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BIRDSTRIKE PREVENTION:
APPLYING AERO-SCIENCE AND BIO-SCIENCE

J.J. Short[1], M.E. Kelley, R.J. Speelman, III & R.E. McCarty
[1]United States Air Force Research Laboratory,
Plans and Programs Directorate (XP), 1864 4th Street, Suite 1 (Bldg 15),
Wright-Patterson AFB OH 45433-7131, USA
Email: jeffrey.short@em.doe.gov

Abstract

When birds and aircraft occupy the same airspace at the same time, bad things happen. Annual US military cost are estimated to exceed US$200 million per year, and costs to world-wide aviation have been estimated at US$3 - $4 billion per year. Much has been done in the past to improve the bird impact resistance of aircraft, and further improvements would be cost effective on some aircraft. However, the law of diminishing returns comes into play, and the penalties involved in creating a truly bird-proof aircraft can become unacceptably high. Several new approaches and technologies for reducing the number of damaging birdstrikes were presented in our paper at the International Bird Strike Committee (IBSC) meeting #23 in London. Progress since IBSC 23 is described in this paper. Some of these new concepts are now mature enough to begin operational testing. These include using infrared and radar to detect birds, as well as audible radar and low-power, laser devices for controlling birds. Collectively, these promising new approaches can be expected to reduce birdstrike costs by at least half. Commercialization of these concepts will require a strong advocacy from the user communities. Some strategies and points of contact are provided.

Key Words: Transparencies, Engines, Avoidance, Engineering, Testing, Birds, Control Methods, Microwaves, Infrasound, Radar, Bird Impact, Structures.

Introduction

Our previous IBSC (#23 and #24) papers (Short, Kelley, and McKeeman, 1996; Speelman, et.al. 1996; Speelman, et al. 1998) discussed new initiatives and technology applications for addressing birdstrike prevention requirements. The primary intent of this paper is to describe recent progress in technology developments to reduce bird hazards to aircraft provided by combining the science of aircraft ("aero-science") and the biological sciences ("bio-science"). This progress creates exciting possibilities for reduction of operational birdstrikes and lends encouragement to additional initiatives for experts from these seemingly unrelated sciences to "Team For Success".

Birdstrike prevention

Costs due to birdstrikes encountered by the worldwide aviation fleet are estimated at over US$3 billion 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 alone 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.

In our work to increase birdstrike protection while also reducing the cost and complexity of providing this capability, we have become increasingly aware of the conditions associated with operational birdstrikes. These conditions, though admittedly not analyzed in a statistically rigorous fashion, became too compelling to ignore. In this awakening, we began to note two things: (1) the frequency of birdstrikes involving large birds was on the increase and the ultimate customers could not accept the cost-weight penalty necessary to tolerate the increased impact energy levels; and, (2) birdstrikes did not appear completely random events since some birds were able to avoid actually colliding with the aircraft—perhaps by reacting to some visual or aural signal that increased their awareness of an impending collision.

Birdstrikes probably will never be eliminated entirely, but the probability of occurrence can be reduced by controlling those factors that attract birds, such as food, shelter, and water and by limiting aircraft flights to those situations, areas, or times where bird populations are at a minimum. Information is widely available on habitat modifications in the vicinity of the airfield that will result in either decreasing or increasing bird populations. Likewise, there are many different techniques for managing bird populations with various active and passive control techniques: bioacoustics, pyrotechnics, and natural predators. Aircrews now rely on Bird Avoidance Models (BAMs) to choose alternate flight routes with reduced relative birdstrike risk. An upgraded and accessible, user-friendly version of the BAM, discussed at IBSC 24 by the first author, is available for flight routes in the United States. Other countries are developing similar, bird hazard risk models for their specific requirements.

There are thousands of studies, reports, and other documents available on the problem–and solutions–to bird hazards to flight. The Annotated Bibliography of Bird Hazards to Aircraft (ABBHA) provides a centralized listing of over 1200 references concerning bird-aircraft interactions (Short 1998). The ABBHA helps speed the transfer of information on topics such as aerospace engineering, bird control techniques, detecting birds, bird remains identification, and aerodrome facility design and landscaping considerations. ABBHA is the result of an United States Air Force effort to transfer the results of birdstrike research and the “lessons learned” from operational experience to benefit organizations affected by bird hazards. The ABBHA is available on the National Wildlife Research Center website (http://199.132.80.3/RIS/RISWEB.ISA#TOPOFREFLIST). (In the pulldown list, select “aircraft.pdt.” Searches for specific references may be performed many different ways, e.g., keywords, years, title, authors, etc.) By mid-2000, the U.S. Dept of Agriculture’s National Wildlife Research Center website (http://www.aphis.usda.gov/ws/nwrc/) will provide a link to the aircraft.pdt database identified as "ABBHA".

Non-random nature of birdstrikes

Understanding and correctly interpreting birdstrike data can be challenging: there are many inconsistencies in the data. A cursory assessment of USAF BASH (1985-1992) data by the second author was briefed at IBSC #23. A review of more current BASH data (1985-99) reveals that the trends reported earlier still hold true. When combined with some civilian birdstrike data, interesting examples of apparent non-random birdstrike patterns arise:

Twenty-seven consecutive birdstrikes on the Boeing (B727) left engine were reported by airlines or airports to the International Civil Aviation Organization data bank in Canada. Also of interest was that 26 of the 27 reported birdstrikes during that period all involved aircraft in Japan. 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, for that matter, in other parts of the world. This apparent situation is an artifact of the data reporting form and is not an actual birdstrike phenomena. Apparently the translation of the reporting form produced the strange trend. When the reporting form was originally translated from English to Japanese, Engine #1 (the left engine) was interpreted as “the first engine that was struck”; and the “first engine” could have been either the left engine or the right engine. When the completed form was translated back into English and entered in the data bank, the birdstrikes were entered as “Engine #1,” which is the left engine in the usual parlance of the aviation industry for multi-engined aircraft.

An important lesson is that we must exercise caution in interpreting results of birdstrike data. There ARE real trends out there, but one must first consider the possibility that a particular source of data is flawed and the trend is caused by the flaw rather than by bird behavior.

