NASA/CR-1999-209110

NASA Low Visibility Landing and Surface Operations (LVLASO) Atlanta Demonstration: Surveillance Systems Performance Analysis

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Prepared for Langley Research Center
under Contract NAS1-19214

June 1999

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ABSTRACT

NASA conducted a series of flight experiments at Hartsfield Atlanta International Airport as part of the Low Visibility Landing And Surface Operations (LVLASO) program. LVLASO is one of the sub-elements of the NASA Terminal Area Productivity (TAP) program, which is focused on providing technology and operating procedures for achieving clear-weather airport capacity in instrument-weather conditions, while also improving safety. LVLASO is investigating various technologies to be applied to airport surface operations, including advanced flight deck displays and surveillance systems. The purpose of this report is to document the performance of the surveillance systems tested as part of the LVLASO flight experiment. There were three surveillance sensors tested: primary radar using Airport Surface Detection Equipment (ASDE-3) and the Airport Movement Area Safety System (AMASS), Multilateration using the Airport Surface Target Identification System (ATIDS), and Automatic Dependent Surveillance - Broadcast (ADS-B) operating at 1090 MHz. The performance was compared to the draft requirements of the ICAO Advanced Surface Movement Guidance and Control System (A-SMGCS). Performance parameters evaluated included coverage, position accuracy and update rate. Each of the sensors was evaluated as a standalone surveillance system.

TABLE OF CONTENTS

FIGURES AND TABLES

ACKNOWLEGEMENTS

The authors gratefully acknowledge the contributions of the NASA Low Visibility Landing and Surface Operations team, including Steve Young and Denise Jones, for their guidance and contributions to the research presented in this report. We would also like to thank Vincent Capezzuto of the FAA for his assistance with the ATIDS and ASDE-3/AMASS systems in Atlanta.

1.0 INTRODUCTION

NASA completed a series of flight experiments at Hartsfield Atlanta International Airport as part of the Low Visibility Landing and Surface Operations (LVLASO) program. LVLASO is one of the sub-elements of the NASA Terminal Area Productivity (TAP) program, which is focused on providing technology and operating procedures for achieving clear-weather capacity in instrument-weather conditions at airports while also improving safety [1]. LVLASO is investigating technology to be applied to airport surface operations including landing, roll-out, turnoff, inbound taxi, outbound taxi, and takeoff. Technologies under investigation are advanced flight deck displays and surveillance systems.

The flight deck displays that were tested provided the flight crew with enhanced guidance and situational awareness information through the use of a head-up display (HUD) and a head-down electronic airport map liquid-crystal display (LCD). These displays were integrated with onboard sensors and datalinks as well as ground subsystems that provided relevant surface data. These displays are designed to function in one of two modes: (1) during high-speed roll-out and runway exit, the Roll-Out Turn-Off (ROTO) display symbologies were engaged; and (2) during taxi, the Taxi Navigation and Situational Awareness (T-NASA) displays were engaged.

There were three types of surveillance sensors tested: primary radar using ASDE-3/AMASS, Multilateration using ATIDS, and ADS-B. The purpose of this report is to document the performance of the surveillance systems tested as part of the LVLASO flight experiment. The performance is compared to the draft requirements of the ICAO Advanced Surface Movement Guidance and Control System (A-SMGCS). Each of the sensors was evaluated as a standalone surveillance system.

2.0 SYSTEMS DESCRIPTION

2.1 Surveillance System Architecture

The LVLASO ground architecture, illustrated in Figure 1, includes the following elements:

1. Airport Surface Detection Equipment (ASDE-3) radar - Provides surveillance (position only) of aircraft or vehicles operating on the runway/taxiway area
2. Airport Surface Target Identification System (ATIDS) - Provides surveillance (position and ID) of aircraft and ground vehicles equipped with 1090 MHz ADS-B, Mode-S transponders, and Mode A/C transponders
3. Airport Movement Area Safety System (AMASS) - Provides the following:
    - a) Tracking of ASDE-3 targets
    - b) Data fusion of ATIDS target data with ASDE-3 track data to enhance situational awareness for Air Traffic Control (ATC) and flight crews with Cockpit Display of Traffic Information (CDTI)
    - c) Safety logic to detect runway incursions and other conflicts

4. Differential Global Positioning Systems (DGPS) ground station- Provides differential corrections for navigation and surveillance
5. Digital data link system - Provides the following:
    a) Digital transmission of CDTI data to T-NASA equipped aircraft
    b) Differential corrections transmission to GPS equipped aircraft
    c) Digital transmission of ATC instructions and flight crew acknowledgments
6. ARTS - Provides ASR-9 radar position/ID of airborne aircraft near the airport.

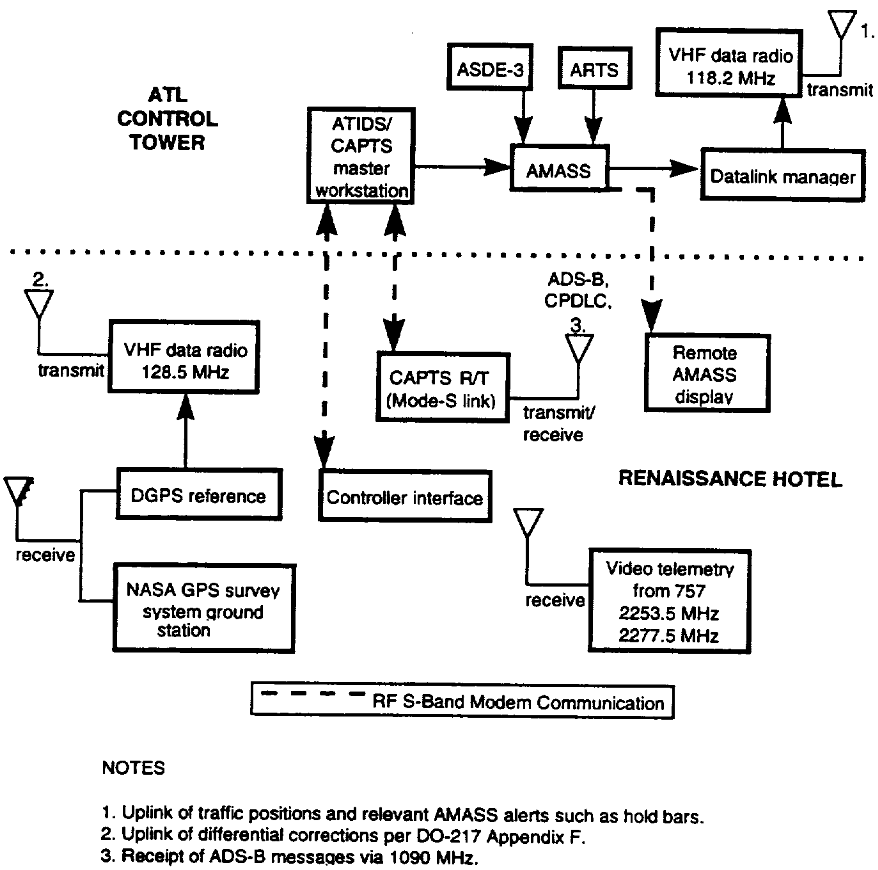

Figure 1. LVLASO Surveillance System Architecture

The LVLASO architecture contains three surveillance sensors, ADS-B, ASDE-3, and ATIDS. The flow of surveillance data is shown in Figure 1. The ASDE-3 provides primary radar information to the AMASS system. The AMASS digitizes and tracks the radar returns. ATIDS sends aircraft position information derived either from multilateration or from ADS-B position reports with aircraft tail number to AMASS. ARTS supplies the flight information, such as aircraft type and flight information, by matching the aircraft 3A identity code. The surveillance data from all three sensors is fused by AMASS. This traffic information is displayed for ATC (at the controller interface) and broadcast by VHF data link to the NASA 757 for display on the cockpit CDTI.

2.2 Multilateration

Multilateration and target identification was accomplished with an ATIDS system developed by Cardion, Inc. called Cooperative Area Precision Tracking System (CAPTS). ATIDS is based on SSR technology and is an enhancement to current airport primary surveillance equipment, which at ATL is ASDE-3/AMASS. ATIDS augments the ASDE-3/AMASS surveillance with aircraft identification and surveillance to fill in coverage gaps of the ASDE-3 radar. ATIDS is a multilateration system that 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 Mode S avionics.

The ATIDS architecture consists of ATIDS remote receiver/transmitters (RTs), modems and an ATIDS master work station (MWS). Mode S short squitter and Mode A/C multilateration are used to locate and identify aircraft. 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 nominally 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 RTs. As installed at Atlanta, the ATIDS system uses 5 RTs, shown in Figure 2. The system is configured to provide coverage only on the north side of the airport.

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.

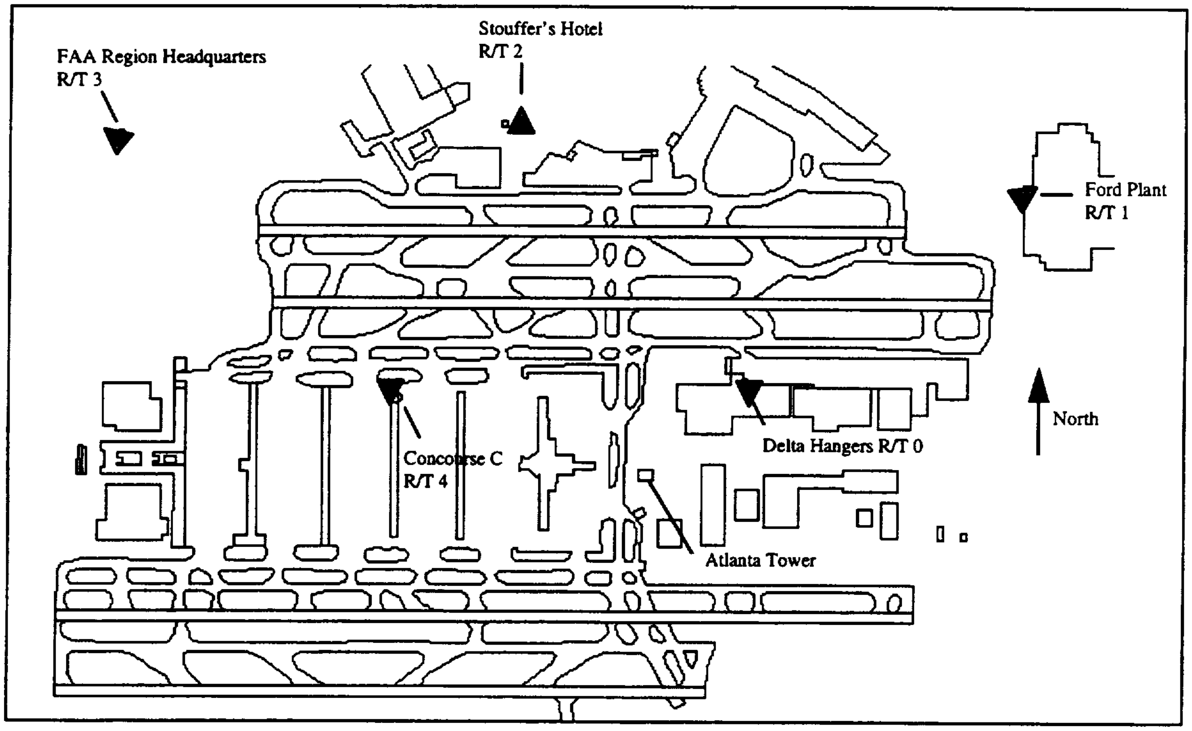

Figure 2. Configuration of ATIDS RTs

2.3 Automatic Dependent Surveillance Broadcast (ADS-B)

ADS-B is a function on an aircraft that periodically broadcasts the aircraft state vector (position and velocity) [4]. Air traffic control can receive the state vector reports to accurately display traffic identity and position. Other aircraft can receive the information for use in collision avoidance and CDTI applications.

ADS-B, as implemented in the Atlanta tests, consisted of a Collins GPS receiver and Mode S extended squitter transponder. Differential corrections were broadcast from a local area differential system and received by the NASA 757. Aircraft position was calculated once per second and the most recently computed position was transmitted nominally twice per second. Two different ADS-B messages were transmitted, depending on whether the aircraft was airborne or on the airport surface. The airborne ADS-B message includes type code (information on airborne or surface message and precision category of the data), surveillance status, turn indicator (turning or not turning), altitude (either barometric or GNSS derived), and encoded latitude and longitude (17 bits). The surface ADS-B message includes type code (same as airborne), ground speed, track angle and encoded latitude and longitude. ADS-B transmissions alternate between the top and bottom mount antennas when airborne. ADS-B transmissions are only radiated from the top mount antenna when the aircraft is on the ground.

2.4 ASDE-3/AMASS

The ASDE-3 is a Ku band primary radar used for airport movement area surveillance. It is intended to provide controllers with enhanced visibility of airport surface traffic in low visibility conditions, thereby increasing safety and reducing runway incursions. It uses an antenna rotating once per second, resulting in a target update at the same rate. The ASDE-3 provides surveillance of aircraft and vehicles operating on runways and taxiways that are in direct line of site to the radar. Non-movement areas such as grass and ramp areas are intentionally filtered out. The ASDE-3 installed at ATL is a production unit installed on top of the air traffic control tower.

The Airport Movement Area Safety System (AMASS) is a prototype add-on to the ASDE-3 radar designed to improve the ability of the radar to detect and prevent runway incursions. AMASS takes radar return inputs from the ASDE-3 and digitizes it and determines the centroid and extent information of airport surface targets. Using this digitized data, the AMASS can track aircraft and vehicles on the airport surface and provide automatic cautions or warnings of conflicts and runway incursions.

2.5 Fusion of Surveillance Data

In addition to ASDE-3, AMASS can accept inputs from other surveillance sensors and fuse the data to provide controllers with one surveillance picture. At ATL, AMASS fused data from the following sources:

- ARTS arrival database information
- ASDE-3/AMASS target track information
- ATIDS 1090 MHz ADS-B target information, and
- ATIDS 1090 MHz multilateration target information

The resulting fused surveillance data was output to a controller interface and to a datalink manager to be transmitted to the NASA 757. No analyis was conducted for this report on the performance of the surveillance fusion process.

3.0 METHODOLOGY

3.1 Test Conditions

A complete description of the tests can be found in the NASA test plan [2]. Following is a brief description of the operations, with emphasis on the test conditions relative to surveillance.

3.1.1 NASA 757 Tests

The LVLASO flight test operations began in the ramp area just north of runway 8L/26R at ATL at the fixed-base operator (FBO), Mercury Air Center. At the beginning of each test, the responsible flight deck crewmember called for taxi instructions from ATL ATC. On receipt of the instruction, the captain taxied the test aircraft to the designated runway. The test aircraft either conducted a cycle (takeoff/circle/land) or taxied down the runway, depending on the experiment. Finally, after roll-out and turn-off from the runway, the test aircraft taxied back to the FBO ramp area thus emulating a "gate-to-gate" operation. A typical takeoff/circle/land test is shown in Figure 3, which shows the ADS-B position reports plotted on the north movement area.

In this case, the NASA 757 taxied from the FBO (north center of figure), taxied via Alpha, Dixie, and Echo to runway 26L. It took off from runway 26L, circled the around the airport, landed on runway 26R, exited on B5, and taxied back to the FBO via Bravo, Charley, and Alpha. See Appendix F for a diagram of the airport runways and taxiways.

The runs were repeated with the following variables, as listed in Table 1:

- Near peak or non-peak traffic conditions
- Time of Day (TOD): Day (D) or Night (N)
- HUD: Yes (Y) or No (N)
- Map LCD: Yes (Y) or No (N)
- Pilot, co-pilot assignments
- Land: Takeoff (Y) or Taxi only (N) run
- Exit: Name of exit taken off runway
- Operation: North (N) or South (S) side operation

Tests were performed both during the day and at night. A majority of the tests were performed at night to approximate low visibility conditions. Aircraft state data and datalink data were electronically recorded for post-processing. Surveillance system output files were recorded for each test.

3.1.2 Vehicle to Vehicle Tests

ADS-B coverage tests were conducted for vehicle to vehicle surveillance, whereby the 1090 MHz ADS-B reception performance of a vehicle on the surface was evaluated. This application is a potential extension of the airborne application using direct aircraft to aircraft ADS-B transmissions to obtain traffic information. The alternative approach, which was also tested, is for vehicle to obtain traffic information from a TIS (Traffic Information Service) data link. In either implementation, the goal is to improve pilot situational awareness by a visual display of traffic information in the cockpit.

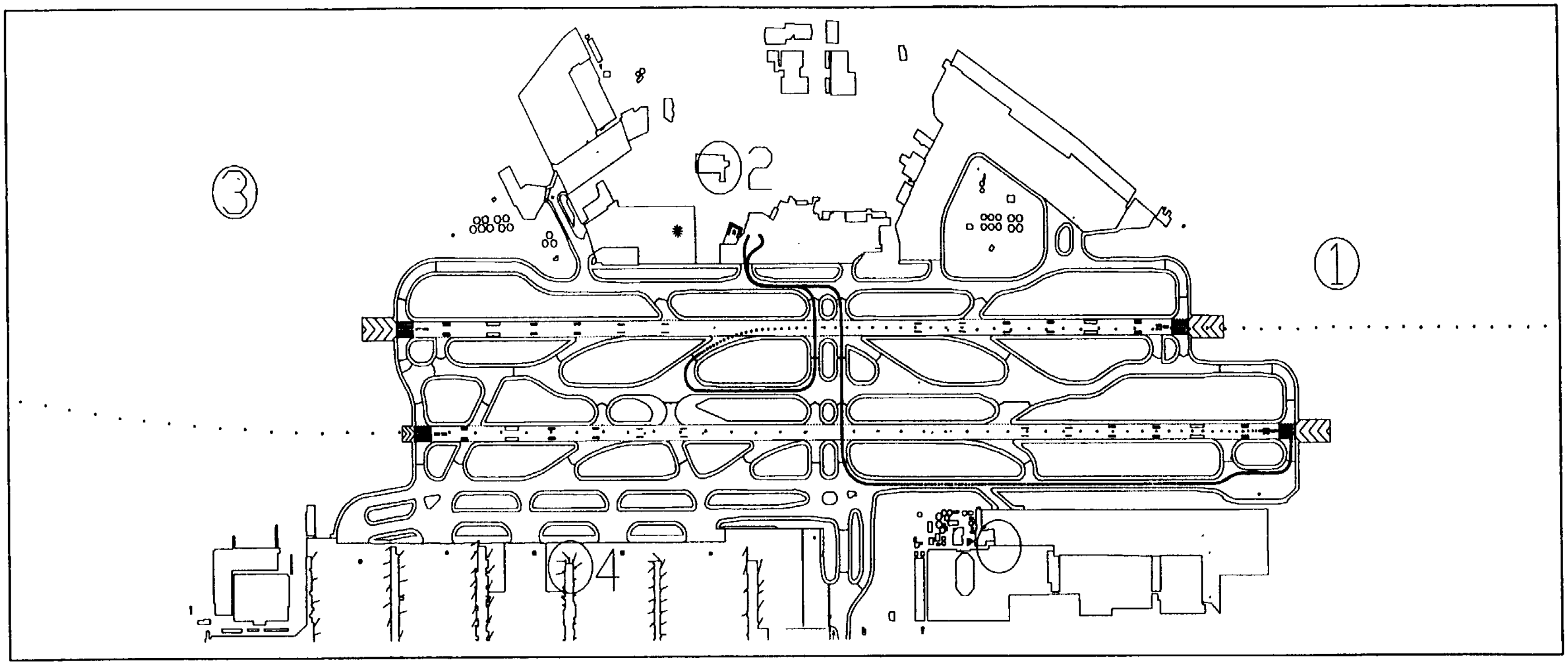

Figure 3. Typical NASA 757 Takeoff and Landing Test Operation (Test 7)

To test the feasibility of this function on the airport surface, several vehicle to vehicle scenarios were tested. A van was equipped with an ADS-B receiver and antenna mast with an adjustable height (2.5 - 15 meters). An ATIDS RT provided the ADS-B reception/decoding. An aircraft transponder antenna and a ground plane were used in conjunction with the ADS-B receiver. The van was used to simulate a GA or small commuter aircraft with a low antenna height (2.5 meters) and an air carrier aircraft by raising the antenna to 6 meters. The van and the NASA 757 could then experiment with various scenarios where one aircraft would be required to receive the ADS-B transmissions of the other.

The first scenario involves an aircraft at a runway/taxiway intersection waiting to cross while an aircraft is on final approach to that runway. The second scenario is similar, involving an aircraft holding short of a runway while another aircraft takes off on that runway. The holding aircraft must be able to see the aircraft on the active runway on the cockpit display. To test these scenarios, the van was parked while the NASA 757 landed or departed on one of the north side runways. The ADS-B reports transmitted by the 757 were recorded at the van and later analyzed for coverage gaps.

The third scenario involves one aircraft following another. For taxi operations in low visibility, a following aircraft must be able to receive the ADS-B position reports of the aircraft in front of it. To test this, the van followed the NASA 757 while it taxied on the movement area. The ADS-B reports transmitted by the 757 were recorded at the van and later analyzed for coverage gaps.

3.1.3 Van Tests

To further analyze the coverage of the surveillance systems, a van equipped with a 1090 MHz ADS-B pallet was driven on the airport surface. The van was driven in the ramp areas to determine the performance of ADS-B in blocked and high multipath regions. The van was driven through the entire length of each ramp area. The van was also driven on the taxiways at a constant velocity to obtain more coverage data. For all van tests, the surveillance output files were recorded for later analysis.

3.2 Data Collection

3.2.1 NASA 757 and Van Tests

Multilateration and 1090 MHz ADS-B data were logged at the ATIDS Master Work Station for the B-757 runs. The runs included departures, arrivals, north side movement area taxiing and south side movement area taxiing. The surveillance performance assessment was performed for the region where ATIDS was optimized to provide coverage. Extracts from the log files of several runs were used to create a master file for the north side movement area. The master file includes unprocessed 1090 MHz message data and position processed data. Multilateration coverage, ADS-B coverage, and ADS-B update rate were evaluated using the B-757 master file.

Table 1. Experiment Variable Matrix (NASA 757)

#	Date	Start	Stop	TOD	HUD	LCD	Captain	Land	Exit	Oper
T1	8/20	00:08	00:50	D	Y	Y	HVASTA	Y	B3 (26R)	N
T2	8/21	02:36	03:09	N	Y	Y	PENNY	Y	B3 (26R)	N
T3	8/22	00:18	00:48	D	Y	Y	PRAH	Y	B3 (26R)	N
T4	8/23	00:06	00:39	D	Y	Y	SMITH	Y	B3 (26R)	N
4	8/20	02:37	02:58	N	N	N	HVASTA	N	M4 (27R)	S
5	8/20	03:53	04:17	N	N	Y	HVASTA	N	P (27L)	S
6	8/20	01:04	01:20	N	Y	Y	HVASTA	N	E3 (26L)	N
7	8/20	03:12	03:42	N	Y	Y	HVASTA	Y	B5 (26R)	N
8	8/20	04:28	04:52	N	Y	Y	HVASTA	Y	B5 (26R)	N
9	8/21	00:36	01:11	N	Y	Y	HVASTA	Y	A4 (26R)	N
13	8/21	01:28	02:23	N	N	N	PENNY	N	N4 (27L)	S
14	8/21	03:26	03:50	N	N	Y	PENNY	N	N4 (27L)	S
15	8/21	04:43	04:59	N	Y	Y	PENNY	N	E3 (26L)	N
16	8/21	04:03	04:32	N	Y	Y	PENNY	Y	B5 (26R)	N
17	8/22	03:18	03:47	N	Y	Y	PENNY	Y	B3 (26R)	N
18	8/22	03:58	04:20	N	Y	Y	PENNY	Y	A4 (26R)	N
22	8/22	02:39	03:01	N	N	N	PRAH	N	T (27R)	S
23	8/22	04:28	04:52	N	N	Y	PRAH	N	P (27R)	S
24	8/22	01:08	01:33	N	Y	Y	PRAH	N	E3 (26L)	N
25	8/23	02:34	03:00	N	Y	Y	PRAH	Y	B5 (26R)	N
26	8/23	03:08	03:36	N	Y	Y	PRAH	Y	B5 (26R)	N
27	8/23	03:45	04:06	N	Y	Y	PRAH	Y	A4 (26R)	N
31	8/24	02:19	02:34	N	N	N	SMITH	N	M18 (9L)	S
32	8/23	04:14	04:32	N	N	Y	SMITH	N	T (27R)	S
33	8/23	00:47	01:01	N	Y	Y	SMITH	N	E3 (26L)	N
34	8/24	00:47	01:09	N	Y	Y	SMITH	Y	B11 (8L)	N
35	8/24	02:42	03:10	N	Y	Y	SMITH	Y	B11 (8L)	N
36	8/23	23:13	23:39	N	Y	Y	SMITH	Y	A6 (8L)	N
38	8/7	19:31	20:00	D	N	Y	VERST	N	E11 (8R)	N
40n	8/7	00:16	00:37	N	N	Y	VERST	N	B11 (8L)	N
40s	8/7	00:48	01:20	N	N	Y	VERST	N	M (9L)	S
41	8/7	03:00	03:13	N	Y	Y	VERST	N	B7 (8L)	N
42	8/7	03:31	04:00	N	Y	N	VERST	Y	B11 (8L)	N
43	8/7	04:45	05:09	N	Y	N	VERST	Y	B7 (8L)	N
44	8/7	04:10	04:35	N	Y	N	VERST	Y	A6 (8L)	N
45	8/2	21:00	21:25	D	Y	Y	VERST	Y	B11 (8L)	N
46	8/7	18:45	19:21	D	Y	Y	VERST	Y	B11 (8L)	N
49	8/5	23:12	23:29	D	N	Y	BROWN	N	E3 (26L)	N
51	8/5	01:01	01:18	N	N	Y	BROWN	Y	B3 (26R)	N
52	8/7	02:35	02:49	N	Y	Y	BROWN	N	E11 (8R)	N
53	8/5	02:59	03:24	N	Y	N	BROWN	Y	B5 (26R)	N
54	8/5	03:42	04:05	N	Y	N	BROWN	Y	B3 (26R)	N
55	8/5	04:15	04:34	N	Y	N	BROWN	Y	A4 (26R)	N
56	8/5	22:27	23:00	D	Y	Y	BROWN	Y	B3 (26R)	N
57	8/7	17:11	17:40	D	Y	Y	BROWN	Y	N10 (9R)	S
58	8/6	00:34	01:09	N	Y	Y	BROWN	Y	B1 (26R)	N
D1	8/25	19:19	19:45	D	Y	Y	VERST	Y	B3 (26R)	N
D2	8/26	15:22	15:45	D	Y	Y	VERST	Y	B3 (26R)	N
D3	8/26	19:26	19:56	D	Y	Y	VERST	Y	B3 (26R)	N
D4	8/27	15:23	15:47	D	Y	Y	VERST	Y	B3 (26R)	N
D5	8/27	18:46	19:24	D	Y	Y	VERST	Y	B3 (26R)	N
D6	8/28	15:39	16:02	D	Y	Y	VERST	Y	B3 (26R)	N
D7	8/28	19:07	19:33	D	Y	Y	VERST	Y	B3 (26R)	N

The master file represents a single pass on each of the runways and taxiways on the north side movement area. The data collection was performed during low traffic periods, thus degradations in multilateration and ADS-B surveillance performance due to garbling were minimized. A similar master file was created for the ASDE-3/AMASS using the same run numbers and time periods that were used in creating the ADS-B/multilateration master file.

While ATIDS is capable of Mode A/C multilateration, the scope of the ATL trials did not include an evaluation of Mode A/C multilateration. The Mode A/C performance needs to be evaluated if the system is to provide standalone (e.g., operations without a primary sensor like radar) surveillance.

3.2.2 Vehicle to Vehicle Tests

For the scenarios described in Section 3.1.2, the 1090 MHz ADS-B data from the NASA 757 was recorded by the receiver in the van. Several arrivals, departures, and follow tests were performed. These output files were later plotted and evaluated qualitatively for coverage performance.

4.0 TEST ANALYSIS AND RESULTS

4.1 Multilateration Surveillance Evaluation

4.1.1 Coverage

4.1.1.1 Data Collection

The B-757 master file (See 3.2.1) was used in the evaluation of multilateration coverage.

4.1.1.2 Analysis Method

ATIDS multilaterates on both the 1090 MHz ADS-B transmissions and the short squitter transmissions emitted by the B-757s Mode S transponder. The ADS-B transmissions from the master file were used to evaluate horizontal and vertical coverage performance for the following reasons:

- Multilaterated ADS-B transmissions provide a higher number of data samples than the multilaterated short squitters due to the higher transmission rate (e.g., twice a second as opposed to once a second).
- ADS-B decoded positions provides the location of the B-757 for each RT reception whether or not a multilateration position solution was determined.

While ADS-B transmissions are more susceptible to bit errors due to message length (112 bits) than the short squitter (56 bits), there is no degradation in multilateration performance over the short squitter. Only the message type (first five bits) and the 24 bit address field of both message types are used in the multilateration processing. Errors in the remaining bits do not affect multilateration processing. Thus the probabilities of receiving/decoding a multilateration useable ADS-B transmission and multilateration useable short squitter are similar.

4.1.1.3 Results

Figure 4 provides a plot of multilateration position updates for the master file. The density of the position reports is influenced by velocity and multilateration position update performance. Updates on the taxiways tend to be more dense than the runways due to differences in taxi velocities (e.g., slower taxi velocities result in shorter distances between updates). Missed position updates result from any of the following causes: surveillance system failures (i.e., loss of synchronization); surveillance system inefficiencies (i.e., timing errors, non-optimized correlation/tracker); random Mode S message garbling; and multipath.

The north side of the airport was divided into 6 regions as illustrated in Figure 5. Potential coverage gaps were identified with missing consecutive updates exceeding 2 seconds. Loss of coverage in Region 1 was positively identified as the result of a system failure. Surveillance was provided in Region 1 for other runs as illustrated in the Run 49 coverage plot, Figure B-1. Region 3 is known to be a problem area due to multipath off the Delta hangars [4]. Typically, only two RTs receive 1090 MHz transmissions that are useable for multilateration in this region. Adding an additional RT on the east end of the Delta hanger could solve the problem of lost updates. This had not be done because full coverage in this region is not critical to ATIDS role in ATL as a secondary sensor to the ASDE-3/AMASS.

The cause of Region 3 missed updates on the runway was investigated. It was determined that the RT receptions to perform multilateration were available, however system processing resulted in dropped updates. Based on studying data not included in the master file, it was determined that the updates were frequently being dropped during periods of high acceleration and deceleration. Multipath was eliminated as the cause by evaluating regions that were not affected by multipath as was the taxiway in Region 3. The problem is illustrated in Figure B-2, which shows positions being dropped during periods of high acceleration and deceleration for a departure and the subsequent arrival. The problem was more prevalent with NASA B-757 than for commercial aircraft, potentially due to the difference in the periodicity of the Mode S transmissions between the B-757 and commercial aircraft. Commercial aircraft have a nominal short squitter transmission rate of 1 per second. The B-757 transmitted both short and long squitter. At times the long squitter transmissions, which are used for both ADS-B and multilateration, occurred within .1 seconds of the short squitter transmissions. When this happened during rapid acceleration or deceleration, the logged data showed that CAPTS failed to generate updates.

It is critical that an aircraft taxiing on the movement area not disappear from ATC surveillance. Data shows that loss of surveillance can potentially occur as an aircraft stops in certain regions. Figure B-3 provides a plot made from a composite of several overlying runs. The plot shows that there are no regions where position reports do not get generated. However, reduced update rate performance is experienced in regions of poor coverage, such as Region 3 (B-1).

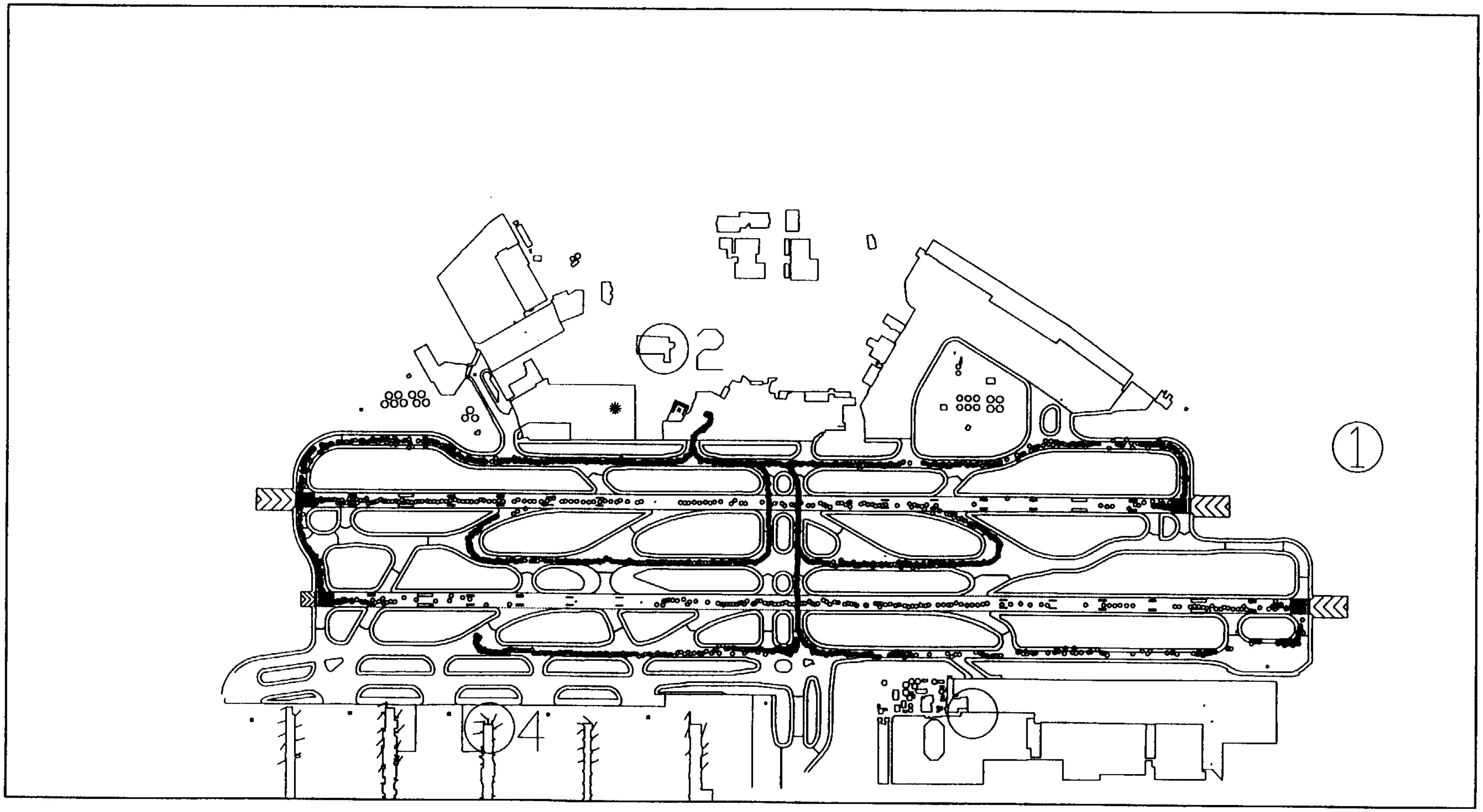

Figure 4. Multilateration Master File Multilateration Coverage Plot

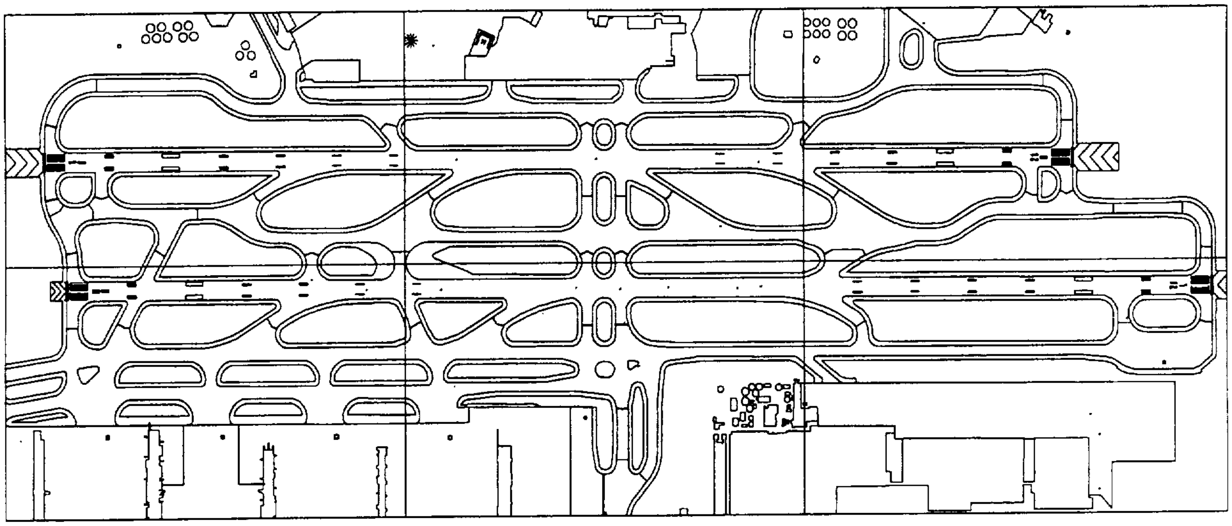

Figure 5. ATL North Movement Area Divided into Six Regions

Table 2 provides a summary of the system performance. An important factor to be considered is that ATIDS is an R&D prototype, thus not a fully mature product. As discussed above, some updates were lost due to a system failure. The test data also indicates that additional updates can potentially be recovered. Transmission reception of error free or low error rate (less than 25% of the address bits corrupt) from three or more RTs is required to determine a position. In 61 percent of the no solution cases, three or more RTs received useable multilateration transmissions. The test data suggests that deficiencies in system processing may be playing a significant role in the missed updates, particularly for Regions 1 and 3. Of the updates that have potential for recovery, 53 percent were received by 4 to 5 RTs.

