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Scott T. Philibin

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Introduction

A question has lingered over the Aviation Industry for over 30 years. Can we improve the visibility of aircraft to birds so as to reduce the probability of bird aircraft collisions? At the outset, I want to make clear that reducing bird hazards to aircraft is a comprehensive and systemic problem which can be mitigated in part by active control of causative factors in and around airports. However, aircraft rapidly transition out of the airport boundary in a matter of seconds and are still transitioning miles away from the airport at altitudes where birds may still be commonly found. It will only be an onboard system that can significantly reduce the bird hazard in this airspace. Our work both in application and research has been utilizing variations in aircraft mounted lighting to reduce this hazard.

Collisions between wildlife and aircraft worldwide are increasing in number and severity. The United Kingdom's Central Science Laboratory estimates that wildlife strikes to aircraft cost the aviation industry worldwide as much as one billion dollars each year. In the United States alone the annual loss is estimated at $300-$400 million. [1] National Transportation Safety Board Chairman Jim Hall has stated that birdstrikes are on his list of most wanted concerns. Assistant Secretary of Agriculture, Jim Dunn, has stated that "...There has never been a greater potential for catastrophe than in the current conflict between wildlife and aviation." During a four month period in late 1999, at Detroit Metropolitan Airport alone, Northwest Airlines suffered over $24 million in damage due to bird ingestion. [2]

Paul Eschenfelder, Air Line Pilots Association Wildlife Specialist, states that "Worldwide, wildlife populations have continued to expand. The resident Canada Goose population in the United States has quadrupled since 1987. Pratt and Whitney estimates it will double again in five years to over six million resident birds. The Snow Goose population has become so extreme it is denuding its summer range in Canada. The gull population in the Great lakes Area cannot find nesting space and has begun nesting on building rooftops. The Cormorant, a fish eating bird just slightly smaller than a goose has experienced a resurgent population." [3]

Eschenfelder also notes:

> While modern jet engines are designed to be very hardy in some respects, they no longer meet the safety level contemplated by regulators for bird ingestion due to the increased number of large flocking birds. The FAA/JAA Joint Engine Harmonization Working Group is currently working with a new TOR to develop increased standards for bird ingestion. Currently, the largest bird an engine has to be designed and demonstrated to ingest is a four pound bird—about the size of a fat gull or skinny duck. The engine must only ingest one of these flocking birds and demonstrate no run on time, only safe shutdown. None of the engines currently flying are designed or built to survive an ingestion of an 8-15 pound goose, pelican, stork, vulture or 25 pound swan. [4]

Obviously, even small improvements in birdstrike reduction can have significant economic impact. This paper will discuss critical issues related to the problem including current research and trial programs and the future direction the research is moving towards.

Avian Senses of Hearing and Vision

In order to address the development of an onboard collision avoidance system, it is helpful to look at the relevant physiological characteristics of birds in order to insure successful efforts in providing them with adequate warning of impending danger.

Hearing

Noise can provide some degree of warning for birds. It has some effect in stationary installations such as airports. However, some researchers have speculated that the increasing rise in birdstrikes is the result of effective efforts to reduce aircraft noise. A variety of observers have noted that when we were low and slow with large propeller - driven aircraft, bird hazards were not as large a problem. In the jet age, the effective difference in the speed of sound, in relation to the speed of jet aircraft, is marginal in providing adequate advance warning for a bird in order to execute an evasive maneuver. A Swedish report states that as the noise levels decrease at airports, bird breeding in surrounding woodlands increases, escalating the danger of collisions. The same report mentions that some airports fire hailstones into the air and even use controlled gas explosions at irregular intervals to try to cope with the problem. [5]

