

Improved Location/Identification of Aircraft/Ground Vehicles on Airport Movement Areas – Results of FAA Trials

By

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BIOGRAPHIES

Rick Castaldo is FAA's Product Manager for Airport Surface Traffic Automation (ASTA) which encompasses several surface surveillance technologies. Carl Evers and Alex Smith are Systems Engineers at Rannoch Corporation and for the past four years have been conducting research and development for the Volpe Center and FAA to improve surveillance of aircraft and other vehicles on the airport runway surface and surrounding areas. Please direct any inquiries to cevers@rannoch.com.

ABSTRACT

This paper describes the development, implementation, and testing of the Airport Surface Target Identification System (ATIDS), and presents results of initial trials conducted at Atlanta Hartsfield International Airport. The overall goal of the research is to implement cost effective surveillance systems that can reduce the risk of runway incursions. A runway incursion occurs when a vehicle strays onto an active runway, usually caused by human error.

The U.S. National Transportation Safety Board has identified the prevention of runway incursions as a high-priority safety issue. Approximately 200 runway incursions occur each year in the United States and several serious accidents involving loss of life have occurred (Detroit, December 1990; Los Angeles, February 1991, St. Louis 1994). One of the FAA initiatives to address this safety issue is ATIDS. ATIDS provides the location and identification of all aircraft and vehicle traffic on the airport movement area and in selected ramp and gate areas. ATIDS is based on SSR technology and is an enhancement to current airport primary surveillance equipment which is primarily the Airport Surface Detection Equipment-3/Airport Movement Area Safety System (ASDE-3/AMASS).

INTRODUCTION

ATIDS represents a "near term" solution to identifying all vehicles on the airport surface. Whereas future airport surveillance may be based almost exclusively on the concept of Automatic Dependent Surveillance Broadcast (ADS-B), there is a short term need to identify or "tag" aircraft on the runway surface that are detected by ASDE radar. Furthermore, it is desirable (if not essential) to do so without requiring aircraft to equip with additional avionics.

ATIDS is a multilateration system that basically receives SSR transmissions from aircraft and triangulates, or multilaterates from several receiver locations, to pinpoint the location of an SSR transponder. The system is designed to operate with aircraft equipped with Mode A/C and S avionics. ATIDS also receives and processes aircraft ADS-B transmissions (GPS derived) therefore accommodating a mix of equipped aircraft. This paper presents a summary of our evaluations to date, including accuracy, coverage, and update rate test results. In addition we present an overview of the multilateration system and describe the integration of this system into the U.S. National Airspace System. This paper contains only the understanding and views of the authors and is not intended to represent the official position of FAA.

FAA Surface Surveillance Initiatives

The FAA has several initiatives to enhance safety and efficiency of airport surface operations, including:

- Airport Surface Detection Equipment-3 (ASDE-3) - primary radar for locating surface traffic and providing a situational display to tower controllers.
- Airport Movement Area Safety System (AMASS) - safety automation add-on to ASDE-3 which provides runway incursion detection

and alerting capability. AMASS also adds a centroiding and tracking capability to ASDE-3.

- Airport Surface Detection Equipment-X (ASDE-X) - low cost surface surveillance/safety automation capability which provides surface traffic location/identification and runway incursion detection and alerting capability.
- Airport Surface Target Identification System (ATIDS) - surface surveillance add-on to ASDE-3 which provides both location and identification of surface traffic. Uses both multilateration and ADS-B surveillance techniques.

The FAA is currently planning to install surface surveillance systems at the nation's busiest 70 airports. ASDE-3/AMASS and ATIDS will be installed at the top 34 airports and ASDE-X will be installed at the remainder. As a minimum, all 70 airports will receive ASDE primary radar. Primary radar is required at the major airports because of the need to detect non-cooperative (e.g., no avionics equipage required) vehicles on the airport movement area, especially unauthorized vehicles. ADS-B has the potential to provide better surveillance performance at a lower ground element cost than primary radar. However, ADS-B is not a near term alternative to primary radar for surface operations.

