1-1-2009

Could avian radar have prevented US Airways Flight 1549's bird strike?

Tim Nohara
Accipiter Radar Technologies Inc.

Nohara, Tim, "Could avian radar have prevented US Airways Flight 1549's bird strike?" (2009). *2009 Bird Strike North America Conference.* Paper 3.
http://digitalcommons.unl.edu/birdstrike2009/3

Could avian radar have prevented US Airways Flight 1549's bird strike?

Tim J. Nohara, B.Eng, M.Eng, P.Eng, Ph.D, Accipiter Radar Technologies Inc.

Key Words: avian, radar, bird, tracking, detection, strike, real-time, advisory, BASH, affordable, aircraft, 3D, 1549, ATC, pilot

ABSTRACT

The heroic ditching in the Hudson River of US Airway's Flight 1549 following multiple bird strikes with Canada geese has increased public awareness of bird aircraft strike hazards (BASH); and has focused attention on new tools such as avian radar to help further improve aviation safety. Reports in the media have suggested that had avian radars been deployed at LaGuardia, this bird strike could have been avoided. Indeed, there is mounting evidence supporting existing avian radar's ability to provide wildlife control and air operations personnel with greatly improved bird situational awareness which can be used to reduce bird hazards around airports for improved safety. But can avian radar provide pilots with the ability to sense and avoid specific bird hazards? The question requires careful consideration and is the subject of this paper. Using the Hudson incident as a case study, this paper examines the coverage and location accuracy needed if bird warnings to pilots are to be acted upon, followed by a look at the ability of today's avian radars to provide these.

1. INTRODUCTION

Over the past 40 years, avian radar systems have been the subject of research, development, and use by researchers and consultants (biologists and ornithologists). During this decade, the U.S. Navy [Weber et al, 2005; Nohara et al, 2005] reported on developments and applications of avian radar for Bird Aircraft Strike Hazard (BASH) and Natural Resource Management (NRM) on military airfields. In early 2007, the Department of Defense's (DoD's) Environmental Security Technology Certification Program (ESTCP) funded a three-year project called Integration and Validation of Avian Radars (IVAR) to carry out independent field trials and analysis to demonstrate the performance of avian radar [http:\\www.estcp.org\Technology\SI-0723-FS.cfm] and to publish results to the broader scientific community [Klope et al, 2009]. In mid-2006, the Federal Aviation Administration (FAA) began its own Avian Radar Assessment Program to evaluate off-the-shelf avian radars in a civil aviation setting. Radars have been installed at Seattle-Tacoma International Airport, Chicago O'Hare, and JFK to date, and have undergone extensive testing to characterize performance in a complex airport setting and to develop guidance on how best to integrate avian radars with existing wildlife control and safety practices at airports. Already, several real-time (tactical) and statistical (strategic) wildlife management applications have been identified and shown with today's avian radars to be effective in improving aviation safety through greatly improved bird situational awareness [Nohara, 2009]. These applications serve as force multipliers for wildlife control and air operations staff, helping them to be more effective, both on and adjacent to the airport property, where the majority of bird strikes occur. Today's avian radars can already support these uses.

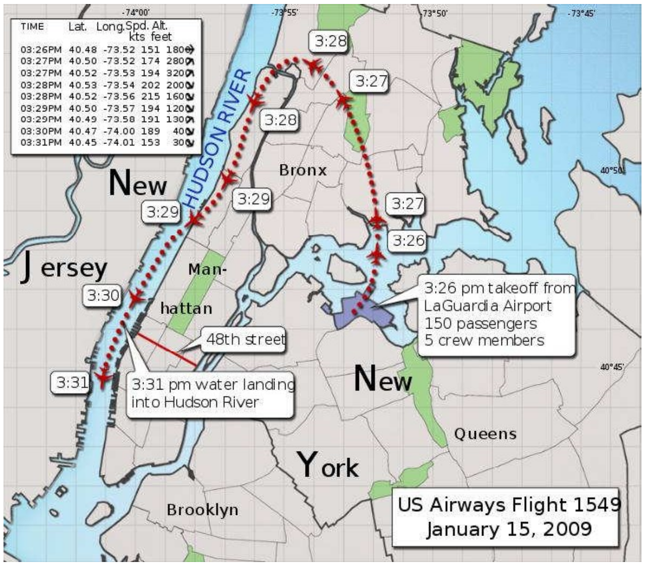
The heroic efforts of Captain Chesley Sullenberger and First Officer Jeff Skiles on January 15, 2009 have drawn considerable media attention to bird strikes, and to the role pilots play, especially *well beyond* the airport. Multiple bird strikes with Canada geese occurred 5 km out from LaGuardia at almost 3,000' AGL. At the National Transportation Safety Board (NTSB) Public Hearings on June 9, 2009, Captain Sullenberger noted that he saw birds and an instant later, his windscreen was full. When asked "… what significance do bird warnings play in your awareness during and after takeoff?", he testified "In my experience, the warnings that we typically get are routine and general and not specific in nature and therefore have limited usefulness." [NTSB, 2009] In light of this, it is timely to consider how avian radar could provide improved situational awareness of bird hazards *well beyond* the airport property to air traffic controllers and pilots at busy commercial airports, today and in the future.

