered by various aircraft areas of concern. Analytical tools used in structural analysis of the birdstrike event can then be used to predict when significant consequences will be experienced. This can then be used as criteria for the artificial intelligence process.

Another source of information for real time avoidance is through use of infrared detection. As with radar, some infrared systems must filter out bird image information. This information could be used as discussed above. Feasibility demonstrations have already been conducted.

The other approach to birdstrike reduction is taking action which will cause birds to avoid the flight path of the aircraft. It is believed that if given the chance birds will avoid confrontation with an aircraft and that most collisions are a result of the bird not knowing about the aircraft in time to get out of the flight path. Techniques such as strobe lights and rotating geometric patterns, to increase aircraft visibility have been experimented with for some time. The results are inconclusive. These techniques all have a prerequisite for their effectiveness and that is the bird must first look in the direction of the aircraft.

Research has shown that while birds are insensitive to ultrasound, or sound at frequencies above that heard by humans, they do detect infrasound, or sound at frequencies below that heard by humans. Under laboratory test conditions they respond to this sound in a manner indicative of visually searching for a source. It is theorized that this system will cause the birds to look around for the sound source and that this will increase their opportunity to see and thus avoid the aircraft. The first probable application of this infrasound warning technique could be in a ground-based system for use at an airfield.

While the process is not understood, it has been observed that birds can detect and avoid high energy radar beams. If the ground-based infrasound warning system proves viable, then second and third generation spin-offs would be considered. The second generation would modulate a radar beam with an override frequency that would carry the infrasound message. The power and range of this radar beam would only be as necessary to cause birds in the danger zone to search for the sound source and thereby hopefully see the approaching aircraft. The third generation will attempt to benefit from the close anatomical relationship between a bird's hearing system and its balance system. If the modulated radar infrasound message can be received in a format or volume that temporarily disturbs the balance system, the bird may take direct evasive action to avoid, or it may involuntarily fall out of, the danger zone.

Another source of leads on deterrence of bird activity in the danger zone is coming from attempts to identify and understand clues about the birdstrike event being non-random. Early and cursory assessment of USAF and civilian birdstrike databases reveal some interesting examples: more on one wing than the other; more on landing or on takeoff; and more on one model of a particular aircraft than on another model of the same aircraft. Pursuit of one of these trends has already revealed that an overlap of engine sound frequencies and bird distress call sound frequencies seems to correlate with a reduction in birdstrike probability. Are we talking to the birds without realizing it? Are they picking up a message that can be exploited for mutual benefit? This entire topic of combining aero-science and bio-science to reduce the problem offers exciting possibilities.

## Tolerable

When the inevitable proof reoccurs that two objects cannot occupy the same airspace at the same time, hopefully the aircraft has sufficient structural integrity to tolerate the birdstrike energy without catastrophic loss of aircraft or aircrew. With only about one out of a thousand birdstrikes resulting in such a loss this is indeed the case in most birdstrikes. Tolerance of the birdstrike event means the aircraft subsystem(s) being impacted must safely absorb the energy of accelerating some portion of the bird mass to some significant fraction of aircraft speed and do this in an elapsed time corresponding to the aircraft traveling a distance of about the bird length (or width depending on impact direction).

Absorbing birdstrike energy occurs through deformation of the aircraft structure. Obviously, not all birdstrike energies can be tolerated. It then becomes a tradeoff of cost, weight penalty, and probability of occurrence in setting the level of required tolerance.

Allowable damage is always a topic of discussion. It is easy to take a position that there be "no damage"-- a desire to just clean off the bird debris as one would the insect debris on an automobile. This is a position which carries with it a penalty for vehicle performance as well as procurement cost and life cycle cost. Since only a few aircraft will encounter the high energy birdstrikes it becomes more of a question about the costs of managing this risk of encounter. The discussion will generally resolve itself into degrees of damage that should be tolerated for each of the frontal-facing areas. These degrees of damage will reflect the decreasing probabilities of increasing birdstrike energies as well as the mission-dependent flight consequences of the damage.

For some critical structures and surfaces this means design for, and test to verify, an ability to sustain flight after a bird impact weight of eight pounds (3.6Kg). For the majority of the aircraft frontal area this means design for, and test to verify, an ability to sustain flight after a bird impact weight of four pounds(1.8Kg). For the engines, the requirements vary but are essentially driven by engine inlet size and include bird weights up to eight pounds (3.6Kg) as well as multiple 1.5 pound (0.7Kg) and 2.5 (1.1Kg) birds. For certification, each subsystem will have criteria related to the damage that can be allowed. These criteria for various impact weights, and locations, can range from a requirement: To have no effect on flight; to being able to fly at reduced speeds for a given duration believed reasonable to locate a landing field; to accepting the birdstrike as a non-recoverable event.

