Progress Report on Development of a Terminal Area Bird Detection and Monitoring System Using the ASR-9*†

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1. Introduction

Bird strikes are an increasing concern for military and civil aviation as airport operations and bird populations continue to increase. The number of reported bird strikes by civil aviation has escalated more than three-fold in the last decade, with the majority of bird strikes occurring in the immediate vicinity of the airport -- below 3,000 ft and within 5 miles (Cleary, et al., 2000).

Current automated bird strike risk assessment tools such as the US Bird Avoidance Model (BAM) and Avian Hazard Advisory System (AHAS) (Kelly, 1999; Kelly, et al., 2001) utilized by the Air Force do not currently provide the timely real-time detection of bird activity in the immediate airport vicinity that is needed for civil aviation operations (Blokpoel and MacKinnon, 2001). AHAS is able to detect regional-scale bird movements through sophisticated processing of WSR-88D (NEXRAD) weather radar data and continues to be improved. However, most of the WSR-88Ds scan the surface too infrequently (5-7 minutes) and are too far away from most civil airports to provide the coverage needed for timely warnings in the terminal area.

In 1999, National Transportation Safety Board (NTSB) recommended that the Federal Aviation Administration (FAA) pursue AHAS technology to reduce bird strike risk at airports (NTSB, 1999). Subsequently, FAA has tasked Lincoln Laboratory to investigate the use of existing terminal radars such as the Airport Surveillance Radar (ASR-9) and Terminal Doppler Weather Radar (TDWR) as the basis for a real-time terminal area bird monitoring and strike warning system.

Figure 1 shows the proposed architecture for a Terminal Avian Hazard Advisory System (TAHAS). The ASR-9, with its rapid, broad area scan rate (5 sec) and on-airport location, is well-suited to serve as the primary detection sensor. Where available, a TDWR (or a nearby NEXRAD) could provide improved altitude information and small target detection capability. The radar data will be input to real-time processing algorithms that will identify and track bird flocks and isolated bird targets within the terminal area, providing guidance for airport bird control operations and real-time warnings that could be relayed by air traffic control or direct datalink to pilots.

One or more interfaces to internal or external databases are envisioned as components of the system. The databases could assist the automated detection algorithm by providing cueing based on historically favored bird locations (e.g., roosts) as well as regional-scale migratory bird movements obtained from AHAS. Locations and estimates of bird movements generated by the system could be stored in a database for subsequent reference by airport wildlife management personnel to help direct mitigation efforts.

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† Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Air Force.

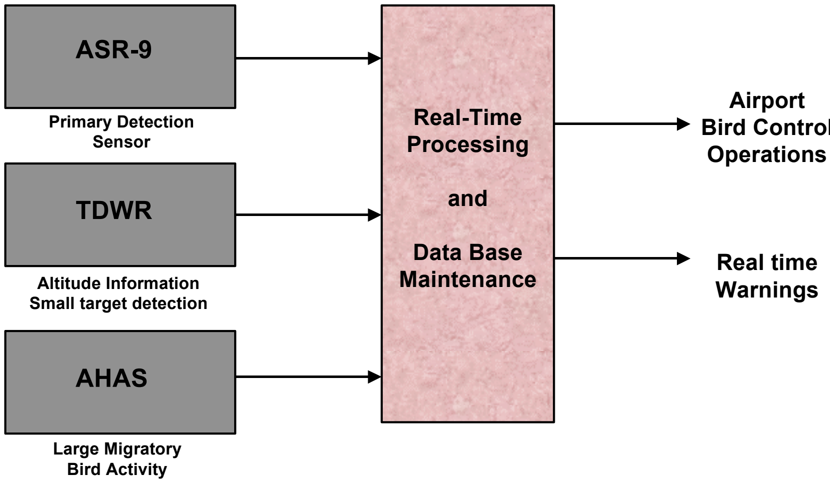

Figure 1. Proposed Terminal Avian Hazard Advisory System architecture.

(Troxel, 2001) describes an initial automated real time bird flock detection algorithm based on processing of data from an ASR-9 outfitted with a Weather Systems Processor (WSP). This first-phase TAHAS implementation utilizes image pattern matching feature detectors and fuzzy logic data fusion techniques to detect moving flocks of birds at 1-minute intervals in reflectivity and Doppler velocity data from the ASR-9. The output of the flock detector is a 6-level map of bird flock intensity extending to a range of 20 km from the airport. Figure 2 is a block diagram illustrating the stages of the flock detection algorithm.