The paper is organized as follows. Section 2 provides an overview of the Flight 1549 bird strike, extracting the necessary information that is analyzed in Section 3. Section 3 examines the accuracy needed for actionable bird advisory information, i.e. information that results in improved bird situational awareness and that may be acted upon. In Section 4, avian radar antennas are reviewed in order to understand the coverage they provide and the accuracy of bird location information they are capable of producing. Finally, Section 5 concludes with a summary and conclusions.

2. REVIEW OF FLIGHT 1549 BIRD STRIKE

The information in this section concerns the flight path of US Airways 1549 and the nature of aircraft traffic around New York City.

Figure 1 illustrates the flight path of US Airways 1549 on 15 January 2009 beginning at 3:26 pm. The multiple bird strike accident began as a routine westbound departure on Runway 4 with a planned initial climb to 5,000' at a heading of 360° on a climb out to 15,000'. Runway 4 has a bearing of 44° magnetic and 32° true. At 3:27 pm, approximately one and a half minutes after takeoff, the aircraft struck an approaching flock of Canada geese. The bird strikes occurred at a latitude, longitude of approximately 40.83°,-73.87° at a distance of 5 km beyond the airport and at an altitude of approximately 850 m (2700'-2800') due north of LaGuardia airport. The bird strikes occurred at an elevation angle of approximately 10° above the horizontal from the airport. The weather was clear with winds of 19 km/h from the north (www.weatherunderground.com). And as Dr. Richard Dolbeer described at the NTSB Hearings [NTSB, 2009], a strike at this altitude is somewhat of an anomaly.



TIME	Lat.	Long.	Spd. kts	Alt. feet
03:26PM	40.48	-73.52	151	1800→
03:27PM	40.50	-73.52	174	2800↗
03:27PM	40.52	-73.53	194	3200↗
03:28PM	40.53	-73.54	202	2000↘
03:28PM	40.52	-73.56	215	1600↘
03:29PM	40.50	-73.57	194	1200↘
03:29PM	40.49	-73.58	191	1300↗
03:30PM	40.47	-74.00	189	400↘
03:31PM	40.45	-74.01	153	300↘

Figure 1: Flight path of Flight 1549 (Wikipedia)

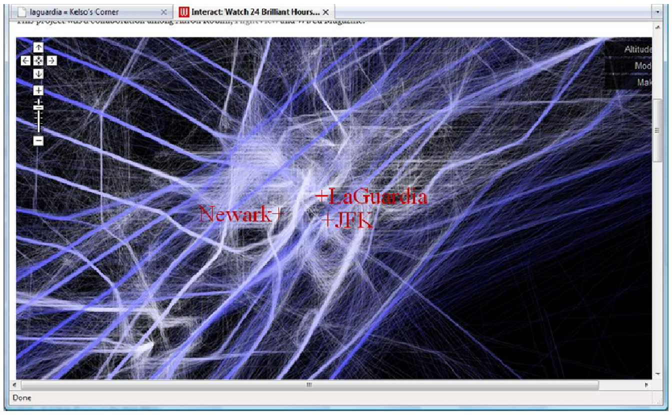


Figure 2: 24 hour aircraft traffic around New York City on 12 Aug 2008 (23 Feb 2009 Wired Magazine, Andrew Blum)

The aircraft traffic patterns around New York City are illustrated in Figure 2 for a 24 hour period. Lighter colors are lower altitudes and darker colors are higher altitudes. Each year, about 2 million aircraft pass over New York's airspace. With three major airports, LaGuardia, JFK and Newark, and nine runways, the result is a most dense airspace that operates at capacity. Delays occurring in New York due to weather or other factors are expensive and cause ripple effects across the country. Planes must stay in their assigned lanes for safety and capacity. Significant research is underway to consider new lanes and flight protocols with the objective of increasing capacity and reducing delays by just a few minutes. There is an abundance of resident and migratory birds in the area. As a result of this particularly challenging aviation environment, any proposed new use of bird location information to alter flight paths of aircraft would require extensive study before implementation.

