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Wildlife in Airport Environments: Chapter 13 Radar Technology to Monitor Hazardous Birds at Airports

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Radar Technology to Monitor Hazardous Birds at Airports

Bird strikes are the most common wildlife hazard to aviation safety (Dolbeer et al. 2000). Advances in habitat management at airports through the elimination and reduction of attractants, in combination with hazing and lethal control, have reduced avian hazards <152 m (500 feet) above ground level. Bird strikes above this altitude, however, are beyond the limits of traditional wildlife control techniques (Dolbeer 2011). Traditional avian survey methods used to monitor birds at airports (Cleary and Dolbeer 2005; Chapter 14) often fail to provide essential information on local bird activity and migration at higher altitudes, hazardous bird use of attractants near airports, and bird activity at night—information that could be provided by the strategic use of radar technology at and near airports (Dolbeer 2006).

Radar in its simplest form is transmission of a pulse of energy, reflection of a portion of the transmitted energy by a target, and reception of the returned energy by a receiver (Eastwood 1967). The time delay between transmission and reception is used to determine the range of a given target. Radar can generally provide each target's bearing, flight speed, and altitude (depending on the type of radar antenna), having been originally developed to track enemy aircraft during World War II (Lack and Varley 1945). Early users of radar discovered that it could detect and track birds, commonly referred to as "angels" (Lack and Varley 1945). Biologists have exploited the ability of radar to detect and track birds for several decades, including radars located at airports. The first major, coordinated use of a group of radars to study bird movements over a large region was initiated in Canada in 1964 to address bird collisions with aircraft (Eastwood 1967). This was soon followed by additional evaluation (Gauthreaux 1972) and the recognition of radar's potential as an effective tool for providing early warnings of birds hazardous to aircraft (Blokpoel 1976). Some uses of radar relied on co-opting existing radar technology for bird detection (Blokpoel 1976; see the following sections), but radar technology has been recently adapted to detect birds in the airport environment (Federal Aviation Administration 2010). Different types of radar operate at different spatial scales (i.e., resolution and extent) and can be used to gather different types of data on bird movements in the atmosphere. In this chapter, for each type of radar used currently in ornithology, we provide information on technical capabilities and limitations, types of data that can be acquired, and how they can or are being used to detect hazardous birds. We also suggest how this technology could complement existing management practices (e.g., habitat modification) to reduce the risk of bird collisions with aircraft.

Radar Sensors Used in Ornithology

Tracking Radar

Tracking radar has been used to gather detailed information on the flight paths and speeds of individual migrating and foraging birds (Bruderer and Steidinger 1972, Griffin 1972, Able 1977, Kerlinger 1982, Larkin and Frase 1988, Bruderer 1999, Bäckman and Alerstam 2003). Small, military tracking radars (40–200 kW) have narrow beams (e.g., < 1°–3°) and can detect individual targets from 0.1 to 6.0 km (< 0.1 to 3.8 miles). Radar "locks on" a target, and the radar antenna follows it until the target moves too far away and the return signal is lost, or until another target enters the beam at the same range, causing the radar to switch to the new target. The position of the target in three-dimensional space and the strength of the reflected signal are digitally recorded continuously for subsequent analysis. Tracking radar can provide information that could prove useful to study behavioral responses of birds to approaching aircraft. Tracking radar also can provide information on wingbeat patterns (Bruderer et al. 2010), data that could be used to identify or classify targets to species or groups. Although the number of targets sampled may be limited, the beam can be rotated in a horizontal surveillance mode to sample migrating birds over a greater area (Bruderer et al. 1995). It is also possible to operate tracking radar in a fixed-beam mode and to monitor birds passing through the stationary beam (Larkin and Eisenberg 1978, Schmaljohann et al. 2008).