With the addition of ATIDS at ASDE-3/AMASS airports, position identification will be provided for cooperative targets currently equipped with either Mode S or Mode A/C transponders. ATIDS also provides surveillance of ADS-B equipped aircraft and ground vehicles. ATIDS provides location and tags for all aircraft on the airport movement area, in selected ramp and gate areas, to the tower for display on ASDE-3/AMASS. Tags obtained from ATIDS are correlated to the ASDE-3/AMASS tracks.

ATIDS Trials

The FAA conducted a market survey and alternatives analysis and selected multilateration as the leading ATIDS candidate based on the requirements shown in Exhibit 1. The feasibility of a COTS based multilateration system was demonstrated at the FAA Technical Center in 1994 by Cardion, Inc. with their Cooperative Area Precision Tracking System (CAPTS). Based on this demonstration, the FAA decided to further evaluate a multilateration system

at a busy operational airport. Lincoln Laboratory provided installation and test support.

| Category | Requirement |
|---|---|
| Aircraft Equipage | No new/added avionics/antenna installations or avionics and airframe modifications. |
| Aircraft Position | Provides positive discrete identification of commercial air carrier & general aviation aircraft which can be correlated to ASDE-3 targets. |
| Airport Equipment Transition to End-State | Installed system shall support transition to ADS-B with no added hardware and only minor software modifications. |
| Development Risk | "LOW" - use of COTS and existing proven technologies. |
| Fielding Time | Time to field fully functional system less than 3 years. |
| Major Airport Operational Suitability | (1) Operate 24 hours a day and under all weather conditions including those that may temporarily preclude flight operations. (2) Capable of operating in airport SSR and TCAS environment. (3) Capable of correctly locating and identifying a minimum of 256 aircraft in movement, ramp and gate areas. (4) Capable of verifying target identification over any 2 - 3 second interval in a major airport environment. |
| Cost/Benefit | An overall ATIDS benefit-to-cost ratio greater than one. |

Exhibit 1. ATIDS Requirements

SYSTEM DESCRIPTION

The ATIDS architecture consists of ATIDS remote stations, modems and an ATIDS server. Mode S short squitter and Mode A multilateration is used to locate and identify aircraft. The system is capable of being implemented in the near term as virtually all aircraft that operate at major airports are equipped with either Mode S or Mode A/C transponders. The Mode S short squitter multilateration element uses ATIDS remote

stations to time stamp and decode Mode S aircraft identification. These squitters are pseudo-randomly transmitted by aircraft transponders once per second. The time stamped and decoded squitters are transmitted via radio modems to the ATIDS server for position processing. Using multilateration, aircraft position is determined each time squitters are received from three or more remote stations.

Mode A/C multilateration works on the same principle as Mode S multilateration with the exception that it requires the Mode A/C transponder to be interrogated to elicit a reply. The transponder responds to ATIDS remote station "whisper-shout" interrogations which permits a separation of responses in time for equi-range transponders. The transponder reply contains the beacon 4096 code information for identification of the aircraft.

ATIDS has the capability to receive and process ADS-B transmissions via the DGPS Mode S long squitter data link. The system can simultaneously support both Mode S short squitter/Mode A/C multilateration and ADS-B. Additionally, ATIDS will multilaterate on ADS-B transmissions, thus providing a back-up. An overview of the Atlanta R&D ATIDS process is shown in Exhibit 2.

ATLANTA TEST SITE

Atlanta is the fourth largest airport in the United States, handling over 20 million passengers annually [1]. The airport has 4 main parallel runways as

shown in Exhibit 3. Both of the outer runways can be used for independent parallel approaches during IFR with the inner runways typically being used for departures. There are several high speed taxiways that are used for arrivals. In VFR, all four runways can be used for departures or arrivals. There are six main concourses used for commercial traffic located at the center of the airport.

