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AIRCRAFT BIRDSTRIKES: PREVENTING AND TOLERATING

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ABSTRACT

Aircraft repeatedly prove that birds and aircraft cannot occupy the same airspace at the same time. In an average year about 3000 birdstrikes cause 50-80 million US dollars in damage to USAF aircraft. To the worldwide aviation fleet this problem is estimated to cost more than three 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 can be used to greatly reduce the number of birdstrikes, especially with flocks of birds and with large individual birds. These emerging technologies combine aero-science and bio-science to lower the frequency of birdstrikes.

Key Words: Transparencies, Engines, Avoidance, Engineering, Testing, Control Methods, Microwaves. Radar, lnfrasound, Ultrasound, Bird impact, Artificial Birds, Birds, Aircraft, Airports

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 collisions. A series of words can be used to summarize these collisions: Rare, costly, predictable, reducible, and (usually) tolerable. The intent of this paper is to establish a basis for conversations about establishing and validating birdstrike resistance and birdstrike avoidance 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 ("Significant" in terms of damage and risk to the aircraft.) Serious birdstrike are measured in occurrences per million flight hours. Historical records accumulated in the 1970's showed that about 95% of all birdstrikes to USAF aircraft were at bird weights of less than 4 pounds (1.8Kg). Reported birdstrikes with non-USAF aircraft showed similar trends. 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 lowaltitude 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. However, the above numbers are for average years, and the costs in dollars is MUCH larger in the years where one of the lost aircraft was a large aircraft (B-1 in 1987, E-3 AWACS in 1995). When the aircraft has many people on board, the cost in lives can also be large. Costs due to birdstrikes encountered by the worldwide aviation fleet are estimated at over three billion US dollars per year. A large portion of those costs are associated with canceling commercial passenger flights and arranging alternative flights/aircraft for the passengers. The costs associated with the impact damage are a function of several primary variables: Bird weight, number of birds, impact speed, impact location(s) on the aircraft, phase of flight when the birdstrike occurred, and the effect of the damage on the aircraft's ability to fly and to land safely.

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, Some bird species tend to be encountered as single birds, while strikes with other bird species typically involve flocks of birds. The probability of collision with a given weight bird is therefore predictable, and the probability that those collisions will involve flocks of birds can also be estimated. 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 w[i]th 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. Some of the work being done by the International Birdstrike Research Group is also creating computerized models of bird flocks that can be used in conjunction with other software to assess the likelihood that a particular aircraft/bird flock encounter will produce significant damage to multiple aircraft components (example: two or more engines with one birdstrike event).

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. Excellent sources of expertise in the US on habitat management include the USAF Bird Aircraft Strike Hazard (BASH) Team and various experts in the US Department of Agriculture (USDA). Dr. Richard Dolbeer (phone 419 625-0242, fax 419 025-8465, e-mail nwrcsandusky@lrbcg.com is located at the Denver Wildlife Research Center (USDA/ADC/DWRC) in Sandusky Ohio. The BASH team, currently led by Major Dave Arrington, can be contacted at telephone 505-846-0698 (fax 505-846-2710) at the Air Force Safety Center (HQ AFSC/SEFW), Kirtland AFB, New Mexico, 87117-5671. E-mail address for Maj Arrington is arringtd@smtps.saia.af.mil. The e-mail system is currently being changed, so you might have more success in reaching another BASH Team member who's on the new system. Eugene LeBoeuf's e-mail is ieboeufe@kafb.saia.af.mil.

The inevitable suggestion for avoidance by relying upon the pilot to see the bird and maneuver 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. To make things worse, if the aircraft is on a collision course with the bird the bird will appear as a stationary speck, which is much more difficult to see than a moving speck. Stated another way: the pilot is much more likely to see a bird that he is NOT going to hit than one he will hit.

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 such as far more engine strikes on one wing than the other; two-engine birdstrike events for one four engine aircraft almost always being with engines on the same wing; 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 call be exploited for mutual benefit? This entire topic of combining aero-science and bio-science to reduce the problem offers exciting possibilities.