Weather Surveillance Radar

In the USA, weather surveillance radar (WSR) has been used to study bird movements and bat roosts since the late 1950s. In the early 1990s the WSR-88D (also known as NEXRAD, or NEXt Generation RADar) replaced the older WSR-57, WSR-74S, and WSR-74C radars in the national network. There are now 159 sites throughout the USA and overseas locations (Fig. 13.1). WSR-88D technology is more advanced than technology in older WSRs (Crum and Alberty 1993, Crum et al. 1993, Klazura and Imy 1993), and the improved sensitivity enhanced detection of weak targets such as birds, bats, and insects (Larkin 1984). These powerful (500 kW) and sensitive (45.8 dB) *S*-band (10-cm-wavelength) Doppler WSRs have a 1.0° beam, and when the beam is tilted 0.5° above the horizontal, the radar can detect concentrations of biological targets up to 240 km (149 miles) away and intense precipitation at a maximum range of 460 km (286 miles). The antenna of the WSR-88D is computer controlled and repeatedly scans the atmosphere through a sequence of predefined elevation angles, antenna rotation rates, and pulse characteristics (i.e., volume coverage patterns), depending on the radar's mode of operation. Two operational modes exist—a precipitation mode and a clear-air mode—and selection of an operational mode is closely related to the detected coverage of precipitation. The WSR-88D is sensitive enough to detect birds, bats, and concentrations of insects in precipitation mode. When no precipitation is detected, the radar operates in clear-air mode and samples the same volume of airspace more slowly, making it possible to detect the reflected energy from small objects such as insects and even dust and smoke particles. Since August 2008, the resolution of the reflectivity data has increased to 0.25 km (820 feet) by 0.5° to match the velocity data, and velocity data were extended from 230 to 300 km (143 to 186 miles). By May 2013, all WSR-88D stations will have been upgraded to dual-polarization technology that will add three new base products (differential reflectivity, correlation coefficient, and specific differential phase) that will aid meteorologists and biologists in identifying and quantifying radar returns from weather and biological targets in the atmosphere (Zrnic and Ryzhkov 1998, Gauthreaux et al. 2008).

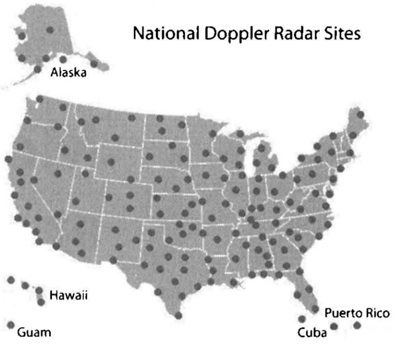

Fig. 13.1. Locations of the 159 WSR-88D stations throughout the USA and territories. Map available at http://radar.weather.gov/index.htm

Biological Data Provided by the WSR-88D

The WSR-88D can readily detect aerial biological targets, and several investigators have used it to study bird migration (Gauthreaux and Belser 1998, 1999*b*, 2003*a*; Diehl and Larkin 2005), bird roosts (Russell and Gauthreaux 1998, Russell et al. 1998), bat colonies (McCracken 1996, McCracken and Westbrook 2002, Horn and Kunz

2008), and concentrations of insects aloft (Westbrook and Wolf 1998). The WSR-88D can be used to quantify the number of birds in migration aloft (Gauthreaux and Belser 1998, 1999*a*; Black and Donaldson 1999; Diehl et al. 2003, Gauthreaux et al. 2008) and has been used to study regional bird migration patterns on the northern Gulf Coast (Gauthreaux and Belser 1999*b*), in the Great Lakes region (Diehl et al. 2003), across the USA–Mexico borderlands region (Felix et al. 2008), and at a continental scale (Gauthreaux et al. 2003). Digital data files can be obtained from the WSR-88D archives at the National Climatic Data Center in Asheville, North Carolina, USA, and detailed methods of analyzing data from the WSR-88D can be found in Gauthreaux and Belser (2003*a*), Diehl and Larkin (2005), Gauthreaux et al. (2008), and Buler and Diehl (2009).

Within 120 km (75 miles) of the radar, WSR-88D can be used to delimit important migration stopover areas by measuring bird density (birds per cubic kilometer) in the beam as they begin a migratory movement (Gauthreaux and Belser 2003*b*, Bonter et al. 2009, Buler and Diehl 2009). Within minutes of the onset of nocturnal migration, the distribution and density of echoes in the radar beam can provide information on geographical ground sources of the migrants, and satellite imagery can be used to identify the topography and habitat type that characterize these areas (Gauthreaux and Belser 2003*b*). Bird stopover areas have been mapped using the displays of the WSR-88D for areas in eastern Louisiana and southern Mississippi (Buler and Diehl 2009), for radar sites around the Great Lakes (Bonter et al. 2009), and for several sites at and near military installations (Fischer et al. 2012). At ranges >120 km, this approach can be used to delimit locations of postbreeding and nocturnal roost sites of birds such as purple martins (*Progne subis*; Fig. 13.2), as well as to quantify the density of birds (Russell and Gauthreaux 1998) and bats (Horn and Kunz 2008).

