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COPING STRATEGIES FOR THE AIRCRAFT BIRDSTRIKE PROBLEM: RESISTING IMPACTS, AVOIDING COLLISIONS, AND ...

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When birds and aircraft occupy the same airspace at the same time, bad things happen. Annual DoD costs probably exceed \$200 Million per year, and dollar losses to world-wide aviation have been estimated at \$3 Billion to \$4 Billion per year (in US dollars). Much has been done in the past to improve the bird impact resistance of aircraft, and some further improvements would be cost effective on some aircraft. A new manufacturing technology for aircraft transparencies that can increase strength while slashing costs by 80% is one promising approach. However, the “law of diminishing returns” comes into play, and the penalties involved in creating a truly “bird-proof” aircraft would be unacceptably high. Several new approaches and technologies for avoiding birdstrikes could be used to reduce the number of damaging birdstrike collisions. Some of these approaches are being used, and others are mature enough to enter the operational testing stage. Collectively, the more promising concepts could reduce birdstrike losses by 50% to 80% for those aircraft and/or airports that make use of them. Some strategies and points of contact for those wishing to pursue the new concepts will be provided. There are many facts and trends that optimists can focus on to be encouraged, and (for want of a better term) “good luck” has often been a factor in past birdstrike mis haps that kept severe damage from becoming a disaster. There are also many facts and trends that pessimists can focus on to be discouraged. An attempt will be made to provide a “good news” slant on many facts that are worrisome to many, to improve the spirits of those receiving the information and help them focus on key problems and candidate solutions. (Key Words: Transparencies, Engines, Avoidance, Engineering, Next Generation Transparency, Testing, Birds, Control Methods, Microwaves, Infrasound, Radar, Bird Impact, Structures)

To be presented and used in generating discussions at the first combined Bird Strike Committee USA and Bird Strike Committee Canada meeting in Richmond, British Columbia from May 9-13, 1999.

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 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. 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 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. 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 419 625-8465, e-mail nwrscandusky@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 leboeufe@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 of apparent non-random birdstrike patterns. These examples include:

- (1) More birdstrikes on landings than on takeoff for almost all aircraft. This was a moderate trend for most aircraft (about a 55% to 45% split between landings and takeoffs), but some aircraft had an overwhelming tendency toward “landings only,” with an 80% to 20% split. The F-15E was one aircraft with the 80:20 split, and the F-15E engine is very noisy on takeoff. Other types of aircraft (F-16s, etc) at the same bases as the F-15E did not have a similar “landings only” tendency, so the tendency is due to the aircraft rather than the airport. Other F-15 aircraft have different (and less noisy) engines, and tend to have close to a 50:50 ratio between birdstrikes on takeoffs and birdstrikes on landings. The 80:20 ratio for the F-15E is an example of one model of a particular aircraft having drastically different birdstrike patterns than other models of the same aircraft. Since the different models look about the same (from the birds’ perspective) something other than vision must be different from the birds’ perspective. If the difference is NOT sound, what could it be? Engine noise differences would certainly seem to be the probable explanation.

- (2) Some airports have a strong tendency toward more birdstrikes during takeoffs, while other airports have a strong tendency toward more birdstrikes during landings. This is due largely to local terrain and prevailing winds. The prevailing wind will largely determine the direction of most takeoffs and landings, with other factors such as noise abatement also being considerations. The terrain surrounding airports is rarely symmetrical, and the local bird populations will be strongly influenced by the terrain features. Many airports are built with one end sticking into a body of water (ocean, lake, swamp, etc). It is therefore reasonable to expect birds to be more plentiful on one end of a runway than the other. If most takeoffs are toward the end with more birds, then birdstrikes at that airport are more likely to occur during takeoffs than landings.
- (3) Two-engine birdstrike events for the B747 four engine aircraft almost always involve engines on the same wing (both left engines or both right engines; rarely one from each wing). Odds against from random chance: 20,000 to one. This apparently IS a real phenomena. The apparent situation: something about the B747 attracted the attention of bird flocks, the flock got an earlier start on its escape maneuver, the flock ALMOST got out of the way, with the “tail end Charlies” of the flock being the ones that got hit. Engine birdstrike data for the B767 and B757 were also checked. The B767 uses the same engines as the B747, and engine birdstrike data seems to indicate this aircraft also has a “one wing only” tendency. The B757 engine birdstrike data indicated no such tendency. The birdstrike data suggested the B757 aircraft tended to go more through the center of flocks, at least in comparison to the B747 and B767.
- (4) Further pursuit of the “one wing only” tendency has already revealed that the only large “spike” in the plotted sound spectrum of a B747 engine is an almost exact match for one of three large “spikes” in the sound spectrum of a bird call. Are we already 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.