Atlanta typically has approximately 50 aircraft on the movement area during peak hours of operation. This level of traffic, coupled with the number of runways and crossing traffic, makes Atlanta an ideal candidate for ATIDS to provide positive aircraft identification. Most of the traffic at Atlanta is larger commercial aircraft, and we estimate from our data analysis that 90% of the aircraft are equipped with Mode S. The airport is equipped with an ASDE-3 radar, allowing for the evaluation of target registration and ASDE-3/ATIDS tagging correlation.

The airport has the usual variety of structures close to the runways (concourses, hotels, hangers, etc.) which can be used for placement of receiver/transmitters (R/Ts). Exhibit 3 shows the locations selected for the north side of the airport. R/T sites were selected to optimize coverage of airport movement areas, preferably as high as possible to minimize blockage. Also, R/T sites were selected to give good geometry solutions, analogous to GPS Dilution of Precision (DOP).

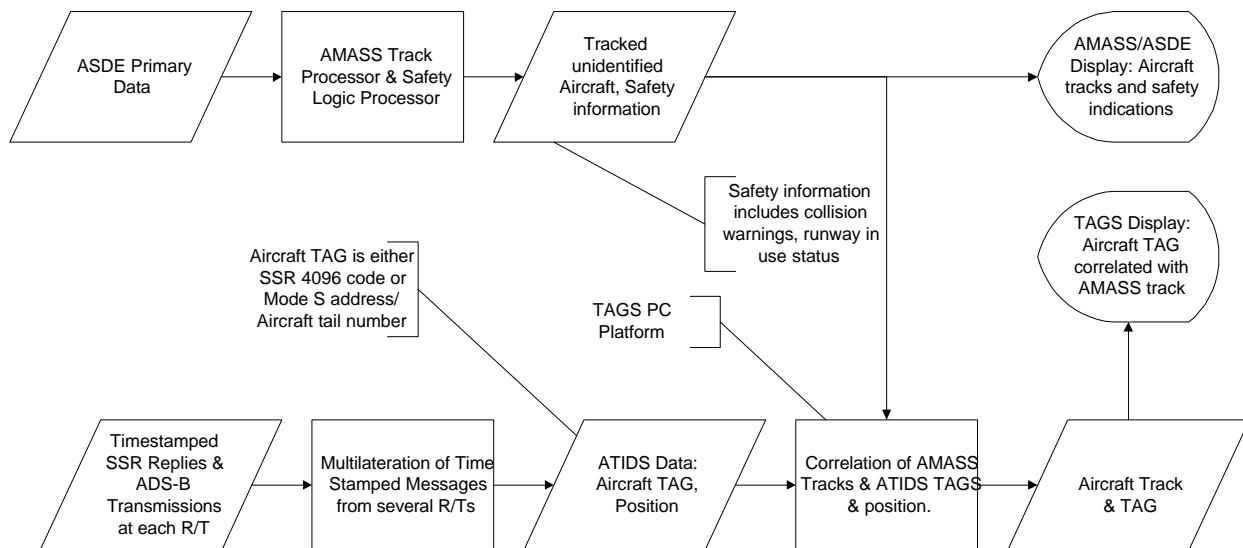


Exhibit 2. Overview of Atlanta R&D ATIDS Process

RESULTS

In this section of the paper we discuss the system coverage, accuracy, multipath performance, and ability to correlate targets from different sensors.

Coverage

The GPS/Mode S long squitter is a valuable tool for assessing coverage as it has a high effective update rate (twice per second). An ADS-B equipped ground vehicle was driven at a constant speed on the runways and taxiways on the north side of the airport. The testing was conducted late at night to minimize effects of interference and to minimize disruption to airport operations. ADS-B reception performance was assessed for each R/T and is summarized in Exhibit 4. Scatter charts showing position detections on an airport map were plotted and used to identify locations where each R/T had potential coverage gaps.