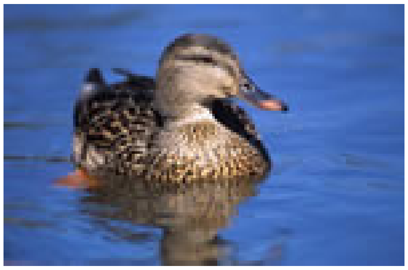
Vision

Birds have a highly developed vision system which they utilize to track or intercept prey or to avoid predators. Birds are acutely aware of their surroundings through vision. The eyes of most birds are on the side of their heads. This placement allows them to see the things on each side at the same time as well as in front of them. This arrangement provides a wide field of vision so that they are able to see danger as quickly as possible. The field of vision can be as large as 340 degrees. With widely spaced eyes, judging distances and depth perception are more difficult, except in the area in the eyes of the overlapping field of view. If we look around, we see birds intercept insects, fish, mammals and other birds with astonishing accuracy. In short, birds have astonishing capabilities and options for avoiding danger. They operate in a three dimensional world and are typically of limited mass and high aerodynamic capability. If they are warned of potential danger with sufficient time to react, they will get out of the way.

Avian Eyesight Research

This paper is primarily focused on the consideration of knowledge about the visual capacities of birds and the application of this knowledge to the prevention of the birdstrike menace. A detailed discussion of avian eye anatomy follows. It is excerpted from Ramel's work which appears on his website, Earth-Life Web Productions. (See footnotes) [6]

> A bird's eye is very similar in its basic structure to a human eye. Though with certain modifications and differences, the eyes make up a much larger percentage of the head weight in birds than in a man, e.g., 15% for a common Starling but only 1% for man. This is partly because a bird's eyes are larger relative to its skull than a human's and partly because the skull is lighter, i.e. no heavy jaw bone and teeth.



> A bird's eye is fitted into its skull and is capable of very little movement. Therefore birds can often be seen moving their heads in order to change their visual relationship to something. The majority of bird's the eyes are placed much closer the sides of the head than in humans. This gives the bird a greater overall field of view, but greatly reduces its binocular vision (the area in which both eyes can see an object).

> In man, binocular vision is about 140 degrees out of a total of about 180 degrees. In a pigeon, the binocular area is only 20-30 degrees out of a total field of vision of 300-340 degrees. The situation is different in many raptors and owls. For these birds, as in many insectivorous birds, binocular vision, important in making judgments of distance, is more necessary and so they have their eyes closer to the front of their heads. This is most evident in owls where the total field of view is reduced to about 110 degrees with a binocular vision of 70 degrees. This is why owls turn their heads to watch you walk past. An owl can turn its head through over 200 degrees but cannot move its eyes in its head at all.

The most important parts of the bird's eye are:

- The Eyelids - birds have 3 eyelids; one upper and one lower eyelid, of which the lower is more moveable, and a nictitating membrane. This nictitating membrane is between the other two eyelids and the cornea and has its own lubricating duct equivalent to our tear duct. It is used in cleaning and protecting the eye.
- The Cornea - The protective covering on the outer surface of the eye.
- The Anterior Chamber - The space immediately behind the cornea and leading to the iris and the lens. It is filled with a fluid called the aqueous humor.
- The Iris - A muscularly operated diaphragm which controls the amount of light entering the eye. It is colored which is what gives the eye its color. At the center of the iris is the variable hole through which the light actually passes on its way into the eye; this is called the pupil.
- The Lens - A transparent convex or lens shaped body with a harder outer layer and a softer inner layer. It serves to focus the light on the retina. Its shape can be altered by means of the ciliary muscles which are attached to the eye by means of the zonular fibers.
- The Posterior Chamber - The bulk of the eye and is the space behind the lens and between the lens and the retina. It is filled with a clear jelly-like substance called the vitreous humor.
- The Retina - The inner light receptive part of the eye. It is covered in special photoreceptive cells called rods and cones. Towards the center of the retina is an area called the fovea centralis, which has a greater density of receptors or rods and cones. This is the area of greatest visual acuity, i.e. sharpest and clearest detection of objects. The number of receptors per square millimeter determines the degree of visual acuity an animal has. The more receptors, the higher its ability to distinguish individual objects at a distance. In some birds such as hawks, kingfishers and swallows, the eye has two fovea, one for sideways viewing and one for forward viewing. In many raptors the fovea centralis has far more rods and cones than in humans, which allows these birds their spectacular long distance vision.

