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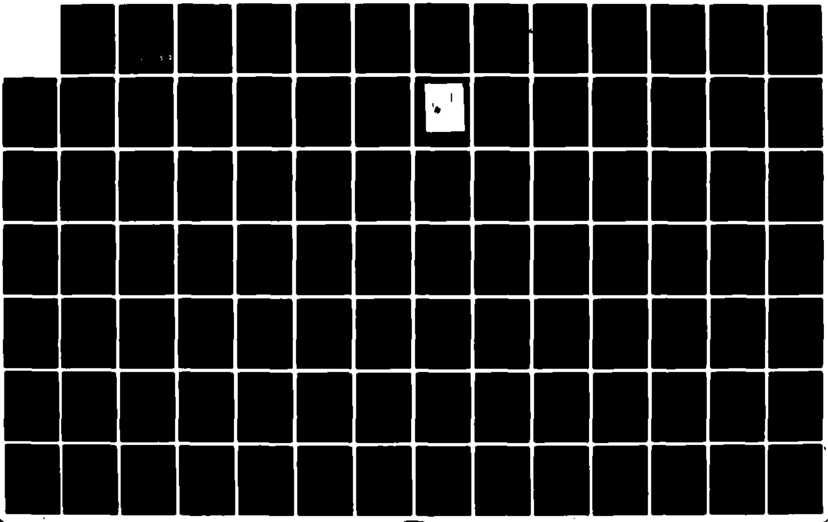

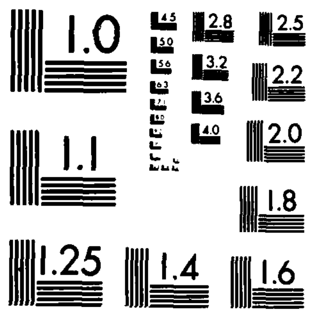

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Mode S Baseline Radar Tracking

AD A 125930

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November 1982

Final Report

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16. Abstract

Tests and evaluation were conducted to determine the baseline performance characteristics of the Moving Target Detector (MTD) and Radar Data Acquisition System (RDAS) as an integral part of the Mode S sensor. The MTD and RDAS were separately evaluated to determine their capability to provide radar data suitable for utilization by the Mode S sensor and Automated Radar Terminal System (ARTS).

The specific test objectives were to: (1) determine that the design modifications made to the Mode S sensor to provide the capability of interfacing to either an MTD or RDAS were in compliance with the Federal Aviation Administration engineering requirement, FAA-ER-240-26 (appendix VIII); (2) provide radar baseline technical performance data to characterize the MTD, RDAS, Mode S, and ARTS; and (3) determine if the minimum radar tracking requirements are adequate to provide reliable radar track data to an air traffic control (ATC) facility.

It was concluded that the Mode S sensor, when integrated with an MTD-2 radar digitizer, can provide reliable primary radar track data to the ARTS III system for automated radar track acquisition.

It was also concluded that the tested RDAS did not perform at an acceptable level.

17. Key Words	18. Distribution Statement
Mode S MTD SRAP/RDAS RDAS	This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

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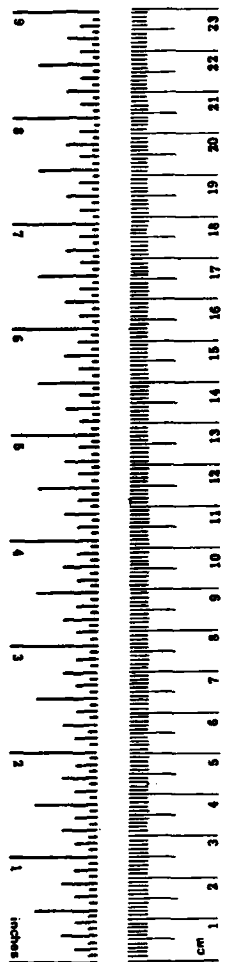
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

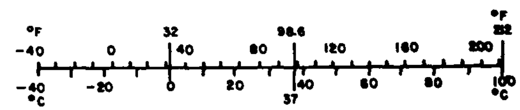
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

The purpose of these tests and evaluation (T&E) was to: (1) verify that the design modifications required to interface the Mode S sensor to either a Moving Target Detector (MTD) or a Radar Data Acquisition Subsystem (RDAS) were in compliance with the Federal Aviation Administration engineering requirement, FAA-ER-240-26, appendix VIII (reference 1); (2) provide radar baseline technical data to characterize the system performance of the Mode S sensor coupled with either an MTD or RDAS; and (3) determine if the coupled system can achieve air traffic control (ATC) radar tracking standards.

BACKGROUND.

The present method of controlling aircraft in an ATC terminal environment relies upon secondary radar Air Traffic Control Radar Beacon System (ATCRBS) for the automated data acquisition and processing. These data are input to an Automated Radar Terminal System (ARTS) III to generate target track information on a Data Entry and Display Subsystem (DEDS) console for all beacon equipped aircraft.

Ideally, an automated ATC terminal area should also be serviced by a primary (reflection) radar system capable of providing automatic acquisition and tracking of all aircraft in the system's field of view. Until recently there has been difficulty incorporating radar data available from the airport surveillance radar (ASR) into an automated system such as the ARTS III. These problems have been caused by the inability of radar processors to adequately reject ground, precipitation, and angel clutter while still maintaining good detectability in the desired coverage pattern.

During the mid-1970's, two different radar data processors were developed in an effort to overcome these problems and interface with the ARTS III.

MOVING TARGET DETECTOR. This radar data processor, developed by the Massachusetts Institute of Technology, Lincoln Laboratory, employs coherent linear filtering and adaptive thresholding techniques. Extensive testing, conducted jointly by Lincoln Laboratory and the FAA Technical Center, resulted in three reports being published on the performance of the MTD. Two of the reports were prepared by Lincoln Laboratory: "Description and Performance of the Moving Target Detector," report No. FAA-RD-76-190 (reference 2), and "Comparison of the Performance of the Moving Target Detector and the Radar Video Digitizer," report No. FAA-RD-76-191 (reference 3). The third report was prepared by the Technical Center: "Test and Evaluation of the Moving Target Detector," report No. FAA-RD-77-118 (reference 4). This first experimental model of the MTD was referred to as the MTD-1. The MTD delivered for testing with the Mode S, referred to as the MTD-2, has an enhanced software processing capability.

RADAR DATA ACQUISITION SUBSYSTEM. This radar data processor is part of the Sensor Receiver and Processor (SRAP) developed by the Sperry Univac Corporation to provide digital processing of signals from primary and/or secondary radars. A production model of the SRAP was tested at the Technical Center in the late 1970's. The RDAS processes primary radar normal and moving target indicator (MTI) video signals. The processor utilizes hit/miss filtering and adaptive hit-count thresholding techniques to detect potential targets.

Sperry Univac provided the technical expertise to determine if the inputs to the RDAS were acceptable. The FAA in conjunction with Sperry Univac, conducted a series of RDAS/ASR-7 sensitivity measurements. Both the FAA and contractor were in agreement that the ASR-7 and the RDAS met approved levels of sensitivity to provide acceptable radar target detection.

To date, all testing performed on the Mode S sensors had been limited to beacon (secondary radar) operation only. The MTD-2 and the RDAS radar processors were delivered to the Technical Center Mode S sensor in September 1980 along with the interfaces to provide the sensor with radar report data from either radar processor.

DESCRIPTION OF EQUIPMENT

This section is presented to give a brief description of the systems and equipment used to determine the radar tracking performance of the Mode S/MTD and the Mode S/RDAS system configurations. Prior to describing the related systems and equipment, parameters critical to radar tracking performance are defined. Comprehending the meaning of these parameters and how they relate to the Mode S/RDAS and Mode S/MTD system is essential to understanding the detailed analysis presented in this report.

1. The MTD target report quality, a two-bit field in an MTD radar report, is equal to the number of coherent processing intervals (CPI's) which makeup the target minus one. A CPI is generated by sequentially processing eight pulses in each MTD range cell, where the transmitter pulses are modulated between two pulse repetition frequencies switching at the end of each CPI.

2. The MTD target report confidence is a measure of whether the report is likely to be false. A single CPI target or a target requiring the zero doppler velocity filter to declare it is most likely to be false and, so, is given "low" confidence.

3. RDAS target reports are assigned a "quality" before dissemination to the Mode S sensor. This quality value is dependent on the total number of radar hits minus an applied threshold value. These target reports will be subjected to a third level of discrimination in the Mode S sensor, the "Mode S RDAS quality filter."

4. RDAS reports that are not associated with Mode S beacon reports are subjected to a special quality filter. This filter attempts to provide for regulation of false radar reports due to clutter breakthrough, especially point clutter due to strong ground returns. Regulation is accomplished by desensitizing or blanking within zones where persistent returns occur.

5. A radar track is initiated after reports (which do not correspond with aircraft presently under beacon- or radar-only tracking) from two consecutive scans meet range and azimuth comparison criteria and the first report has high confidence.

6. Radar track transition from an "initial" state to a "normal" state occurs when the number of M radar report-to-track correlations are received within N consecutive scans where M and N are site-adaptable parameters.

7. Radar reports that correlate with existing tracks are disseminated as correlated data only after the corresponding track has been declared "mature." The Mode S internal track number (surveillance file number (SFN)) is disseminated as part of the report message.

8. Radar track maturity is defined as the occurrence of radar report-to-track correlations for K consecutive scans where K is a site-adaptable parameter.

9. Radar reports that do not correlate with mature radar tracks are disseminated as uncorrelated data, provided the reports have high confidence and report quality greater than zero.

MODE S SENSOR.

The Mode S System is a cooperative surveillance and communication system used for ATC. Each Mode S transponder equipped aircraft is assigned a unique discrete address which provides a surveillance interrogation and reply protocol that inherently supports data link communication to or from that particular aircraft.

In order to provide for an evolutionary transition from an all ATCRBS environment to one consisting of the Mode S, the Mode S sensor is completely compatible with ATCRBS.

The sensor employs a monopulse direction finding technique using a 5-foot vertical aperture beacon antenna collocated with the radar antenna.

The major sensor functions (figure 1) are categorized as follows:

1. Those which involve the generation and processing of signals and operate on a microsecond time scale (e.g., modulator/transmitter, multichannel receiver, and Mode S and ATCRBS processors).

2. Those which involve channel transactions and operate in a millisecond time scale commensurate with the dwell time of the interrogator antenna on a target (e.g., channel management and ATCRBS reply correlation).

3. Those which are paced by the antenna scan time and operate on a 1-second time scale (e.g., surveillance processing, data link processing, network processing, and performance monitoring).

A more detailed description of the Mode S sensor relative to beacon operation may be found in report No. FAA-RD-80-36, "Discrete Address Beacon System (DABS) Baseline Test and Evaluation" (reference 5). Radar target report data from a collocated primary radar digitizer are input to the sensor at the scan processing level (figure 1). Here the surveillance processing function performs Mode S and ATCRBS scan-to-scan correlation. Beacon reports are further correlated with digitized primary reports. These reports are transmitted to ATC facilities as radar-reinforced beacon reports. Radar substitution reports are transmitted to ATC in beacon format for those radar reports correlating with coasted beacon tracks. Radar reports that do not correlate with either beacon reports or beacon tracks are classified as radar-only reports.

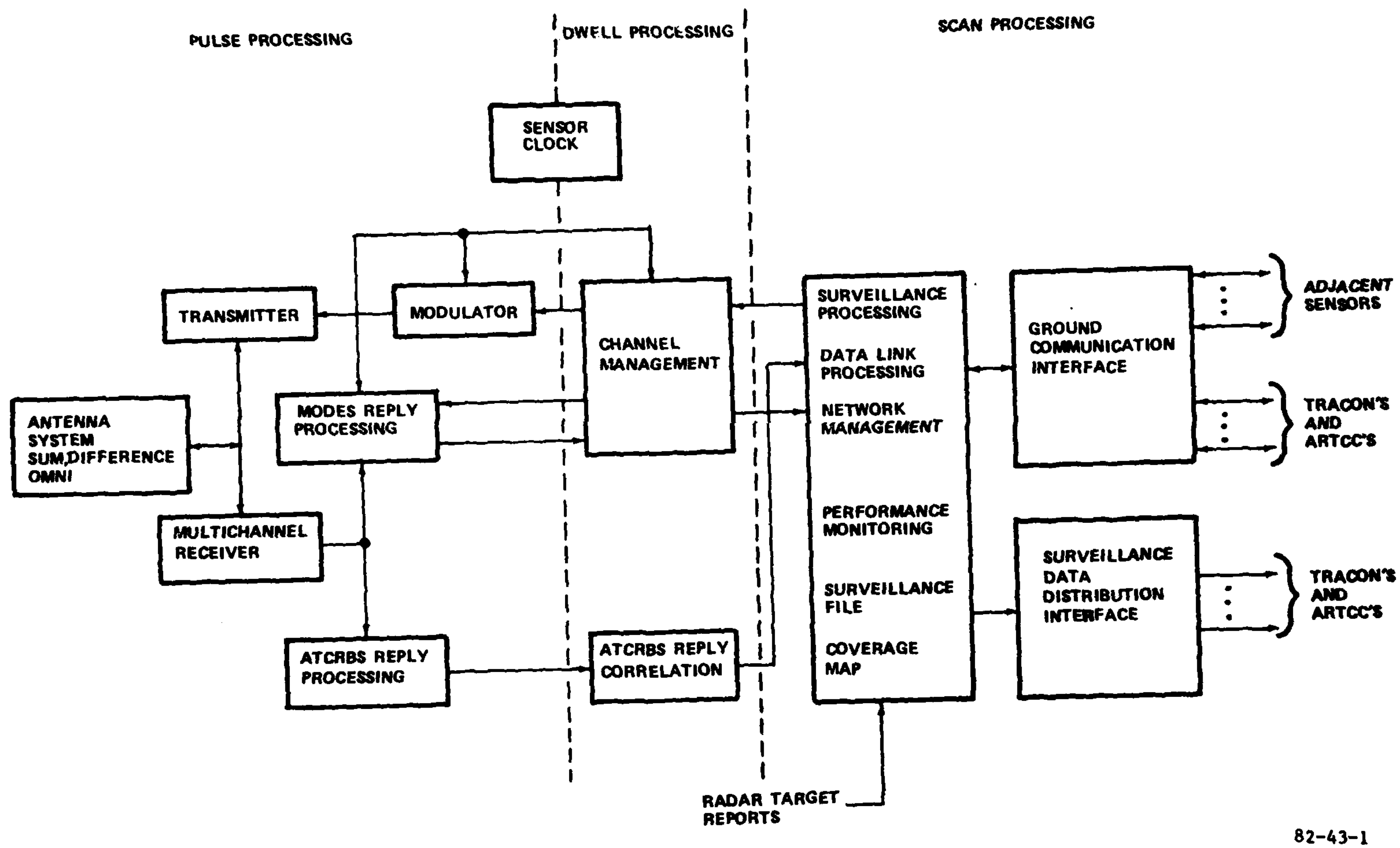


FIGURE 1. MODE S SENSOR FUNCTIONAL BLOCK DIAGRAM

The Mode S sensor performs radar-only tracking when interfaced with an MTD or RDAS radar digitizer. Each radar digitizer uses a completely different approach for target detection, which, in turn, provides some target information unique to each digitizer. When the Mode S is receiving MTD reports, MTD report confidence is used as an additional criteria for track initiation, MTD report quality is used in track smoothing algorithms, and both are used as uncorrelated data dissemination criteria. When the Mode S receives RDAS reports, the reports are reformatted to an MTD format acceptable to the Mode S. The confidence and quality fields associated with an MTD report are defaulted to high confidence and quality of one, which makes the track initiation confidence criteria, the track smoothing algorithms, and the uncorrelated data dissemination criteria transparent to RDAS data.

However, the RDAS report quality field is subjected to a Mode S quality filter prior to attempting track initiation and radar track update. This filter is unique for RDAS data and is transparent to MTD data.

MOVING TARGET DETECTOR.

The MTD-2 is a digital signal processor employing linear, wide dynamic range, coherent doppler filtering, and thresholding techniques. Doppler filtering is accomplished by sequentially processing groups of eight samples in each range gate of 1/16 nautical mile through a two-pulse canceller and converting the remaining time samples into frequency (Doppler) information using digital filter techniques. The MTD-2 contains a bank of eight doppler filters. One of these filters includes zero radial velocity.

The nonzero radial velocity cells are level detected using a mean level of the signals in the same velocity filter averaged over 1/2 mile in range on either side of the cell of interest. In addition, the MTD-2 contains a digital ground clutter map which establishes the thresholds for the zero radial velocity filter. The clutter level in the ground clutter map adapts to a value based on the average level in the previous eight scans. This allows all eight filter outputs, approximately 2,900,000 range- azimuth-velocity cells, to be independently thresholded every radar scan. The MTD-2 uses a multiple pulse repetition rate for each group of eight pulses to eliminate blind speeds and second-time-around ground clutter returns.

RADAR DATA ACQUISITION SUBSYSTEM.

The RDAS receives normal and MTI analog video along with basic timing signals from the radar. The input video are converted by analog-to-digital converters to a series of 10-bit words representing the amplitude of the input, sampled every 625 nanoseconds. The quantized video is then rank ordered and converted into target hit data and clutter hit data. The clutter hit data generated from the normal video is used by the RDAS to determine which to use, MTI or normal video, for target processing for a particular area. The processing logic employs hit/miss filtering and adaptive hit-count thresholding techniques to detect potential targets. Each target report is assigned a quality value which is defined as the number of hits counted on a target minus the applied hit count threshold.

The Mode S sensor receives the target reports and subjects them to a third level of discrimination based on their quality. Target reports that pass the quality filter are processed by the Mode S radar tracking software. The remaining target reports not used to update radar tracks or initiate new tracks are returned by the Mode S sensor interface to the RDAS. These uncorrelated radar reports are then counted and compared to a false report threshold. If the count exceeds the false report threshold, the rank order threshold is raised, reducing target hit sensitivity.

PRIMARY RADAR SYSTEM, ASR-7.

The ASR-7 is a solid-state, dual-channel, S-band, surveillance radar employing all digital video processing. The radar outputs normal and MTI video signals and synchro as well as azimuth pulse generator data for display by plan position indicator (PPI) systems. In addition to the standard normal and MTI video, logarithmic video processing may be selected on either type of video. Circular polarization and four selectable modes of sensitivity time control are provided to permit optimal operation during severe weather.

AUTOMATED RADAR TERMINAL SYSTEM.

The ARTS III is a modular system comprised of an input-output processor (IOP), DEDS console, common equipment cabinet, and a digital tape drive. The IOP is a general process computer that provides the expansion of the main computer memory core in 8,000 word modules. The system at the Technical Center Terminal Automated Test Facility (TATF) presently employs a memory size of 32,000 (32K) words. The IOP accepts azimuth status information words and target report messages from the Mode S sensor. It performs target tracking, display functions, and keyboard input functions from the controller, and outputs data functions to the DEDS display.

VIDEO RECONSTITUTOR.

The video reconstitutor (VR) generates PPI primary and beacon video signals, based on information contained in the digital messages disseminated by the Mode S sensor. The digital message formats are specified in report No. FAA-RD-80-14, section 4, "DABS Baseline Test and Evaluation" (reference 6). The VR signals are used to drive a conventional ARTS display. The VR provides the potential for eliminating the broadband link between the transmitter and the indicator sites while retaining the PPI display as backup to the ARTS digital system.

DISCUSSION

TEST CONFIGURATION.

The baseline performance of the Mode S radar tracking function was determined using the test configuration of figure 2. The ASR-7 provided the basic radar transmitter/receiver functions for all radar tests. The radar processors, the RDAS and the MTD, converted the radar receiver signals into digital radar reports for input to the Mode S sensor. These radar reports were further processed in the Mode S sensor (using software release 8.2) to reinforce beacon reports or substitute for coasted beacon tracks. Any remaining radar reports were used to initiate or update radar-only tracks. The Mode S sensor disseminated digital surveillance messages (Mode S, ATCRBS, and primary) to the ARTS III IOP and to the VR.

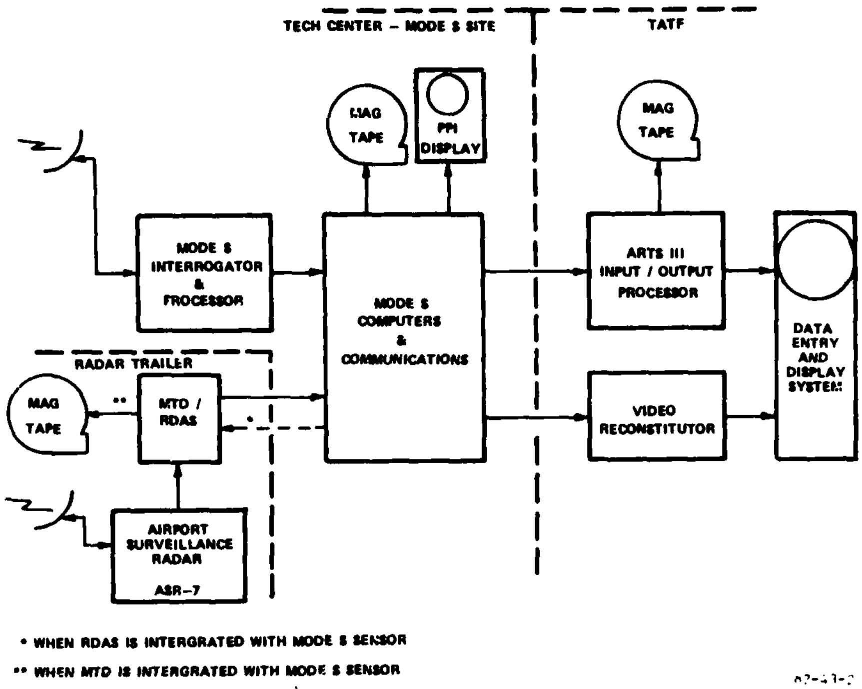


FIGURE 2. TEST CONFIGURATION BLOCK DIAGRAM

The ARTS III IOP processes the digital surveillance messages, using revision 2 All Digital Software (ADS2) for presentation on an all digital or time-shared display. The VR generated beacon and primary broadband video for presentation on the DEDS when operated in the time-shared mode.

The Mode S sensor was site-adapted to disseminate correlated and uncorrelated target reports to the ARTS system. Radar reports that correlate to mature tracks were disseminated as correlated data. Track maturity was site-adapted to declare a radar track mature after the occurrence of two sequential correlations, which defines the third report associated with the track as correlated data. Uncorrelated radar reports were disseminated if they had high confidence and report quality greater than zero. Radar track transitions from initial tracks to normal tracks were site-adapted for three correlated radar reports within four consecutive scans. Initial tracks failing to meet these criteria are dropped. Normal radar track drop criteria were site-selected for three consecutive track coasts.

The ARTS III ADS2 operational software was modified to filter out all surveillance messages (beacon and primary) flagged by the Mode S sensor as possible false targets. A second modification was made so that the ARTS would output primary radar track symbols to the displays immediately instead of waiting until establishing its own track files on correlated targets from the Mode S sensor.

TEST METHOD.

The basic philosophy in testing the Mode S primary radar tracking functions was to establish the Mode S baseline performance based on radar report data accepted from either the MTD or the RDAS. Prior to testing, the Mode S site adaptable primary radar tracking parameters were set to recommended nominal values defined in the ER.

The principle method of establishing baseline performance on primary radar tracking was to collect report and track data while conducting controlled flight tests. The aircraft employed was a Cessna 172, a single engine, four passenger aircraft. This aircraft was selected because it was equivalent in reflective surface to small aircraft recommended by the ATC Flight Inspection Manual (reference 7) for flight inspection of air surveillance radar facilities. The flight plan consisted of various flight patterns designed to test different aspects of primary radar tracking.

The primary report and track data were collected at all major data extraction points within the ARTS/Mode S/MTD and the ARTS/Mode S/RDAS system configurations during the flight tests. Prior to each flight test the ARTS III data extraction system as well as the MTD data extraction system, when integrated with the Mode S sensor, were manually time synchronized to the WWVB time-of-day recorded by the Mode S data extraction subsystem. Time synchronization was necessary for subsequent analysis to provide continuity of statistical data collected at all points. Figure 3, the Mode S Radar Baseline T&E matrix, states the overall purpose of this test activity. Below that, specific objectives are listed with a breakdown of the more critical parameters in each objective to be investigated. The test activities to accomplish each investigation are given in the second column for each parameter. A more detailed description of the test activities is given in the appendix. The method of presenting the results of each test activity to support analysis is given in the third column. The fourth column summarizes the conclusions sought based on the results obtained from the test activities.

In order to analyze primary radar tracking performance within the immediate surveillance coverage of an airport, it was necessary to conduct departures and landings to exercise specific tracking functions implemented in the Mode S sensor. The radar track initiation statistics were evaluated against the following two ATC performance standards:

1. A primary target should be observed within 1 mile of the departure end of runway for proper identification (reference 8). (This standard is important because of the difficulty in distinguishing primary targets from one another.)

2. The Mode S surveillance processor should provide correlated primary targets for controller display monitoring within three to five scans of detection while flagging or eliminating those false target reports not associated with moving targets (reference 9).

The radar track termination statistics were compared to the ATC service termination standard determined as follows:

1. Under normal conditions ATC radar service is terminated automatically when the aircraft making an instrument approach has landed or the tower sights the aircraft, whichever comes first (reference 8). Using this statement as a guide, proper

Purpose: To establish baseline performance on Mode S primary radar tracking when coupled either with an MTD or RRAS.

Specific Objectives	Test Activity	Data Reduction and Analysis (DRAA) Presentation	Interpretive Analysis
ER Compliance			
1. Track initiation	4,6,8	Tables of track initiation sequences	Does the software comply with the ER requirements?
2. Track maturity	4,6,8	Analysis of listings	Are these requirements sufficient for reliable radar tracking?
3. Report dissemination	1-9	Table of target reports disseminated	Same as above
4. Target velocity test	4,6,8	Tables	Same as above
5. Track termination	5,7,9	Track firmness histories	Same as above
6. Radar/beacon reinforcement	10	Analysis of listings	Same as above
7. Radar/beacon substitution	10	Analysis of listings	Same as above
Technical Performance			
1. Tracking at local airport	4,5	Statistics (BSR, track drops/swaps/coasts) plots/tables track drop characteristics	Can automated radar tracking be achieved and still maintain display quality in regard to false tracks?
2. Tracking at satellite airports	6,7,8,9	Same as above	Same as above
3. Sensitivity in clear air	1	Statistics (BSR, track drops/swaps/coasts) track history plots	Same as above
4. Sensitivity over clutter	2,3	Statistics (BSR, track drops/swaps/coasts) track history plots	Does the VR provide a means of notifying a controller of the presence of a target prior to the display of an ARTS track symbol?
5. Radar/beacon merger	10	Percent radar/beacon correlation	Same as above
6. Radar/beacon substitution	10	Percent radar/beacon substitution	Same as above
7. False alarm rate	10	Statistics	Same as above
ATC Performance			
1. Clear air FAR (1 per scan)	10	Mode S FAR ARTS	Are the DEDS displays usable with the false alarm rates achieved?
2. Clutter FAR (10 per scan)	10	Mode S/ARTS FAR's/plots of false targets	Same as above
3. Track Acquisition (3 to 5 scans after detection)	4,6,8	Departure delay tables (first detect to ARTS display)	Does the performance meet ATC minimum standards?
4. Maintain reliable tracks	1,9	Tables of statistics (BSR's, drops, swaps, coasts, and data loss)	Same as above
5. Target ID detection on departure (1 nmi end of runway)	4,6,8	Analysis of listings/review of 35mm film	Same as above
6. Service termination	5,7,9	Same as above	Same as above

Test Activity Flight Segments

1. Low altitude radial
2. S-turn patterns over clutter
3. Tangential flight over clutter
4. Atlantic City Airport departures
5. Atlantic City Airport approaches
6. Smithville departures
7. Smithville approaches
8. Bader Field departures
9. Bader Field approaches
10. Live environment

FIGURE 3. MODE S RADAR BASELINE T&E MATRIX

service termination on an aircraft making a final approach for landing will be considered to occur when the track terminates after radar detection is lost followed by the proper number of track coasts.