Coverage on the west side of the airport is excellent. However, potential coverage gaps on the east side in front of the Delta hangers were identified. Further testing focusing on the east side was performed to assess the impact of potential coverage gaps on multilateration performance. Mode S multilateration data (Exhibit 5) was collected with a slow moving test

vehicle. The R/Ts at the Stouffers and Ford plant sites had low squitter detection performance for test vehicle locations in front of the Delta hanger. Low priority triads with greater HDOP were used by CAPTS in computing position solutions. This region included a 2500 ft section of the taxiway E and a 1000 ft section of runway 26L. Position updates were still available in these two regions, however at a lower update rate and lower accuracy. The cause of the poor R/T reception performance was identified during multipath testing as discussed later.

Mode S multilateration position data was collected on over 50 aircraft targets of opportunity to assess system update rate. CAPTS averaged an update rate of 1.4 seconds between tracker accepted updates for each aircraft on the movement area. The CAPTS system was configured to use squitters (Downlink Format-11) solely for updating position. Further gains in update rates are available with the CAPTS by using replies (Downlink Format-0) to TCAS interrogations.

The placement of R/Ts was optimized for coverage on the airport movement area. The layout of the concourses perpendicular to the movement area presented line of sight siting problems. Coverage in all or selected ramp areas could be provided with the installation of additional R/Ts.