3. ACCURACY NEEDED FOR ACTIONABLE BIRD ADVISORY INFORMATION

Bird location information must have sufficient accuracy in order to justify the possible use of such information in delaying a flight or altering its flight path at a busy commercial airport. In this section, we consider the accuracy needed for such information to be actionable in these ways.

3.1 *Accuracy Needed*

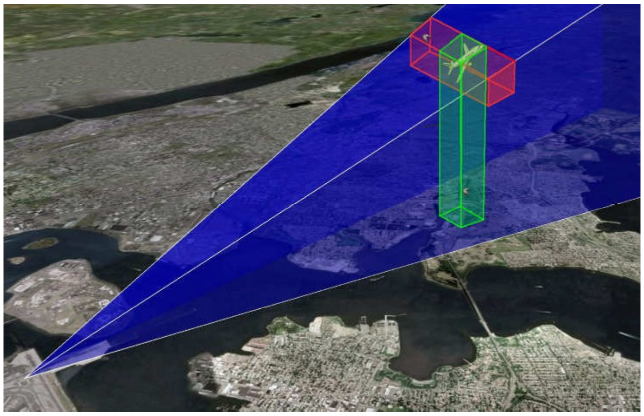


Figure 3: Must resolve non-threatening situations: birds at safe distance from aircraft, separated in lat,long or height.

In order to predict a possible bird strike reliably at distances 5 km away from the airport, one must be able to track such birds with sufficient accuracy in location (latitude, longitude, and height), speed and heading that false positives are avoided. A false positive provides an indication that a bird strike is imminent when in fact it is not. Delaying aircraft unnecessarily is costly, and altering an aircraft's normal flight profile while climbing raises safety issues that must be carefully considered.

But how accurate do bird tracks need to be before they could be considered actionable? A reasonable start at answering this question begins by a review of target accuracies associated with existing airport sensor systems. Consider first the Traffic Collision Avoidance System (TCAS) used presently to avoid mid-air collisions between aircraft. The bearing of nearby aircraft is derived from on-board antennas typically with a 1 to 2 degree angular resolution or beamwidth, and height information is provided by Mode C altitude broadcasts typically accurate to +/- 100'. Next, consider a typical digital airport surveillance radar (e.g. DASR-11) that is used by air traffic controllers to manage aircraft. It uses an antenna with a 1.4 degree bearing beamwidth and has a range resolution of about 150 m. Finally, consider that near mid-air collisions between aircraft are typically defined as separations less than 500' or 150 m.

Given the above discussion, and for our purposes in the sequel, we will consider a sensor that provides a bird location resolution of 150 m or less (i.e. +/- 75 m accuracy) in each of the horizontal (lat-long) and the vertical planes as necessary (but not sufficient for reasons described earlier and below) to be actionable. A sensor with a 1.7 degree angular resolution in both planes at 5 km distance will provide this.

Figure 3 illustrates two non-threatening situations that need to be resolved by any bird alerting system to avoid false positives. The situation illustrated in red shows an aircraft and a flock of birds (represented by the bird symbol) at the same altitude but with lat,long coordinates that represent a significant horizontal separation. The second situation is illustrated in green and shows the aircraft and a flock of birds at the same lat-long coordinates, but with a significant vertical separation as they are at very different altitudes. A resolution of 150 m (+/- 75 m accuracy) means that the bird alerting system can identify the above situations whenever the vertical or horizontal separation exceeds 150 m.

Consider finally that the 1549 bird strike occurred about ninety seconds after take-off. During this time, geese traveling at say 50 knots (ground speed) would travel more than 2 km. Since aircraft follow known flight patterns, predicting their positions ninety seconds into the future is one thing, but doing the same for birds which are uncooperative (they do not cooperate with controllers in following assigned flight paths) is another thing altogether. The ability to predict the precise location of a flock of birds ninety seconds into the future adds considerable additional uncertainty or inaccuracy that is beyond the scope of this paper. This additional prediction uncertainty would need to be considered in any study to assess the impact of delaying flights in response to the presence of birds 5 km out from the airport.