2. Aircraft departures and landings were conducted at the Atlantic City Airport to establish baseline tracking performance for primary radar surveillance for a local airport. Likewise, aircraft departures and landings were conducted at Smithville and Bader Field airports to establish baseline tracking performance for primary radar surveillance in and around satellite airports.

Airports remotely located with respect to the Mode S sensor are termed satellite airports if the sensor has primary responsibility of providing surveillance coverage over the airport.

System performance in the clear and over ground clutter was judged by the ATC performance standard specified for a 1-square meter target at a range of 55 nautical miles flying either inbound or outbound (reference 9). The probability of detection of the target by this criteria should be greater then 0.8, which, in turn, should be sufficient for the Mode S sensor to maintain a reliable track on a target.

System sensitivity in the clear was determined by conducting radial flights from the radar site. The flight tests were flown at an altitude of 1,000 feet. The test aircraft proceeded outbound until primary radar detection was lost, then returned inbound until crossing over the radar site. The results on the radial flights were expected to exceed the detection requirements specified in the previous paragraph since the flights were conducted within 25 nautical miles of the radar site.

System sensitivity over a ground clutter environment was determined by conducting S-turn flight patterns and tangential flight patterns over Atlantic City/Absecon ground clutter areas depicted in figure 4. The runs were conducted for both test configurations, two S-turn runs and two tangential runs.

Concurrent with the flight tests, a separate investigation was conducted to determine the quality of Mode S disseminated data presented on the DEDS display. This was achieved by reducing data collected on targets of opportunity. Technical performance criteria, such as false radar track initiation rate by the Mode S sensor and the ARTS III, radar beacon reinforcement, radar substitution, uncorrelated report dissemination rate, and the correlated false radar report dissemination rate by the Mode S sensor were established to provide a statistical base to judge the level of display acceptability. The false alarm results were compared to the ATC performance standards of:

1. The surveillance processor shall output fewer than one false correlated target report per scan averaged over a 1-hour period during normal operating conditions (reference 9).

2. Peak rate of display of false radar targets shall be fewer than 10 per scan averaged over a 1-hour period under extreme conditions of "angel" activity (reference 9). Interpretive analysis of the remaining criteria was performed by comparing the results to expected results and with empirical evaluation of the 35mm film taken on the DEDS display during the flight tests.

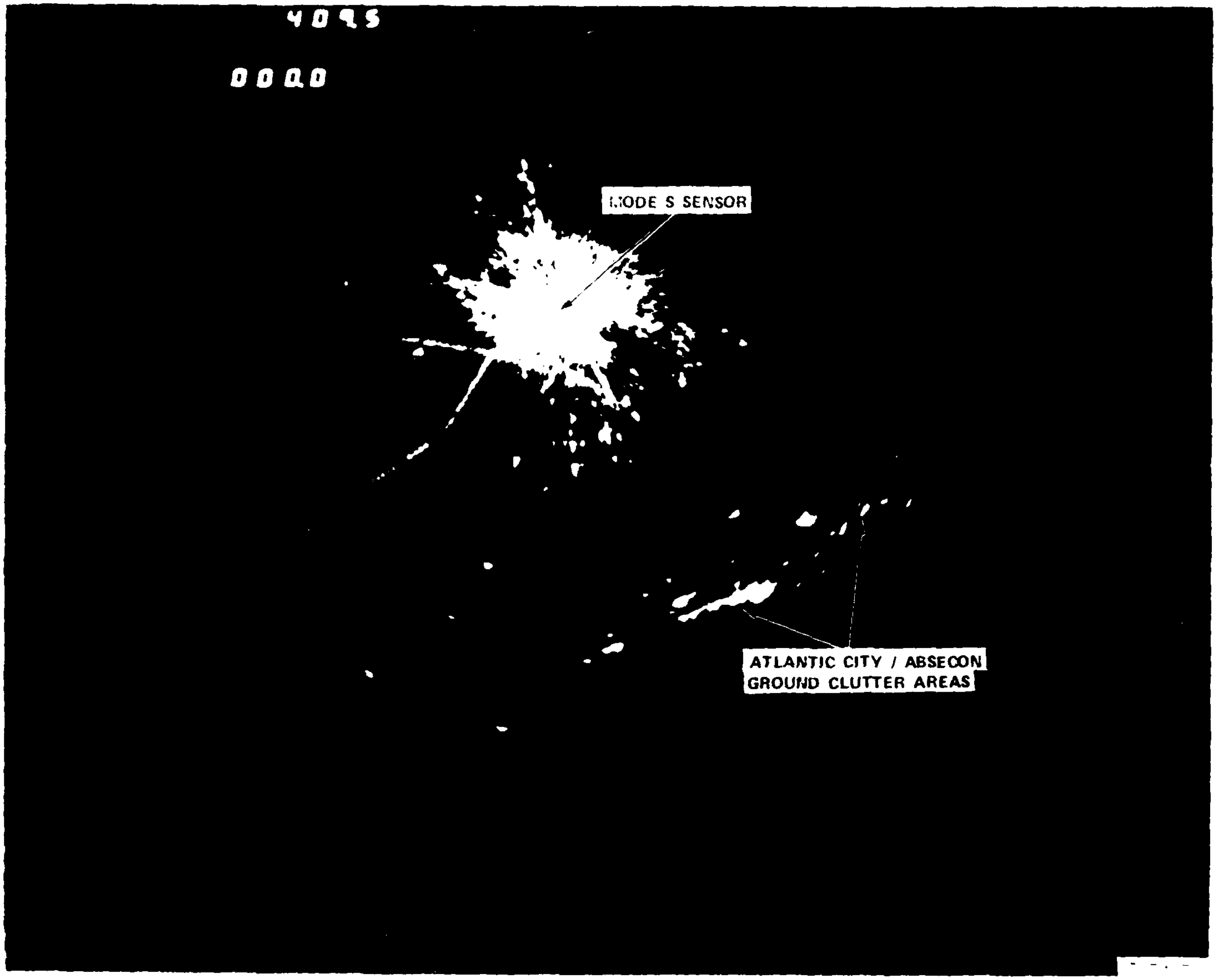


FIGURE 4. ATLANTIC CITY/ABSECON GROUND CLUTTER AREAS

DATA COLLECTION

Magnetic tape units at the MTD processor, Mode S, and ARTS III equipment provided the media for collecting data, which was analyzed on a time/scan comparison basis. The output of the RDAS processor was recorded by the Mode S magnetic tape unit at the Mode S input radar buffer. A camera was setup at one of the ARTS III displays and photographs were taken during the tests. The following data were recorded at the indicated equipments:

Recorded Data	MTD	Mode S	ARTS III
Time of day	X	X	X
MTD reports	X	X	
RDAS reports		X	
Mode S surveillance data block		X	
Surveillance Messages		X	X
ARTS III track data block			X

A dual tracking patch was implemented in the Mode S sensor to allow primary radar reports to be used for reinforcing Mode S beacon reports or update coasted tracks and still be available for radar-only processing. In this manner surveillance reports for both conditions were available for data collection and subsequent analysis. Normally, the radar report would be discarded after being used to reinforce a beacon report or update a coasted beacon track.

DATA REDUCTION

Data collected on the controlled test aircraft during the flight tests were reduced to establish baseline tracking performance by the Mode S sensor, integrated with either the MTD or the RDAS, to provide reliable primary radar track data to the ARTS III system for automated primary radar track acquisition. The performance criteria used to establish the baseline tracking performance of the Mode S primary radar tracking software are given in the following paragraphs.

1. Radar Track Drops. This number represents the number of times a Mode S SFN changed during a flight segment excluding the following conditions:

a. When the track drops as a result of the aircraft flying outside the surveillance coverage of the radar site.

b. When the track drops as a result of the aircraft making a final approach and landing.

2. Radar Track Swaps. The number of times Mode S SFN's swap to other tracks.

3. Blip-Scan Ratio (BSR). The BSR for either radar digitizer is based on the radar reports collected in the Mode S radar report buffer unless otherwise specified. The BSR for the Mode S sensor and the ARTS III system were based on tracker output (correlated data). For conformity of results between each of the three system levels, the BSR was considered for each test segment starting with the first surveillance message processed by the ARTS III IOP up to and including the last target detection of the test segment. This method of determining the BSR for report and track level will be used in this report unless otherwise specified.

Additional system performance criteria analyzed are given in the following paragraphs. These criteria were based on data collected on targets of opportunity by the Mode S data extraction subsystem and the ARTS data extraction system.

These data were reduced and analyzed to judge the technical performance of each surveillance tracking system and the display quality generated by the ARTS III IOP on the DEDS displays.

4. Radar Beacon Reinforcement. The percent radar beacon correlation (RBC) was derived with the following equation:

$$\text{Percent RBC} = \frac{\text{Total number of beacon reports with the radar reinforced flag set}}{\text{Total number of beacon reports}} \times 100.$$

The percentage of RBC was determined by reducing 300 scans of data collected during each flight check. All beacon reports that were within the spatial position of the ASR-7 antenna pattern defined below were considered.

Range: 1 to 48 nautical miles
Elevation angle: 2° to 16°
Altitude: 20,000 feet
Azimuth: 0° to 360° excluding 120° to 140°

The range, elevation angle, and altitude filters were selected to exclude beacon targets flying beyond the coverage or on the fringe of the radar antenna pattern. The azimuth filter was selected to eliminate a known beacon reflection wedge created by the Technical Center hanger located near the Mode S sensor.

5. Radar Beacon Track Substitution. The radar beacon substitution percentage was derived by employing the following equation:

$$\text{Percent Substitution} = \frac{\text{Number of beacon tracks updated by primary radar reports}}{\text{Total number of beacon tracks not updated by beacon reports}} \times 100.$$

The radar substitution percentage was based upon the same 300 scans analyzed to determine RBC. Again, only beacon tracks located in the spatial position of the ASR-7 radar antenna pattern defined by the parameters listed previously were used.

6. False Radar Track Rate and Persistance. The false radar track rate and the false radar track life was determined at the Mode S surveillance file and the ARTS tracking file. All radar tracks initiated over a 100-scan period during each flight check were analyzed.

An automated program was developed by Technical Center engineers to assist in reducing Mode S radar track data recorded on the data extraction tape to determin the false radar track rate for the Mode S/MTD and Mode S/RDAS system configurations. This program provides a list of likely radar false tracks based on one or more of the following criteria:

a. Short track life of four scans or less (track initiation to last report update).

b. Low track BSR (less than 33.3 percent).

c. Unreasonable speed (greater than 400 knots or less than 50 knots).

d. Unreasonable heading change (noncoast track heading greater than 40°).

The listing provided a track history on each likely false radar track including the start and stop range and azimuth of the track and track BSR.

Each likely false radar track in turn was examined subjectively. For any questionable case, additional program listings were gathered consisting of scan by scan accounts (report and track data) on the target and analyzed to determine its track status. A likely false radar track that dropped in the vicinity of an airport was considered a real target. Table 1 presents a list of the airports within the radar coverage area of the Mode S sensor and their locations with respect to the sensor.

7. Uncorrelated Radar Report Dissemination Rate. This rate of dissemination was determined by reducing the same 300 scans of data analyzed to determine RBC. The data reduction filters, such as range and azimuth, were not employed allowing all data collected to be considered. The total number of uncorrelated radar reports disseminated were averaged over a 300-scan interval.

8. Correlated False Radar Report Dissemination Rate. This rate of dissemination was determined in a manner similar to the uncorrelated radar report dissemination rate. The total number of correlated reports with the false target flag set were averaged over a 300-scan interval.

RESULTS AND ANALYSIS

The results and analysis of the ARTS/Mode S/MTD and the ARTS/Mode S/RDAS flight tests have been divided into appropriate test segments which address specific objectives. Departures and landings from the Atlantic City Airport (ACY) are discussed first, followed by departures and landings at satellite airports. The departures and landings were further segmented into complete departure-to-landing sequences and presented individually. These segments are accompanied with expanded plots of disseminated primary radar reports containing the appropriate test aircraft track segment. Data tables also accompany each test segment. The first

TABLE 1. LIST OF ALL AIRPORTS WITHIN SURVEILLANCE COVERAGE OF THE TECHNICAL CENTER MODE S SENSOR

Airport	Location from Sensor: True Bearing (degrees)	Location from Sensor: Distance (nmi)
Lentine	025	22.4
(Toms River) Miller	027	31.8
Manahawkin	043	19.9
Eagle Nest	044	17.2
Smithville	067	5.3
Bader	136	7.7
Ocean City	187	11.6
Nordheim	203	4.5
Cape May	209	31.0
Woodbine	214	17.6
Millville	256	24.2
Kroelinger	280	23.2
Vineland	284	19.0
Rudy's	285	24.0
Piney Hollow	300	17.9
Geiser	304	22.3
Cross Keys	305	26.0
Albion	319	26.5
Hammonton	326	15.1
Camden (Burlington Co.)	326	27.2
Burlington Co.	337	32.8
Red Lion	343	29.0
McGuire	358	34.2

table presents the time related events leading up to the establishment of an ARTS primary radar track for controller display monitoring. The second table contains the baseline technical performance of the test configuration based on surveillance data collected on the controlled test aircraft. Low altitude radial flights are discussed concerning system sensitivity in the clear; ground clutter flights are discussed concerning system sensitivity over ground clutter. These segments are accompanied by expanded plots presenting individual test runs for each test segment, e.g., an outbound low altitude radial run and an inbound low altitude radial run.

In conjunction with the above, a table is presented containing the statistical summary of the technical performance achieved on each test segment. A final analysis section is concerned with the overall systems performance to judge the quality of data disseminated to the ARTS III IOP and the VR. Tables are also presented containing the technical performance on ARTS/Mode S/MTD flight tests and the ARTS/Mode S/RDAS flight test based on data collected on targets of opportunity.

PART 1: ARTS/MODE S/MTD FLIGHT TESTS.

LOCAL AIRPORT RADAR SURVEILLANCE. The primary purpose of this flight segment was to establish the combined ARTS/Mode S/MTD primary radar track initiation delay encountered after aircraft departures from a local airport. The delay for this ACY run, as well as the following three ACY runs, was used to establish a baseline performance for the above systems in displaying correlated surveillance track data to a noncorrelating user. In addition, these test sequences provided primary radar surveillance data to establish baseline tracking performance within the immediate surveillance coverage of a local airport as well as track termination characteristics when the aircraft lands. Analysis of these data identified any problems in MTD target detection, Mode S primary radar tracking and dissemination, and ARTS III displaying of radar track data.

ACY Run No. 1. Figure 5 shows an expanded plot of all primary radar reports disseminated to the ARTS III IOP for 93 scans. This plot contains the track of the controlled test aircraft from departure to touchdown on ACY runway 26. In addition, false primary radar tracks and disseminated uncorrelated primary radar reports are shown, represented by the random placement of dots as compared to the dot track generated on the test aircraft.

Table 2 lists the delay time within the test configuration on critical events leading to track initiation on the test aircraft. The events are categorized starting with the aircraft takeoff. The time of this event was called out by the copilot each time the aircraft was airborne. The following critical events listed in table 2 are: the initial radar report disseminated by the MTD to the Mode S sensor, the first uncorrelated primary radar surveillance message disseminated by the Mode S sensor, the establishment of the initial primary radar track by the Mode S sensor, the first correlated primary surveillance message with the false target flag set (FTF=1) disseminated by the Mode S sensor, the first correlated primary surveillance message with the false target flag cleared (FTF=0) disseminated by the Mode S sensor, the first Mode S primary surveillance message received and displayed by the ARTS III system, and the first time an ARTS track data block was available. Along with each critical event other data are provided such as the time of the event, the cumulative time delay from departure, the cumulative scan delay from departure, the range and azimuth of the aircraft during the event, and, if pertinent for the event, the Mode S SFN.

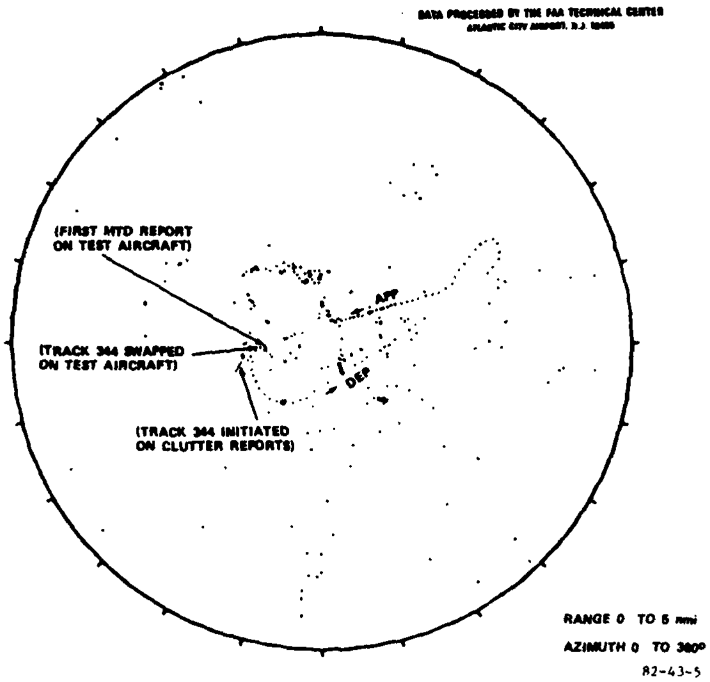


FIGURE 5. MODE S/MTD ACY DEPARTURE AND LANDING ON RUNWAY 26

TABLE 2. MODE S/MTD TRACK INITIATION DELAYS FROM ACY RUNWAY 26 (RUN NO. 1)

		Cumulative Delay				
Event	Time	Time (sec)	Scans	Range (nmi)	Azimuth (deg)	SFN
Takeoff	09:33:55					
Initial MTD Report	09:34:31.6	36.6	7	0.97	266.86	
First Mode S Uncorrelated	None					0
Mode S Track Initiated	09:34:36.1	41.1	8	1.19	260.62	344
First Mode S Correlated FTF Set	None					
FTF Cleared	09:34:40.8	45.8	9	1.06	262.82	344
ARTS Displayed Track	09:34:41.2	46.2	9	1.06	262.88	344
ARTS Track Data Block	09:34:45.9	50.9	10	1.08	260.0	344

Table 3 contains the statistical summary of the technical performance for this test segment.

TABLE 3. MODE S/MTD BASELINE TRACKING PERFORMANCE FROM ACY RUNWAY 26

Detailed Track Analysis

Track Drops: 2
Track Swaps: 2 - Track 344 swapped from clutter to test aircraft
- Track 344 swapped from test aircraft to clutter

Track	Time	ARTS Track Coasts
344	09:35:51.4	No detection by the MTD radar digitizer
194	09:36:41.8	No detection by the MTD radar digitizer

Blip-Scan Ratio (9%)

MTD (Report Level)	Mode S (Track Level) SFN		ARTS III (Track Level)	No. Samples
86.8 (76 samples)	344	94.1	94.1	17
	194	85.7	85.7	7
	312	100	100	32

The aircraft departure from ACY runway 26 was at 09:33:55; touchdown was at 09:40:48. Refering to table 2, the MTD detected the test aircraft 36.6 seconds after departure (approximately seven scans later). This report had high confidence and a quality of one, satisfying the uncorrelated dissemination criteria setup for this test but was not disseminated. This anomaly was observed in all attempts to disseminate uncorrelated surveillance messages within 1 nautical mile of the Mode S sensor. A trouble report was submitted to the Joint Configuration Control Board (JCCB) for investigation after an initial investigation failed to reveal the reason for the occurrences.

In addition, this report was available as a first report candidate for track initiation. Actually, no radar track was initiated on the test aircraft, but rather, a radar track which was initiated on reports generated from ground clutter returns swapped onto the test aircraft.

Several events leading to the clutter-to-aircraft track swap are shown in figure 5. The relative position of the clutter track prior to swapping on the test aircraft, the relative position of the first MTD radar report generated on the test aircraft, and the relative position of the second MTD radar report generated on the test aircraft which was used to update the clutter track are indicated. The events leading to the track swap are detailed below.

Four scans after the test aircraft departure the Mode S sensor initiated track 344 on reports generated from ground clutter returns. At this time the range and azimuth of track 344 was 1.22 nautical miles and 256.08°. The range and azimuth of the test aircraft was 0.74 nautical miles and 273.21° (as reported by the Mode S beacon track established on the test aircraft). The position of track 344 was updated to 1.15 nautical miles and 266.62° to the sensor two scans later by similar clutter reports. On the seventh scan track 344 coasted. The predicted position of track 344 was updated to 1.16 nautical miles and 276.77°. On the same scan the Mode S sensor received the first MTD radar report on the test aircraft with a reported position of 0.97 nautical miles and 266.86°. On the eighth scan the second MTD radar report was received on the test aircraft with a reported position of 1.00 nautical mile and 265.89°. At this time, with the track association windows expanded, the predicted position of track 344 was 1.17 nautical miles and 272.35°. The MTD report fell within the zone one association window and was used to update track 344, as specified by FAA-ER-240-26. This prevented a normal track initation on the test aircraft. On the following scans, track 344 continued to be updated by reports generated on the test aircraft.

The remaining events of table 2 are based upon track 344 being initiated on the test aircraft on the eighth scan. The minimum azimuth difference criteria of the target velocity test was satisfied by reviewing the position information from the previous two reports generated on the aircraft with a reported azimuth difference of 2.99°.

As specified by FAA-ER-240-26, the target velocity test requires all primary radar tracks initiated within 20.2 nautical miles (ER nominal value) to be considered as possible false tracks until they meet one of the following movement criteria:

1. The range difference between the current range and the initial range exceeds 0.5 nautical mile (ER nominal value of 50 one-way range units).

2. The azimuth difference between the current azimuth and the initial azimuth exceeds 2.82° (ER nominal value of 128 azimuth units). If neither criteria is met within 10 scans (ER nominal value) the track would be dropped from the surveillance file.

The first correlated report disseminated by the Mode S sensor occurred on the third scan of detection, nine scans after departure. An ARTS primary track symbol was displayed immediately for controller display monitoring. The VR provided a broadband display as well. The ARTS track data block was available on the following scan when the second Mode S surveillance report was received.

From the results in table 2, the Mode S sensor provided usable correlated reports to the ARTS III system on the third scan of detection. This was in compliance with the ATC standard of making available correlated primary target reports to a display processer within three to five scans of initial detection for controller display monitoring. Specific identification by observing the test aircraft within 1 mile of the departure end of runway was not clearly achieved. An ARTS track was established on the test aircraft within the acceptable criteria, but the track was observed originally on clutter two scans prior. Upon reviewing 35mm film taken of the DEDS display during this test segment, several scans had to be viewed before it was realized the track swapped on the real correlated target. Also, the VR generated several uncorrelated target video signals in close proximity to the test aircraft over the scans of interest.

In table 3 it is seen that track continuity was not maintained over this test segment. During this period the ARTS displayed three seperate tracks on the test aircraft. The average track life for the three tracks was nearly 19 scans long. The ARTS displayed reliable track data 54 of the 76 scans analyzed. The first track, 344, was dropped as a result of being updated by a report generated from clutter returns. The MTD report used was of low confidence, quality of zero, and located in the zone two association window of Mode S primary track 344. The incorrect update became possible when the MTD failed to detect the aircraft leaving the clutter report as the only report update candidate. The track predicted heading was diverted from the aircraft's true heading, which made correlation with correct reports difficult on the following track updates. Track 344 was updated by clutter reports on the next two scans, then dropped after three misses.

The second Mode S track, 194, was short, with an ARTS track life of only seven scans. The MTD failure to detect the aircraft for seven consecutive scans caused the track to drop.

The third Mode S track established on the test aircraft was maintained until the aircraft descended to an altitude of 100 feet prior to landing. The Mode S sensor initiated track 312 on scan 362, but presentation on the DEDS display was delayed until scan 366 when the target velocity test was satisfied. The VR presented the aircraft for controller monitoring prior to ARTS tracking. The VR generated broadband symbols with an azimuth extent of 0.7° (referred to as half-azimuth extent) for two scans on uncorrelated primary reports, and generated broadband symbols with an azimuth extent of 1.4° (referred to as full-aziumth extent) for four scans on correlated reports flagged as false.

Figure 6 illustrates what is presented on a DEDS display by the VR and the ARTS III system from the time a target is initially detected (upon takeoff) until an ARTS track is assigned. The plus symbol represents the radar site, and above that a runway is presented for clarity. The first two symbols starting at the end of the runway represent an uncorrelated target detected for two scans. These simulated broadband symbols were generated by the VR with half-azimuth extent. Now assuming that the Mode S sensor initiated a track on the target, the next two symbols generated with full-azimuth extent represent a correlated target flagged as false for two scans. The ARTS III system purged these reports, thus, no ARTS track symbol is displayed. The final three symbols represent a correlated target with the false target flag cleared for three scans. At this time the ARTS primary radar track symbol is displayed along with the broadband symbol. Normally, the ARTS track symbol would overlay the broadband symbol, but is offset on the illustration for clarity.

The landing on ACY runway 26 resulted in an acceptable track termination. On the approach, primary radar detection was lost as the aircraft descended to an altitude of 100 feet (altitude reported by the aircraft's Mode S transponder), roughly two scans prior to landing. Mode S track 312 was dropped at 090:40:49:11, three scans after detection was lost.

