

# Using radar cross-section to enhance situational awareness tools for airport avian radars

TIM J. NOHARA, Accipiter Radar Technologies Inc., 576 Highway 20 West, P.O. Box 939, Fonthill, Ontario, Canada L0S 1E0 [tnohara@accipiterradar.com](mailto:tnohara@accipiterradar.com)

ROBERT C. BEASON, Accipiter Radar Corporation, 40 Centre Drive, Orchard Park, NY 14127 USA

PETER WEBER, Accipiter Radar Technologies Inc., 576 Highway 20 West, P.O. Box 939, Fonthill, Ontario, Canada L0S 1E0

**Abstract:** Digital avian radars can track bird movements continuously in the vicinity of airports without interruption. The result is a wealth of bird-track data that can be used in mitigation efforts to reduce bird strikes on and near airfields. To make the sheer volume of bird track data generated by digital avian radars accessible to users, we developed tools to transform these data into analytical and visualization products to improve situational awareness for wildlife and airfield personnel. In addition to the parameters traditionally associated with radar tracking (latitude, longitude, altitude, speed, and heading), we have implemented a procedure to estimate the radar cross-section (RCS) of a target, which is related to its size or mass. This additional information can provide wildlife and airfield managers with the knowledge they need to prioritize their efforts to deal with the greatest hazards first.

**Key words:** aircraft, airfield management, alert, aviation safety, BASH, bird strike, human–wildlife conflicts, radar, radar cross-section, situational awareness, wildlife hazard

**BIRDS POSE A THREAT** to aviation safety and cost air carriers and insurance companies approximately \$2 billion each year (Dolbeer et al. 2009). More than 60% of bird–aircraft collisions occur within the confines of airfields (Dolbeer 2006). Conservationists also should be concerned with bird–aircraft collisions because birds never survive such events. Airfield management can reduce the chances of a bird strike by making the habitat unattractive to avian species and by harassing or removing individual birds that remain despite airfield manipulations. Visual monitoring techniques (e.g., bird population sampling) are currently used to provide information on the community of birds present on airfields and how the avian community changes over time. But visual monitoring provides limited information on bird-strike threats. On a given airfield, bird strikes are infrequent, irregular, and under-reported (Linnell et al. 1999), but avian radar can serve as an independent monitor of strikes and near-misses (Klope et al. 2009), and it can provide automatic warning of developing threats.

Digital avian radars are tools used to help monitor and reduce the threat of bird–aircraft strikes. Small, airport-based, digital avian radars introduced over the past decade have now been tested extensively by the U. S. Department of

Defense (DoD; Brand 2010a) and the Federal Aviation Administration (FAA; FAA 2010, Herricks et al. 2010). The testing was conducted to assess and validate a radar’s ability to generate high-resolution, localized bird-movement information and to generate guidance on the acquisition, deployment, operation, and integration of avian radars into military and civil airport operations. The assessments included both short-term experiments designed to measure specific system characteristics and performance criteria, as well as long-term radar sampling to capture seasonal cycles of bird movements (such as migration) and behaviors. As part of the validation studies, teams of visual observers during the spring and fall at 4 test sites confirmed that tracks automatically generated by the digital avian radars were, in fact, produced by birds (Brand 2010a). In addition to radar system performance validation, these studies included the intended users in the operational assessments to help develop and integrate new tools into airfield wildlife management. Based in part on the aforementioned studies, the FAA Advisory Circular 150/5220-25 on avian radar was issued (FAA 2010), substantiating the ability of the digital avian radars tested to continuously track bird movements in the vicinity of airports without interruption.

Our objective in this paper is to describe how an end-user can exploit the demonstrated strengths of digital avian radars to transform the wealth of track data they generate into meaningful and useful situational awareness and to report on a new development: measuring radar cross-section (RCS). Radar cross-section can be used as an indicator of relative size or mass, which is an important metric used to evaluate the hazard presented by a bird tracked by radar. The hardware design of avian radars and their software algorithms responsible for clutter suppression, target detection and tracking, and data storage and distribution has been described elsewhere (Nohara et al. 2005, Weber et al. 2005).