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 tile 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 Bird Avoidance Models (BAMs) and are used for comparing alternate flight corridors as to their relative risk for birdstrikes. An upgraded and much more user-friendly version of the BAM has just been produced for flight routes in the United States (a BASH Team project with the Air Force Academy creating the new BAM).

In a related effort, Turkey Vultures (Cathartes aura) have been studied to try to more accurately determine their flight habits so the BAM could do a better job of predicting when and w here Turkey Vultures would be most plentiful so those high risk times/areas could be avoided more often.

Why the special interest in Turkey Vultures? It's certainly not because of their friendly disposition and pleasing appearance! About 1% of USAF birdstrikes are with Turkey Vultures (Cathartes aura) yet these impacts result in about 40% of the damage. Eight birds were captured and fitted with miniaturized transmitters that could be tracked by satellite. Other birds were outfitted with short range radio transmitters for tracking in the local area. Data which was gathered was combined with information from many other data sources and used in the improved Bird Avoidance Models. With this better understanding of the vulture flight patterns, both the birds and aircraft will be better off. Just this improvement in Turkey Vulture understanding may result in a USAF damage reduction of about $5M per year.

Three new approaches to birdstrike reduction are being explored.

I. The first approach involves active deterrence *of* bird activity from the aircraft flight path, using special sounds and "audible" radar to help birds notice aircraft sooner and get out of the way. Laboratory tests have determined what modulations can be added to radar that will allow birds to hear the radar, and have identified types of sounds that get the *desired* bird reaction of looking around for the sound source. 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 source. This would cause the birds to look around for the sound source and this would 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, with the sound stimuli being timed to give the impression that an approaching aircraft was the source of the sound. When an aircraft was not approaching, no sound stimuli should be given.
- Tests with wild birds at a couple different test sites (including the USUA facility in Sandusky OH) have verified that when either special sounds or "audible" microwaves are used (stimuli used several seconds before arrival of high speed vehicle), birds detect an approaching vehicle sooner and begin their escape maneuver sooner than when no stimuli is used.
- Te USDA test utilized wild birds captured hours or days before the test. Ten birds were placed in a large cage which was on the edge of a straight stretch of read (road closed to other traffic for the test). After the birds settled down, a pickup truck began a high speed (70MPH) run. When the vehicle was a couple seconds away from the cage, a sensor on the road activated the stimulus (noise, audible microwave, or no stimulus). Five runs were made with most of the birds, then the birds were released and tests repeated with another group of birds. A VCR camera and tape recorder was used to continuously record the bird behavior.
- The tests showed the birds had no tendency to get used to and to ignore the stimuli when it was not a "false alarm" and the stimuli was always followed by arrival of the scary high speed vehicle. In fact, there was some indications that the birds started to learn that the stimuli was associated with the scary vehicle and their ability to detect and dodge away from the vehicle improved.
- Similar tests had previously been run at a different location (near a land fill) using uncaged wild birds that were lured onto a road by using food. In that situation, the birds noticed the approaching vehicle many seconds before they had to move, and tended to play "chicken," staring at the vehicle and delaying their escape maneuver until the last second. When sound and modulated microwave stimuli was used in this test setup, we expected little effect since the birds already saw the vehicle in plenty *of* time. However, the added stimuli seemed to add a ”nervousness factor,” and the birds left much earlier than before. The nervousness factor would further improve the success rate for birds avoiding aircraft.