The speed at which these requirements must be met is generally tied to the anticipated speed in the birdstrike environment. (For USAF aircraft about 70% of birdstrikes occur at altitudes below 500 feet and about 90% occur at altitudes below 2000 feet.) For some aircraft, such as for commercial cargo and passenger use, the weight and cost penalty for achieving tolerance is reduced by imposing a requirement to stay below a certain speed when in an altitude band that places the aircraft in the high risk birdstrike environment.

Structural analysis computer codes are becoming available for use in designing subsystems to tolerate the birdstrike energy. These codes have become quite efficient in reproducing the non-linear material behavior characteristics that occur during a birdstrike event--an event that may last only 0.001 seconds and result in generation and dissipation of a birdstrike force approaching 100,000 pounds. The use of these codes has greatly reduced the historical and costly design, test, redesign cycle. While the need for test facilities to support this cut-and-try approach has diminished they are still used for design validation and flight certification testing.

## TESTING AND CERTIFICATION

All external components having a forward-facing projected area are subject to birdstrikes. It is reasonable to expect those who are responsible for such subsystems to certify compliance with birdstrike tolerance requirements.

As analytical codes mature for analysis of structural response to the birdstrike event, there is less need to demonstrate compliance via actual testing. Dependence on such codes in lieu of testing requires experience in their use and an understanding of the degree of departure of the design being analyzed, from a design which was verified in full scale testing to be in agreement with predictions.

The item being tested should be representative of operational hardware and should be mounted in support structure representative of the actual aircraft in order to take into account the dynamics of structural response to the actual birdstrike event. The testing should include environmental extremes representative of conditions likely to be encountered in an actual birdstrike.

Testing should include impact locations where: Maximum stiffness is expected; where maximum deflection is expected; where critical support structure, actuating mechanisms, power lines, fuel lines or hydraulic circuits are hidden and otherwise presumed safe; and, where impact shock dynamics can activate or dislodge electro-hydraulic switching or actuating mechanisms that are critical for continued flight. Establishing the degree of allowable damage was discussed in the previous section.

The use of artificial, wild, or domestic birds is a choice that must be based on several factors. Under the proper conditions artificial birds create realistic impact loading and they are economical, both in preparation and in clean-up. They do invariably leave certification authorities with an uncomfortable feeling of "But--are the results real?". Wild birds representative of those expected in actual operation certainly answer this question but they are costly to acquire and environmental protection considerations make it difficult to justify their use. Commercially available birds, such as domestic chickens, are bred to have a different structure than wild birds. All real birds used in testing are painlessly killed, frozen/refrigerated until ready for test, and then warmed to room temperature and adjusted in weight to the desired test condition. Both wild birds and domestic birds are also costly to use in terms of facility clean-up after each test. The series of choices frequently ends up by using artificial birds for development testing and domestic birds for certification testing.

A typical bird impact range is shown in Figure 1. The components consist of a tank for holding pressurized air, a pressure release valve, a chamber for holding a sabot which holds the impact projectile, a tube for directing the projectile as it is accelerated by the pressurized air, a constrained portion of the tube to strip the sabot from the impact projectile, instrumentation for measuring the velocity and orientation of the projectile, a station for mounting the item to be impacted and a backstop (not shown) for absorbing residual energies. Numerous electrical interconnections are incorporated for safety and data acquisition. Provisions are made to enclose the impact area with insulating blankets or curtains and for use of heating or cooling equipment. These are removed just prior to the actual test so as to not interfere with the test.

High speed photography is accomplished with motion picture or video equipment. A capture rate of 5000 frames per second has been found to be minimal for analysis of results. Multiple cameras and lighting are synchronized and activated as part of the automatic firing sequence. By strategically locating and synchronizing selected cameras, and use of computer-aided film analysis,

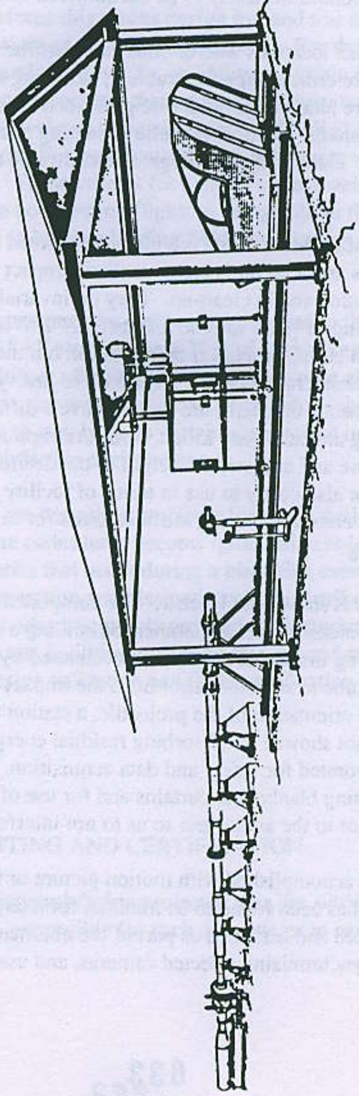

FIG 1 BIRDSTRIKE TEST FACILITY

a three-dimensional, time-based, deflection map of the item being impacted can be created. This map can be compared to the predicted deflection map. Under certain conditions, this comparison lends credence to further use of the predictive tools and can significantly reduce the quantity of tests required.