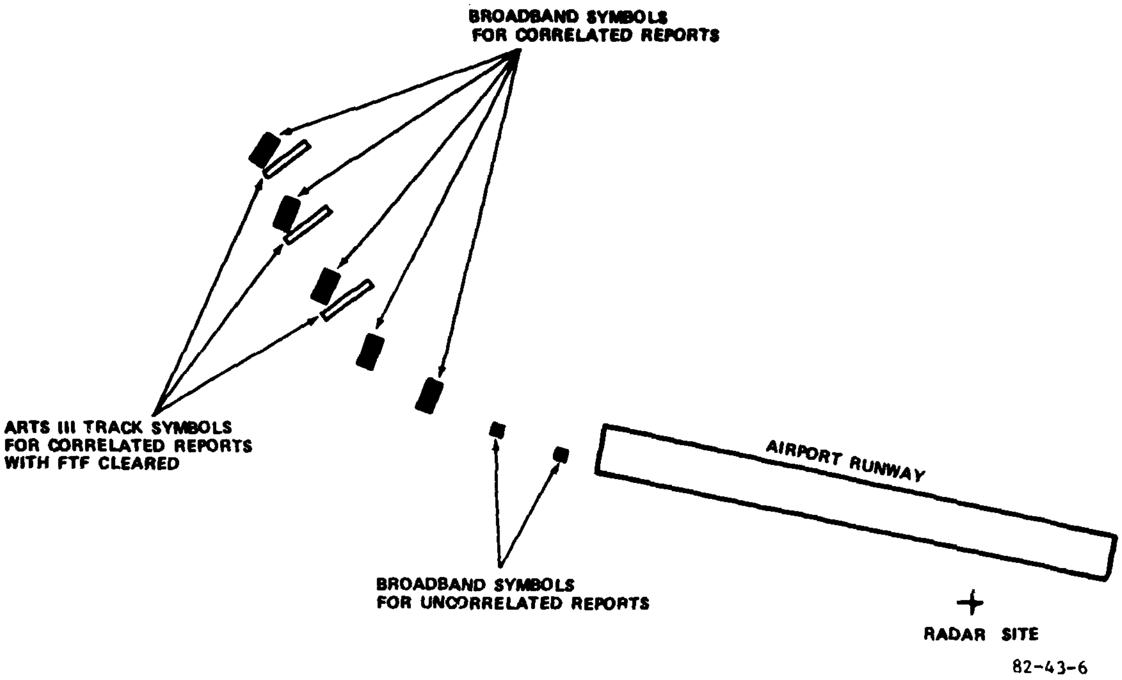


FIGURE 6. AIRCRAFT DEPARTURE PRESENTED ON A DEDS DISPLAY

ACY Run No. 2. Figure 7 shows an expanded plot of all primary radar reports disseminated to the ARTS III IOP for 87 scans. This plot contains the track of the controlled test aircraft from departure on ACY runway 26 to touchdown on ACY runway 13. Also, false primary radar tracks and uncorrelated radar reports are shown collectively for the same period. Table 4 lists the delay time for critical events leading up to track initiation. Table 4 is identical to table 2 and presents similar track initiation delay data for this run. Table 5 contains a statistical summary of the technical performance.

The aircraft departure from ACY runway 26 was at 09:41:24; touchdown on ACY runway 13 was at 09:46:48. As can be seen in table 4, the MTD first detected the test aircraft 37.5 seconds after departure (approximately eight scans later). This report was used to update track 356 which had been initiated on automobile traffic detected by the MTD digitizer. The automobile traffic is shown in figure 7 as a concentration of dots located just before the test aircraft was initially detected, and in the descending path of the aircraft just prior to landing. On the following two scans the Mode S sensor initiated track 8 on the test aircraft. Both reports having high confidence and quality greater than zero were disseminated as uncorrelated reports to the ARTS III IOP and the VR. As noted from table 4, the disseminated uncorrelated radar reports contained range greater than 1 nautical mile. The VR displayed simulated broadband primary radar targets on the DEDS based on the digital information received. These uncorrelated target reports were displayed with half-azimuth extent.

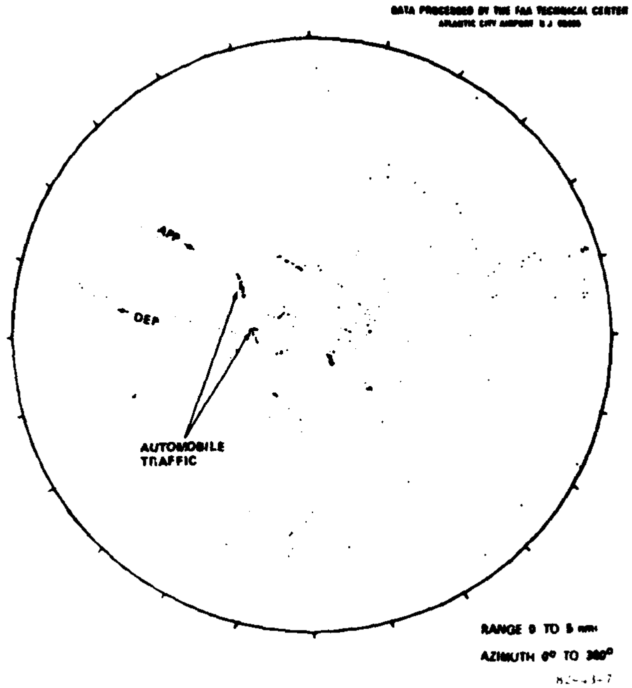


FIGURE 7. MODE S/MTD ACY DEPARTURE AND LANDING AT RUNWAYS 26/13

TABLE 4. MODE S/MTD TRACK INITIATION DELAYS FROM ACY RUNWAY 26 (RUN NO. 2)

Event	Time	Cumulative Delay Time (sec)	Cumulative Delay Scans	Range (nmi)	Azimuth (deg)	SFN
Takeoff	09:41:24					
Initial MTD Report	09:42:01.5	37.5	8	1.14	271.56	
First Mode S Uncorrelated	09:42:06.2	42.2	9	1.3	272.4	0
Mode S Track Initiated	09:42:11.0	47.0	10	1.34	273.08	8
First Mode S Correlated FTS Set	09:42:15.6	51.6	11	1.4	273.6	8
FTF Cleared	09:42:34.4	70.4	15	1.78	275.71	8
ARTS Displayed Track	09:42:34.9	70.9	15	1.78	275.71	8
ARTS Track Data Block	09:42:39.6	75.6	16	1.76	276.0	8

TABLE 5. MODE S/MTD BASELINE TRACKING PERFORMANCE FROM ACY RUNWAY 26/13

Detailed Track Analysis

Track Drops: 0
Track Swaps: 1 - track 8 swapped from test aircraft to clutter
Track Life: 65 scans - complete test segment

Time	ARTS Track Coasts
09:42:45.30	No detection by the MTD radar digitizer
09:43:14.45	No detection by the MTD radar digitizer
09:45:01.60	No detection by the MTD radar digitizer
09:46:07.37	No detection by the MTD radar digitizer
09:47:13.02	No detection by the MTD radar digitizer
09:47:17.70	No detection by the MTD radar digitizer

Blip-Scan Ratio (%)

MTD (Report Level)	Mode S (Track Level)	ARTS III (Track Level)	No. Samples
90.8	90.8	90.8	65

The first correlated report disseminated by the Mode S sensor occurred on the fourth scan of detection as expected since track maturity was achieved after track initiation. This surveillance report, as well as the next three reports, were disseminated, flagged as false targets, and were purged by the ARTS III system. However, the VR continued to provide primary broadband symbols for controller display monitoring. These correlated reports were displayed with full azimuth extent.

The first displayed ARTS III primary track symbol occurred 70.9 seconds after departure at 09:42:34.9. Both the minimum azimuth difference and the minimum range difference criteria were exceeded, satisfying the target velocity test on this scan. On the following scan the ARTS III track data block was available nine scans after the test aircraft was initially detected.

To summarize the performance of this test segment, it was noted that the Mode S sensor was not able to identify the controlled test aircraft as a real correlated target until the eighth scan of detection. The first report on the test aircraft was incorrectly used to update another track, delaying track initiation for one scan. This delay was attributed to the failure of the MTD to filter out local automobile traffic. Four additional scans were added to the overall delay as a result of the decision-making process in determining whether track 8 was a real aircraft, thus, preventing compliance with the minimum standard of displaying correlated targets within three to five scans of detection, while flagging those false target reports which are not associated with moving targets. A second ATC mimimum standard for identifying a particular primary radar target by monitoring the target on the display starting within 1 mile of the departure end of the runway was met. Reviewing 35mm film taken of the DEDS display during this test segment, regenerated broadband video on the test aircraft was observed prior to the initial ARTS track symbol. The ARTS track symbol was displayed for the test aircraft just within 1 mile of departure.

As seen in table 5, track continuity was maintained for the complete test segment. During this period the ARTS displayed reliable track data for 59 of 65 scans analyzed for an ARTS III BSR of 90.8 percent. Failure by the MTD to detect the test aircraft resulted in all six ARTS track coasts.

The landing at ACY runway 13 resulted in an unacceptable track termination. On the final approach primary radar detection was lost just prior to landing at 09:46:44. Mode S track 8 swapped onto false reports generated from automobile traffic along Tilton Road. The Mode S track remained active for ten scans (nine scans after the test aircraft landed), then dropped after three coasts at 09:47:43.5. The ARTS III track remained active before dropping at 09:47:50.4.

ACY Run No. 3. Figure 8 shows an expanded plot of all primary radar reports disseminated to the ARTS III IOP for 96 scans. This plot contains the track of the controlled test aircraft from departure to touchdown on ACY runway 13. Table 6 lists the delay time within the test configuration on critical events leading up to track initiation on the test aircraft. Table 6 is identical to table 2 and presents similar track initiation delay data for this run. Table 7 contains the statistical summary of the technical performance.

The aircraft departure from ACY runway 13 was at 09:47:26; touchdown was at 09:54:12. The MTD first detected the test aircraft 19.0 seconds after departure (approximately four scans) (see table 6).

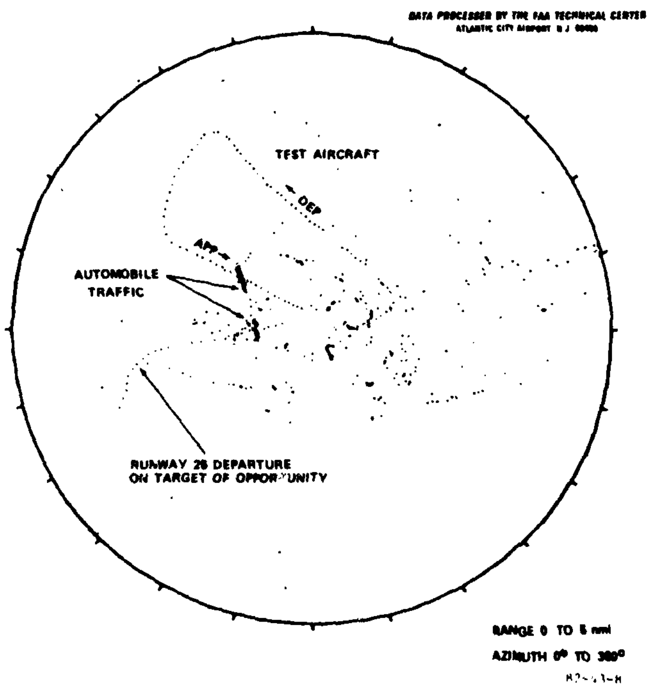


FIGURE 8. MODE S/MTD ACY DEPARTURE AND LANDING AT RUNWAY 13

TABLE 6. MODE S/MTD TRACK INITIATION DELAYS FROM ACY RUNWAY 13

		Cumulative Delay				
Event	Time	Time (sec)	Scans	Range (nmi)	Azimuth (deg)	SFN
Takeoff	09:47:26					
Initial MTD Report	09:47:45.0	19.0	4	0.39	76.77	
First Mode S Uncorrelated	None					0
Mode S Track Initiated	09:47:55.5	29.5	6	0.52	89.08	193
First Mode S Correlated FTF Set	None					
FTF Cleared	09:48:00.2	34.2	7	0.66	88.64	193
ARTS Displayed Track	09:48:00.7	34.7	7	0.66	88.64	193
ARTS Track Data Block	09:48:05.4	39.4	8	0.69	90.0	193

TABLE 7. MODE S/MTD BASELINE TRACKING PERFORMANCE FROM ACY RUNWAY 13

Detailed Track Analysis

Track Drops: 1
Track Swaps: 1 - SFN changes of 193 to 139
Track Life: SFN = 193 (12 scans)
SFN = 230 (52 scans)

Track	Time	ARTS Track Coasts
193	09:48:43.7	No detection by the MTD radar digitizer
230	09:50:49.1	Surveillance message lost between Mode S and ARTS II

Blip-Scan Ratio (%)

MTD (Report Level)	Mode S (Track Level) SFN		ARTS III (Track Level)	No. Samples
97.5	193	91.7	91.7	12
(79 samples)	230	100	98.1	52

This report had low confidence and was not available as a first report candidate for track initiation. On the second of the following two scans, the Mode S sensor initiated track 193 on the test aircraft. Both reports having high confidence and quality greater than zero, satisfied the uncorrelated report dissemination criteria for this test but were not disseminated. This nondissemination of uncorrelated data is the same dissemination anomaly addressed in ACY run No. 1.

The first correlated report disseminated by the Mode S sensor occurred on the fourth scan of detection as expected. The surveillance report was immediately displayed by the ARTS for controller display monitoring, having already satisfied the azimuth difference criteria of the target velocity test when initiated. The VR provided a broadband symbol of full azimuth extent for display. An ARTS track data block was available on controller request on the following scan at 09:48:05.4.

From the results shown in table 6, an ARTS track symbol was displayed for controller monitoring on the fourth scan of detection in compliance with the ATC minimum standard of displaying correlated targets within three to five scans of detection. Positive target identification was achieved. The ARTS track was established on the test aircraft within 1 mile of the departure end of the runway. Target detection by the MTD for this test segment was excellent, with a detection of 97.5 percent (as shown in table 7).

Target detection was determined from the time the aircraft was first detected up to and including the time the aircraft was last detected. Track BSR for the Mode S sensor and the ARTS was determined over the period starting with the first Mode S correlated non-false target flagged report and including the last received report on the aircraft. This period was selected to maintain a consistent measurement of track performance between the two tracking systems. The difference in BSR between the Mode S sensor and the ARTS was caused by the loss of a surveillance message disseminated by the Mode S sensor, but not received by the ARTS III IOP. Overall, the data analyzed indicated a total of six surveillance messages were lost on the controlled test aircraft. The other five surveillance messages are discussed in the remaining test segments. A trouble report was submitted to the JCCB concerning the loss of surveillance data between the Mode S sensor and the ARTS III system.

As indicated in table 7, track continuity was not maintained over this test segment. The first track established, track 193, swapped on clutter returns and eventually dropped. The next radar track established, track 230, occurred 14 scans later and was maintained on the test aircraft until touchdown on runway 13. The track terminated correctly after three consecutive misses, 10 scans after touchdown. The ARTS displayed reliable track data for 51 of 52 scans on track 230. For the one scan coasted, the surveillance message was lost in dissemination between the Mode S sensor and the ARTS III system.

There were two anomalies in this test segment related to Mode S radar tracking functions, specifically, radar association/correlation and radar track initiation.

The first anomaly occurred during scan 507. The correct radar report to update track 193 was used instead to update track 139 (clutter track). This update was considered a track swap. With this report used, track 193 was updated by the next best candidate which appeared in its zone two association window (the correct report appeared in the zone one association window of track 193). Track 193, updated by the wrong report, diverted the track predicted position for the next scan update causing the eventual track drop. Investigation revealed that the report used to update track 139 during scan 507 was in the zone two association window of track 139, but was still used to update the track. This update was not in compliance with the specifications defined in FAA-ER-240-26 for the primary radar association/correlation functions.

The second anomaly occurred during scans 508 through 520. No reliable track file was established on the test aircraft for the next 14 scans after track 193 swapped on clutter. Over this period, primary radar reports were received on all but one of these scans. During scan 508 the report was used to update another radar clutter track 38 and was not available for use in radar track initiation. During scan 509 the aircraft was flying tangential to the radar site and the radar report confidence flag was set low, even though the report quality was three. The aircraft was not detected by the MTD on the following scan. On scan 511 the radar report was disseminated as uncorrelated to the ARTS III and the VR and was available for the first report for a track initiation pair. Track initiation, again, was prevented in scan 512 when the radar report was used to update coasted beacon track 186. During scans 513 through 516 reports were received with high confidence from the MTD. These radar reports were sufficiently near each other to meet the report-to-report correlation criteria to initiate a track. A track should have been initiated on scan 514. Track initiation was delayed until scan 520, six scans later. Investigation of the Mode S radar track initiation software has revealed no reason for this delay.

ACY Run No. 4. Figure 9 shows an expanded plot of all primary radar reports disseminated to the ARTS III IOP for 96 scans. This plot contains the track of the controlled test aircraft from departure to touchdown on ACY runway 31. Table 8 is identical to table 2 listing the delay time on critical events leading up to track initiation. Table 9 contains a statistical summary of the technical performance.

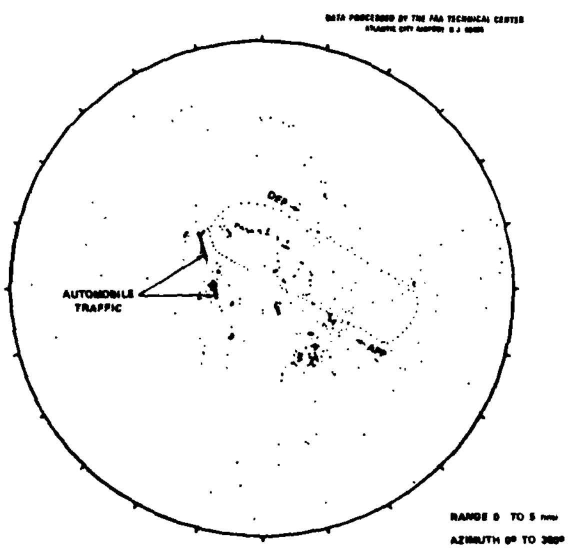


FIGURE 9. MODE S/MTD ACY DEPARTURE AND LANDING AT RUNWAY 31

TABLE 8. MODE S/MTD TRACK INITIATION DELAYS FROM ACY RUNWAY 31

Event	Time	Cumulative Delay Time (sec)	Scans	Range (nmi)	Azimuth (deg)	SFN
Takeoff	10:00:47					
Initial MTD Report	10:00:52.2	5.2	1	0.34	340.66	
First Mode S Uncorrelated	None					0
Mode S Track Initiated	10:00:57.0	10.0	2	0.40	331.88	156
First Mode S Correlated FTF Set	None					
FTF Cleared	10:01:01.4	14.4	3	0.47	325.11	156
ARTS Displayed Track	10:01:01.9	14.9	3	0.47	325.11	156
ARTS Track Data Block	10:01:15.9	28.9	6	0.71	315.0	156

TABLE 9. MODE S/MTD BASELINE TRACKING PERFORMANCE FROM ACY RUNWAY 31

Detailed Track Analysis

Track Drops: 0
Track Swaps: 0
Track Life: 74 scans - complete test segment

Time	ARTS Track Coast
10:01:44.9	No detection by the MTD radar digitizer
10:02:27.5	No detection by the MTD radar digitizer
10:03:10.3	No detection by the MTD radar digitizer
10:03:57.9	No detection by the MTD radar digitizer
10:06:09.5	Surveillance message lost between Mode S and ARTS III
10:06:37.5	No detection by the MTD radar digitizer

Blip-Scan Ratio (%)

MTD (Report Level)	Mode S (Track Level)	ARTS III (Track Level)	No. Samples
93.2	93.2	91.9	74

The aircraft departure from ACY runway 31 was at 10:00:47; touchdown was at 10:06:56. The MTD first detected the test aircraft 5.2 seconds after departure (approximately one scan later) (see table 8). On the following scan the Mode S sensor initiated track 156 on the test aircraft. Both reports satisfied the uncorrelated report dissemination criteria setup for this test, but were not disseminated to the ARTS III IOP or the VR.

The first correlated report disseminated by the Mode S sensor occurred on the third scan of detection, as expected, since track maturity was achieved after track initiation. This surveillance message disseminated with the false target flag cleared was displayed immediately by the ARTS for controller display monitoring and the VR provided a broadband representation in full azimuth extent for display as well. The ARTS track data block was established on the sixth scan of detection, delayed because of no update on the fourth scan of detection. The ARTS III requires two consecutive surveillance messages to establish the track data block.

From the results in table 8 the Mode S sensor was able to identify the controlled test aircraft as a real correlated target on the third scan of detection, in compliance with the minimum standard of tracking correlated targets within three to five scans of detection. Aircraft identification was also met by observing the aircraft moving initially 0.5 nautical mile from the point of takeoff.

In table 9 it can be noted that track continuity was maintained for the complete test segment. During this period the ARTS displayed reliable track data for 68 of 74 scans for an ARTS III BSR of 91.9 percent. Failure by the MTD to detect the test aircraft resulted in the track being coasted on five scans. The sixth track coast was caused by the loss of a surveillance message disseminated by the Mode S sensor to the ARTS III IOP.

The landing conducted at ACY runway 31 resulted in an acceptable track termination. On the approach, primary radar detection was lost as the aircraft descended to an altitude below 100 feet just prior to landing on the same scan at 10:06:54. Three scans after detection was lost, Mode S track 156 was dropped.

Again, the only anomaly noted for this test segment was the failure of the dissemination function in the Mode S sensor to disseminate uncorrelated radar reports to the ARTS III IOP. Analysis of the surveillance file 156 for the second report indicated that the dissemination flag was set high.

SATELLITE AIRPORT RADAR SURVEILLANCE. The primary purpose of these flight segments was to establish the combined ARTS/Mode S/MTD primary radar track initiation delay encountered after aircraft departures from satellite airports. In addition, these test segments provided primary radar surveillance data to establish baseline tracking performance within the surveillance coverage of satellite airports as well as track termination characteristics when the aircraft landed.

Smithville Departures and Landings. Figure 10 shows an expanded plot of all primary radar reports disseminated to the ARTS III IOP for 50 scans. This plot contains the track of the controlled test aircraft from departure to touchdown at the Smithville Airport, 5.3 nautical miles northeast of the Mode S/MTD radar site. Run 1 in table 10 lists the delay times on critical events leading up to track initiation for a departure at the Smithville Airport plotted in figure 10. The

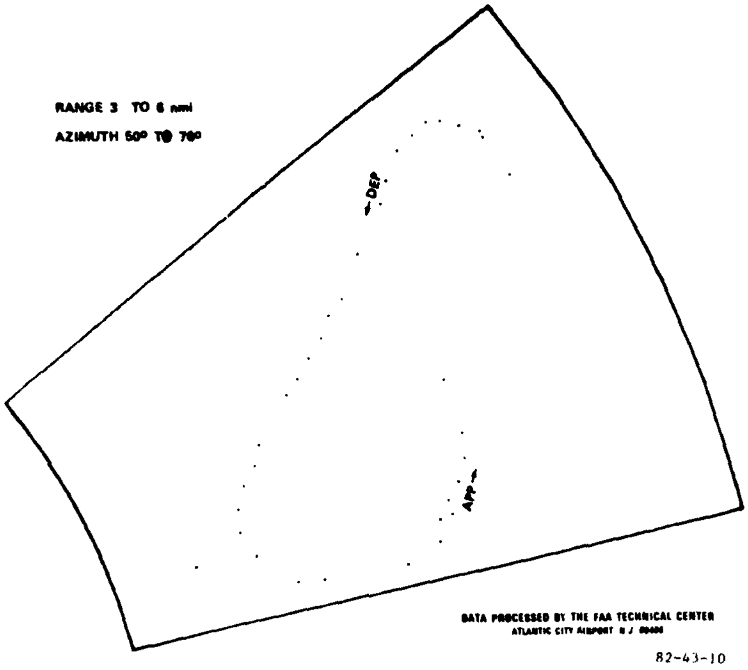


FIGURE 10. MODE S/MTD SMITHVILLE DEPARTURE AND LANDING

events are categorized starting with the aircraft takeoff to the establishment of an ARTS III track data block. Along with each critical event, other data are provided such as the time of the event, the cumulative time delay from departure, the cumulative scan delay from departure, the range and azimuth of the aircraft during the event, and, if pertinent, the Mode S SFN. Run 2 of table 10 lists a second departure at Smithville Airport. Table 11 contains the statistical summary of the technical performance.

The first aircraft departure from the Smithville Airport was recorded at 10:12:26; touchdown was at 10:18:02. Referring back to run 1 in table 10, the MTD first detected the test aircraft 14.9 seconds after departure (approximately three scans later). In the following scan the Mode S sensor initiated surveillance file 352 on the test aircraft. Both reports having high confidence and quality of three were disseminated as uncorrelated reports to the ARTS III IOP and the VR. The VR displayed simulated broadband primary radar symbols of half-azimuth extent on the DEDS based on the digital information received.

The first correlated report disseminated by the Mode S sensor occurred on the third scan of detection, as expected, since track maturity was achieved after track initiation. This surveillance message, as well as the next two messages, were disseminated, flagged as false targets, and purged by the ARTS III system.

However, the VR continued to provide broadband representation of the aircraft for controller display monitoring. The display of these reports were distinguished from the previous uncorrelated reports by full azimuth extent broadband symbols.

TABLE 10. MODE S/MTD TRACK INITIATION DELAYS FROM SMITHVILLE AIRPORT

Event	Time	Cumulative Delay Time (sec)	Cumulative Delay Scans	Range (nmi)	Azimuth (deg)	SFN
Run No. 1						
Takeoff	10:12:26					
Initial MTD Report	10:12:40.9	14.9	3	5.60	57.22	
First Mode S Uncorrelated	10:12:41.0	15.0	3	5.60	57.22	0
Mode S Track Initiated	10:12:45.8	19.8	4	5.59	55.92	352
First Mode S Correlated FTF Set	10:12:50.4	24.4	5	5.59	54.95	352
FTF Cleared	10:13:04.4	38.4	8	5.40	53.02	352
ARTS Displayed Track	10:13:04.9	38.9	8	5.47	53.02	352
ARTS Track Data Block	10:13:09.6	43.6	9	5.35	53.0	352
Run No. 2						
Takeoff	10:16:32					
Initial MTD Report	10:16:44.8	12.8	2	5.60	58.60	
First Mode S Uncorrelated	10:16:44.9	12.9	2	5.60	58.60	0
Mode S Track Initiated	10:16:49.6	17.6	3	5.59	57.61	303
First Mode S Correlated FTF Set	10:16:54.3	22.3	4	5.70	57.2	303
FTF Cleared	10:17:08.3	36.3	7	5.80	55.3	303
ATC Displayed Correlated FTF Set	10:17:08.8	36.8	7			
FTF Cleared	10:17:08.3	36.3	7	5.80	55.3	303
ATC Displayed Track	10:17:08.8	36.8	7	5.80	55.28	303
ATC Track Data Block	10:17:22.9	50.9	10	6.0	54.0	303

The first displayed ARTS III primary radar symbol occurred 38.9 seconds after departure at 10:13:04.9. The minimum azimuth difference criteria of the target velocity test of 2.82° from initial azimuth to current azimuth was satisfied five scans after initial detection. On the following scan, six scans after the test aircraft was initially detected, the ARTS track data block was available.

The problem encountered during this test segment was that the Mode S sensor was not able to distinguish the controlled test aircraft as a real correlated target until the sixth scan of the MTD target detection. Three scans were added to the overall delay as a result of the decision-making process in determining whether or not track 352 was a real aircraft. This prevented compliance with the minimum standard of displaying correlated targets within three to five scans of initial detection, while flagging those false target reports which are not associated with moving targets. However, the aircraft identification criteria were met by first detecting the aircraft 0.2 nautical mile from position of departure by observing the primary broadband video generated by the VR.

