February 2002

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PRESENTED FOR THE 2002 FEDERAL AVIATION ADMINISTRATION TECHNOLOGY TRANSFER CONFERENCE
02/02

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Abstract: Research conducted by the U.S. Department of Agriculture's (USDA) National Wildlife Research Center (NWRC) indicates that low- to moderate-power, long-wavelength lasers (630–650 nm) provide an effective means of dispersing some "problem" bird species under low-light conditions, while presenting no threat to the animal or the environment. The NWRC researchers tested the hypothesis that birds would avoid the beam or beam spot produced by a laser in low ambient light. In the format of controlled, replicated, 2-choice experiments with captive birds, Canada geese (*Branta canadensis*; 6 groups; 4 birds/group) exhibited extreme avoidance of laser beams over 80-minute periods, with 96% of the birds moving to untreated (control) areas. Concurrent work involving the use of lasers against double-crested cormorants (*Phalacrocorax auritus*) at night roosts resulted in the abandonment of roosts by several thousand birds after 3 nights of treatment. In addition, waterfowl (Anatidae) species (including Canada geese), wading birds (Ardeidae and Threskiornithidae), gulls (Laridae), vultures (Cathartidae), and American crows (*Corvus brachyrhynchos*) have exhibited avoidance of the laser beam during field trials, but response is dependent upon context and species. The low power levels, directivity, accuracy over distance, and silence of laser devices make them safe and effective species-specific alternatives to pyrotechnics, shotguns, and other traditional avian dispersal tools. Further, hand-held laser devices and automated, fixed-position laser systems would likely prove a safe and effective enhancement of bird management efforts at airports. Here we 1) review research relating to the use of lasers as avian repellents, 2) discuss the application of laser technology in dispersing birds from the airport environment, and 3) review the laser products designed specifically for bird dispersal.

Since 1903, when Orville Wright reported the first strike of a bird by an aircraft, society has witnessed dramatic growth in the number and types of aircraft, and has grown dependent upon the industry for travel and commerce. During this same period, some wildlife species populations, benefiting from human alterations to the environment, have exhibited rapid population growth, reaching the level of pest status (e.g., Ankney 1996, Dolbeer 1998, Smith et al. 1999, Tyson et al. 1999). The result of increased frequency of aircraft movements combined with growth and expansion of wildlife populations is the higher probability of a wildlife strike (particularly by birds) that will cause substantial damage, financial loss, and injury or loss of life (see Dolbeer et al. 2000). Based on a strike report rate of only 20% from 1990 to 1999, in the United States alone wildlife strikes cost the civil aviation industry a minimum of 94,373 hours annually in aircraft down time, $51.01 million annually in direct monetary losses, and $27.28 million annually in associated costs (Cleary et al. 2000). Moreover, between 1960 and 1998 more than 100 lives were lost as a result of wildlife strikes to civilian aircraft in the USA (Cleary and Dolbeer 1999). Within the airspace and grounds of airports, the legal responsibility of ensuring a safe operating environment (including management of wildlife species to prevent strikes) falls to the airport sponsors and managers (see Cleary and Dolbeer 1999).

Whether applied in a wilderness situation or the bounds of an urban airport, effective wildlife population management requires a sound knowledge of the ecology of the species involved (Dolbeer 1998), as well as the availability to managers of proven socially acceptable methodologies (Blokpoel and Tessier 1986, Dolbeer 1998, Smith et al. 1999, Blackwell et al. 2000). Successful management strategies are typically integrated and can involve habitat alteration, visual, auditory, physical, and chemical repellents, or population control in the form of reproductive inhibition or culling (Dolbeer 1999). The procedures involved in conducting a wildlife hazard assessment and the instigation of a wildlife hazard management plan, as well as the legislative guidelines governing wildlife management at U.S. airports (national laws and international treaties), were recently compiled in a handbook for wildlife managers (Cleary and Dolbeer 1999).