Table 2. Coverage Performance Summary with Coverage Gaps

1090 MHz Message Category	Percent out of total transmitted 1090 MHz messages
Position solution obtained	78.8
No solution - Region 1 missed updates due to system failure of unknown cause	4.0
No solution - Region 3 missed updates due to system failure to properly correlate position updates	4.1
No solution - potentially recoverable missed updates with 3 or more RTs receiving (excluding Regions 1 and 3)	8
No solution - Not recoverable updates w/2 or less RTs receiving (all regions)	5.1
Total	100

In cases where only 2 RTs successfully decoded multilateration useable messages multipath was the key factor. Reducing the impact of multipath on any given RT is a difficult technical challenge. Achieving optimum coverage requires RT diversity.

The problem of uncorrelated updates could be re-analyzed by reprocessing the data with changed tracker parameters, but time constraints limited exploring this analysis. Instead, coverage performance was reassessed using replacements to Regions 1 and 3 with surveillance data recorded from other runs that experienced lower acceleration/deceleration. The replacements to the regions still exhibited missed updates with 3 or more RTs receiving, but not to the degree of the master file runs. Figure B-4 provides a plot of the corrected master file. Table 3 provides a summary of the performance. While the system performance for position solutions did improve, there is room for more improvement. There is a high probability of recovering a position solution for receptions of 4 or more RTs. Some of the 3 RT reception cases may be recoverable.

Table 3. Coverage Performance Summary with Coverage Gaps Corrected

1090 MHz Message Category	Percent out of total transmitted 1090 MHz messages
Position solution obtained	82.3
No solution - potentially recoverable missed updates with 4 or more RTs receiving	7.4
No solution - potentially recoverable missed updates with 3 RTs receiving	5.4
No solution - potentially not recoverable updates w/2 or less RTs receiving	4.9
Total	100

Reception performance by RT and by region (defined in Figure 5), for the master file, is provided in Table 4. Plots showing B-757 Mode S transmission reception by RT are provided in Figures B-5 through B-9. RTs 0 and 1 exhibited fairly consistent reception throughout the coverage area. RT 2 experienced poor performance in Region 3 due to multipath associated with the Delta hangers. RT 4 also experienced loss of updates in front of the Delta hangers. RT 4 does not have line of sight with this region. Poor surveillance in Region 3 was a significant factor in overall coverage performance. Position solution performance increased from 82.3% to 87.7% when Region 3 was excluded from the coverage assessment.

Several commercial traffic departures were examined to determine altitude coverage. Traffic was consistently monitored from the surface up to a minimum of 500 feet Above Ground Level (AGL). On average, coverage was provided up to 1000 feet AGL.

4.1.2 Accuracy

4.1.2.1 Data Collection

The B-757s multilaterated Mode S transmissions were logged by ATIDS during a taxi only run (no departures/arrivals). During the same run, Ashtech differentially corrected GPS data were logged in the B-757. The Ashtech data provided a truth source for the multilaterated position data.

Table 4. Mode S Message Reception by RT

Region	RT0 Reception	RT1 Reception	RT2 Reception	RT3 Reception	RT4 Reception	Recorded Position Solutions
1	76.4	95.4	92.9	92.9	92.1	84.5
2	89.2	83.4	74.8	97.2	88.6	89.2
3	93.3	87.1	33.7	81.9	93.3	44.6
4	74.7	92.6	91.5	85.8	87.1	84.0
5	87.0	87.3	95.1	76.7	89.1	92.8
6	90.6	91.9	90.0	88.8	80.2	86.2
All Regions	84.3	89.8	83.4	85.5	88.1	82.3
All Regions Except 3	83.0	90.1	90.4	86.0	87.4	87.7

4.1.2.2 Analysis Method

Both the Ashtech DGPS and the multilateration position reports are time stamped with GPS time. The multilateration position report time stamps are generated at the ATIDS Master Work Station (MWS) after the reports are received at the RTs and sent to the MWS. The multilateration report time stamps are corrected to compensate for an estimated 200 microseconds of communications delay between the RTs and the MWS.

Linear interpolation is used to determine the Ashtech DGPS position at the times corresponding multilateration report position updates. The Ashtech GPS position is corrected to account for the displacement between the GPS and Mode S antennas on the B-757s fuselage. Cross track, along track, and total horizontal error were analyzed. The accuracy assessment was performed using raw multilateration position reports (i.e., data was not track processed).

4.1.2.3 Results

Multilateration accuracy performance results, shown in Table 5, were compiled for several straight segments of the movement area. Taxiway C experienced accuracy performance that was significantly better than the R26L and Taxiway E runs. Horizontal Dilution of Precision (HDOP) was a major factor in the differences in performance for the three segments. When the ATIDS system receives a Mode S squitter by more than three RTs, the system selects the triad solutions that have the best HDOP value. Accuracy performance for Taxiway C was very good, because the position solutions were the result of triads that had HDOP values consistently close to 1. A wider range of HDOP values were experienced for R26L and Taxiway E, accordingly accuracy was degraded as compared to the Taxiway C segment.

Figures B-10, B-12, B-14, B-16 and B-18 provide plots of multilateration position with respect to centerline and Ashtech DGPS position. Figures B-11, B-13, B-15, B-17 and B-19 illustrate cross track and along track errors that were experienced for each runway/taxiway straight segment. The R26L segment experienced the largest errors. The accuracy performance on R26L varied significantly from run to run as can be seen by comparing Figure B-17 and B-19. There were several cases in the ATIDS input files where receptions were available for better DOP triad solutions, yet poorer DOP triads were used for providing position solutions. The system problems identified in the coverage results section also adversely impact accuracy performance.

Table 5. Multilateration Accuracy Results

		Along Track Position Error (meters)			Cross Track Position Error (meters)			Total Horizontal Position Error (meters)		
Location	No. of samples	Mean	Std Dev	95%	Mean	Std Dev	95%	Mean	Std Dev	95%
R26L	610	4.8	6.7	±12.1	1.0	5.2	±10.6	8.5	4.8	±15.8
Taxiway D	1937	0.2	3.3	±6.1	-0.8	2.1	±4.4	3.4	2.0	±6.9
Taxiway E - East	611	-5.2	6.4	±18.9	1.3	7.0	±12.8	8.7	6.6	±21.7
Taxiway E - West	1136	-2.2	3.6	±8.3	-0.6	5.5	±10.9	6.1	3.3	±12.1
Taxiway C	870	-1.6	2.7	±6.4	0.7	2.0	±4.1	3.1	2.1	±7.4

4.1.3 Update Rate

4.1.3.1 Data Collection

The B-757 corrected master file was used in the evaluation of multilateration update rate performance.

4.1.3.2 Analysis Method

Mode S transponders are specified to transmit DF11 short squitters at a nominal interval of once a second [5]. Data recorded in ATL has shown that many aircraft squitter at rates faster than the specified rate. In fact, the B-757s transponder was recorded by ATIDS to generate squitters nominally every .645 seconds. The objective of the update rate analysis was to determine a surveillance update rate for an aircraft transmitting squitters to specification. The analysis was performed using the multilaterated DF 17 transmissions which were transmitted at a rate of twice per second. The results were normalized for once a second transmission rate to provide an expected surveillance performance for a transponder squittering at a rate of once per second. The corrected master file was analyzed to assess update rate performance.

4.1.3.3 Results

Figure 6 provides a histogram of update success rate with a transmission rate normalized to once a second update rate. The 98% success rate occurs at the 4 second update interval. The success rate at the one second update interval is 45%. Figure 7 provides a histogram representing the distribution of updates. While not shown in Figure 7, the nominal update interval occurs at 1.1 seconds. As can be seen from Figure 7, there are peaks near 2, 3 and 4 seconds. These peaks represent cases where ATIDS failed to update the position for one or more Mode S transmissions and determined position on subsequent transmissions.

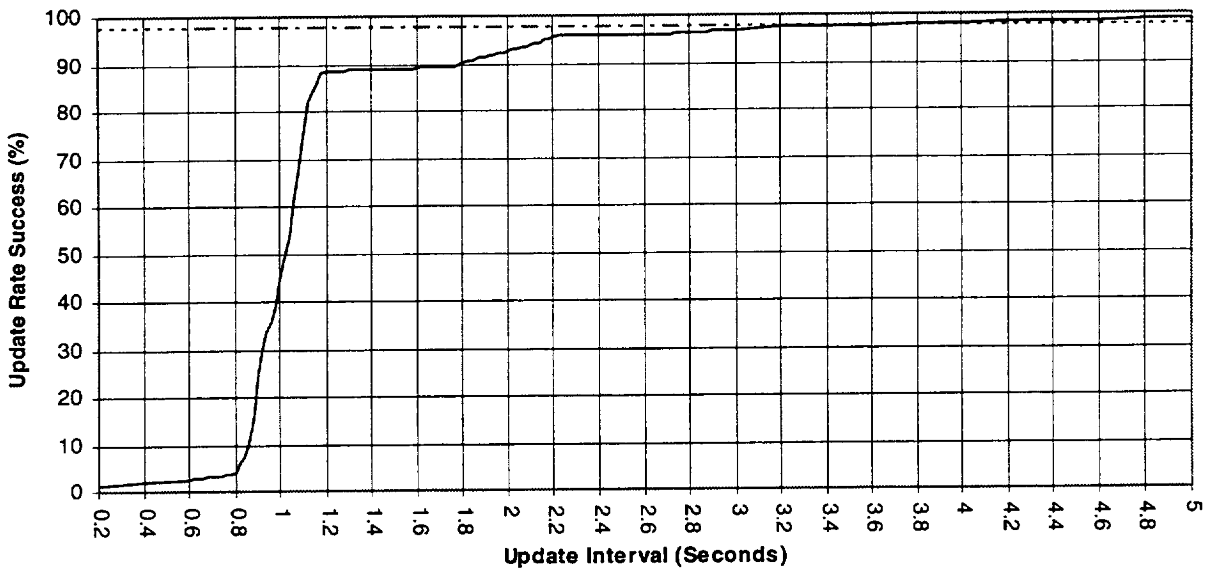

Figure 6. Multilateration Update Rate Success

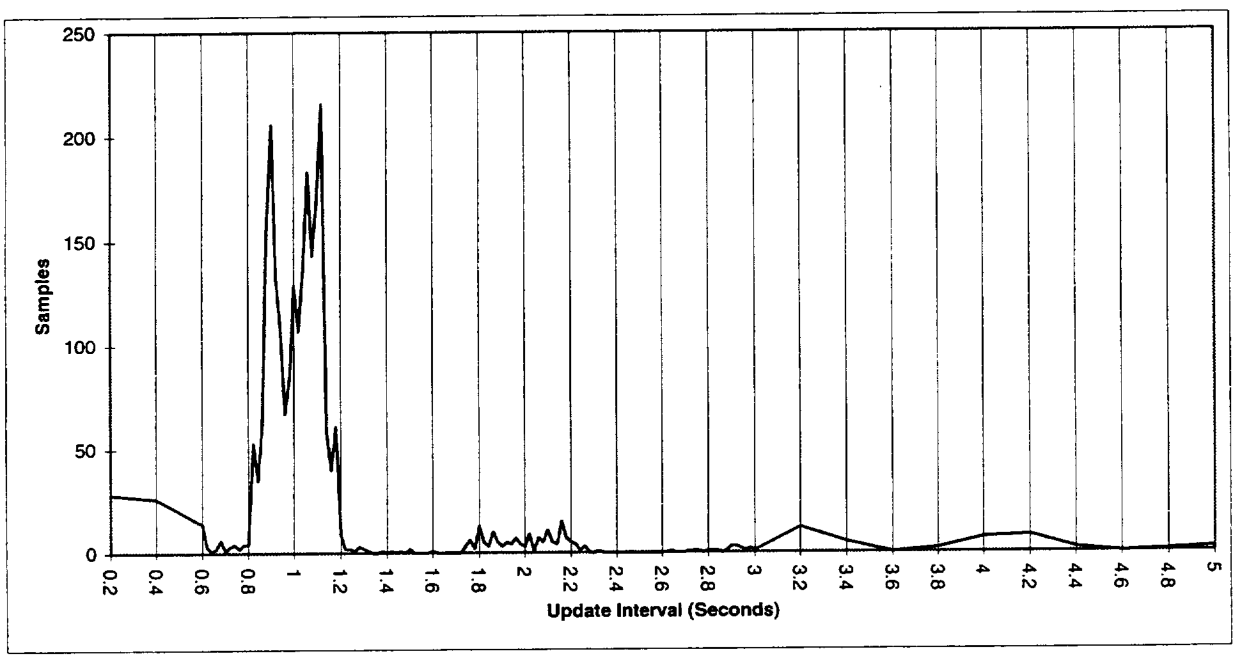

Figure 7. Multilateration Update Distribution

4.1.4 Comparison to Requirements

Table 6 provides a comparison of multilateration performance to proposed A-SMGCS requirements. A performance summary for all three surveillance technologies is provided in Table 16. See Appendix A for a detailed description of the proposed A-SMGCS requirements.

Table 6. Multilateration Performance/Requirements Comparison

PARAMETER (APPENDIX A)	A-SMGCS REQUIREMENT	MULTILATERATION RESULTS
A.1.1 Identification	Identify authorized targets	Compliant.
A.1.2 Operating Conditions	All weather and topographical performance	Not evaluated.
A.1.3 Incursion Detection	Enable incursion detection	Not evaluated.
A1.4 Unauthorized Targets	Surveillance of unauthorized targets	Not compliant. Only transponder equipped aircraft are detected.
A.1.5 Route Deviation	Enable detection of deviations from assigned route	Not evaluated.
A.2.1 Surveillance Coverage Area	Runway/Taxiway Ramp Area	Not compliant. Coverage gaps were experienced. Not evaluated.
A.2.2 Surveillance Altitude Coverage	Up to 500 feet above surface	Compliant. Altitudes of 1000 ft. achieved.
A.2.3 Surveillance Approach Coverage	10 NM along approach Note - Seamless coverage from the approach phase to the surface phase must be provided.	Compliant. 1.5 NM coverage achieved. The coverage may not be sufficient to support some airports using off-site approach radar.
A.2.4 Traffic Loading	a) Aircraft (movement area): 100 b) Aircraft (ramp area): 100 c) Ground vehicles (movement area): 25 d) Ground vehicles (ramp area): TBD	Not evaluated. Up to 13 targets observed. Not evaluated. Not evaluated. Not evaluated.
A.2.5 Covered Speed	Up to 250 kts on final a) approach and runways b) Up to 80 kts on runway exits c) Up to 50 kts on straight taxiways and 20 kts in curves	Not compliant. Position reports lost during periods of hard acceleration and deceleration. Compliant. Compliant.

PARAMETER (APPENDIX A)	A-SMGCS REQUIREMENT	MULTILATERATION RESULTS
A.2.6 Surveillance Position Accuracy	a) Longitudinal position accuracy -10 meters (95%)	Not Compliant. System demonstrated +/-5.8 to +/-5.9 meters (95%) on the taxiways, but experienced +/-18.2 meters (95%) on runway. Potentially resolvable system deficiencies were identified.
	b1) Lateral position accuracy - 10 meters (95%) for runways and taxiways	Not compliant. System demonstrated +/-3.6 to +/-12.6 meters (95%) on the taxiways and experienced +/-11.5 meters (95%) on runway.
	b2) 3 meters (95%) stand region	Not compliant. System will not meet performance based on runway/taxiway accuracy performance.
	c) Vertical position - 20 meters (95%)	Compliant. Transmitted altitude data from encoding altimeter meets requirement.
A.2.7 Surveillance Velocity Accuracy	Speed < 1 knot	Not evaluated.
	Direction of movement < TBD	Not evaluated.
A.2.8 Update Rate	<1 per second	Not compliant. A 4 second update interval (98%) was demonstrated.
A.2.9 Update Success Rate	98%	Not compliant.
A.2.10 Latency	< 1 second	Compliant. Assuming a 200 millisecond RF modem communications delay and 100 to 200 milliseconds of multilateration/display processing delay should result in an overall latency of less than 400 milliseconds.
A.2.11 Reference point accuracy	3 meters (95%)	Not evaluated. A database of aircraft Mode S and Mode A/C antenna locations would need to be generated and maintained. The safety logic would use the information to determine the nose location.
A.2.12 Surveillance Integrity	2.0×10^{-3} Vis 1 2.0×10^{-5} Vis 2,3 2.0×10^{-6} Vis 4	Not evaluated.
	False targets	Not evaluated.
A.2.13 Surveillance Continuity	2.0×10^{-2} Vis 1 2.0×10^{-3} Vis 2,3 2.0×10^{-3} Vis 4	Not evaluated.
A.2.14 Surveillance Availability	.999	Not evaluated.

4.1.5 Conclusions

The prototype ATIDS did not meet coverage, accuracy and update rate requirements. In examination of ATIDS log data, it appears that there are some processing problems. Missed position updates occurred even when error free Mode S transmissions were available at RTs that provide favorable DOP. Additionally, there were cases where unfavorable DOP triads were used instead of available higher DOP triads. The position processing problems were most prevalent for the B757 which transmitted both the short squitter DF11s and long squitter ADS-B DF17s. The problem resulted in lost updates and potentially degraded accuracy.

ATIDS accuracy performance would have benefited from track position smoothing. A tracker was used for position update sanity checks, but was not used for position smoothing. Track position smoothing is performed for the ASDE-3/AMASS.

The system update rate performance is limited by the specified transponder squitter rate of a nominal update rate of once a second, uniformly distributed over the range from .8 to 1.2 seconds. Assuming perfect squitter reception, ATIDS could not meet the once a second (98%) surveillance update rate requirement.

The ATIDS ATL installation provided multilateration coverage out to 1.5 NM. This may not be enough to provide overlapping coverage with the approach radar at some facilities. ATIDS was sited to provide good DOP for the movement area. Accuracy performance beyond runway threshold is degraded due to DOP performance issues. Accuracy performance on approach was not assessed.

4.2 ADS-B Surveillance Evaluation

4.2.1 Coverage

4.2.1.1 Data Collection

To analyze the ADS-B coverage performance, the master file derived from several NASA 757 runs (described in Section 3.2) and the van log files were used.

4.2.1.2 Analysis Method

The ADS-B master file was plotted on the ATL map to determine if coverage gaps existed. The master file was also analyzed to determine which RTs received an error-free ADS-B message for each position update. The error-free reception files were plotted by RT to find coverage gaps for each receiver. The ADS-B reports received at each RT were also analyzed to determine the percentage that were received in error and how many bits were in error. Finally, the vehicle to vehicle files were examined to evaluate the scenarios described in Section 3.2.2.

The performance of an ADS-B system is a function of the location and number of receivers. The results presented here are dependent upon the configuration of ATIDS, which is primarily a multilateration system. The receivers were sited to optimize their ability to meet this function.

They are arranged to provide the best possible geometry for determining position. If the receivers were arranged to provide the best ADS-B coverage, it is likely that the ADS-B performance would be improved. It is also possible that fewer receivers, cited more effectively for ADS-B could be used, while maintaining the same performance of ATIDS. Therefore, the results presented here must be viewed in the context of an ADS-B system that doubles as a multilateration system.

4.2.1.3 Results

Figure 8 shows the master ADS-B file plotted on the ATL map. A circle is plotted for each position update where at least one of the five RTs received an error-free transmission. For this file, several gaps existed where more than two transmissions were missed. Each of these areas were examined for different runs, and none of the areas were found to be consistently missing updates. It may be concluded that as a system of five ADS-B receivers, where only one of the five receivers is required to receive an error-free transmission, ADS-B provides 100% movement area coverage.

Figure C-1 shows the error-free reception performance of RT 0, sited on top of the Delta hangar on the south east border of the coverage area. This RT received 54.8% of the transmissions error-free. RT 0 had good coverage on the east side of the region and poor coverage on the west side.

RT 1 was cited on top of the Ford plant on the east side of the coverage area. Figure C-2 shows the error-free reception for this RT. RT 1 had the best reception performance (69.2%) with reliable coverage of all areas except the west side of taxiway "E" and runway 26L. This was most likely due to multipath caused by the Delta hangar.

Figure C-3 shows error-free reception for RT 2, cited on top of the Renaissance Hotel. This RT had very poor coverage on taxiway "E" and large coverage gaps on runway 26L. Otherwise, this RT performed well with 59.5% coverage. These coverage gaps were also most likely due to multipath from the Delta hangar.

RT 3 was located on top of the FAA's Regional Office building. As shown in Figure C-4, this RT covered taxiway "E" very well, compensating for the poor coverage there by RTs 1, 2, and 4. RT 3 was not able to cover the General Aviation (GA) ramp area or the north taxiway "A" however, likely due to blockage from buildings and fuel tanks in the northwest region of the airport. Overall, RT 3 received 59.9% of all transmissions error-free.

Figure C-5 shows the reception performance of RT 4 located on top of Concourse C. This RT had good coverage on the west side of the movement area and very poor nonexistent coverage on the south east side. This was likely due to blockage from the other airport concourses. This large blocked area resulted in the lowest overall reception performance of 52.6%.

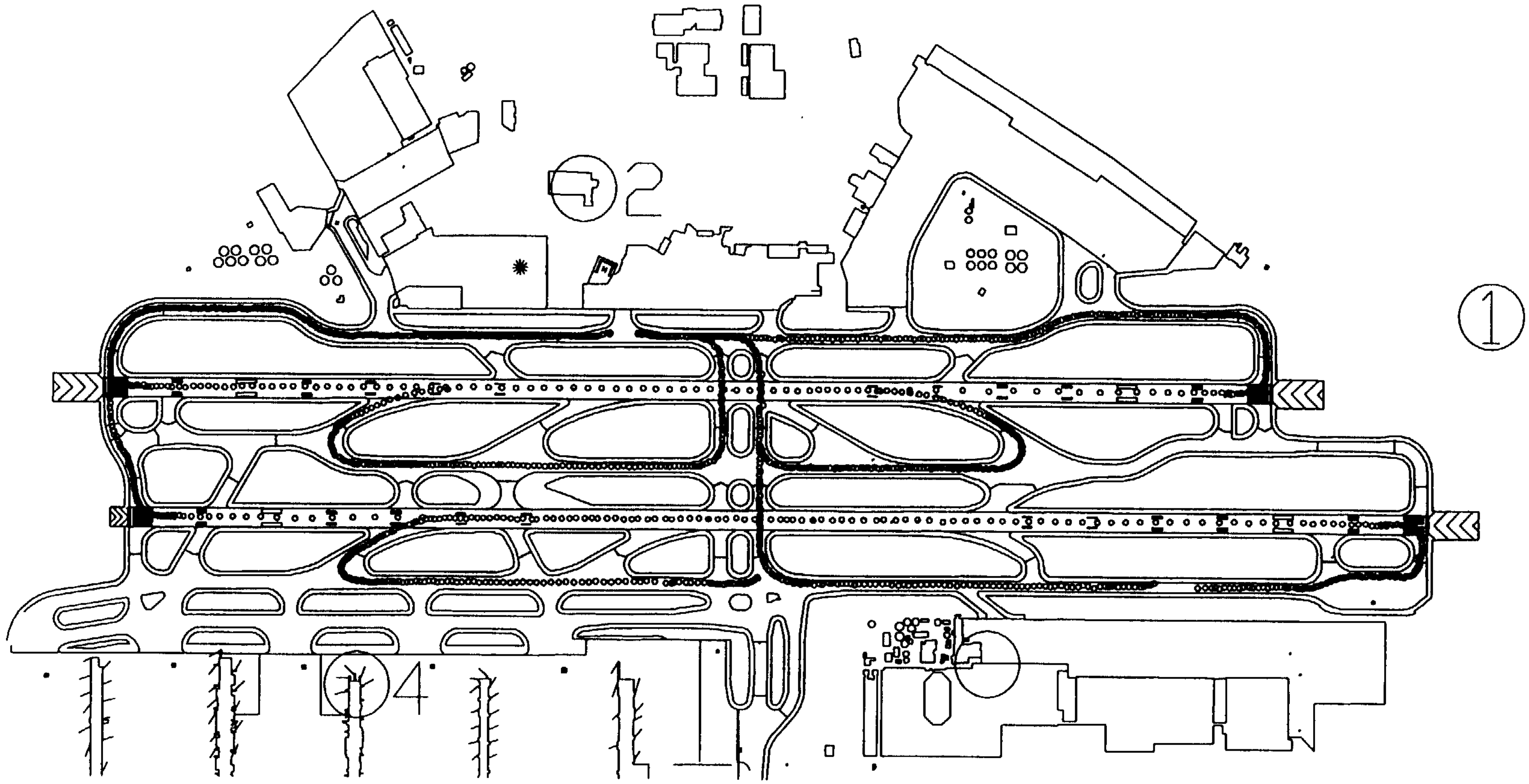

Figure 8. ADS-B Master File Coverage Plot

To further confirm the area specific coverage performance of each RT, the north side movement area was broken down into six regions and reception statistics were compiled for each region. See Figure 6 for a diagram of the regions and Table 7 for the reception results. The system received better than 98% reception in each region except 3 and 4. Region 3 is near the Delta hangers which is a source for multipath. RT 2 experienced severe multipath in Region 3. RT 4 experience blockage in Region 3 from buildings and hangers.

Table 7. ADS-B Regional Reception Performance By RT

	Region 1	Region2	Region 3	Region 4	Region 5	Region 6	All Regions
At Least 1 RT of 5	98.9%	98.0%	95.0%	95.6%	98.1%	99.6%	96.5%
RT 0 (Delta Hangar)	52.4%	73.4%	65.5%	36.4%	57.5%	64.6%	54.8%
RT 1 (Ford Plant)	88.4%	58.3%	50.6%	80.2%	58.3%	78.2%	69.2%
RT 2 (Renaissance Hotel)	69.2%	42.9%	8.6%	68.8%	80.7%	54.4%	59.5%
RT 3 (FAA Region)	65.7%	91.0%	70.7%	47.3%	48.7%	62.5%	59.9%
RT 4 (Concourse C)	80.8%	54.6%	4.1%	56.4%	58.9%	53.6%	52.6%

Bit error analysis was conducted to determine if error correction would enhance reception performance. For each RT (Table 8), the data output files were examined to determine what percentage of total transmissions had been received with no errors, what percentage had no message bits in error but with failed parity (error in parity bits), what percentage had 1, 2, or 3+ bits in error. The remainder either had too many errors to be recognized as from the NASA 757 or were not received at all. The RTs generally received around 60% with no error and about 2% of each 0 bit (failed parity), 1 bit, or 2 bit errors. If error correction were to be applied, it is thought that only the 0 bit and 1 bit error messages could be recovered, and some of the 2 bit error messages could be recovered. For the data analyzed, that would improve the reception percentage of each RT by about 6%.

Table 8. ADS-B Bit Error Statistics by RT

	Expected Replies	Error Free	Failed Parity 0 Bit Errors	1 Bit Error	2 Bit Errors	3 or More Bit Errors	Not Received
At Least 1 RT	3348	96.5%	-	-	-	-	-
RT 0 Delta Hangar	3348	54.8%	3.0%	2.5%	3.0%	22.2%	14.6%
RT 1 Ford Plant	3348	69.2%	2.9%	1.9%	1.4%	13.6%	11.1%
RT 2 Renaissance Hotel	3348	59.5%	2.8%	1.9%	2.1%	16.1%	17.5%
RT 3 FAA Region	3348	59.9%	2.7%	2.8%	2.5%	18.5%	13.5%
RT 4 Concourse C	3348	52.6%	2.4%	2.1%	1.9%	23.2%	17.9%

The van was driven on the movement area to investigate 1090 MHz ADS-B coverage performance for ground vehicles. The van ADS-B coverage results are provided in Table 9. The reception performance for the van ADS-B transmissions was similar to the results obtained for the B-757 (Table 7).

Table 9. Van ADS-B Reception Percentage by Region

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	All Regions
Received error-free by at least 1 RT	98.3%	98.5%	97.0%	97.2%	97.1%	97.6%	97.5%

In addition to the NASA 757 tests, van tests were also conducted. An ADS-B equipped van was driven through the ramp areas to evaluate the coverage in these areas. The ADS-B transmissions were recorded at the ATIDS Master Work Station. These output files were analyzed for reception percentage and coverage gaps. Figure C-6 shows the ADS-B reports received by at least one RT error-free. Large coverage gaps exist in ramp areas 1 and 3. Ramp 2 was not tested. Ramp 4 showed better coverage, but still with large gaps in coverage. Ramp 5 showed the best coverage of 96%. Overall, the ramp areas had 69% coverage (Table 10), well below the 96.5% coverage of the movement area. Because 1090 MHz ADS-B requires clear line of sight to consistently receive, none of the five RTs had complete coverage of all the ramp areas.

Analysis of the individual RT performance in the ramp area confirms the line of sight requirement for reception. RT 0 had almost no reception of the ramp areas because of it relative placement. RT 1 fared slightly better, with partial coverage of the north side of the ramps. RTs 2 and 3 performed well, with a good angle and line of sight to most of the ramp areas. RT 4 received only in ramps 3 and 4, the ramp areas adjacent to its placement on concourse C.

Table 10. Van ADS-B Reception Percentage by Ramp Area

	Ramp 1	Ramp 3	Ramp 4	Ramp 5	All Areas
Received error-free by at least 1 RT	50.1%	59.5%	74.1%	95.9%	68.6%

ADS-B approach coverage performance was assessed, keeping in mind that the system was optimised for surface surveillance. Figure C-7 provides a plot of approach coverage. RT 3 (Regional Office Building) was the only RT aimed eastward along the approach. RT 3 first detected the B757 at 17 NM. RT 3 dropped surveillance between 13.3 NM and 7.4 NM. At approximately 4.8 NM, the other RTs started receiving error free receptions. The gap in surveillance was experienced in other runs for eastbound and westbound approaches. The results show that there was adequate coverage to provide seamless operations with the approach radar.

4.2.2 Accuracy

4.2.2.1 Data Collection

ADS-B data collected during B757 taxi-only runs was analyzed to access accuracy performance. The truth source was provided by Ashtech GPS data that was logged in the B-757 and at the DGPS base station.

4.2.2.2 Analysis Method

Both the Ashtech DGPS and the ADS-B position reports are time stamped with GPS time. While the both Ashtech and the ADS-B GPS receivers have a one hertz output, the outputs have different times of applicability. The time of applicability for each Ashtech update is known to occur at each GPS epoch. Unlike the Ashtech, the ADS-B GPS receiver position outputs do not occur at each GPS epoch. The exact time of applicability of the ADS-B position reports is therefore unknown. The ADS-B position reports are time stamped at the Master Work Station after incurring time delays associated with ADS-B avionics communications and the RT to MWS communications.

Straight segments of a B-757 taxiing were analyzed for accuracy performance. Cross track, along track, and total horizontal error were analyzed. The communications delays primarily show up as an along track bias error. The Ashtech position data was processed to minimize the along track mean error thus removing this bias. Linear interpolation was used to determine the Ashtech DGPS position that corresponded in time to the ADS-B position updates. One limitation of this approach is that it artificially minimizes the along track mean and along track 95% numbers. However, cross track accuracy performance (e.g., mean, standard deviation, 95%) numbers and along track standard deviation are not affected by the analysis method.

4.2.2.3 Results

ADS-B position reports use the Compact Position Reporting (CPR) format as a means of encoding latitude and longitude values in a 34-bit message. This formatting scheme divides the globe into approximately square discrete grid coordinates. The true position is then mapped to the closest grid position. To achieve globally unambiguous decoding, there are actually two different grid spacings defined, which produce grids that match up at some locations and do not match at others. Because this method is discrete, the positions reported tend to jump as can be seen by Figures C-13 and C-15. The large jumps are attributed to the actual position transitioning from one grid location to the next, therefore the CPR algorithm reports the position to be on one grid line at one instance and then on the new grid line the next second. The smaller jumps are attributed to the odd/even second grid differences given they exist at that location.

Table 11 provides the results of the accuracy assessment. Longitudinal mean is zero because of the analysis method. The true longitudinal accuracy can be expected to be close to the .1 meter lateral mean, based on the assumption that DGPS errors are approximately equal in all directions horizontally.

Table 11. ADS-B Accuracy Results

	Along Track Position Error (meters)			Cross Track Position Error (meters)			Total Horizontal Position Error (meters)		
	Mean	Std. Dev.	95%	Mean	Std. Dev.	95%	Mean	Std. Dev.	95%
Runway/Taxiway	0.0	0.5	±0.9	-0.1	0.6	±1.4	0.7	0.4	±1.42

4.2.3 Update Rate

4.2.3.1 Data Collection

To analyze the ADS-B update rate, the NASA 757 master data file was used.

4.2.3.2 Analysis Method

For purposes of this analysis, the definition of a position update was established to be any error-free ADS-B report rather than a new or unique position update. This is an important distinction because the DGPS position was updated in the aircraft once per second, but position information was transmitted pseudo-randomly at a nominal rate of twice per second. This typically resulted in the same position being transmitted twice (and sometimes three times) consecutively. This definition was chosen because it better reflects the ability of the system to receive ADS-B information independent of the aircraft equipage. The performance of the system is not penalized for the position calculation rate of an individual aircraft. Also, it is expected that the calculation rate will be increased in an operational system, so using this method better reflects the performance potential of this system.

It is known that the Collins ADS-B unit transmits the Mode S extended squitter pseudo-randomly at a nominal rate of once every 0.5 seconds. If perfect reception were achieved by the system, the ATIDS output files would include an ADS-B position update approximately twice every second. The data showed occasional missed updates when none of the RTs received an error-free transmission. To quantify the amount of missed updates, the time difference between valid ADS-B updates was calculated for each update and statistics were compiled on this data.

4.2.3.3 Results

It was determined in the coverage analysis that updates were missed 3.5% of the time. Analysis of the time interval data reveals information about how often multiple consecutive updates were missed and the update rate performance. Figure 9 shows the distribution of time intervals. It is clear from the figure that the nominal update rate was 0.5 seconds with a jitter of 0.1 seconds. Most of the updates occurred 0.5 ± 0.1 seconds after the previous one. Occasionally an update was missed so the next distribution of update intervals is centered around 1 second. Figure 10 shows the cumulative update interval curve with a 98% line. The probability of receiving an update within the nominal update interval plus the jitter (0.6 seconds) was 96.3%. There was a 98% probability of receiving an update within 0.95 seconds, thus exceeding the one-second requirement.

4.2.4 Vehicle to Vehicle ADS-B Coverage

4.2.4.1 Data Collection

The B757 ADS-B transmissions were received and logged by the test van 1090 MHz ADS-B receiver. During taxiing operations, ADS-B transmissions originated from the B757 top mounted antenna. Both the top and bottom mount antennas were used when the wheels were up (e.g., squat switch deactivated). Depending on the scenario, as described in the 4.2.4.3, the test van was either stationary or moving behind the taxiing B757.

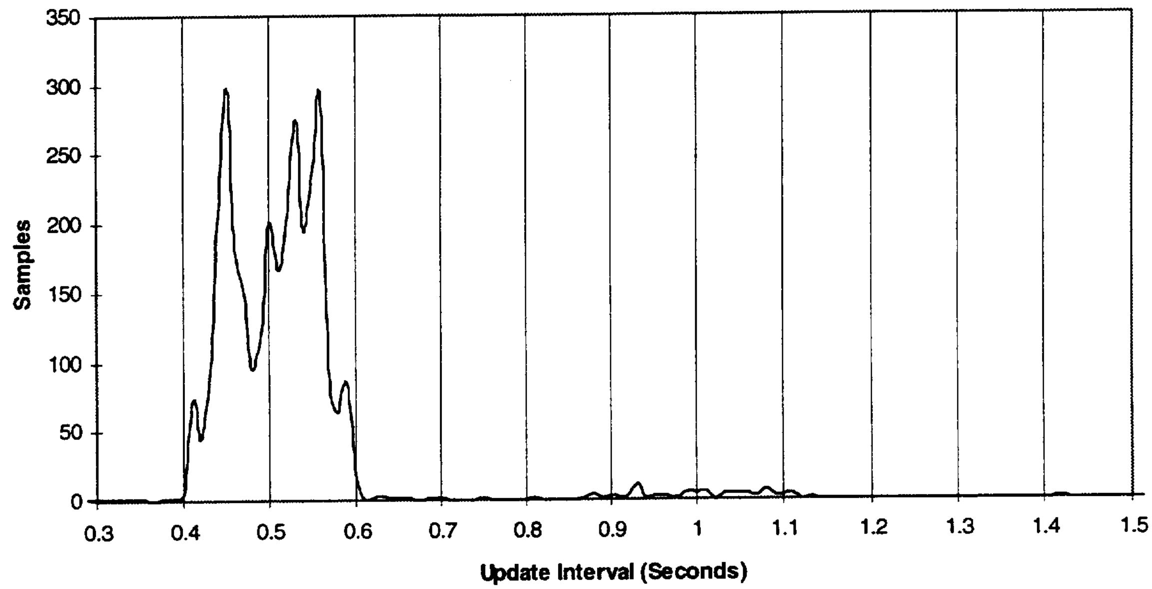

Figure 9. ADS-B Update Interval Distribution

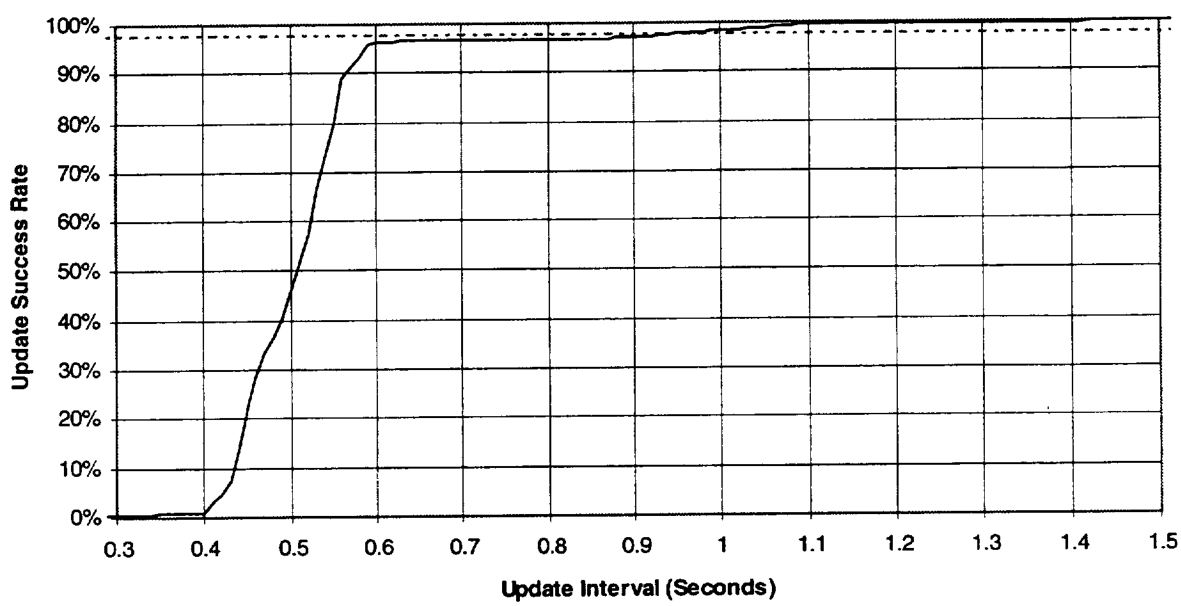

Figure 10. ADS-B Update Success Rate

4.2.4.2 Analysis Method

ADS-B update position plots were used as the primary means for assessing vehicle to vehicle surveillance performance. The plots provided a good picture of the performance limitations of 1090 MHz ADS-B for the vehicle to vehicle application, although quantitative assessments were limited.