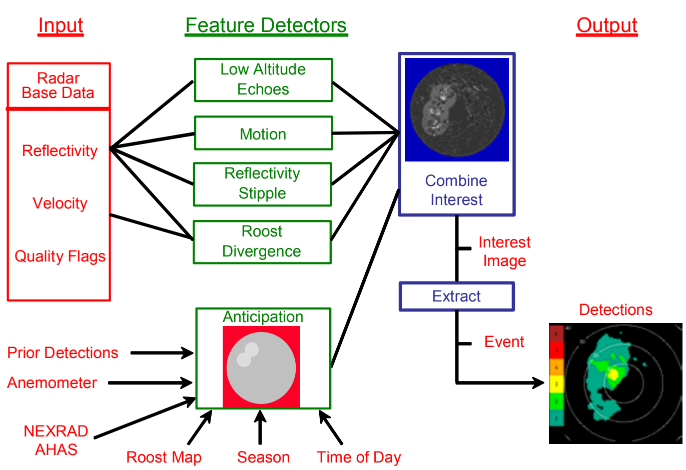

Figure 2. TAHAS bird flock detection block diagram.

The flock detection algorithm was found to perform well at detecting the numerous bird and bat flock events that were observed with the ASR-9 at Austin-Bergstrom International Airport (AUS) in Texas. However, the initial algorithm had difficulty discriminating regions of birds from light rain echoes having similar levels of reflectivity. The paper also reiterated the need to develop a capability for detection and tracking of individual or small groups of birds. In the past year, several important activities and software enhancements have been completed that address these needs:

1. A weather classifier module has been added to the flock detection algorithm that significantly reduces false alarms from weather.

2. Data collected during a 2-week field measurement study at AUS have shown that the ASR-9 can detect individual or small groups of birds.

3. An integrated, high-update rate (10 sec) bird tracking sub-algorithm has been added to TAHAS to generate tracks of individual or small groups of birds within 10 km of the airport.

2. Elimination of Weather from Flock Detector Output

As described in Troxel, 2001, the TAHAS flock detection algorithm processes the ASR-9 WSP base data imagery looking for features and characteristics to discriminate bird flocks from other signals. The principal characteristics of bird flock echoes are:

1. Low reflectivity (generally less than 20 dBZ).

2. Low-altitude (returns from the low beam exceeding those from the high beam).

3. Echo movement consistent with bird flock motion.

Unfortunately, the above characteristics are also frequently associated with vertically shallow, moving light rain echoes, making discrimination on these characteristics alone problematic. Two additional spatial reflectivity characteristics have been identified that can be used to help distinguish bird flock echoes from weather echoes:

1. Regions of precipitation tend to exhibit more spatial reflectivity variance than bird flock echoes.

2. Areas of low reflectivity rain often surround or are otherwise connected to regions of higher reflectivity that exceed values typically associated with bird flocks.

A weather classification module that exploits these additional characteristics has been added to the TAHAS flock detection algorithm. Briefly, the weather classification module works by extracting spatially connected regions of reflectivity that exceed a near-noise threshold of 0 dBZ. Each region is then assigned a consensus score (0-255) based on the amount of reflectivity variance, and the extent of areas within the region that exceed mid- and high-reflectivity thresholds (25 dBZ and 35 dBZ, respectively). If the score is high enough (> 128), then the whole region is flagged as weather, except that weather flagging is not permitted to extend into regions of high bird flock anticipation based on prior detections. The capability of the weather echo classifier to reject weather declines near the edges of the data, since not enough of the surrounding image pixels can be seen to provide the spatial context needed. For this reason, the final bird flock detections are clipped at 20 km range (the ASR-9 WSP base data that are input to the flock detector extend to about 30 km).

Figure 3 shows selected example input reflectivity and final 6-level bird detections from scans 11 minutes apart. The weather detection images from the weather classifier are also shown. In this event, a light rain shield surrounding two thunderstorms approached the Congress St. bridge in Austin, TX just as large numbers of bats were making the daily exodus from their roosts at dusk. Initially the bat and weather echo regions are separated, but eventually they become connected. The anticipation regions that are computed based on prior recent detections are successfully used in this case to prevent the weather classifier from extending the weather areas into the areas associated with the ongoing bat activity

At this time, some occasional false detections on weather echoes still occur. Additional tuning of the scoring functions used to form the consensus weather classification score may help. The most common cause of weather breakthrough is from isolated light rain echo regions that are very uniform and do not have any spatial connection to an area of higher reflectivity. These areas may still be discounted as bird flock echoes if the high beam reflectivity exceeds the low beam reflectivity, but this discriminator is imperfect owing to the broad elevation overlapping fan-shaped beam patterns of the ASR-9.