- After all test runs were completed with some of the birds, the stimuli were given without the vehicle. The birds initially reacted to just the stimuli, but soon learned that the stimuli was now a false alarm and they stopped reacting. This verified one of the basic premises used in this program: Don't give false alarms to the birds. Tile aircraft will be the threat, and the equipment would be designed to deliver stimuli to the birds only when an aircraft (the threat) was present.
- Test results indicate the number of birdstrikes that occur during takeoffs and landings might be reduced by 60% for large aircraft (cargo and bomber aircraft, etc.) and by more than 95% for smaller aircraft (fighters, trainers, etc.). We would consider a_^{2}0% reduction as a significant improvement, and the hoped-for coal when we began the effort was to have a 50% reduction in these birdstrikes on and near airports. If 50% is defined as complete success, and data suggests results will be much better than that, it certainly seems reasonable to conclude that this technology should continue to he pursued.
- It might also be possible to create a "dizziness beam" using special modulations on radar, which could force even stubborn birds to avoid runways and glide slopes and cause birds in flight to dive away from aircraft. The "dizziness beam" is not being actively pursued as part of our ongoing program, but information has been found that shows a "dizziness beam" type effect has accidentally been created many times in the past with various radar systems. (We really don't have to have "dizziness" as the result. Any severe discomfort that did not involve injury and that disappeared as soon as the bird left the area would be effective and suitable.) It is quite likely that a radar system could be created that would have a dizziness-inducing modulation. Such a radar could be used as a ground-based system or as an airborne system. The groundbased system would have a sharply focused beam that would force birds away from runways and keep birds out of glide slopes of aircraft during final approach and takeoff. An airborne system would have the dizziness modulation only present when the radar beam was aimed directly in front of the aircraft. This would mean that birds that were in danger of being hit would be forced to dodge away from the beam, but birds that were not posing a hazard would detect nothing.
- The present contract effort is nearing completion, and the contractor (Raven Inc.) will be producing commercially available systems for airports and aircraft that will utilize the concept of helping birds to avoid aircraft.

II. The second conceptual approach would use aircraft radar to detect birds on a collision course with an aircraft in flight and advise the pilot how to avoid the bird with a gentle maneuver.
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 pursued in the detect birds/warn pilot system would 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.

- A small contract effort is in progress with Raytheon (formerly Hughes) studying this concept using the radar units on the $-2 and F-1 5E aircraft. Results to date show that both types of radar could detect even small birds at 2-3 miles with over a 90% probability. Large single birds and flocks of birds would be much easier to detect than single small birds, and could be detected at much greater distances. When you consider that the detect bird/tell pilot system would probably never tell the pilot about small single birds, and that a warning probably would not be given until the aircraft was much closer than 2-3 miles, it is readily apparent that the aircraft radars could do the job of detecting the birds that we would try to avoid.
- We expect the system to be used primarily during high speed, low altitude missions, and this is where the biggest payoffs would be achieved. Most of the damaging birdstrikes (Class A, B, and C mishaps) to USAF aircraft occur during high speed, low altitude missions. The system may also produce payoffs during other phases of flight, but such payoffs would be bonuses.
- The "Artificial Intelligence" function needed to track birds and decide if they were or, a collision course would not pose much of a technical challenge. The state-of-the-art in computer software has already progressed far beyond the capability needed for tracking birds.

- The system would have various features and adjustment capabilities designed in so the system could satisfy the needs of many different operational users, and could be used in many different situations. Features would probably include selectable sensitivity settings for the aircrew. Some pilots of some aircraft might wish to be told about and dodge away from even fairly small birds. (Reasons: aircraft easily damaged, damage expensive, bird population low so not many warnings anyway.). Other pilots might wish to only be told about bird flocks plus medium and large single birds. (Many small birds means too many warnings, aircraft not significantly damaged by small birds.) Some pilots have expressed a preference for an audible warning (bird, 2 miles, climb 200 feet). Other pilots want a "bird" figure shown on the HUD, so that when they change the aircraft flight path slightly the bird shape disappears from the HUD. The system would have a data storage capability to record bird activity noted during the mission. The bird data could be used by maintenance personnel in troubleshooting the system after a mission, a well as by researchers interested in studying birds. A 'mute' setting would be available for pilots that didn't want to have any inputs from the system, and a "combat off' position would be used to turn the system off completely during combat situations to eliminate all radar emissions that were not looking for combat targets.
- One other possible application of the "detect birds/tell pilot" system would he to evaluate the effectiveness of other measures (strobe lights, landing lights, special markings/colors, etc.) that are believed to influence birds and change birdstrike risks. For example, many people are convinced that using landing lights has a big effect. Unfortunately, some are convinced that landing lights help birds avoid aircraft while others are certain that landing lights lure birds to the aircraft and cause an increase in the number of birdstrikes. Who is right? And, do you get a different answer when different birds species are involved? (Some birds attracted to the light and some birds avoid the light?) An argument on the issue would be won today by whomever is tile best debater or can yell the loudest. It might be best to have good data on bird behavior and let the birds decide whether something increases or reduces birdstrike risks. One way to settle the argument: aircraft with the "detect birds/tell pilot" system could fly some sorties with landing lights, strobe lights, or other bird control device turned on and fly other sorties with the lights/devices turned off. The differences in bird reactions could be evaluated from the data collected by the radar system.
- The small contract effort with Raytheon is nearing completion. The next logical stop will involve creating a prototype system that could be flown and operationally evaluated. This could be on a B-2, an F-1 SE, or a test aircraft of some kind that had a B-2 or F-1 5E radar unit installed. One possibility for future testing: Raytheon has a small fleet of A-4 aircraft and one of those aircraft has a F-1 5E radar installed. Probably the biggest challenge will not be a technical challenge, it will be the very common financial challenge: who has the money to fund the next step in the research.