The greatest limitation of the WSR-88D for use in biological studies has been the size of the radar's legacy pulse volumes (1° × 1 km), which increases with increasing distance. This corresponding growth prohibits its gathering information on small, individual targets and combines the return from several different types of targets into one pulse volume. The upgrade to superresolution should improve this shortcoming, but resolution cells (0.5° × 250 m) will still be sampling a large volume of atmosphere. Because the lowest antenna scan is at an angle of 0.5° above the horizontal, it is commonplace for low-flying targets to go undetected because they are below radar coverage.

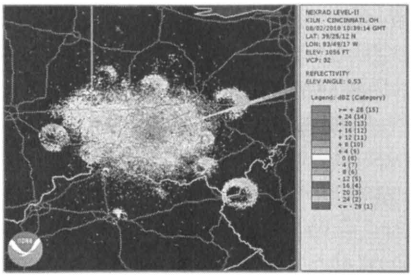

Fig. 13.2. Display of the WSR-88D radar at Cincinnati, Ohio, USA, at 1039 GMT on 2 August 2010. The circles show Purple Martins (*Progne subis*) departing from overnight roosts. The strobe is from the rising sun, which emits microwaves similar to those emitted by the radar. The density of birds can be estimated from the reflectivity scale (in decibels relative to *Z*, or dBZ) on the right.

Fig. 13.3. Locations and station codes of the 45 terminal Doppler weather radar units in the USA. The units are located near airports to monitor wind shear and severe weather.

Terminal Doppler Weather Radar

Although terminal Doppler weather radar (TDWR) has not been assessed adequately for its ability to detect migrating birds, its operational characteristics suggest it should be an excellent sensor for that purpose (Istok et al. 2008). TDWR was developed for the Federal Aviation Administration in the early 1990s to detect real-time wind shear and high-resolution precipitation data, and as of 2009, 45 units were deployed near major airports across the USA (Fig. 13.3). The radar operates at the C band or 5-cm wavelength (5,600–5,650 MHz) and has a peak power of 250 kW. Antenna beam width is 0.55°, and the antenna completes twenty-three 360° sweeps every 6 min in severe/hazardous mode. Reflectivity of targets can be measured to 460 km distant while Doppler (radial) velocity of targets can be measured to 89 km (55 miles). Although similar in operation to the WSR-88D, the resolution of TDWR is greater, and TDWR antennae can scan below an angle of 0.5° above the horizontal, providing information on bird activity at the scale of an airfield.

High-Resolution Marine Surveillance Radars

Casement (1966) was one of the first to use marine surveillance radar on a ship to study bird migration, and interest in using marine radar to study bird movements subsequently increased (Williams et al. 1972, Williams 1984). Because of the relatively low cost of marine surveillance radar, this technology has been used extensively for bird detection at airports (e.g., MacKinnon 2006) and for environmental impact studies (e.g., National Academy of Sciences 2007).

Technical Specifications

The following radar characteristics are known to influence the results obtained from radar studies of bird movements:

- Transmitter power (e.g., 5, 10, 25, 50, or 60 kW)
- Frequency or wavelength
- Pulse length and corresponding pulse repetition frequencies
- Antenna beam characteristics
- Antenna rotation speed
- Tuning of the receiver
- Magnetron or solid state
- Gain setting
- Range setting
- Ground and sea- and rain-clutter settings
- Beam-brilliance setting

Most of the small, mobile radars used to monitor bird movements have been low-powered (5–60 kW) marine-surveillance radars of 3- or 10-cm wavelengths and are commonly referred to as "avian radars." The transmitter power of the avian radar should be as high as possible (≥25 kW) to maximize resolution and sensitivity. Long pulse lengths enhance detectability but have lower resolution, whereas short pulse lengths increase resolution with decreased detectability. The greater the transmitter power, the greater the cost, but a 50-kW radar operating on short pulse will produce superior results for bird detection than a 10-kW unit operating on short pulse. Marine radars can be purchased in either of two wavelengths—3 cm (*X* band) or 10 cm (*S* band)—and there is considerable debate among users of these two radar types regarding which one is best. Both have been used to study bird movements aloft, but no published study has compared them at the same location and under similar weather conditions. Precipitation attenuates 3-cm wavelengths considerably more than it does 10-cm signals (LGL Environmental Research Associates 2000); consequently, intense precipitation will greatly decrease the chances of detecting targets using 3-cm radar. Regardless of wavelength, small-target detection during heavy precipitation is not likely.