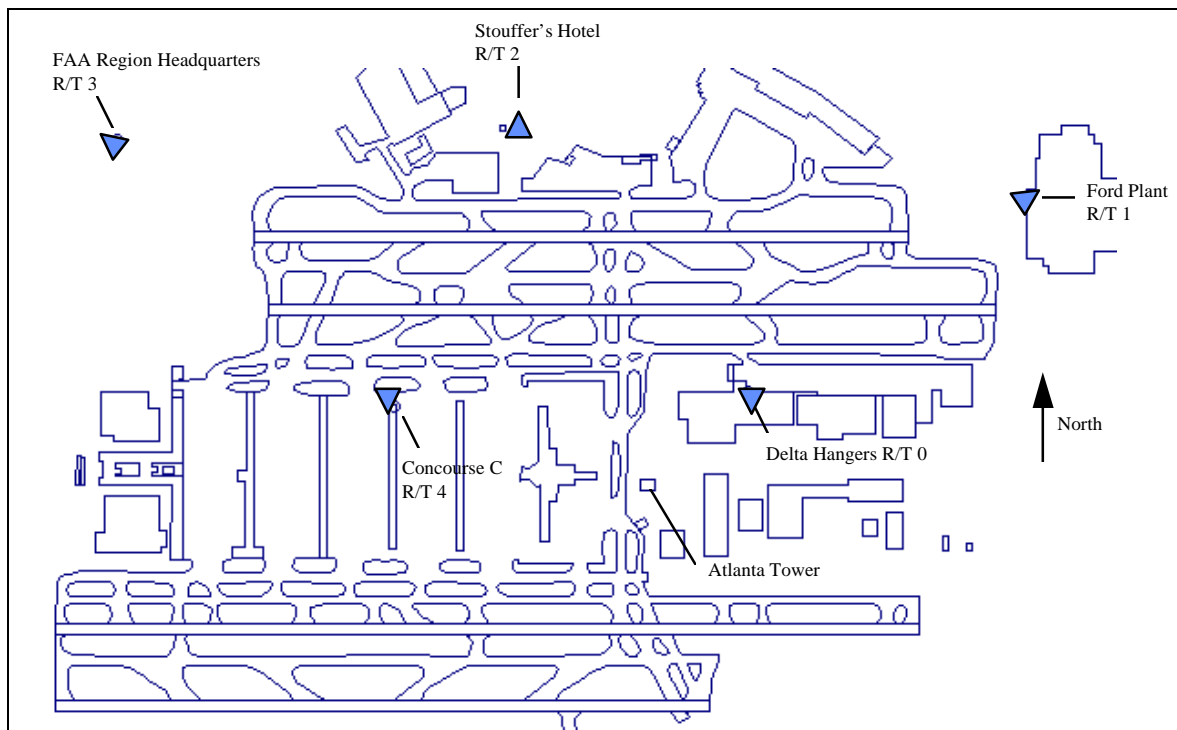


Exhibit 3. Atlanta Layout and R/T Positions

Flight crews normally switch their transponders off when they exit the runway per the guidance in the Airman's Information Manual [2]. However, there were several instances where aircraft transponders were left on until arrival at the gate, which allowed us to evaluate coverage into the ramp areas. Aircraft entering the ramp areas on either east or west side of the Concourse C R/T were tracked up to 300 ft into the ramp areas from the Concourse C north end. Blockage from the concourses prevented tracking deeper into the ramp area.

| R/T | % Reply Reception |
|--------------------------|-------------------|
| Delta Hanger R/T | 75.5 |
| Ford Plant R/T | 76.2 |
| Stouffers R/T | 75.1 |
| Region Headquarters R/T | 80.5 |
| Concourse C R/T | 83.3 |
| 3 or more R/Ts out of 5* | 91.9 |

* required to compute a multilateration solution

Exhibit 4. Receiver/Transmitter Coverage

ADS-B Operation

A critical requirement for ATIDS is to provide surveillance in an environment where some users are ADS-B equipped and others are transponder equipped. ADS-B testing was performed to demonstrate:

- Operation in a mixed ADS-B/transponder environment.
- Capability to receive & process ADS-B transmissions.
- Multilateration on ADS-B transmissions to enhance continuity of function and integrity.

A ground vehicle equipped with Collins prototype ADS-B avionics was driven on the movement area. At the same time, aircraft targets with their transponders "on" were also operating on the movement area. ATIDS received both the ADS-B long squitters and the aircraft transponder short squitters. ADS-B long squitters transmissions were decoded to determine position. Short squitters were multilateration processed to compute position. ATIDS displayed both positions of the ADS-B equipped vehicle and the multilaterated positions of aircraft.

Testing demonstrated ATIDS capability to prioritize position reports based on the accuracy of the source. The highest priority position reports available are used for correlation with ASDE-3/AMASS. The system allocates report priority in the following order:

- DGPS/Mode S long squitter.
- Mode A/C or Mode S multilateration.
- GPS/Mode S long squitter.

Testing demonstrated that ATIDS can determine ADS-B target position by multilateration. Such a capability provides for enhanced surveillance continuity of function for ADS-B equipped vehicles, and is essentially a back up in the event of a loss of differential corrections, satellite failure, GPS signal blockage, or failure of DGPS avionics. ATIDS correlated ADS-B position to multilaterated position via matching time of arrival and Mode S address of any two position reports for a given target. Correlated positions were compared to validate ADS-B position reports, thus providing an ADS-B system (i.e., satellites, ground equipment and avionics) monitoring capability for surface operations.