### Analytical needs

As with any instrumentation that continuously collects data, digital avian radars generate large volumes of information. To be beneficial, those data must be analyzed and presented in a manner that is relevant to the user. The most important details of avian radar tracks include the 3-dimensional locations of the target and its identification. The more accurate and precise the data, the more useful they are. Location is of obvious importance to track the position of a bird accurately over the terrain. Location accuracy also affects calculations of the bird's speed and direction. Altitude is important for determining whether the bird poses a threat to aircraft in flight.

The identity of the target is another important characteristic for users because the identity indicates the mass of the target. The force of a collision, and resulting damage to the aircraft, is directly proportional to mass of the bird or group of birds (Dolbeer et al. 2000). Thus, the identity of the target is an indication of its hazard. Birds can be separated from aircraft and ground vehicles based on their sizes, as seen by the radar, using RCS (Knott 2008). However, the RCS of large flocks of large birds will overlap in value with those from small vehicles. An additional aid to distinguish birds is behavior; ground vehicles and aircraft typically follow linear paths, whereas birds often meander.

Although radar cannot discern among similar species, it is possible to distinguish among hazard guilds (i.e., groups of bird species that

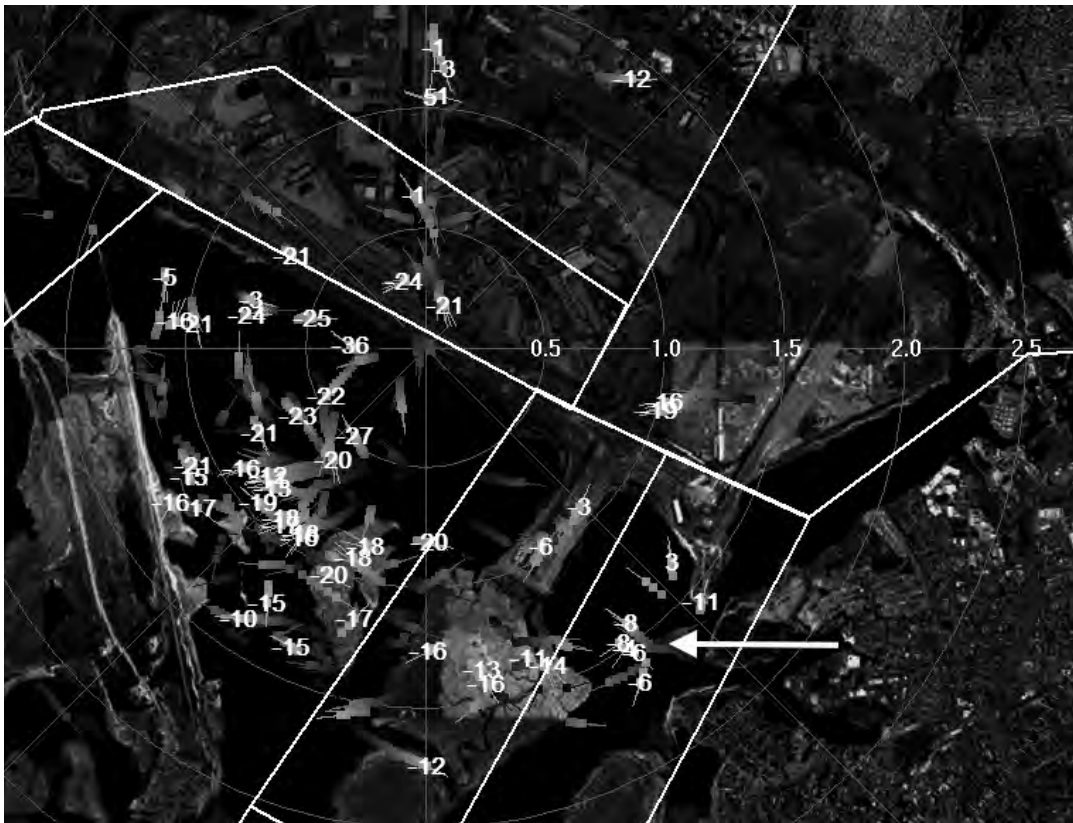
are similar in mass and behavior) with some confidence. Individual avian radar targets can be assigned to an avian hazard guild based on its RCS, flight speed, altitude, and flight behavior. For example, vultures and soaring raptors can be distinguished from other groups based on their periodic circling (Beason et al. 2010).