4.2.4.3 Results

Scenario 1 - Arrival monitoring. Figure C-8 provides a plot of the B757 ADS-B reports received by the ADS-B receiver in the test van. With several runs made, Figure C-8 provides a good representative plot of coverage. The test van antenna was positioned at a height of 3 meters. Line of sight was maintained throughout the approach. Reception was lost during aircraft banking when turning on to the 8L approach. During the straight segment of the approach, there were 6 time periods when gaps in updates exceeded 4.8 seconds (e.g., update rate of an airport surveillance radar). The largest time gap was 10.8 seconds. These gaps were experienced mostly when the B757 was on the last five miles of the approach.

Scenario 2 - Runway occupancy monitoring. Figure C-9 provides a plot of the B757 ADS-B reports received by the ADS-B receiver in the test van. The test van was parked on the north east corner of the airport. The antenna was set to a 3 meter height. Line of sight was maintained throughout the approach and during taxiing. As shown in Figure C-9, there were significant drops in ADS-B updates during B757 taxiing. Several antenna heights and parking locations were tried. All site/antenna height configurations experienced significant loss of updates.

Scenario 3 - Aircraft in-trail spacing monitoring. Figure C-10 provides an illustration of the B757 top mount antenna ADS-B transmissions recorded by the test van as it followed the aircraft. The van ADS-B antenna height was set to 3 meters, which is equivalent to the antenna height of a small aircraft. The van maintained a spacing of approximately 200 meters behind the B757 up to the stop point identified in the figure. At the start point of this run, the van was driven parallel to the taxiway centerline, but 10 meters offset from the centerline. Consistent receptions were maintained through the first turn. After the first turn, the van was repositioned to a centerline path. When the van lined up behind the B757 and both were traveling in a straight line, reception was lost. As soon as the B757 initiated a turn towards runway 8L, receptions were reestablished. The B757 crossed runway 8L and stopped at the 8R hold line. The van was driven off into the grass area to the side of the aircraft. Reception was maintained while the van was next to the B757. During the departure on 8R, ADS-B reception was lost for two segments of time.

Additional testing was performed with the B757 stationary and the van positioned behind the aircraft. Testing confirmed that there is a blind spot behind the B757 where ADS-B transmissions are not received. Even with the antenna mast set to 15 meters (e.g., approximate height of a B747 top mounted antenna), ADS-B transmissions were not received.

4.2.5 Comparison to Requirements

Table 12 provides the performance of ADS-B compared to the proposed A-SMGCS requirements.

4.2.6 Conclusions

Compliance with the A-SMGCS coverage, accuracy, and update rate requirements were demonstrated for the ADS-B surface surveillance. 1090 MHz ADS-B is susceptible to multipath and blockage from buildings and hangars. Five RTs provided sufficient diversity to ensure high confidence ADS-B position report reception. ATIDS was configured for multilateration with RTs placed around the perimeter of the coverage area. This placement may not required for ADS-B. There is potential to meet A-SMGCS requirements with less receivers. From the update rate analysis, it may be concluded that squitter rates must be 0.5 seconds or faster to meet the 98% in 1.0 second requirement. The ADS-B accuracy with LAAS far exceeded the A-SMGCS accuracy requirements.

1090 MHz ADS-B met the A-SMGCS approach surveillance requirements. Coverage was limited to approximately 7 NM. ATIDS was optimized for surface surveillance. Approach coverage performance could be improved even more via optimization of antenna alignment and wing settings, and reduction of RT cable losses.

Vehicle-to-vehicle 1090 MHz ADS-B did not demonstrate sufficient performance to support TIS. The vehicle-to-vehicle coverage test results were consistent with the ADS-B ground system results in that each ADS-B receiver did not provide full coverage in areas where line-of-sight was maintained. The vehicle ADS-B receiver experienced coverage gaps when monitoring ADS-B aircraft arrivals. Conversely, based on data link symmetry, an ADS-B receiver equipped arrival can be expected to experience the same loss of surveillance on taxiing aircraft on the runway. Degraded coverage performance can be overcome by through receiver diversity with the ground system implementation. However, diversity is not an option for vehicle based surveillance. One alternative that was demonstrated successfully in ATL was a separate VHF based TIS data link. The VHF data link maintained consistent coverage performance for surface operations. Implementation of 1090 MHz ADS-B traffic information services may require transmission source augmentation (e.g., low power 1090 MHz repeaters located at the ADS-B ground receive sites to reinforce the ADS-B transmissions).

Table 12. 1090 MHz ADS-B Performance/Requirements Comparison

PARAMETER (APPENDIX A)	A-SMGCS REQUIREMENT	1090 MHZ ADS-B RESULTS
A.1.1 Identification	Identify authorized targets	Compliant. 4096 code available from 1090 MHz transmission provides a means to identify aircraft with conversion to call sign. Planned ADS-B implementation includes ADS-B transmission of call sign.
A.1.2 Operating Conditions	All weather and topographical performance	Not evaluated.
A.1.3 Incursion Detection	Enable incursion detection	Not evaluated.
A1.4 Unauthorized Targets	Surveillance of unauthorized targets	Not compliant. Only ADS-B equipped vehicles are detected.
A.1.5 Route Deviation	Enable detection of deviations from assigned route	Not evaluated.
A.2.1 Surveillance Coverage Area	Runway/Taxiway (Ground system) Runway/Taxiway (Vehicle to vehicle) Ramp Area (Ground system)	Compliant. Not compliant. Not Evaluated.
A.2.2 Surveillance Altitude Coverage	Up to 500 feet above surface	Compliant. Coverage extends well beyond the 500 feet.
A.2.3 Surveillance Approach Coverage	10 NM along approach Note - Seamless coverage from the approach phase to the surface phase must be provided.	Compliant. Coverage provided out to 7 NM, which is more than enough to ensure coverage overlap with an approach radar or terminal area ADS-B sensor.
A.2.4 Traffic Loading	a) Aircraft (movement area): 100 b) Aircraft (ramp area): 100 c) Ground vehicles (movement area): 25 d) Ground vehicles (ramp area): TBD	Not evaluated. Not evaluated. Not evaluated. Not evaluated.
A.2.5 Covered Speed	Up to 250 kts on final a) approach and runways b) Up to 80 kts on runway exits c) Up to 50 kts on straight taxiways and 20 kts in curves	Compliant Compliant. Compliant.

PARAMETER (APPENDIX A)	A-SMGCS REQUIREMENT	1090 MHZ ADS-B RESULTS
A.2.6 Surveillance Position Accuracy	a) Longitudinal position accuracy -10 meters (95%) b1) Lateral position accuracy - 10 meters (95%) for runways and taxiways b2) 3 meters (95%) stand region c) Vertical position - 20 meters (95%)	Compliant. Demonstrated accuracy of +/-.9 meters. Compliant. Demonstrated accuracy of +/-1.4 meters. Not evaluated. Movement area accuracy results suggest that 3 meter accuracy can be met. DGPS accuracy in areas near structures needs to be tested. Compliant. Transmitted altitude data from encoding altimeter meets requirement.
A.2.7 Surveillance Velocity Accuracy	Speed < 1 knot Direction of movement < TBD.	Not evaluated. Planned ADS-B implementations will include transmission of speed. Speed derived from position reports will exceed requirement. Not evaluated. Planned ADS-B implementations will include transmission of heading.
A.2.8 Update Rate	<1 per second	Compliant.
A.2.9 Update Success Rate	98%	Compliant.
A.2.10 Latency	< 1 second	Not evaluated.
A.2.11 Reference point accuracy	3 meters (95%)	Not evaluated. The planned 1090 MHz ADS-B implementation will be compliant. ADS-B avionics will transmit reference information.
A.2.12 Surveillance Integrity	2.0×10^{-3} Vis 1 2.0×10^{-5} Vis 2,3 2.0×10^{-6} Vis 4 False targets	Not evaluated. Not evaluated. False targets are a low probability event due to parity checking and capability to cross check ADS-B transmissions received from multiple ground receivers.
A.2.13 Surveillance Continuity	2.0×10^{-2} Vis 1 2.0×10^{-3} Vis 2,3 2.0×10^{-3} Vis 4	Not evaluated.
A.2.14 Surveillance Availability	.999	Not evaluated.

4.3 ASDE-3/AMASS Surveillance Evaluation

4.3.1 Coverage

4.3.1.1 Data Collection

The coverage assessment was performed using the ASDE-3/AMASS master data file. The data collection was limited to VFR periods with no rain.

4.3.1.2 Analysis Method

An assessment of coverage was performed with the master file. Potential coverage gaps identified in the ASDE-3/AMASS master file were further investigate to verify repeatability of gaps with other runs. Approach coverage was evaluated. Coverage performance was also analyzed for commercial traffic to ensure that the coverage is maintain for a wide variety of aircraft/vehicle types and sizes. The commercial traffic data was analyzed to identify potential coverage gaps and false tracks. False tracks are those that meet one of the following criteria:

- A track that does not have another established track leading up to or away from it, meaning that it is not a continuation of a dropped track.
- A track that pops up for a short period in an area where ASDE-3/AMASS coverage performance is consistently good.

Other observations were used to that help confirm the existence of false tracks such as:

- Identifying pop up tracks in the middle of the runway when it is 'hot' due to an arrival or departure.
- Identifying pop up tracks at locations where there are no intersections. Aircraft and ground vehicles rarely cross runways at any location other than intersections. Additionally, the target extent information was used to identify tracks that are too large to be ground vehicles.

4.3.1.3 Results

Figure 11 provides a plot of the ASDE-3/AMASS master file. Approach coverage is limited to inside the runway thresholds. Consistent coverage with firm track updates was maintained for the movement area with the exception of a 125 meter section of Taxiway E in front of the Delta hangar. Line of sight from the tower to this area is blocked by the hanger. Other B757 runs were examined. The coverage of the B757 consistently was lost in the same area in front of the hangar. On examination of data files with commercial traffic, heavy aircraft (e.g., L1011) maintained track in this region, but other aircraft did not.

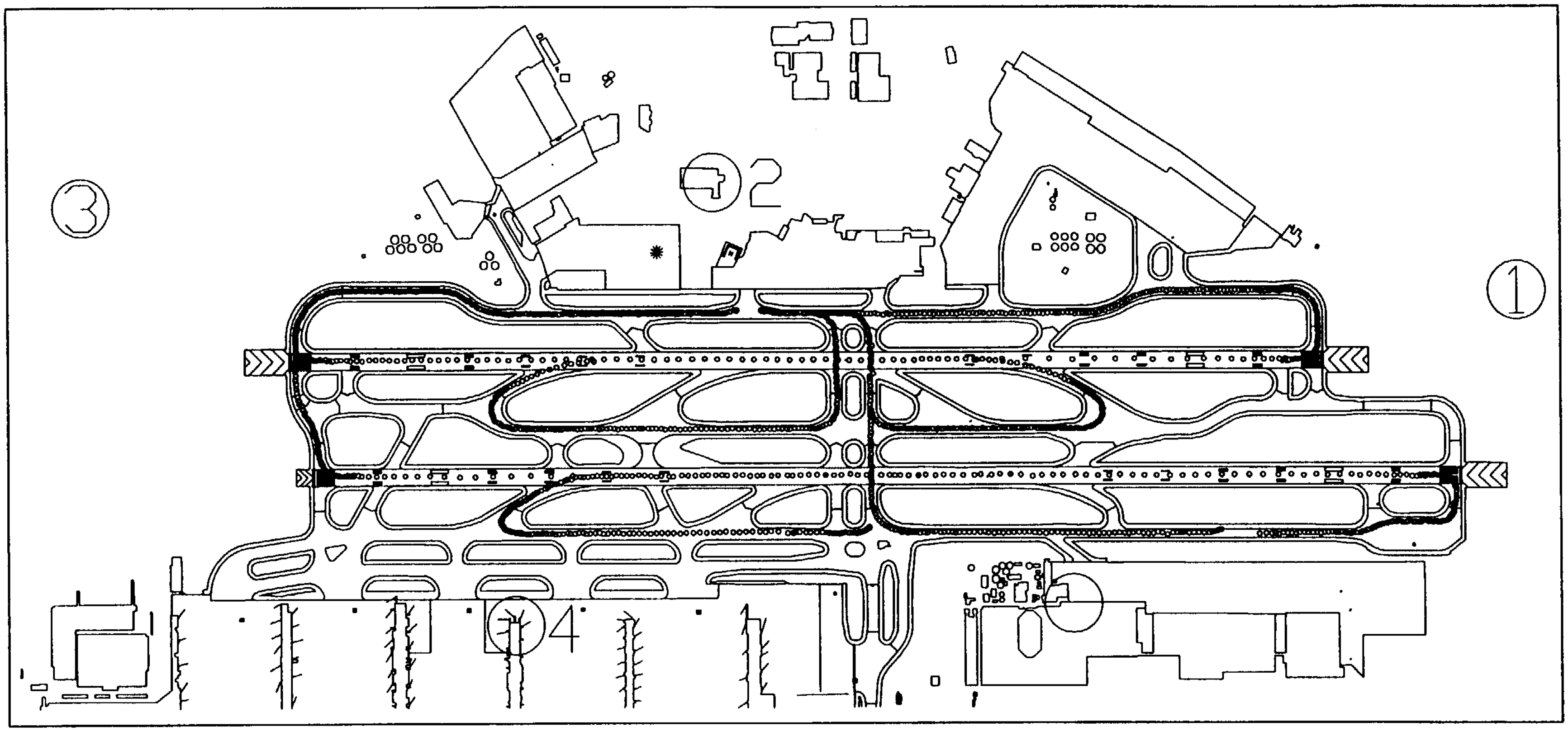

Figure 11. ASDE-3/AMASS Master File Coverage Plot

Figure D-1 provides a plot of commercial traffic over a period of 20 minutes with 32 operations. The AMASS data was analyzed to identify false tracks. Some examples of false tracks are identified in Figure D-1, based on the analysis criteria identified in paragraph 4.3.1.2. The false tracks identified on taxiway E in front of the Delta hangars are the one exception to the criteria established in 4.3.1.2. These false tracks pop up in an area of poor coverage. However, the probability is very low that an aircraft could taxi to the location where there are false tracks without detection. In most cases, the false tracks show up as tracks moving in directions other than in the direction of normal traffic flow. There were cases where false tracks popped up in the middle of a runway when it was 'hot' due to an arrival or departure. Several of the false tracks popped up at locations where there are no intersections. At ATL, ground vehicles rarely cross runways at any location other than intersections. Ground vehicle operations, except in emergencies, are very limited during high traffic periods. There is an unusually high level of activity with more than 10 pop up tracks on the runway over a 20-minute departure push. Additionally, the target extent information indicated that these tracks were often too large to be ground vehicles.

Figures D-2 and D-3 provide two commercial traffic scenarios where coverage was lost for vehicles crossing runway 8L. In the first scenario, Figure D-2, a vehicle of unknown type taxied up to the hold line on a runway 8L high speed ramp. The system dropped track when the vehicle was stopped and failed to reestablish track until after the vehicle had proceeded 76 meters past the hold line. In the second scenario, Figure D-3, ASDE-3/AMASS experienced two periods where the track was coasted while an aircraft was crossing runway 8L. In the first coast period, the ASDE-3/AMASS gives a false indication that the aircraft is turning to taxi down the runway. In the second period, the track was coasted into the grass area and outside of the runway safety zone. It is not known why surveillance updates were lost in both of these scenarios. Examination of other ASDE-3/AMASS files showed that surveillance was maintained for other traffic.

4.3.2 Accuracy

4.3.2.1 Data Collection

The accuracy assessment was performed using the ASDE-3/AMASS master data file and the corresponding Ashtech DGPS data logged in the B-757.

4.3.2.2 Analysis Method

An analysis of ASDE-3/AMASS accuracy with respect to target centroid was performed. The analysis was first performed by correlating the Ashtech position reports in time with the ASDE-3/AMASS position reports. Linear interpolation is used to determine the Ashtech position at each ASDE-3/AMASS update time. Straight segments of a B-757 taxi only run were analyzed for accuracy performance. Cross track, along track, and total horizontal error were analyzed with respect to the B-757s centroid, nose, and tail. The accuracy assessment was performed using track processed ASDE-3/AMASS position reports. AMASS track speed and heading accuracy performance were evaluated using the speed and heading derived from the Ashtech position reports as truth.

An analysis was performed to determine if ASDE-3/AMASS extent information could be used to meet the reference point accuracy requirement. Reference point information is required to detect hold line violations into the runway safety zone. Target extent provides information about the length and width with respect to the target centroid of an aircraft under surveillance. Extent information of the B-757 was compared to the aircraft's actual length and width.

4.3.2.3 Results

The accuracy results for ASDE-3/AMASS are provided in Table 13. Figures D-4, D-6, D-8, D-10 and D-12 provide plots of along-track and cross-track position error for five straight runway/taxiway segments. The ASDE-3/AMASS maintained consistent along track and cross track position accuracy performance across the three runway/taxiway segments. Figures D-5, D-7, D-9, D-11 and D-13 provide a plot of ASDE-3/AMASS track position and corresponding Ashtech position for the same segments.

Table 13. ASDE-3/AMASS Accuracy Results

	Along Track Position Error (meters)			Cross Track Position Error (meters)			Total Horizontal Position Error (meters)		
	mean	Std. Dev.	95%	mean	Std. Dev.	95%	mean	Std. Dev.	95%
Runway/Taxiway	-.43	3.2	+/-5.5	.22	2.4	+/-4.5	3.50	2.0	+/-6.4

Table 14 provides the results of the speed and heading accuracy assessment. The largest errors in speed occur at low speeds. Figure 12 provides a plot showing the B-757 stopped for 40 seconds before accelerating. During the stopped periods ASDE-3/AMASS reported speeds up to 6 knots. It took more than 10 seconds after initiating acceleration for the velocity to go above the 6 knot value, thus giving a delayed indication of aircraft acceleration.

Table 14. ASDE-3/AMASS Speed and Heading Accuracy Results

	Mean Error	Standard Deviation
Speed	1.9 knots	1.6 knots
Heading	4.7 deg	4.3 deg

ASDE-3/AMASS target extent information was analyzed for the hold line violation detection application. Figure 13 provides a comparison of ASDE-3/AMASS extent and true B-757 measurements. Aircraft nose location, derived from length information, is critical for detecting a hold line violation. Uncertainty in locating the nose of the aircraft adds time delay to alerting. The ASDE-3/AMASS length measurement varied by approximately +/- 10 meters from the true length. The combination of centroid position error with extent error does not support a +/- 3 meter reference point accuracy.

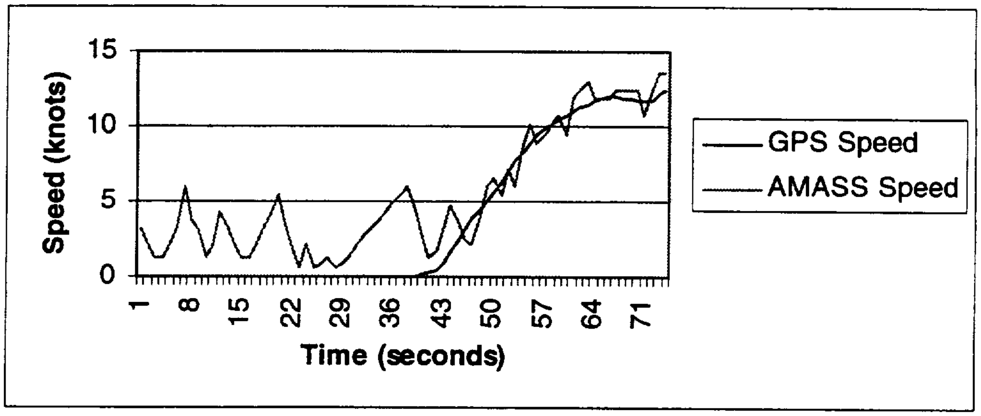

Figure 12. ASDE-3/AMASS Velocity Plot

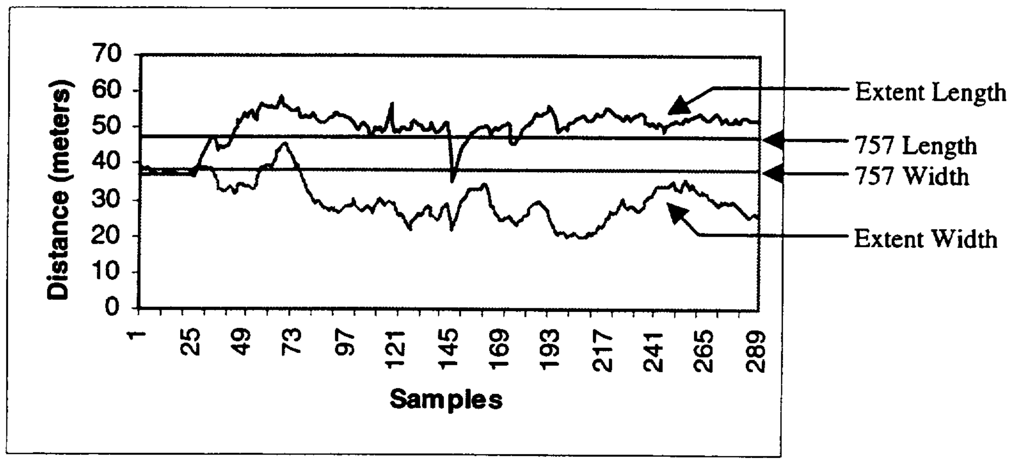

Figure 13. ASDE-3/AMASS Extent Plot

4.3.3 Update Rate

4.3.3.1 Data Collection

The B757 master file of ASDE-3/AMASS surveillance data was used in the evaluation of update rate.

4.3.3.2 Analysis Method

Update success rate and distribution of updates were analyzed using firm track updates. Coasted updates were not included in the assessment.

4.3.3.3 Results

Figure 14 provides a histogram of the update success rate for the ASDE-3/AMASS. The 98% success rate occurs at 1.05 seconds. Figure 15 provides a histogram presenting the distribution of updates. The radar maintained consistent once a second updates in all regions except the one region in front of the Delta hangars where updates were lost.

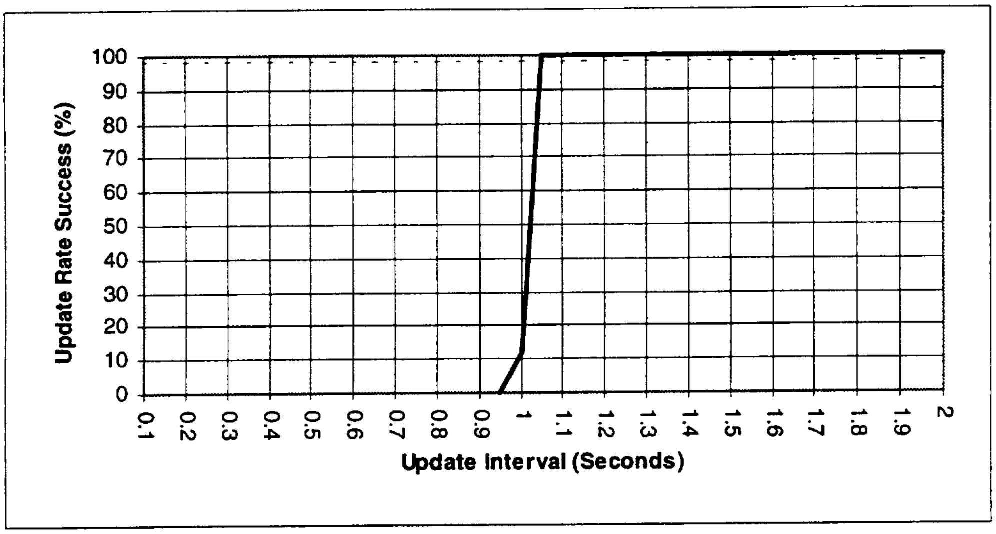

Figure 14. ASDE-3/AMASS Update Rate Success

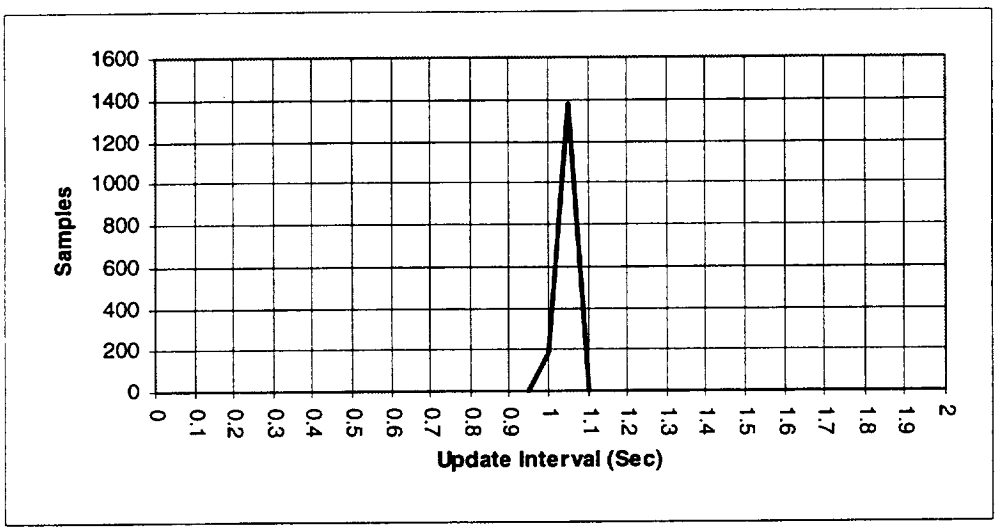

Figure 15. ASDE-3/AMASS Update Distribution

4.3.4 Comparison to Requirements

Table 15 provides the performance of ASDE-3/AMASS compared with proposed A-SMGCS requirements.

Table 15. ASDE-3/AMASS Performance/Requirements Comparison

PARAMETER (APPENDIX A)	A-SMGCS REQUIREMENT	ASDE-3/AMASS RESULTS
A.1.1 Identification	Identify authorized targets	Not compliant.
A.1.2 Operating Conditions	All weather and topographical performance	Not evaluated.
A.1.3 Incursion Detection	Enable incursion detection	Not evaluated.
A1.4 Unauthorized Targets	Surveillance of unauthorized targets	Compliant.
A.1.5 Route Deviation	Enable detection of deviations from assigned route	Not evaluated.
A.2.1 Surveillance Coverage Area	Runway/Taxiway Ramp Area	Not compliant. Coverage gaps were experienced due to blockage and limitation on ASDE-3 look down angle (e.g., loss of coverage on taxiway D between the north and south sides). Not evaluated.
A.2.2 Surveillance Altitude Coverage	Up to 500 feet above surface	Not evaluated.
A.2.3 Surveillance Approach Coverage	10 NM along approach Note - Seamless coverage from the approach phase to the surface phase must be provided.	Not compliant. Coverage does not extend beyond threshold, therefore will not ensure overlapping coverage with the approach radar.
A.2.4 Traffic Loading	a) Aircraft (movement area): 100 b) Aircraft (ramp area): 100 c) Ground vehicles (movement area): 25 d) Ground vehicles (ramp area): TBD	Not evaluated. Up to 31 AMASS tracks observed. Not evaluated. Not evaluated. Not evaluated.
A.2.5 Covered Speed	Up to 250 kts on final a) approach and runways b) Up to 80 kts on runway exits c) Up to 50 kts on straight taxiways and 20 kts in curves	Compliant. Compliant. Compliant.

PARAMETER (APPENDIX A)	A-SMGCS REQUIREMENT	ASDE-3/AMASS RESULTS
A.2.6 Surveillance Position Accuracy	a) Longitudinal position accuracy -10 meters (95%)	Compliant. Demonstrated +/- 5.5 meters (95%).
	b1) Lateral position accuracy - 10 meters (95%) for runways and taxiways	Compliant. Demonstrated +/- 4.5 meters (95%).
	b2) 3 meters (95%) stand region	Not compliant. System will not meet performance based on runway/taxiway accuracy performance.
	c) Vertical position - 20 meters (95%)	Not compliant. Vertical information not provided by system.
A.2.7 Surveillance Velocity Accuracy	Speed < 1 knot	Not compliant. Demonstrated 1.9 knot error. Errors up to 5 knots during slow speeds.
	Direction of movement < TBD	Not evaluated.
A.2.8 Update Rate	<1 per second	Compliant.
A.2.9 Update Success Rate	98%	Compliant.
A.2.10 Latency	< 1 second	Compliant. Latency < .1 seconds.
A.2.11 Reference point accuracy	3 meters (95%)	Not compliant. System does not provide a means to accurately determine the location of a reference point.
A.2.12 Surveillance Integrity	2.0×10^{-3} Vis 1 2.0×10^{-5} Vis 2,3 2.0×10^{-6} Vis 4	Not evaluated.
	False targets	Not compliant. Incidence of false targets on the runway was high.
A.2.13 Surveillance Continuity	2.0×10^{-2} Vis 1 2.0×10^{-3} Vis 2,3 2.0×10^{-3} Vis 4	Not evaluated.
A.2.14 Surveillance Availability	.999	Not evaluated.

4.3.5 Conclusions

ASDE-3/AMASS met the A-SMGCS accuracy and update rate requirements, but did not meet the coverage requirements. Coverage gaps were experienced on the taxiways. Approach coverage is limited to the runway thresholds, which will not ensure overlapping coverage with the approach radar. While the ASDE-3/AMASS demonstrated a high probability of position update success, it did experience a missed detection for runway safety zone entry detection. It is not known if the incident was vehicle type/size dependent.

ASDE-3/AMASS was observed in ATL to incur a significant level of false tracks in critical areas such as runways and high speed exits. False tracks tend to appear in predictable locations. These present problems for AMASS safety logic, resulting in false alerts for AMASS. During low visibility operations, flight crews with traffic displays would have difficulty distinguishing between real traffic and false targets.

ASDE-3/AMASS provides the aircraft centroid position. The system extent data does not provide accurate nose and tail location information. This can result in a large degree of uncertainty in determining if and when an aircraft has crossed the hold line on entry to the runway or on exiting the runway. This uncertainty may result in delaying time to alarm for runway incursions.

It should be mentioned that although the ASDE-3 at Atlanta is an operational system, the AMASS used for the tests is a prototype. It is expected that some of the performance observed, such as track processing, will be improved when AMASS becomes operational.

5.0 SUMMARY AND RECOMMENDATIONS

5.1 Summary of Comparison to Requirements

Table 16 provides a summary comparing multilateration, 1090 MHz ADS-B, and ASDE-3/AMASS surveillance performance with the proposed A-SMGCS requirements.

Table 16. Summary of Surveillance Performance/Requirements Comparison

PARAMETER (APPENDIX A)	A-SMGCS REQUIREMENT	MULTILATERATION	1090 MHZ ADS-B	ASDE-3/AMASS
A.1.1 Identification	Identify authorized targets	●	●	O
A.1.2 Operating Conditions	All weather and topographical performance	NE	NE	NE
A.1.3 Incursion Detection	Enable incursion detection	NE	NE	NE
A1.4 Unauthorized Targets	Surveillance of unauthorized targets	O	O	●
A.1.5 Route Deviation	Enable detection of deviations from assigned route	NE	NE	NE
A.2.1 Surveillance Coverage Area	Runway/Taxiway Ramp Area	O NE	● NE	O NE
A.2.2 Surv.Altitude Coverage	Up to 500 feet above surface	●	●	NE
A.2.3 Surv. Approach Coverage	Seamless coverage w/approach radar	●	●	O
A.2.4 Traffic Loading	a) Aircraft (movement area): 100 b) Aircraft (ramp area): 100 c) Ground vehicles (movement area): TBD d) Ground vehicles (ramp): TBD	NE NE NE NE	NE NE NE NE	NE NE NE NE
A.2.5 Covered Speed	a) <250 kts (final approach and runways) b) Up to 80 kts on runway exits c) Up to 50 kts (straight) & 20 kts (curves)	O ● ●	● ● ●	● ● ●
A.2.6 Surveillance Position Accuracy	a) Longitudinal - 10m(95%) b1) Lateral -10m(95%) runway/taxiways b2) Lateral - 3m (95%) stand region c) Vertical position - 20 meters (95%)	O O O ●	● ● NE ●	● ● O O
A.2.7 Surveillance Velocity Accuracy	Speed < 1 knot Direction of movement < TBD	NE NE	NE NE	O NE
A.2.8 Update Rate	<1 per second	O	●	●
A.2.9 Update Success Rate	98%	O	●	●
A.2.10 Latency	< 1 second	●	NE	●
A.2.11 Reference point accuracy	3 meters (95%)	NE	NE	O
A.2.12 Surveillance Integrity	2.0×10^{-3} Vis 1, 2.0×10^{-5} Vis 2,3,4 False targets	NE NE	NE NE	NE O
A.2.13 Surveillance Continuity	2.0×10^{-2} Vis 1, 2.0×10^{-3} Vis 2,3,4	NE	NE	NE
A.2.14 Surveillance Availability	.999	NE	NE	NE

Key: ● - Compliant   O - Not Compliant   NE - Not Evaluated

5.2 Multilateration Surveillance Recommendations

1. Approach coverage/DOP should be addressed as part of the multilateration site surveys for DFW. The system needs to ensure overlapping coverage with the approach radar at the accuracy level equivalent to or better than the radar.

2. Multipath mitigation techniques should be investigated and tested. Improvements in this area may help to reduce the number of receiver transmitter sites required for multilateration. Additionally, reducing the impact of multipath on the transmissions will benefit accuracy performance.

3. A multipath model should be developed and integrated with the multilateration accuracy model. This new model should be used to evaluate DFW sites. Careful site selection can help to minimize the impact of multipath.

4. Analysis/simulations should be performed using ATL data to assess compliance with the following A-SMGCS requirements:

   A.1.3 Incursion Detection

   A.1.5 Route Deviation

5. Mode S multilateration performance should be re-evaluated at DFW to determine if the installed system(s) will achieve A-SMGCS accuracy, update rate and accuracy requirements. ATIDS as implemented at ATL did not demonstrate compliance with these requirements.

6. Mode A/C multilateration should be evaluated at DFW. The test results should be evaluated to determine the number of sites requiring receive only ground stations, as opposed to receive/transmit ground stations.

7. Perform a multilateration test at DFW to ensure compliance with the A-SMGCS requirements that were not evaluated in ATL, including:

   A.1.2 Operating Conditions

   A.2.1 Surveillance Coverage (Ramp Area)

   A.2.2 Traffic Loading

   A.2.7 Surveillance Velocity Accuracy

   A.2.11 Reference Point Accuracy

8. The Ashtech DGPS data files and multilateration input data files collected in ATL should be used to test the processing performance of the DFW multilateration system(s) prior to installation. This approach could be used to provide early resolution of the types of problems that were experienced in ATL including:

a) Tracker related dropout experienced during periods of acceleration and deceleration.

b) Loss of position updates experienced when both Mode S short squitters and ADS-B long squitters are transmitted from the same aircraft.

c) Degraded accuracy performance that occurs when the system fails to use available RTs that provide good DOP position solutions.

5.3 ADS-B Surveillance Recommendations

1. The ADS-B/multilateration ground stations should be configured at DFW to provide maximum approach coverage. This should include using low loss cables and properly configured directional antennas.

2. An evaluation should be performed to determine if the number of ground stations can be reduced for ADS-B only (e.g., no multilateration capability) system installations.

3. Analysis/simulations using ATL data should be performed to determine compliance with the following A-SMGCS requirements:

   A.1.3 Incursion Detection

   A.1.5 Route Deviation

4. A test and evaluation of 1090 MHz ADS-B should be performed at DFW to verify compliance with the following A-SMGCS requirements:

   A.1.2 Operating Conditions

   A.2.1 Surveillance Coverage (Ramp Area)

   A.2.2 Traffic Loading

   A.2.7 Surveillance Velocity Accuracy

   A.2.10 Latency

   A.2.11 Reference Point Accuracy

   Note: Prototype 1090 MHz ADS-B avionics used in testing should be compliant with the RTCA 1090 MHz Minimum Operational Performance Standards. The changes to the ADS-B avionics used in ATL will be significant. Some of the major changes are: increased GPS receiver position and velocity output rate to the ADS-B transmitter; variable ADS-B transmission rate; and transmission of GPS antenna location.