Notably, despite an increase in concern over safety, health, and property damage associated with wildlife populations at airports and elsewhere over the last 3 decades (Blokpoel 1976, Conover and Chasko 1985, Dolbeer 1998, Blackwell et al. 1999), management options have been progressively restricted toward use of non-lethal methods (Dolbeer 1998, Smith et al. 1999, Blackwell et al. 2000). Moreover, few effective non-lethal technologies are presently marketed, and those available are often limited in effectiveness by circumstance (Mason and Clark 1992, Clark 1998, Dolbeer 1998, Blackwell et al. 1999). However, recent work by the U.S. Department of Agriculture's (USDA) National Wildlife Research Center (NWRC; Glahn et al. 2001, Blackwell et al. 2002) indicates that low- to moderate-power, long-wavelength lasers (630–650 nm) provide an effective means of dispersing some "problem" bird species under low-light conditions, while presenting no threat to the animal or the environment.

The term "laser" is an acronym for Light Amplification by Stimulated Emission of Radiation. The concept of using lasers as avian visual repellents was introduced nearly 30 years ago (Lustick 1973), but received little attention and no formal research (i.e., work comprising controls and adequate replication) until the NWRC began their investigation. Our objectives are to 1) review research relating to the use of lasers as avian repellents, 2) discuss the application of laser technology in managing in dispersing birds from the airport environment, and 3) review the laser products currently available and designed specifically for bird dispersal.

Use of Lasers as Avian Repellents

Avian vision represents a primary sensory pathway and is, subsequently, highly developed. Electrophysiological studies of the avian retina suggest that birds can distinguish colors ranging from the ultraviolet (350 nm) to the red (750 nm; Bowmaker 1987, see also Bennett et al. 1994), spanning the visual range of humans (400–700 nm). In fact, light has been used as a means of bird control (Meanley 1971), and has been investigated as a means of increasing avian awareness of aircraft (Land 1969, Larkin 1975, Thorpe 1977; see also Blackwell et al. 2001). Lustick (1973), however, hypothesized that avian behavior might be manipulated more effectively by use of an intense and coherent light source (i.e., a laser).

Lustick (1973) used captive birds and relied on concentrated laser beams that produced radiant energy (454–514 nm, ≥500 mW) exceeding maximal permissible exposure (MPE) levels for animals and humans (U.S. Occupational Safety and Health Administration [OSHA] 1991, American National Standards Institute [ANSI] 1993). His results varied by species (gulls [Laridae], mallards [*Anas platyrhynchos*], and European starlings [*Sturnus vulgaris*]), as well as beam intensity. Lustick suggested that birds with higher concentrations of rhodopsin, (rod) pigment sensitive to light intensity rather than hue, should be more sensitive to intense light. High rhodopsin concentration (i.e., indicating scotopic versus photopic vision) is characteristic of most avian species that forage or migrate at night (e.g., owls [Strigiformes], waterfowl [Anatidae], and wading birds [Ardeidae]; Sillman 1973). For example, mallards, the more crepuscular of the species tested by Lustick, exhibited a higher degree of avoidance of the intense (1–3 W) beam. However, irritation due to beam intensity produced avoidance behavior in all species tested. Yet, while the use of intense laser beams to deter bird use of the airport environment is impractical both from a safety and an ethical standpoint, Lustick's work demonstrates the potential for the use light as a visual avian repellent.

Advances in technology have now made available lasers that pose little risk of eye damage to humans or birds (laser Class-II and Class-III B categories). Laser classification is determined by the amount of radiant power within a 7-mm aperture at a distance of 20 cm (Code of Federal Regulations 21, Subchapter J, OSHA 1991). The Class-II category comprises lasers that emit visible beams at a radiant power ≤1 mW (low power continuous wave; OSHA 1991). The Class-III B category of lasers includes moderate-power lasers (5–500 mW, continuous wave) that are generally not capable of producing hazardous diffuse reflection except for conditions of intentional staring done at distances close to the diffuser (OSHA 1991). Both the ANSI and the Center for Devices and Radiological Health have each established MPE limits for laser products based on exposure time. The first limit is 0.25 seconds, known as the human aversion time or "blink reflex", which is the first line of defense against over exposure to laser radiation. The second limit is 10 seconds considered a "worst case scenario" for time of exposure. Based on these expected exposure times, energy output, beam diameter and other parameters, a nominal hazard zone (NHZ), also known as the nominal ocular hazard distance, is calculated for a laser device. The NHZ, however, considers only direct exposure to the unaided eye. Directly viewing laser beams with binoculars or other optical equipment greatly increases the hazard zone.