The results of a second departure from Smithville Airport are shown in run 2 of table 10. This departure was similar to the first departure except for a two-scan delay in establishing an ARTS track data block. The delay was caused by the failure of the MTD to detect the test aircraft on the seventh scan after initial detection. The ARTS track initiated on the previous scan was dropped, but the Mode S track remained active since it was a mature track.

The Mode S track was updated during the following two scans and correlated reports were disseminated to the ARTS III IOP. The ARTS established a new track on the test aircraft and a track data block was available on controller request in the ninth scan after initial detection.

In table 11 it can be shown that track continuity was maintained for the complete test segment plotted in figure 10. During this period the ARTS displayed reliable track data for 31 of 38 scans for an ARTS III BSR of 81.6 percent. This BSR was considered acceptable since the test aircraft remained below the elevation angle of 1° of the Mode S/MTD radar site for the complete segment. Failure by the MTD to detect the test aircraft resulted in six ARTS track coasts. Radar resolution limitations are attributed to the seventh ARTS track coast. A second aircraft, beacon equipped, crossed the path of the test aircraft and only one MTD report was generated. This report was used to reinforce the beacon report received on the crossing aircraft.

Both landings conducted at the Smithville Airport resulted in acceptable track terminations. On the first approach, primary radar detection was lost as the aircraft descended to an altitude of 200 feet, roughly four scans prior to landing. Three scans after detection was lost Mode S track 60 was dropped at 10:11:51.4. The second landing at Smithville Airport was identical to the first, resulting in Mode S track 352 dropping at 11:15:55.8, three scans after primary radar detection was lost.

Bader Field Departures and Landings. Figure 11 shows an expanded plot of all primary radar reports disseminated to the ARTS IOP for 32 scans. This plot contains the track of the controlled test aircraft from departure to touchdown at Bader Field 7.7 nautical miles southeast of the Mode S/MTD radar site. Run 1 of table 12 lists the delay times on critical events leading up to track initiation for a departure at Bader Field plotted on figure 11. Table 12 is identical to table 10 and presents similar primary radar track initiation data for this test segment. Table 13 contains the statistical summary of the technical performance.

TABLE 11. MODE S/MTD BASELINE TRACKING PERFORMANCE FROM SMITHVILLE AIRPORT

Detailed Track Analysis

Track Drops: 0
Track Swaps: 0
Track Life: 38 scans - complete test segment

Time	ARTS Track Coasts
10:13:33.9	MTD report used to reinforce nearby beacon aircraft
10:13:43.4	No detection by the MTD radar digitizer
10:14:16.4	No detection by the MTD radar digitizer
10:14:49.3	No detection by the MTD radar digitizer
10:15:03.4	No detection by the MTD radar digitizer
10:15:08.3	No detection by the MTD radar digitizer
10:15:17.5	No detection by the MTD radar digitizer

Blip-Scan Ratio (%)

MTD (Report Level)	Mode S (Track Level)	ARTS III (Track Level)	No. Samples
84.2	81.6	81.6	38

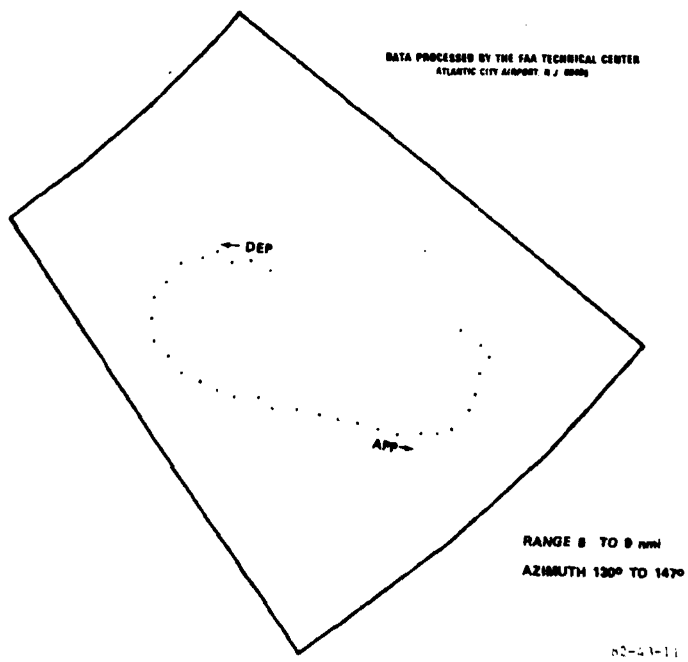


FIGURE 11. MODE S/MTD BADER FIELD DEPARTURE AND LANDING

TABLE 12. MODE S/MTD TRACK INITIATION DELAYS FROM BADER FIELD AIRPORT

Event	Time	Cumulative Delay Time (sec)	Cumulative Delay Scans	Range (nmi)	Azimuth (deg)	SFN
Run No. 1						
Takeoff	11:18:31					
Initial MTD Report	11:18:47.5	16.5	3	7.04	138.65	
First Mode S Uncorrelated	11:18:52.3	21.3	4	7.0	138.6	0
Mode S Track Initiated	11:18:57.0	26.0	5	6.98	139.42	172
First Mode S Correlated FTF Set	11:19:01.6	30.6	6	6.9	139.6	172
FTF Cleared	11:19:20.4	49.4	10	6.81	143.26	172
ARTS Displayed Track	11:19:21.3	50.3	10	6.81	143.26	172
ARTS Track Data Data Block	11:19:26.0	55.0	11	6.83	143.00	172
Run No. 2						
Takeoff	11:21:51					
Initial MTD Report	11:22:13.4	22.4	4	7.17	138.34	
First Mode S Uncorrelated	11:22:18.1	27.1	5	7.2	138.3	0
Mode S Track Initiated	11:22:22.8	31.8	6	7.11	138.16	179
First Mode S Correlated FTF Set	11:22:27.4	36.4	7	7.0	139.0	179
FTF Cleared	11:22:50.9	59.9	12	6.5	139.74	179
ARTS Displayed Track	11:22:51.8	60.8	12	6.5	139.74	179
ARTS Track Data Block	11:22:56:5	65.5	13	6.31	139.0	179

TABLE 13. MODE S/MTD BASELINE TRACKING PERFORMANCE FROM BADER FIELD

Detailed Track Analysis

ARTS Track Coasts: 0
Track Drops: 0
Track Swaps: 0
Track Life: 28 scans - complete test segment

Blip-Scan Ratio (%)

MTD* (Report Level)	Mode S (Track Level)	ARTS III (Track Level)	No. Samples
100	100	100	28

*MTD BSR based on MTD output buffer.

The first aircraft departure from Bader Field was recorded at 11:18:31; touchdown was at 11:21:45. Referring to run 1 of table 12, the MTD first detected the test aircraft 16.5 seconds after departure (approximately three scans later). This report was used to update a coasted beacon track and was not available for use in primary radar track initiation. As specified in FAA-ER-240-26, an attempt was made to update coasted beacon tracks using radar reports that met report-to-track correlation requirements prior to performing radar track initiation and radar track update functions. The Mode S sensor initiated track 172 on the test aircraft on the third scan of detection. Both MTD reports used to initiate track 172 met the uncorrelated dissemination criteria and were disseminated to the ARTS III IOP and the VR.

The first correlated surveillance message disseminated by the Mode S sensor occurred on the following scan, as expected, since track maturity was achieved after the track was initiated. This surveillance message, as well as the next three messages, were disseminated, flagged as false targets, and purged by the ARTS III system.

Up to this point the only presentation of the test aircraft on the DEDS display was generated by the VR. The broadband video of the test aircraft over these seven scans was as follows:

On the first scan the broadband target symbol was displayed with full-azimuth extent, the next two scans with half-azimuth extent, and the following four scans with full-azimuth extent. The first report was displayed with full-azimuth extent because it was used to update a coasted beacon track and was considered correlated.

The first ARTS III primary radar symbol displayed occurred 49.4 seconds after departure at 11:19:21.2. The mimimum azimuth difference criteria of the target velocity test of 2.82° from initial azimuth to current azimuth were satisfied eight scans after initial detection. On the following scan the ARTS track data block was available.

The problems encountered with this test segment were similar to those encountered in the previous test segment. The Mode S sensor was not able to distinguish the controlled test aircraft as a real correlated target until the eighth scan of detection. Mode S track initiation was delayed one scan by a substitution on a beacon track having a firmness of five. At this time the substitution window was so large (per ER specification) that an erroneous update took place. The second reason for the delay in establishing an ARTS III track was the criteria setup in the target velocity test. Determining whether or not track 172 was real delayed the dissemination of a correlated surveillance message with the false target flag cleared for four scans, preventing the minimum standard of dissemination correlated aircraft targets within three to five scans of initial detection. The requirement for aircraft identification within 1 mile of the departure end of runway was met by observing the broadband symbols on the test aircraft starting 0.2 nautical mile from departure. The results of a second departure from Bader Field are shown in run 2 of table 12. Similar results were noted.

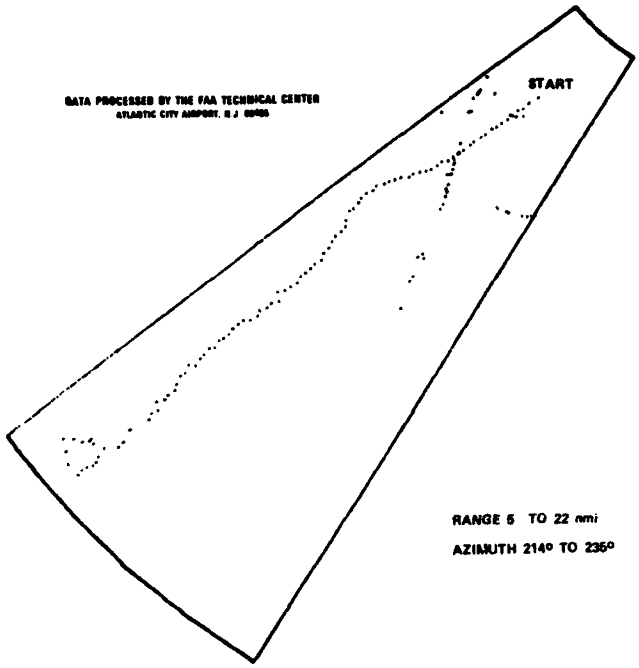
Referring to table 13, it can be shown that track continuity was maintained for the complete test segment. During this period the ARTS displayed reliable track data for all 28 scans analyzed for an ARTS BSR of 100 percent.

Both landings conducted at Bader Field resulted in acceptable track terminations. On the first approach the test aircraft was last detected at 11:17:41.9, seven scans prior to touchdown at 11:18:15. Mode S track 67 dropped after three misses. The second landing at Bader Field was similar to the first. Primary radar detection was lost as the aircraft descended to an altitude of 100 feet, six scans prior to touchdown at 11:21:40. Mode S track 172 dropped after three misses.

BASELINE PERFORMANCE IN THE CLEAR. The purpose of this flight segment was to provide radar surveillance baseline performance data on radar tracking of a low flying small aircraft. The test aircraft flew at an altitude of 1,000 feet to the outer fringe of primary radar coverage on a 240° radial relative to the Mode S sensor at the FAA Technical Center. Once out of primary radar coverage, approximately 24 nautical miles, the test aircraft returned to the sensor on the same radial.

Figure 12 shows expanded plots of all primary radar reports disseminated to the ARTS III IOP during the low altitude radial flights. Figure 12a plots the track of the controlled test aircraft as it proceeded outbound for 110 scans; figure 12b plots the track of the controlled test aircraft as it proceeded inbound for 146 scans. Table 14 contains a statistical summary on the technical performance obtained on this test segment between 6 and 19 nautical miles.

A review of table 14 shows that primary radar surveillance approached a level of reliability normally associated with beacon surveillance. Track continuity was maintained over the track segments between 6 and 19 nautical miles with an ARTS BSR of 98.8 percent. The ARTS displayed a reliable track for 217 of 220 scans analyzed. The Mode S BSR was 99.2 percent over the same period. The difference between the results was attributed to a loss of a surveillance message disseminated by the Mode S sensor to the ARTS III IOP. The second ARTS track coast was attributed to an MTD report failing to fall within the Mode S track association windows, preventing a track update for that scan. The Mode S sensor did disseminate the report as uncorrelated to the ARTS. Failure by the MTD to detect the test aircraft resulted in the third ARTS track coast.



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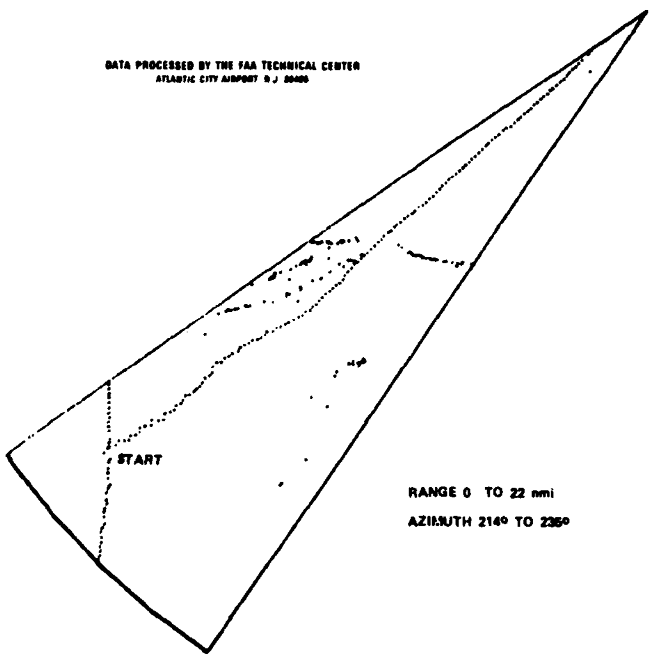

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FIGURE 12. MODE S/MTD LOW ALTITUDE RADIALS

TABLE 14. MODE S/MTD BASELINE TRACKING PERFORMANCE IN THE CLEAR

Detailed Track Analysis

Track Drops: 0
Track Swaps: 0
Track Life: 109 scans - complete outbound test segment
144 scans - complete inbound test segment

Run No.	Time	ARTS Track Coasts
1	09:38:12.6	Surveillance message lost between Mode S and ARTS III
2	09:44:59.8	Mode S disseminated radar report as uncorrelated
2	09:54:30.9	No detection by the MTD radar digitizer

Blip-Scan Ratio (%)
(Between 6 and 19 nmi)

Run No.	MTD* (Report Level)	Mode S (Track Level)	ARTS III (Track Level)	No. Samples
1	100	100	99.1	109
2	99.3	98.6	98.6	144
1&2	99.6	99.2	98.8	253

*MTD BSR based on MTD output buffer.

BASELINE PERFORMANCE OVER GROUND CLUTTER. The purpose of the following flight segments was to provide radar surveillance baseline performance data of primary radar tracking for a small aircraft flying over ground clutter. The clutter region was centered over Atlantic City/Absecon Island 7.5 nautical miles and 145° from the Mode S radar site (figure 4).

Figure 13 shows expanded plots of all primary radar reports disseminated to the ARTS III IOP during the period when the test aircraft was performing an S-turn flight pattern over local ground clutter areas. Figure 13a plots the track of the controlled test aircraft as it proceeded southbound over the clutter area for 163 scans. Figure 13b plots the track of the controlled test aircraft as it returned and proceeded northbound over the clutter area for 117 scans.

Table 15 contains a statistical summary of the technical performance. A review of table 15 indicated that primary radar surveillance approached a level of reliability normally associated with beacon surveillance. Track continuity was maintained over this test segment with an ARTS BSR of 96.6 percent. The ARTS III displayed a reliable primary radar track for 228 of 236 scans analyzed. Failure by the MTD to detect the test aircraft accounted for all eight ARTS III displayed track coasts.

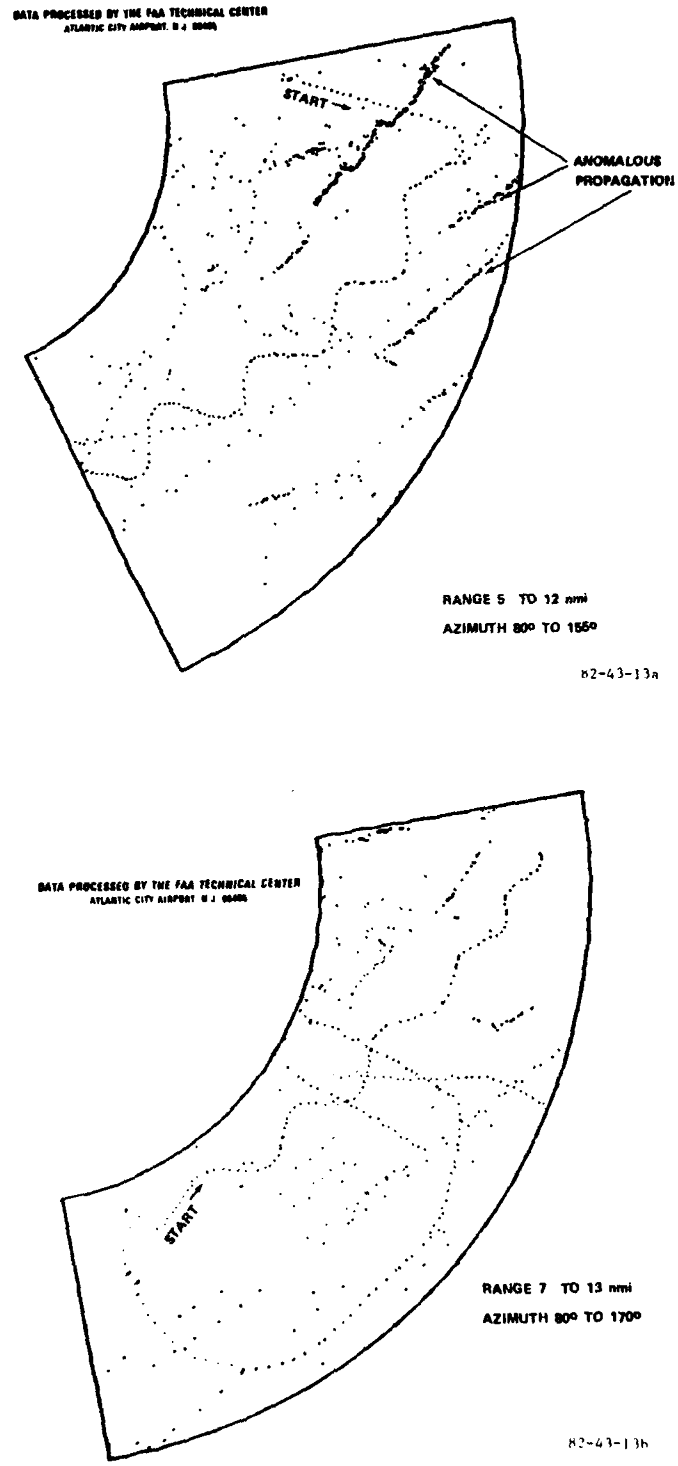

FIGURE 13. MODE S/MTD S-TURN FLIGHT PATTERNS OVER GROUND CLUTTER

TABLE 15. MODE S/MTD BASELINE TRACKING PERFORMANCE ON S-TURN FLIGHTS OVER GROUND CLUTTER

Detailed Track Analysis

Track Drops: 0
Track Swaps: 0
Track Life: 236 scans - complete test segment

Run No.	Time	ARTS Track Coasts
1	10:20:03.7	No detection by the MTD radar digitizer
	10:30:18.8	No detection by the MTD radar digitizer
	10:30:28.3	No detection by the MTD radar digitizer
	10:30:42.3	No detection by the MTD radar digitizer
2	10:31:38.5	No detection by the MTD radar digitizer
	10:34:41.1	No detection by the MTD radar digitizer
	10:35:04.3	No detection by the MTD radar digitizer
	10:35:51.3	No detection by the MTD radar digitizer

Blip-Scan Ratio (%)

Run No.	MTD (Report Level)	Mode S (Track Level)	ARTS III (Track Level)	No. Samples
1	97.1	97.1	97.1	140
2	95.8	95.8	95.8	96
1&2	96.6	96.6	96.6	236

Figure 14 shows expanded plots of all primary radar reports disseminated to the ARTS III IOP for tangential flights by the controlled test aircraft over local ground clutter areas. Figure 14a contains the track of the controlled test aircraft as it proceeded northbound over the clutter area for 87 scans. Figure 14b contains the track of the controlled aircraft proceeding southbound over the ground clutter area for 100 scans.

Table 16 contains a statistical summary of the technical performance. A review of these data indicated that the primary radar surveillance again approached a level of reliability normally associated with beacon surveillance. Track continuity (ARTS BSR of 97.9 percent) was maintained over this test segment. The ARTS III displayed a reliable primary radar track for 183 of 187 scans analyzed. The Mode S BSR was 99.5 percent over the same period. The difference between the two results was attributed to the loss of three surveillance messages disseminated by the Mode S sensor to the ARTS III IOP. Failure by the MTD to detect the test aircraft accounted for the fourth ARTS track coast.

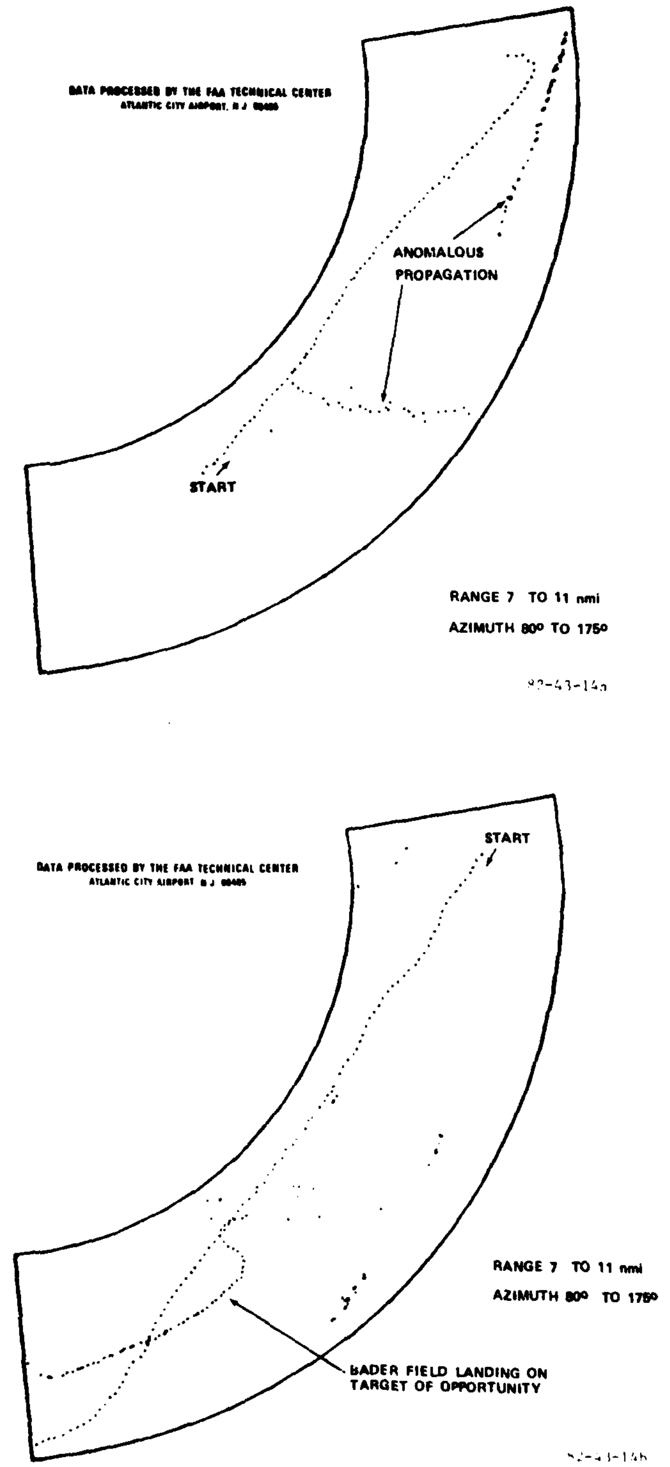

FIGURE 14. MODE S/MTD TANGENTIAL FLIGHT PATTERNS OVER GROUND CLUTTER

TABLE 16. MODE S/MTD BASELINE TRACKING PERFORMANCE ON TANGENTIAL FLIGHTS OVER GROUND CLUTTER

Detailed Track Analysis

Track Drops: 0
Track Swaps: 0
Track Life: 187 scans - complete test segment

Run No.	Time	ARTS Track Coasts
1	10:58:22.7	Surveillance message lost between Mode S and ARTS III
2	11:00:52.4	Surveillance message lost between Mode S and ARTS II
	11:01:01.5	Surveillance message lost between Mode S and ARTS III
	11:03:36.7	No detection by the MTD radar digitizer

Blip-Scan Ratio (%)

Run No.	MTD* (Report Level)	Mode S (Track Level)	ARTS III (Track Level)	No. Samples
1	100	100	98.9	87
2	99.0	99.0	97.0	100
1&2	99.5	99.5	97.9	187

*MTD BSR is based on MTD output buffer.

From these results it was concluded that MTD detection over areas of ground clutter was sufficient to provide reliable report data to the Mode S sensor to perform radar tracking. The Mode S sensor properly updated the primary radar track with the correct radar report and successfully disseminated surveillance messages to the ARTS III IOP and the VR in compliance with ER requirements. Track reliability was maintained by the ARTS III employing the ADS2 software, generating a correlated primary radar track symbol "/" (virgule) on the DEDS display along with establishing a track data block. The VR displayed a radar slash with full-azimuth extent each scan for each disseminated report.

PROBABILITY OF FALSE RADAR TRACKS. A separate evaluation on the performance of this system's configuration was the level of acceptability of what is presented on the DEDS displays as representing a true air traffic environment. A major problem in implementing automated radar tracking in today's terminal display processor system is deterioration in display quality for man/machine interface caused by false radar tracks generated by conditions such as ground clutter, weather clutter, anomalous propagation, and nonaircraft moving objects, e.g., birds and automobile traffic. ATC standards have been setup defining some minimum requirements to maintain DEDS display quality. These standards (e.g., the allowable false alarm rate) were presented earlier in the section "Test Method."

The technical performance determined from data collected on targets of oportunity for the baseline tests conducted January 28 and March 27, 1981, is presented in table 17. This table contains the false track initiation rate by the Mode S sensor and the ARTS III IOP as well as the ARTS false track display rate. Also provided in table 17 are the following Mode S performance criteria: the percent radar beacon reinforcement, the percent radar substitution, the uncorrelated radar report dissemination rate, and the correlated false radar report dissemination rate. The measurement of these performance criteria was described in detail in the section "Data Reduction."

The probability of generating false radar tracks was measured in a clear weather environment over a 100-scan period. Special data reduction programs were developed to summarize the possibility of each radar track being false. Individual track analysis was performed to make the final determination.