## Analytical and visualization tools

### Tactical tools

The underlying target information that forms the basis of all analytical and visualization tools should include precise time, location, and size information for every track update (Brand 2010*b*). A track report or update results when the automatic tracking algorithms associate a new detection with an existing track. These updates are filtered and organized continuously to calculate the flight path and speed of the bird(s) for real-time display to users and are stored for post-processing, display, and retrieval.

Radar cross-section estimation using avian radars is a recent and important advancement for target identification. It is a measure of a target's reflective area as detected by the radar, and for birds it is related to the water content of their body (which is conductive) and is related to mass. A bird's reflective area as seen by a radar varies with aspect angle, the largest cross-section typically occurring when the bird is viewed from the side and smallest when viewed from the head or tail. However, the strength of the reflected signal is not the same as the RCS. The strength or intensity of a target's reflected signal varies inversely and nonlinearly with the target's distance from the radar as a result of wave propagation, the target's geometry relative to the radar, and radar transmission characteristics, in addition to its RCS. Thus, the strength of the received signal is not a measure of target size. Radar cross-section, on the other hand, is a property of a target and, hence, is independent of the distance of the target from the radar. To estimate RCS, the radar signal intensity first must be extracted for a given target and then corrected for wave propagation effects. A well-known radar equation (Skolnik 2008) describes the deterministic relationship between intensity, RCS, and range  $R$  (i.e., the distance the target is from the radar). Intensity



**Figure 1.** An example of an airspace safety exclusion zone breached by a flock of geese (arrow) crossing the approach to runway 4R in the early morning of May 17, 2010, at John F. Kennedy International Airport. The incident was captured by an avian radar located at the airport.

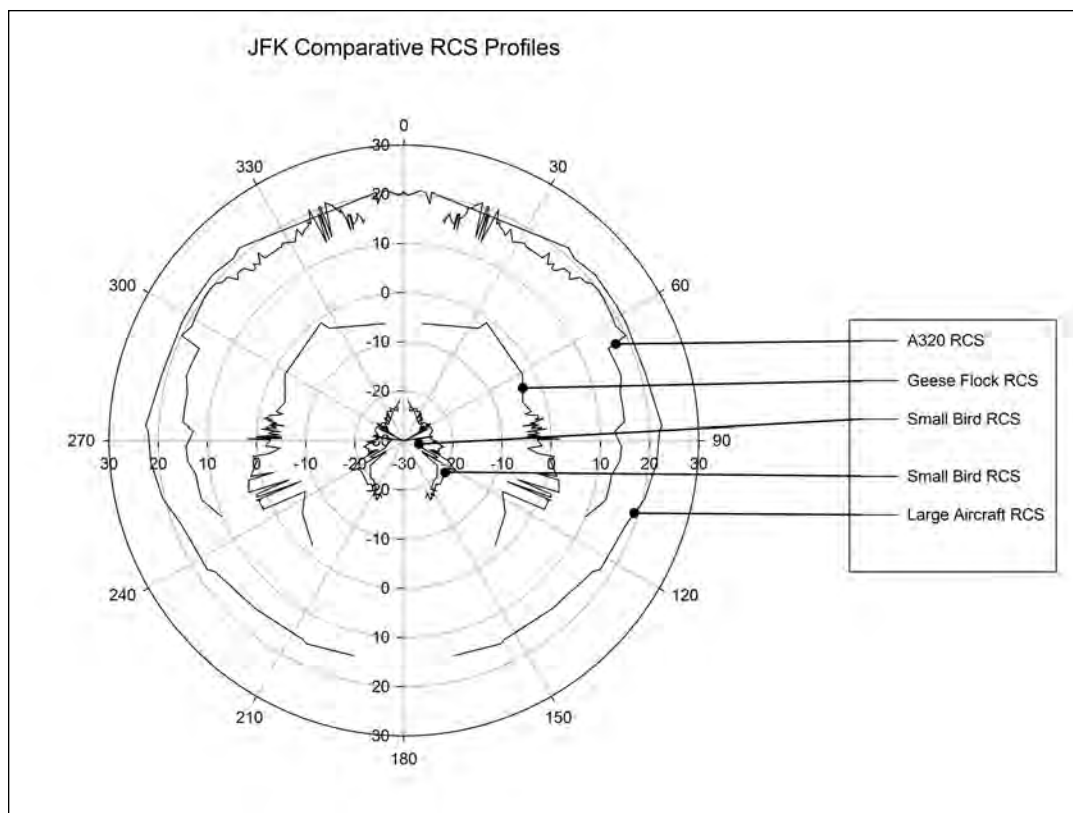
of the received signal is proportional to RCS for a target at a given range, and varies with changes in target range as  $R^{-4}$ .