III. A third concept would use various sensors (radar, visual, IR, etc.) plus some computer software that would detect birds, recognize what bird situations posed a significant risk (birds on or near runways), and advise airport personnel so they could take appropriate actions to reduce the birdstrike risks.

- The third concept also appears to have great promise, and would probably be both more effective and less expensive than we expected when we issued a "call for proposals" to pursue it. Unfortunately, severe cuts in research funding forced us to select none of the proposals.
- The proposals were so promising that we suggested to several of the companies that they should consider forming teams and pursuing the concept with private funding. Each of the key technologies that the detect birds/tell airport personnel system would need have recently had dramatic improvements in capability and sharp reductions in cost. A system that could have been produced three years ago for perhaps one million dollars might be obtainable today for fifty thousand dollars.
- Several companies are pursuing the team approach idea, and one prototype system has already been demonstrated that can detect birds with visual and IR cameras, plus a motion detector which activates a VCR recorder to document bird or animal activity for later viewing, and shuts off the recorder when no activity is occurring. This prototype system has many of the features we would expect in a prototype that would be produced after several years of research. You might say that we are several years ahead of schedule and WAY under budget on the program... if we had a program. A secondary goal or philosophy underlying all of

this research is for solutions to be beneficial for both the aircraft and the birds and that the research (and any resulting final systems) not be injurious to the birds, the environment, or people in any way.

Two of the concepts (detect birds/tell pilot, and detect birds/tell airport personnel) could also be used to gather detailed information on bird behavior in flight and on the ground, day and night. This information could not only be used to further improve BAMs and other birdstrike prevention efforts, but also could be used by bird researchers with little or no interest in aircraft.

- High speed, low level routes tend to be in remote areas where there are no human bird watchers. Bird migrations also tend to be at night. Bird flight activity (altitudes, quantities, time of day, etc.) as recorded by the "detect bird/tell pilot" system might be invaluable data for some researchers, data that would be unobtainable from any other source.

Tolerable

When the inevitable proof recurs 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. 3i 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 (3.6K,). For tile 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 pound (1.1 Kg) 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 nonrecoverable event.

A nonrecoverable event would be a birdstrike mishap that was so severe that the cost (initial costs, operational costs, and/or penalties to performance) of designing an aircraft to survive such an event was unacceptable. Hopefully this type of mishap would also be an extremely rare event that would cause very few catastrophic accidents. Encounters with flocks of Canada Geese could be such a nonrecoverable event. No engines or other aircraft structures are designed to survive impacts with multiple 12 pound birds. More importantly, no two engine aircraft is designed to survive if both of its engines are destroyed in the same event. Those who like to have things to worry about can focus on the fact that the population of Canada Geese continues to increase rapidly.

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 50^0 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 tile birdstrike energy. The use of these codes has greatly reduced tile 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 will also be responsible for certifying that the subsystems meet or exceed birdstrike tolerance requirements. In many cases some government agency is represented during certification tests, but they are typically there to observe rather than to direct or conduct the test.

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 some (or all) 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 expected 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.