Birdstrikes during various phases of flight or for different airfields can show interesting trends:

More birdstrikes occur on landings than on takeoff for almost all aircraft; a 50:50 ratio between landing and takeoff birdstrikes is expected. Most aircraft exhibit ratios close to the expected: nominally, a 55% to 45% ratio between landings and takeoffs (Table 1). (The T-38 is the only USAF aircraft showing the reverse trend; i.e., more birdstrikes during takeoff.) The data on some aircraft demonstrate an overwhelming tendency toward birdstrikes occurring on landings. 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. The F-15E engine is very noisy using takeoff power settings. Other F-15 models with different—and quieter—engines have close to the expected ratio between takeoff and landings. Since the various F-15 aircraft models look about the same (i.e., have essentially the same frontal area image), something other than appearance must be creating this disparity in the ratios. Engine noise differences certainly seem to be the probable explanation.

Table 1. Aircraft landing to takeoff ratios from 1985-99 USAF data for selected aircraft. “Landing” includes descent, final approach, and landings. “Takeoff” includes takeoff, climb, and missed approach. Results are similar to those reported at IBSC #23.

Aircraft and Model	Landing:Takeoff Ratio
T-37 (all)	1.04
T-38 (all)	0.75
F-15 A,B,C,D	1.41
F-15 E	2.48
F-16 (all)	1.61
KC-10 (all)	2.05

KC-10 aircraft operating from Barksdale AFB, Louisiana, exhibit a quite high ratio of landing to takeoff birdstrikes as compared with several other “home” airfields (Table 2). Barksdale historically has had blackbird hazards to flight in the vicinity of the airfield. A review of the KC-10 birdstrike-species data is inconclusive—though encouraging—regarding the possibility that blackbirds might be alerted to the engine noise ahead of the departing aircraft: only three birdstrikes with blackbirds (two unidentified) were reported for all KC-10s (two on takeoff, one on landing). (As a comparison, ten KC-10 birdstrikes involved Rock Doves, ***Columba livia***). Only one KC-10 birdstrike at Barksdale involved a blackbird (Starling; during climb).

Table 2. Aircraft landing to takeoff ratios from 1985-99 USAF data for KC-10 aircraft at selected airfields. "Landing" includes descent, final approach, and landings. "Takeoff" includes takeoff, climb, and missed approach. Results are similar to those reported at IBSC #23.

Installation Reporting	**Landing:Takeoff Ratio**
Barksdale AFB, Louisiana	3.55
March AFB, California	1.59
McGuire AFB, New Jersey	1.67
Seymour Johnson AFB, North Carolina	2.22
Travis AFB, California	1.74

The KC-10 engine spectrum (Figure 1a) shows the highest peak energy at approximately 2400 Hertz (Hz) but also a high peak below 100 Hz. The peak at ~2400 Hz is close to a high peak (~2500 Hz) in the Red-winged Blackbird (***Agelaius phoeniceus***) distress call spectra (Figure 1b). The distress call spectrum for the Starling (***Sturnus vulgaris***) shows a relatively high peak below 500 Hz that other blackbird species (e.g., Common Grackle, ***Quiscalus quiscalus***) distress calls do not display (Figure 1 c & d). Perhaps Red-winged Blackbirds and Grackles attend to the mid-range frequency sounds of the KC-10 while Starlings are more aware of the low frequency sounds. Or, maybe it is the frequency "rhythm" or magnitude of the sound that best gets the attention of blackbirds.

Another indicator of the influence low frequency sounds may have on blackbirds comes from some research from the late 1960's . A broadcast of T-37 aircraft noise was proposed as a way to keep blackbirds leaving nearby roost sites from overflying the airfield at Moody AFB, Georgia. This "curtain" of noise was believed anecdotally to show a desired, repulsive effect but the data was inconclusive and this technique was not pursued. The T-37 aircraft exhibits the majority of its frequency spectra below 1000 Hz (Figure 1 e & f) with a single peak on the ground at 5760 Hz. T-37 aircraft also experience the closest 50:50 ratio of landing to takeoff for all aircraft operating in the USAF fleet (see Table 1). Perhaps the relatively low, frequency peaks in the noise spectrum can help explain this aspect; but, much more work needs to be done. A rigorous examination of the birdstrike data for different aircraft—military and civilian—during different phases of flight, as related to the sound spectra of those aircraft, is needed to improve the understanding of how birds react to aircraft noise and may help to improve bird awareness of approaching aircraft.

Figure 1. Sound spectra for: (a) KC-10 aircraft; (b) Red-winged Blackbird distress call; (c) Starling distress call; (d) Common Grackle distress call; (e) T-37 aircraft recorded 10 degrees off the nose; and, (f) T-37 aircraft flying overhead (200 feet above ground level, operating at 96% rpm). Note that the magnitude (Y-axis values) of the various spectra differ.

Figure 1 (a)

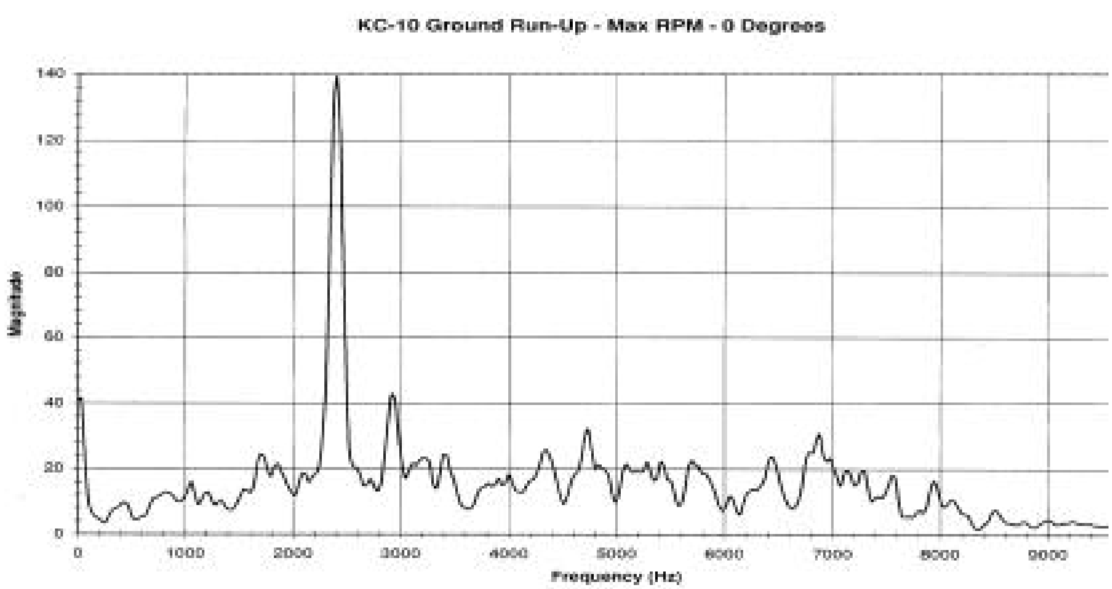


Figure 1 (b)