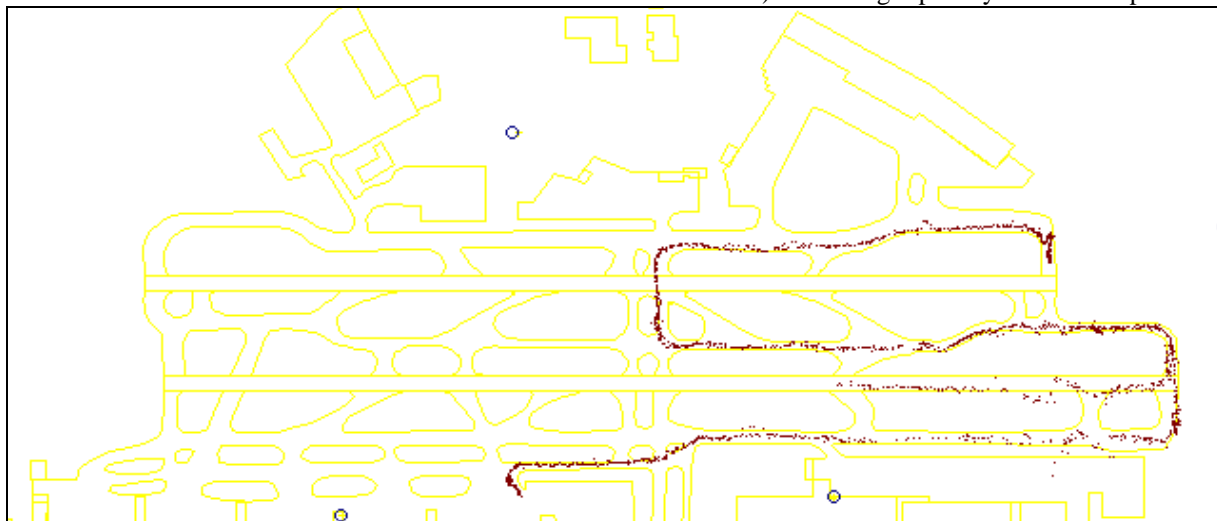


Exhibit 5. Multilateration Coverage

During the multilateration/ADS-B testing, a loss of differential corrections occurred and was detectable by monitoring multilateration and ADS-B position data.

Accuracy Performance

Accuracy results are summarized in Exhibit 6. For reliable and accurate tagging correlation the tagging system must have a position accuracy which is the same order as ASDE-3/AMASS accuracy. While testing with a high accuracy reference was not performed during the Atlanta trials, Mode S multilateration position data was collected during ADS-B testing. The test vehicle avionics were configured in the airborne mode (i.e., data link format supporting 3 meter resolution). Radial distances between DGPS position and multilaterated raw position were computed for each ADS-B report. Results from these tests and FAA Technical Center testing show similar accuracies for ASDE-3/AMASS and multilateration. The effective multilateration accuracy is expected to be less than 30ft when a tracking filter and a more accurate reference source are used.

Multipath Performance

The test vehicle was driven slowly on the airport movement area to locate areas where R/Ts could not reliably detect vehicle transponder squitters. The area in front of the Delta hangers was identified as a multipath problem for both R/Ts 1 and 2 (see Exhibit 3). Multipath was verified as a problem source by placing radar absorbent material in the suspected path of the interfering signal and showing improved direct path squitter detection at the R/Ts. An important finding of this testing is that, unlike primary radar, multipath does not cause false targets for ATIDS. A time delayed reflected signal has a low probability of overlapping with the direct path signal's preamble P1 pulse, which is used for Time Of Arrival determination.

Cardion's system demonstrated the capability to multilaterate accurately even with one R/T detecting squitters with 25% of the data bits corrupted and two R/Ts detecting high confidence squitters. However,

multipath did impact the system's ability to use highest priority (e.g., low HDOP) triads, thus at times reducing the position accuracy of targets in the multipath problem areas. For some airports, multipath problem areas may necessitate installation of additional R/Ts.

Correlation Performance

At ASDE-3/AMASS airports, the radar will serve as the primary source for surveillance and ATIDS will provide target position/IDs which are correlated to the ASDE-3/AMASS tracks for tagging. The tag must be attached to an ASDE-3/AMASS displayed arrival or departure within seconds after the aircraft enters the movement area. Once the tag is assigned to an ASDE-3/AMASS track the tag will be maintained until either the aircraft leaves the movement area or ASDE-3/AMASS drops the track.

Tag correlation algorithms were developed to provide a low probability of false correlation and a rapid acquisition of new targets. Preliminary results indicated that 92% of the ASDE-3/AMASS updates were successfully correlated to correct multilateration updates. Targets were correlated at a rate of 1.5 per second. A correlation rate of greater than the update rates of either system occurs because an ASDE-3/AMASS update can be correlated reliably to any multilateration update occurring within +/- 1 second. There can be up to three multilateration updates within a the time window. Correlation is accomplished by projecting multilateration position correction based on time/velocity/heading and comparing delta position, velocity and heading between multilateration and radar data. The key parameters target reports processed for correlation were evaluated and are shown in Exhibit 7. The results given in Exhibit 7 are for raw (untracked) data for the high speed (runway) portion of the approaches and departures. The difference in position is consistent with the measured accuracies, and the velocity difference for this data is of the order of 10%. These differences in position, velocity and heading contribute to high confidence in the tag correlation.