4. COVERAGE AND ACCURACY OF AVIAN RADAR ANTENNAS

With a bird alerting system sensor resolution of 150 m established in Section 3, we can now direct our attention to the question of whether existing avian radars could have provided such resolution, so as to provide actionable bird location information in the context of 1549.

4.1 *Avian Radar Antennas*

The radar antenna limits the accuracy of bird location information. At the present time, two varieties of antennas are commonly used with avian radar at airports. Array antennas are used (see Figure 4), and can be rotated horizontally, denoted herein as an H-array, as well as vertically (i.e. the plane of rotation is perpendicular to the ground instead of co-planar with it), denoted herein as a V-array. Dish antennas are also used (see Figure 5) and rotate horizontally. The central axis of a dish is inclined (tilted) upward, so that its beam illuminates a cone of space above the ground.

Figure 4: Avian radar array antenna in horizontal orientation (i.e. the base plate is parallel to the ground). The based plate would be mounted perpendicular to the ground for a vertical array orientation.

Figure 5: Avian radar dish antenna.

4.2 *Avian Radar at LaGuardia for Flight 1549*

In the following analysis, each antenna is examined in terms of its ability to resolve the two false-positive situations presented in Section 3. However, to make the conclusions drawn from the analysis easier to appreciate in the context of 1549, we will assume that the aircraft in Figure 3 is at a height of 850 m AGL (as was 1549 at the strike), and the two bird flocks shown (the red and green situations) are each separated 800 m from the aircraft. This separation is an extreme case where the green bird situation is very close to the ground.

The analysis assumes that avian radar dish and array antennas are located at LaGuardia airport in their usual configurations. Two paired radar configurations are illustrated (although the reader can infer other combinations of radars). The first is an H-array/V-array combination, located near the centre of Runway 4 and/or Runway 31. Two sub-cases are reviewed, one with the V-array aligned to cover Runway 4, and the other with the V-array aligned to cover Runway 31. The second configuration is a pair of co-located, up-tilted dish radars, one with a *lower* beam covering 2 to 6 degrees vertically, and the second with an *upper* beam covering 6 to 10 degrees. Each antenna/configuration is examined against the flight characteristics of 1549 presented in Section 2.

Figures 6, 7 and 8 show the beam patterns for an H-array with an assumed 1 deg beam width which is readily available at X-band. At 5 km distance, the horizontal accuracy is about +/- 43 m, well within the desired +/- 75 m accuracy. The horizontal scan pattern covers a full 360 degrees as illustrated in purple in Figure 6. Two individual beams during the scan are illustrated in red. The beam pointed due north is directed towards the aircraft and green flock from Figure 3.

The red, horizontally-displaced flock is easily resolved from the aircraft; however, the green-displaced flock is not resolved. This is better understood with reference to Figure 7. The +10 degree vertically-oriented fan beam of the H-array is shown extending from 0 to 10 degrees and provides no ability to distinguish between the height of the aircraft at 850 m and the height of the green flock near the ground at 50 m AGL. The extent of the beam width indicated by the green trapezoid in Figure 7 includes both targets so they can not be resolved. So while the H-array can identify horizontally-displaced benign situations, it cannot identify vertically-displaced ones, and will generate false positives, even with 800 m of separation.

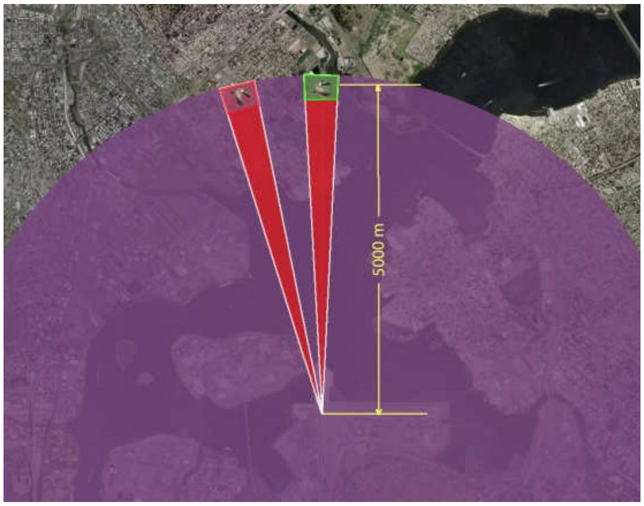


Figure 6: Horizontal scan pattern for H-array.