5. ADS-B accuracy performance should be evaluated with WAAS as the position sensor.

6. Enhanced runway incursion safety logic should be developed and tested. This logic can take advantage of the highly accurate position, velocity, and heading information that ADS-B provides. The potential benefits are enhanced time to alert and false alert

performance of safety logic. Additionally, ADS-B data can be used to determine the aircraft nose and tail location, thus providing a means to detect runway safety zone violations.

7. Avionics based safety logic using ADS-B surveillance should be developed and tested for surface operations.

8. Vehicle-to-vehicle ADS-B should be re-tested with the NASA aircraft transmitting ADS-B data alternatively out of the top and bottom antennas for surface operations. The tested implementation was to squitter out the top and bottom antennas for airborne and top only for surface operations. Going to an alternating squitter implementation may help ADS-B reception performance for an aircraft following another aircraft.

9. Vehicle-to-vehicle ADS-B surveillance should be evaluated with two aircraft. The ATL testing was performed with an aircraft and a ground vehicle.

10. Methods such as 1090 MHz ADS-B reinforcement should be investigated to resolve vehicle to vehicle surveillance reception performance problems.

11. Ground vehicle ADS-B data link (assuming not 1090 MHz) tests should be performed. The performance should be evaluated against the A-SMGCS requirements.

5.4 ASDE-3 Surveillance Recommendations

1. The problem of false targets needs to be resolved.

2. Analysis/simulations using ATL data should be performed to determine compliance with the following A-SMGCS requirements:

    A.1.3 Incursion Detection

    A.1.5 Route Deviation

3. Test and evaluation of ASDE-3 surveillance should be performed at DFW to verify compliance with the following A-SMGCS requirements:

    A.1.2 Operating Conditions

    A.2.2 Surveillance Altitude Coverage

    A.2.4 Traffic Loading

4. Test and evaluation of ground vehicle surveillance performance should be performed.

REFERENCES

1. *Plan of Test for the Low Visibility Landing and Surface Operations (LVLASO) System Flight Experiment*, S. Young & D. Jones, NASA Langley Research Center (Unpublished).

2. *Draft Manual of Advanced Surface Movement Guidance and Control Systems (A-SMGCS),* ICAO All Weather Operations Panel, June 1997.

3. *Minimum Aviation Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B),* Version 6.2, RTCA Paper No.350-97/SC186-110, November 1997.

4. *Positive Identification of Aircraft on Airport Movement Area – Results of FAA Trials*, Rick Castaldo, Carl Evers, Alex Smith, IEEE Aerospace and Electronic Systems Magazine, June 1996.

5. *Minimum Operational Performance Standards for ATCRBS/Mode S Airborne Equipment,* RTCA/DO-181A, 1993.

APPENDIX A

SURFACE SURVEILLANCE REQUIREMENTS

Introduction

This section describes the performance requirements for airport surface surveillance. The requirements shown here are a compendium of those that have been developed by ICAO and RTCA [1, 2] for Advanced Surface Movement Guidance and Control Systems (A-SMGCS). The requirements are categorized here according to operational and performance requirements. Operational requirements are qualitative in nature, and describe the basic functional capability of the system. Performance requirements are primarily those that have a quantified performance specified.

A.1 Operational Requirements

A.1.1 Identification

The surveillance function should provide identification and labelling on authorized movements.

A.1.2 Operating Conditions

The surveillance function should be immune to operationally significant adverse effects of weather and topographical conditions.

A.1.3 Incursion Detection

The surveillance function should enable the detection of any incursions into the areas used for aircraft movement.

A.1.4 Unauthorized Targets

The surveillance function should continuously indicate the position of unauthorized aircraft, vehicles and objects, while they are in restricted areas.

A.1.5 Route Deviations

The surveillance function should provide adequate information to enable detection of deviations from the assigned route.

A.2 Performance Requirements

A.2.1 Surveillance Coverage area

Area of the aerodrome in which surveillance is provided.
Minimum: Airport movement area

A.2.2 Surveillance Altitude coverage

Altitude over the coverage area up to which the surveillance is required to be provided.
Minimum: Up to approximately 500 ft.

A.2.3 Surveillance Approach coverage

Distance from each runway direction at which inbound aircraft will be under surveillance.
Minimum: From at least 10 NM.

Note - This may be provided by approach surveillance radar. The primary requirement is to provide seamless coverage from the approach phase to the airport surface.

A.2.4 Traffic loading

Number of aircraft/vehicles to be covered by the surveillance function, defined as the maximum number of:

a) Aircraft on movement area:	100
b) Aircraft on apron area (where required):	100
c) Ground vehicles on movement area:	TBD
d) Ground vehicles on apron area (where required):	TBD

A.2.5 Covered speed

Aircraft/vehicle speeds which the surveillance function must accommodate.

a) Up to 250 kts for aircraft on final approach, missed approach and runways

b) Up to 80 kts on runway exits

c) Up to 50 kts on straight taxiways and 20 kts in curves.

A.2.6 Surveillance position accuracy

The difference between a target's measured position and its true position. It is specified in terms of the 95% horizontal and vertical accuracy performance.

a) Longitudinal position accuracy

Minimum: 10 m

b) Lateral position accuracy

1) Runways and taxiways

Minimum: 10 m

2) Stand (apron) region

Minimum: 3 m

c) Vertical position accuracy

Minimum: 20 m

A.2.7 Surveillance velocity accuracy

The difference between a target's measured velocity (speed and heading) and its true velocity. It is specified in terms of the 95 per cent lateral and vertical speed and heading performance.

Speed: 1 knot
Direction of movement: TBD

A.2.8 Update rate

Maximum time interval at which surveillance reports must be updated.

1 second

A.2.9 Update success rate

The minimum probability of receiving a surveillance report on each target.

98%

A.2.10 Latency

The maximum time between when the target position is determined and its transmission to or use by the control function.

1 second maximum

A.2.11 Reference point accuracy

Longitudinal accuracy of the location on the aircraft or vehicle to which the system will be referring in a surveillance position report.

Maximum 3 m

A.2.12 Surveillance integrity

Surveillance integrity relates to the trust which can be placed in the correctness of the surveillance information. Integrity includes the ability of the surveillance function to provide timely and valid warnings to the user when the system must not be used for the intended operation.

Surveillance integrity risk is the probability of an undetected failure which results in incorrect surveillance information potentially leading to a loss of separation or other hazardous condition.

Note - This leads to derived requirements for minimization of false targets.

Table A-1. Surveillance Integrity

	Visibility Condition		
	1	2,3	4
Integrity Risk (per hour)	2.0×10^{-3}	2.0×10^{-5}	2.0×10^{-6}
Time to Alert (seconds)	10	10	2

A.2.13 Surveillance continuity

Surveillance continuity is the capability of the surveillance function (comprising all elements necessary to process and transmit surveillance information) to perform the surveillance function without non-scheduled interruption during the intended surface operation.

Surveillance continuity risk is the probability that the system will be interrupted and not provide surveillance information over the period of the intended operation.

Table 5-14. Surveillance Continuity Risk (Per Hour)

	Visibility Condition		
	1	2,3	4
Continuity	2×10^{-2}	2×10^{-3}	2×10^{-3}

A.2.14 Surveillance availability

Surveillance availability is an indication of the ability of the surveillance function to provide usable service within the specified coverage area, and is defined as the portion of time during which the information is used by air traffic control and/or the aircraft flight crew.

Surveillance availability is specified in terms of the probability of the surveillance function being available at the beginning of the intended operation.

0.999 (all visibility conditions)

REFERENCES

Draft Manual of Advanced Surface Movement Guidance and Control Systems (A-SMGCS), 16th Meeting of the ICAO All Weather Operations Panel, Montreal, June 1997.

The Role of GNSS in Supporting Airport Surface Operations, Draft Report, RTCA SC-159, Working Group 4B, August 1998.

APPENDIX B

MULTILATERATION DATA

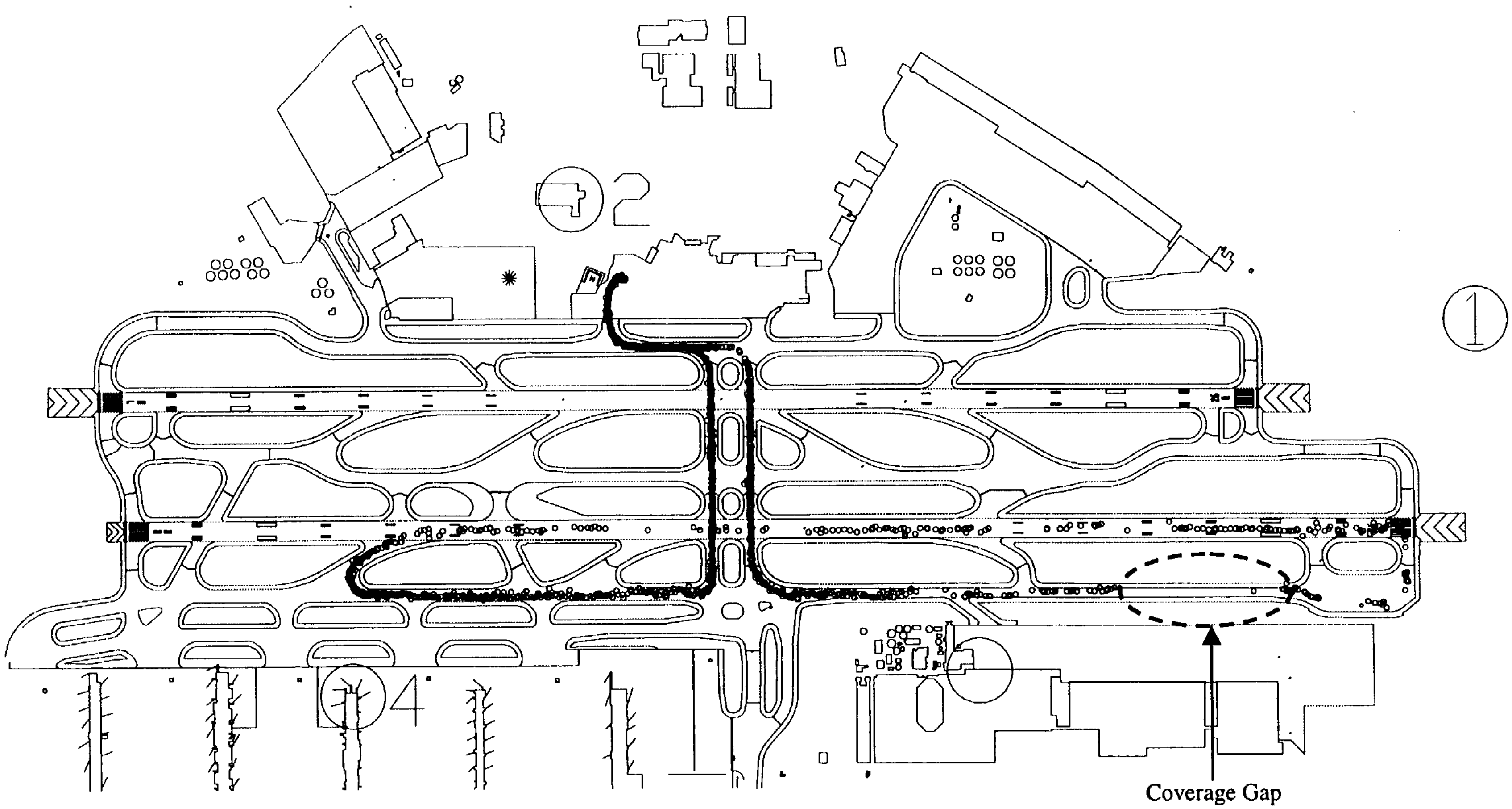

Figure B-1. Run 49 Multilateration Coverage Plot

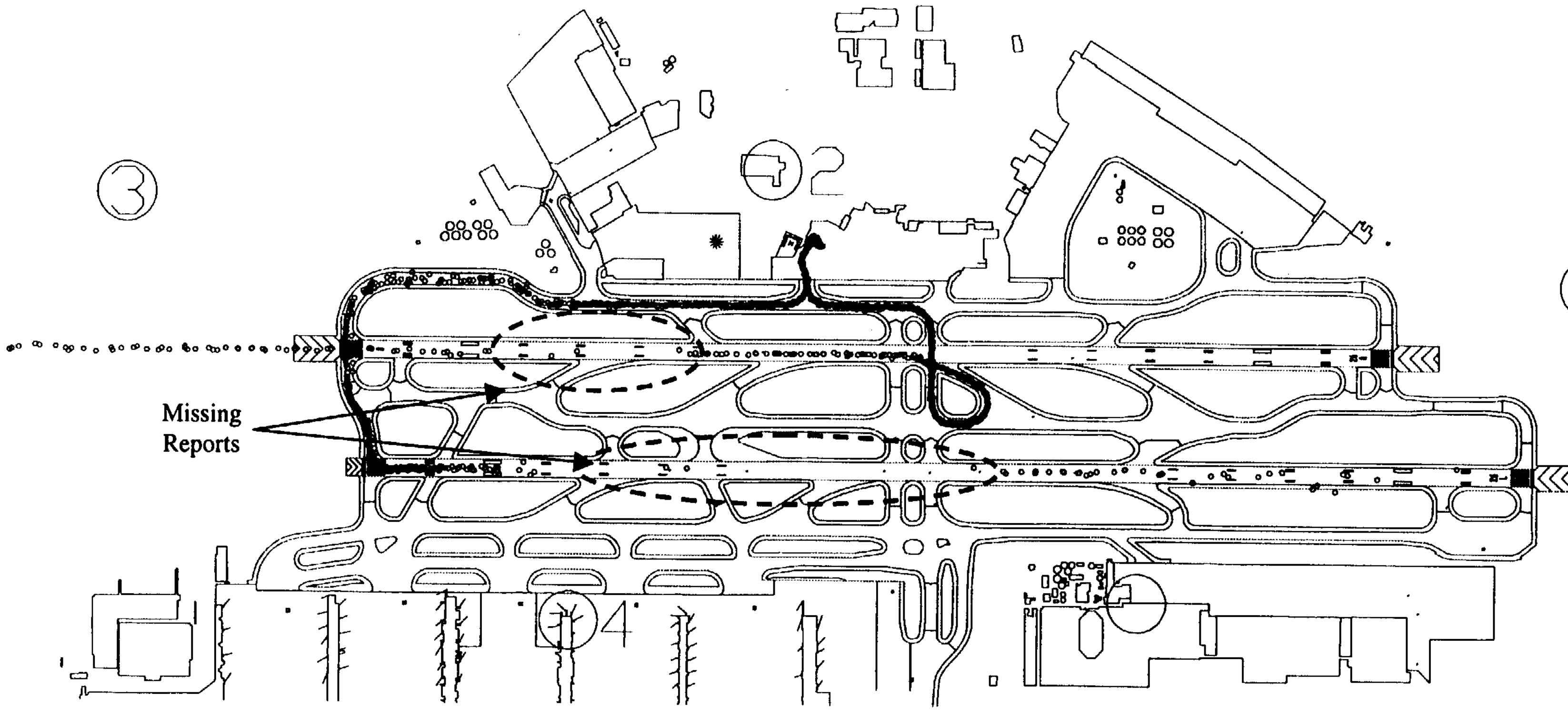

Figure B-2. Run 43 Multilateration Coverage Plot Showing Lost Updates During Acceleration/Deceleration Periods