- (5) 27 engine birdstrikes in a row were all reported as being on the left engine for the B727. Odds against this happening due to random chance: about 10,000,000 to one. Explanation: 26 of the 27 reported birdstrike in that time period all involved aircraft in Japan, and all the data was reported by airlines or airports to the world-wide data bank in Canada. Japanese to English language translation of the reporting form produced the strange trend. When the reporting form was translated from English to Japanese, Engine #1 (the left engine) apparently became “the first engine we’re going to talk about.” The “first engine” could be the left engine, or the right engine. When the completed form was translated back into English and entered in the data bank, all the birdstrikes were entered as “Engine #1,” which is the left engine.
- (6) The data banks of engine manufacturers were also checked. The B727 engines returned for repairs due to birdstrikes showed no such left vs right tendency for B727 birdstrike in Japan or in other parts of the world. This is an example of the need for caution in analyzing data. There ARE real trends out there, but one must first consider the possibility that a particular source of bank has a bad flaw and the trend is caused by the flaw rather than by some sort of bird behavior.

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 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. This BAM comes from a BASH Team project, with Air Force Academy personnel functioning as the contractor creating the new BAM.

In a related effort, Turkey Vultures (*Cathartes aura*) have been studied to try and more accurately determine their flight habits so the BAM could do a better job of predicting when and where 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% to 2% of USAF birdstrikes are with Turkey Vultures, yet these impacts result in about 40% of the damage (dollar losses) in an average year. 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 discussed below.

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 a 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 USDA 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.

- The 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 road (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 were 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.

- After all test runs were completed with some of the birds, the stimuli was 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. The 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.

- 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. Cheese balls and cheese curls were the overwhelming first choice of the birds. 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 were each used in this test setup, we expected little effect from either stimuli 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.

- 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 20% reduction as a significant improvement, and the hoped-for goal 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 be 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 ground-based 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 has been completed, and various avenues are being pursued by industry to produce and make commercially available systems for airports and aircraft that utilize the concept of helping birds to avoid aircraft.
- One of many possibilities for follow-on funding was to seek commercial support based on the strong preferences shown by birds for cheese curls and cheese balls. National advertising campaigns for the products could include assertions such as "birds prefer (brand X) three to one over garbage!" Although we did manage to persuade one company to provide a couple cases of cheese curls for a Birdstrike Committee USA meeting, the company didn't seem interested in redirecting their advertising campaign.

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. However, most aircraft radars and ground-based radars consider the radar returns from birds as unwanted clutter. These radar systems typically filter out and discard bird data. The new concept being pursued: create a “detect birds/warn pilot” system that would use bird radar return data and process it in combination 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 was performed by Raytheon (formerly Hughes) studying this concept using the radar units on the B-2 and F-15E 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 such a system on military aircraft would 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 on 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 fighter pilots said they would want to only get warning when the collision was 5 seconds away, while B-2 aircrews said they would want 30 seconds warning so they could make a very gentle avoidance maneuver.
- The birdstrike situations that would NOT produce a warning to the aircrew would also be adjustable. One way to mark the adjustment knob would be to mark the dollars saved by each avoidance maneuver. The system would use the aircraft speed, number of birds, and the size of the birds to estimate the dollar damage if a collision would occur, and also estimate the likelihood of a collision if no warning was given. For example, a setting of \$400 would result in warnings when there was a 4% chance of a collision that could produce 10,000 in damage, or a 1% chance of a collision that would cost an average of \$40,000. The pilot could decide how much the tradeoff was worth. Put a dollar value on the loss in training value from increasing his altitude by 200 feet for 30-60 seconds, and use that setting. Then, (statistically speaking) every time a warning was given and heeded, he saved his Wing that amount of money.
- The artificial intelligence function would not only determine when collisions with birds were likely, but would also be able to recognize situations where avoidance actions should NOT be attempted. If birds were detected on the runway when the aircraft was about to touch down during landing or about to lift off during takeoff, warnings would probably not be issued since the pilot could not take actions at that late date to prevent a collision. If the pilot wished to be told of the birds even when avoidance was not possible, that could be another option that could be selected. Messages might be something like “birds on runway; land anyway; do not do touch and go,” or “birds on runway; continue takeoff.”