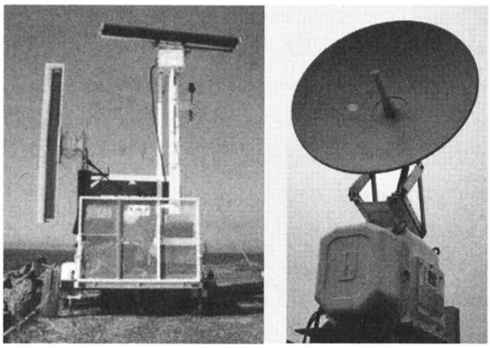

Fig. 13.4. Antenna configurations commonly used in avian radar systems are designed to detect and track hazardous birds at airports: (*left*) slotted arrays for horizontal and vertical scanning, and (*right*) parabolic dish antennas.

In typical horizontal surveillance mode (Fig. 13.4), the radar beam samples 20–25° of vertical airspace and has a horizontal (azimuth) resolution of 1.0–2.3°. These radars can detect movements of individual birds out to several kilometers, and the exact range of detection depends on the power of the radar and the size of the birds. In horizontal surveillance mode the altitude of a target cannot be measured because of the vertical extent of the radar beam. To address this limitation, the radar transmitter/receiver and array antenna can be tilted 90° so that the sweep of the antenna is vertical (Fig. 13.4). In vertical surveillance mode (20° in horizontal and 1° in vertical) the altitude of a target can be accurately measured, but the 20° sweep from horizon through zenith to opposite horizon is restricted to one axis. Because of the axial surveillance pattern of vertical scanning radar, targets moving parallel to the axis of the sweep show true ground speeds as they are tracked. Targets moving at increasing angles to the axis of antenna sweep show reduced ground speeds, and targets moving perpendicular to the sweep have zero ground speeds and appear stationary (if they have enough detections to be tracked).

Some investigators have used a single radar for horizontal and vertical surveillance (Harmata et al. 2003), whereas others have used two radars, one each for horizontal and vertical surveillance (Harmata et al. 1999). An alternative design replaces the open-array antenna with a rotating, parabolic antenna (Fig. 13.4) that projects a narrow, conical (e.g., 2.5–4.0°) beam that can be raised or lowered (Gauthreaux and Belser 2003*b*, Nohara et al. 2005). When the conical beam is elevated in the horizontal surveillance mode, the altitude of an echo is a trigonometric function of the range of the echo and the angle of antenna tilt. When the antenna is elevated 30°, for example, the altitude of a target is one-half of the range. The advantage of the parabolic dish is that information on range and altitude can be obtained for each echo. The open-array antenna samples a greater volume of airspace, but the altitude of a target in the vertical scan cannot be associated with the track of a target in the horizontal scan. The parabolic antenna samples a smaller volume of atmosphere but has higher gain, and three-dimensional information on each target can be measured. Antenna rotation speed is dependent on gear configuration and is usually ~24 revolutions per minute. Higher rotation rates are possible and provide additional detections for tracking a target, but a target receives fewer radar pulses per detection at higher rotation speeds.