TABLE 17. MODE S/MTD SYSTEMS PERFORMANCE CRITERIA ESTABLISHED ON TARGET OF OPPORTUNITY DATA

	Test Dates	
	1/28/81	3/27/81
Mode S False Radar Track Initiations	1.24	2.27 (per scan)
Mode S False Radar Tracks After Velocity Filtering	0.28	1.05 (per scan)
ARTS III False Radar Track Initiations	0.31	1.36 (per scan)
ARTS III Displayed False Radar Tracks	3.0	9.7 (targets per scan)
Radar Beacon Reinforcement	92.3	88.4 (%)
Radar Substitution	50.0	77.6 (%)
Uncorrelated Radar Report Dissemination Rate	8.7	8.6 (per scan)
Correlated False Radar Report Dissemination Rate	7.2	8.3 (per scan)

In the first flight test shown in table 17, the Mode S false track initiation rate was 1.24 tracks per scan (these are tracks that disseminated at least one correlated radar report). Fourteen of these tracks (11.3 percent of the false primary tracks) were initiated beyond the coverage of the target velocity test; 87.3 percent of the tested tracks completely failed to pass the target velocity test and were eliminated by the ARTS III system. The ARTS III established 31 tracks with an average false track persistance of 9.24 scans per false track from the 28 false Mode S tracks that were not tested or passed the target velocity test.

From the results of the first test, the Mode S sensor did not perform acceptably in outputting fewer than one false target per scan to be processed by the ARTS III IOP. One of the false tracks, attributed to bird activity, remained active for 137 scans, of which only 100 scans were counted in the false alarm analysis. This represented the worse case condition for a single track since the method used to determine the false alarm rate considered all radar tracks initiated within a 100-scan interval. The movement of this track was generally less than 30 knots and consistantly experienced heading changes greater than 40°. The track initiated beyond the range coverage of the target velocity test and was not tested.

Figure 15 is a plot showing the Mode S primary radar track generated on birds along with two beacon tracks on targets of opportunity. As noted in figure 15, the plotted dots on the primary radar track are irregular compared to the plotted symbols on the two beacon tracks. The beacon track plotted above the primary radar track is shown as 100 percent radar reinforced, while the beacon track plotted below the primary radar track shows a failure to merge a radar report with a beacon report because of azimuth separation. This is noted by the beacon-only symbol and the radar-only symbol plotted for a one-scan update.

For the second flight test shown in table 17, the Mode S false track initiation rate was 2.27 tracks per scan. Twenty-eight of these tracks (12.3 percent of the false primary tracks) were initiated beyond the range coverage of the target velocity test; 70.7 percent of the tested tracks completely failed to pass the target velocity test and were eliminated by the ARTS III system. The ARTS III established 136 tracks with an average false track persistance of 7.2 scans from the 105 false Mode S tracks that were not tested or passed the target velocity test.

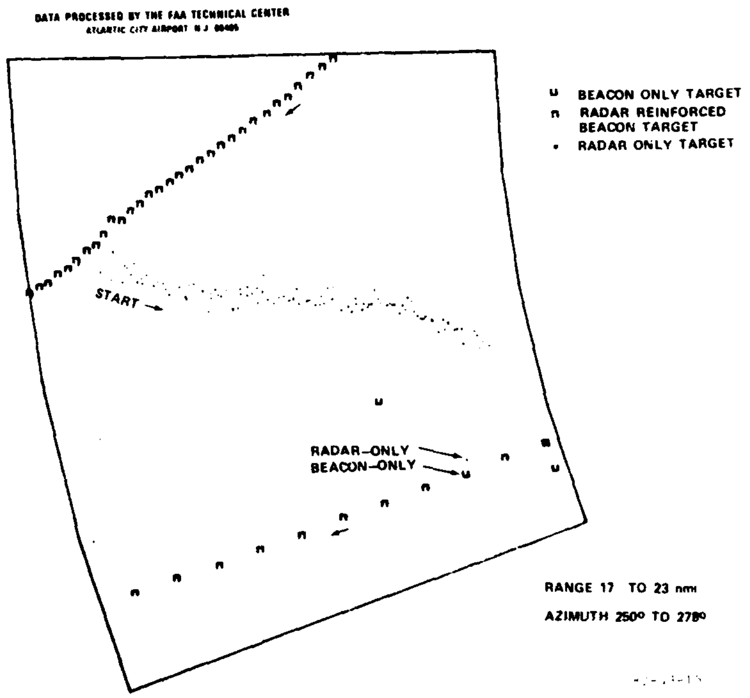

FIGURE 15. EXPANDED PLOT OF FALSE RADAR TRACK ESTABLISHED ON BIRDS FOR THE JANUARY 28 MODE S/MTD FLIGHT TEST

From the results of the second test the Mode S sensor false target dissemination rate exceeded the acceptible dissemination rate for normal conditions. Anomalous propagation (AP) was the major factor in the failure to meet the ATC minimum standard. The AP was concentrated around and north of Absecon Island along the coastline, as pointed out in figure 16. Figure 16a is an expanded plot of all primary radar surveillance messages (correlated and uncorrelated) disseminated by the Mode S sensor for 150 scans. From figure 16a it can be shown that the MTD digitizer was too sensitive to the AP, generating far too many radar reports. Figure 16b is a similar expanded plot of all correlated primary messages processed by the ARTS III system over the same 150 scans. Comparing this plot with figure 16a, it can be shown that the target velocity test partially eliminated the false tracks generated on the AP. The reason for this is that the AP exhibits movement not unlike a true target. This accounted for a significant increase in the number of false tracks passing the target velocity test, as indicated by the 87.3 percent eliminated in the first test as opposed to the 70.7 percent eliminated in this test. The ARTS III system displayed 9.68 false radar tracks per scan, which was close to exceeding the ATC minimum rate of display requiring fewer than 10 false radar targets per scan under extreme conditions.

The difference between the number of false Mode S tracks processed by the ARTS III system and the actual number of ARTS false tracks generated is related to the way both systems handle track coasts. By the time the Mode S sensor disseminates a correlated primary surveillance message to the ARTS III IOP, the track is mature and requires three consecutive misses (coasts) before the track is dropped. The ARTS system, upon receiving a surveillance message with a previously unused Mode S SFN, immediately establishes its own track on the target and initiates a track firmness count related to a seven-scan history of the track. The ARTS track drop criteria depend on this track firmness count. Therefore, a mature Mode S track will remain active up to two consecutive coasts, but the ARTS track may be dropped depending on the track firmness count.

Most of the primary false tracks that pass the target velocity test satisfied the azimuth difference criteria. Combining the results of both flight tests, 66.7 percent of the these tracks were within 5 nautical miles of the sensor. Within this range the azimuth difference criteria are less than one-half that of the range difference criteria.

RADAR/BEACON CORRELATION. The results of radar beacon reinforcement for the two flight tests are shown in the fifth row of table 17. The purpose for establishing these criteria for baseline performance was to determine the effectiveness of merging radar reports to beacon reports by range and azimuth comparison. The criteria for beacon reinforcement were: the magnitude of the azimuth difference between the radar report and the beacon report not to exceed 20 azimuth units (Au's) (0.44°), and the magnitude of the range difference not to exceed 50 one way range units (0.51 nautical mile).

One concern when radar beacon reinforcement fails is the potential to establish a separate radar track along with a beacon track on the same aircraft target. This becomes possible if radar reports associated with a beacon equipped aircraft become available to the radar tracking software for processing. The results, depending on the degree of failure to merge radar reports to beacon reports, may cause degradation in DEDS display quality with two tracks (primary and secondary) displayed on a single aircraft.

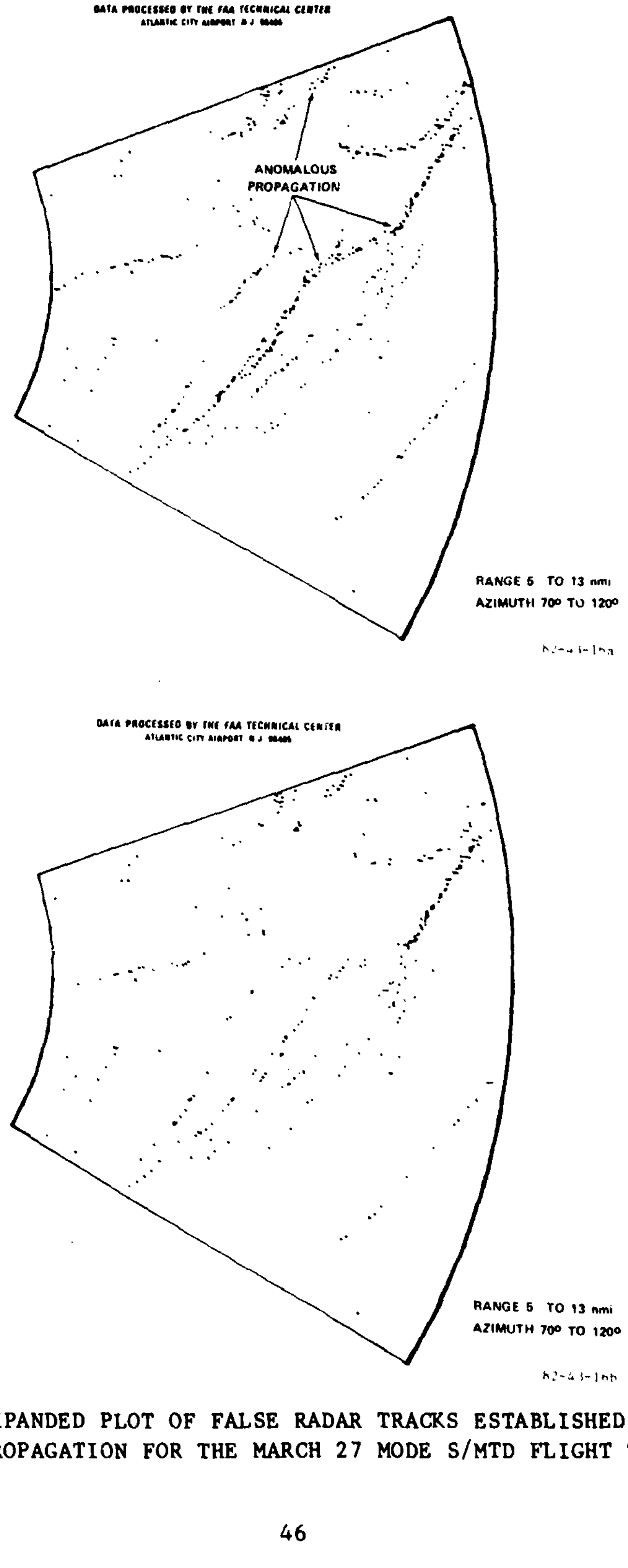

FIGURE 16. EXPANDED PLOT OF FALSE RADAR TRACKS ESTABLISHED ON ANOMALOUS PROPAGATION FOR THE MARCH 27 MODE S/MTD FLIGHT TEST

To provide a realistic measurement of the overall environment, certain constraints were made on where in the environment samples would be taken. Measurements were made on all beacon aircraft within 1 to 48 nautical miles, elevation angle from 2° to 16°, and an altitude up to and including 20,000 feet. One additional filter was used to eliminate sampling of data in a known beacon reflection zone between 120° and 140°

For the baseline test of January 28 (as noted on table 17), the radar beacon reinforcement achieved on targets of opportunity was 92.5 percent, which was considered acceptable being close to expected MTD detection capability. For the March 27 baseline test, it was shown that the radar beacon reinforcement achieved on targets of opportunity was 88.4 percent, which was lower than expected but still acceptable. From the data analyzed, the major failure to correlate radar reports to beacon reports was due to azimuth separation. Further investigation revealed that most failures occurred while the aircraft was flying tangential to the radar site. No report merge failure was found as a result of range separation.

One case was observed on the March 27 flight test, where primary radar tracks were initiated on a beacon equipped aircraft flying an orbital pattern around the Mode S/MTD radar site. The aircraft was at an altitude of 5,000 feet and at a range of 20 nautical miles. Detection of the aircraft by the MTD was 97.5 percent (160 samples), but reinforcement of the beacon reports was only 58.5 percent. This track alone accounted for a drop in the radar beacon reinforcement in this test by 3.6 percent. Sixty-two radar reports not used for reinforcement became available to the radar tracking software for processing. Many of the MTD reports were of low confidence, and were not available as first report candidates for track initiation; however, some Mode S tracks were still initiated. One track in particular was displayed on the DEDS console as a reliable track for four scans, then coasted out the following two scans. Again, in all 62 cases the azimuth difference between the beacon report and the radar report exceeded the azimuth difference criteria for radar beacon reinforcement.

The results of radar substitution for the two flight tests are shown in the sixth row in table 17. The purpose of establishing these criteria for baseline performance was to determine the level of improvement in beacon tracking when using radar reports to update coasted beacon tracks. The environmental constraints used in measuring radar beacon reinforcement were used to measure these criteria as well.

For the baseline test of January 28, the radar substitution rate of 50.0 percent achieved on targets of opportunity was unacceptable compared to the expected MTD detection capability. For the baseline test of March 27, the radar substitution of 77.6 percent achieved on targets of opportunity was considered marginally acceptable. Investigation as to why the percentages were lower than expected revealed that, in most cases, no MTD report was available when the beacon tracks coasted.

These percentages were the correct substitution rates since almost an equal number of erroneous substitutions occurred on beacon tracks associated with aircraft, which either landed or entered the beacon zenith cone and coasted for three or more consecutive scans. The advantage of updating coasted beacon tracks, using radar reports to enhance beacon tracking, was lossed due to so many erroneous radar substitutions. The DEDS display quality was also reduced by the extension of beacon tracks by incorrect radar substitutions.

Two other performance criteria were established to determine baseline performance. They were: the Mode S uncorrelated radar report dissemination rate and the Mode S correlated false radar report dissemination rate. The purpose of these criteria was to provide some measurement of the amount of data displayed by the VR on the DEDS console not associated with ARTS track symbols.

In table 17 for the first flight test it can be shown that the VR added an average of 14.9 broadband radar symbols not associated with ARTS track symbols on the DEDS display each scan. Forty-five percent of these broadband symbols were generated from correlated primary reports flagged as false targets, while 55 percent were generated from uncorrelated primary reports. On the second flight test the VR added an average of 16.9 broadband radar symbols not associated with ARTS track symbols on the DEDS display each scan. Forty-nine percent of these broadband symbols were generated from correlated primary reports flagged as false targets, while 51 percent of these broadband reports were generated from uncorrelated primary reports. These results were similar to the results obtained on the first flight test. Most of these reports were false and made monitoring aircraft departures difficult prior to display of ARTS track symbols.

PART 2: ARTS III/MODE S/RDAS FLIGHT TESTS.

LOCAL AIRPORT RADAR SURVEILLANCE. The primary purpose of this test was to establish the combined ARTS/Mode S/RDAS radar track initiation delay encountered after aircraft departure from a local airport. This delay time establishes a baseline of performance for the preceding systems in displaying correlated radar surveillance track data to an uncorrelating user. Analysis of these data also identified major problems in RDAS target detection, Mode S radar tracking and dissemination, and ARTS III displaying of radar track data.

Results and analyses for different runway departures at ACY are presented. The results and analysis of each takeoff to touchdown interval at ACY are individually presented. Each takeoff is accompanied with two plots, one depicting the actual flightpath of the test aircraft and the second depicting disseminated radar data to an ATC facility. In conjunction with the plots, two data tables accompany each takeoff. The first table presents the time related events leading up to the establishment of an ARTS III track for controller display monitoring. The second table contains the baseline performance of surveillance data collected on the test aircraft. These data provided the necessary information to determine the combined ATC radar track initiation delay encountered for local airport departures and ARTS/Mode S/RDAS technical performance. To supplement the ACY data, similar flight patterns were flown at satellite airports, Bader Field and Smithville Airport.

The following baseline performance parameters were measured for the test aircraft: RDAS report BSR, Mode S radar track BSR, and ARTS III radar track BSR.

Figures 17 through 26 are the rho-theta plots of the controlled test aircraft. For comparison purposes, two plots are presented on one page. The actual flight patterns of the test aircraft are represented by the top plots; the Mode S radar surveillance plots are shown below. Data for the actual flight pattern plots were provided by using the Mode S "dual tracking" software which allowed both Mode S and radar tracking of the test aircraft simultaneously. The top figures are plots of Mode S disseminated track data. Each bottom plot represents all radar reports disseminated to the ARTS III IOP which had their quality and confidence bit set high.

Because the RDAS interfaces with an ASR for its radar inputs, there are some expected limitations in radar detection, specifically, the ASR-7's MTI system which has design limitations on target detection. The RDAS selects the MTI radar video inputs for target detection over ground clutter areas and normal ASR-7 video in the remaining coverage area. Atlantic City Airport, Bader Field, and Smithville Airport are all within the MTI zones of RDAS input radar video selection.

The MTI design is such that target detection depends upon the radial velocity of the moving target (radial velocity being the velocity component of the aircraft's ground speed directed along a radial line from the radar antenna). Therefore, when an aircraft flies tangential to the radar antenna, the radial velocity is at a minimum and MTI target detection is the least sensitive. This problem was evident in the local airport departures when the test aircraft became tangential to the radar antenna.

ACY Departure/Touchdown Runway 13. Figures 17 and 18 are plots of the test aircraft flight pattern flown at ACY runway 13 from takeoff to touchdown. Table 18 depicts the critical delay times in radar track initiation and the cumulative ARTS/Mode S/RDAS delays. Table 19 provides a statistical summary of the test aircraft baseline performance. These performance data included: RDAS report BSR and Mode S/ARTS III track BSR's.

A comparison of figure 17 to figure 18 indicates that radar detection did not occur during the takeoff interval on the test aircraft. Radar track initiation and termination occurred on four separate occasions during the 128-scan takeoff/ touchdown interval. Analyses were conducted to determine the RDAS and Mode S radar surveillance performance. Emphasis was given to the cause or causes of late radar track initiation and the absence of radar track continuity.

Analysis of the data collected in table 18 revealed that the first reliable report occurred seven scans after takeoff. These data were not disseminated to the ARTS III IOP as an uncorrelated radar report. Investigation revealed that there were no uncorrelated radar reports disseminated within 1 nautical mile. This problem is currently being investigated.

The Mode S radar track initiation function correctly started an initial track (track 79) after reports from two consecutive scans met the Mode S report-to-report correlation criteria. Track 79 was disseminated to the ARTS III IOP as a mature track with its false track flag (FTF) set. A mature track is defined as the occurrence of track correlation for "K" scans, where K is a Mode S site-adaptable parameter and was set at two for all tests. The FTF was correctly set when the radar track was initiated with a range of less than 20 nautical miles. This range is also a Mode S site-adaptable parameter. The resetting of the FTF required a change in the current report range by 0.5 nautical mile or a change in current azimuth by 2.8° relative to the radar track's initial range and azimuth. This change in position must occur within 10 scans, a Mode S system parameter, or the track will automatically be dropped.

The ARTS III required that the Mode S correlated report data have its FTF reset before initiating a radar track. Radar track 79 was not displayed during the interval the FTF was set. Track 79 had a Mode S track life of one scan and never initiated an ARTS III track. This radar track was dropped after the RDAS failed to detect the test aircraft on three consecutive scans.

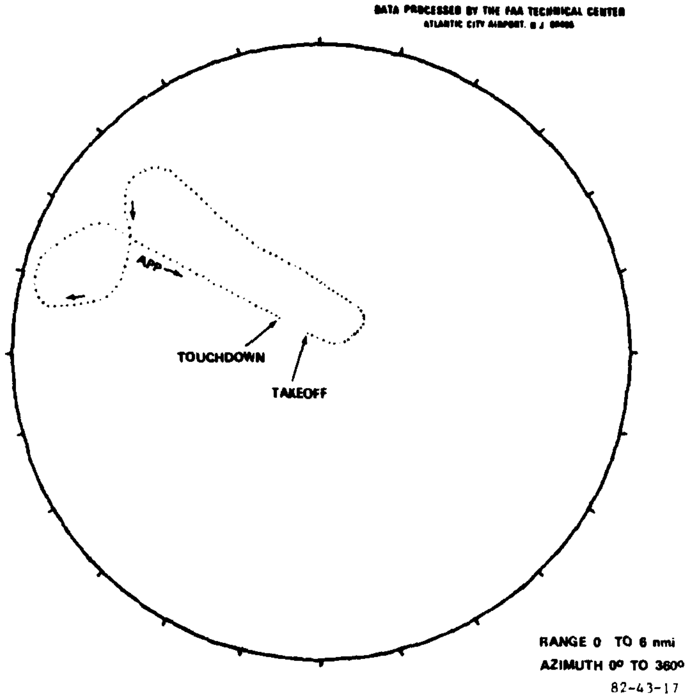

FIGURE 17. TEST AIRCRAFT FLIGHT PATTERN FOR ACY DEPARTURE AND LANDING ON RUNWAY 13

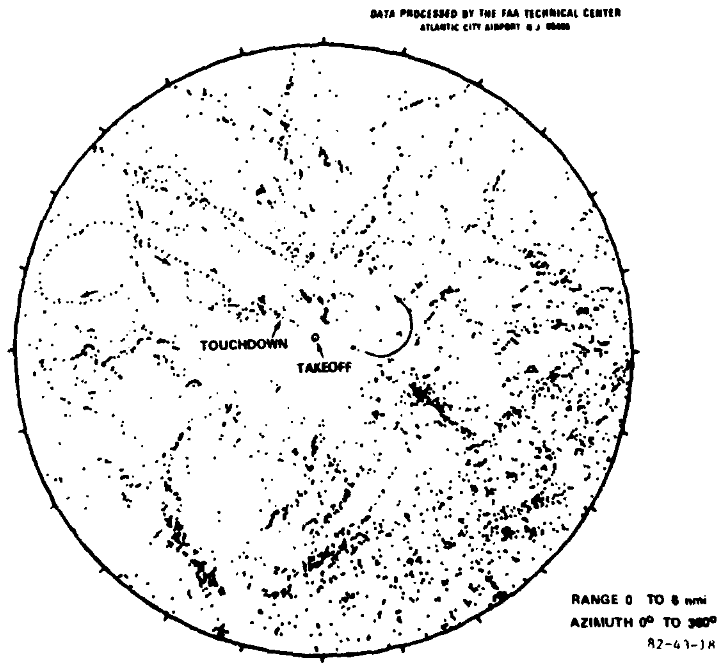

FIGURE 18. MODE S/RDAS ACY DEPARTURE AND LANDING ON RUNWAY 13

TABLE 18. MODE S/RDAS TRACK INITIATION DELAYS FROM ACY RUNWAY 13

Event	Time	Cumulative Delay Time (sec)	Scans	Range (nmi)	Azimuth (deg)	SFN
Takeoff	10:10:58			0.30	348.35	
Initial MTD Report	10:11:32.1	34.1	7	0.64	63.90	
First Mode S Uncorrelated	None					
Mode S Track Initiated	10:11:36.8	38.8	8	0.75	62.38	79
First Mode S Correlated FTF Set	10:11:41.4	43.4	9	0.8	60.4	79
FTF Reset	Track Drop					
Next RDAS Report	10:12:55.6	117.6	25	1.41	356.57	
Mode S Uncorrelated Report	10:12:55.6	117.6	25	1.4	356.6	0
Mode S Track Initiated	10:13:00.3	122.3	26	1.46	353.32	227
First Mode S Correlated FTF Set	Never Set					
FTF Reset	10:13:00.4	131.4	28	1.7	346.7	227
ARTS Displayed Track	10:13:09.6	131.6	28	1.59	349.0	227
ARTS Track Data Block	10:13:13:6	135.6	29	1.7	309.0	227

TABLE 19. MODE S/RDAS BASLELINE TRACKING PERFORMANCE FROM ACY RUNWAY 13

Track Drops: 3
Track Swaps: 0

RDAS Report (BSR)	Mode S Track (BSR)	ARTS Track (BSR)	Scans
78.9% (128 scans)	100% Track 79	None	1
	97.6% Track 227	97.6% Track 227	42
	97.6% Track 62	92.9% Track 62	42
	100% Track 372	100% Track 372	2

Investigation revealed that for the first 25 scans after departure, RDAS target detection was intermittent when the test aircraft was turning and flying tangentially to the radar antenna. This was not unusual for the RDAS because it uses the ASR-7 MTI video in ground clutter. When the test aircraft turned in the airport flight pattern, it became tangential for a number of scans and the radial velocity became minimum. RDAS target detection was lost and radar track 79 was dropped.

The next RDAS report used by Mode S to initiate a radar track occurred 25 scans after departure and was disseminated as uncorrelated. The first reliable correlated radar track occurred 26 scans after departure as track 227. Correlated track data were disseminated to the ATC facility with its FTF correctly reset 28 scans after departure and was displayed on the DEDS. Radar track 227 continued to be displayed over the next 42 scans.

Table 19 indicates both the Mode S and ARTS III radar track BSR's were 97.6 percent. This track was dropped after the RDAS failed to provide target detection of the test aircraft in a turning maneuver for which the aircraft was tangential relative to the radar antenna.

The next RDAS report used to initiate a Mode S radar track occurred six scans after radar track 227 was dropped. Radar track 62 was initiated on the following scan with its FTF set. This flag remained set for two scans. In terms of displaying radar correlated track data at an ATC facility, this represented a consecutive nine-scan interval of no tracked radar surveillance. Track 62 remained for a 42-scan interval and provided Mode S and ARTS III track BSR's of 97.6 percent and 92.9 percent, respectively. The degraded ARTS BSR occurred when two Mode S disseminated correlated radar reports were not received. This problem is currently being investigated to determine if the ARTS III IOP receives the Mode S disseminated data.

The last track drop and reinitiation occurred during the final approach to runway 13. Radar track 62 was dropped after the RDAS missed three consecutive target detections eight scans prior to touchdown. The last RDAS target report occurred at an altitude of 400 feet. Target detection during final approach should have improved because the flightpath was such that the MTI radial velocity was near maximum and the ASR-7 radar was providing a strong radar target to the RDAS. In all probability, target detection was lost because the RDAS clutter threshold, which the MTI target return must exceed for detection, was of such magnitude it prevented detection. The ARTS III displayed track data were lost for six consecutive scans during the interval. Radar track 372 was initiated two scans before touchdown with its FTF reset. This track was disseminated as correlated track data and was displayed on the DEDS one scan prior to touchdown. Track 372 provided a BSR of 100.0 percent for both the Mode S and ARTS III for a two-scan interval.

The RDAS provided a report BSR of 78.9 percent during the 128-scan takeoff to touchdown interval, and a report BSR of 28.0 percent for the first 25 scans after takeoff.

New radar tracks, initial tracks, were correctly initiated by the Mode S radar track initiation function. Correct transition from an initial track to a normal track occurred when the radar track passed the "M out of N" criteria. M and N are Mode S parameters, M represents the hit count for initial tracks and N the scan count for initial tracks. Those radar tracks that did not meet these criteria were terminated.

It was evident from these results that an ARTS III radar track symbol was not displayed within the three- to five-scan minimum requirement to meet the ATC criteria and was not acceptable. The results also indicate radar track continuity is a problem and does not meet the ATC minimum standards in maintaining reliable radar tracks. It was determined that inadequacies in RDAS target detection accounted for all the Mode S radar track drops on the test aircraft.