One largely inadvertent advantage of using domestic chickens that weigh 4 pounds is that a structure that survives a 4 pound chicken is probably going to also survive a strike from a large wild bird that weighs more than 4 pounds. Why can we consider a 4 pound chicken as being a suitable substitute for a 4.7 pound Turkey Vulture? Reason: chickens are dense and compact, and all 4 pounds will hit on or next to the target during a birdstrike test. When the aircraft is in ,ii-alit ,,ii-alit and collides with a large wild bird (example: 8 pounds) the flying bird is less dense than the non-flying chicken. The flying bird is also "spread out" much more than chicken shot out of a bird gun. As a result, much of the wild bird's mass will miss the "weak point" on the aircraft. All of these factors combine in a fortuitous way. When concern is expressed that birdstrike certifications may not be adequate because Turkey Vultures (and other birds) weigh more than 4 pounds, there is some validity in saying that a 4 pound chicken impact might be harder to survive than an impact with a Turkey Vulture.

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 qualification testing.

A typical bird impact test facility would include a tank for holding pressurized air, a pressure release valve, a chamber for holding a sabot which holds the impact projectile (the bird), 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 of some sort for absorbing residual energies. Numerous electrical interconnections are incorporated for safety and data acquisition. Provisions are often 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, triangulation techniques can be used to create a three-dimensional deflection map of the item being impacted. 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 some facilities for testing rotating targets such as jet engines, the automatic firing sequence includes additional controls to assure hitting the desired location. At 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 Projectiles.

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 several locations, to include Arnold AFB, TN 37389, Boeing Commercial Aircraft Co. Seattle WA 98124, Lockheed-Martin Tactical Aircraft Systems Worth TX 76101-0748, PPG Industries, Inc. Huntsville AL 35804, and the University of Dayton Research Institute Dayton OH 45469-0101.

Facilities for testing of rotating articles are located in the US at Air Force Research Laboratory's Bird Impact Test Range, Wright-Patterson AFB, OH, 45433-6563. Each engine manufacturer also has a facility for use relative to their engines.

RESEARCH: CHANGING OF THE GUARD

In the early 1970s an office was established in the Laboratory at Wright-Patterson AFB to develop solutions to serious aircraft birdstrike problems, starting with the F-l 11. In the last 25 years this office, which came to be known as the "We Do Windows Gang," has used a total budget of about fifty million dollars to solve many problems for many aircraft, and documented savings to the Department of Defense are close to two Billion dollars. In recent years we have used our knowledge about the birdstrike problem to not only help create structures that can survive impacts. but also pursued ways to avoid those impacts in the first place.

However, a large cut in all AF research funding forced all organizations in the Air Force Research Laboratory to select technology areas they would abandon. Guidelines used in selection areas to abandon were deciding what the "core technologies" for each organization were, and dropping everything that didn't fit as a "core" technology. There was no dispute that birdstrike prevention was an important area that provided huge return on investment. However, core technologies for our portion of the AFRL (Air Vehicles Directorate) include such things as combat survivability, flight controls, and cooling systems. It was hard to argue that "understanding birds and how to avoid them" fit in well with these areas, and Birdstrike Prevention became an orphaned program.

Many organizations have expressed strong support for the research to continue, and several organizations have expressed interest in the technologies and research being transferred to them. We are striving to make sure that the research continues to be performed by SOMEONE, and that research is not delayed or halted during this transition period. We expect the best to happen, but are also planning on how to minimize problems should no government research organization take over the research. The two ongoing contract efforts are both nearing completion, and the technologies they are developing are showing enough maturity that it is reasonable to expect the next phase of both programs will involve operational systems being produced, evaluated, and made available to all. The third technical area never became a funded program in the first place, but efforts to persuade companies to "press on" anyway have been at least partially successful.

One of the final desired results of a program is to successfully transition technology to the operational users, and "Tech Transition" is one of the ways of measuring success. Perhaps we can claim with some accuracy that we are probably succeeding in transitioning technology for THREE of our TWO programs. (150% success rate; How's that for going out as a winner?)

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.

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