- 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. (Reasons: If there were many individual small birds distributed along the flight path and there would be too many warnings. If the aircraft would not be significantly damaged by individual small birds, dodging would not be worthwhile and the pilot need not be told.)
- Some pilots have expressed a preference for an audible warning (example: “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 should also have a data storage capability to record bird activity noted during the mission, although that feature would not be needed for the basic system to work. The bird data could be used by maintenance personnel in troubleshooting the system after a mission, as well as by researchers interested in studying birds. This function could also be used during the initial development of the system, determining what various birds and bird flocks “looked like” to the radar system, and then using that data to help decide what level of bird threat would be avoided.
- A "mute" setting would be available for pilots that didn't want to have any inputs from the system for some reason. The “mute” setting would be a good choice when the pilot has a serious in-flight emergency (lost engine, flight control problems, etc), which dictates he should make as few flight control inputs as possible, and he should minimize the number of additional things to think about or deal with. The pilot might also want to use the mute setting if he/she thought the number of warnings was excessive and suspected a malfunction. The system could still collect and store bird behavior data which would be used in the troubleshooting process after the flight. Perhaps the system was malfunctioning (fix it), perhaps the sensitivity was too low (adjust it), or perhaps there were just a lot of birds that the pilot did not see (adjust flight planning and update BAMs).

- 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 be 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 the best debater or can yell the loudest. Personally, I'd rather 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 has been completed. 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-15E, or a test aircraft of some kind that had a B-2 or F-15E radar unit installed. One possibility for future testing: Raytheon has a fleet of A-4 aircraft and one of those aircraft has an F-15E 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. About \$1M would produce the first flight demonstrator which could then be tested and evaluated. Once the final system was finalized and perfected for that initial aircraft (example: F-15E), the cost to retrofit the entire fleet would be small. Creating software is fairly expensive, but making copies of

software costs almost nothing. Since the plan would be to create largely generic software, the cost to adapt the F-15E software and create “detect birds, tell pilot” systems for other types of aircraft would be much less. A total one-time investment of \$10M could yield ANNUAL savings to DoD of \$30M-\$50M. The system could also be adapted for use on commercial aircraft and should be effective in preventing catastrophic mishaps involving flocks of Canada Geese during approaches to airports and during climbouts after takeoff.

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 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. 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 (1.1 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 (or nonsurvivable) 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 would be unacceptable. Hopefully this type of mishap would also be an extremely rare event that would cause very few catastrophic accidents. Encounters with flocks of large birds such as Canada Geese or Snow Geese could be nonrecoverable events. 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 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. 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 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 flight 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 a 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 and 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 while domestic real birds are used for certification 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. The time is so short that the bird does not have time to deviate noticeable from its flight path. 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 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-111. 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 selecting 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 a huge return on investment.

However, "understanding birds and how to avoid them" involves a combination of many dissimilar types of knowledge such as bird behavior, aircraft and ground radar, mission planning, aircraft capabilities and damage tolerance, and pilot preferences/needs/desires. Perhaps one could refer to these different knowledge areas as some of the "core technologies" of birdstrike prevention. The core technologies for our portion of the AFRL (the Air Vehicles Directorate) did not include "understanding birds and how to avoid them," so 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 both expect the best to happen, and are planning on how to minimize problems should no government research organization take over the research. The two contract efforts are both completed, and the

technologies they investigated 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 "Technology 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?)

LET'S GET OPTIMISTIC!!!

It is easy to find reasons for pessimism. The population of Canada Geese is growing very rapidly throughout North America, AFRL has dropped research to deal with the birdstrike problem, and "almost accidents" due to serious birdstrikes seem to happen more and more frequently. Rather than depress ourselves with reality, let's put on our rose colored glasses, look for silver linings in the clouds, remind ourselves that it's always darkest before the dawn, and examine a few worrisome areas with a Pollyanna attitude. With this mindset, perhaps we can convince ourselves that things aren't so bad after all.

First, let's consider the growing population of Canada Geese, and let's just consider the problem as it relates to USAF and other DoD military aircraft. It's true, the population is growing rapidly in both the US and Canada. It's also true that no aircraft are designed to survive encounters with flocks of these birds. But wait! DoD aircraft have more flexibility in WHERE they can fly. They don't have to move paying passengers around the country. So, all we have to do is find those terrains and parts of North America where the population is NOT growing, and only fly military aircraft there. (Plots of Canada Goose population are attached to this paper.)