ACY Takeoff/Touchdown Runway 31. Figures 19 and 20 are plots of the test aircraft flightpath flown at ACY runway 31 from takeoff to touchdown. Table 20 depicts the critical delay times in radar track initiation and the cumulative ARTS/Mode S/RDAS delays. Table 21 provides a statistical summary of the baseline performance.

A comparison of figure 19 to figure 20 indicates that radar detection did not occur during the takeoff or the turning interval for the test aircraft. Table 20 shows that radar track initiation and termination occurred on three separate occasions during the 87-scan takeoff/touchdown interval. One track swap occurred during this interval. Emphasis was given to the cause of late radar track initiation and the absence of radar track continunity.

Analyses were conducted to determine the RDAS and Mode S radar surveillance performance. The data collected in table 20 indicate that the first RDAS report occurred four scans after departure. Five scans after departure the Mode S track initiation software correctly started an initial track. This track (track 283) occurred after reports from two consecutive scans met range and azimuth comparison criteria. Radar track 283 was terminated before it became mature, consequently, no dissemination of correlated data occurred.

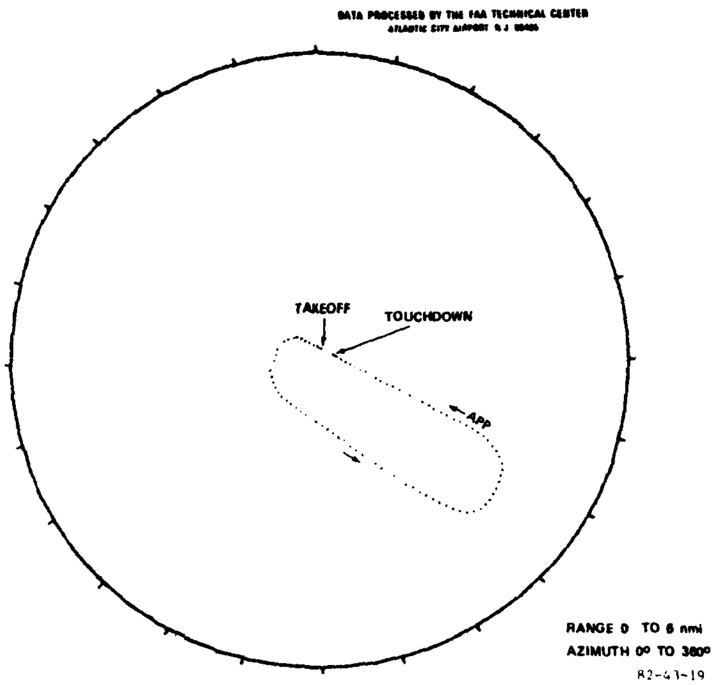

FIGURE 19. TEST AIRCRAFT FLIGHT PATTERN FOR ACY DEPARTURE AND LANDING ON RUNWAY 31

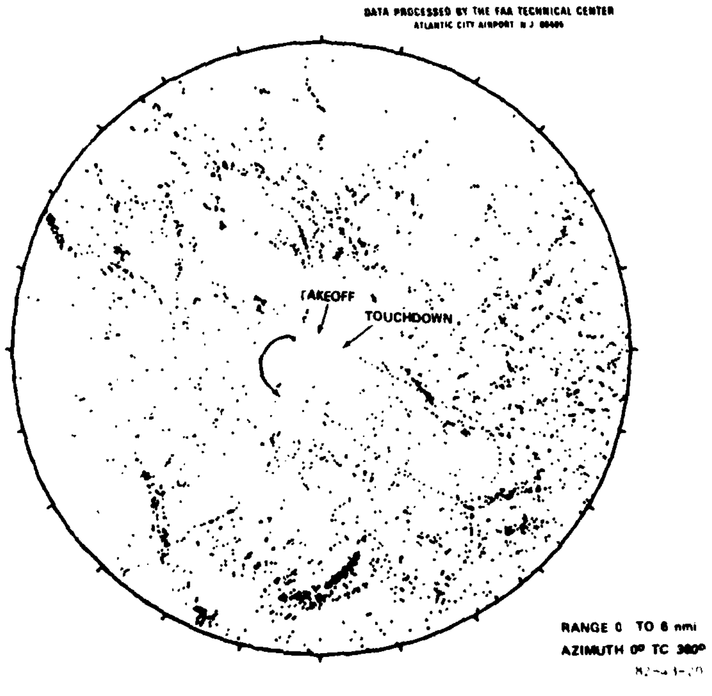

FIGURE 20. MODE S/RDAS ACY DEPARTURE AND LANDING ON RUNWAY 31

TABLE 20. MODE S/RDAS TRACK INITIATION DELAYS FROM ACY RUNWAY 13

		Cumulative Delay				
Event	Time	Time (sec)	Scans	Range (nmi)	Azimuth (deg)	SFN
Takeoff	09:56:36			0.31	343.17	
Initial RDAS Report	09:56:55.2	19.2	4	0.60	317.31	
Mode S Track Initiation	09:57:04.4	28.4	5	0.70	305.97	283
First Mode S Uncorrelated Report	09:57:45.8	69.8	13	1.9	246.8	0
First Mode S Correlated Report	None (track 283 terminated)					
Next RDAS Report	09:58:36.3	120.3	24	1.23	178.53	
Mode S Uncorrelated Report	09:58:36.3	120.3	24	1.2	178.5	0
Mode S Track Initiation	09:58:36.3	129.7	26	1.41	169.91	328
Mode S Correlated Report with FTF Set	Never Set					
Mode S Correlated Report with FTF Reset	09:58:50.2	134.2	27	1.5	165.8	328
First ARTS Displayed Track	09:58:50.8	134.8	27	1.47	168.0	328
First ARTS Displayed Data Block	09:58:54.4	138.4	28	1.5	163.0	328

TABLE 21. MODE S/RDAS BASELINE TRACKING PERFORMANCE FROM ACY RUNWAY 31

Track Drops: 2
Track Swaps: 1 - Track 283 swapped from test aircraft to false track 109

RDAS Report (BSR)	Mode S Track (BSR)	ARTS Track (BSR)	No. Scans
80.5% (87 Scans)	100% Track 283	None	1
	91.1% Track 328	88.9% Track 328	45
	100% Track 109	100% Track 109	13

Investigation revealed that the Mode S next scan azimuth position prediction was in error by approximately 180°. The cause of this problem is being investigated.

The error in predicting the correct azimuth of the next radar report prevented radar track 283 from transitioning from an initial track to a normal track when the next RDAS report occurred at the correct azimuth. Track position predictions continued from the azimuth position that was in error, this caused track 283 to be dropped.

The first disseminated uncorrelated radar data occurred 13 scans after departure. The next scan RDAS target detection was lost before a track could be established by the Mode S. This occurred when the test aircraft turned and flew tangentially to the radar antenna.

The next RDAS report used by Mode S to initiate a radar track occurred 24 scans after departure. The first reliable correlated radar track occurred 26 scans after departure as track 328. Correlated track data were disseminated to the ATC facility with its FTF correctly reset and was displayed on the DEDS within one scan. Radar track 328 continued to be displayed for a 45-scan interval.

Table 21 indicates the Mode S and ARTS III radar track BSR's were 91.1 and 88.9 percent, respectively. The difference in BSR's was caused by the ARTS III coasting the track for one additional scan when a disseminated Mode S report was not received.

A track swap occurred on the final approach to runway 31. The cause of this problem was the failure of the detected report to occur in either of the two Mode S predicted radar track 328 association zone windows. During this interval an active false radar track (track 109) was in close proximity. The next RDAS radar report received for track 328 associated nearer to the false track prediction than to the prediction made for the real track. The RDAS report on the test aircraft was used to update the position of false track 109. This problem led to the dropping of track 328, the test aircraft, and the track swapping to track 109. Radar track 109, now the test aircraft, remained for 13 scans. Mode S and ARTS III provided radar track BSR's of 100.0 percent. The last RDAS target report occurred while the test aircraft was at an altitude of 200 feet.

Table 21 indicates the RDAS report BSR was 80.5 percent during the 87-scan takeoff to touchdown interval. The RDAS report BSR for the first 25 scans after departure was an unacceptable 56.2 percent.

It was evident from these results that an ARTS III radar track symbol was not displayed within the three to five scans of detection delay needed to meet the ATC criteria and was not acceptable. The results also indicated radar track continuity is a problem and does not meet the ATC minimum standards in maintaining reliable radar tracks. It was determined that inadequacies in RDAS target detection and false radar reports accounted for the Mode S radar track drops and swap on the test aircraft.

ACY Takeoff Runway 13 and Touchdown Runway 22. Figures 21 and 22 are plots of the test aircraft flightpath from takeoff on ACY runway 13 to touchdown on ACY runway 22. Table 22 depicts the critical delay times in radar track initiation and the cumulative ARTS/Mode S/RDAS delays. Table 23 provides a statistical summary of the baseline performance. This performance data included: RDAS report BSR and Mode S/ARTS III track BSR's.

This was the second of two departures from runway 13. The difference between this departure and that shown in figures 17 and 18 was that the test aircraft did not begin a turn until it was approximately 3.75 nautical miles from the end of the runway. This flight pattern provided an improved MTI detection sensitivity by not flying tangentially to the radar antenna until a firm Mode S track was established. Radar track initiation occurred only once during the 64-scan takeoff to touchdown interval.

Analysis of the data collected indicated no major problems in either RDAS target detection or Mode S radar tracking. As expected, RDAS target detection improved when the test aircraft continued to fly on a radial after departure. Table 22 indicates the first RDAS target detection occurred six scans after departure when the aircraft altitude was 300 feet. Mode S track 87 was initiated seven scans after departure and correlated radar track data were disseminated on the following scan with its FTF set. The FTF was reset on the following scan and was displayed on the DEDS. Radar track 87 continued to be displayed for a 53-scan interval. This track was dropped after the RDAS missed three consecutive target detections three scans prior to touchdown.

Table 23 indicates both the Mode S and ARTS III radar track BSR's were 92.5 percent. The RDAS provided a report BSR of 81.3 percent during the 64-scan takeoff to touchdown interval. The RDAS report BSR for the first 25 scans after takeoff was 80.6 percent and indicated a significant improvement relative to the takeoff from runways 13 and 31, which had reported BSR's of 28.0 and 56.0 percent, respectively.

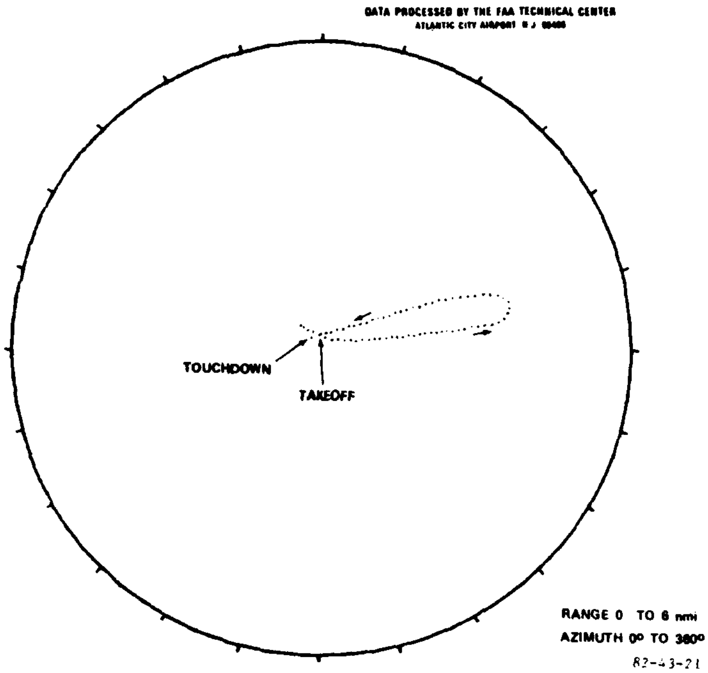

FIGURE 21. TEST AIRCRAFT FLIGHT PATTERN FOR ACY DEPARTURE RUNWAY 13 AND LANDING ON RUNWAY 22

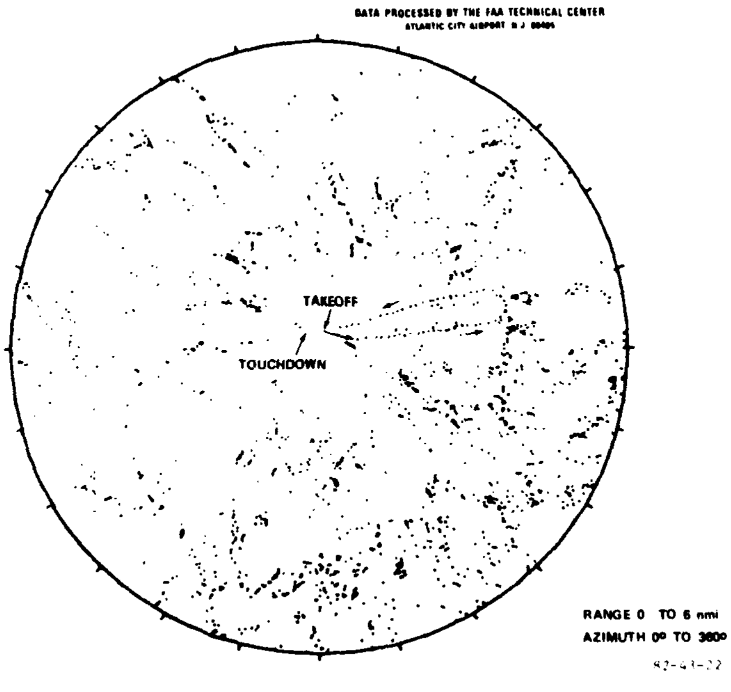

FIGURE 22. MODE S/RDAS ACY DEPARTURE ON RUNWAY 13 AND LANDING ON RUNWAY 22

TABLE 22. MODE S/RDAS TRACK INITIATION DELAYS FROM ACY RUNWAY 13/22

Event	Time	Cumulative Delay Time (sec)	Cumulative Delay Scans	Range (nmi)	Azimuth (deg)	SFN
Takeoff	10:21:49			0.37	337.46	
Initial RDAS Report	10:22:18.5	29.5	6	0.60	73.15	
First Mode S Uncorrelated Report	None					
Mode S Track Initiation	10:22:23.3	34.3	7	0.70	75.70	87
First Mode S Correlated Report with FTF Set	10:22:27.9	38.9	8	0.8	76.9	87
First Mode S Correlated Report with FTF Reset	10:22:32.2	43.6	9	1.2	77.7	87
First ARTS Displayed Track	10:22:32.2	43.6	9	0.89	78.0	87
First ARTS Displayed Data Block	10:22:41.5	52.5	11	1.08	80.0	87

TABLE 23. MODE S/RDAS BASELINE TRACKING PERFORMANCE FROM ACY RUNWAY 13/22

Track Drops: 0
Track Swaps: 0

RDAS Report (BSR)	Mode S Track (BSR)	ARTS Track (BSR)	No. Scans
81.3% (64 Scans)	92.5% Track 87	92.5% Track 87	52

From the results shown in table 22, an ARTS track symbol was displayed for controller monitoring on the fourth scan of target detection. This was in compliance with the ATC minimum standard of displaying correlated targets within three to five scans after report detection. Radar track continuity was not a problem and met the ATC minimum standard in maintaining reliable radar track data for controller monitoring.

SATELLITE AIRPORT RADAR SURVEILLANCE. Typical flight patterns were flown at nearby Bader Field and Smithville Airport to establish radar track initiation delay times and to determine radar surveillance baseline performance. These data delay times supplement the delay times established at the Atlantic City Airport. The flightpaths during these tests were not the same as those flown at ACY. They do not include as one segment a takeoff to touchdown interval. The first segment presented in each of the satellite airport patterns is the approach to land data, followed by the departure data. The results and analysis for Bader Field are presented first.

Bader Field Approach/Touchdown and Takeoff. Figures 23 and 24 are plots of the test aircraft flightpath flown at Bader Field. Table 24 depicts the critical delay times in radar track initiation and the cumulative ARTS/Mode S/RDAS delays. Table 25 provides a statistical summary of the test aircraft baseline performance.

Comparison of figure 23 (beacon data) to figure 24 (actual radar data) indicated an undesirable problem occurred on final approach. Radar surveillance for track 142 was terminated 12 scans prior to runway touchdown when the aircraft was at an altitude of 900 feet and descending. Analysis of this problem indicated inadequate RDAS target detection caused radar track 142 to be terminated.

Analysis of the first 25 scans of departure data in table 24 indicated the first RDAS report occurred eight scans after takeoff. The altitude of the test aircraft was 400 feet. The first Mode S track initiated (track 48) occurred 11 scans after departure. Correlated data were never disseminated; termination occurred when radar reports did not update track 48. Investigation revealed that the RDAS reports were available and not used by the Mode S radar track update function. Analysis of the data indicated that the Mode S next scan tracking position prediction was not adequate to locate the position of the test aircraft. This problem is related to the Mode S surveillance algorithm which ultilizes an alpha/beta filter to update the track position. The values for the filter are based upon the report quality value. There is normally one of four possible quality values used by the alpha/beta filter to update the next scan track position. Each value selected is based on past track attributes. In the processing of RDAS targets, the quality field in the radar report buffer is defaulted to one value "1." This caused severe limitations in smoothing the next track predicted position and caused degradation in position prediction estimates. This next scan prediction degradation caused the delay in establishing a reliable Mode S radar track.

Mode S predicted the range position of the next RDAS report at 8.34 nautical miles. The maximum allowable deviation from this range prediction was ±0.44 nautical mile. The next scan RDAS report position was at 7.0 nautical miles. This represents a difference between the Mode S predicted position and the actual RDAS position of 1.34 nautical miles, far greater than the allowable prediction error of 0.44 nautical mile. The range position of the Mode S dual track was 7.0 nautical miles and was in agreement with the RDAS report position.

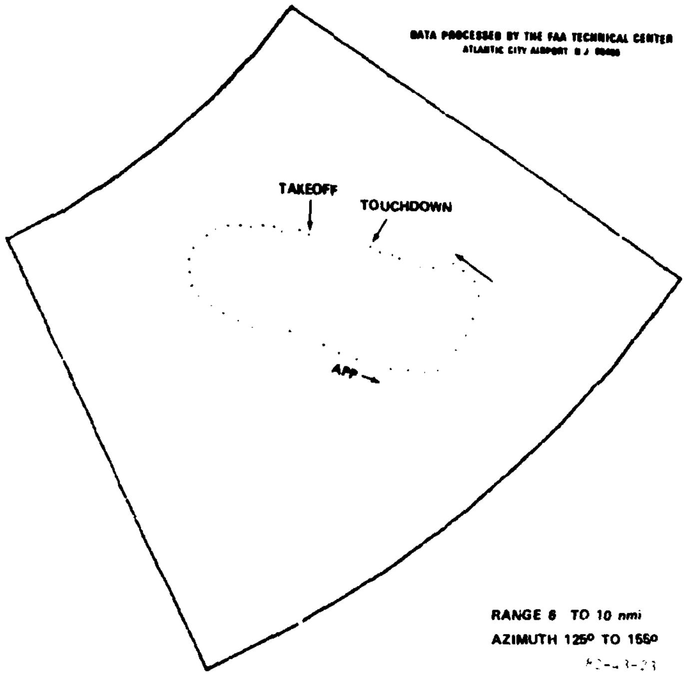

FIGURE 23. TEST AIRCRAFT FLIGHT PATTERN FOR BADER FIELD DEPARTURE AND LANDING

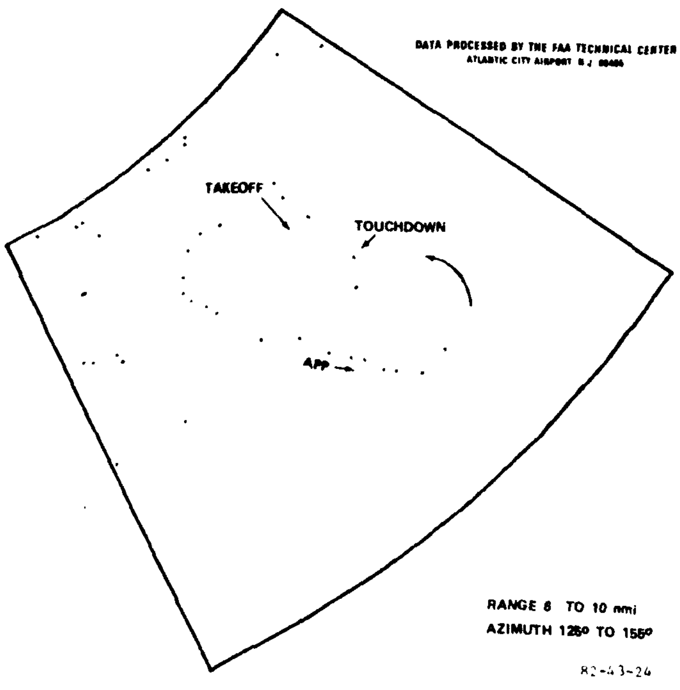

FIGURE 24. MODE S/RDAS BADER FIELD DEPARTURE AND LANDING

TABLE 24. MODE S/RDAS TRACK INITIATION DELAYS FROM BADER FIELD

Event	Time	Cumulative Delay Time (sec)	Cumulative Delay Scans	Range (nmi)	Azimuth (deg)	SFN
Takeoff	11:21:59			7.39	136.76	
Initial RDAS Report	11:22:38.4	39.2	8	6.85	140.52	
Mode S Track Initiation	11:22:52.5	53.5	11	6.85	143.39	48
First Mode S Uncorrelated Report	11:22:43.1	44.1	9	6.8	142.01	0
First Mode S Correlated Report	None (track 48 terminated)					
Next RDAS Report	11:23:11.3	72.3	15	7.20	145.24	
Mode S Uncorrelated Report	11:23:11.3	72.3	15	7.20	145.24	0
Mode S Track Initiation	11:23:16.0	77.0	16	7.31	144.65	344
Mode S Correlated Report with FTF Set	11:23:20.6	81.6	17	7.4	144.4	344
Mode S Correlated Report with FTF Reset	11:23:48.2	109.6	23	8.2	141.6	344
First ARTS Displayed Track	11:23:48.6	109.2	23	8.14	142.0	344
First ARTS Displayed Data Block	11:23:52.9	113.9	24	8.27	141.0	344

TABLE 25. MODE S RDAS BASELINE TRACKING PERFORMANCE FROM BADER FIELD

Track Drops: 1
Track Swaps: 0

RDAS Report (BSR)	Mode S Track (BSR)	ARTS Track (BSR)	No. Scans
67.6% (25 scans)	100% Track 48	None	1
	69.2% Track 344	60% Track 344	9

Table 24 indicates the next RDAS report available for Mode S track initiation occurred 15 scans after departure and was disseminated as an uncorrelated radar report. Mode S initiated radar track 344 sixteen scans after departure. The first correlated track data were disseminated on the following scan with the FTF set. This flag was reset 23 scans after departure and was displayed on the DEDS. This represented a nine-scan delay before radar track data could be displayed on the DEDS. It was evident from these results that the three to five scans of detection delay needed to meet the ATC criteria was not met and, therefore, not acceptable.

The RDAS report BSR (table 25) for the initial 25 scans after departure was 67.6 percent. The Mode S radar track BSR for track 344 was 69.2 percent; the ARTS III BSR during the same interval was 60.0 percent. The degraded ARTS III BSR was caused by coasting two additional disseminated Mode S reports. The problem with lost data between Mode S and the ARTS III is under investigation.

Smithville Approach/Touchdown and Takeoff. Figures 25 and 26 are plots of the test aircraft approach/touchdown and takeoff flight pattern flown at Smithville Airport. The location of this airport is 5.3 nautical miles and 67° relative to the Technical Center's Mode S sensor. Table 26 depicts the critical time delays encountered during radar track initiation and the cumulative ARTS/Mode S/RDAS delays. Table 27 provides a statistical summary of baseline performance.

There were no noticeable problems encountered during the final approach or touchdown. RDAS target detection was lost two scans prior to touchdown after the test aircraft descended below an altitude of 200 feet. Normal radar track termination occurred after three consecutive reports were not detected.

Analysis of the data in table 26 indicated that the RDAS detected the test aircraft two scans after runway departure when the test aircraft attained an altitude of 200 feet. These data were disseminated to the ARTS III IOP as an uncorrelated radar report. The RDAS reports received on the second and third scans were not used by the Mode S to initiate a radar track. Both of these reports had low RDAS quality values and, in all likelihood, were removed by the Mode S quality filter.