An orthographic view of the H-array scanning through the 1549 bird strike is shown in Figure 8. The H-array would have detected the bird strike (at the upper part of its fan beam) and would have provided a good ground track, but it could not have determined whether the geese were near the ground or near the aircraft.

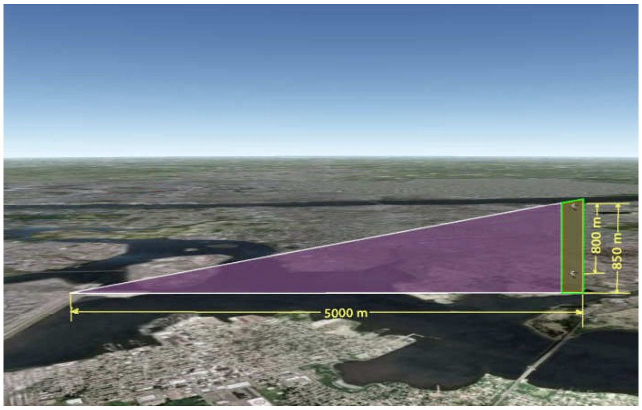


Figure 7: Vertical coverage pattern for H-array.

Figure 8: Beam from H-array scanning through location of bird strikes.

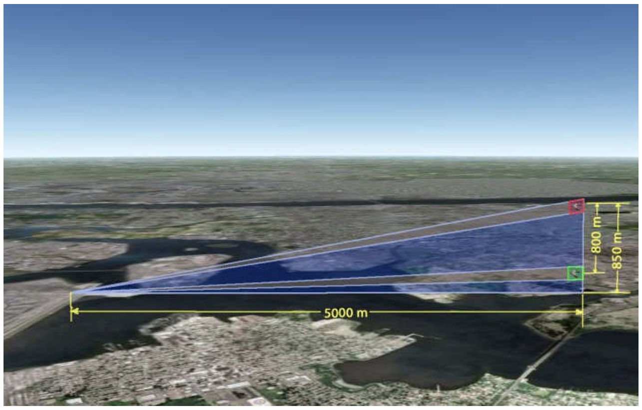


Figure 9: Portion of vertical scan pattern for V-array.

Next, consider the V-array beam patterns shown in Figures 9, 10 and 11. The situations simply reverse as it is the same scanning antenna as the H-array, now oriented vertically. Figure 9 illustrates a 10 degree portion of the vertical scan pattern of the V-array with two particular beams illustrated in a transparent color, one shown directed at the green flock and the second at the aircraft (and red flock) located 10 degrees above the horizontal. The V-array easily resolves the vertically-displaced green flock located 50 m AGL from the aircraft at 850 m AGL, but provides no information on the horizontal displacement of the red flock from the aircraft.

Figure 10 better illustrates the horizontally-displaced, red flock situation. The horizontal beam width of the V-array is now a full 20 degrees (i.e. +/- 10 deg) as indicated by the red trapezoid and results in an extent of +/- 850 m from the centerline at 5 km range. The beam cannot resolve the aircraft located at the centerline and the red flocks displaced horizontally 800 m to the west. So while the V-array can identify vertically-displaced benign situations, it cannot identify horizontally-displaced ones, giving false positives even with 800 m of separation from the aircraft.

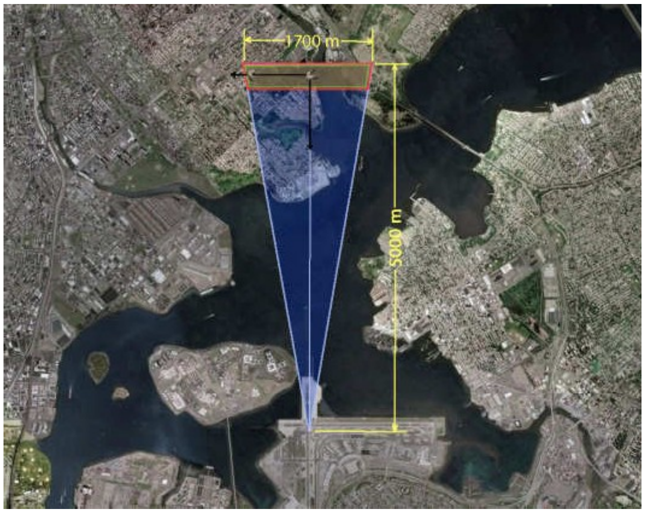


Figure 10: Horizontal coverage pattern for V-array. Only the front half of coverage footprint is shown.