When tuned properly, avian radars can detect individual birds within 2–3 km (1–2 miles) and large flocks of large birds to 10–14 km (6–9 miles; Gauthreaux and Belser 2003*b*). Desholm et al. (2004) reported that European thrushes (*Turdus* spp.) can be detected with 10- and 12-kW units to 6.0 km from the radar, and with a 25-kW, 3-cm-wavelength radar in clear weather, an 800-g duck can be detected to 2.2 km (1.4 miles) for short pulse and 3.2 km (2 miles) for long pulse, whereas the maximum range of detection for small passerines is 800–1,000 m (2,625–3,281 feet). They also report that a 500-g pigeon-like target can be detected at 4.0 km (2.5 miles) for short pulse and 5.5 km (3.4 miles) for long pulse with a 60-kW, 10-cm-wavelength radar in clear weather. Other radar ornithologists have found that a 12-kW radar (with an open-array antenna) can routinely detect flocks of waterfowl to 5.6 km (3.5 miles), individual hawks to 2.3 km (1.4 miles), and single, small passerines to 1.2 km (0.75 miles; Cooper et al. 1991, 2004). Range discrimination depends on pulse length used, and with short pulse lengths, minimum detectable range can be as close as 20–30 m (66–98 feet); however, not all marine radars detect biological targets equally (J. Kube, Institut für Angewandte Ökologie, personal communication, 2005).

Radar Performance and Data Quality

Technical limitations can affect the quality of data gathered by avian radars. The aspect of the bird relative to the radar beam affects the amount of energy reflected back to the radar receiver, such that head-on and tail-on detections have smaller radar cross sections than broadside detections. The radar cross section (RCS) of a bird is dependent on properties such as size, mass, and water content, and is independent of the range of the target relative to the radar. To determine RCS, intensity of a target's radar signal must first be measured and then corrected for wave propagation effects (Nohara et al. 2011). Because RCS is size dependent, it can be used to estimate the sizes of birds in radar tracks. The position of the bird in the radar beam is another important consideration. Radar beam width is defined as the angle where the energy at the center of the beam is reduced by one-half (or −3 dB). If two identical targets are located at the same range, the target at the edge of the radar beam will produce a weaker echo than the target at the center of the beam. Similarly, a strong target outside the radar beam can be detected as a weak target. The latter problem is amplified when using an array antenna (20–25°), because the power loss beyond the half-power point is more gradual than power loss in high-gain pencil beams. When birds fly low to the ground, they often go undetected by marine radar. In a review of bird migration studies with radar, Bruderer (1997) reported that marine radar missed about 40% of

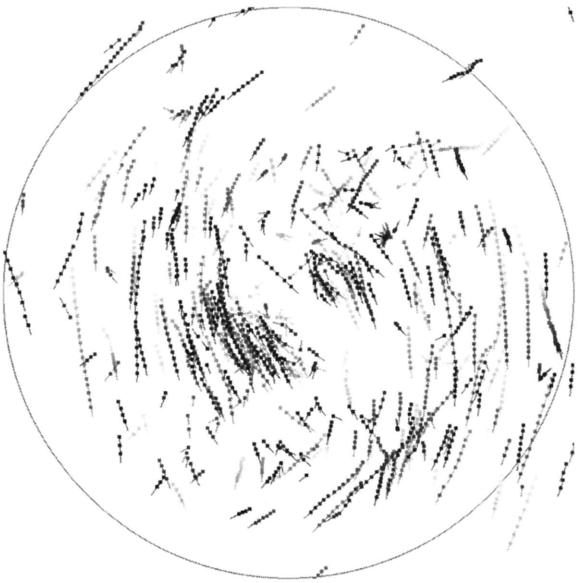

Fig. 13.5. **An image generated from digitally processed data from a Furuno 2155-BB radar with a parabolic dish (4° beam width) elevated 30° above the horizontal showing tracks of nighttime migrating birds in fall over coastal Maryland, USA. Tracks are series of target detections, and the current position and heading of the target are indicated with "lollipop" symbols.** Source: Tim J. Nohara, Accipiter Radar Technologies Inc.

birds flying below 50 m (164 feet), but when birds were flying above 50 m, only 8% were undetected.

Return from ground objects produces clutter in radar displays, and if the ground-clutter return signals are strong and extensive, return from birds will be obscured. Although algorithms have been developed to filter clutter, in many instances, bird detection over areas where clutter has been removed is reduced, particularly when the targets are small, single birds. Constant false-alarm rate processing can be used to detect return signals from moving targets in clutter, but the clutter threshold must be consistent between scans, a requirement that is likely to be violated.