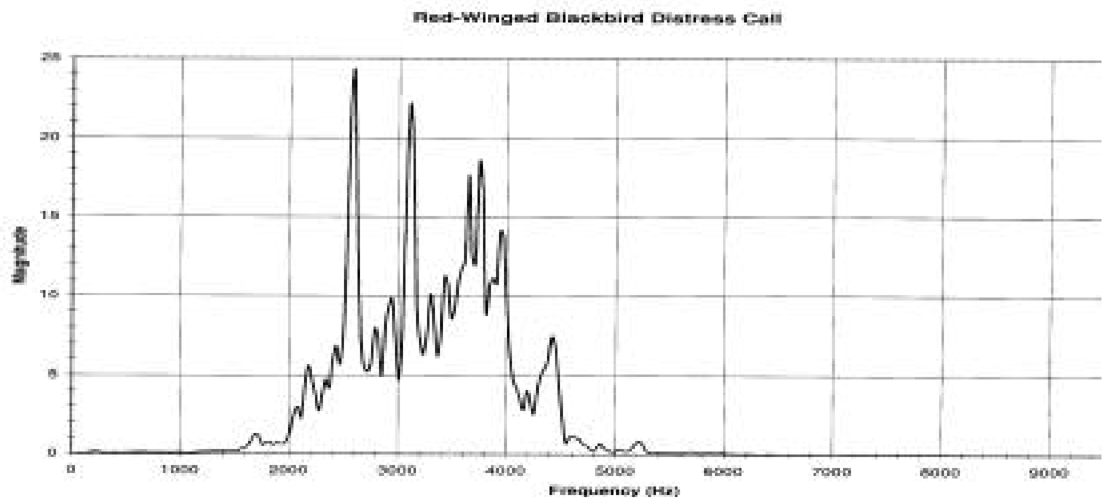


Figure 1 (c)

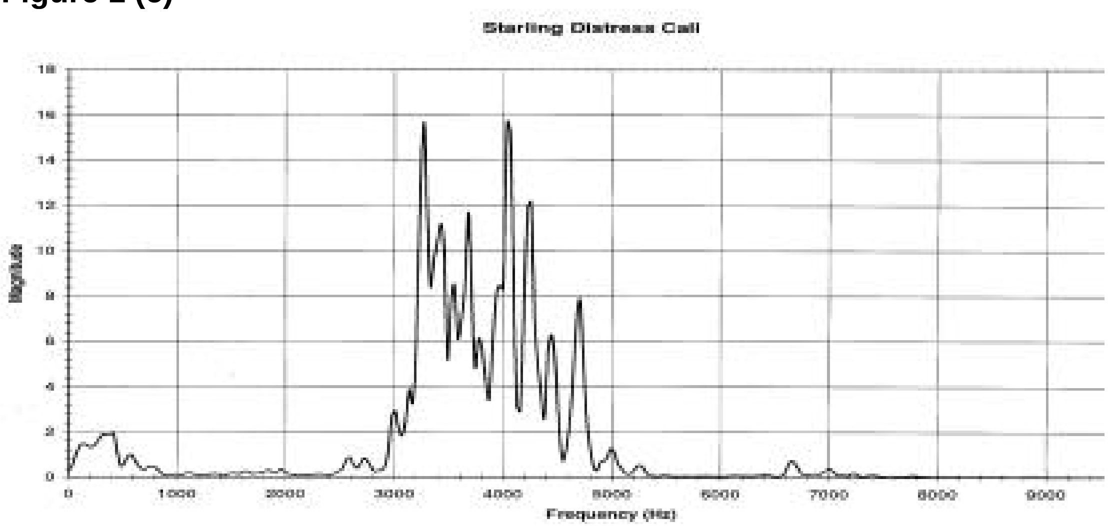


Figure 1 (d)

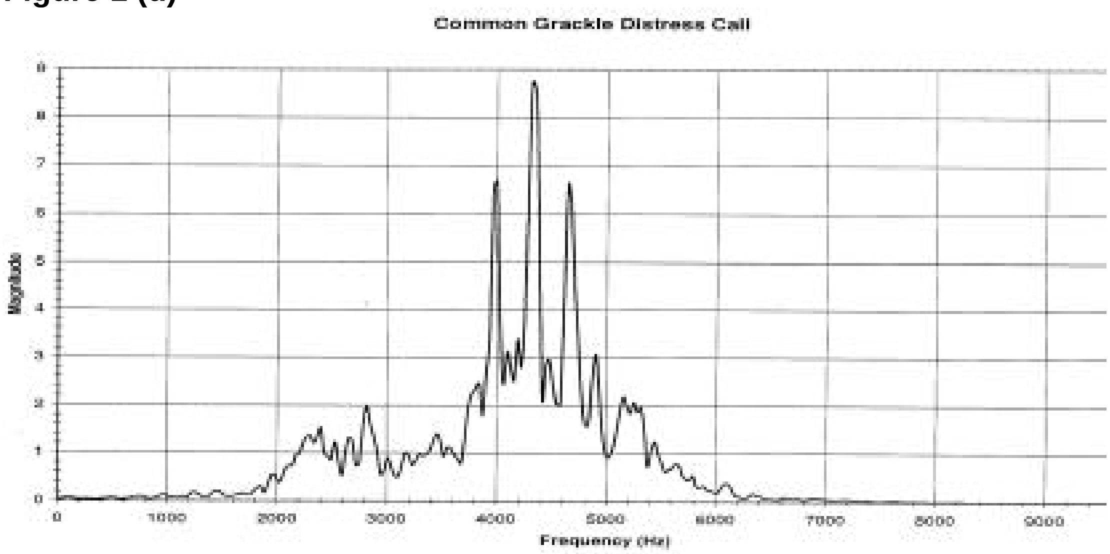


Figure 1 (e)