For example, consider a commercial jetliner with RCS of  $100 \text{ m}^2$  (Knott 2008) and a bird with RCS of  $0.01 \text{ m}^2$  (Eastwood 1967, Edwards and Houghton 1959). The aircraft's size as seen by the radar is 10,000 times larger than the bird. If both targets are at the same distance from the radar, the intensity of the aircraft's signal will be 10,000 times larger than that of the bird. On the other hand, if the bird is 1 km from the radar and the aircraft is 10 km from the radar, their signal intensities will be the same.

To be used reliably as a measure of size, RCS must be calibrated against a target of known size. We calibrated the radar at the John F. Kennedy International Airport (JFK) using radar track data taken from an A320 aircraft recorded around the time of a reported bird strike that took place in the early morning of May 17, 2010 (Figure 1). A review of the recorded avian radar track data from JFK and Jamaica Bay, which

forms the southern boundary of the airport, indicated that a large flock of geese entered the airspace at the approach to runway 4R, which we define as a safety exclusion zone in this example. The track data we analyzed included an A320 aircraft (the radar track was correlated with the Flightwise track [<http://flightwise.com/tracking>]) to confirm aircraft identity) and the flock of geese that was struck (confirmed by correlating the bird strike time and location information from the strike report with the radar tracks), as well as other bird targets of opportunity selected from tracks over Jamaica Bay. The avian radar system we used to record the data consists of an X-band Furuno FR8252 transceiver equipped with a  $4^\circ$  dish antenna elevated  $5^\circ$ , and an Accipiter® Digital Radar Processor (Software version 6.7.7.6, Fonthill, Ontario, Canada).

For our example, the RCS calibration procedure was designed to cause the A320 aircraft around JFK to return a maximum RCS value of approximately  $+20 \text{ dBm}^2$  ( $100 \text{ m}^2$ ). This



**Figure 2.** The radar cross-section (RCS) profile for each of the targets recorded by an avian radar at John F. Kennedy International Airport (JFK) around the time of the bird strike depicted in Figure 1. The top of the circle (0°) represents the target’s head or nose and the bottom (180°) represents the tail. The sides are represented by 90° and 270°. Tracks include the A320 aircraft involved in the strike, the large flock of geese involved in the bird strike, another aircraft north of the airport, and smaller birds (i.e., small RCS) south of the airport.

is illustrated in Figure 2, which also plots the estimated RCS values for 5 individual target tracks as a function of the aspect angle to the target as viewed from the radar. Because we have full target location and heading information, as well as RCS, with each track update, we can calculate the target aspect angle for each update and determine an RCS profile for each target (Figure 2). The unidentified large aircraft has an RCS profile with values nominally of +20 dBm<sup>2</sup>. The A320 RCS profile (generated from its radar track that began 15 km out and continued to 1 km) is slightly smaller and has a maximum value of +20 dBm<sup>2</sup>. The RCS values for the flock of geese are much smaller than and well-separated from the aircraft and in the expected range. The 2 small bird RCS profiles are noticeably smaller than the the RCS values for the flock of geese. We did not identify the species of the smaller birds; rather, we infer they are smaller because their RCS values are