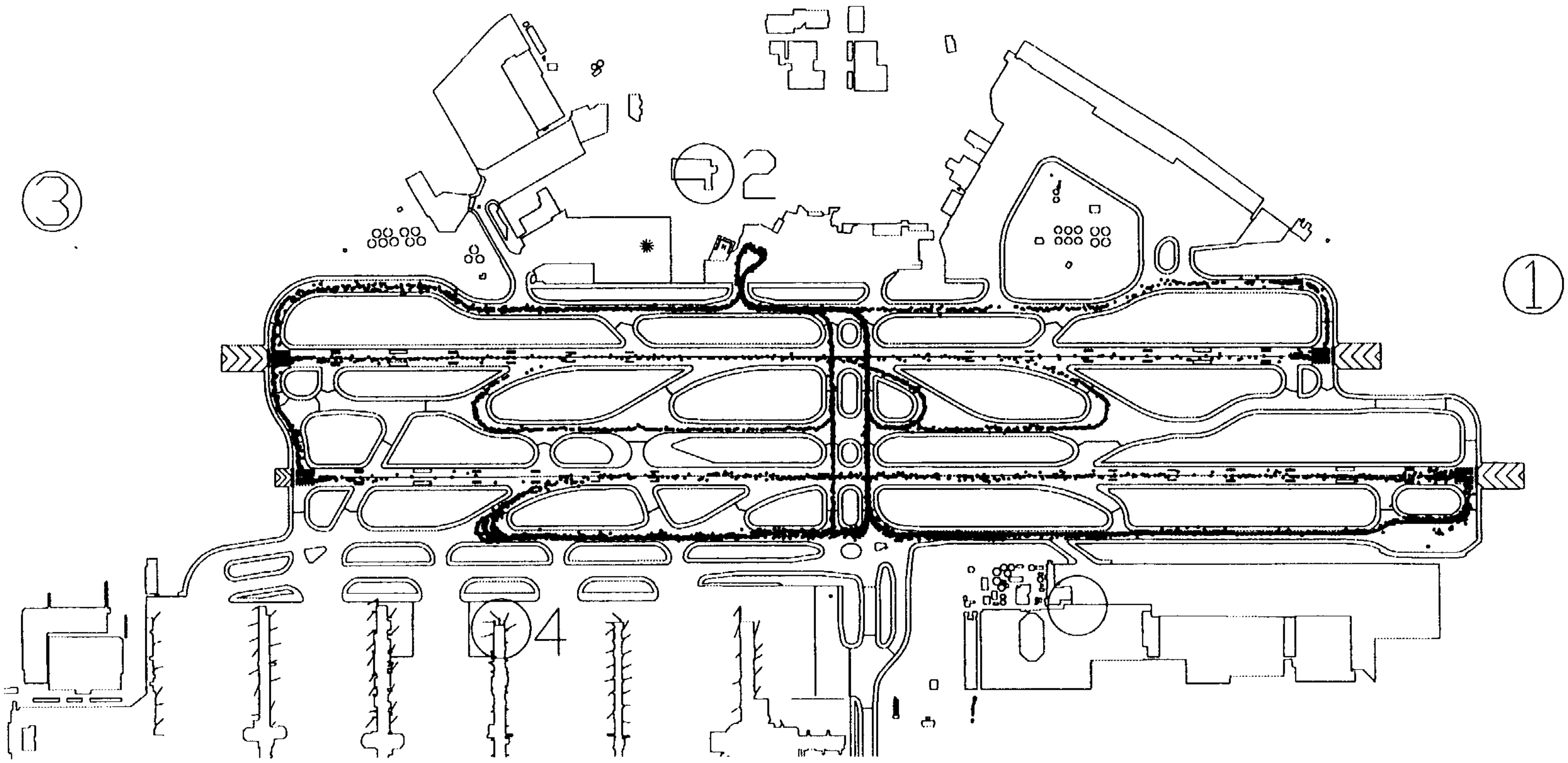

Figure B-3. Coverage Plot for Composite of Overlaid Runs

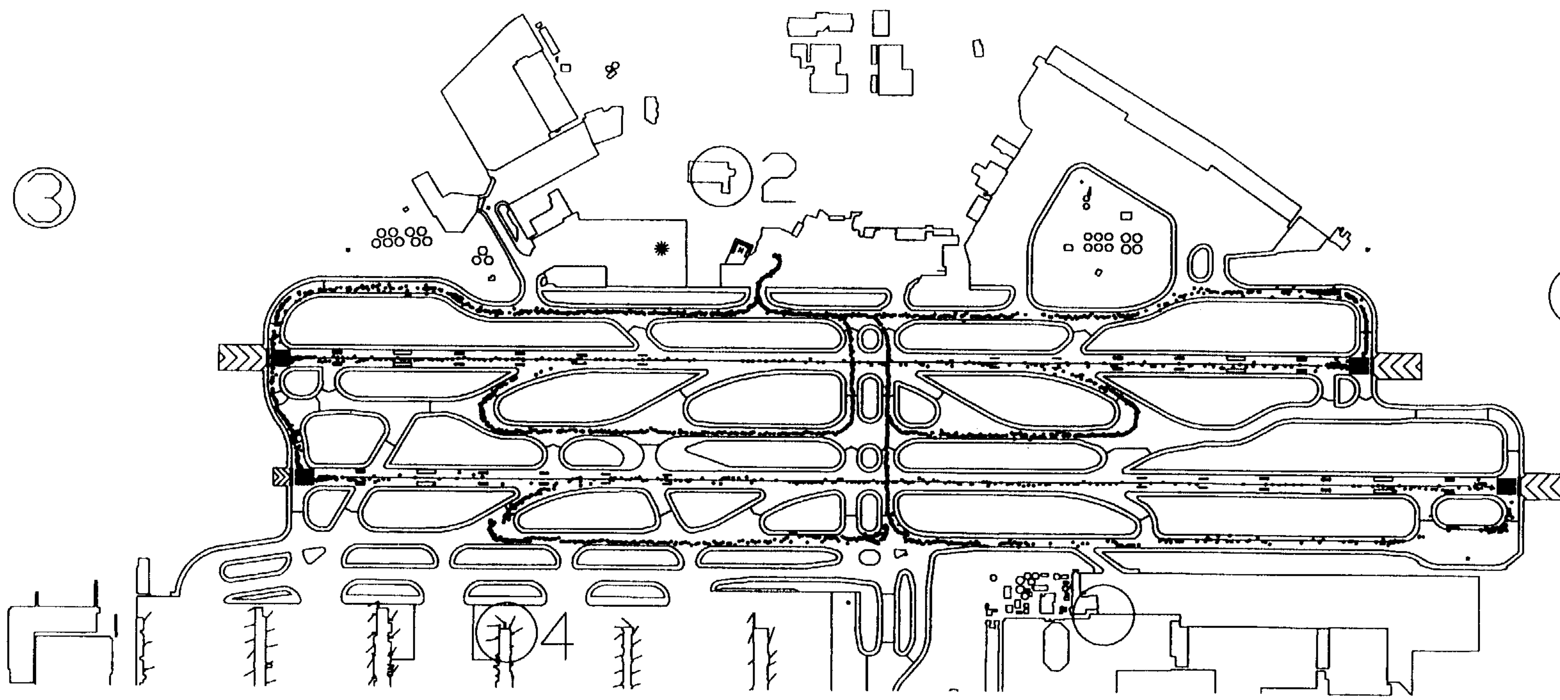

Figure B-4. Corrected Multilateration Master File Coverage Plot

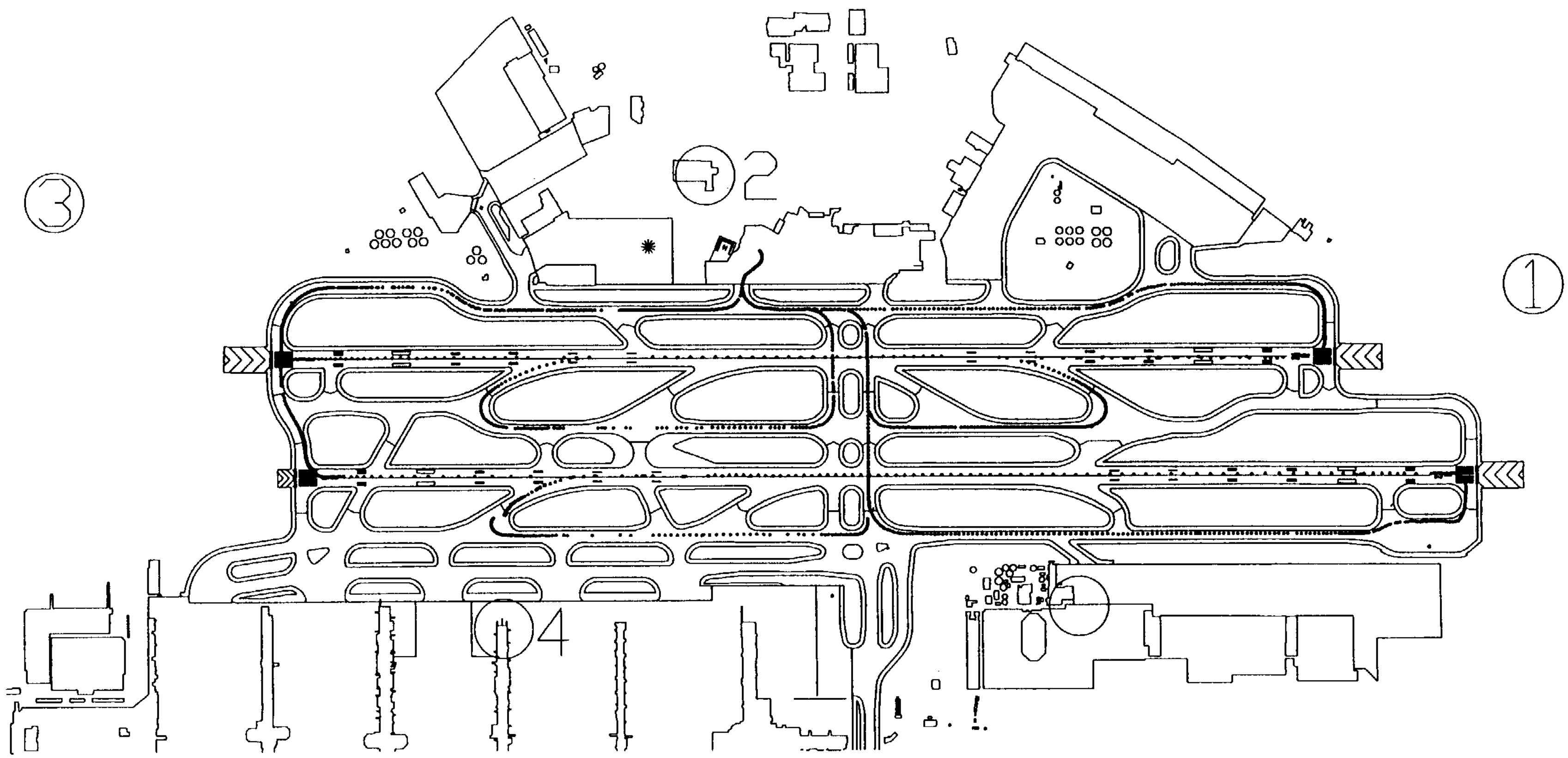

Figure B-5. Corrected Master File RT 0 Coverage Plot

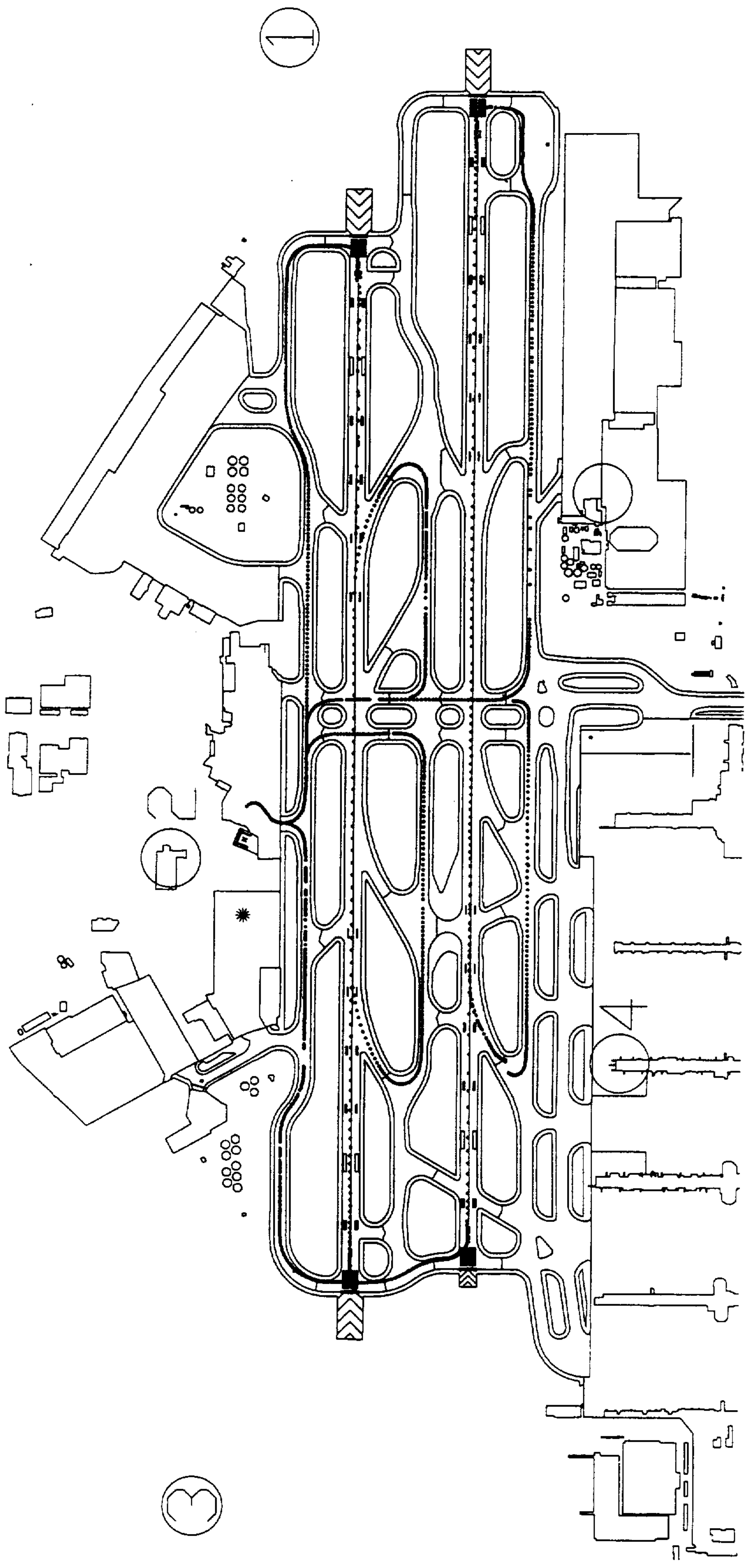

Figure B-6. Corrected Master File RT 1 Coverage Plot

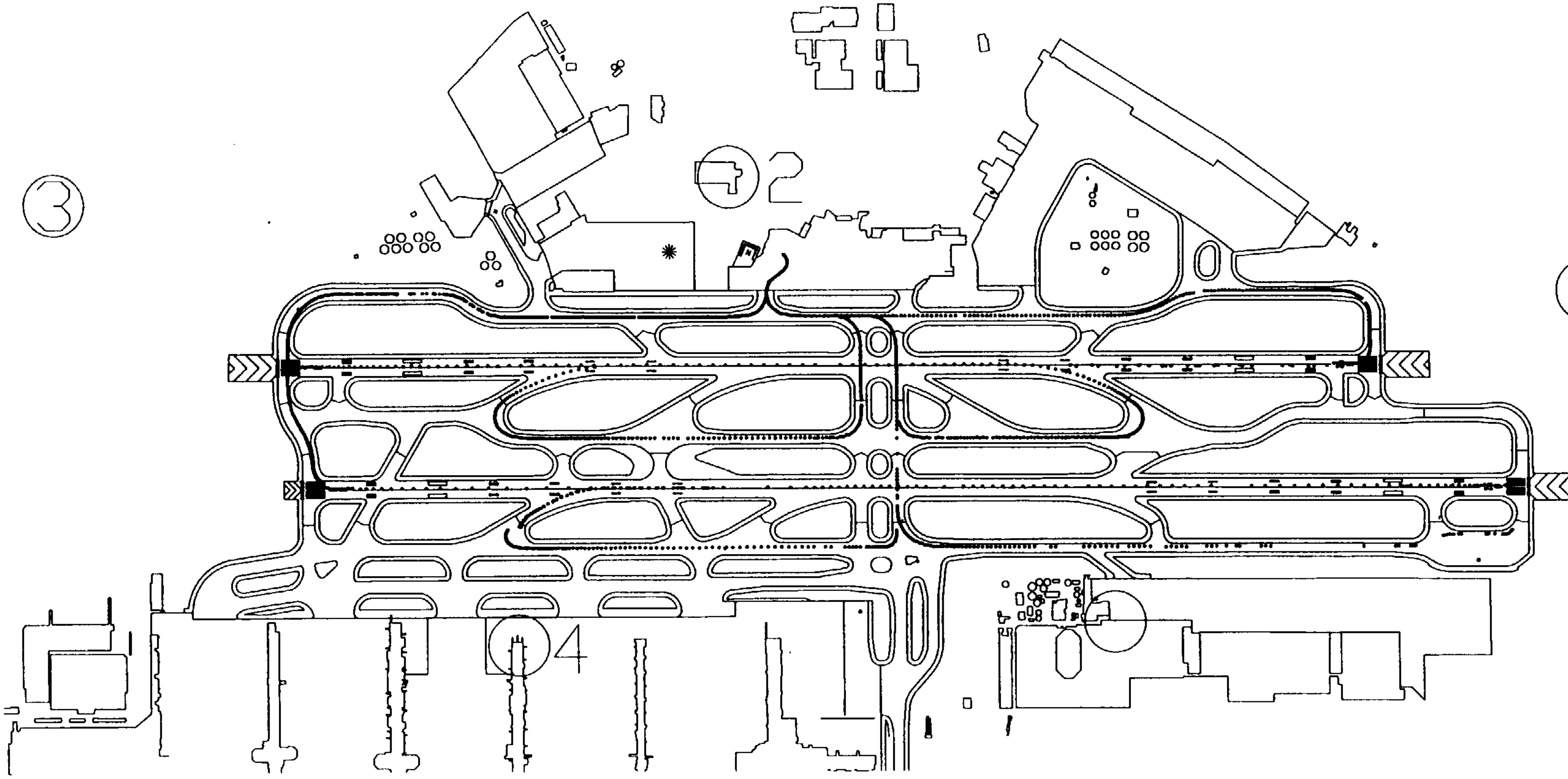

Figure B-7. Corrected Master File RT 2 Coverage Plot

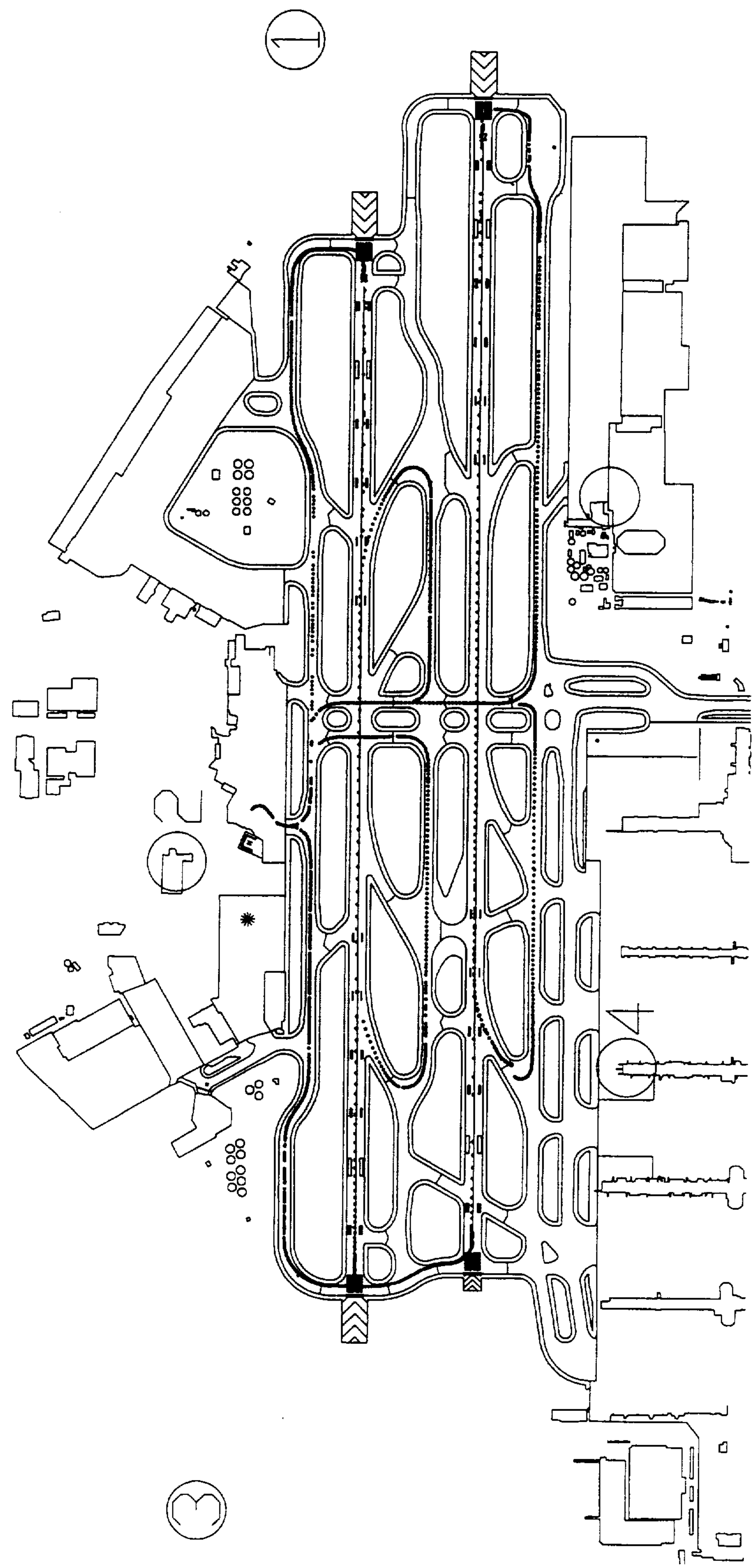

Figure B-8. Corrected Master File RT 3 Coverage Plot

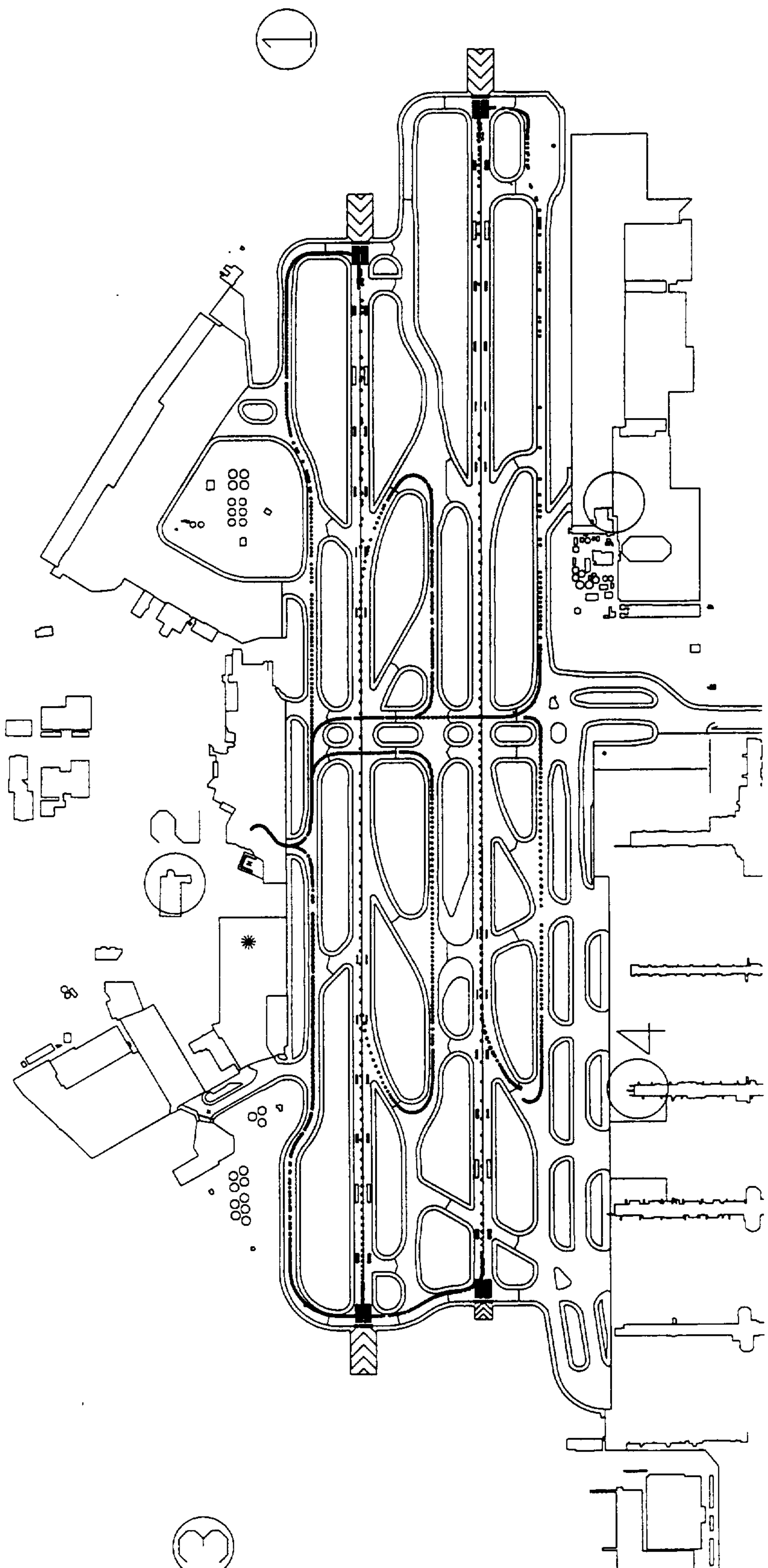

Figure B-9. Corrected Master File RT 4 Coverage Plot

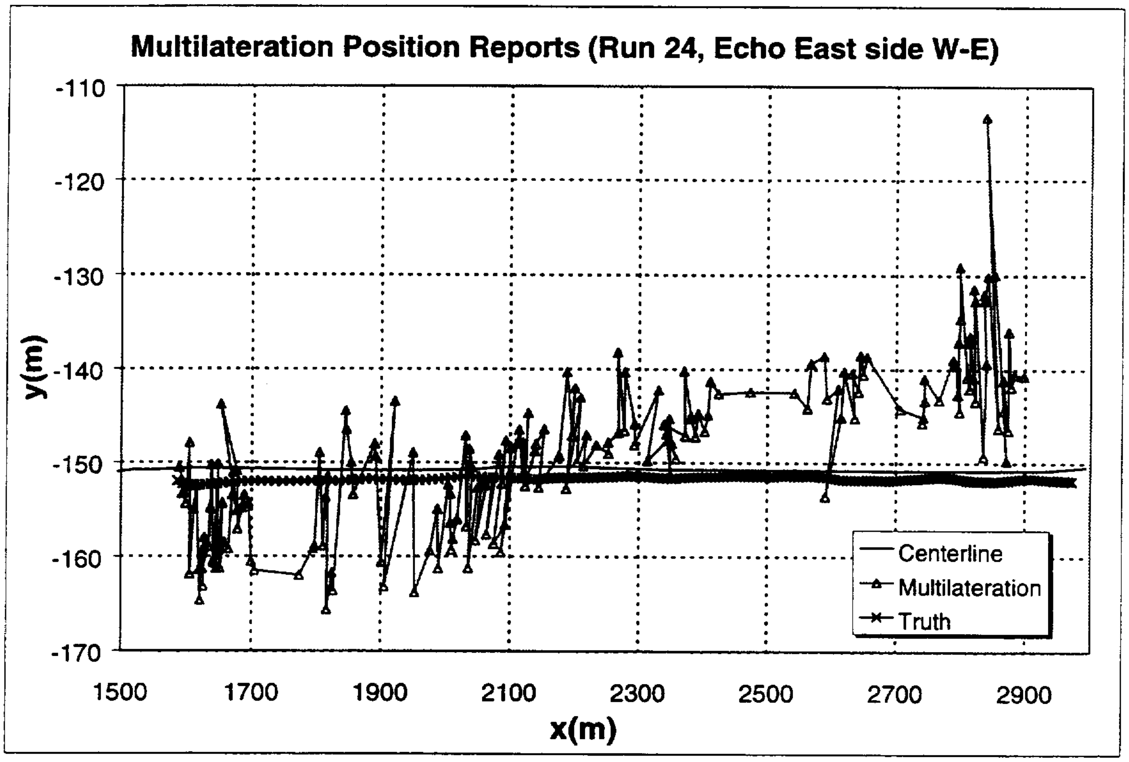

Figure B-10. Multilateration Position Reports (Run 24, Taxiway Echo East side)

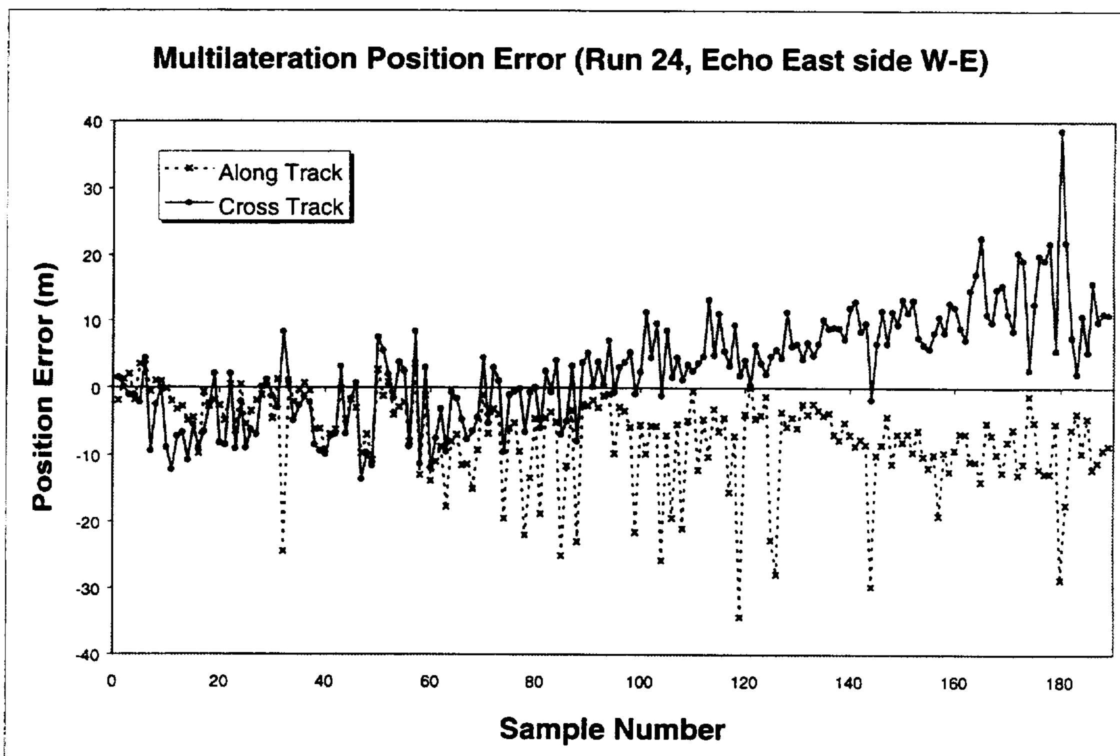

Figure B-11. Multilateration Position Errors (Run 24, Taxiway Echo East side)

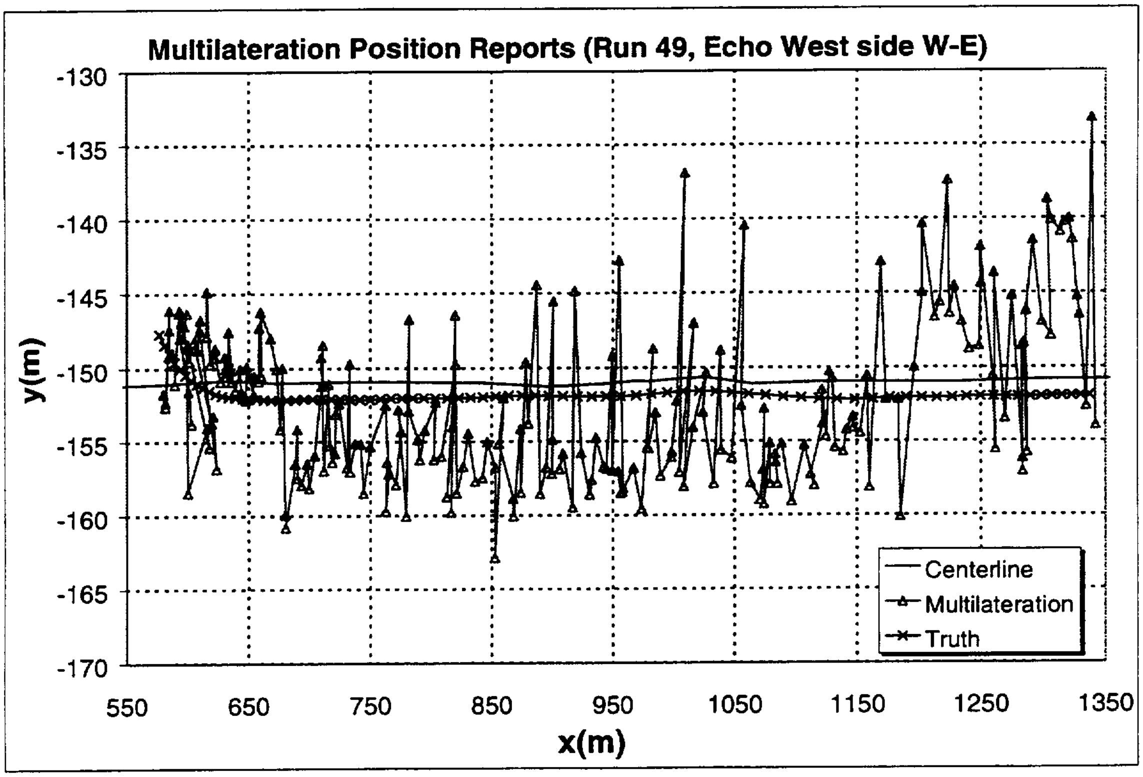

Figure B-12. Multilateration Position Reports (Run 49, Taxiway Echo West side)

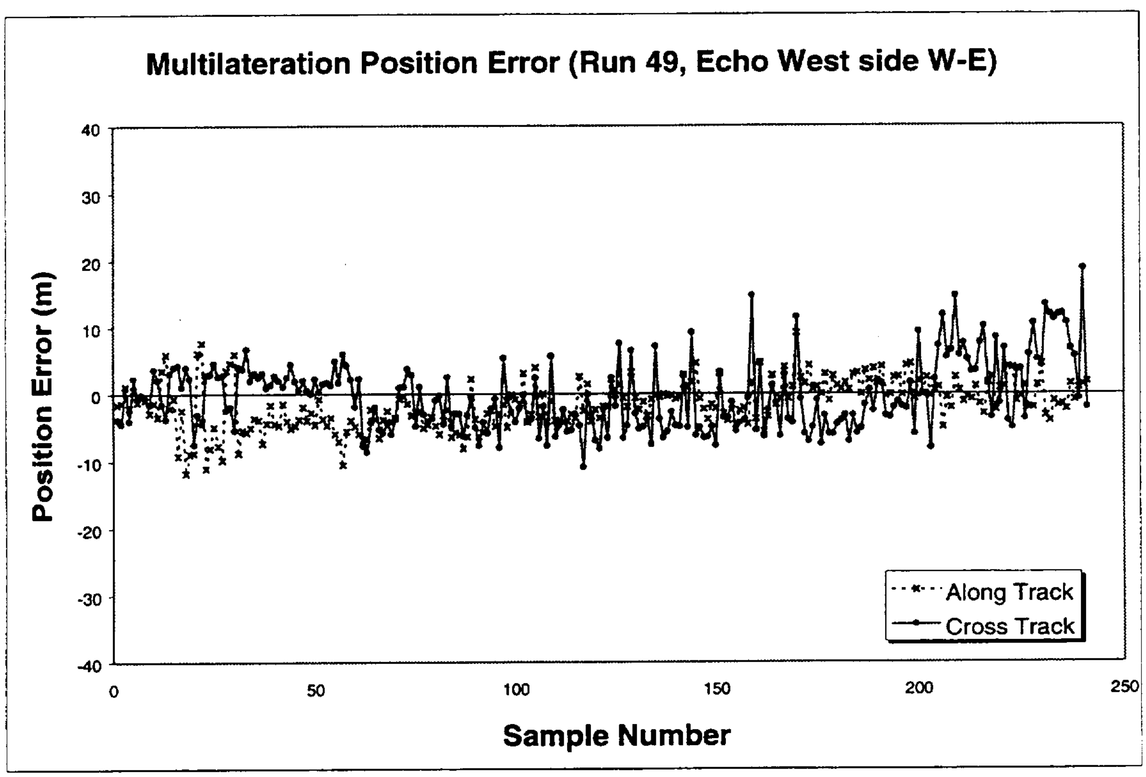

Figure B-13. Multilateration Position Errors (Run 49, Taxiway Echo West side)

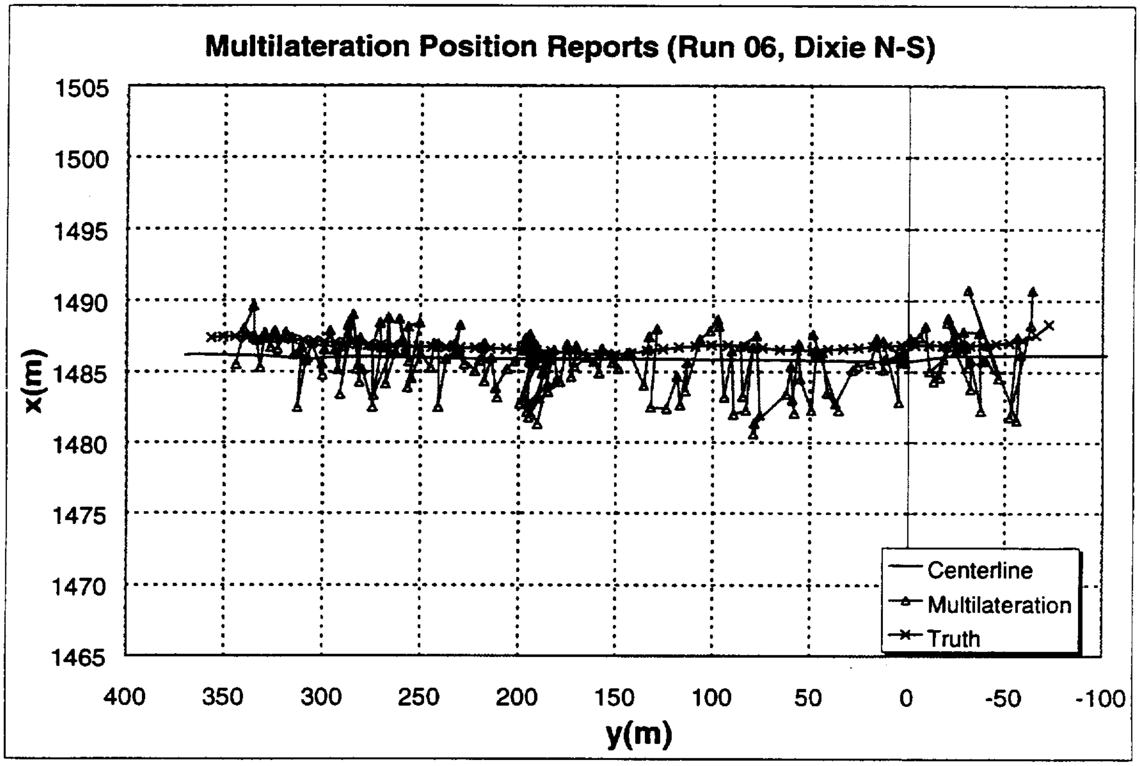

Figure B-14. Multilateration Position Reports (Run 06, Taxiway Dixie)

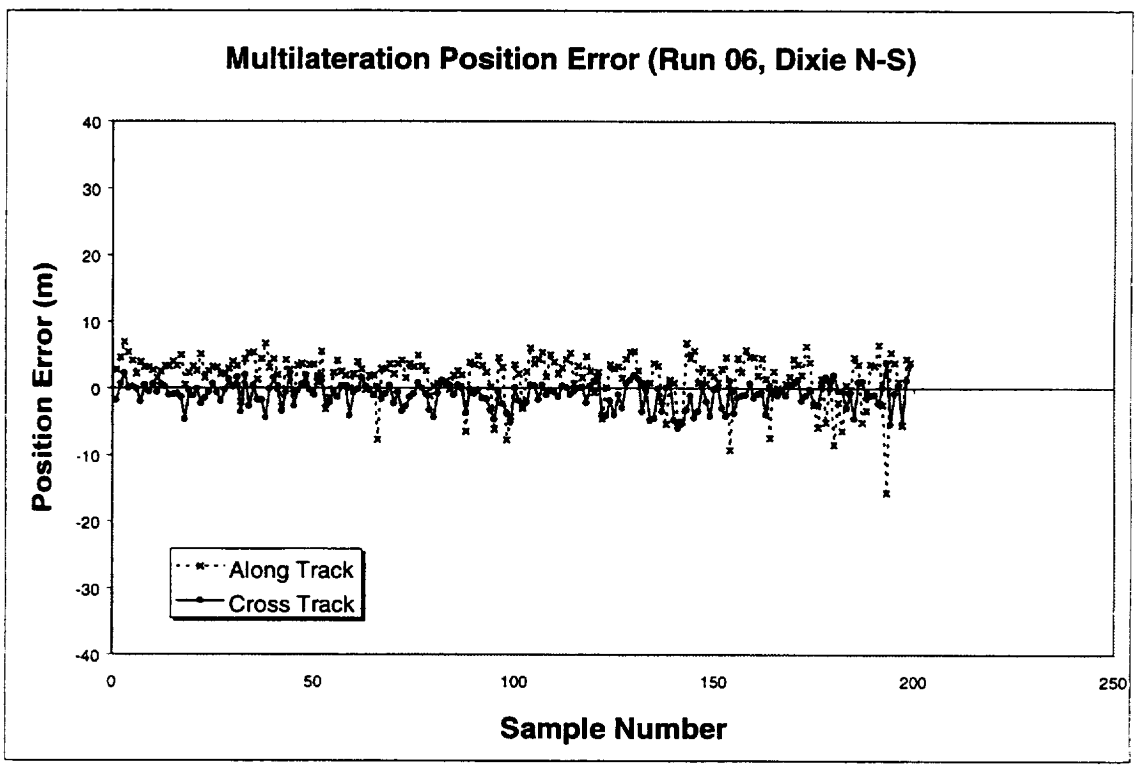

Figure B-15. Multilateration Position Errors (Run 06, Taxiway Dixie)

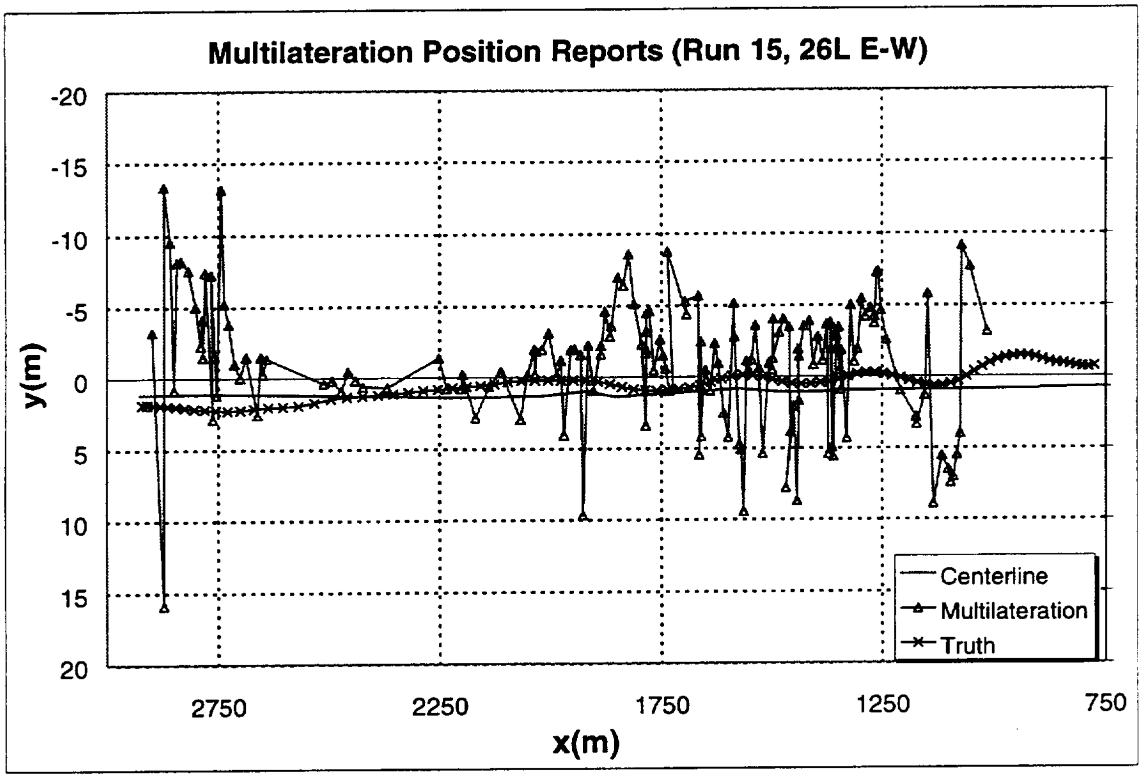

Figure B-16. Multilateration Position Reports (Run 15, Runway 26L)

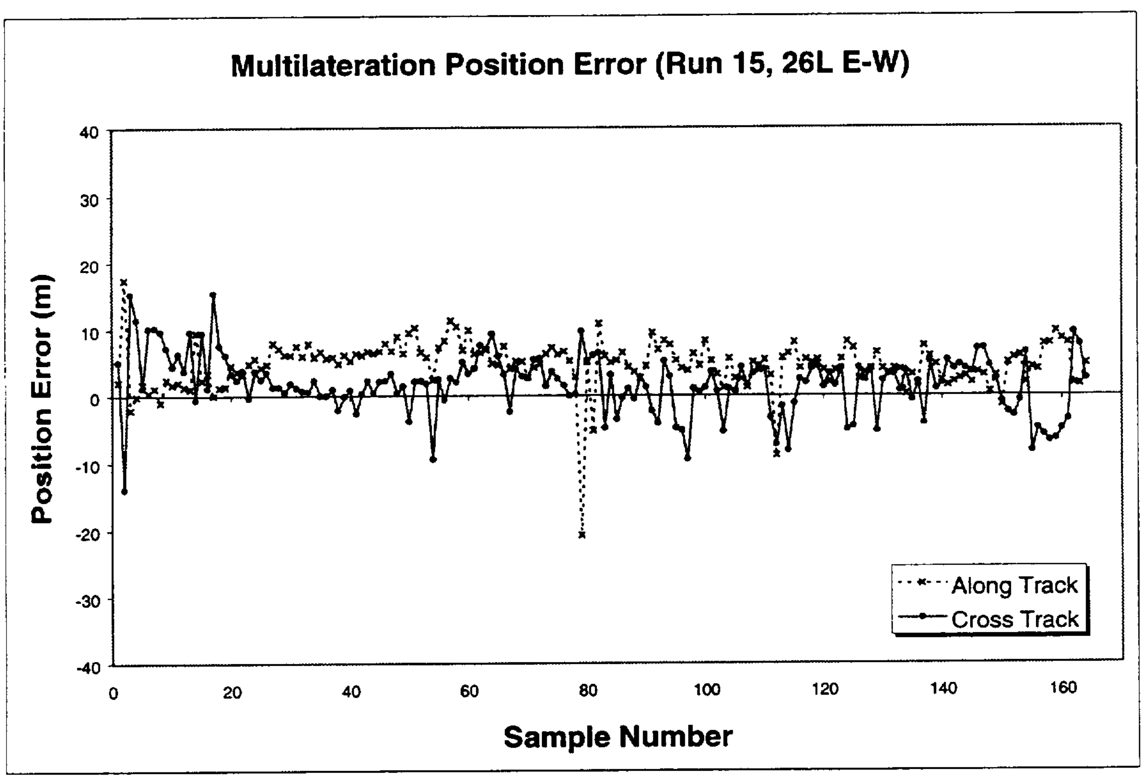

Figure B-17. Multilateration Position Errors (Run 15, Runway 26L)

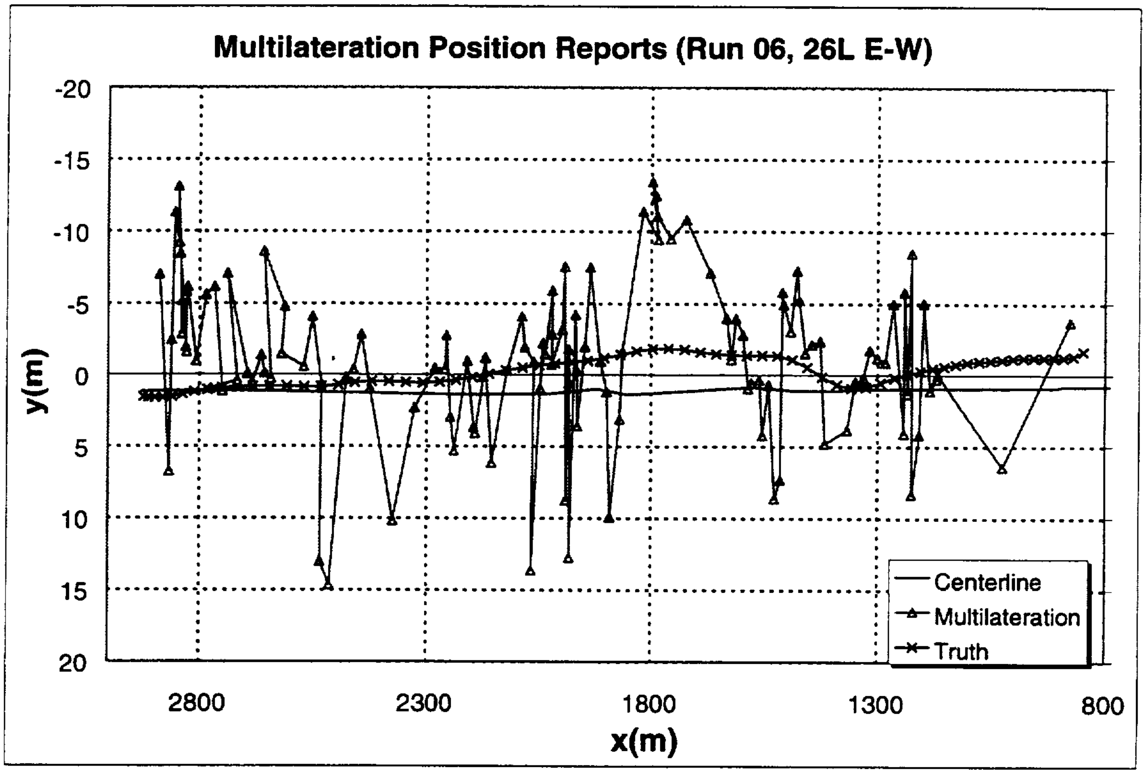

Figure B-18. Multilateration Position Reports (Run 06, Runway 26L)

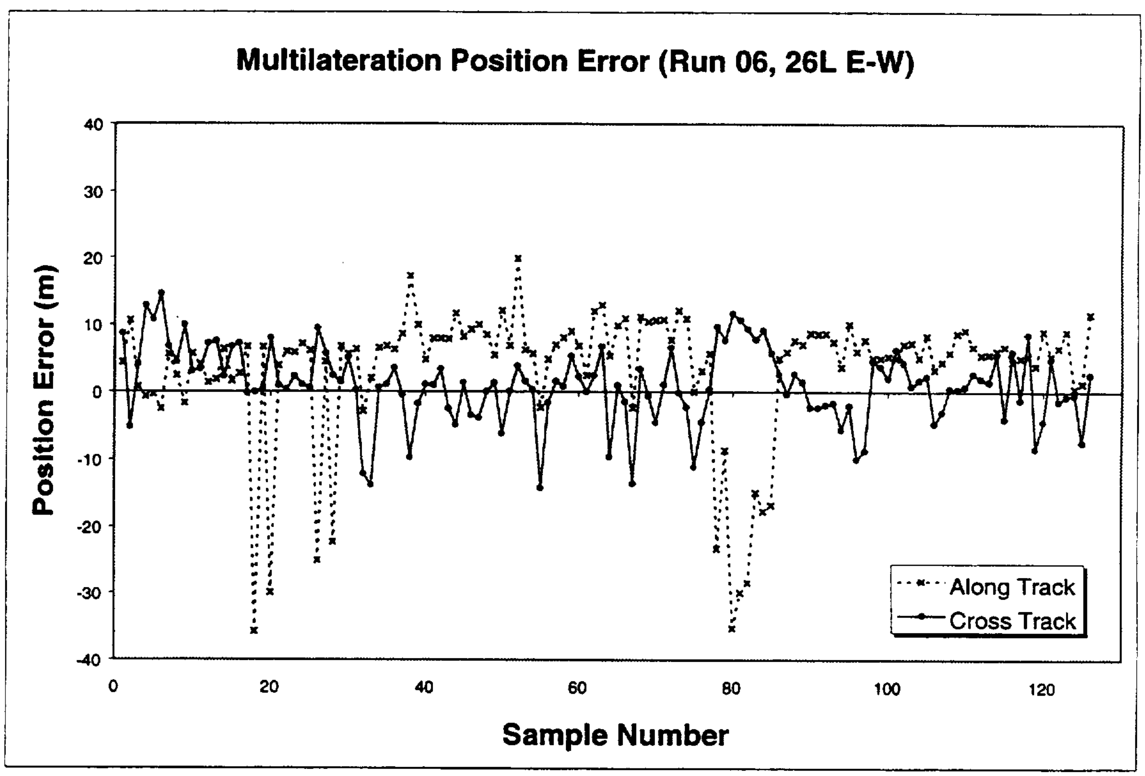

Figure B-19. Multilateration Position Errors (Run 06, Runway 26L)

APPENDIX C

ADS-B DATA

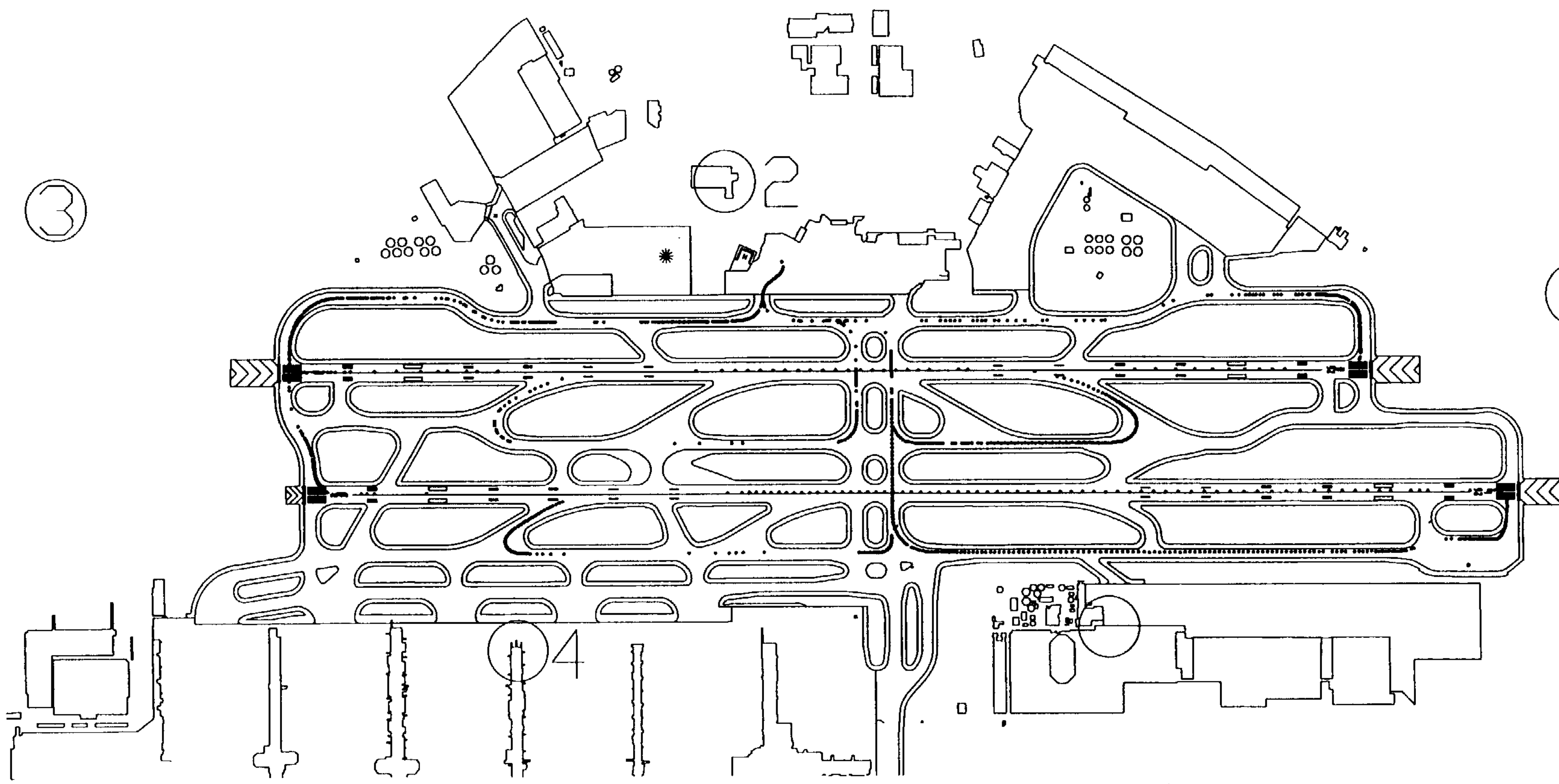

Figure C-1. ADS-B Coverage For RT 0 (Delta Hangar)