  We have about 200,000 receptors per mm^2; sparrows however have about 400,000 while a buzzard has an incredible 1,000,000 receptors per mm^2. The fovea itself can also be lens shaped increasing the effective number of receptors per square millimeter. Buzzards for instance have distance vision 6 to 8 times better than ours; part of this is a result of the lens shaped central fovea which acts something like a two power magnifying lens. [5]

USDA Research - National Wildlife Research Center - Phase 1

In 1999, Richard Dolbeer and Brad Blackwell of the National Wildlife Research Center (USDA), together with representatives of the FAA and Precise Flight, set out to quantify the behavioral aspect of several bird species in response to a moving vehicle and lighting. The research objective was to quantify avoidance behavior by the following bird species:

- Brown Headed Cowbirds
- Canada Geese
- European Starlings
- Herring Gulls
- Mourning Doves

These bird groups were subjected to a vehicle driven near to them with the following treatment scenarios:

- Vehicle – No lights
- Vehicle – Steady Lights
- Vehicle – Pulsing lights

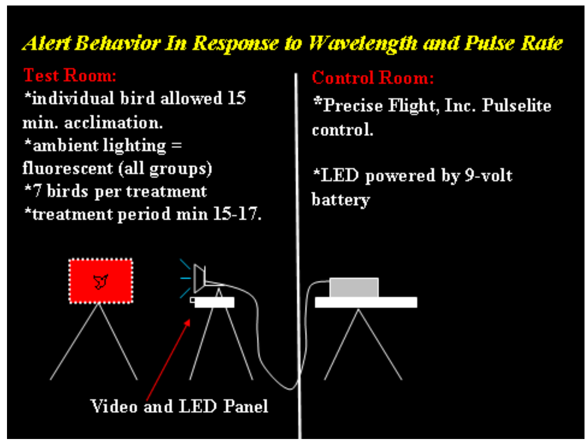
The lights were mounted and spaced consistent with aircraft landing lights test on a truck chassis. The lights were powered with a Precise Flight, Inc. Pulselite Control Unit which enabled them to either pulse or be turned on steady. The truck was driven at a rate consistent with aircraft takeoff speeds near a small group of caged birds identified above. The bird individual reaction time was recorded and computed knowing the frame rate of the camera to obtain the Mean Reaction Distance.

Review of the films and calculation of the Mean Reaction Distance showed an improvement in avoidance responses by Brown-Headed Cowbirds, but limited response by Canada Geese, European Starlings, Herring Gulls, and Mourning Doves. The Brown Headed Cowbirds exhibited earlier and more cohesive avoidance reactions to approaching vehicles. Because of the dramatic effect shown with this species, they were re-tested; however we recorded differing results than our initial test. This dramatic difference led the research team to attribute the varying ambient light to the varying results. Biologists suspect contrast may be a key factor. [7]

USDA Research - National Wildlife Research Center - Phase 2

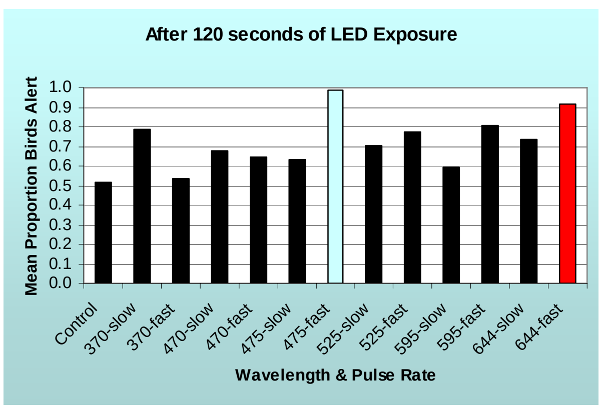
Our objective in Phase 2 of our research was to quantify the potential behavioral differences in avian response to specific wavelength and pulse frequency. Our Phase 1 testing led us to research the potential response differences when avian specific contrast was greater or pulse rate was closer to the avian flicker fusion rate. The premise for the research was that if key components of a bird's visual capability in the visual sensory perception namely:

- Color or Combination of Colors in the birds visual spectrum
- Flicker Fusion Rate – Ability to perceive fast moving objects



Could be exploited, our field response could be improved dramatically. Our research intended to find a combination of these visual characteristics that would produce a consistent and measurable response.

The test utilized LED lamps set to similar intensity with a fixed wavelength frequency from small infrared to ultraviolet and varying pulse widths to determine an alert reaction on the part of the test birds. This pilot study found that between 91% and 99% of the birds exposed to the 475-nm and 644-nm (blue) lights when pulsed at a rapid rate exhibited an alert behavior. This reaction occurred repeatedly and consistently as the light treatment was reapplied to the subject birds.



Biologically, the findings are consistent in that birds are likely to use contrast in foraging and predator detection. A patent application followed Phase 2 based on a process and an apparatus for the avoidance of wildlife impacts on vehicles by means of a pulsing light at spectral and interruption frequency specific to the hazard species. Patents Pending were filed by the USDA and Precise Flight on the results of this research. [8]

USDA Research - National Wildlife Research Center - Phase 3

The objective of Phase 3 of the test series was to take our findings from the lab and apply them to the outdoor environment. The light remained stationary although the testing was conducted on days with bright sun and little or no wind to take these variables from our results.

The test setup was similar to that used in Phase 2 with the exception of the use of incandescent lights in theater cans with colored gels. In this configuration light intensity could not be as carefully controlled as the gels combined with a high rate pulsing incandescent light contained its own spectral characteristics.

Results of these tests are being evaluated at this time. However, preliminary results showed that pulse rate was the driving factor for capturing the bird's attention. Incandescent lighting technology limited our capability in color and precise spectral control, and while color may play a key role, we moved forward with the strongest position we had with the known limitations of current aircraft lighting equipment.

In identifying pulse rate as a critical piece of this puzzle, we refined our pulse capability by refining the Pulselite unit to operate an incandescent lamp to 30 Hz with distinct pulse control.

USDA Research - National Wildlife Research Center - Phase 4

Present testing utilizes the truck mounted lights in combination with the colored gels and a multiple frequency Pulselite unit. We wanted to re-introduce movement combined with color and pulse frequency and light to reevaluate the initial test procedure. In our initial tests with the cage at the side of the road, some species did not react to the vehicle as looming danger, specifically Canada Geese. The Geese in the initial test had effectively hunkered down in the grass to avoid detection. A better sense of approach and the imminent reaction to move out of the way needed to be introduced. To accomplish this, the truck will be driven directly at the caged birds eliciting a sense of looming danger. As in Phase 1 of our test procedure, Mean Distance to the threatening vehicle will be measured.

Conclusion

In an intensely practical sense, the task of improving aircraft visibility by birds has the potential to dramatically reduce the rate of birdstrikes to aircraft. This goal will be achieved through education about what improvements can be made to aircraft visibility as well as continuing research and the application of that research to existing aircraft fleets. Much more is known about the nature of avian vision than was the case thirty years ago— or even a few years ago. Industry safety experts can no longer disregard the data. While quantification of the effects of pulsed light and color on preventing birdstrikes remains challenging, the task is achievable. Precise Flight, Inc., through its pioneering work, remains on the leading edge of this effort within the industry. Representatives of Precise Flight invite inquiries and consultation by general aviation representatives and others who wish to learn more about our efforts to address the massive annual loss caused by birdstrikes and to dramatically lessen what many have determined to be the major aircraft safety challenge of our time.

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