Briot (1996) reported the first anecdotal observations of gulls (Laridae) moving away from laser beams (4 types of lasers, including a Class-III B, 5–10-mW, He-Ne laser) during field trials. However, despite reported use of lasers in avian dispersal and the relative safety of Class-II and -III B devices, questions remained as to the number of avian species that would react to a laser, and whether birds would habituate. Blackwell et al. (2002), subsequently, evaluated the avoidance behavior of a number avian species in captive situations where controls and replication were possible. They conducted 2-choice cage tests to quantify the effectiveness of an AC-powered, Class-III B, High-performance Uniphase, 10-mW, He-Ne, 633-nm laser (use of trade names does not imply endorsement by the U.S. Department of Agriculture) as a visual repellent (treating a perch) against brown-headed cowbirds (*Molothrus ater*) and European starlings. Using a similar 2-choice design, Blackwell et al. (2002) also evaluated the effectiveness of the hand-held, Class-II, battery-powered, 68-mW, 650-nm, diode laser (Laser Dissuader™; SEA Technology, Inc., Albuquerque, New Mexico, USA) in dispersing (i.e., targeting birds with the laser) European starlings and rock doves (*Columba livia*) from perches and Canada geese (*Branta canadensis*) and mallards from grass plots. All experiments were conducted under low ambient light (≤3 lx) conditions.

In 3 experiments with stationary and moving laser beams treating a randomly selected perch, brown-headed cowbirds were not repelled. Similarly, a moving beam did not repel European starlings from treated perches, nor were they dispersed when targeted. Rock doves exhibited avoidance behavior only during the first 5 minutes of six 80-minute dispersal periods. Notably, 6 groups of Canada geese (4 birds/group) exhibited marked avoidance of the beam during 20-minute periods (N = 23), with a mean 96% of birds dispersed from laser-treated plots. Blackwell et al. (2002) describe the behavior exhibited by the Canada geese as a neophobic avoidance response to the approaching beam or beam spot contrasted against a dark background. Six groups of mallards (6 birds/group) were also dispersed ($\bar{x}$ = 53%) from treated plots during 20-minute periods (N = 12), but habituated to the beam after approximately 20 minutes. These data underscore the fact that the success of wildlife control methods is dependent upon species and context; bird reactions to lasers will depend upon species-specific retinal physiology (Endler 1990), the perception of danger, and the ecology of predator/threat avoidance behavior (Blackwell et al. 2002).

Subsequent to work by Blackwell et al. (2002), Cepek et al. (2001) conducted a field trial to examine the long-term effectiveness of the Laser Dissuader™ when used to disperse Canada geese from a traditional roost (the 148-ha Lake Galena, Buck County, Pennsylvania). Their dispersal efforts, conducted on 4 nights from 23 through 26 January 2001, resulted in a steady decrease of roosting birds from 18,000 individuals on 23 January 2001 to 1,600 individuals on 26 January 2001. Morning post-treatment counts also showed a decreasing number of Canada geese from 24 to 26 January. Post-treatment counts on 29 and 30 January 2001 showed an increase of only 3,282 and 3,098 geese respectively (approximately 18% of the original number). Important to the success of this dispersal operation was the combination of roost composition (i.e., migrants mixed with non-migrants), winter climate, and the condition of geese using the lake (i.e., individuals experiencing high energy demands because of winter stress).