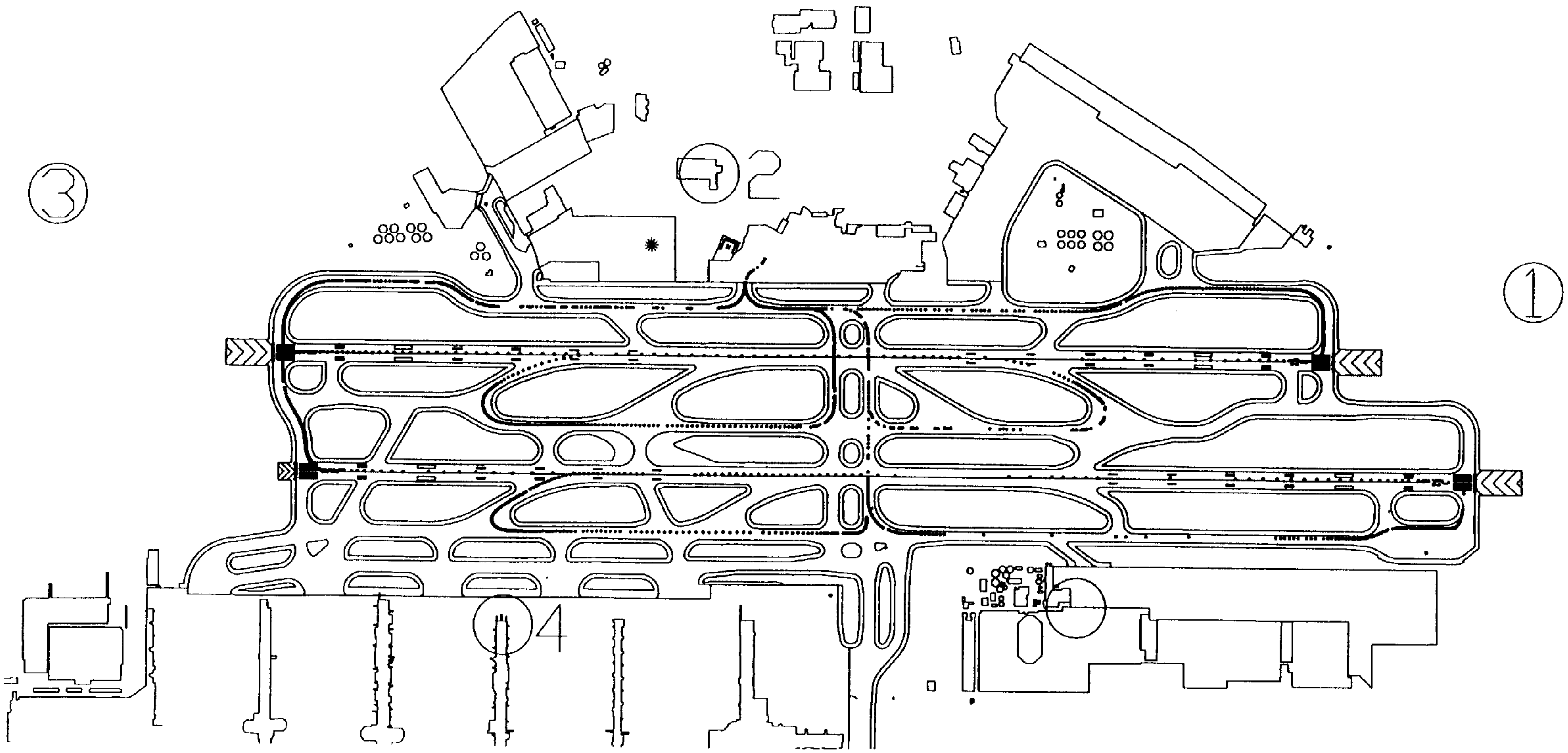

Figure C-2. ADS-B Coverage For RT 1 (Ford Plant)

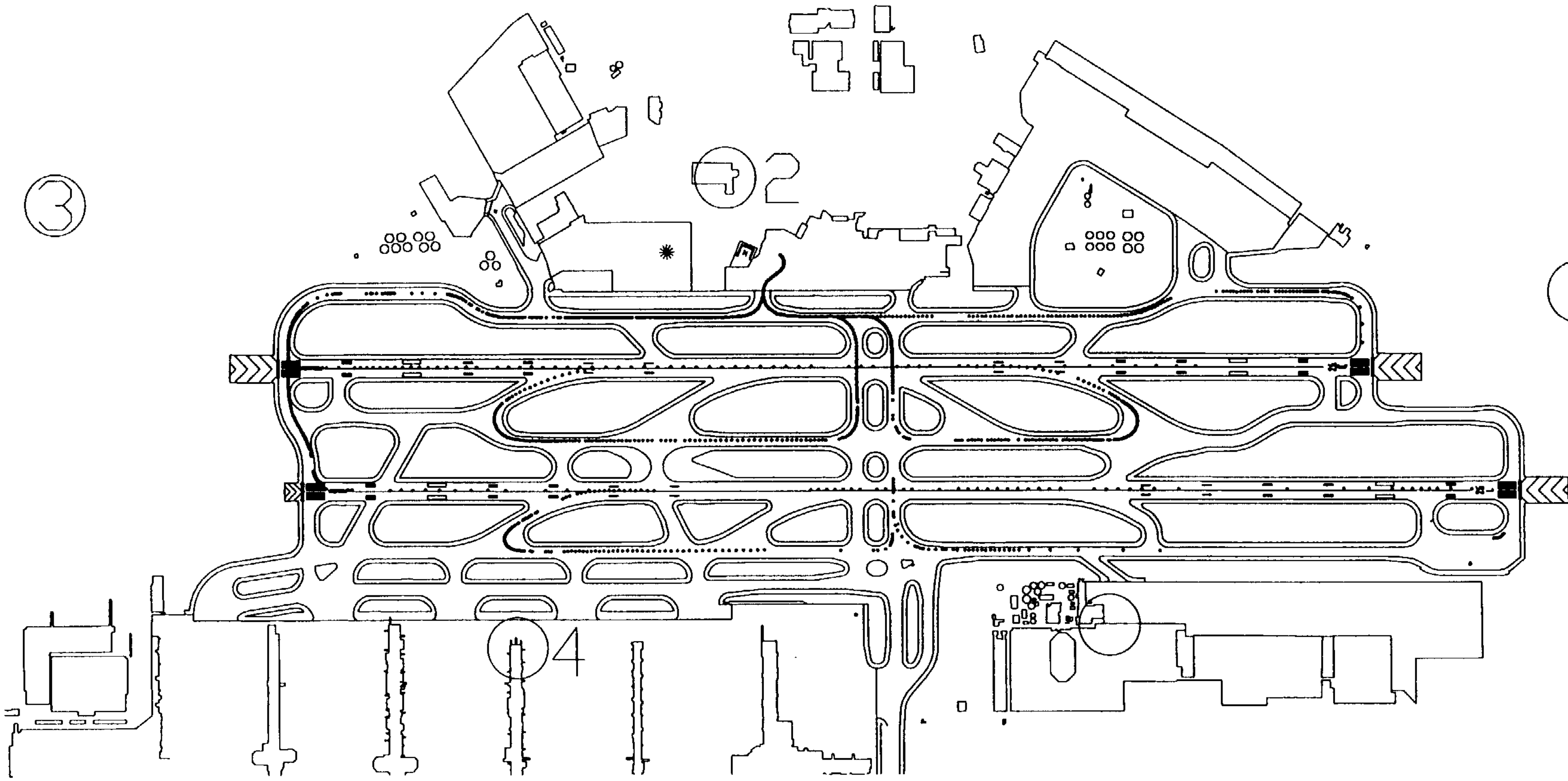

Figure C-3. ADS-B Coverage For RT 2 (Renaissance Hotel)

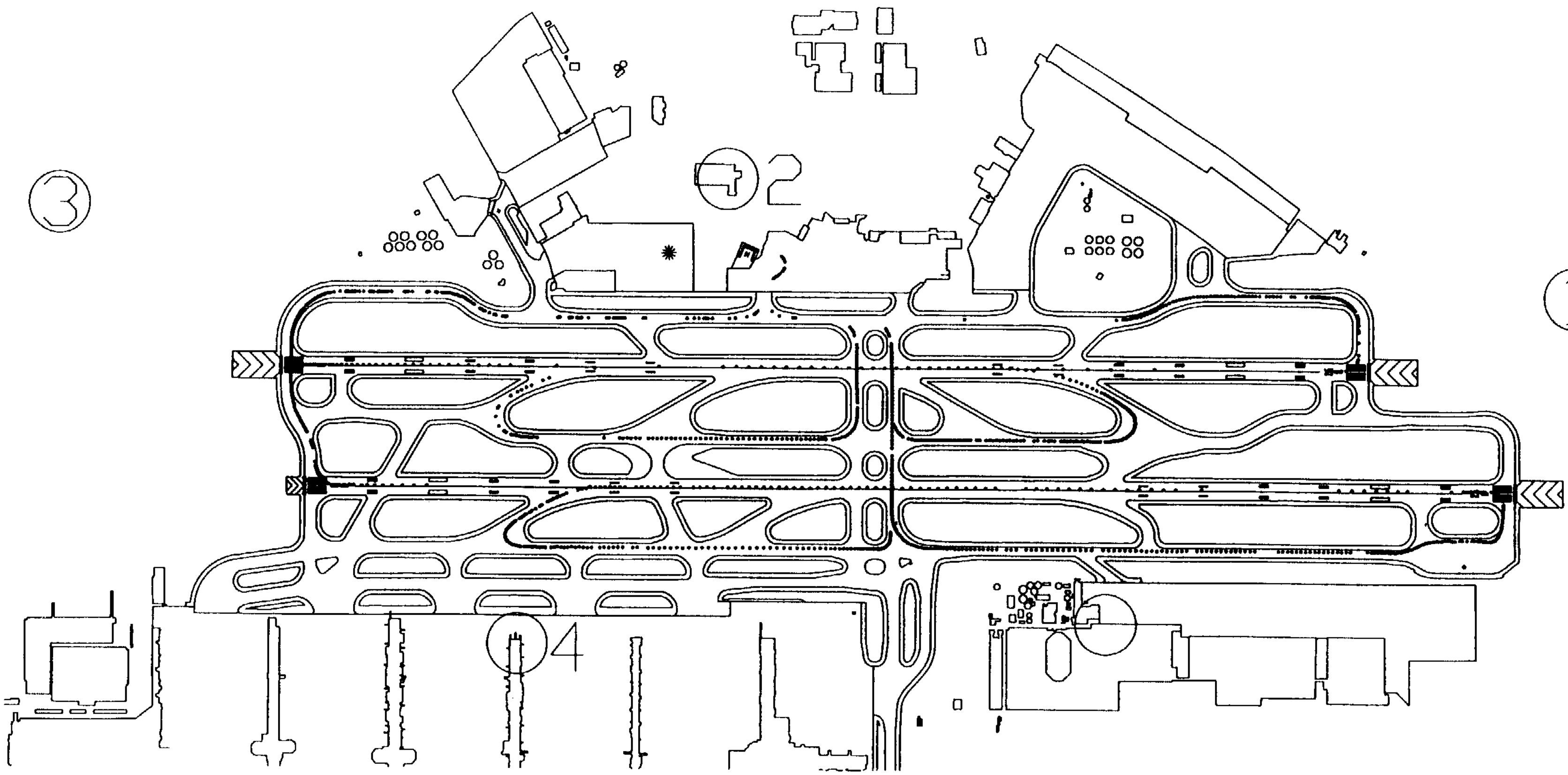

Figure C-4. ADS-B Coverage For RT 3 (FAA Region)

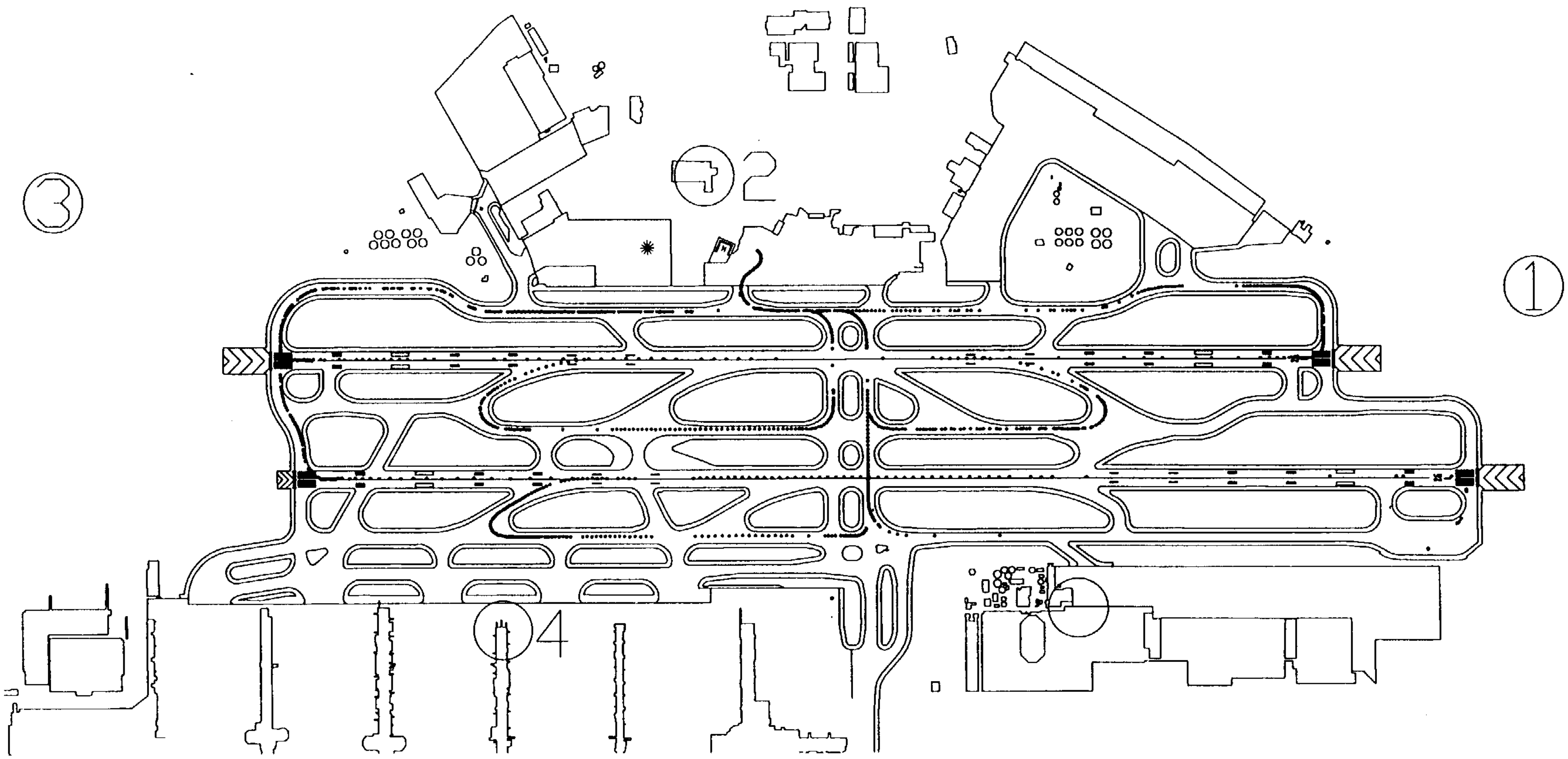

Figure C-5. ADS-B Coverage For RT 4 (Concourse C)