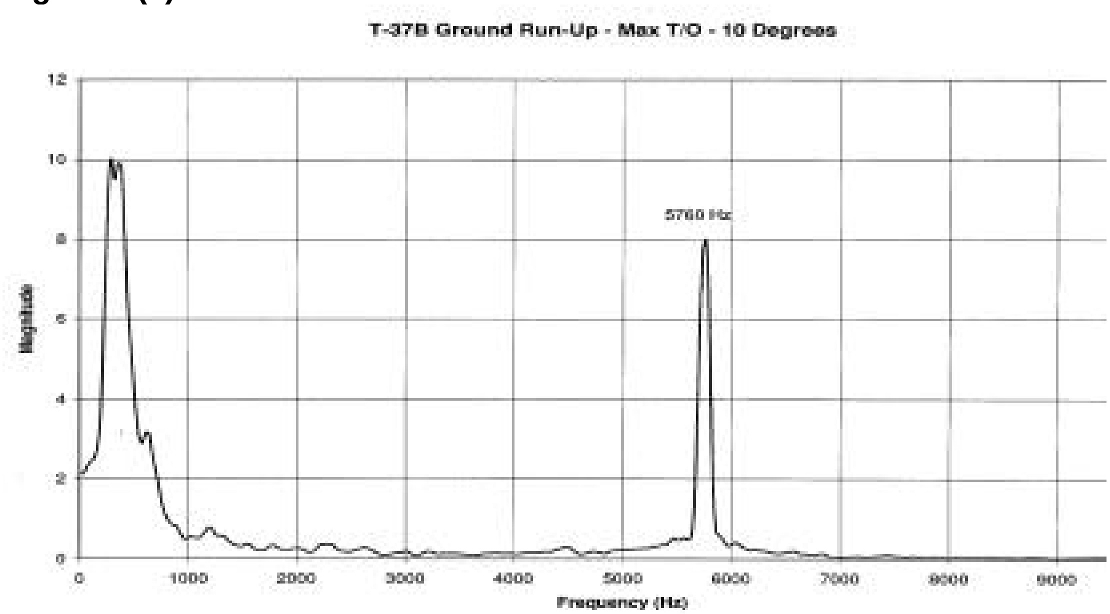
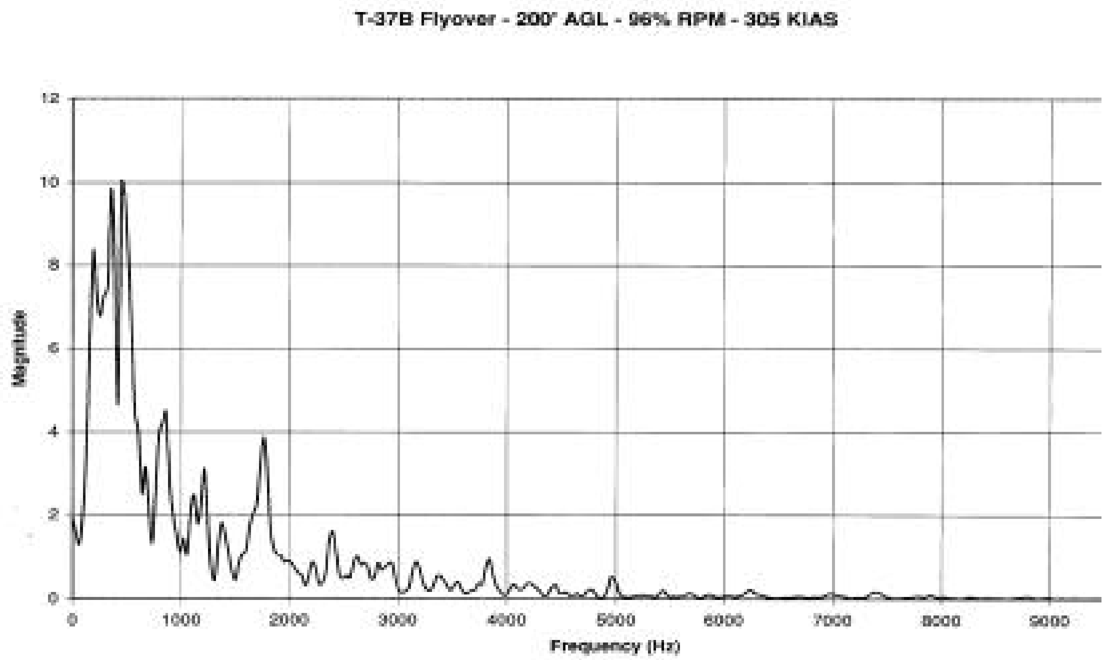


Figure 1 (f)



Other civilian aircraft data exhibit a “one-wing-only” tendency for birdstrikes:

Two-engine birdstrike events for the B747, a four-engine aircraft, almost always involve engines on the same wing (both left engines or both right engines; rarely one from each wing). (This phenomena has been well-documented over the years without a good explanation.) 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.

Further pursuit of this “one wing only” phenomenon 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 for certain bird vocalizations. Our paper (Short, Kelley, and McKeeman 1996), showed apparent overlaps between certain engine noises and distress call frequencies for certain bird species. Thorpe (1996) postulated that aircraft with noisier engines may have lower birdstrike rates than aircraft with “quiet” engines. Additionally, certain engines may have “built-in” frequencies, during their operation that will elicit greater awareness by certain species of birds. Are the birds picking up a message from the engines that can be exploited for mutual benefit? Or, is the one-wing-only tendency an artifact of escaping flocks of birds causing the last birds "off" in the flock to be the ones impacted? Additional research into these aspects of jet engine noise may lead to new advancements in the acoustical control of birds.

Progress on preventing birdstrikes

Recent technology advances are providing several new systems to prevent birdstrikes: hand-held, laser bird control devices; remote, bird "sensing" on airfields; airborne radar detection of birds; and, using "audible" microwaves to control birds.

Ground-based Detection System
These systems use various sensors (radar, visual, infrared) plus some computer software that would detect birds, recognize what bird situations pose a significant risk (birds on or near runways), and send warnings so airport personnel could take appropriate actions to reduce the birdstrike risks. Each type of detection system has its own advantages as well as its particular limitations; a combined approach may provide an optimum system at an affordable cost.

Ivey (1999) reported on a near-catastrophic, nighttime, birdstrike incident with a dozen Canada Geese (***Branta canadensis***) and a C-12 aircraft at Davison Army Airfield (AAF), Fort Belvoir, Virginia. Shortly thereafter, Davison airfield management installed a thermal (infrared) imaging system to locate wildlife "intruders" with good results. Davison AAF managers and the Army Night Vision Laboratory are in the process of acquiring an improved, off-the-shelf, infrared (IR) system for reinstallation on the Davison tower (Figure 2). The new system will probably include a visual, image-intensifier system as backup for the IR. The display will be with a direct video "feed" to a monitor inside the tower. The entire system will be "slaved" to inexpensive, motion detectors which will help with their security requirements as well as with their bird intruder warning needs. Total expected acquisition cost for the entire system is US $ 100,000.