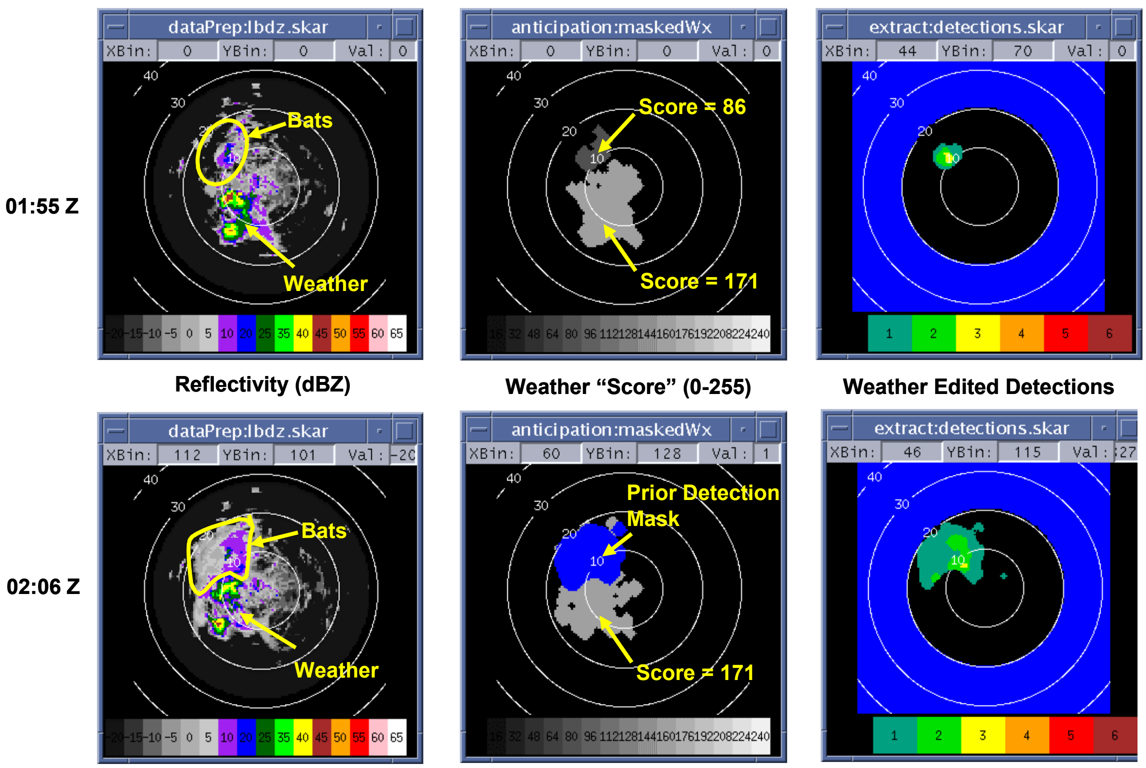

Figure 3. Example editing of weather from bird flock echoes. Leftmost images are ASR-9 low beam reflectivity. Middle images are the consensus weather score (regions with scores > 128 are considered weather). Rightmost images are final 6-level flock detections.

3. Detection and Tracking of Individual Birds

The initial TAHAS implementation focussed on detection of flocks of birds. However, a full-fledged bird strike warning system needs to detect and track isolated and small groups of birds as well (for example, bird acrtivity at JFK airport in New York is often comprised of small groups of birds flying back and forth to a nearby landfill and wildlife refuge). Primary radar detections of individual birds have frequently been observed in ASR-9 target channel processor output in the past (especially during migratory episodes), so it is expected that the ASR-9 should not have difficulty detecting and tracking individual birds or small groups of birds given sufficient radar cross-section and fairly consistent movement.

During November 2001, a two-week measurement program was undertaken at AUS to ascertain the ability of the ASR-9 to detect individual or small groups of birds in the immediate airport vicinity. Simultaneous measurements provided by an X-band Mobile Avian Radar System (MARS) operated by Geo-Marine, Inc. were used to identify periods of nearby bird and bat activity that were subsequently examined in the recorded ASR-9 WSP data. High-speed animations of ASR-9 reflectivity images 10 seconds apart revealed considerable numbers of individual bird echo tracks in addition to the larger bird flock movements. The bird echoes can be seen much more readily in a movie loop than by examining an image from any single scan (because of their motion). The top half of Figure 4 shows bird echoes in 10-km range PPI displays of the ASR-9 WSP dual-beam and high beam reflectivity data products (the dual-beam reflectivity is a time-averaged composite of high beam and low beam reflectivity). Bird detections reported by the MARS system at the same time are shown in the range vs. height plot in the lower half of the figure.