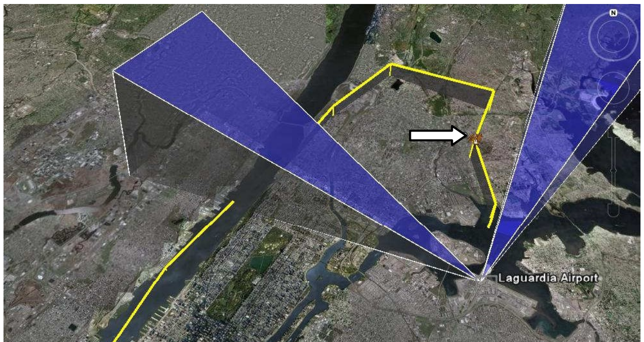


Figure 11: Portion of coverage pattern for V-array aligned to Runway 4 and to Runway 31. 1549 flight path is shown along with location of bird strike marked by arrow.

An orthographic view of the V-array scanning through a relevant portion of its scan pattern is shown in Figure 11, along with the 1549 flight path and bird strike. Two cases are shown, one with the V-array aligned to Runway 4 and the other with the V-array aligned to Runway 31. Since the 1549 bird strike occurred at a bearing of 360 degrees, neither of the two V-arrays would have seen or detected the birds. The 1549 accident illustrates the importance of having 360 degree coverage of birds at airports. V-arrays are inefficient in providing such coverage and would require about nine radars aligned 20 degrees apart to give 360 degree coverage and the corresponding height information. Even if a bird strike occurs at 5 km aligned with the V-array coverage pattern, as shown above, the V-array still cannot identify the red, horizontally-displaced false positive situation.

Finally, we turn our attention to the horizontally scanning dish antenna, and in particular, a configuration that has two dish radars with overlapping lower and upper beams as described earlier. At a distance of 5 km, the 4 degree circular beam width of each dish antenna has a diameter of about 340 m and hence provides a spatial accuracy of about +/- 170 m in all dimensions. So while the 4 deg dish could have identified horizontal and vertical separations of 800 m illustrated in the previous examples, it could not have provided the +/- 75 m accuracy derived in Section 3.

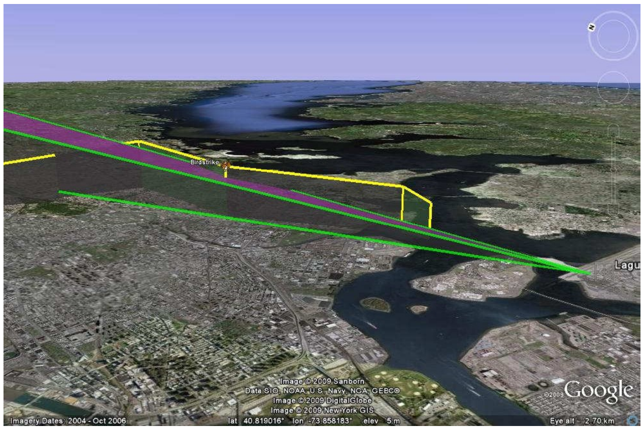


Figure 12: Lower dish antenna beam scanning through the location of the 1549 bird strikes.

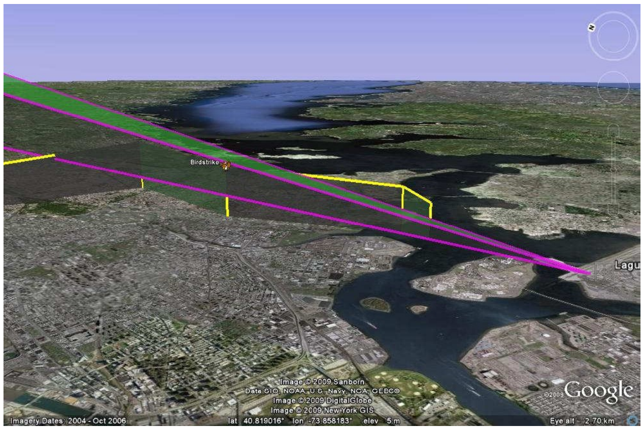


Figure 13: Upper dish antenna beam scanning through the

location of the 1549 bird strikes.