First, let's consider terrain. Terrains that should be avoided because they have the same sort of rapid increase in bird population are wet areas (rivers, lakes, etc), plains, plateaus, hills, and forests. (Forests were a disappointment; why would Canada Geese populations be growing there? Oh, well.) No data was provided on terrains of desert or glaciers. Let's be optimistic, say "no news is good news," and assume those terrains are OK for military aircraft to use. That's especially good news since both Canadian and US aircraft have a suitable terrain in their country.

Perhaps those two types of terrain are not enough for all military aircraft in North America. OK, let's look for portions of the US where the Canada Goose population is not growing. (Sorry; no comparable areas in Canada were found that did not have bad bird population trends.) Good news! New England, Wyoming, Oregon, and Washington (Washington state, not Washington DC) all look fairly good, with comparatively small bird populations and without strong growth trends. In addition, California does not look too bad although the trend is in the wrong way. So, all we have to do to avoid the Canada Goose problem is to perform all military flights only in those areas. (Since we are only looking for good news now, we won't bother to mention disadvantages with this concept.)

The Canada Goose problem for commercial aircraft could be dealt with in a similar manner. If someone imposed comparable flight restrictions on passenger aircraft, this would be very GOOD NEWS for some companies and agencies, such as Amtrak and bus lines. It would also be GOOD NEWS for the construction industry in those few states. (Disadvantages won't be discussed.)

Now that the Canada Goose population problem has been addressed, let's take a look at some mishaps and see if we can find reasons for optimism. Here's one way to look at it: If we considered each mishap as a "warning" we could view them as "good news" because the mishaps could have been worse. If we can use them as warnings and take actions that will prevent disasters with large loss of life, this would really be GOOD NEWS. And, since

we are trying to find good news, let's not focus solely on birdstrike mishaps. To see how this concept would work, consider the following mishaps.

1. AWACS aircraft hits flock of birds on takeoff, loses two engines on one wing; Class A accident.
2. Large passenger aircraft in flight develops fire inside the fuselage. Fire spreads, aircraft is destroyed.
3. Boeing aircraft full of passengers has the "empty" center fuel tank explode, destroying the aircraft.
4. B757 has Canada Goose go down each engine during landing approach.
5. B757 hits flock of starlings on takeoff, both engines effected. Apr 8 99 newspaper article describes Feb 22 99 mishap as one engine destroyed plus right wing extensively damaged; 400 dead birds.
6. DC9 has multiple large birds (Snow Geese) in each engine during landing approach. Both engines badly damaged, both stop working. About two weeks later, another DC9 has one Canada Goose "destroy" one engine during landing approach, and a second Canada Goose damages the landing gear.
7. Lear Jet with full load of passengers hits flock of birds on takeoff, both engines badly damaged.
8. Passenger aircraft hits one bird during landing approach. Bird causes significant structural damage to the wing as it passes THROUGH the wing tank, lodging toward the back of the wing. Severe vibration prompts pilot to shut down the engine, but ruptured fuel tank does not ignite and enough wing structural strength remains for landing.

The above mishaps are GOOD NEWS because only two of the mishaps had fatalities, and at least half of the people survived even the fatal mishaps. The center fuel tank explodes mishap had only 8 killed, and the inflight fire had 23 killed. To really convert these mishaps to GOOD NEWS all we have to do is treat them as warnings and take appropriate actions to prevent similar mishaps in the future which could have large loss of life.

I think I just heard remarks such as "What! That's wrong! The first three mishaps had MANY fatalities and NO survivors!"

I'm referring to three EARLIER mishaps, not the ones you're thinking of. The AWACS was an E-4 (B747) which was a Class A accident because of the dollar damage to the aircraft (\$1.6M), but it landed safely. The "fuselage fire" mishap was a 1983 DC-9 mishap which had the fire start at the rear of the aircraft, and the pilot managed to land in Cincinnati OH in time for 23 of the 46 on board to escape before the aircraft was gutted. The center fuel tank explosion occurred with a B737 in Manila (Phillipines) in May 1990 at the airport terminal as the aircraft was being pushed back from the gate, cause not determined but "vapours ignited probably due to damaged wiring,...."

For those that are wondering about the other mishaps.... The B757 mishap with Canada Geese occurred several years ago, and both engines survived and kept operating. The other mishaps all occurred earlier this year in the US. The DC9 that lost both engines did not crash because the pilot managed to get one of the damaged engines running again, providing enough residual thrust to reach the runway.

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.

This paper also made a brief attempt to examine the birdstrike problem with an overly optimistic viewpoint.

Perhaps some of you have been soothed and made more content from this attempt. Then again, perhaps you are not soothed.

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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Attachments: Collection of Canada Geese population plots extracted from the internet