Two methods of collecting and processing avian radar data exist. At first, investigators manually extracted the echo data from the radar display (or a digital image of the display; Fig. 13.5) and then performed analyses to compute descriptive statistics. Manual data extraction is labor-intensive, time-consuming, and presents the possibility of bias. More recently, radars with digital processors have been used to gather raw radar data from the receiver and then process that data using proprietary algorithms. The algorithms mask ground clutter and use the data from target detections to generate target tracks that are reported either in spreadsheet format with information for every detection in a track (e.g., reflectivity, range, size of echo, and speed) or as plots showing target tracks. Automatic digital processing is extremely fast and eliminates the potential bias associated with manual data extraction and processing, but automatic processing algorithms also have shortcomings and must be evaluated carefully to expose systematic biases in the algorithms. Algorithms that require a certain number of detections before tracking begins could potentially exclude fast targets that produce fewer than the required number of detections. Hundreds of targets can be tracked at once, but as the number of targets increases, so does the possibility that tracking algorithms may switch between nearby targets and treat two different tracks as one. When the radar is recording a large number of detections from rain or waves, the tracking algorithms will produce false tracks that satisfy the algorithms, but they are not real bird tracks. There is clearly a need to carefully ground truth the reports of data from digitally processed radar return, but few published studies have done so.

Radar Validation

The determination of the number of targets per echo and the identification of the source of the echo (e.g., birds, or bats, or insects) on avian radars can be problematic. One cannot generally discriminate an individual target from a tight cluster of targets, because a single large target may produce the same echo as a tight group of smaller targets. It is nearly impossible to discriminate echoes from similarly sized birds and bats on the basis of echo characteristics, and flight behavior may be similar between foraging bats and nocturnally foraging birds (e.g., nighthawks) and between migrating bats and migrating birds engaged in linear flight. This uncertainty has led investigators to refer to the sources of echoes in radar studies as "biological targets." It is possible to characterize targets by their airspeed if one knows the speed and direction of the wind at the altitude where a target is detected. Once the airspeed of the target is calculated, it can be assigned to categories of bird types based on airspeed

(Harmata et al. 1999). In some instances the flight behavior of a target may offer clues to its identity (e.g., circling of a raptor in a thermal), but claims of target identification based on size of target (number of pixels) are likely incorrect. Many attempts to statistically link echo characteristics to the identity of hundreds of known targets have shown no significant relationship (O. Hüppop, Institut für Vogelforschung Vogelwarte Helgoland, personal communication, 2006). The best means of identifying the sources of radar echoes involve simultaneous visual observations during the day with binoculars, telescope, or high-definition video, as well as the use of thermal imaging (Gauthreaux and Livingston 2006) and infrared devices (Plissner et al. 2006) at night. Because light may attract birds, insects, and bats that feed on insects, techniques that require illuminating targets should be avoided. Radar targets can be verified only when they are within the range limits of the method used for verification.

Use of Avian Radar Data

MacKinnon (2006) compiled information on small radars used to detect, monitor, and quantify bird movements that pose a threat to aircraft. Avian radars have been deployed at both military (e.g., Klope et al. 2009, Beason et al. 2010*a*, Coates et al. 2011) and civil airfields (Federal Aviation Administration 2010), although inherent differences between the two types of airfields will determine how avian radar data can be applied to reduce the risk of bird strikes. Civil aircraft strike most birds near airports in the approach and departure corridor (Dolbeer et al. 2009), whereas military aircraft have the additional risk of striking birds during low-altitude, high-speed training flights (Zakrajsek and Bissonette 2005). Civil airfields rely on mitigation of wildlife hazards to reduce bird-strike risks (i.e., habitat management, harassment, and lethal control; Cleary and Dolbeer 2005), whereas military airfields also use bird avoidance models to schedule low-level training flights during periods with low strike risk (Zakrajsek and Bissonette 2005). Avian radars could provide substantial data (e.g., local bird use and migration at higher altitudes, use of attractants near airports, and nocturnal activity; Dolbeer 2011) for use in Wildlife Hazard Management Plans (Cleary and Dolbeer 2005), trend analysis, and real-time warnings both to air operations staff and air traffic control personnel (Blokpoel and MacKinnon 2001, Kelly et al. 2007). Avian radar data can also be used to develop local bird-strike risk management models specific to civil or military airfields (Coates et al. 2011) and as a metric to assess bird–aircraft collision mitigation strategies (Klope et al. 2009).