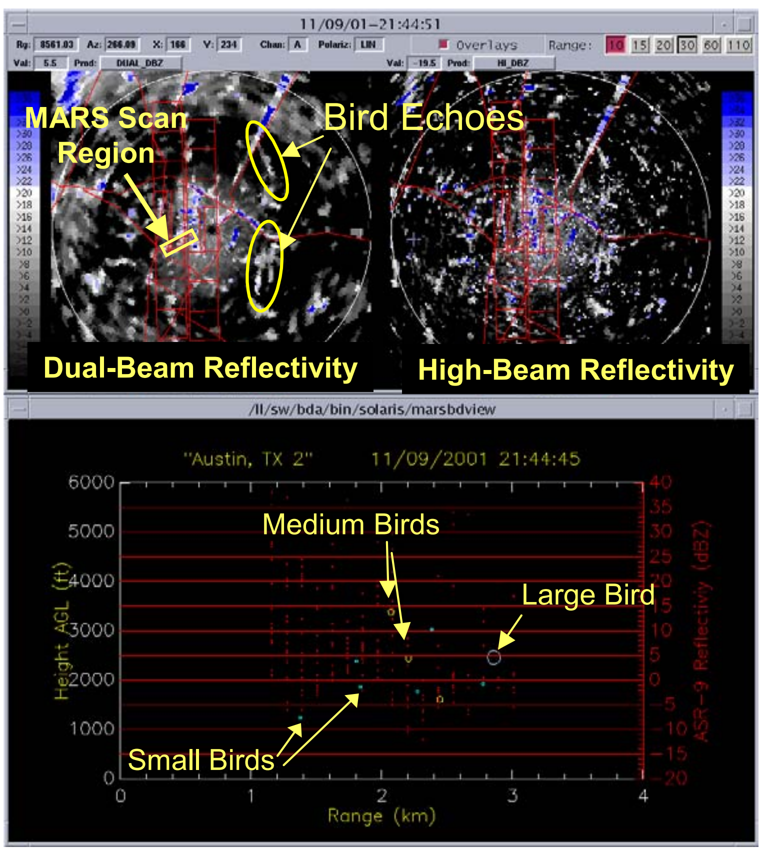

Figure 4. Bird detections seen in corresponding data from the AUS ASR-9 WSP (top) and MARS X-band bird detection radar (bottom). The range ring in the ASR-9 data is at 10 km.

4. Development of the TAHAS Bird Tracker Module

Given the encouraging results of the ASR-9 bird observability study, development of a real-time, high-update rate bird tracking module has proceeded and has now been incorporated into the TAHAS prototype software. As discussed previously, The flock detection subalgorithm processes ASR-9 WSP data once every minute. This is an adequate rate for monitoring flock movements, but a more frequent update rate is needed for tracking of isolated bird movements. Due to the alternating low beam/high beam scan strategy of the ASR-9, a complete set of low and high beam base data products are received and processed by the tracker once every 10 seconds.

Figure 5 shows the diagnostic display used for monitoring the bird tracking function of the TAHAS system. Range rings are at 5 km intervals out to 10 km. The airport runways with 3-mile approach and departure corridors and major highways are shown with red overlays. Basically, the tracker works by accumulating scan-to-scan differences of low reflectivity signals. The upper row of images in the figure show the reflectivity from the current scan, the prior scan (10 seconds ago), and the pixel-by-pixel intensity difference between the two scans after linearly rescaling the differences to the interval [0,255]. As the differences accumulate, moving targets appear as trails in the cumulative motion image (lower left image). A recursive temporal decay scalar is applied to the prior difference values so that the older segments in the trail eventually fade from view. Thus, each trail in the cumulative motion image has a bright leading “head” that diminishes toward the “tail”. These trails are then extracted by first running a pattern matching filter on the cumulative motion image to produce an “interest” image having values between 0 and 255 that indicate the degree to which the cumulative motion image values match the pattern expected for a trail (lower middle image). The tracks are extracted by thresholding the interest image at the ambiguity midpoint value of 128 and then thinning the extracted interest regions to single pixel wide “chains” of points that represent the final bird track (lower right image). Attributes are then computed for each track (e.g., speed, direction, echo intensity).