Concurrent with the Blackwell et al. (2002) study, Glahn et al. (2001) used a Class-III B, 5-mW, He-Ne, 633-nm laser (Desman™ Laser model FL R 005) and the Laser Dissuader™

(described above) to disperse double-crested cormorants (*Phalacrocorax auritus*) from night roosts near southern U.S. aquaculture facilities. Cormorants typically abandoned roosts after 3 nights of harassment. With regard to the ethical aspect of using lasers as avian dispersal tools, Glahn et al. (2001) also reported laboratory findings of no ocular damage to cormorants after direct exposure to the Class-III B Desman™ Laser at distances as small as 1 m.

Urban roosts of the American crow (*Corvus brachyrhynchos*) have also been the focus of recent laser research (Gorenzel et al. in review). High densities of American crows in urban roosts are a nationwide problem with concerns ranging from health issues, property damage, and increased risk of bird strikes. At 73 urban roosts, Gorenzel found initial dispersal upon treatment with both the Desman™ and Dissuader™ lasers, but reoccupation of all roosts the same night after treatment. Further, no roosts were abandoned. Notably, these roosts were well lighted and the areas heavily trafficked by pedestrians and automobiles. In contrast, Blackwell et al. (2002) report extreme avoidance of the beam from the Dissuader™ by American crows occupying a large rural roost. Unlike the urban roosts treated by Gorenzel, conditions at this rural roost included little traffic by pedestrian or automobile and no artificial lighting. Here, again, the importance of context (noted above) as related to perceived threat is likely important. In addition, ambient conditions (e.g., artificial light) can also influence retinal physiology.

Specifically, a characteristic of avian visual physiology, common to amphibians, reptiles, and fish as well (but likely absent in mammals) is the phenomenon of pigment migration (Arey 1916; Walls 1942; Blough 1956; Adler and Dalland 1959). Adler and Dalland (1959), working with the European starling, explained this phenomenon as the movement of melanin granules in the retinal pigment epithelium extending into processes between the outer segments of the visual cells. When an animal is dark-adapted (a condition which urban roosting crows might not completely attain because of artificial light sources), the pigment remains at a retinal depth somewhat greater than that of the rods and cones, leaving these elements exposed to illumination. Upon illumination of the retina the melanin granules migrate toward the light and to a retinal depth intermediate between the rods and cones.

Application of Lasers to the Airport Environment

Birds pose hazards to aircraft movements at airports because of nesting, feeding, and loafing proximate to runways and flocking in the immediate airspace. Cleary and Dolbeer (1999) noted that 78% of the 22,935 bird strikes to aircraft reported to the U.S. Federal Aviation Administration (1990–1998) comprised gulls and terns, raptors, blackbirds (Icteridae), European starlings, waterfowl, and doves (Columbidae). For species active at night or during crepuscular periods (e.g., some waterfowl and wading birds), laser dispersal has advantages (situation-specific) over traditional wildlife control methods such as firearms and explosive devices. Specifically, lasers are silent and can be safely used in and around structures. Further, lasers offer greater directivity and accuracy over distance, a factor particularly important in dispersing birds from bodies of water. Also, the use of lasers to disperse birds roosting on or near runways can decrease the overall desirability of airport grounds to a species, thereby reducing the threat of bird strikes during the species' active period. For example, the abandonment of night roosts by double-crested cormorants exposed to laser treatments resulted in reduced cormorant depredation of nearby aquaculture facilities (a problem that occurred during daylight hours; Glahn et al. 2001).