almost 0.01 times those of the flock of geese. The RCS values shown in Figure 2 are illustrative of the variation of bird RCS values that we have observed over the past year from several sites (unpublished data). We found that the JFK flock of geese had RCS values between -10 and 0 dB m<sup>2</sup> (i.e., 0.1–1 m<sup>2</sup>) and the smaller birds we tracked had RCS values from -30 to -20 dBm<sup>2</sup> (i.e., 0.001–0.01 m<sup>2</sup>). These data support the premise that large flocks of geese are distinguishable from smaller birds based on RCS. Thus, in our example an RCS threshold of -10 dBm<sup>2</sup> could be used to allow only larger birds and flocks to trigger the threshold for safety exclusion zones. Based on our results for determining RCS, we developed a display that responds to a safety exclusion zone intrusion by changing color (Figure 3). In this example, the threshold or intrusion logic is based on number of bird tracks, RCS, and direction of movement. Such



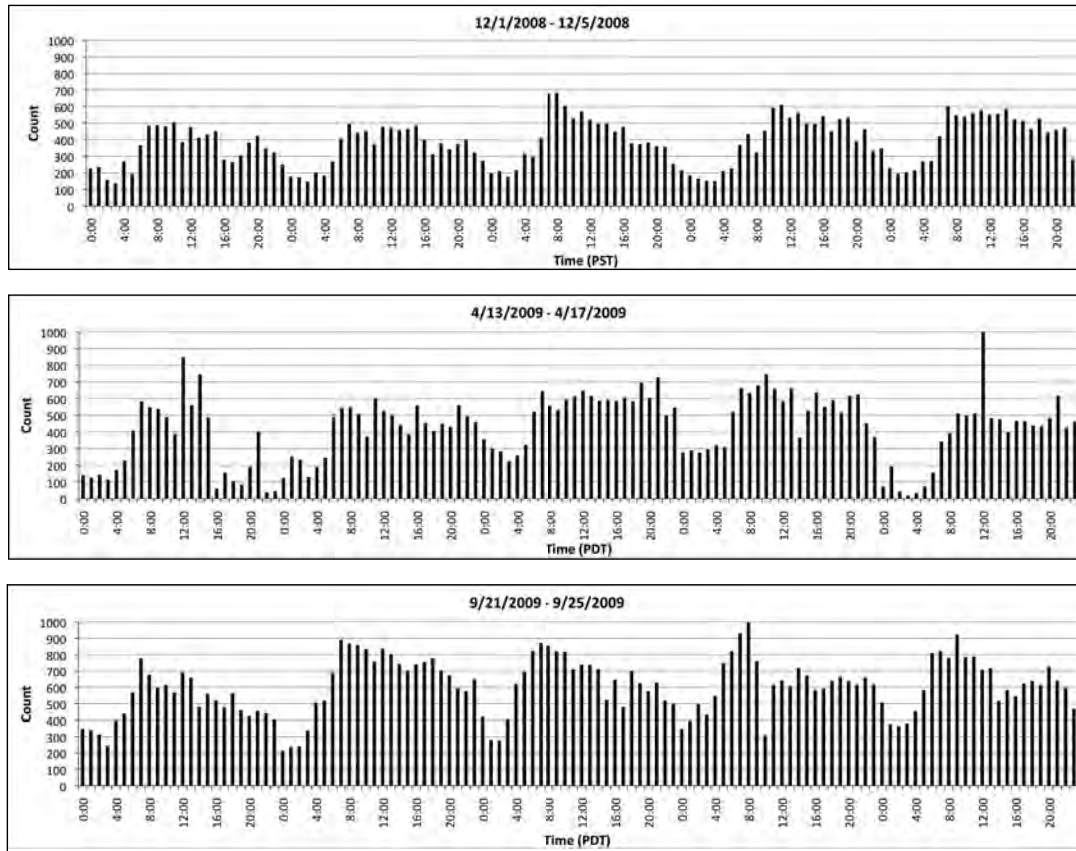
**Figure 3.** Avian radar alert display for a bird strike discussed in the text for John F. Kennedy International Airport. One safety exclusion zone is marked in black (**a**), indicating “severe” condition, whereas another is gray (**b**), indicating locally “moderate” conditions. The criteria for the safety exclusion zones are set by the airfield biologists and controllers. (Alert zones are colored red and yellow in the actual screen image.)