The Davison AAF system covers a 5,500 foot runway. A similar system that would cover an airfield supporting large, jet aircraft would use different optical lenses or redundant, IR-units to provide adequate coverage. Ideally, any infrared bird detection system should be integrated with an appropriate radar warning for those birds in flight to and from the airfield. Also, if motion detector systems are already in place at the airfield for security purposes, those systems could be integrated to collect information on some bird movements or could be used to trigger additional attention on a particular area, vis-a-vis birds, by airfield management.

Figure 2. A system similar to the Lockheed Martin LTC500 Uncooled, IR Camera may become the new thermal imaging system at Davison AAF.

A system to “detect birds and advise airport personnel” appears to have great promise. In 1998, a "call for proposals" was issued by the Air Force Research Laboratory (AFRL) to pursue such a ground-based bird hazard advisory system. Unfortunately, none of the proposals could be funded due to severe cuts in research funding. The proposals were so promising that several of the companies were encouraged to form integration teams and to pursue the concept with private funding. Each of the key technologies that an airfield warning system would need, have recently undergone dramatic, technological improvements in capability and reductions in cost. Several vendors offer similar technologies as the Davison AAF system that can detect birds with visual and infrared cameras. This type of system has many of the features we would expect in a prototype that would be produced after several years of research. A system for a typical USAF airfield that could have been acquired three years ago for (conservatively) US$ 1 million might be obtainable today for one-half that amount.

Radar Detection

Conceptually, with relatively inexpensive modifications to the existing information processing software, it should be possible to use an aircraft’s on-board, radar system to detect birds on a collision course with an aircraft in flight and advise the pilot how best to maneuver to avoid the bird. The bird target data would be combined with aircraft flight path information, processed with an artificial intelligence network, and used to reliably predict bird collisions. For those bird targets that have a high probability of causing a serious incident, the aircrew could be given a warning of the impending mishap in time to take evasive action. A birdstrike advisory system for military aircraft would be used primarily during enroute phase, and during high-speed, low-altitude, training missions where most of the seriously damaging birdstrike mishaps to USAF aircraft now occur.

In 1998, a study was completed by Raytheon evaluating the feasibility of the existing, airborne radar units on the B-2 and F-15E aircraft to provide bird warnings during flight. As expected, large individual birds and flocks of birds were detectable at much greater distances than single small birds. However, even small (passerine-size) birds were detectable with both types of radar at 2-3 miles with over 90% accuracy (Table 3). Even though an airborne birdstrike advisory system would probably never be used to inform the pilot about small birds, the data could be retained for other types of analysis.

Table 3. Review of airborne radar data and findings from Raytheon study.

Aircraft	USAF Birdstrikes	Two second search of volume (azimuth x elevation)	Probability of Detection (0.001 m2 @ 2nm)
F-15 E	300 birdstrikes	30 degrees x 10 degrees	1 look – 87% 4 looks – 99%
B-2	25 birdstrikes	20 degrees x 5 degrees	1 look – 84% 4 looks – 99%

The system could also have a data storage capability to record bird activity encountered during the mission, although that feature would not be needed for the basic system to work. This function could also be used during the initial development of the system to determine bird and bird flock algorithms, and then use that data to help decide what level of bird threat is apparent. This bird data could be used by researchers interested in studying birds as well as maintenance personnel in troubleshooting the system problems after a mission. 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 risk models”).

One other possible application of the "detect birds/tell pilot", airborne bird advisory system would be to evaluate the effectiveness of other measures (strobe lights, landing lights, special markings/colors, etc.) that are believed (by some) to influence birds and change birdstrike risks. Such a system could provide good baseline data on bird behavior and to measure the effects of new systems on reducing birdstrike risks. Aircraft with the airborne system could fly some sorties with landing lights, strobe lights, or other bird control device actuated and fly other sorties with the lights/devices not operating. The bird reactions could be compared using the data collected by the radar system. Conducting this flight evaluation phase in a manner which acknowledges and manages the associated risks will be critical in subsequent decisions for aircraft design and operation.

Any aircrew advisory system must accommodate a variety of requirements and idiosyncrasies. The birdstrike advisory system would need to have various features and adjustment capabilities designed in so the system could satisfy the requirements of many different operational users, and could be used in many different situations. Features would probably include selectable, bird-target sensitivity settings. In some situations pilots might desire advisories about even small birds (i.e.; aircraft is easily damaged; or, damage is prohibitively expensive). Other pilots might wish to only be warned about bird flocks plus medium-to-large single birds. Birdstrike situations that would NOT produce a warning to the aircrew could also be incorporated. A "mute" setting would be available for pilots to reduce feedback from the system to limit information "overload". An "off" position would be used to turn the system off completely when mission needs dictate. It will be challenging to work closely with the aircraft operators—as well as the system developers—to create a useful, effective system.

Probably the biggest challenge is not technical, it will be to find the sponsors with funding for operational evaluation of a prototype system. It is estimated that about US $1 million could produce a system for flight demonstration. Once the final system is perfected for an initial aircraft the expected cost to retrofit the entire fleet of that aircraft would be relatively 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 software and create airborne bird warning systems for other types of aircraft radar would be much less. We expect that a total one-time investment of US $10 million could yield an annual savings to DoD of US$30-$50 million.

Laser Devices

Advances in technology have made available compact, low power, lasers capable of producing beams across the light spectrum. Lasers produce intense beams of light that are monochromatic (i.e., a specific wavelength), coherent (photons of light in a fixed-phase relationship), and collimated (i.e., the beam exhibits a very low rate of expansion or deviation from parallel). Why might an intense monochromatic beam of light serve as an avian frightening device? We suggest that the intensity of a laser beam (either fixed or in motion) would be atypical of anything a bird encounters in the natural environment and, therefore, avoided. For example, Briot (1996) observed gulls moving away from a laser beam (four types of lasers, including a 5 to 10 mW He-Ne laser producing a beam at the 530 nm wavelength) that was moved toward them (but not aimed at their eyes). However, there is a paucity of data from controlled, experiments to determine the response of birds to various low-power, laser-light configurations.