The tracker sub-algorithm runs in TAHAS as a separate processing thread that executes asynchronously with the flock detection sub-algorithm. The two processing threads access the same ASR-9 WSP input data source, but having them operate as separate threads means that the high update rate tracker sub-algorithm does not have to wait for the computationally slower flock detection sub-algorithm. Products from the two process threads (bird flock maps and individual bird tracks) are transmitted on the TAHAS output stream as soon as they are computed for immediate display.

Some additional algorithm refinement and adjustment of thresholds is likely needed to achieve optimal tracking performance. Some of the weaker and short-lived bird tracks are being rejected. False tracks are sometimes generated on slow-moving, low cross-section aircraft (typically, general aviation aircraft), and on road traffic.

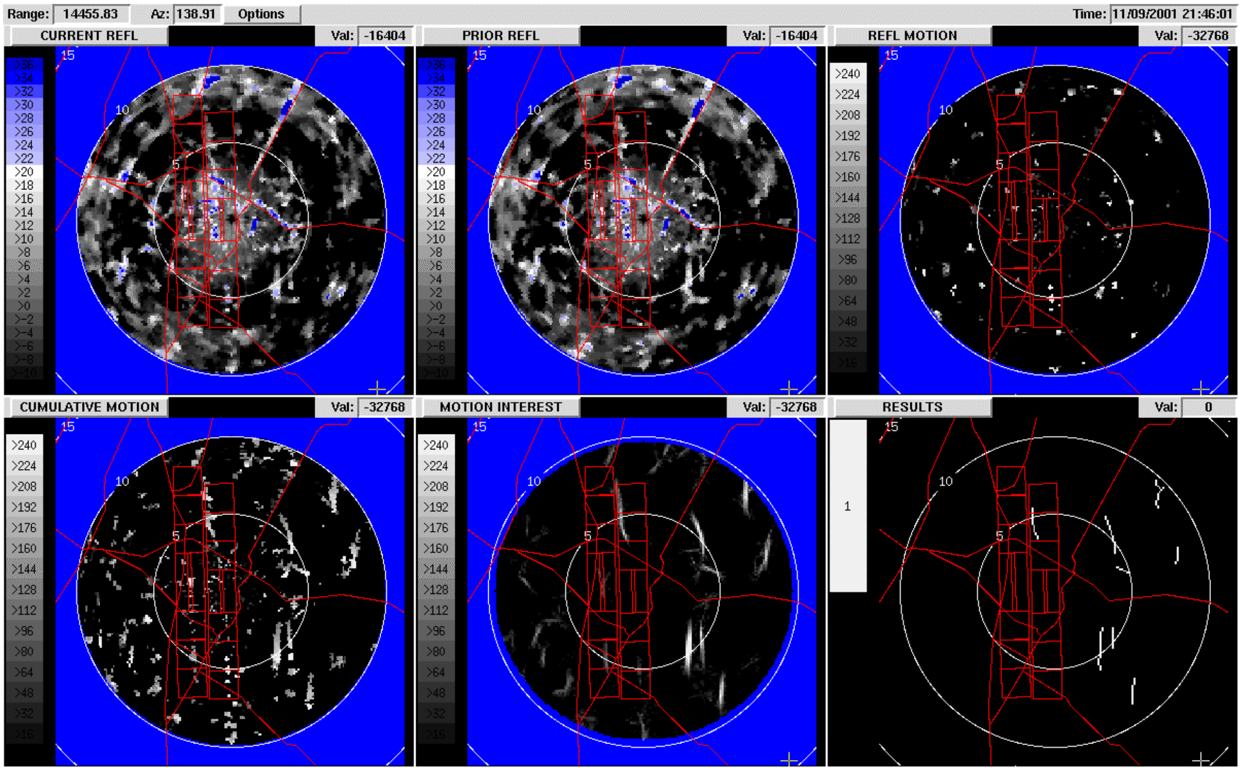

Figure 5. TAHAS tracker analysis display. (upper left) current scan reflectivity; (upper middle) prior scan reflectivity; (upper right) reflectivity motion difference image for the current scan after rescaling to the interval [0, 255]; (lower left) cumulative reflectivity motion difference image; (lower middle) motion interest image after thin line filtering; (lower right) resulting bird tracks after thresholding and extraction.