a display can be used in airport operations rooms, maintenance rooms, and, potentially, in the tower cab for air traffic controllers (Nohara 2009). This display is easy to interpret quickly and, hence, works well in situation rooms where operators are extremely busy with other tasks. Because the alert is based on the size of the targets, the number of targets, and their direction of movement, only those conditions that have been determined by the airfield biologists and managers to be hazardous will trigger an alert. In this example (Figure 3), a safety exclusion zone on the display lights up yellow for moderate and red for severe alert conditions in response to predetermined parameters. If no zones are triggered, the display shows the background map, indicating that the hazardous bird condition is low everywhere.

### Strategic tools

Strategic tools are used to exploit bird-track data recorded from a few minutes to several years previous. Such tools allow biologists to investigate the spatial and temporal patterns of bird abundance, movements, and deviations from long-term baselines of local populations and migrants. With these movements referenced to geographical information systems (GIS), the data can be imported into tools that are familiar to users (e.g., ArcGIS) to investigate abundance and movement patterns.

As an example of the application of an analytical tool, the temporal patterns of daily activity at Seattle-Tacoma International Airport were observed to be similar in form over 3 different seasons: winter, spring, and fall (Figure 4). The lowest hourly counts were at night, with



**Figure 4.** Hourly track counts (abundance) observed at Seattle-Tacoma International Airport over 3 5-day periods, one in the winter, one in the spring, and one in the fall. Daily abundance is cyclical from day to day, with fall and spring periods showing higher total counts than winter.

counts dramatically increasing around sunrise and remaining elevated until after sunset. The number of nighttime tracks was highest in the fall and spring, coinciding with nocturnal migration.

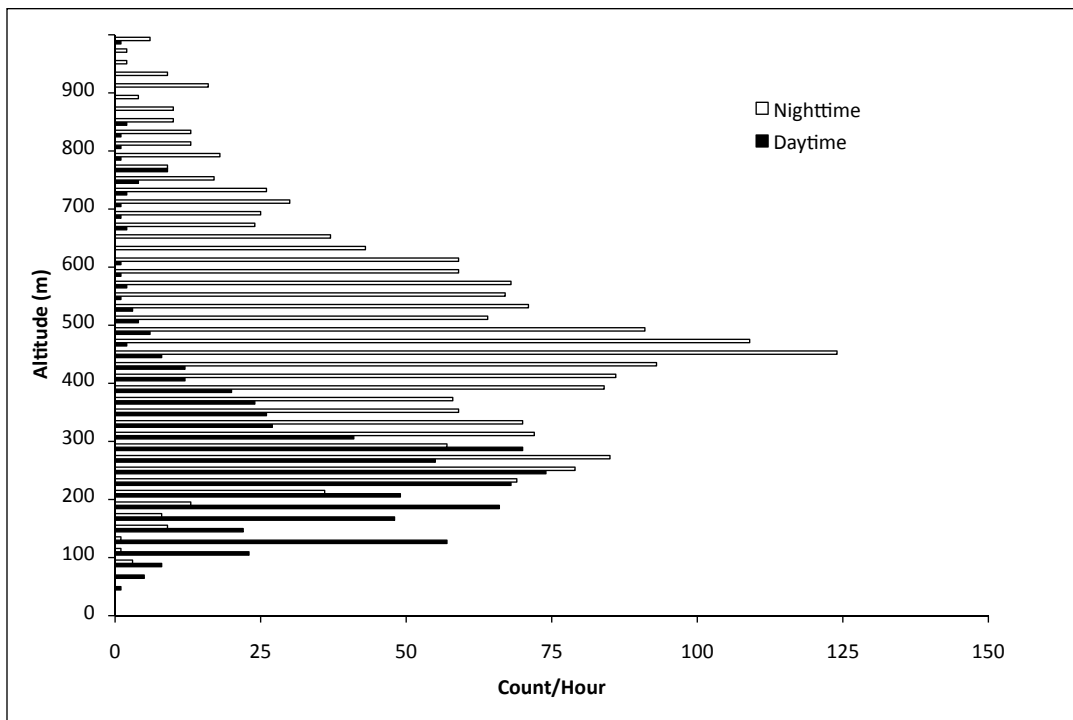
Altitudinal distributions provide additional information on hazardous bird movements around an airfield. For example, Figure 5 shows the height distributions during 2, 1-hour periods at Kingsville, Texas, located near the Gulf of Mexico. The altitudinal distribution of nocturnal migrants differs noticeably from the altitudes of diurnal movements. Although there are more birds moving at night, altitude and numbers do not reveal the relative hazards. In this instance, the RCS data revealed that the nocturnal migrants were much smaller birds than the diurnal birds, which would constitute a greater safety hazard.