However, some “problem” bird species are primarily diurnal (e.g., the European starling), whereas the effectiveness of low- to moderate-power lasers as avian dispersal tools appears to increase with contrast between the beam or beam spot and ambient light. Further, for diurnal species that might roost on airport grounds (e.g., European starlings and rock doves), the retinal physiology of the species relative to withstanding intense light (e.g., solar) or artificial light that might prevent complete dark adaptation (see above) is a factor in the effectiveness of laser dispersal. Also, sensitivity to a particular wavelength does not necessarily mean that wavelength can be used to elicit avoidance behavior (Blackwell et al. 2002). For example, long-wave-length sensitivity has been demonstrated in the European starling (peak absorption within certain retinal cone pigments, ?$_{max}$, of 563 nm, Hart et al. 1998), rock dove (up to 615 nm, Bowmaker 1987), and mallard (?$_{max}$ = 570 nm, Jane and Bowmaker 1988), species exhibiting no beam avoidance or a limited response during the Blackwell et al. (2002) study. Further, species with different behavioral ecologies likely exhibit maximum sensitivity to different ranges of the spectrum (Bowmaker 1987). Clearly, as noted above, no wildlife control method is a panacea, and integration of techniques (e.g., habitat management, laser dispersal, and lethal control) and application of control methods according to species ecology is critical to controlling threats posed by wildlife using the airport environment.

In addition, as the aforementioned studies indicate, avoidance behavior in birds exposed to laser beams was achieved by use of contrast, rather than intense radiation that can cause tissue damage. Thus, use of lasers on airports can limit the need for (but not replace) lethal control methods, while maintaining efficiency in controlling bird problems. Still, as with firearm use at airports, wildlife control personnel should be trained to use laser devices and knowledgeable of the risks involved by inadvertent exposure of pilots and local ground traffic. Information on regulatory authority and safety specifications for laser use in avian damage management has been compiled by the NWRC (Glahn and Blackwell 2000).

Lasers Designed for Avian Dispersal

Lasers designed for avian dispersal, and tested by the NWRC, include the Class-III B, 5-mW, He-Ne, 633-nm Desman© Laser model FL R 005 and the Class-II, battery-powered, 68-mW, 650-nm, diode Laser Dissuader™. The Desman™ laser was developed specifically for bird dispersal and is marketed by Reed-Joseph International Company for approximately $7,500 U.S. The NHZ for the Desman™ is 12.7 m considering the “blink Reflex” and 43.6 m considering a 10 second exposure (Soucaze-Soudat and Ferri 1997). The Laser Dissuader™, developed as a threat deterrent security device for the military and law enforcement agencies, is considered safe for use against humans; the NHZ for the Laser Dissuader™ is 25.0 m when considering a 10 second exposure (Dennis et al. 1999). The Dissuader™ is produced and marketed by SEA, Inc. and available for approximately $5,600 U.S. The USDA’s Wildlife Services (WS) biologists currently use the Desman™ laser in the operational program, and have used the Laser Dissuader™ as well. However, because of research involving the Laser Dissuader™ and based on recommendations by the NWRC, SEA, Inc. developed the related Class-III B, 650-nm, Avian Dissuader™ (SEA, Inc.). The Avian Dissuader™ (approximately $900 U.S.) is also currently in use by WS biologists in the operational program. In addition, Avian Systems, Inc. (Louisville, KY) has partnered with SEA, Inc. to develop a fixed-position laser-based avian dispersal system (approximately $7,000 U.S.) that incorporates a radar system to detect flocks of birds and a version of the Dissuader™ that operates on signal from the radar.

Summary

Blackwell et al. (2002) suggested that because of the response of avian species exposed to the long-wavelength lasers evaluated to date, as well as anecdotal field observations of the response of Canada geese and wading birds to the 650-nm Laser Dissuader™ (see Appendix 1, Blackwell et al. 2002), laser technology will likely prove to be a valuable non-lethal component of integrated bird management plans for airports. Integration of techniques (noted above) is critical to the effectiveness of any strategy to control wildlife populations, particularly when one considers the variety habitats and wildlife species sharing space with airport operations. However, in some instances (e.g., dispersal of Canada geese, double-crested cormorants, or other waterfowl), lasers can limit the need for chemical repellents and explosive dispersal devices (Glahn et al. 2001), thereby decreasing costs to the airport and safety threats to the wildlife manager and airport personnel.

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