An orthographic view of the lower dish's beam scanning through the 1549 bird strike is shown in Figure 12. Since the bird strike occurred at an elevation angle of 10 degrees, the lower beam (2 to 6 degrees) would not have seen the birds. The upper dish (with beam illustrated in Figure 13) would have seen and tracked the birds, but again, not with the desired +/- 75 m accuracy needed to resolve false positives down to 150 m separation. While larger dish antennas (i.e. with a beam width of 1.7 degrees) would provide the required accuracy, we would need at least five of them with their beams stacked to provide coverage similar to the H-array. This approach is complex and expensive.

5. SUMMARY AND CONCLUSIONS

This paper illustrates that if today's commercially available avian radars had been deployed at LaGuardia in the usual manner, an actionable alert to pilots of US Airways 1549 to delay takeoff or alter the flight path would not have been justified. To reliably predict a bird strike at a range of 5 km beyond the airport, further improvement in accuracy of 3D bird location information (latitude, longitude and height) is needed to avoid false positives. In addition, a careful study of the impact such delays or flight path changes would have in the context of the dense, New York City airspace would have to be carried out first.

Section 4 illustrates the importance of 360 degree coverage as bird strikes can occur anywhere around the airport. The V-array would not have seen the 1549 bird strike, and the H-array and dish antennas need improvements in accuracy for a long range bird strike prediction such as this. Good accuracy simultaneously in both the horizontal and vertical dimensions is necessary to identify benign situations, and resolve false-positives. The dish antenna is a good compromise for getting modest accuracy in both dimensions and 360 degree coverage. Unlike the H-array or V-array, the dish gives 3D latitude, longitude, height, speed and heading information for every tracked target in its beam.

Improving accuracy significantly while maintaining coverage and controlling costs requires a new approach such as the multi-beam technology illustrated above [Weber et al, 2007]. Recent field trials have demonstrated that +/- 75 m accuracy at 5 km is indeed achievable and affordable. This technology, when available in production units, will be backwards compatible with existing avian radars. This means that upgrades will be affordable and straight forward. It also means that situational awareness for wildlife control and air operations personnel will only get better over time, incrementally, in a spiral development manner. It also means that avian radars will be able to provide more accurate information even at longer ranges for the benefit of other aviation safety uses such as the bird strike warning to pilots considered herein.

REFERENCES

[Nohara, 2009] T.J. Nohara, "Reducing Bird Strikes- New Radar Networks Can Help Make Skies Safer", The Journal of Air Traffic Control, Fall 2009

[Klope et al, 2009] M.W. Klope, R.C. Beason, T.J. Nohara, M.J. Begier, "Role of Near-miss Bird Strikes in Assessing Avian Hazards", Human Wildlife Conflicts Journal 3(2):208-215, Fall, 2009

[NTSB, 2009] "Public Hearing in the matter of the landing of US Airways Flight 1549 , N106US, in the Hudson River, Weehawken, New Jersey, January 15, 2009" Transcripts June 9, 2009, NTSB Board Room and Conference Center, 490 L'Enfant Plaza, Washington, D.C., 20024.

[Nohara et al, 2007] T.J. Nohara, P. Weber, A. Ukrainec, G. Jones, A. Premji, "An Overview of Avian Radar Developments - Past, Present and Future", Bird Strike 2007 Conference, September 10-13, 2007, Kingston, Canada

[Nohara et al, 2005] T.J Nohara, P. Weber, A. Premji, C. Krasnor, S. Gauthreaux, M. Brand and G. Key, "Affordable Avian Radar Surveillance Systems For Natural Resource Management And BASH Applications", IEEE Radar Conference, Arlington, Virginia, May 9-12, 2005.

[Weber et al, 2007] P. Weber and T.J. Nohara, "Device and method for 3D height-finding radar", PCT/CA2007/001186. Patents pending.

[Weber et al, 2005] P. Weber, T. Nohara and S. Gauthreaux, "Affordable, real-time 3-D avian radar networks for centralized North American bird advisory systems", Bird Strike Conference., Vancouver, B.C., Canada, Aug. 14-18, 2005.