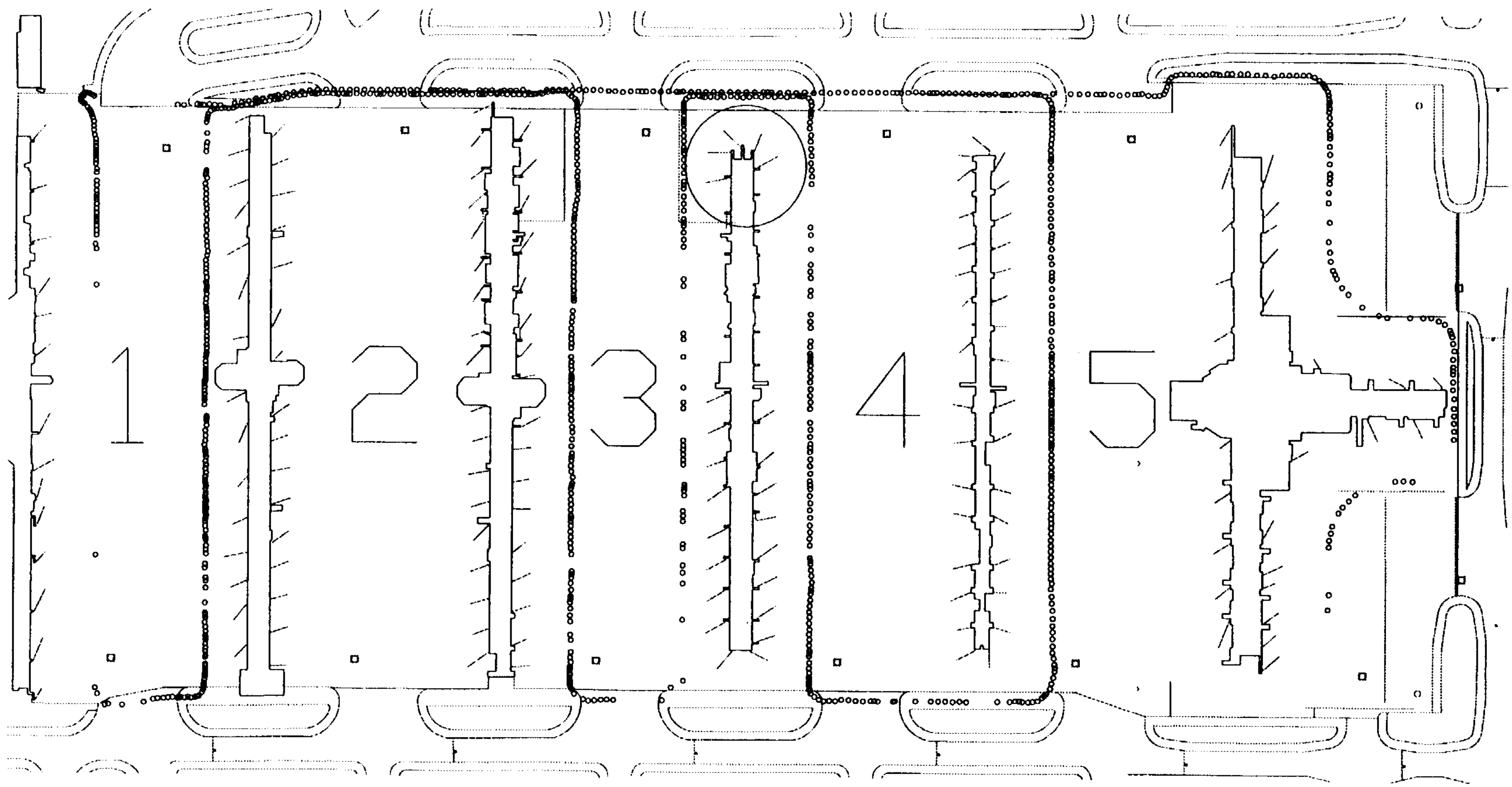

Figure C-6. Ramp Area ADS-B Coverage: 1 of 5 Received Error-Free

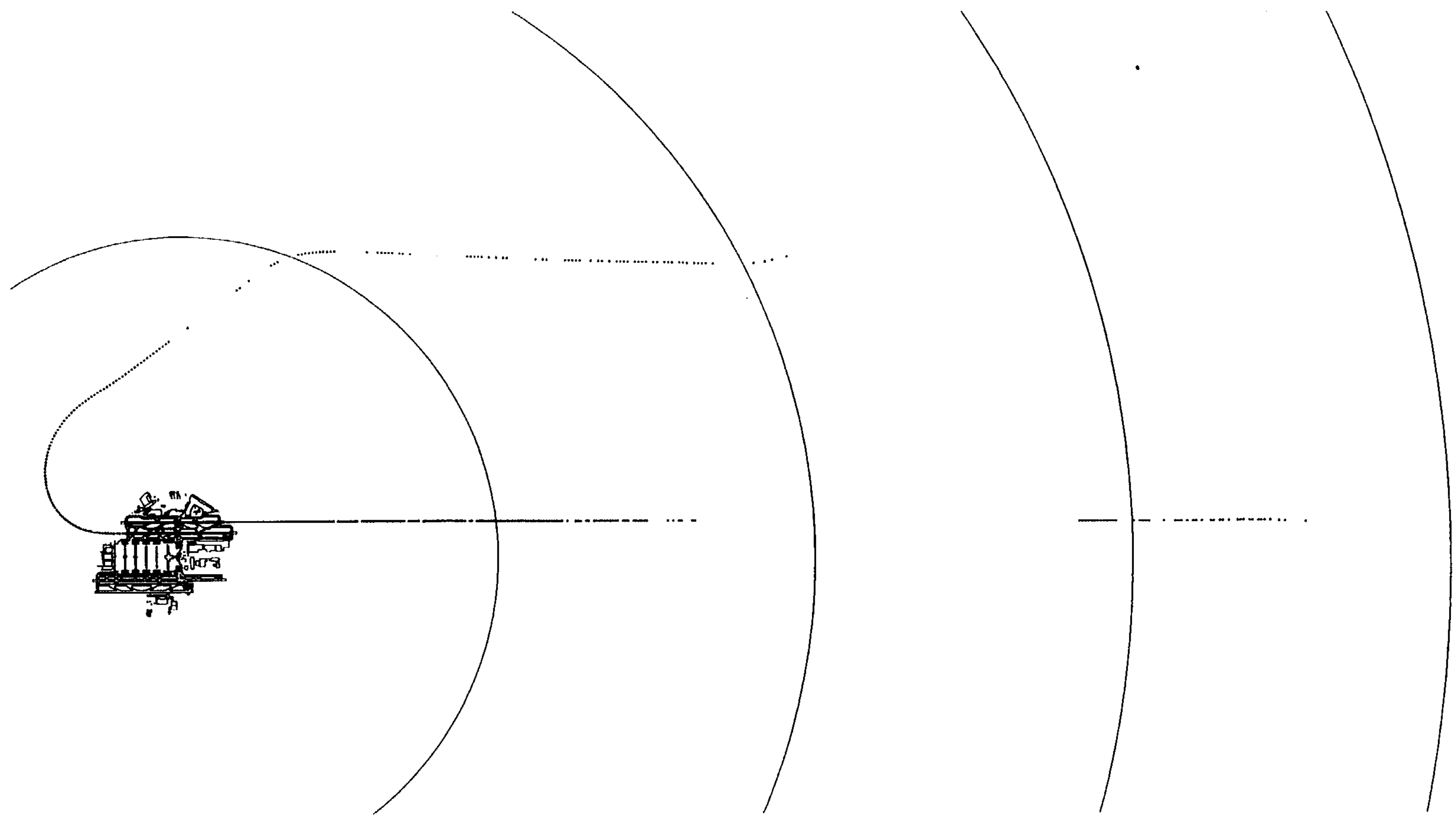

Figure C-7. ATIDS ADS-B Approach Coverage

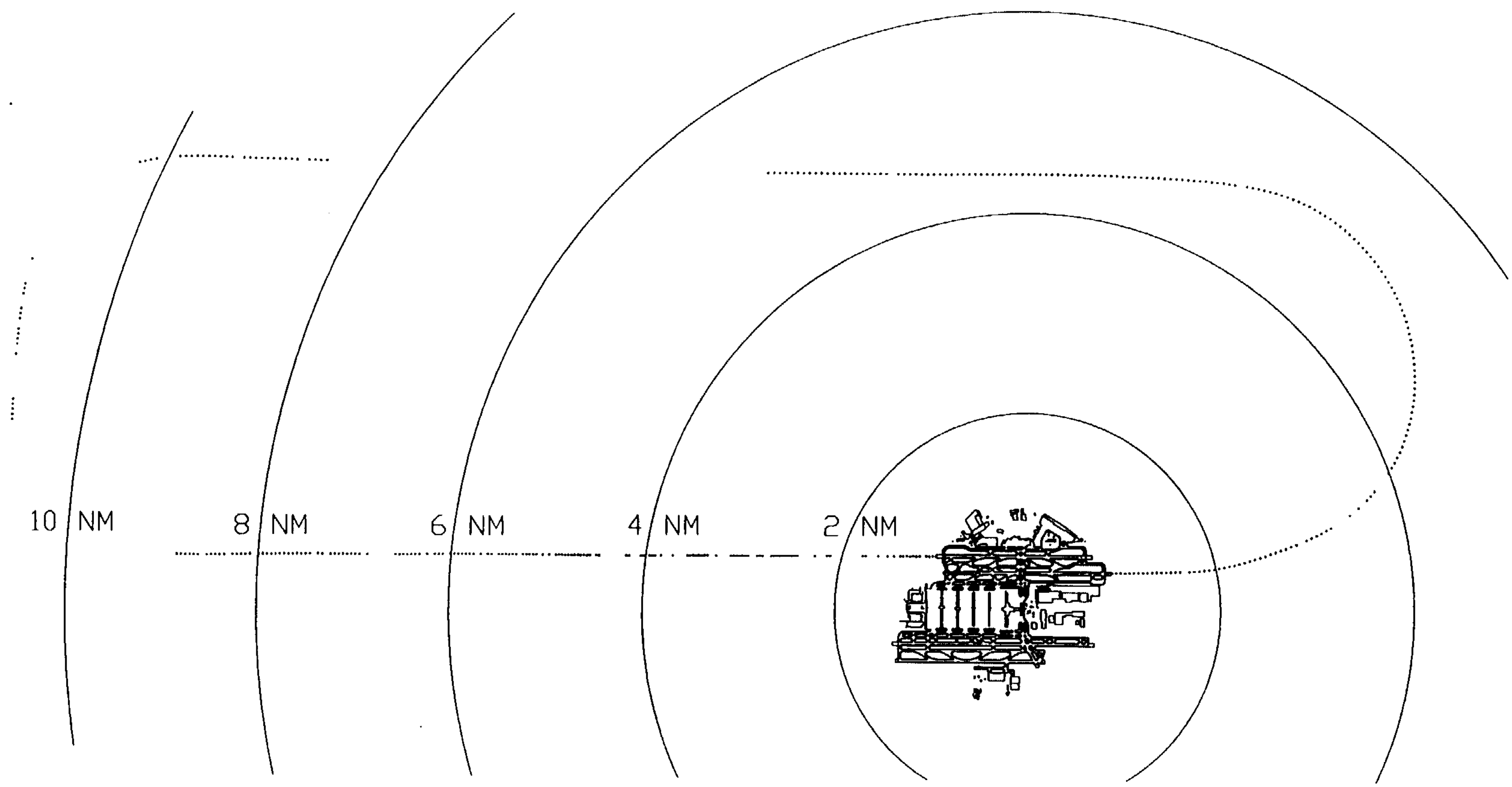

Figure C-8. ADS-B Reception Plot of a B757 Arrival Logged by Stationary Van

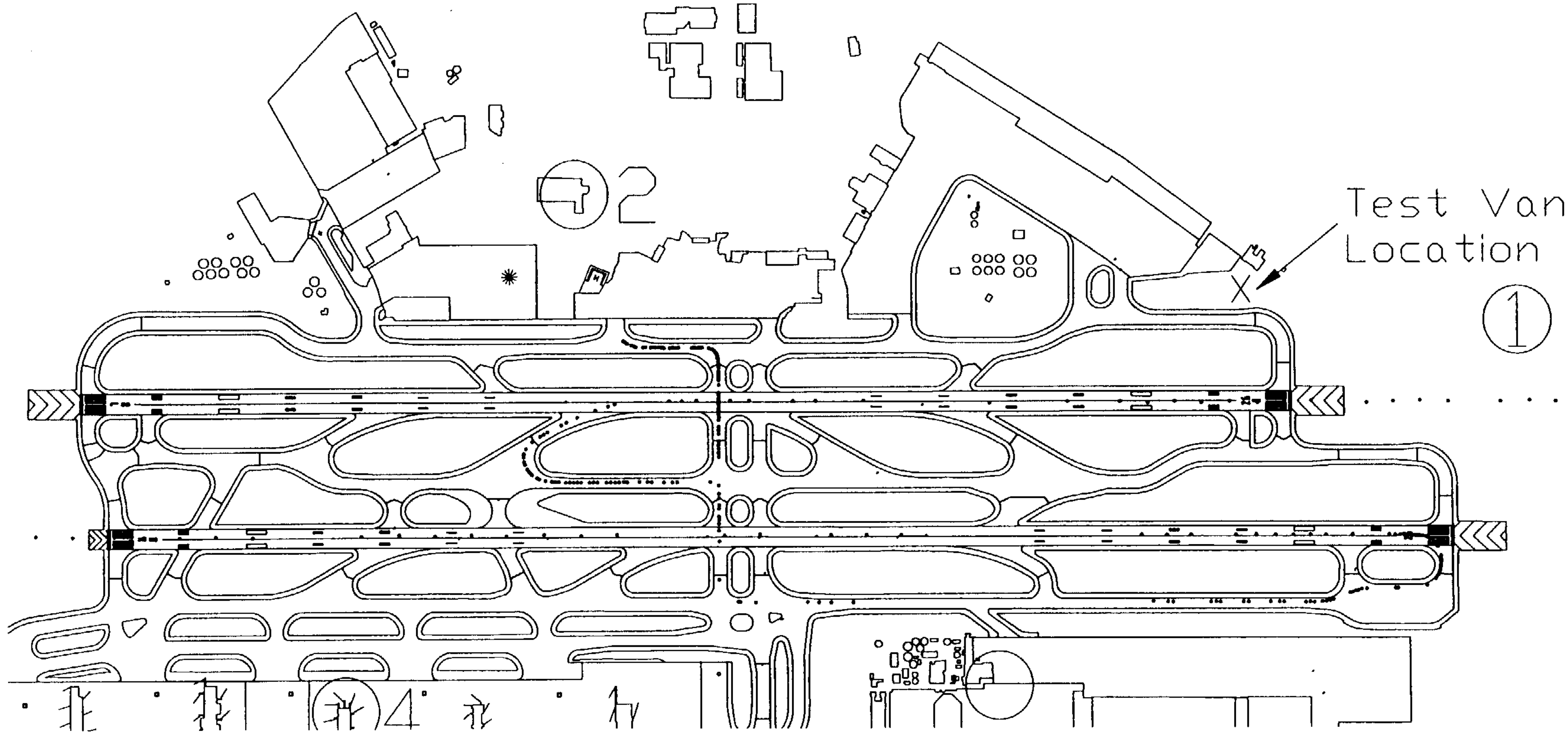

Figure C-9. ADS-B Reception Plot of Taxiing B757 Logged by Stationary Van

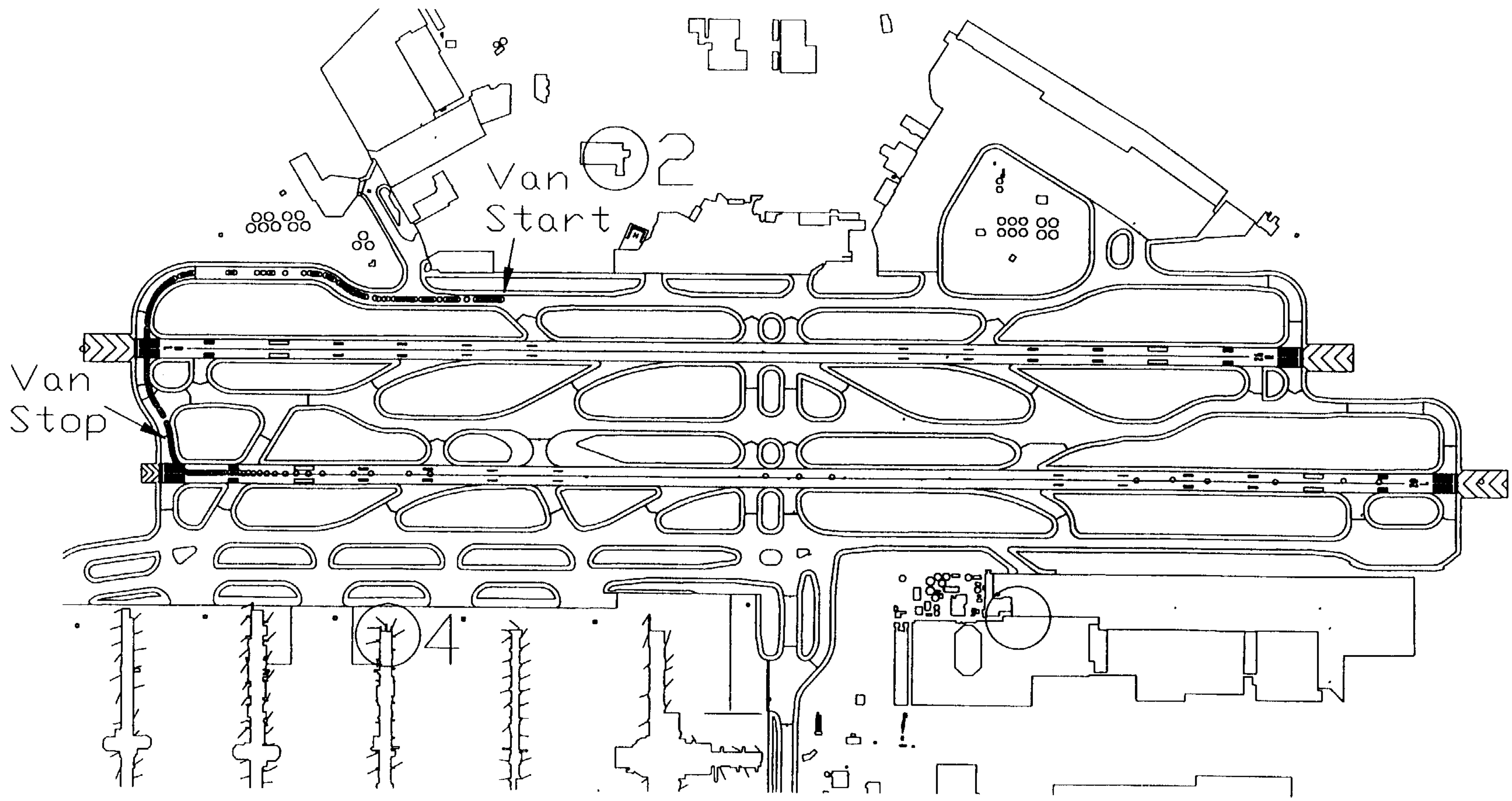

Figure C-10. ADS-B Reception Plot of Taxiing B757 Logged by Following Van

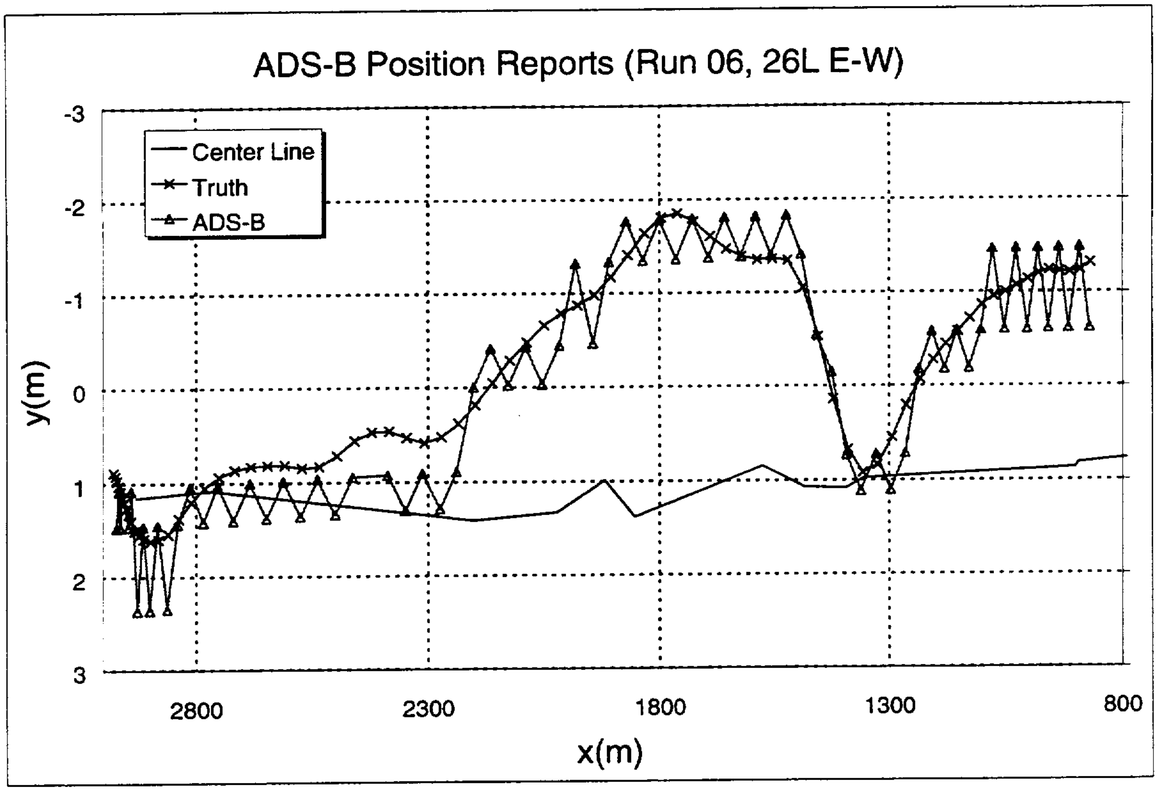

Figure C-11. ADS-B Position Reports for Run 06 on Runway 26L

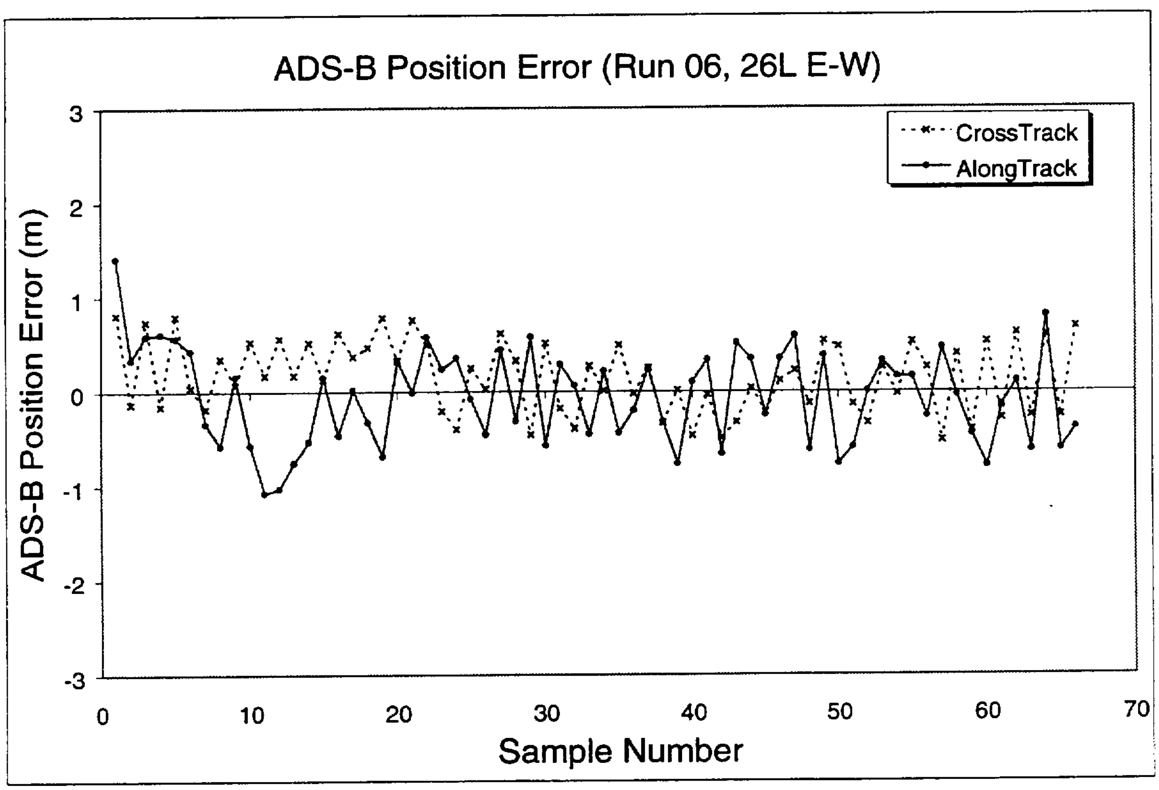

Figure C-12. ADS-B Position Error for Run 06 on Runway 26L

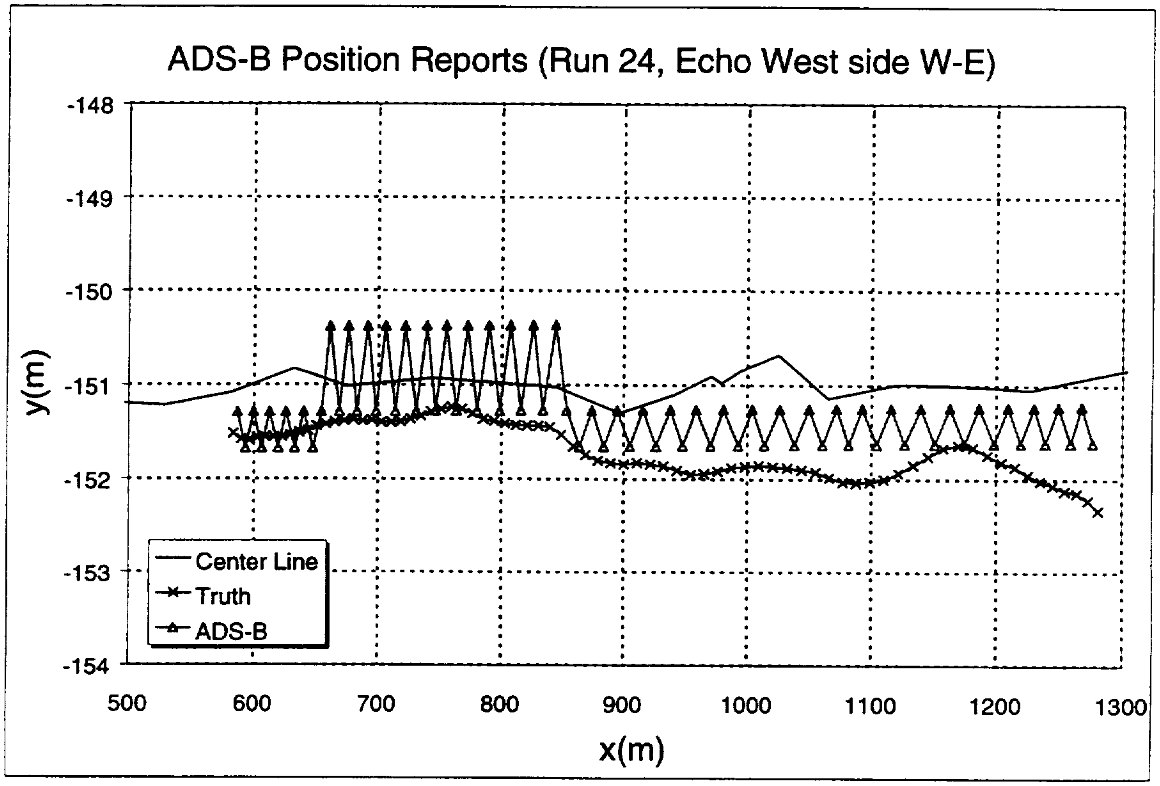

Figure C-13. ADS-B Position Reports for Run 24 on the West Side of Taxiway Echo

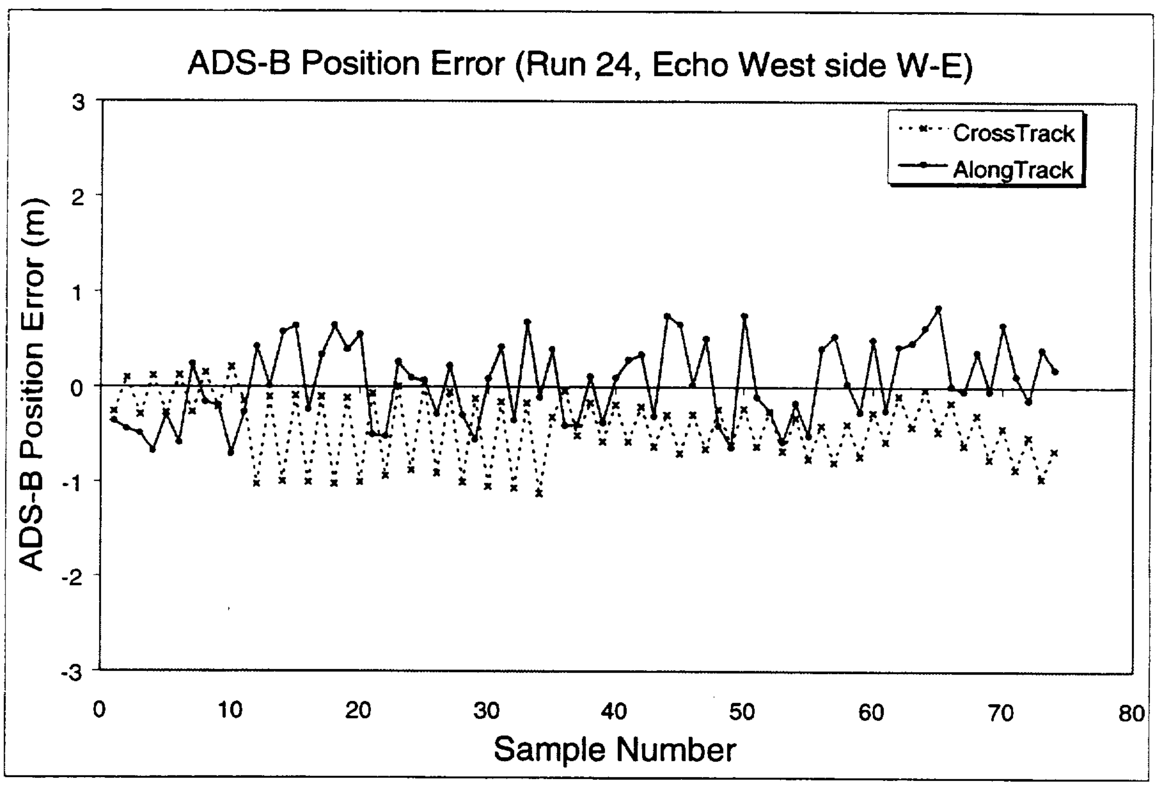

Figure C-14. ADS-B Position Error for Run 24 on the West Side of Taxiway Echo

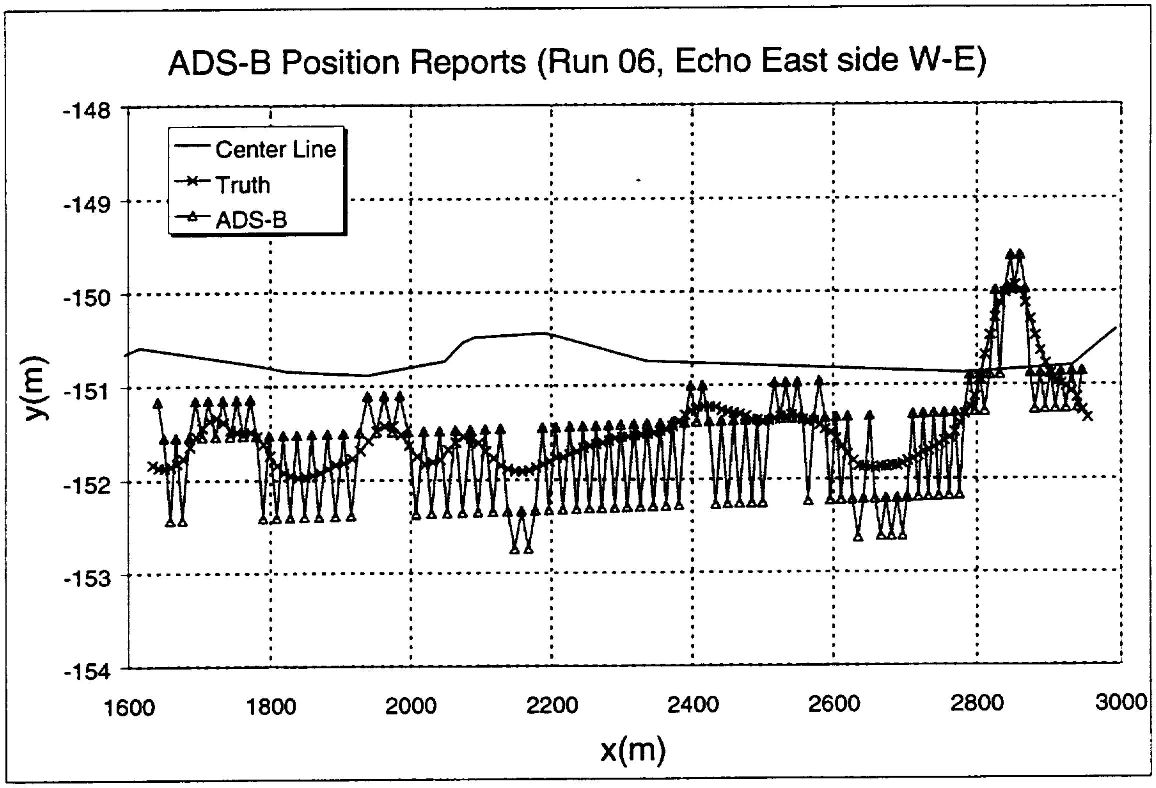

Figure C-15. ADS-B Position Reports for Run 06 on the East Side of Taxiway Echo

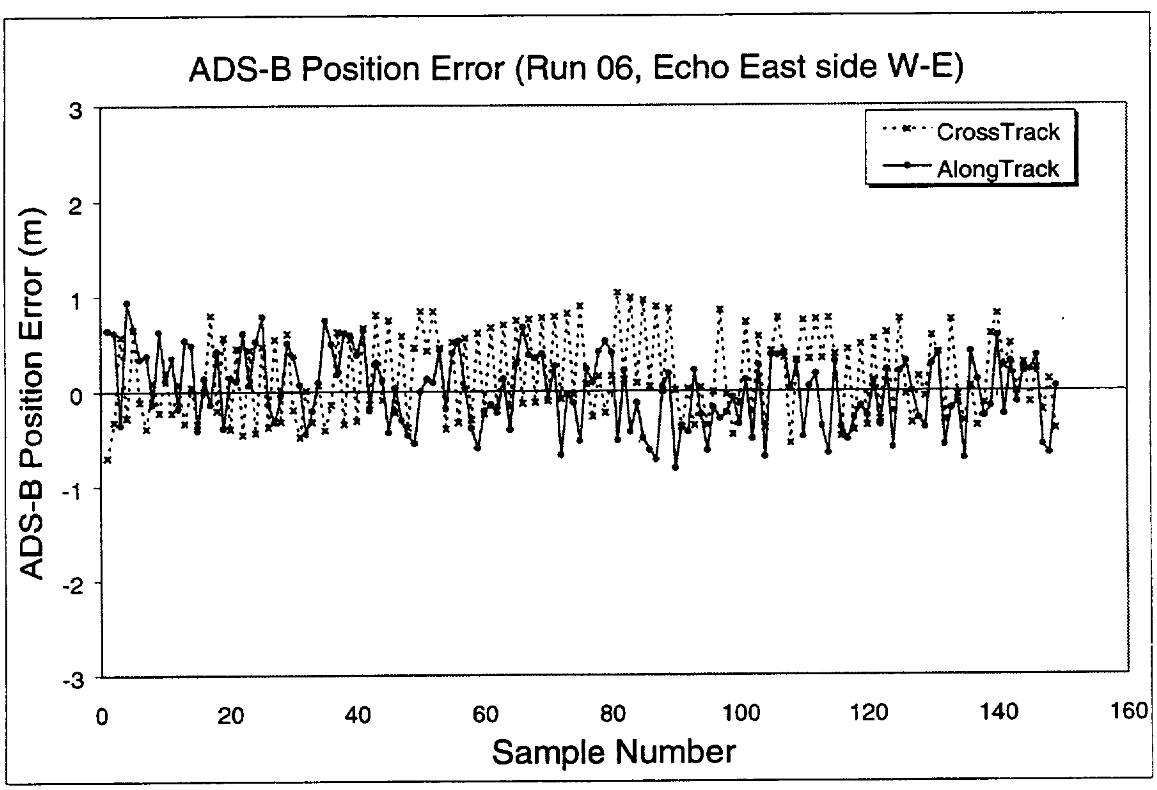

Figure C-16. ADS-B Position Error for Run 06 on the East Side of Taxiway Echo

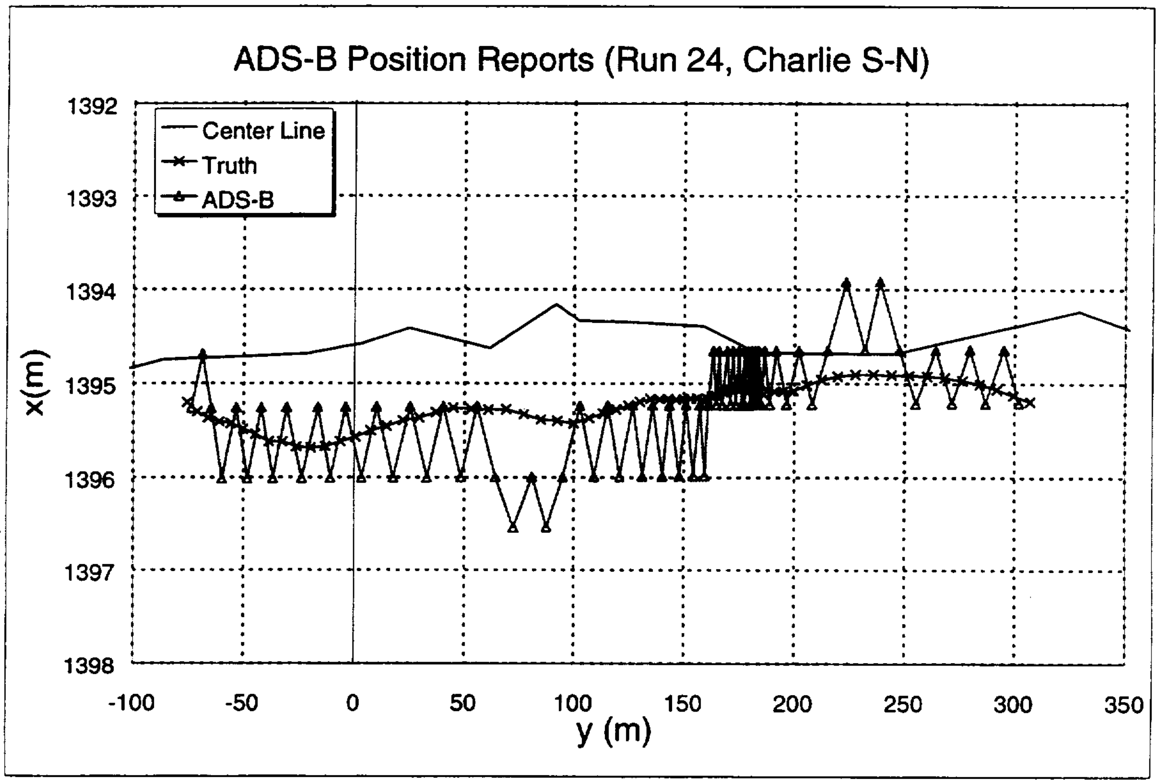

Figure C-17. ADS-B Position Reports for Run 24 on Taxiway Charlie

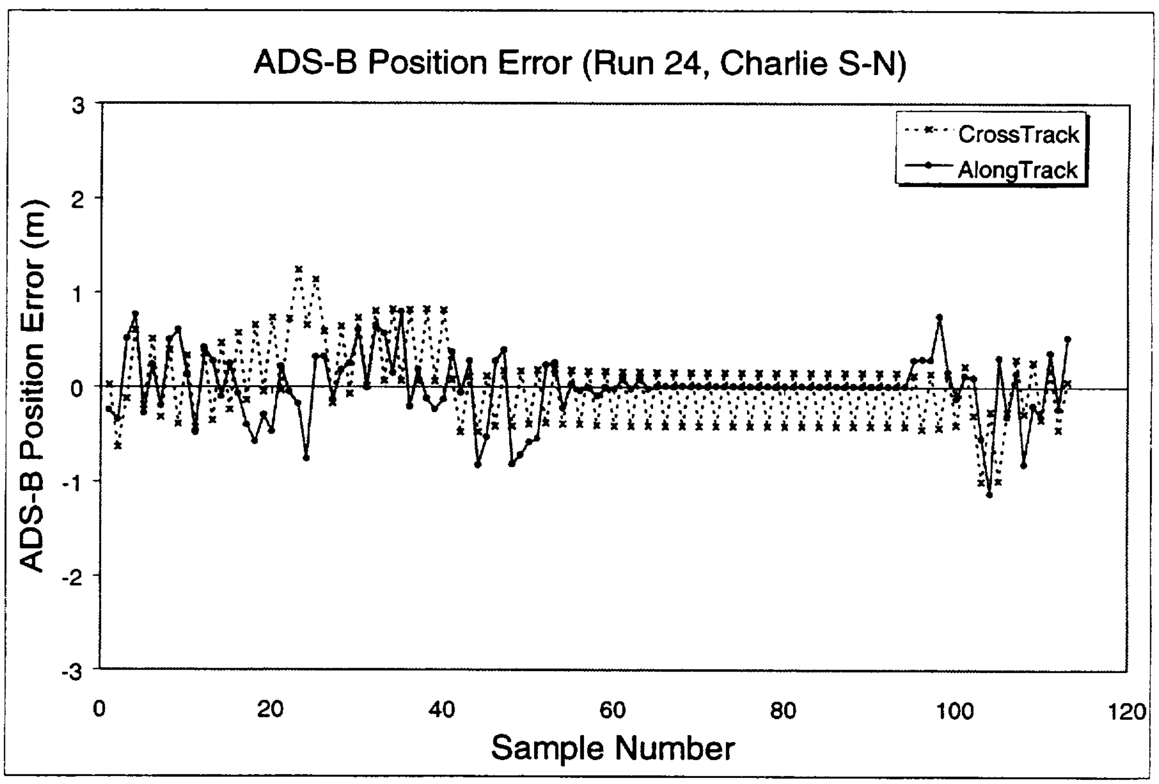

Figure C-18. ADS-B Position Error for Run 24 on Taxiway Charlie

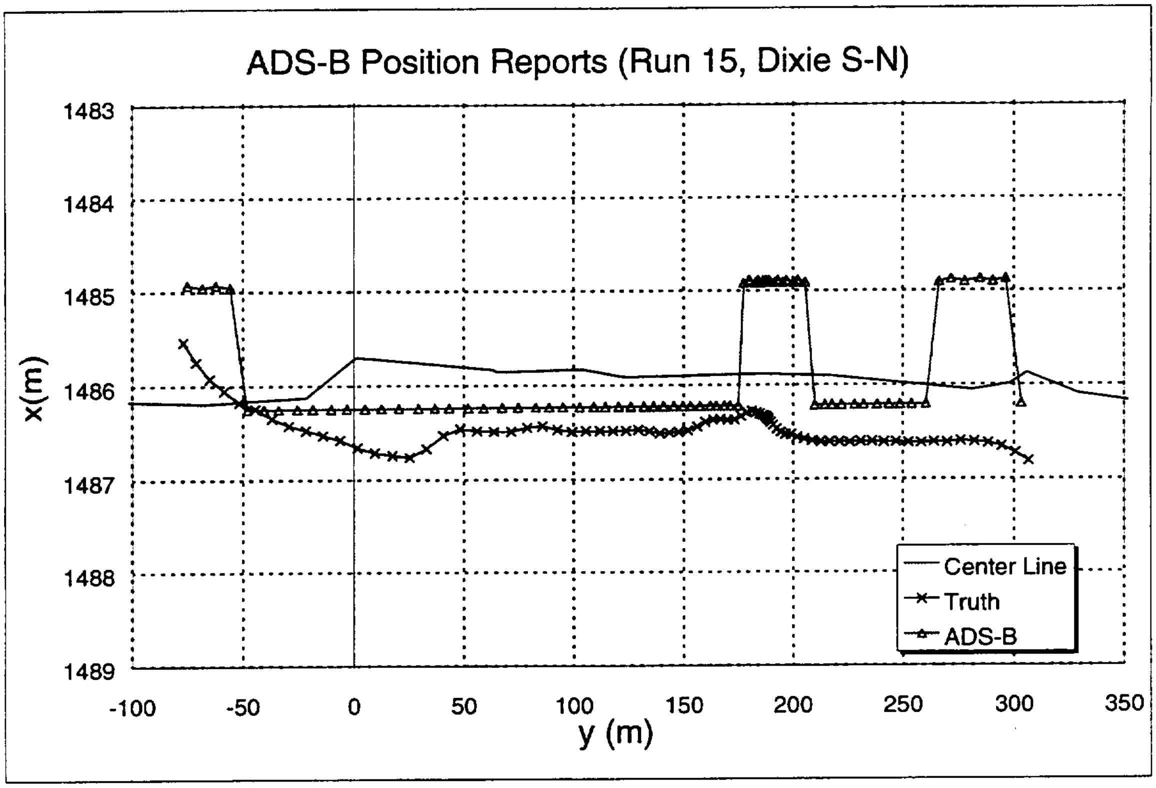

Figure C-19. ADS-B Position Reports for Run 15 on Taxiway Dixie

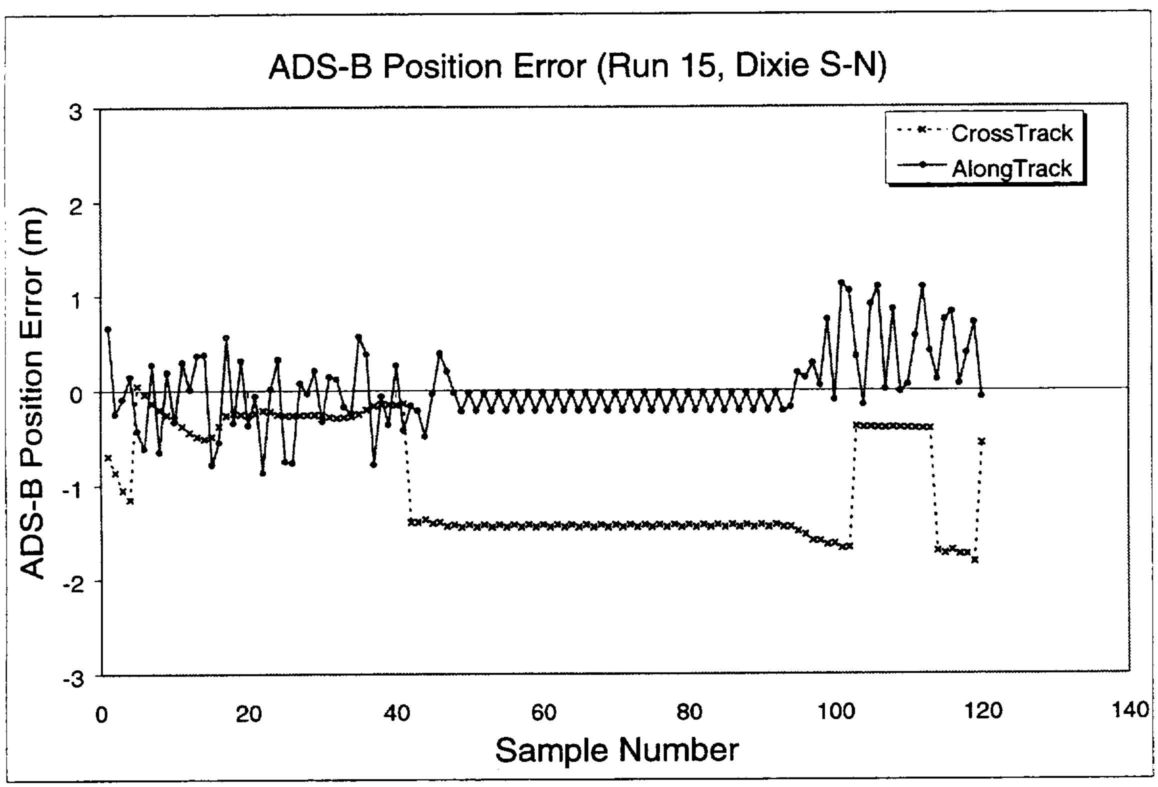

Figure C-20. ADS-B Position Error for Run 15 on Taxiway Dixie

APPENDIX D

ASDE-3 DATA

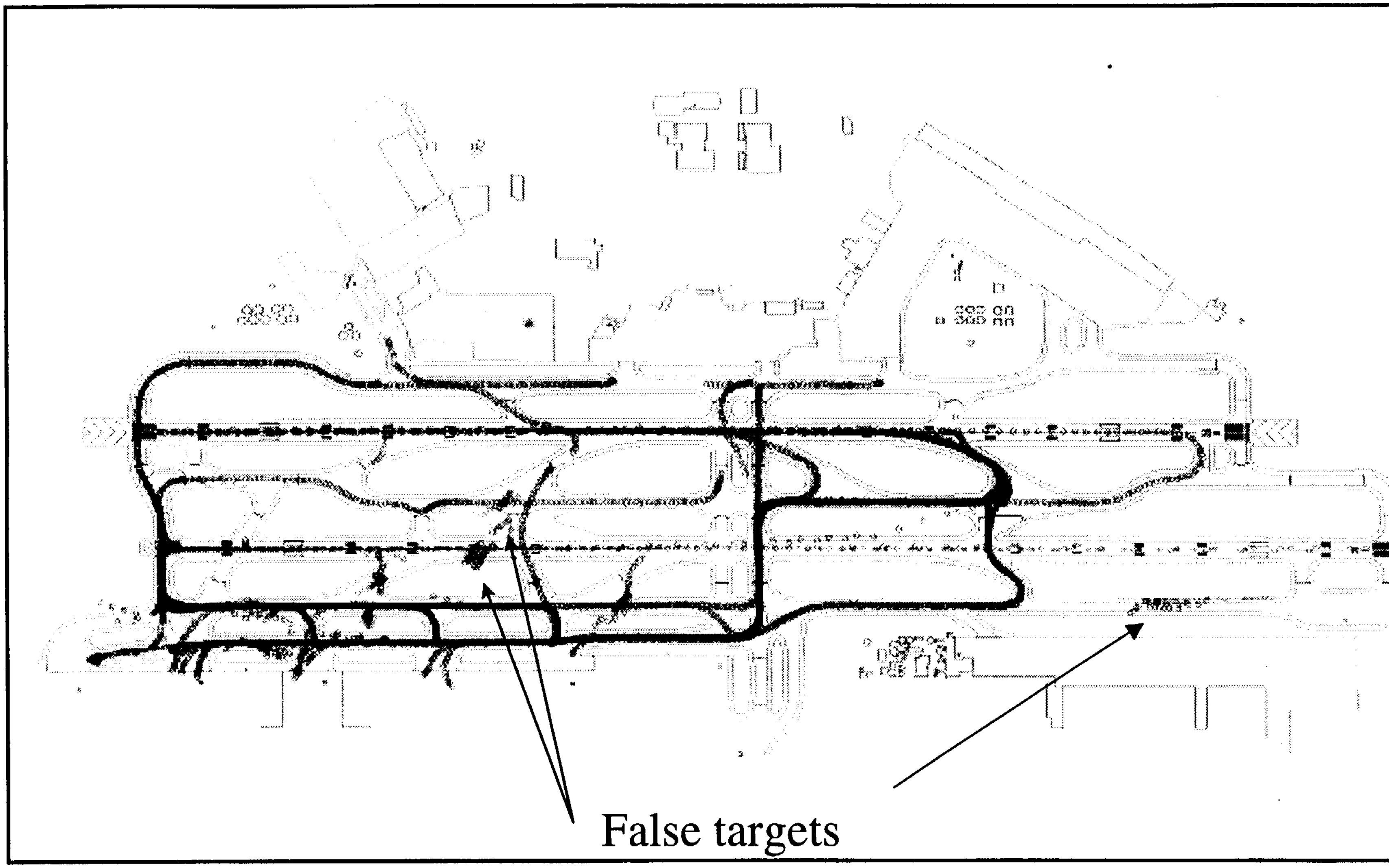

Figure D-1. ASDE-3/AMASS Commercial Traffic Coverage Plot

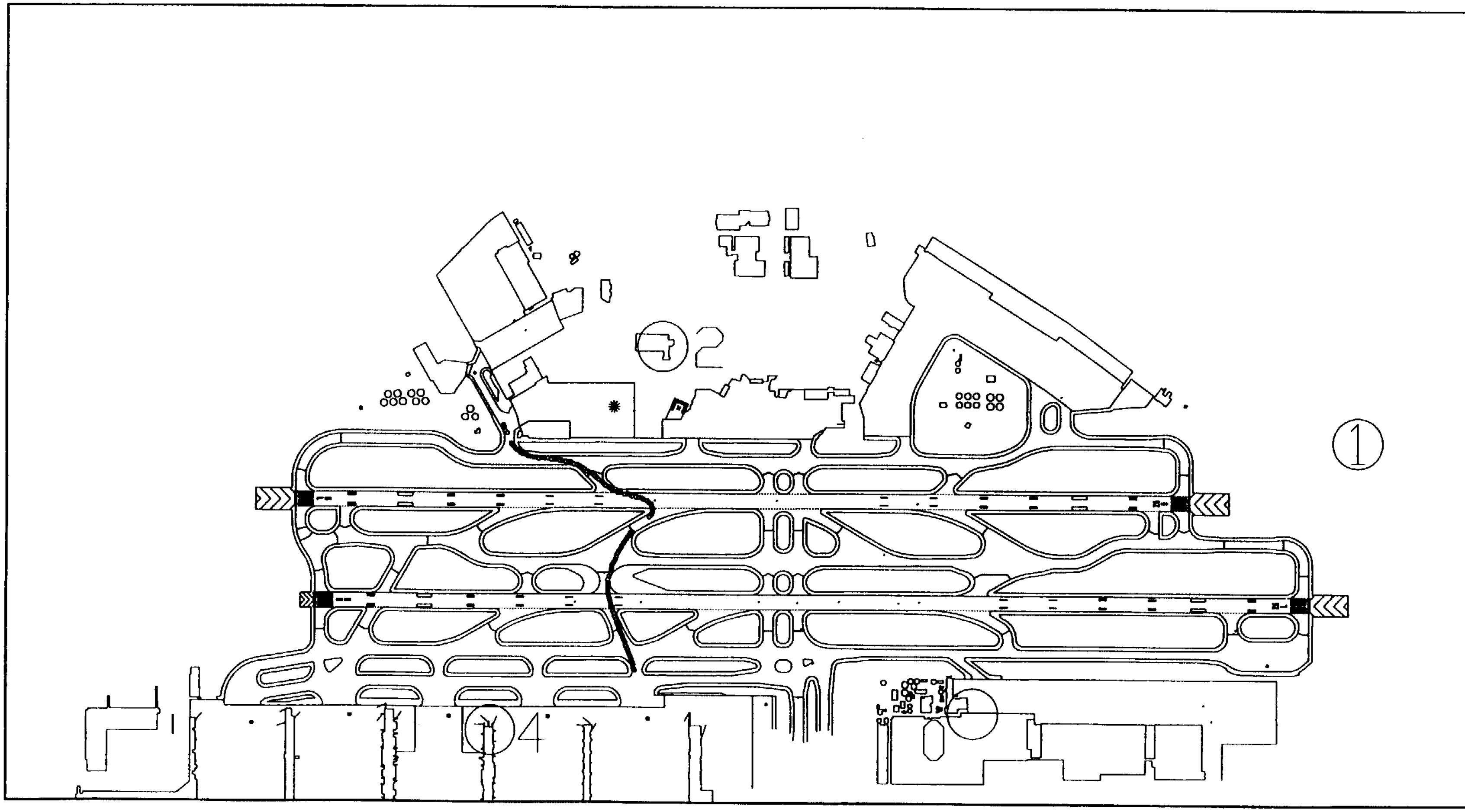

Figure D-2. ASDE-3/AMASS Commercial Traffic Runway Crossing Plot 1

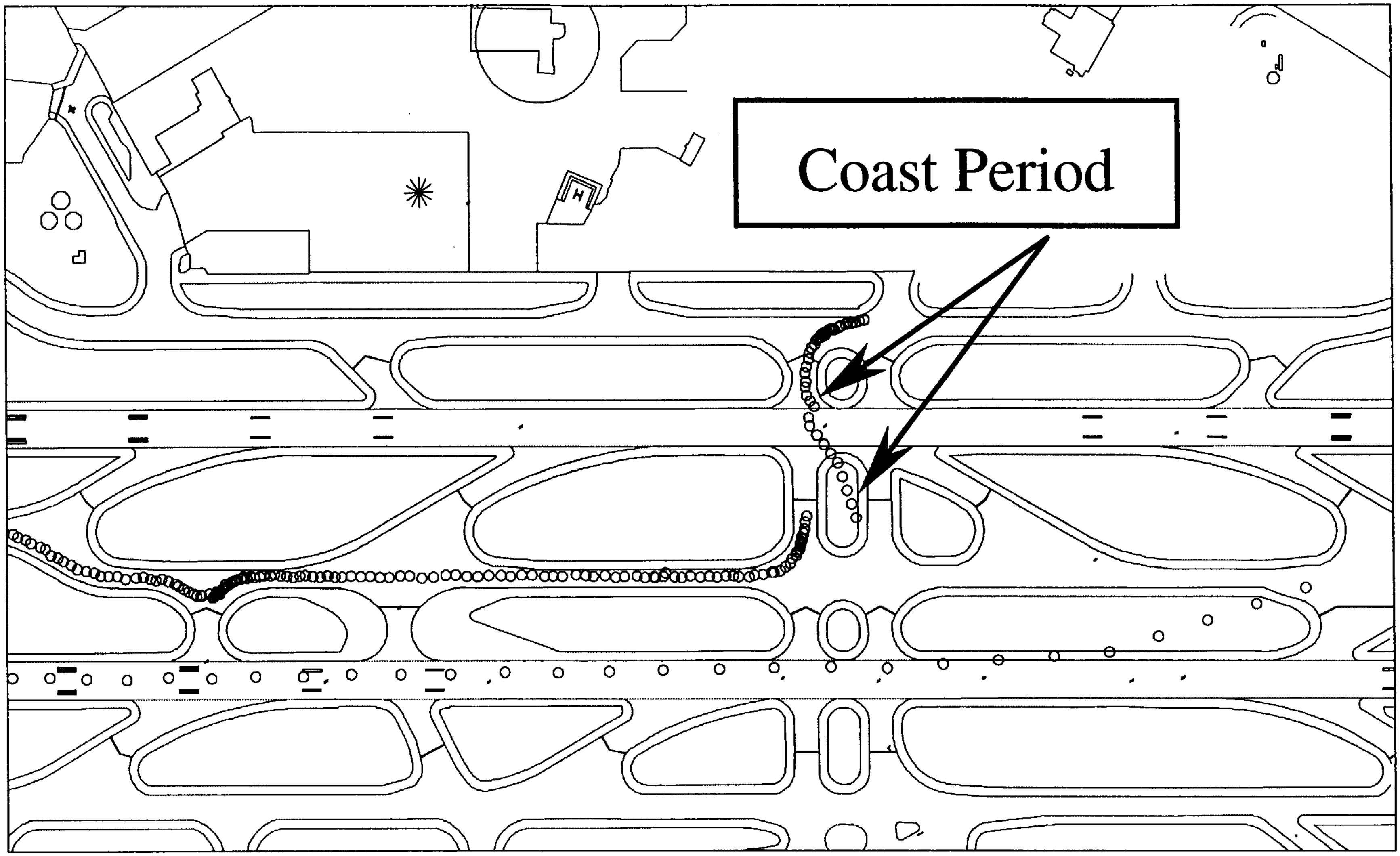

Figure D-3. ASDE-3/AMASS Commercial Traffic Runway Crossing Plot 2

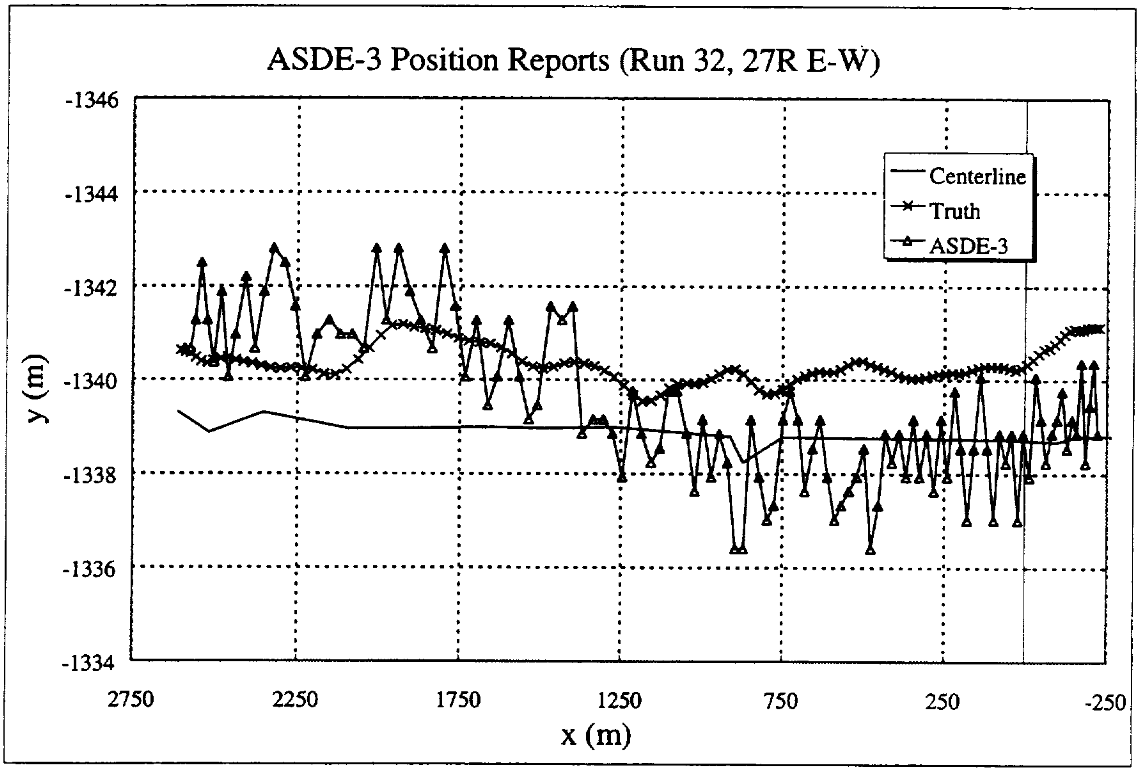

Figure D-4. ASDE-3/AMASS Position Reports Plot for Run 32 on Runway 27R

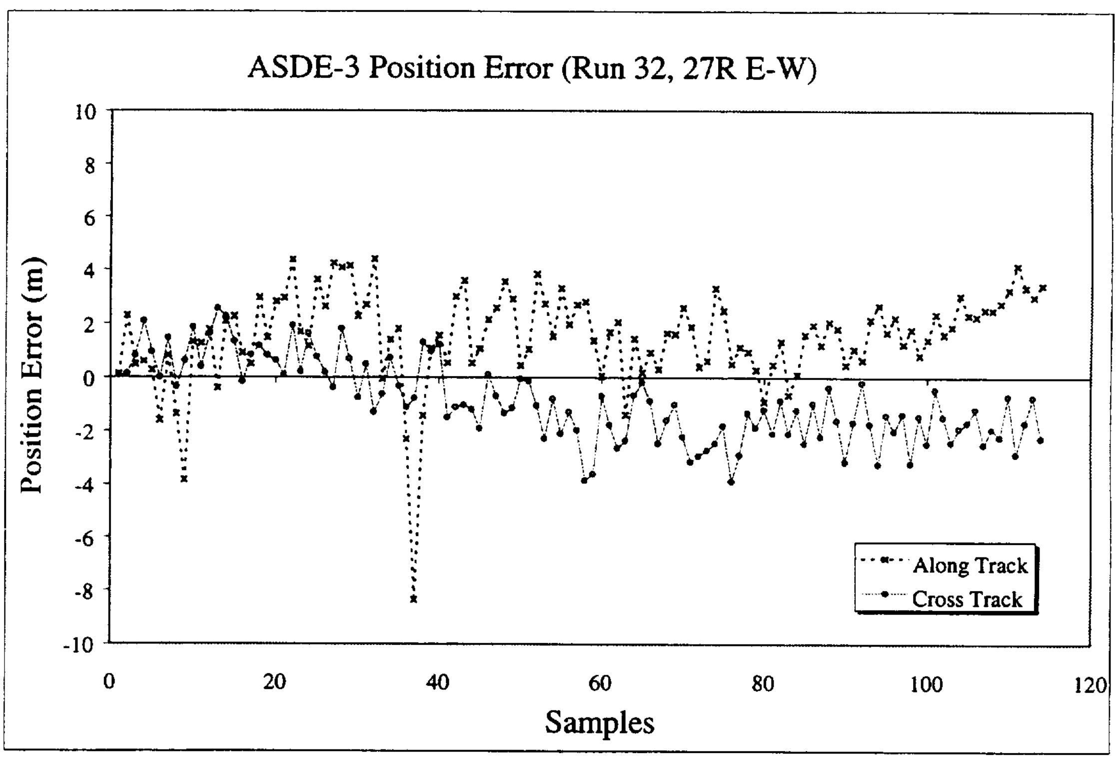

Figure D-5. ASDE-3/AMASS Position Error Plot for Run 32 on Runway 27R

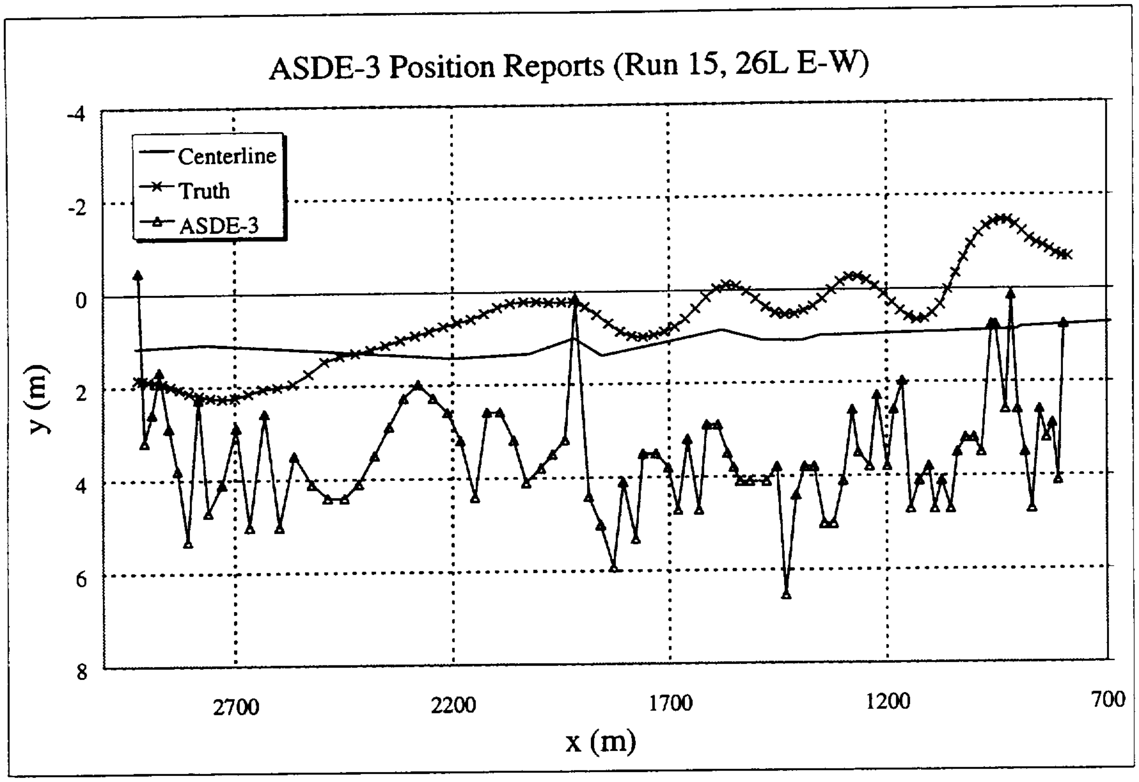

Figure D-6. ASDE-3/AMASS Position Reports Plot for Run 15 on Runway 26L

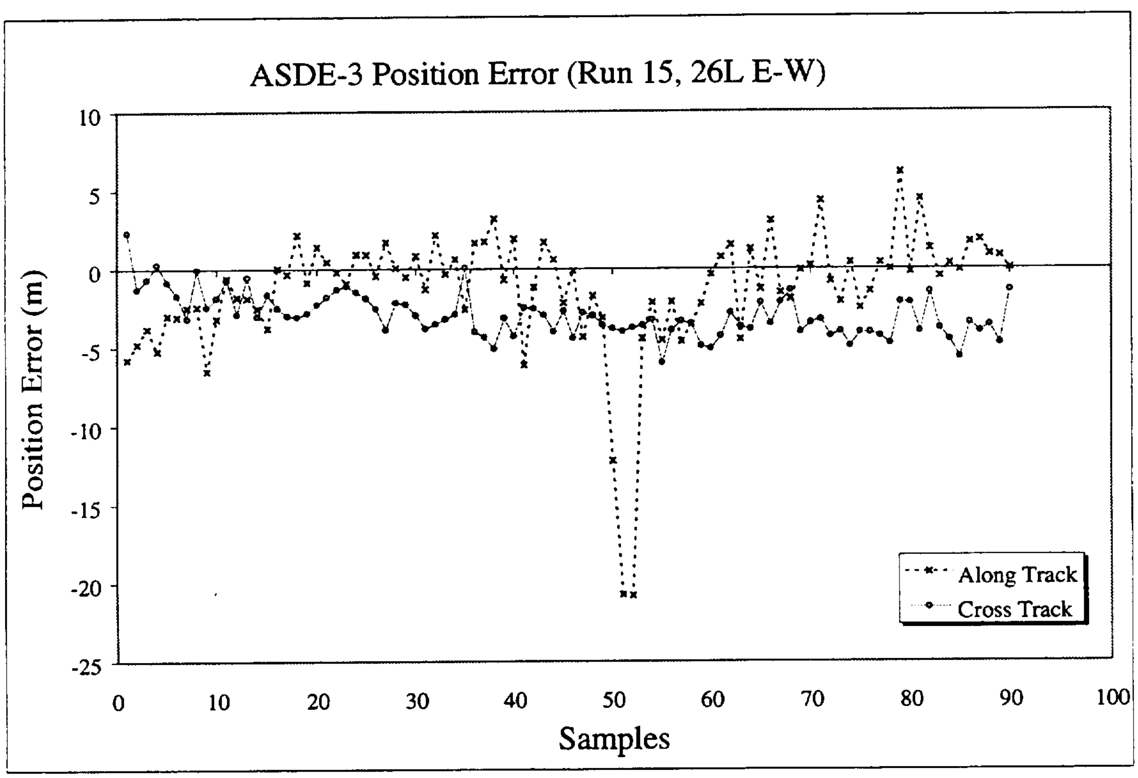

Figure D-7. ASDE-3/AMASS Position Error Plot for Run 15 on Runway 26L

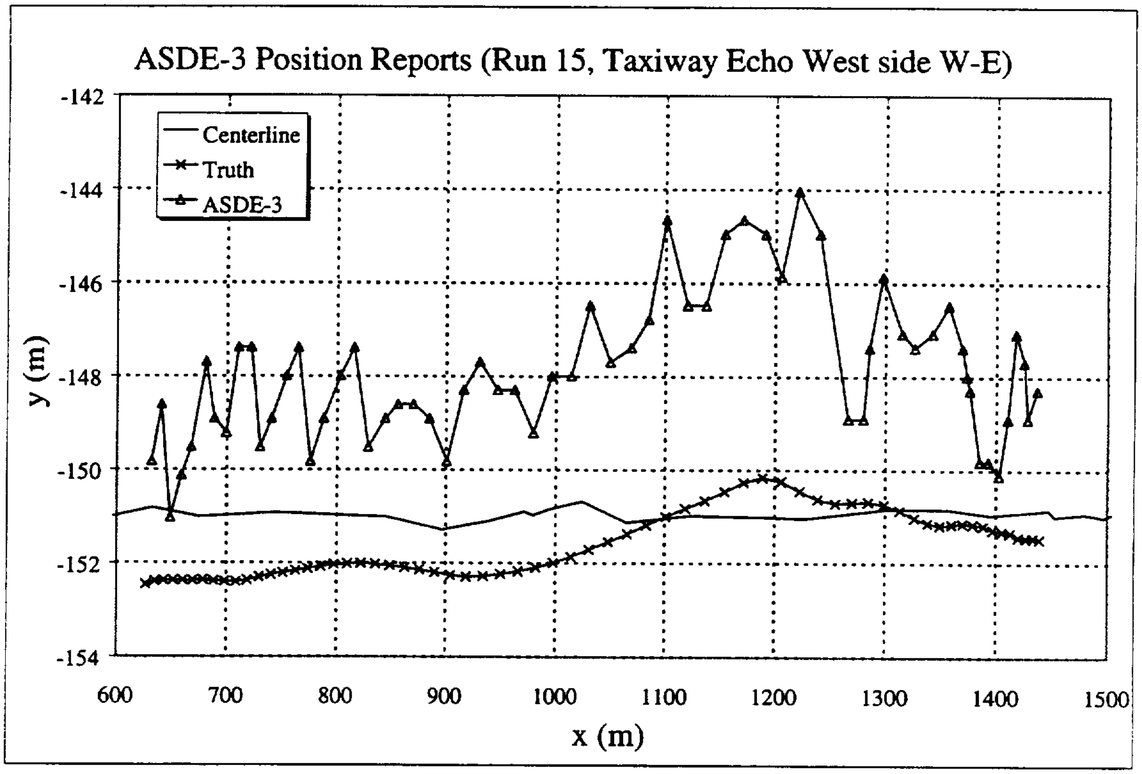

Figure D-8. ASDE-3/AMASS Position Reports Plot for Run 15 on Taxiway Echo

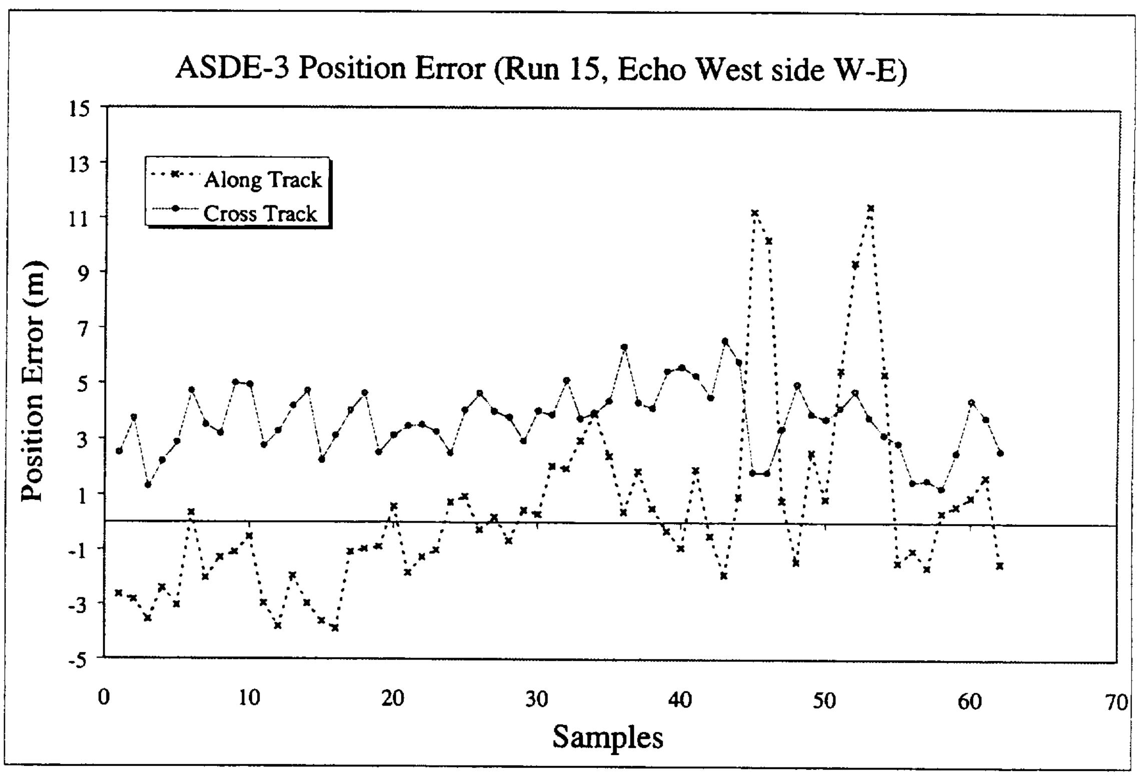

Figure D-9. ASDE-3/AMASS Position Error Plot for Run 15 on Taxiway Echo

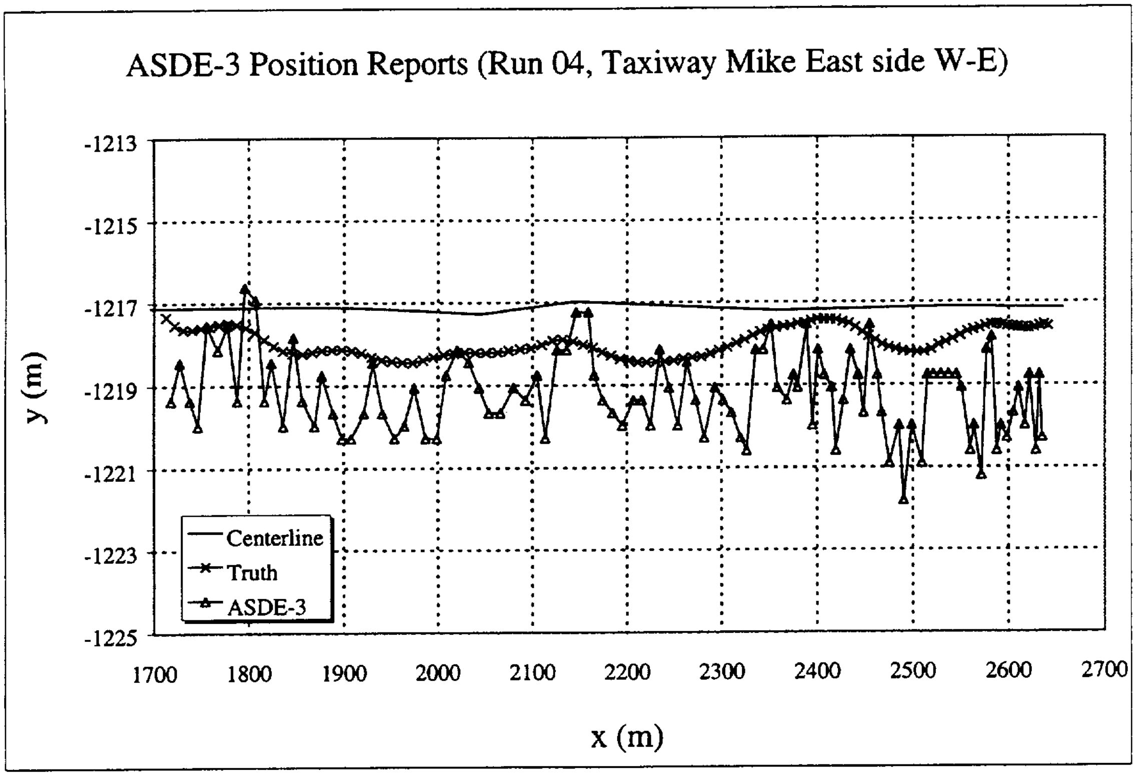

Figure D-10. ASDE-3/AMASS Position Reports Plot for Run 04 on Taxiway Mike

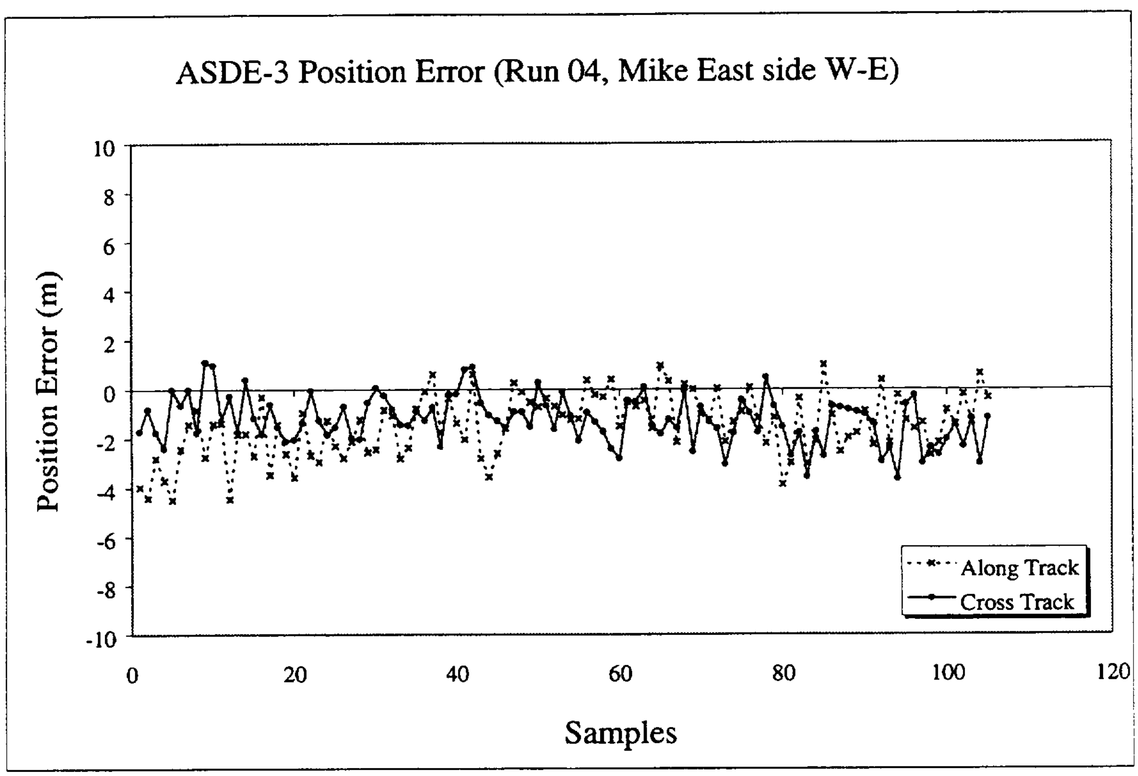

Figure D-11. ASDE-3/AMASS Position Error Plot for Run 04 on Taxiway Mike

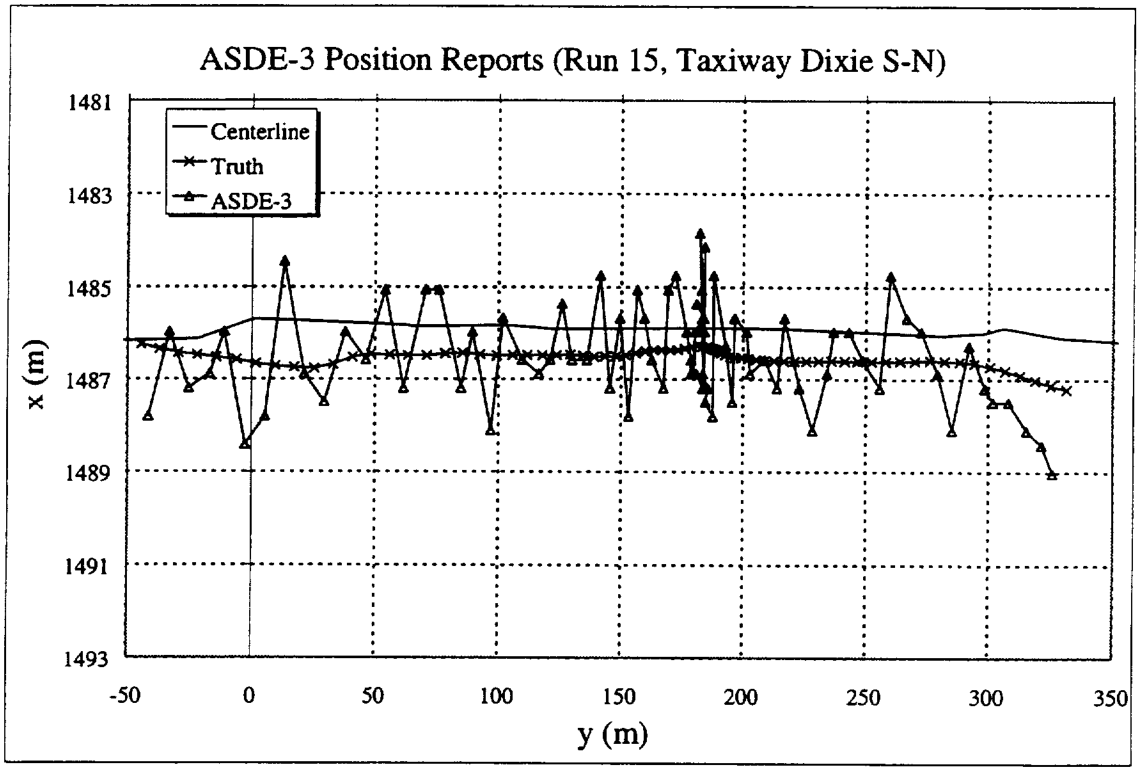

Figure D-12. ASDE-3/AMASS Position Reports Plot for Run 15 on Taxiway Dixie

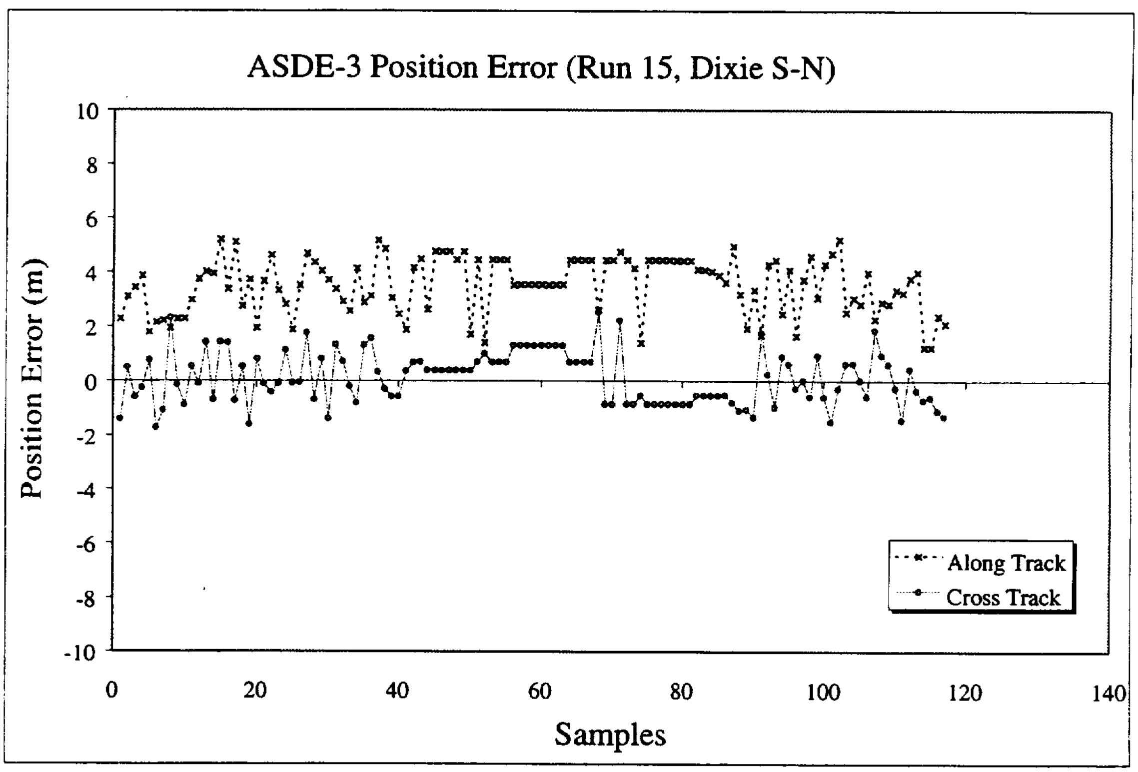

Figure D-13. ASDE-3/AMASS Position Error Plot for Run 15 on Taxiway Dixie

APPENDIX E

ACRONYMS

A-SMGCS - Advanced Surface Movement Guidance and Control Systems
ATIDS - Airport Surface Target Identification System
ATC - Air Traffic Control
AMASS - Airport Movement Area Safety System
ARTS - Automated Radar Terminal System
ASDE-3 - Airport Surface Detection Equipment
AWOP - All Weather Operations Panel
CAPTS - Cooperative Area Precision Tracking System
CDTI - Cockpit Display of Traffic Information
CG - Center-of-Gravity
DGPS - Differential Global Positioning System
FAR - Federal Aviation Regulation
GNSS - Global Navigation Satellite Systems
GPS - Global Positioning System
HDD - Head-Down Display
HUD - Head-Up Display
ICAO - International Civil Aviation Organization
ILS - Instrument Landing System
JAR - Joint Aviation Requirement
LCD - Liquid-Crystal Display (LCD)