In facilities for rotating targets the automatic firing sequence includes additional controls to assure hitting the desired location. On one facility for rotating targets the launching sequence is so precise that a test can be conducted where the bird goes between two blades and the back of the blade hits the bird. Generally the rotating item is connected to the drive mechanism through frangible couplings. For some of these rotating target tests, multiple launch tubes are used and in some cases spring loaded mechanisms are used in lieu of the air cannon to launch the projectile(s).

A second type of facility is also used. Some aircraft certification programs involve testing using a sled-track where rocket motors accelerate the test item to a desired speed. Under these conditions the bird impact tolerance certification can be accomplished at little or no additional cost by suspending the bird carcass in a position where it is hit by the test item.

It is sometimes argued that the lack of airflow in the first type of facility is sufficient reason to justify a requirement to use the second type of facility. Analysis of results from both types of facility shows little basis for this argument. True, the aerodynamic loading does add to the forces on the item being tested but this is well within the scatter of forces from the bird impact. True, the aerodynamic flow field does exert forces that can change the trajectory of the bird, but for birds of a size sufficient to damage the structure, this course alteration is insignificant. Unless there is some overriding reason such as to assure that the external trajectory of impact debris does not interfere with an engine or control surface, then the cost of the second technique, solely for birdstrike certification, is not warranted.

Facilities for testing of non-rotating articles are located in the US at:

- Arnold Engineering Development Center
  Bird Impact Test Range
  Arnold AFB, TN 37389, USA

- Boeing Commercial Aircraft Co.
  Birdstrike Test Facility
  P.O. Box 3707
  Seattle WA 98124, USA

- Lockheed-Martin Aircraft Systems
  Structural Test and Fluid Dynamics Lab
  P.O. Box 748
  Ft Worth TX 76101-0748, USA

- PPG Industries, Inc.
  Aircraft Products (Qualification testing)
  P.O. Box 2200
  Huntsville AL 35804, USA

- University of Dayton
  Research Institute
  300 College Park
  Dayton OH 45469-0101, USA

Facilities for testing of rotating articles are located in the US at:

- Wright Laboratory
  Bird Impact Test Range (WL/POM)
  Wright-Patterson AFB, OH, 45433-6563, USA

- Each engine manufacturer has a facility for use relative to their engines

## CONCLUSION

This paper was assembled as a means to start conversations. Conversations to explore possibilities. Possibilities of sharing in the development, validation and application of technology to improve flight safety by reducing the costly consequences of mid-air collisions between birds and aircraft.

Each of the authors has many years of experience in improving aircraft birdstrike tolerance and would welcome a chance to explore possibilities for applying or extending the underlying technologies.

## ABOUT THE AUTHORS

Ralph Speelman III, telephone 513-255-3336 (fax 513-476-4275). Ralph has been involved in this subject area for some 25 years. His topics of familiarity include all aspects of development, validation and transition of technology to improve the birdstrike resistance of aircraft subsystems.

Malcolm Kelley, telephone 513-255-6524 (fax 513-476-4275). Malcolm has been involved in this subject area for some 15 years. His primary area of expertise is in finding ways to obtain longer service life of components that have been increased in design complexity to provide increased birdstrike tolerance. For the past four years he has focused his attention on innovative technologies to reduce birdstrike probability.

Robert McCarty, telephone 513-255-5060 (fax 513-476-4275). Bob has been involved in this subject area for some 20 years. His primary topic of expertise is the development and validation of computer codes for analyzing structural response to the birdstrike event and in reducing the cost of designing components to absorb this energy. For the past five years he has focused his energy on development of a capability to injection mold aircraft windshield systems including incorporation of integral frame.

Jeffrey Short, telephone 301-903-1387 (fax 301-903-1397). Jeff has been involved in this subject area for some 20 years. His areas of expertise include airbase bird hazard control, bird avoidance modeling, and analysis of birdstrike risks. For the past two years he has focused his attention on exploring the feasibility of innovative technologies for reducing birdstrike probability.

James Terry, telephone 513-255-2734 (fax 513-475-4531). Jim has been involved in this subject area for some 10 years. His primary area of emphasis is in developing and transitioning abilities to meet the increased energy absorption requirement without an undesirable increase or decrease in other characteristics. For the past three years he has focused his attention on engine birdstrike tolerance.

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