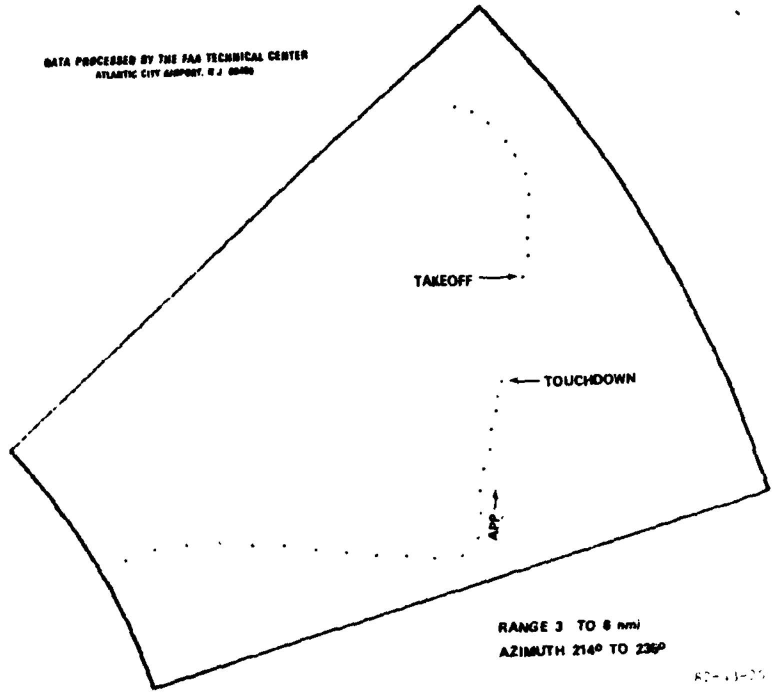

FIGURE 25. TEST AIRCRAFT FLIGHT PATTERN FOR SMITHVILLE DEPARTURE AND LANDING

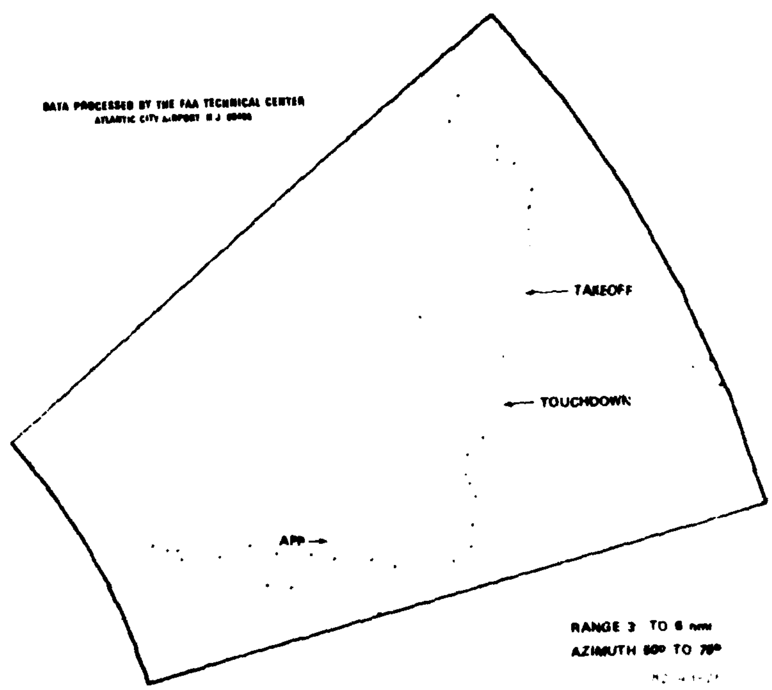

FIGURE 26. MODE S/RDAS SMITHVILLE DEPARTURE AND LANDING

TABLE 26. MODE S/RDAS TRACK INITIATION DELAYS FROM SMITHVILLE AIRPORT

Event	Time	Cumulative Delay Time (sec)	Cumulative Delay Scans	Range (nmi)	Azimuth (deg)	SFN
Takeoff	11:13:14			5.38	61.22	
Initial RDAS Report	11:13:34.3	10.3	2	5.49	59.74	
First Mode S Uncorrelated Report	11:13:34.3	10.3	2	5.5	59.7	0
Mode S Track Initiation	11:13:48.4	24.4	5	5.64	5.64	161
First Mode S Correlated Report with FTF Set	11:13:52.9	28.9	6	5.6	56.1	161
First Mode S Correlated Report with FTF Reset	11:14:06.5	43.0	9	5.6	55.5	161
First ARTS Displayed Track	11:14:06.5	43.5	9	5.53	56.0	161
First ARTS Displayed Data Block	11:14:11.2	47.2	10	5.49	53.0	161

TABLE 27. MODE S/RDAS BASELINE TRACKING PERFORMANCE FROM SMITHVILLE AIRPORT

Track Drops: 0
Track Swaps: 0

RDAS Report (BSR)	Mode S Track (BSR)	ARTS Track (BSR)	No. Scans
90% (20 scans)	100% Track 161	100% Track 161	12

The Mode S sensor initiated radar track 161 five scans after departure. Correlated track data were disseminated on the following scan with the FTF set, and was displayed by the DEDS nine scans after departure when the FTF was reset. As indicated in table 26, the Mode S sensor provided usable correlated reports to the ARTS III system nine scans after departure. It was evident from these results that ARTS III radar track initiation was not achieved within the three to five scans needed to meet the ATC criteria and was not acceptable.

Table 27 indicates the RDAS provided a report BSR of 90.0 percent for the initial 20-scan departure interval. The Mode S and ARTS III radar track BSR's were 100 percent for a 12-scan interval.

Baseline Performance in Clear-Air. The purpose of this flight test was to provide radar surveillance baseline performance data in radar tracking a low-flying small aircraft in clear air. The test aircraft flew at an altitude of 1,000 feet on a 240° outbound radial relative to the Mode S sensor at the FAA Technical Center. The test aircraft continued on this radial beyond the outer fringe of radar range coverage. Once out of coverage, the aircraft turned and returned to the sensor on the same radial.

Figures 27 and 28 are plots of all disseminated radar targets which had high quality and high confidence. Figure 27 presents the outbound test segment and figure 28 the inbound segment. Each segment was analyzed separately between 6 and 19 nautical miles. Tables 28 and 29 depict the baseline performance characteristics for each radial, respectively.

Performance of the low altitude (1,000 feet) 230° outbound radial flight is as follows: the RDAS provided a BSR of 87.9 percent for a 91-scan interval. One major problem occurred during this interval, RDAS radar report detection was lost for seven consecutive scans. This caused the dropping of radar track 202. Radar track 202 was later reinitiated as radar track 001. This problem prevented the Mode S from providing radar track continuity and was not acceptable. Both the Mode S and ARTS track BSR for track 202 were 92.9 percent and 94 percent for track 001 and were acceptable. Radar reinforcement for the Mode S track on the test aircraft was 87.9 percent and acceptable.

The test aircraft continued at 1,000 feet on an outbound radial to determine outer limit of radar range coverage. Target detection was lost at approximately 22 nautical miles. The test aircraft continued outbound to 25 nautical miles where it turned inbound on the same radial. Initial target detection for the inbound radial occurred at 24 nautical miles, 2 miles further out in range. Earlier detection occurred, in all likelihood, due to the effects the aircraft propeller had on the increased cross-sectional area of the reflecting radar surface.

Figure 28 is a plot of the clear-air inbound (1,000 feet) radial; table 29 summarizes the baseline performance characteristics. The RDAS provided a report BSR of 71.4 percent for a 91-scan interval. The test aircraft was first initiated as radar track 159. This track remained for 18 scans and provided a Mode S track BSR of 94.4 percent and an ARTS track BSR of 88.2 percent. The degraded ARTS BSR was cause by one additional coast of the Mode S disseminated data. This problem is now being investigated.

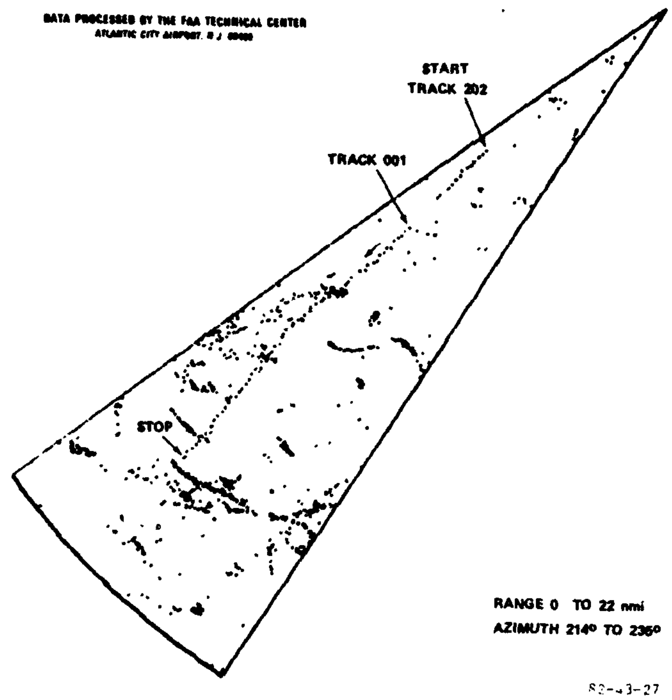

FIGURE 27. MODE S/RDAS LOW ALTITUDE OUTBOUND RADIAL

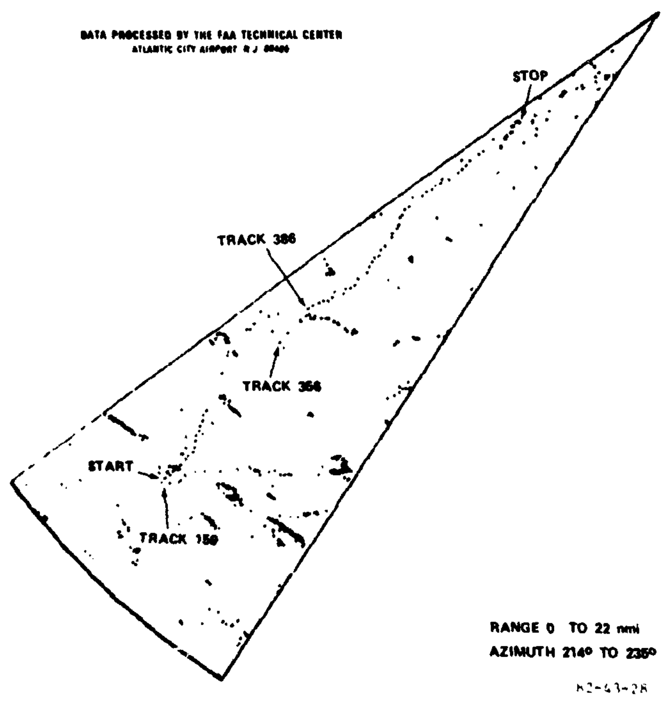

FIGURE 28. MODE S/RDAS LOW ALTITUDE INBOUND RADIAL

TABLE 28. MODE S/RDAS BASELINE TRACKING PERFORMANCE IN THE CLEAR (OUTBOUND RADIAL)

Track Drops: 1
Track Swaps: 0

RDAS Report (BSR)	Mode S Track (BSR)	ARTS Track (BSR)	No. Scans
87.8% (91 Scans)	92.9% Track 202	92.9% Track 202	14
	94% Track 001	94% Track 001	67

TABLE 29. MODE S/RDAS BASELINE TRACKING PERFORMANCE IN THE CLEAR (INBOUND RADIAL)

Track Drops: 2
Track Swaps: 0

RDAS Report (BSR)	Mode S Track (BSR)	ARTS Track (BSR)	No. Scans
71.4% (91 Scans)	94.4% Track 202	88.2% Track 159	18
	66.7% Track 356	66.7% Track 356	3
	85.4% Track 386	82.9% Track 386	41

RDAS target detection became a serious problem for the next 27 scans. Radar track 159 was dropped and reliable radar surveillance was lost for a 27-scan interval. Mode S established radar track 356 for three scans, then dropped the track after three consecutive RDAS target report misses. The RDAS provided a report BSR of only 29.6 percent during this interval.

The next radar track to be established by Mode S was 386. This track remained for 41 scans, the duration of the inbound radial. The Mode S and ARTS track BSR's were 85.4 percent and 82.9 percent, respectively.

The RDAS sensitivity in clear-air was not acceptable. The Mode S was unable to provide radar tracking continuity from the RDAS reports. The radar reinforcement on the Mode S dual track during the 91-scan interval was 68.1 percent and unacceptable.

Baseline Performance Over Ground Clutter. Flight testing was conducted to determine the RDAS target detection capabilities and Mode S radar tracking performance for a small aircraft flying over ground clutter. The clutter region being the 1- by 6-mile Atlantic City/Absecon Island, which is located 8 nautical miles southeast of the FAA Technical Center.

Figures 29, 30, and 32 are plots of the aircraft test patterns flown to provide radar tracking baseline performance characteristics over ground clutter. These plots represent all Mode S disseminated radar data to ARTS IOP. Each plot is accompanied with a data table that summarizes the radar surveillance performance.

The first flight test over ground clutter is presented in figure 29. The test aircraft performed "S" turn maneuvers over the Atlantic City/Absecon Island at an altitude of 3,000 feet. Table 30 is the baseline performance.

Analysis of the data in table 30 indicated no major problems in either RDAS target detection or Mode S radar tracking. During a 92-scan sample track, continuity was maintained with both the RDAS and Mode S. The RDAS report BSR and Mode S track BSR were each 82.6 percent. ARTS III provided track BSR of 80.4 percent. Two disseminated Mode S reports were not received by the ARTS III IOP, this acccunts for the degraded ARTS BSR.

Figure 30 represents the first tangential flight test over ground clutter. During this flight segment the test aircraft remained on a course tangential to the radar antenna. Table 31 presents the corresponding baseline performance characteristics.

Two track swaps occurred during this test interval and both were caused by the Radar Substitution function.

Figure 31 is a plot of the test aircraft in the proximity of Bader Field where the first radar substitution problem occurred. Radar track 309 on the test aircraft was lost when its radar reports were used to update coasting ATCRBS track 342. This ATCRBS target was descending to land at Bader Field. A "·" on the plot represents a radar report. The "X" on the plot indicates radar substitution. The inverted symbol (∩), are beacon reports that were radar reinforced and (∪) are those that were not. Radar substitution of ATCRBS track 342 continued for five consecutive scans, at which time a normal transition from a beacon to a radar

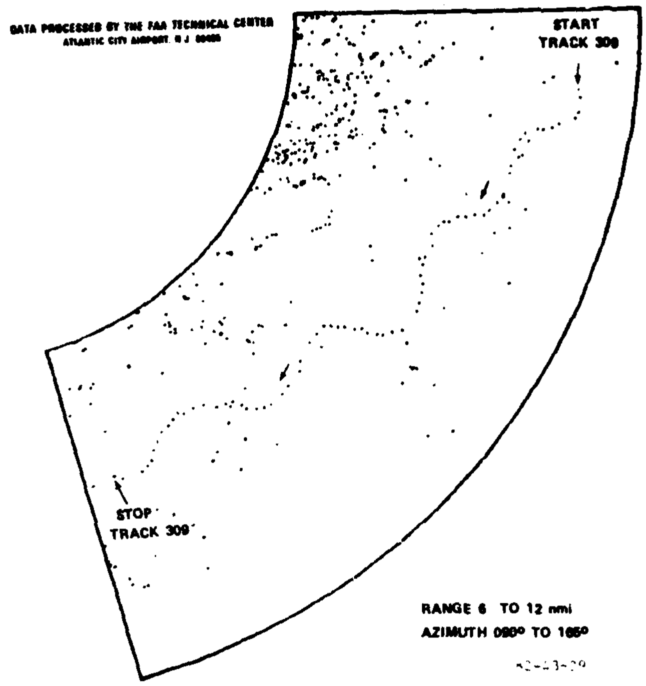

FIGURE 29. MODE S/RDAS "S" TURN FLIGHT PATTERNS OVER GROUND CLUTTER

TABLE 30. MODE S/RDAS BASELINE TRACKING PERFORMANCE ON "S" TURN FLIGHTS OVER GROUND CLUTTER

Track Drops: 1
Track Swaps: 0

RDAS Report (BSR)	Mode S Track (BSR)	ARTS Track (BSR)	No. Scans
82.6% (92 Scans)	82.6% Track 309	80.4% Track 309	92

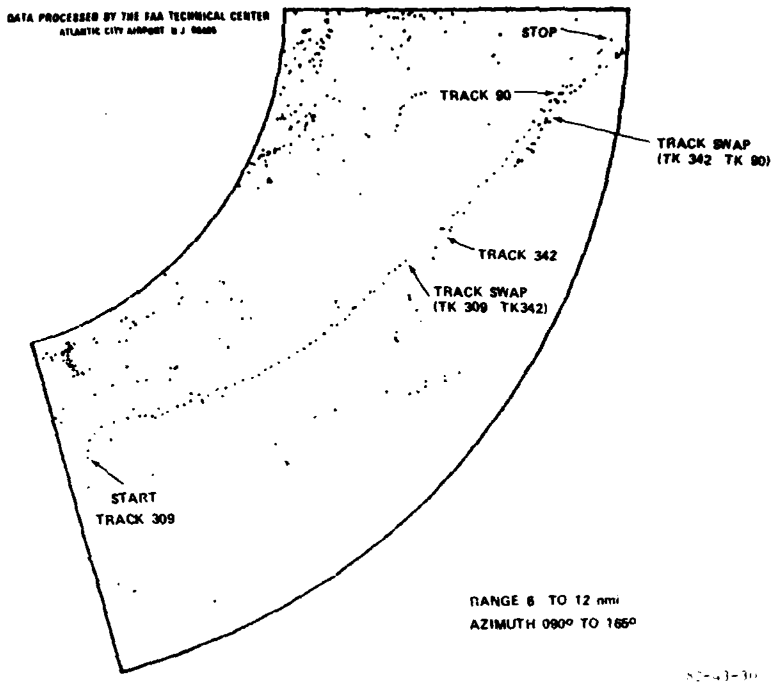

FIGURE 30. MODE S/RDAS NORTHBOUND TANGENTIAL FLIGHT PATTERN OVER GROUND CLUTTER

TABLE 31. MODE S/RDAS BASELINE TRACKING PERFORMANCE ON NORTHBOUND TANGENTIAL FLIGHT OVER GROUND CLUTTER

Track Drops: 2
Track Swaps: 2

RDAS Report (BSR)	Mode S Track (BSR)	ARTS Track (BSR)	No. Scans
88.5% (78 Scans)	77.8% Track 309	77.8% Track 309	27
	71.4% Track 342	71.4% Track 342	14
	80% Track 90	80% Track 90	35

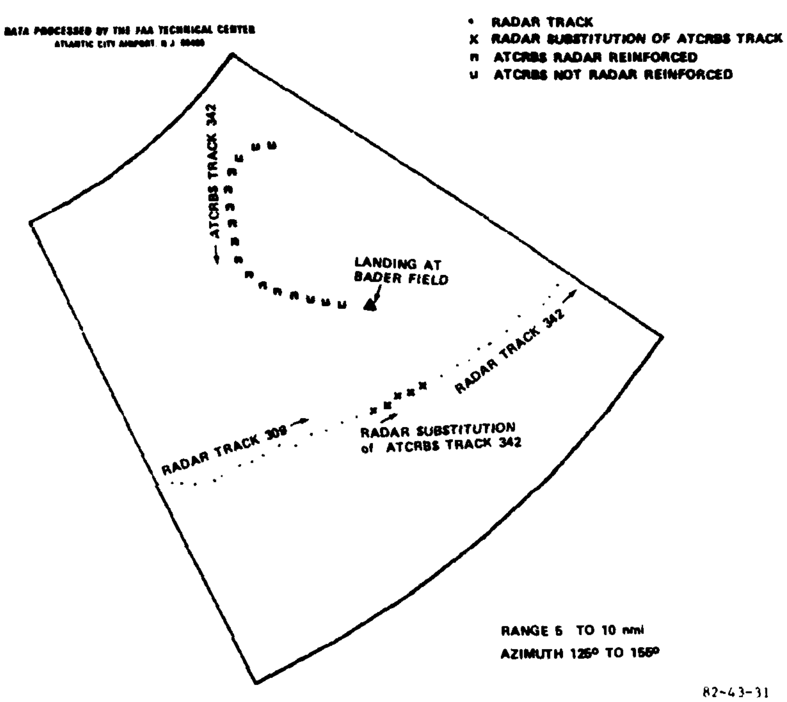

FIGURE 31. TRACK SWAP INITIATED BY RADAR SUBSTITUTION

track occurred. During the same interval of time the actual test aircraft radar track 309 was coasted and later dropped. This problem gave the appearance that the test aircraft, radar track 309, terminated near Bader Field and ATCRBS track 342 did not land, but turned and continued northbound as a radar track. This problem repeated itself 12 scans later. Radar track 342 went into coast when its radar reports were used to update coasted ATCRBS track 90. Radar track 342 was dropped and ATCRBS track 90 transitioned to radar track 90.

Investigation revealed that the Mode S radar tracking software operated correctly as defined in the Mode S ER. During all the radar substitution intervals, the radar report of the test aircraft was within the ATCRBS predicted association zones.

Figure 32 represents the second tangential flight test over ground clutter. During this flight segment the test aircraft remained on a southbound course tangential to the radar antenna. Table 32 presents the corresponding baseline performance characteristics.

The RDAS provided a report BSR of 92.4 percent over a 64-scan interval (see table 32). Radar track 90 was first initiated on the test aircraft and remained for 53-scans. During the next nine consecutive scans, disseminated correlated track data were lost, radar track 90 was dropped, and the test aircraft was later reinitiated as radar track 291. Figure 32 depicts the area where the correlated

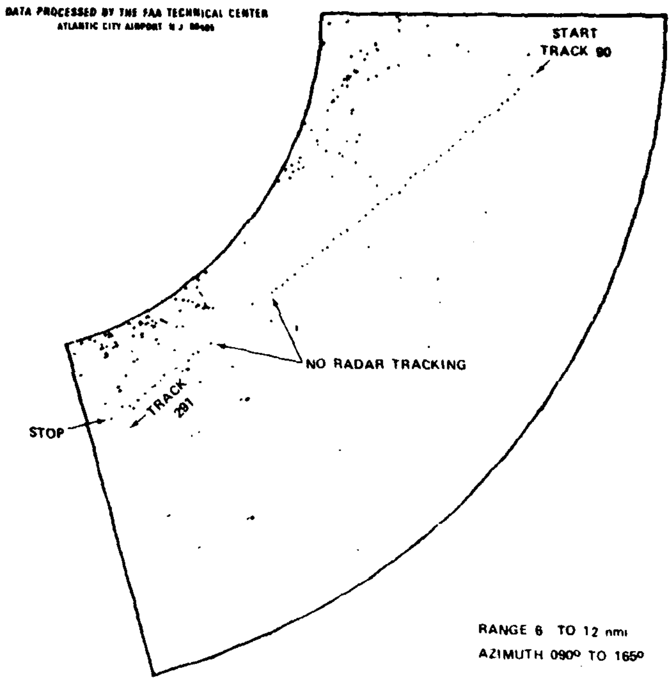

FIGURE 32. MODE S/RDAS SOUTHBOUND TANGENTIAL FLIGHT PATTERN OVER GROUND CLUTTER

TABLE 32. MODE S/RDAS BASELINE TRACKING PERFORMANCE ON SOUTHBOUND TANGENTIAL FLIGHT OVER GROUND CLUTTER

Track Drops: 91
Track Swaps: 0

RDAS Report (BSR)	Mode S Track (BSR)	ARTS Track (BSR)	No. Scans
92.4% (64 Scans)	81.1% Track 90	77.4% Track 90	53
	100% Track 291	100% Track 291	11

track was lost. Mode S provided a track 90 BSR of 81.1 percent; ARTS provided a track BSR of 77.4 percent over a 53-scan interval. Two additional ARTS III coasts accounts for the degraded BSR. This problem of Mode S disseminated data being coasted at the ARTS III is now under investigation. Radar track 291 remained for the 11-scan duration of the flight test and provided Mode S and ARTS track BSR's of 100.0 percent.

Investigation revealed RDAS radar reports were detected and disseminated to Mode S for radar processing during the nine-scan period during which no tracking update occurred. Futher analysis revealed that the RDAS reports on the test aircraft were used to reinforce or radar substitute ATCRBS tracks and were not available for radar track updating. This problem is not unusual, but it is undesirable and accounts for the RDAS report BSR being greater than the Mode S track BSR.

PROBABILITY OF FALSE RADAR TRACKS. The probability of generating false radar tracks was measured in a clear environment over a 100-scan interval. Table 33 is a summary of false radar track initiation rates generated by the Mode S sensor and ARTS III system. Special data reduction programs were developed to summarize the possibility of each radar track being false. Individual track analyses were performed to make the final determinations.

TABLE 33. MODE S/ARTS III 100-SCAN FALSE TRACK SUMMARY

False Mode S Tracks Initiated Per Scan	4.64
False Mode S Tracks After Velocity Filter	3.50
False ARTS III Tracks Initiated Per Scan	5.94
Displayed False ARTS III Tracks Per Scan	29.0
Average ARTS III Track Persistence	4.9
Maximum Displayed Tracks Any One Scan	49.0

For RDAS report processing, the Mode S radar report confidence bit was always set high by default. This always makes available to the local last scan file in Mode S all RDAS reports not removed by the Mode S quality filter. These radar reports are used for future radar track initiation.

The philsosphy followed by the RDAS manufacturer was to optimize the adjustable parameters to increase detectability of weak targets at the expense of generating false radar reports that the Mode S quality filter and tracking algorithms would recognize and remove. A major area of concern was that decreasing the false RDAS radar report rate by changing adjustable RDAS parameters would seriously degrade target detection.

The data depicted in table 33 indicate that the ARTS displayed approximately 29.0 false radar tracks each antenna scan. The average persistence of each false track on the DEDS display was 4.9 scans. The false Mode S radar track initiation rate per scan was 4.64. This rate was reduced to 3.50 per scan after the tracks failed to pass the Mode S false target velocity test, a reduction of 25.6 percent. The ARTS III track initiation rate was 5.9 per scan, an increase of 58.9 percent. The differences between the number of false Mode S tracks after velocity filtering and the increased number of false ARTS III tracks generated are related to the way each system processes track coasts.

ARTS track termination depends on the number of coasts and the firmness assignment when the coast occurred. The first correlated radar track data received from Mode S will be assigned a firmness 1. This count will increment for each track update and decrement for each Mode S coast. Track termination depended on the following ARTS criteria: the firmness equal to 1 or 2 and one Mode S coast, the firmness equal to 3, 4, or 5 and two Mode S coasts, and the firmness equal to 6 or 7 and three Mode S coasts.

In relating this criteria with the increased ARTS false track rate depicted in table 33, consider the following example. The Mode S disseminated a false radar track to the ARTS. The ARTS initiates a radar track with a firmness equal to 1. The next scan Mode S coasts the false track. ARTS will terminate this track because the firmness equaled 1 and one Mode S coast occurred. The next scan Mode S receives a target report which updates the false track. These data are disseminated to ARTS as correlated track data. The ARTS system will initiate a new track with a firmness equal to 1. Therefore, depending on Mode S track updating, there can and do occur more false ARTS radar track initiations than false Mode S tracks.

Figure 33 is a plot of all disseminated radar and beacon report data over the interval of one scan. The specific purpose of the plot was to indicate the excessive number of radar reports that were available after beacon radar reinforcement. The "·" on the plot represent radar track updates. The "X" on the plot indicates radar substitution. The inverted symbols (∩) are beacon reports that were radar reinforced and (∪) are those that were not.

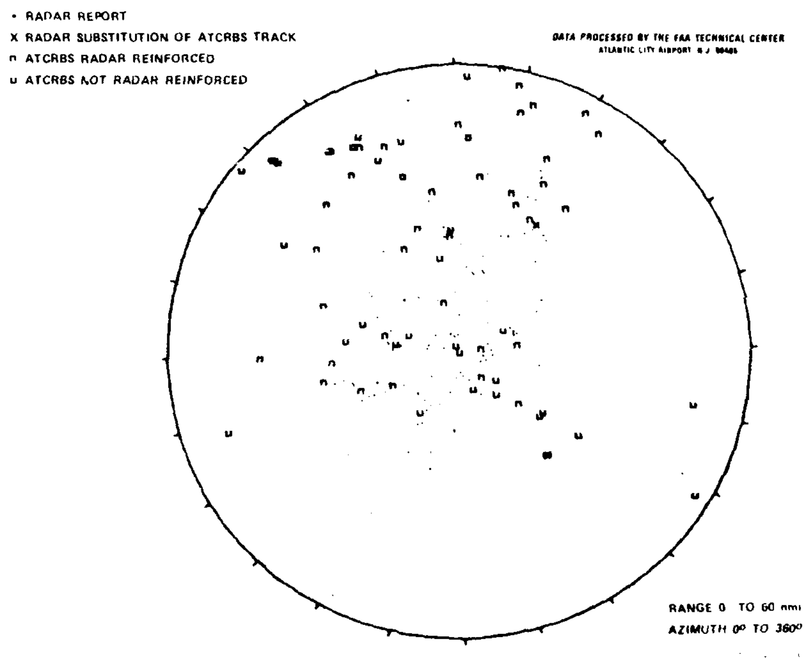

FIGURE 33. DISSEMINATED RADAR/BEACON TRACK DATA FOR ONE SCAN

Detailed analysis indicated that the RDAS generated approximately 186 radar reports per scan to the Mode S input buffer. Forty-two of these reports were used to radar reinforce beacon reports. The remaining 144 radar reports were subjected to the Mode S quality filter where 18 reports were eliminated. There were approximately 126 radar reports available for Mode S surveillance processing. Analysis of the real world environment indicated that there were only 19 radar tracks with their FTF's cleared. Taking into account the radar reports used to update these tracks and those used to generate new radar tracks, there remained an excessive number of false reports.