LVLASO - Low Visibility Landing And Surface Operations
MASPS - Minimum Aviation Systems Performance Standard
NTSB - National Transportation Safety Board
RNP - Required Navigation Performance
ROTO - Roll-Out Turn-Off
RSLS - Runway Status Light System
RSS - Root Sum Square
RVR - Runway Visual Range
SSR - Secondary Surveillance Radar
TCAS - Traffic Alert and Collision Avoidance System
T-NASA - Taxi Navigation and Situational Awareness
TSE - Total System Error

APPENDIX F

HARTSFIELD ATLANTA AIRPORT DIAGRAM

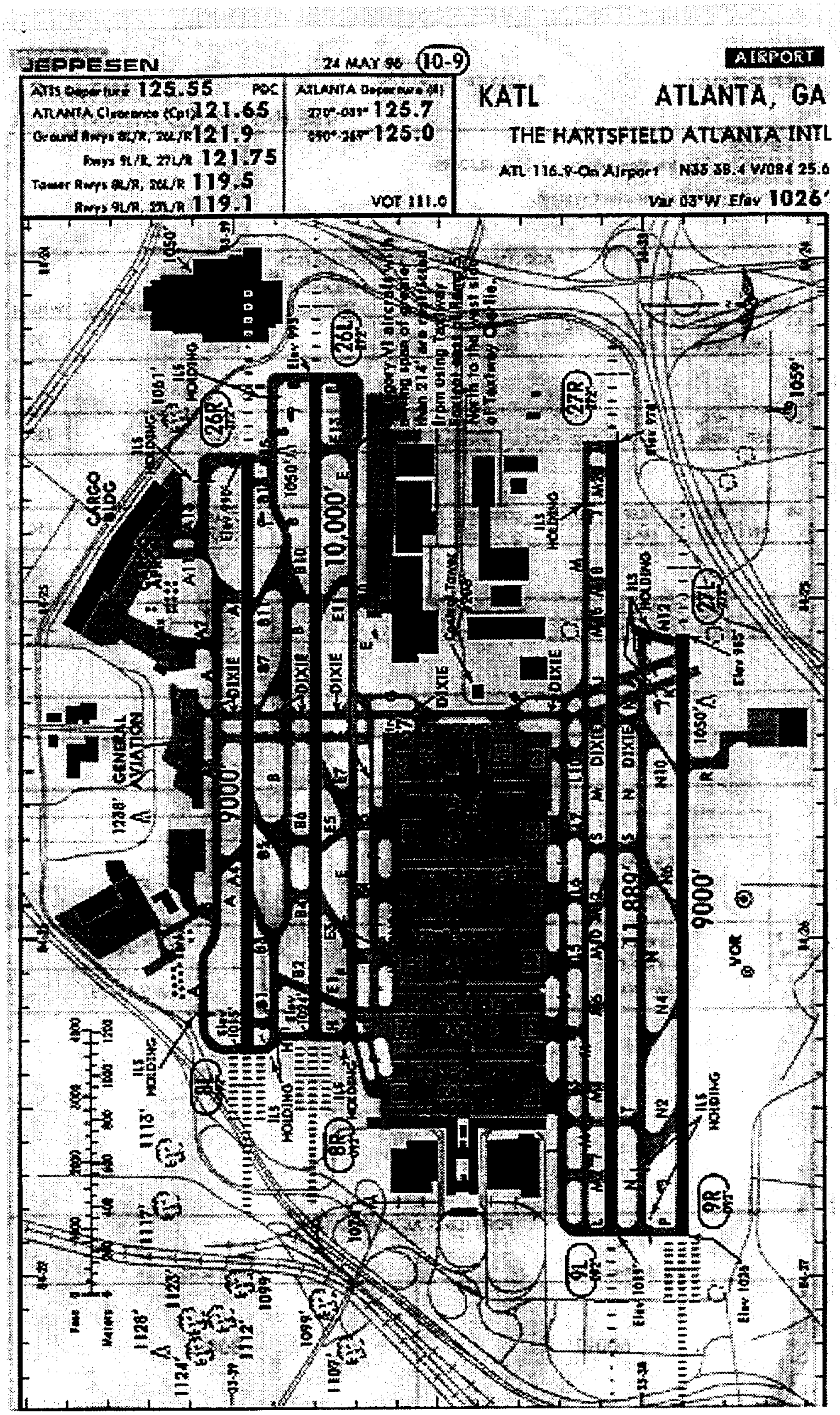

Figure F-1. Atlanta Hartsfield International Airport Diagram

APPENDIX G

NASA 757 ANTENNA LOCATIONS

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1999

3. REPORT TYPE AND DATES COVERED
Contractor Report

4. TITLE AND SUBTITLE
NASA Low Visibility Landing and Surface Operations (LVLASO) Atlanta Demonstration: Surveillance Systems Performance Analysis

5. FUNDING NUMBERS
C NAS1-19214

WU 538-04-13-02

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Rannoch Corporation
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-2199

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/CR-1999-209110

11. SUPPLEMENTARY NOTES
This final report was prepared by Rannoch Corporation under subcontract 26-81U-4903 to Research Triangle Institute for Langley Research Center under NASA contract NAS1-19214, Task 31.
Langley Technical Task Monitor: Robert W. Wills.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 03 Distribution: Standard
Availability: NASA CASI (301) 621-0390

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
NASA conducted a series of flight experiments at Hartsfield Atlanta International Airport as part of the Low Visibility Landing and Surface Operations (LVLASO) Program. LVLASO is one of the subelements of the NASA Terminal Area Productivity (TAP) Program, which is focused on providing technology and operating procedures for achieving clear-weather airport capacity in instrument-weather conditions, while also improving safety. LVLASO is investigating various technologies to be applied to airport surface operations, including advanced flight deck displays and surveillance systems. The purpose of this report is to document the performance of the surveillance systems tested as part of the LVLASO flight experiment. There were three surveillance sensors tested: primary radar using Airport Surface Detection Equipment (ASDE-3) and the Airport Movement Area Safety System (AMASS), Multilateration using the Airport Surface Target Identification System (ATIDS), and Automatic Dependent Surveillance - Broadcast (ADS-B) operating at 1090 MHz. The performance was compared to the draft requirements of the ICAO Advanced Surface Movement Guidance and Control System (A-SMGCS). Performance parameters evaluated included coverage, position accuracy, and update rate. Each of the sensors was evaluated as a stand alone surveillance system.

14. SUBJECT TERMS
Required Navigation Performance (RNP), accuracy, integrity, continuity, availability, validate, requirements

15. NUMBER OF PAGES
106

16. PRICE CODE
A06

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

Model	Maximum Takeoff Weight	Maximum Landing Weight	A	B	C	D	E	F	G	J	K	M	N	Turn Radius
RB211 535C	220,000 LB 99,790 KG	198,000 LB 89,811 KG	124' 10" 38.05 M	155' 3" 47.32 M	45' 1" 13.74 M	60' 0" 18.29 M	79' 4" 24.18 M	24' 0" 7.32 M	21' 3" 6.48 M	48' 2" 14.68 M	2' 5" 0.74 M	35' 0" 10.67 M	15' 4" 4.67 M	98' 0" 29.87 M

Source: FAA Advisory Circular 150/5325-5C

Location	WL	BS	BL
CG	203	1032	0
Nosewheel (bottom)	60	390	0
GPS	306.32	690.12	5.04
Ashtech	306.32	690.12	5.04
Mode S: Upper Antenna	306.32	535.5	4.87

Values are in inches

WL = Waterline — Height (ground is not zero, but ~60)
BS = Body Station — Along fuselage, zero in front of nose
BL = Buttline — Lateral to fuselage, zero is center, positive is left (facing forward)

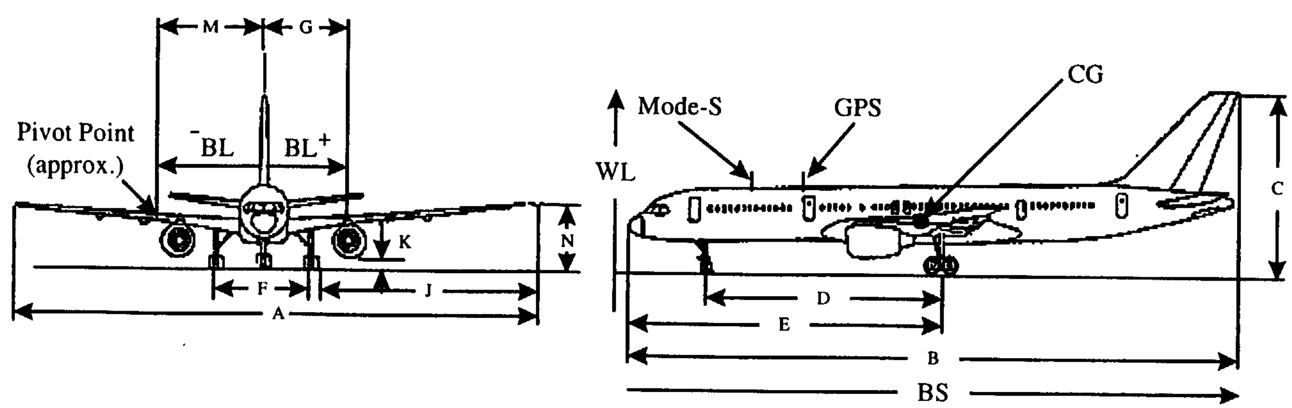

Figure G-1. NASA 757 Antenna Locations