Many professionals involved in reducing bird–aircraft collisions believe that high-resolution marine radar or newly developed avian radar will be an important component of future bird-strike mitigation systems. But questions remain regarding detection and tracking capabilities, reliability, and proper use of avian radar systems at airports (Weber et al. 2005). The use of avian radar is relatively new at civilian airports; Federal Aviation Administration (2010) provides guidelines for selecting and deploying avian radar systems. These guidelines are relatively flexible because of the variability of available hardware and software, as well as the hazards and geography specific to each airfield that influence system performance.

Recent Developments in Avian Radar

Existing shortcomings of horizontal surveillance and vertical avian radar systems have stimulated development of new radar configurations and entirely new systems. Some developers have moved from a two-radar system to a single-radar system with single or dual antennas. Others have changed the type of radar used for vertical scanning, or are in the process of developing Doppler marine radars. The sweep axis of vertically scanning radar can be shifted by 20° every 3 min, resulting in 72 vertical scans for each 20° sector, and nine sectors are sampled in 27 min. This mode of operation generates 360° coverage within 27 min and eliminates the sampling bias of collecting data while operating on only one axis. In addition, a stationary thermal imaging camera (TIC) can be mounted next to the transmitter/receiver unit and pointed vertically to sample targets passing through the fixed 20° field of view of the TIC. The TIC data can be used to identify the sources of the radar echoes. This configuration also can be shifted 90°. A dual-beam antenna radar can be built with two standard dish antennas (4° beam width; Beason et al. 2010*b*). The radar connection can be alternated between the two dishes from one pulse to the next, and the data stream tagged to indicate which antenna was active for each pulse. The beam patterns are identical for both dishes (one dish set to 7° elevation and the second at 11° with overlap at beam half-power points). When the dual-beam antenna radar becomes operational, three-dimensional systems will have altitude computations embedded in the real-time processor. A two-radar system can combine horizontal scanning marine radar (*X* band or *S* band) and frequency-modulated continuous wave radar (two antennas) used to track a bird and to measure altitude and wingbeat pattern and frequency (Borst 2009). An avian radar is also available that uses a monostatic pulse radar and Doppler-like processing to determine target velocities. It processes received echoes in a bank of narrowband, coherently integrating filters that resolve targets within particular velocity bands. Some new avian radar systems are no longer based on marine surveillance radars, such as the solid-state, mobile surveillance and target acquisition radar, which uses an electronic beam (*L* band) to scan 360° with no moving parts and provides three-dimensional target information. Finally, avian radar systems can also be connected to an apparatus that automatically hazes birds when detected by the radar.

Summary

The use of radar to study bird behavior has a long history that began during the early years of military radar. The modernization of the national weather radar system expanded radar ornithology to include studies of bird movements at the regional and continental scales. Adaptation of small, mobile marine radars led most recently to the availability of bird movement data specific to individual airfields. Radar data on migratory bird movements are currently being used to provide air operations personnel (e.g., flight schedulers, planners, and pilots) with near-real-time warnings of hazardous flight conditions caused by large movements of migratory birds. Avian radar data can also be used to develop local bird-strike risk management models specific to a civil or military airfield and to assess bird–aircraft collision mitigation strategies. Additionally, these data can be used in trend analysis and have been cautiously proposed to provide real-time warnings, both to airport operations staff and air traffic control personnel, although the feasibility of the latter application is highly debated (Nohara 2009).

Several reports have indicated that a radar beam pointed directly at a flock of birds resulted in dispersal behavior (Eastwood 1967). These accounts focused mainly on the effect on flight; however, other behavioral effects (e.g., predator detection, foraging ability, and ability to locate cached food) could be influenced by incident microwave radiation and thus could potentially influence survival and fitness. Research is now underway to determine whether microwave radiation emitted by various forms of radar technology influences bird behavior or has potential as a deterrent device (E. Fernández-Juricic, Purdue University, unpublished data).

The broad spectrum of available and developing technology will influence the quality, quantity, and application of radar data to reduce bird–aircraft collisions. The limitations of the data must be acknowledged and additional studies conducted to evaluate appropriate uses of information provided by this technology. The novelty of information collected by radars will not compensate for bias inherent in poor methodology, or for failure to understand how the hardware and software specific to each application influence the information provided.

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