The National Wildlife Research Center Field Station at Sandusky Ohio, is conducting a series of bench-scale and field tests of selected laser systems. Two-choice cage tests to quantify the effectiveness of low-power (10 mW) 633-650 nm lasers in repelling Brown-headed Cowbirds (***Molothrus ater***) from perching and in dispersing Canada Geese. In each of three perch experiments with stationary and moving beams "defending" a randomly selected perch, cowbirds were not repelled, nor was there behavior indicating perception of the laser beam. However, six groups of geese (four birds/group) exhibited marked repellency to the laser beam in 20-minute sessions, with a mean 96% of birds repelled from laser-treated plots. These tests indicate that lasers can be useful in dispersing birds, but also areas that require further research.

Laser "rifles" are being employed to project a narrow, spot of light that apparently "scares" the birds enough to leave these sites. Collectively, tens of thousands of Double-crested Cormorants (***Phalacrocorax auritus***) have been dispersed from their night roosts in response to a tight, 10 mW, He-Ne 632.8-nm laser "rifle" (the Desman™ Laser model FL R 005; Figure 3) and to the more diffuse Laser Dissuader system (see description below; Figure 4; J. Glahn, U. S. Department of Agriculture, National Wildlife Research Center, Mississippi Field Station, Starkville unpublished data). Completely moving a roost usually requires three episodes (at dusk) of moving the laser light-spot across the birds from a 200-300 yards distance. Lasers offer a major improvement over pyrotechnic devices when noise must be kept at a minimum and non-target species may be adversely affected by pyrotechnic controls.

Other laser systems that are in development for law enforcement also may show promise against birds in the wild as well as in hangers or on other structures. A beam from a hand-held, class II ("eyesafe" laser), battery powered, ~60-mW, 650-nm, diode laser [Laser Dissuader™, SEA Technology, Inc., Albuquerque, New Mexico], focused to a 0.15-m spot at 35 m, was successful at moving groups of Canada Geese at night (Figure 4). A two-choice, cage experiment with Canada Geese demonstrated unquestionable repellency by the birds to the laser. There appears to be possible limitation on the use of the system during bright conditions since too much ambient light would lessen the relative visibility of the laser light.

Figure 3. Desman™ Laser model FL R 005.

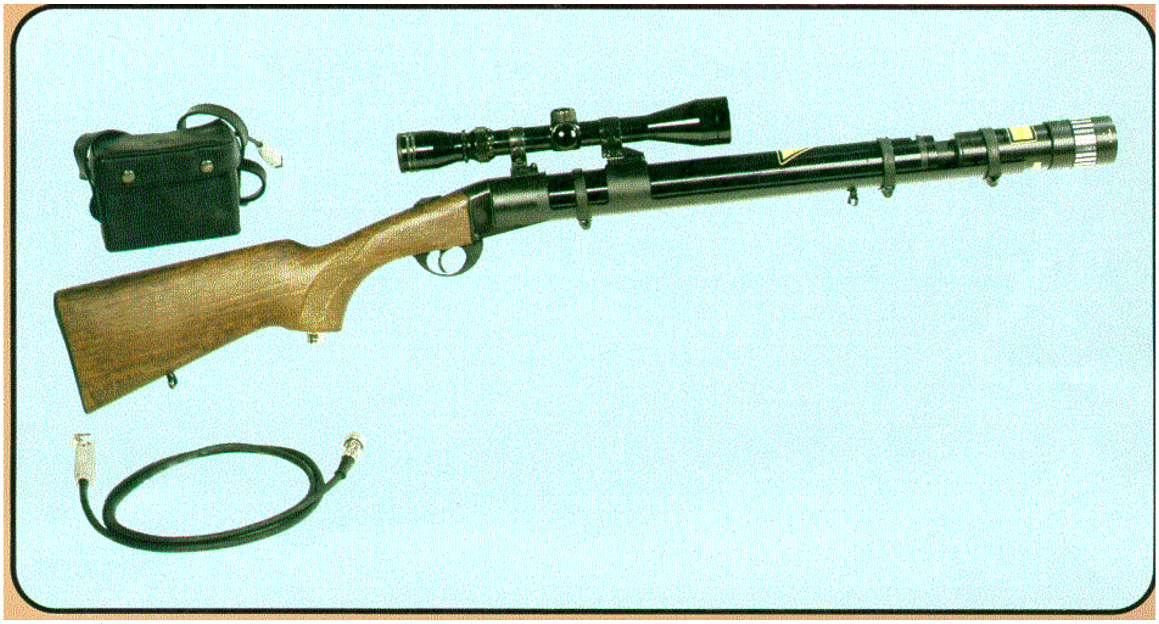


Figure 4. SEA Technology Laser Dissuader™.

The lack of measurable response by cowbirds to a 633-nm, He-Ne, laser should not be construed as evidence of the ineffectiveness of laser technology in repelling birds. As mentioned above, a laser of similar wavelength has been used to disperse Double-crested Cormorants. In addition, Great Blue Herons (***Ardea herodias***) were dispersed from a nocturnal foraging site in response to the 650-nm laser beam (Blackwell and Bernhardt, U. S. Department of

Agriculture, National Wildlife Research Center, Ohio Field Station, Sandusky, unpublished data). However, our nighttime experiments demonstrate that sensitivity to a particular wavelength of laser will likely vary among species (see below). Similarly, the light conditions under which a species perceives and responds to a laser may vary among species and wavelengths. For example, in our experiments there was perceptible (from the human perspective) contrast between the laser and ambient light. Further, wavelength sensitivity does not connote repellence.

Tests are planned on other bird species that pose problems in or on buildings and at airports. In the coming year we will conduct controlled studies with a variety of avian species, settings, and laser configurations. Careful, controlled studies will determine if laser devices can produce the desired effect to move birds and that lasers will have no unanticipated, damaging effects on the birds. Such controlled experiments are needed to better define the uses and limitations (both species-specific and physical) of lasers to repel and disperse birds.

Specifically, controlled studies are needed to evaluate the species-specific and physical limits of lasers as avian repellents. Understanding the range of wavelengths to which a particular species may be visually cognitive is an important aid in designing future experiments. Further, though these data are not readily available for all species, spectral sensitivity may be inferred to some degree from electrophysiological work with congeners, or species of similar ecology. Though the work presented here is preliminary, this integration of sciences offers cost-effective possibilities for birdstrike risk reduction.