5. Development of TAHAS User Display and Database

Real-time diagnostic monitoring displays have been developed for the TAHAS flock detection and bird tracking sub-algorithms. These could serve as initial on-site demonstration displays until a full-fledged user display is developed. Figure 6 is a notional concept of a user display. The display would be similar in appearance to those utilized by current FAA weather detection systems. A graphical area would depict current locations and intensity of bird flocks as well as individual bird tracks. User-selectable overlays would depict airport runways, navigational aids, and other geographic reference marks. An automatic alerting algorithm could check for intersections of bird detections with runway corridors and generate formatted alert messages that would be displayed and up-linked to pilots. It is envisioned that this would be implemented as a java-based display that could be accessed locally or by remote users via web server. User feedback will be solicited to refine the display concept.

In order to support wildlife monitoring and mitigation activities, a continuously updated database of bird detections and statistics related to these will be generated by TAHAS. Development of this subsystem will once again require feedback from airport operators and bird control staff.

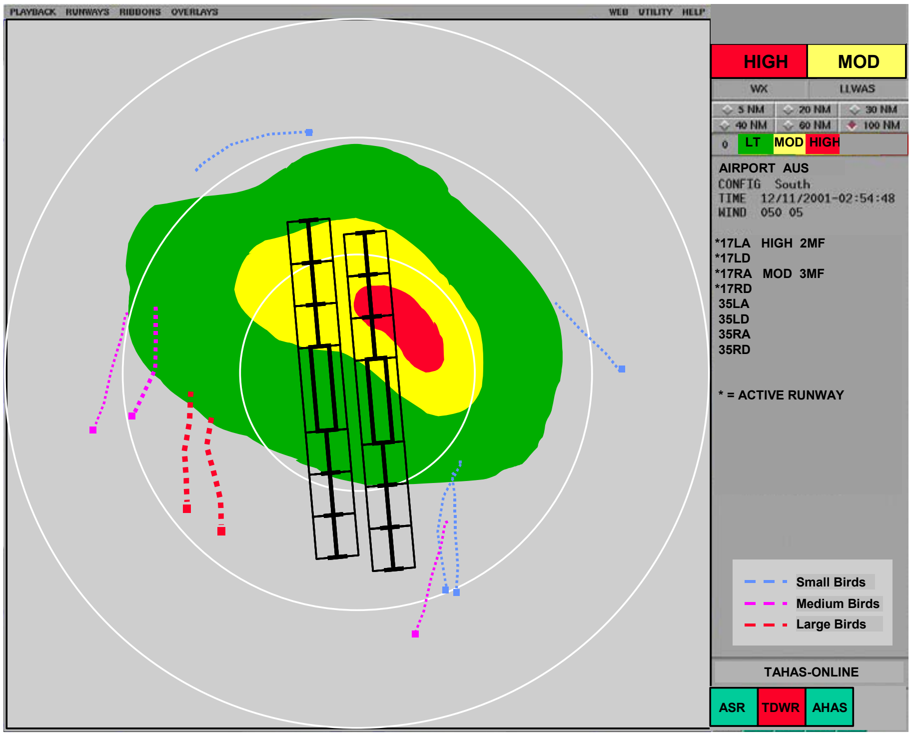

Figure 6. Notional TAHAS user display.

6. Summary

Several important enhancements have recently been made to the TAHAS software that have brought the software to the point where we believe an operational exhibit is feasible. False alarms due to weather in the flock detector output have been substantially reduced through the incorporation of a weather classifier function. This function generates an image of precipitation regions that is used to mask flock detections in those regions. Some false detections from low reflectivity precipitation echoes still occur. Additional tuning of thresholds and algorithm refinement will be performed as additional data are collected and evaluated.

An observability study was conducted at Austin, TX in November 2001 to ascertain the capability of the ASR-9 to detect individual birds in the immediate airport vicinity. The study found that the radar could detect many isolated or small numbers of birds within 10 km of the airport. Following this study, a high-update bird tracking processing thread was developed and added to TAHAS. The tracking algorithm produces updated locations and tracks of birds every 10 seconds. The algorithm is presently being optimized to improve detection of weaker, short-lived bird tracks and to reduce the probability of false tracks from aircraft and road traffic.

A web-based user display and an automatically updated bird activity database still need to be developed. The display will be developed using similar software technology developed at Lincoln Laboratory for FAA weather systems such as the Integrated Terminal Weather System (ITWS), Weather Systems Processor (WSP), and Medium Intensity Airport Weather System (MIAWS). User feedback is essential in developing these if they are to be operationally accepted and useful.

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