| System | Location [ref] | Measured Accuracy | Test Type | Reference/Accuracy |
|------------------------|--------------------|-------------------------------|-----------------------------------|------------------------------|
| ASDE-3/AMASS | FAA Tech Center[3] | 28 ft. (Mean) | Moving target/track position data | DGPS <1 ft. (Post processed) |
| Mode S Multilateration | Atlanta | 31 ft. (Mean) 60 ft. (95%) | Moving target/raw position data | DGPS ≈ 10 ft. (Air Mode) |
| Mode S Multilateration | FAA Tech Center[4] | 23 ft. (Mean) 42 ft. (90%) | Fixed target/raw position data | Laser Tracker ≈ 1 ft. |

Exhibit 6. System Accuracy

Preliminary evaluations have been performed on tag correlation. Surveillance data was collected simultaneously from both ASDE-3/AMASS and CAPTS. Exhibit 8 shows the ATIDS raw position and AMASS tracks for the same aircraft arriving on runway 8R, and taxiing to the main concourse area. ATIDS positions are identified as circles and are tagged. AMASS tracks are identified by dots and are not tagged. Based on the current operational procedures, the aircraft's transponder was turned off soon after exiting the runway. ASDE-3/AMASS maintained the aircraft's track up to the taxiway then dropped the track. A new track was started 5 seconds after the drop and maintained until the aircraft exited the movement area (not shown on the Exhibit).

In the event of a dropped track, the tag has to be reacquired. Dropped tracks are the result of multipath or blockage and can occur anywhere on the movement area. Therefore, it is essential that ATIDS provide full coverage of the movement area for continuous tag correlation. Air crews would be required to have their transponders on during operations on the movement area for both multilateration and ADS-B.

| Parameter | Measured Error (Average) |
|-----------|--------------------------|
| Position | 30.1 ft |
| Velocity | 14.6 ft/sec |
| Heading | 7.8° |

Exhibit 7. Parameter Difference Between ASDE-3/AMASS and ATIDS

FUTURE WORK

To date our testing has focused on evaluation of overall system feasibility. Further testing will concentrate on:

- Real-time integration of ATIDS and ASDE-3/AMASS.
- Performance evaluation of low-cost ASDE-X integrated with ATIDS.
- The impact of transponder loading on system performance.
- Evaluation of multilateration for precision runway monitoring at Atlanta in 1996.
- Feasibility testing at other major airports including DFW in 1996.

CONCLUSIONS

Results from the Atlanta test site have been very encouraging. After initial testing for the optimum R/T placement, we believe that a very cost effective system could be implemented at similar sites, offering the ground controller positive identification of all SSR equipped traffic. Furthermore, in conjunction with the FAA's efforts to evaluate and install low-cost ASDE-X marine radar at several sites, ATIDS would provide a full surveillance capability to airports where controllers currently rely on sight and pilot position reports.



Exhibit 8. ATIDS/AMASS Tracks

ATIDS will also help bridge the gap toward achieving full automatic dependent surveillance. ATIDS using either multilateration or ADS-B has demonstrated sufficient accuracy, coverage and update rate to provide good tag correlation with ASDE-3/AMASS. This type of system will allow full positive surveillance of the inevitable mix of traffic equipage we will experience at major airports over the next 10 to 20 years.

ACKNOWLEDGMENTS

Success of the ATIDS trials at Atlanta is due to a team effort that includes the Volpe Center, FAA Technical Center, The Analytic Sciences Corporation (TASC), Lincoln Laboratory, Cardion Inc., Collins, Jeppesen, and the Atlanta FAA Air Traffic and Airway Facilities divisions.

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