Audible Microwaves

This 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 (hopefully) get out of the way. Laboratory tests have determined that modulations can be incorporated into the radar signal that will allow birds to perceive (“hear”) the radar, and have identified the types of sounds that get the desired bird reaction of “searching” to locate the sound source. Research has shown that while birds are generally insensitive to ultrasound or sound at frequencies above that heard by humans (Hamershock 1992), they can detect infrasound, or sound at frequencies far below that heard by humans (Genova and Castiglia 1995). Under laboratory test conditions birds respond to this sound in a manner suggesting they are visually searching for the source. Conceptually, in their attempt to locate the source of the infrasound, the birds would increase their awareness and thus avoid the aircraft. The infrasound could be from equipment on-board the aircraft or from ground-based equipment directed to cover the takeoff or landing corridors. To avoid habituation the system would operate only when radar detects the presence of a potential birdstrike problem.

Tests with caged, wild birds indicate that "audible" microwaves, when directed at the birds several seconds before arrival of danger (in the form of a truck moving at high speeds) resulted in eliciting an increased awareness and avoidance reaction from the birds. When the truck was 400 feet (130m) away from the cage, a sensor on the road activated a microwave signal from a horn inside the cage. A videotape recorded the birds' behavior. The tests showed that the microwave signals caused the birds to detect the truck and begin their escape maneuver sooner than when no stimuli was used. The birds displayed no tendency to become accustomed to the audible microwave when the stimuli was always followed by arrival of the truck. In fact, there were some indications that some birds started to learn that the stimuli was associated with the approaching danger and their ability to detect and escape before the vehicle arrived was improved. A 20% reduction in birdstrikes at USAF airfields is estimated to be over $US 2 million per year in avoided costs (loss calculations based on USAF BASH data).

The AFRL-contracted effort to explore the feasibility of using audible microwaves was completed in 1998. Private industry is pursuing the development of a commercially available system that utilizes the audible microwave concept to make birds aware of approaching aircraft. Much more testing must be accomplished to discriminate between the effects of the audible microwave stimulus and other factors. Additional tests are planned for the Spring 2000 to determine if the birds will respond to the microwave signal emanating from the vehicle itself.

It might also be possible to create “discomfort” in birds by using special microwave modulations. Similar physiological effects have accidentally been created many times in the past on a variety of vertebrates with various radar systems. A strongly discomforting effect could force even stubborn birds to avoid runways and aircraft flight paths and cause birds in flight to escape the stimulus.

A discomforting effect could be created for use either with a ground-based system or as an airborne system. A ground-based system could have a narrowly-focused beam that would force birds away from runways and keep birds away from approach and takeoff areas. An airborne system would have the discomforting modulation only present when the microwave beam was aimed along the aircraft's flightpath. This would mean that birds that were in danger of being hit would divert away from the beam, but birds that were not posing a hazard would detect nothing. To ensure no adverse environmental effects, these discomforting effects must not injure the birds, humans, or other non-target, animals; would involve only a well-defined sector ahead the aircraft's path; and, would be limited in range. To produce a discomforting effect using microwaves would require funds to develop and validate the system and ensure there are no significant, adverse environmental effects with its use.

AFRL Birdstrike Research: Epilogue

As noted at IBSC 24, funding cuts to Air Force Research Laboratory resulted in the Birdstrike Prevention Program no longer being within the budget. The most current AFRL, Science and Technology Strategic Plan focuses on investments over the next seven years that support the evolution of an air- and space-mission. This, and other USAF organizational business plans, address operational requirements and technology initiatives focused on developing a highly integrated, agile, modern force. These business plans have embedded requirements that may drive future birdstrike, risk-reduction initiatives. For example, one requirement is the desire of the Air Force Materiel Command to reduce by 15 percent, all mishaps due to causes other than human error by fiscal 2002, and 50 percent by fiscal 2005 (Bongiovi 1999).

Cutting overhead costs associated with personnel and unneeded facilities plays a major part in paying for the development of new technologies to support the new aerospace requirements. New technologies must be employed to extend the life, improve mission survivability, and cut the supportability costs of existing airframes. Hopefully, data on the sensitivity of these aircraft to birdstrikes will be used to make intelligent, affordable, aero-science decisions that incorporate bio-science considerations.

One of the ultimate goals of a research and development organization like AFRL is to successfully transition technology to the final, operational users. "Tech Transition" is one of the ways that the AFRL measures success. Another measure 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. As always, a final measure is for the technologies to lower the cost of ownership of aircraft resources.

Typically, airport bird control programs rely upon people to notice birds—usually visually—that would cause hazards to aircraft. These people pass the word and other personnel are tasked with assessing the situation and/or driving the birds away. This approach creates a “built-in” lag between identification of the bird hazard and the actions taken to reduce the hazard. Any breakdown in communication can greatly worsen the situation. A practical, automated bird detection and warning system for airports could help overcome this time lag, greatly reduce birdstrike risks, and reduce operating costs.

Infrared (IR) sensors are capable of detecting birds in flight or on the ground, while radar can detect birds in flight many miles away. Computer software for recognizing and tracking targets has been in wide use for decades—but not for tracking potential bird hazards. A system needs to be developed that is effective, affordable, practical, and adaptable for use on a wide variety of military and civilian airports. The system must not interfere with landing systems or other electronic equipment, should not be disrupted by emissions from such equipment, and must comply with necessary safety or other aviation requirements (e.g., frangibility).

Either a ground-based or airborne bird hazard advisory system would also be useful in gathering detailed information on bird behavior in all types of weather conditions, day and night. This information could be used to further improve Bird Avoidance Models and also could be used by bird researchers with little or no interest in aircraft operations. Bird flight activity (altitudes, quantities, time of day, etc.), as recorded by either the air- or ground-based bird hazard advisory systems, might provide valuable data for some researchers–data that would be unobtainable from any other source. Exploitation of doppler weather radar for tracking and reporting about bird movements would be a significant improvement to warn aircrews about bird hazards “realtime”.

Laser technology has recently been demonstrated as a potentially effective tool in repelling and dispersing birds; however, enough controlled studies have not been conducted for a seamless, implementation by the operators. Directions on the safe, and effective use of these laser systems on various bird situations will need to be provided to ensure proper, reliable results in the field.

There are contacts in the U.S. government that can provide expertise in the transition of birdstrike reduction techniques and can offer additional help with bird strike problems in general. The first two, in particular, have many years of birdstrike program experience and have been important partners with the AFRL team.

The U.S. Air Force Bird Aircraft Strike Hazard (BASH) Team, can provide expertise on bird control issues, especially relating to U.S. military installations and operations. The BASH program is the primary USAF advocate for birdstrike risk reduction. BASH provides funds for testing and fielding new birdstrike prevention innovations as well as training personnel on BASH. The BASH Team is located at the Air Force Safety Center (HQ AFSC/SEFW), Kirtland AFB, New Mexico, 87117-5671). Major Peter Windler, is the current BASH Team leader and can be contacted at telephone 505-846-5674 (fax 505-846-2710) or by email at: windlerp@kafb.saia.af.mil.