**Management implications**

By incorporating the size of individual birds

or flocks with spatial and temporal activity patterns, managers can develop models to predict when and where hazardous wildlife will occur on an airfield. Size, based on RCS, can be used to help distinguish the patterns of small songbirds from those of larger, more hazardous birds so that managers can prioritize their efforts.

As with all sensors, the effectiveness of digital avian radar tools depends on the systematic use of quality assurance methods to maintain information quality. Because radar systems differ in their operational sensitivities, each must be calibrated. Observed RCS from known targets can be used effectively to calibrate the avian radar when the radar is first installed and to monitor its accuracy. The consistency of RCS estimates generated for birds can be maintained from year to year by calibrating RCS for a specific aircraft type against a baseline RCS originally obtained when the radar was first installed. Furthermore, the radar sensitivity



**Figure 5.** Height distributions (reported in 20-m intervals) during one hour of activity taken from two radars at Naval Air Station Kingsville, Texas, one (black) showing the altitude of diurnal activity and the second (outlined) showing the altitudes of nocturnal migrants.

can be adjusted annually to ensure that smaller birds (e.g., down to  $-40$  dBm<sup>2</sup>) are being tracked in sufficient quantity to maintain a uniform operating characteristic for the avian radar.

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**TIM J. NOHARA** is the founding president and CEO of Accipiter Radar Technologies Inc. Beginning in 1994, he assembled a world-class team of radar engineers and scientists focused on the development of avian radar for use at military airports, civil airports, and in natural resource management applications. Prior to this, he was with Raytheon Company working on advancing space-based, airborne and ground-based radar systems. He received the B.Eng degree from McMaster University in 1985, followed by the M.Eng and Ph.D degrees in 1987 and 1991, respectively, in Electrical and Computer Engineering. His graduate work was in radar. He is a licensed professional engineer and a member of the IEEE. His current research interests are in intelligent, wide-area surveillance and information systems for avian and security applications.



**ROBERT C. BEASON** is a radar ornithologist with Accipiter Radar Technologies Inc. He first used marine radars to monitor avian hazards to avian safety while a member of the U.S. Air Force's BASH team in 1971. His subsequent positions include distinguished professor of biology and biophysics at the State University of New York; professor and head of biology at the University of Louisiana, and project leader with USDA/APHIS Wildlife Services' National Wildlife Research Center. He received his Ph.D. degree from Clemson University where his dissertation research involved the use of the FAA ARSR system to monitor waterfowl migration hazards to aviation in the southwestern United States. In addition to radar ornithology and studies of bird migration, his research includes studies on avian navigation and orientation and avian sensory perception.



**PETER WEBER** is a principal radar engineer at Accipiter Radar Technologies Inc. Since 1996, he has worked on the design and development of radar digital signal processing algorithms for both avian monitoring and marine surveillance applications. From 1983 to 1995, he was a research engineer, first at McMaster University's Communications Research Laboratory and then at Raytheon Canada Ltd., where he worked on advanced radar system designs. He received his B.Eng. and M.Eng. degrees from McMaster in 1980 and 1983, respectively. He is currently developing new radar signal processing algorithms that help distinguish bird targets from other radar reflections.



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