Scientists in the U.S. Department of Agriculture (USDA) can provide assistance for characterizing and controlling birds and other wildlife hazards on airfields. Dr. Richard Dolbeer heads the USDA, National Wildlife Research Center Field Office in Sandusky, Ohio. Dr. Dolbeer's telephone number is (419) 625-0242 (fax 419 625-8465) and can also be reached by email at: richard.a.dolbeer@usda.gov.

U.S. Army Captain James Ivey, Airfield Manager at Davison Army Airfield, at Fort Belvoir, Virginia, has experience in deploying an integrated thermal imaging system to warn of airfield bird hazards. He can be reached by phone at (703)-806-7548 (fax 703-806-7171) or email at: James_R_Ivey@belvoir.army.mil.

Conclusion

Through integration of aero-science and bio-science, there has been good progress in the development of new technologies to reduce the aircraft birdstrike hazard. Some of the new technologies will certainly prove to provide additional, non-lethal, weapons or tools for cost effective win-win solutions. Decision makers within the communities represented by airports, airlines, aircraft operators (both military and civil), aircraft manufacturers, and others such as insurance underwriters, will have opportunities to drive the underlying investments necessary to evaluate possibilities and convert potential into reality. Achieving the potential payoffs in flight safety from birdstrike risk reduction will only happen through the continued collaboration and cooperation of aero-scientists, bio-scientists, and resource administrators. Indeed, this need for a unified approach to Team-For-Success in reducing the birdstrike risk was clearly articulated in a 19 Nov 1999 safety recommendation report from the US National Transportation Safety Board to the FAA (Hall 1999).

Additional initiatives are needed to create breakthroughs and yield large improvements in birdstrike prevention. Future technology developments in fields of aero-science or bio-science may play a large role in birdstrike prevention. The potential exists for integrating these sciences to change birdstrike mishaps from "ïnevitable" to "preventable". Developments in security systems, personnel protection remote sensing, information processing, and artificial intelligence offer exciting possibilities for reducing birdstrike risk near airfields and enroute. As a potential user of these technologies, the aviation community should identify its requirements so that they can be presented to those involved in developing and acquiring these new technologies.

Each of the authors has many years of experience in improving aircraft birdstrike tolerance and welcomes the chance to explore new possibilities for

applying new technologies needed for birdstrike prevention or abatement. There must evolve a stronger collaboration between researchers in all disciplines if we are to fully realize the potential of new technologies to solve the problem. Scientists from all disciplines, should be made aware of the part they can contribute. Together we can promote the development and application of cost effective, birdstrike prevention technologies, devices, and techniques by:
(a) compiling and sharing information that will lead to definition, evaluation, and resolution of the birdstrike hazard;
(b) validating commercially produced technologies that reduce bird hazards to aircraft;
(c) supporting cooperative projects for birdstrike threat reduction at military and civilian flight corridors, airfields and associated grounds; and,
(d) recommending implementation of solutions that use proven bird threat reduction techniques.

What will it take to make this happen? Resources! Resources are time, talent, and funding. Resources flow to fix problems, and they flow from those that are responsible for the consequences of the problem(s), to those that can “team-for-success” to reduce the consequences of the problem(s). The resources will flow to fix a particular problem when it is obvious to the resource holder that the return on fixing the problem is greater than the return on fixing some other problem. As the ability to prevent serious birdstrikes becomes an accepted technology, then the consequences of not using this capability will create a "problem" that will demand resolution by those that stand to absorb the legal and fiscal consequences of not having taken appropriate corrective action. This legal assignment of fiscal responsibility for the consequences of failure to have taken known corrective action for a known hazard is well-established. It was a clear message at IBSC meeting 23 (Lehmkuhl 1996). This underlying thought process was a central premise at the IBSC-supported Birdstrike Risk Reduction Workshop for East African Nations, organized in 1996 by ICAO in Nairobi, Kenya.

The resources are available---they are just not yet in the desired account. The payoffs of using them to further reduce the birdstrike risk through integration of aero-science and bio-science are becoming too clear to continue to ignore. For those institutions and organizations that will be expected to absorb the cost penalties of implementing this new technology there will be a growing need to have a conclusive answer to the inevitable challenge: "Yes, but can you show me that it really works to reduce my overall cost?" Towards this end, we must begin to plan for how to conduct operational test and evaluation in a manner which shows a clear answer to this question and yet does it within acceptable operational risks.

About the authors

Jeffrey Short (Colonel, USAFR) has been integral to the USAF birdstrike reduction efforts since 1978. His areas of expertise include airbase bird hazard control, bird avoidance modeling, and analysis of birdstrike risks. At AFRL, he has focused attention on innovative technologies for preventing birdstrikes and the development of an annotated bibliography on bird hazards. Jeff may be reached by telephone (202) 586-2675 or by email at: jeffrey.short@em.doe.gov.

Malcolm Kelley has been involved in this subject area for over 15 years. His primary area of expertise is in finding ways to obtain longer service life of components that have been increased in design complexity to provide increased birdstrike tolerance. For the past seven years he has focused his attention on innovative technologies to reduce birdstrike probability. Mal recently retired from the AFRL and can be reached by phone at 937-767-1803 or by email at: nancy@kelleyequestrian.com.

Ralph Speelman, III, has been involved in this subject area for over 25 years. His expertise includes all aspects of development, validation and transition of technology to improve the birdstrike resistance of aircraft subsystems. Ralph has recently retired from the AFRL and may be reached by telephone at 937-255-6823 (fax 937-255-2237) or by email at: ralph.speelman@wpafb.af.mil.

Robert McCarty has been involved in this subject area for over 20 years. His primary topic of expertise is the development and validation of computer codes for analyzing structural response to the birdstrike event and in reducing the cost of designing components to absorb this energy. For the past seven years he has focused his energy on development of a capability to injection mold aircraft birdstrike-resistant, windshield systems including incorporation of an integral frame. Bob may be reached by telephone at 937-255-5060 (fax 937-656-4275) or by email at: robert.mccarty@wpafb.af.mil.

Any of the authors may be reached by mail at:

U.S. Air Force Research Laboratory
Plans and Programs Directorate (XP)
ATTN: Colonel Jeffrey Short
1864 4th Street, Suite 1 (Bldg 15)

Wright-Patterson AFB OH 45433-7131 USA

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