Analysis of the results indicated that the RDAS generated an unacceptable number of false radar reports and prevented accomplishing the ATC performance standards. These standards are: (1) the surveillance processor shall output fewer than one false correlated target report per scan averaged over a 1-hour period during normal operating conditions, and (2) peak rate of display of false radar targets shall be fewer than 10 per scan on an averaged 1-hour period under extreme conditions. Degradation to Mode S radar correlation and tracking update resulted from the excessive RDAS target report rates.

It was evident from these results that the RDAS does not perform satisfactorily, and an attempt to reduce false radar reports must be accomplished before any future ATC evaluation.

Radar/Beacon Correlation. The purpose of the radar/beacon correlation tests was to determine baseline performance characteristics in a real world environment. An attempt to find a reinforcing RDAS radar report for each beacon report was made by comparison on range and azimuth. To provide a realistic measurement of the overall environment, certain constraints were made on where in the real world environment samples would be taken. Measurements were made on all beacon aircraft within 48 nautical miles, with elevation angles between 2° and 16° and altitudes up to and including 20,000 feet. One additional filter was added to eliminate sampling of data in a known reflection zone, 120° to 140°.

The Mode S criteria for beacon report reinforcement were as follows: the magnitude of the azimuth difference between the radar report and the beacon report not exceed 20 Au's (0.44°), and the magnitude of the range difference not to exceed 50 range units (Ru's) (0.51 nmi).

Table 34 depicts the percent of beacon radar reinforcement determined from data collected on targets of opportunity over a 300-scan interval. Also presented in the table are radar reinforcements rates of the Mode S dual track at Atlantic City Airport in clear-air and over ground clutter.

The beacon radar reinforcement rate on targets of opportunity was 84.6 percent and considered acceptable. It should also be noted that during the same interval, the number of false radar tracks were unacceptable. This measurement was on all beacon aircraft within the constraints of the filtered environment and over a 300-scan interval. Analysis of the data collected indicated that those beacon reports not radar reinforced were caused by either the absence of RDAS target detections or RDAS reports failing to meet the Mode S 20-Au azimuth RBC criteria.

TABLE 34. PERCENT BEACON RADAR REINFORCEMENT

Test Segment	No. Scans	Radar Reinforced	RDAS Report BSR
Filter Environment	300	84.6	NA
ACY Runway 31 Pattern	87	60.9	80.5
ACY Runway 13 Pattern	128	62.5	78.9
ACY Runway 13/22 Pattern	64	66.6	81.3
Outbound Radial	91	87.9	87.8
Inbound Radial	91	68.1	71.4
GND Clutter "S" Turns	92	76.9	82.6
GND Clutter Northbound	78	77.9	88.5
GND Clutter Southbound	64	71.9	92.2

The ACY results in table 34 show that the RDAS report BSR's and Mode S radar track reinforcement rates were considerably different. The test data indicated that radar reinforcement rates were approximately 15 to 20 percent lower than the RDAS report BSR's. Investigation revealed that, in many instances, the RDAS reports were disseminated to the Mode S input processor but were not used to radar reinforce the Mode S report. It was observed that the azimuth difference between the RDAS report and the Mode S report exceeded the 20-Au criteria for radar reinforcement. There were no instances when the RDAS reports were available but failed the Mode S 50-Ru range criteria. The ACY data indicated that the reinforcement degradation was more severe when the test aircraft was flying tangential to the radar antenna. This should not be confused with the target detection degradation that occurs in MTI radar systems.

The reinforcement of the Mode S dual track improved, relative to the RDAS report BSR's, during the clear-air outbound/inbound radials. This improvement resulted from the test aircraft remaining on radial where there is the least amount of azimuth scan-to-scan change.

Radar reinforcement of the Mode S dual track over ground clutter experienced degradation similar to that encountered at ACY. Radar reinforcement of the test aircraft for "S" turns over ground clutter was 76.9 percent, 77.9 percent for the northbound tangential over ground clutter, and 71.9 percent for the southbound tangential over ground clutter. Differences between Mode S report reinforcement and RDAS report BSR's varied considerably. The worse case occurred during the southbound tangential flight. Radar reinforcement of the Mode S track was 71.9 percent; the RDAS report BSR was 92.2 percent. Investigation revealed that the 20.3 percent reinforcement degradation occurred after RDAS reports were available, but failed the Mode S 20-Au azimuth criteria.

Figure 34 is a plot depicting all disseminated beacon data to an ATC facility for an interval of 1 scan in an unfiltered environment. Special symbols were used to depict whether a beacon report was radar reinforced. Descriptions of these symbols are shown on the plot. For this particular figure, a beacon radar reinforcement rate of 57.5 percent was attained on approximately 73 beacon reports. This was unacceptable and indicated problems exist in RBC.

The radar/beacon merge problem is currently under investigation. Two possible causes for this problem have been investigated and eliminated. They were:

1. Errors in Mode S collimation correction angle (CCA) used to correct RDAS radar report azimuth to Mode S azimuth.

2. Errors in Mode S azimuth accuracy.

Erroneous azimuth correction by Mode S collimation correction was examined by comparing the RDAS report azimuth to the Mode S corrected azimuth for those radar reports that were available and not used to radar reinforce the test aircraft. Maximum differences between corrected and uncorrected azimuths were found to be insignificant.

Azimuth accuracy (1-sigma variation) of Mode S beacon reports was less than 0.1°. This accuracy was established during a prior FAA project and was determined by comparing the Mode S surveillance data and reference data obtained from a Nike-Hercules precision aircraft tracking system. Analysis of that data included the calculation of aircraft separation values, which were compared with separation values obtained from the reference tracking system. It was concluded from that data that the azimuth error contributed by Mode S was not significant enough to cause the degradation experienced during these test intervals.

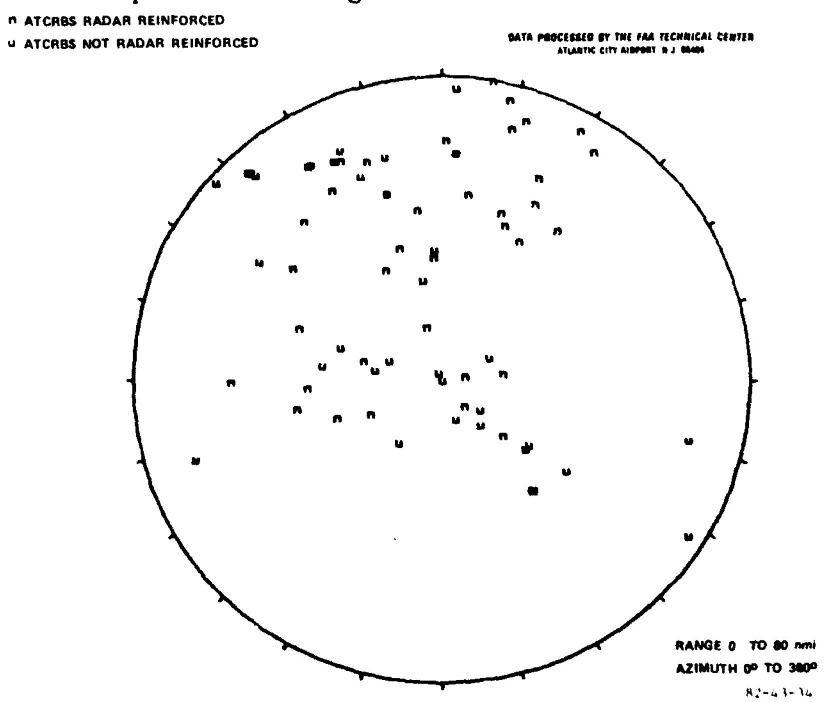

FIGURE 34. DISSEMINATED BEACON TRACK DATA FOR ONE SCAN

SUMMARY OF RESULTS

ARTS/MODE S/MTD SYSTEM CONFIGURATION.

COMPLIANCE WITH ENGINEERING REQUIREMENTS (FAA-ER-240-26).

1. Track initiation was achieved when two available radar reports met report-to-report correlation criteria in all cases but one. A case was observed where track initiation was delayed for six scans. Initial investigation has come up with no reason for this occurrance.

2. In all cases analyzed, primary radar track maturity was achieved as specified after the track was initiated. For these tests track maturity was achieved after two correlated reports were received.

3. All of the uncorrelated primary surveillance messages that were disseminated by the Mode S sensor satisfied the uncorrelated dissemination criteria requiring MTD report high confidence and quality greater than zero. However, MTD reports with a range less than 1 nautical mile that met the above mentioned criteria were not disseminated. All of the correlated primary surveillance messages that were disseminated by the Mode S sensor satisfied the correlated dissemination criteria requiring a primary track to be mature.

4. All radar tracks initiated within the range coverage of the target velocity test were flagged as possible false radar tracks and were tested for reasonable movement. For this test the range coverage extended out to 20.2 nautical miles (4,000 Mode S two-way range units). Tracks that did not satisfy the movement criteria were dropped after 10 scans as specified by FAA-ER-240-26. The false target flag was cleared for tracks that did satisfy the movement criteria in all cases analyzed.

5. All of the radar track drops analyzed resulted in correct termination, as defined by the drop criteria setup for the baseline test. All initial tracks not updated for two consecutive scans and all normal tracks not updated for three consecutive scans were dropped.

6. The Mode S radar/beacon correlation function successfully merged MTD reports to beacon reports which were within the radar/beacon reinforcement window (50 one-way range units and 20 azimuth units) overlaying the position of the beacon reports. In the cases analyzed where beacon reports were not radar reinforced, the MTD reports were outside of the radar/beacon correlation window of the beacon reports or no MTD reports were available.

7. All of the radar beacon substitutions analyzed were performed as specified by FAA-ER-240-26. Many of the substitutions preformed occurred after beacon equipped aircraft landed — which the present substitution algorithm does not take into consideration.

TECHNICAL PERFORMANCE.

1. The total delay encountered starting from takeoff to the display of an ARTS track symbol on the four aircraft departures from the Atlantic City Airport (local departures) varied between 3 to 15 scans. The greatest cause in delay, other than

initial detection by the MTD, was attributed to the Mode S target velocity test in determining whether the aircraft was a true moving target. Delay caused by the target velocity test varied from no additional delay to four additional scans. In three of the four cases, the false target flag was cleared as soon as a track was initiated because the azimuth criteria were satisfied. In the fourth case the test aircraft departed on an almost true radial with very little azimuth deviation. As a result of the heading of the aircraft, the false target flag was not cleared until seven scans after initial detection.

2. Some problems occurred in maintaining track continuity within the immediate surveillance coverage of the Atlantic City Airport. No target detection by the MTD for more than three consecutive scans caused one track on the test aircraft to drop. A combination of events caused two other tracks to drop. For these tracks, no MTD target detection and no MTD report available (correct report used to update another track), respectively, caused the tracks to be updated by clutter reports located in the track zone 2 association window. These updates diverted the predicted track headings which ultimately resulted in track drops.

3. The total delay encountered starting from takeoff to the display of an ARTS track symbol on the four aircraft departures from satellite airports varied between 8 to 12 scans. Three to five scans elapsed before the aircraft achieved an altitude capable of MTD detection; the Mode S target velocity test added between a three- to five-scan delay. The increase in delay caused by the target velocity test noted in the departures from satellite airports as compared to the departures from a local airport was attributed to the azimuth criteria increasing as the range increases.

4. System sensitivity in the clear and over ground clutter for primary radar surveillance approached reliability normally associated with beacon surveillance. The Mode S BSR achieved in the clear (radial flight) was 99.1 percent. The Mode S BSR for the combined results achieved over ground clutter (S-turns and tangential flights) was 97.9 percent.

5. Radar beacon reinforcement achieved on the two flight tests were 92.3 and 88.4 percent, respectively. All failures to merge primary radar reports to beacon reports that were analyzed were due to azimuth separation between the two reports.

6. Radar beacon substitution achieved on the two flight tests were 50.0 and 77.6 percent, respectively. These results were considered lower than expected. Investigation revealed failure by the MTD to detect the aircraft was that primary reason substitution did not take place. Also, the current method of updating coasted beacon tracks performed by the Mode S sensor generates many erroneous radar substitutions after beacon tracks have coasted for three or more consecutive scans.

7. The average number of false primary radar tracks displayed by the ARTS III system on the DEDS console was 3.0 per scan for the first flight test on January 28, and 9.7 per scan for the second flight test on March 27.

8. The average number of uncorrelated primary radar messages disseminated by the Mode S sensor was 8.7 per scan for the first flight test, and 8.6 per scan for the second flight test.

9. The average number of correlated primary radar messages flagged as false targets disseminated by the Mode S sensor was 7.2 per scan for the first flight test, and 8.3 per scan for the second flight test.

10. Of the Mode S false primary radar tracks tested by the target velocity test, 87.3 percent were eliminated from being processed by the ARTS III IOP on the first flight test, and 70.7 percent on the second flight test. Most of the false tracks that passed the target velocity test satisfied the azimuth difference criteria. Of these tracks, 66.7 percent were within 5 nautical miles of the Mode S sensor. Within this range the azimuth difference criteria is less than one-half that of the range difference criteria.

11. Of the Mode S false primary tracks, 11.3 percent were outside the coverage of the target velocity test for the first flight test, while 12.3 percent were outside for the second flight test.

ATC PERFORMANCE.

1. The ATC performance standard, which specifies that the surveillance processor (Mode S) shall output fewer than one false primary radar report per scan to the display processor (ARTS III), was exceeded in both flight tests. Tracks established on bird activity and local automobile traffic contributed a major part in the failure to meet this standard.

2. The ATC standard of displaying fewer than 10 false primary tracks on the DEDS display under extreme conditions was marginally met in the second flight test. The average display of 9.7 false primary radar tracks per scan on the DEDS display was considered somewhat high. It was felt that the conditions under which the test was conducted were not totally sufficient to be considered extreme, even though the anomalous propagation activity was unusually high.

3. The minimum standard of displaying an ARTS track symbol on a correlated target within three to five scans of detection was met three out of four times on departures from the Atlantic City Airport, and two out of four times on departures from satellite airports. Failure to meet this standard was attributed to the criteria used by the target velocity test implemented in the Mode S radar tracking software to determine whether a radar track is associated with a real aircraft target.

4. Reliable radar tracking was maintained on the DEDS display for all flight test segments, except for one takeoff and landing sequence at the Atlantic City Airport.

5. Six primary surveillance messages on the controlled test aircraft were lost between dissemination from the Mode S sensor to the ARTS III IOP.

6. The ATC standard of identifying a primary radar target upon departure within 1 nautical mile of the departure end of runway was met in all cases. With the aid of displaying simulated broadband video generated by the VR, a controller was able to observe the target prior to the establishment of an ARTS track symbol on the target.

7. The ATC standard of terminating service when the target is on its final approach was met three out of four times on landing at the Atlantic City Airport, and all four times on landings at the satellite airports. In the one case when the

test aircraft landed at the Atlantic City Airport, the track continued to be updated by false MTD reports generated from automobile traffic.

ARTS/MODE S/RDAS SYSTEMS CONFIGURATION.

COMPLIANCE WITH ENGINEERING REQUIREMENTS (FAA-ER-240-26).

1. Track initiation was correctly achieved when two available radar reports met report-to-report correlation criteria. There were occassions when radar reports were removed by the Mode S quality filter causing delays in radar track initiations.

2. Reports that correlated with existing radar tracks for two scans were correctly disseminated as correlated track data (K=2). Radar tracks correctly transitioned from initial tracks to normal tracks when three reports were received within four scans, the "M out of N" criteria.

3. Mature radar tracks were disseminated as correlated track data (K=2). Those reports that were not mature were correctly disseminated as uncorrelated data. Uncorrelated radar reports were not disseminated when within 1 nautical mile of the Mode S sensor. This problem is being investigated.

4. The track velocity test correctly dropped radar tracks in 10 scans after track initiation if the initial target position did not change more than 0.5 nautical mile or 1.1°. The FTF was correctly set when radar reports were used to initiate a track within 20.2 nautical miles. This flag was correctly reset when either the range difference, 0.5 nautical mile, or azimuth difference, 2.8°, was exceeded in 10 scans.

5. Radar tracks were correctly terminated if updating did not occur in three consecutive scans.

6. RBC successfully merged radar reports to beacon reports when within the RBC window criteria.

7. Radar substitution correctly terminated beacon tracks after receiving five radar substitutions and converted the beacon track to a radar-only track.

TECHNICAL PERFORMANCE.

1. Delays encountered in displaying an ARTS radar track symbol for each test aircraft departure from Atlantic City Airport were as follows: 28 scans from runway 13 and 27 scans from runway 31. The 28-scan delay encountered during the first runway 13 departure was reduced to a 13-scan departure delay when the test aircraft did not maneuver a tangential turn after takeoff.

2. Delays encountered in displaying an ARTS radar track symbol on the test aircraft departing from satellite airports were as follows: 23 scans from Bader Field and 9 scans from Smithville Airport.

3. RDAS/Mode S/ARTS system sensitivity in clear-air was not acceptable, radar track continuity was not maintained. One track drop occurred during the 91-scan outbound radial. The RDAS provided a report BSR of 87.9 percent. Mode S track

BSR for the first established track was 92.9 percent, and 94.9 percent for the second track established. The ARTS provided track BSR's of 92.9 and 94.0 percent, respectively. Sensitivity for the 91-scan inbound radial were: RDAS report BSR was 71.4 percent, Mode S track BSR's were 94.4 and 66.7 percent, and ARTS track BSR's were 88.2 and 66.7 percent, respectively.

4. RDAS/Mode S/ARTS system sensitivity for "S" turns over ground clutter on the test aircraft for a 92-scan interval were: RDAS report BSR was 82.6 percent, Mode S track BSR was 82.6 percent, and ARTS track BSR was 80.4 percent.

5. Sensitivity for the northbound tangential flightpath over ground clutter for a 78-scan interval were: RDAS report BSR was 88.5 percent, Mode S track BSR's were 77.8, 71.4, and 80.0 percent, and ARTS track BSR's were 88.2, 66.7, and 82.9 percent. ARTS BSR's, in some instances, are lower than the Mode S BSR's because each system processes track coasts differently. Sensitivity for the southbound tangential flightpath over ground clutter for a 64-scan interval were: RDAS report BSR was 92.2 percent, Mode S track BSR's were 81.1 and 100.0 percent, and ARTS track BSR's were 77.4 and 100.0 percent. There was a track swap on the test aircraft during the northbound tangential flight test over ground clutter. Radar track 309 on the test aircraft was lost when its radar reports were used to radar substitute ATCRBS track 342 landing at Bader Field. Radar track 309 was dropped and, after five consecutive substitutions, became radar track 342.

6. Beacon radar reinforcement over a 300-scan filtered environment was 84.6 percent and considered acceptable. Radar reinforcement of the Mode S dual track were: 62.5 percent for ACY runway 14 pattern, 60.9 percent for ACY runway 13 pattern, 66.6 percent for ACY runway 13/22 pattern, 87.9 percent for outbound clear-air radial, 68.1 percent for clear-air inbound radial, 76.9 percent for "S" turns over ground clutter, 77.9 percent for northbound tangential over ground clutter, and 71.9 percent for southbound tangential over ground clutter. Radar reinforcement of the test aircraft was unacceptable in all instances except the 87.9 percent achieved during the outbound clear-air radial.

7. Comparisons between the radar reinforcement rates of the Mode S dual track and the RDAS report BSR's indicated a significant degradation, 10 to 20 percent, occurred when the test aircraft flew tangential to the radar antenna. During these intervals many RDAS reports were not used to radar reinforce the Mode S report because the RDAS report azimuth was outside the Mode S 20-Au azimuth criteria.

8. There were approximately 4.64 Mode S false radar tracks initiated per scan. The Mode S velocity filter reduced this to 3.50 per scan, a reduction of 25.6 percent. The ARTS system initiated approximately 5.94 per scan, an increase of 58.9 percent. This increase was the result of two different target coasting criteria used by the Mode S and the ARTS systems. The average number of false ARTS tracks displayed by the DEDS was 29.0 per scan; the maximum displayed on any one scan was 49.

9. Radar track continuity was not achieved within the surveillance coverage of the Mode S sensor. The number of Mode S track terminations on the test aircraft for each test segment are: three within 128 scans for ACY runway 13 departure, two within 87 scans for ACY 31 runway departure, no track drops with 64 scans for ACY 13/22 departure, one within 25 scans for Bader Field departure, no track drops within 9 scans for Smithville Airport departure, one within 91 scans for the "S"

turns over ground clutter, two within 78-scans for northbound tangential flight over ground clutter, and one within 64 scans for the southbound tangential flight over ground clutter.

ATC PERFORMANCE.

1. The ATC performance standard, which defined that the surveillance processor (Mode S) shall output fewer than one false radar report in clear-air to the display processor (ARTS III), was exceeded. The Mode S initiated 4.64 false tracks per scan.

2. The ATC standard of displaying fewer than 10 false radar tracks on the DEDS display under extreme conditions was not met. The DEDS displayed approximately 29.0 false tracks per scan. There were occasions when 49 false radar tracks were displayed. The average persistence of each track was approximately 4.9 scans.

3. The minimum standard of displaying an ARTS track symbol on a correlated radar target within three to five scans of target detection was not met for departures from Atlantic City Airport, Bader Field, and Smithville Airport. One exception to this was the second departure from ACY runway 13 where the test aircraft remained on an outbound radial until a firm radar track was established. ARTS displayed this track on the DEDS display three scans after the initial RDAS target report.

4. Reliable radar tracking was not maintained on the DEDS display. There were many radar track drops on both the test aircraft and targets of opportunity. The results indicated that inadequate RDAS target detection was the main cause of track drops. A second cause was the severe limitations to Mode S next scan position and velocity track position estimates that occurred from not having the full use of the alpha/beta filter.

CONCLUSIONS

1. It was concluded that the primary radar tracking functions implemented in the Mode S engineering sensor as delivered by Texas Instruments (TI), Incorporated and tested to date, complied with the requirements specified in the Federal Aviation Administration engineering requirement (FAA-ER-240-26 appendix VIII) except for a few cases which are discussed in the "Summary of Results."

2. The specified engineering requirement was sufficient for providing reliable radar tracking when interfaced with the MTD. However, some problems were noted, primarily, in the method of using moving target detector (MTD) reports to update coasted beacon tracks and the method of checking initial primary tracks for reasonable velocity before declaring the tracks real. The engineering requirement specified above was not sufficient for providing reliable radar tracking when integrated with a Radar Data Acquisition System (RDAS). The major reasons being: the generation of an unacceptable number of correlated radar tracks, the frequency of track swaps, and the inability to maintain radar track continuity.

3. The simulated analog presentation by the video reconstitutor (VR), based on digital information received from the Mode S/MTD test configuration, provided a means of displaying a target for Data Entry and Display Subsystem (DEDS) display

monitoring prior to the display of the Automated Radar Terminal System (ARTS) track symbol. This was particularly useful in the cases where the primary radar tracks were being tested by the Mode S *target velocity test*. Identifying targets within excessive clutter areas were hampered by the additional display of simulated broadband symbols generated on the false MTD reports. However, the simulated analog presentation by the VR based on digital information received from the Mode S/RDAS test configuration was unacceptable. The large number of broadband analog symbols generated from false primary radar reports (correlated and uncorrelated) made it impossible to distinguish real targets from false targets.

4. The performance of the baseline test configuration of the ARTS/Mode S/MTD system configuration marginally met the air traffic control (ATC) standards specified in this report. At times the ATC standard of displaying an ARTS track symbol on a target within three to five scans of detection was exceeded but by no more than two scans. Positive target identification could be made in most cases by observing the ARTS track symbol, and in all cases with the aid of simulated broadband symbols by the VR. Track continuity was maintained except in close proximity to the radar site. The number of false primary targets was too high to meet ATC standards.

5. The performance of the baseline test configuration of the ARTS Mode S RDAS systems did not meet minimum ATC standards specified in this report.

RECOMMENDATIONS

ARTS/MODE S/MTD SYSTEM CONFIGURATION.

1. The MTD radar digitizer, as it presently functions, requires further optimization to eliminate detection of birds and local automobile traffic.

2. The target velocity test implemented in the Mode S primary radar tracking software should be modified as follows:

a. The range coverage should be extended to cover the maximum range processed by the Mode S primary radar tracking software.

b. The range difference criteria presently set at 50 one-way range units (0.51 nautical mile) should be reduced to possibly 25 one-way range units (0.25 nautical mile) to minimize the delay in determining whether a target is real or false.

c. The azimuth difference criteria should be made a function of range. The present azimuth difference criteria is a fixed value set at the engineering requirement (ER) nominal value of 128 azimuth units (2.82°). These criteria are approximately 300 feet at a range of 1 nautical mile (one-tenth that of the range difference criteria), and approximately 6,000 feet at a range of 20 nautical miles (twice that of the range difference criteria).

3. Attempts to perform radar substitution should be inhibited on beacon tracks coasted for more than three consecutive scans.

4. An investigation should be conducted to develop techniques to reduce the possibility of primary radar tracks associated with targets landing at an airport from being updated by clutter reports. Two possible solutions to the problem are:

a. All primary radar tracks within some proximity of the airport be dropped after two consecutive coasts.

b. All primary radar tracks within some proximity of the airport be required to be updated by MTD reports having high confidence and target report quality greater than zero.

ARTS/MODE S/RDAS SYSTEM CONFIGURATION.

The RDAS radar digitizer, as it presently functions, should not be interfaced with a Mode S sensor.

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APPENDIX

DESCRIPTION OF TEST FLIGHT ACTIVITIES

The major purpose of this test activity was to determine the primary radar baseline performance of the Mode S sensor when integrated with either an MTD or RDAS. The best way to establish the baseline performance was to collect data while conducting live flights. Specific flight activities were defined to accomplish the test objectives set forth in this report. A detailed description of flight test activities is given in the following paragraphs. Figure A-1 presents the three airports in which touch and go's were executed along with the radial, S-turn, and tangential flight patterns.

ATLANTIC CITY AIRPORT TOUCH-AND-GO'S.

The aircraft conducted two touch-and-go's at each runway open at the time when flight tests were conducted. The copilot called out marks for takeoff on departures and touchdown on approaches, and called when 1 nautical mile from end of runway of departure. These three time marks were used to aid subsequent analysis.

SATELLITE AIRPORT TOUCH-AND-GO'S.

The touch-and-go's conducted at the satellite airports (Bader Field and Smithville) were similar to the touch-and-go's conducted at the Atlantic City Airport. Again, two runs were conducted at each airport with the copilot calling out the takeoff, touchdown, and 1 nautical mile departure points.

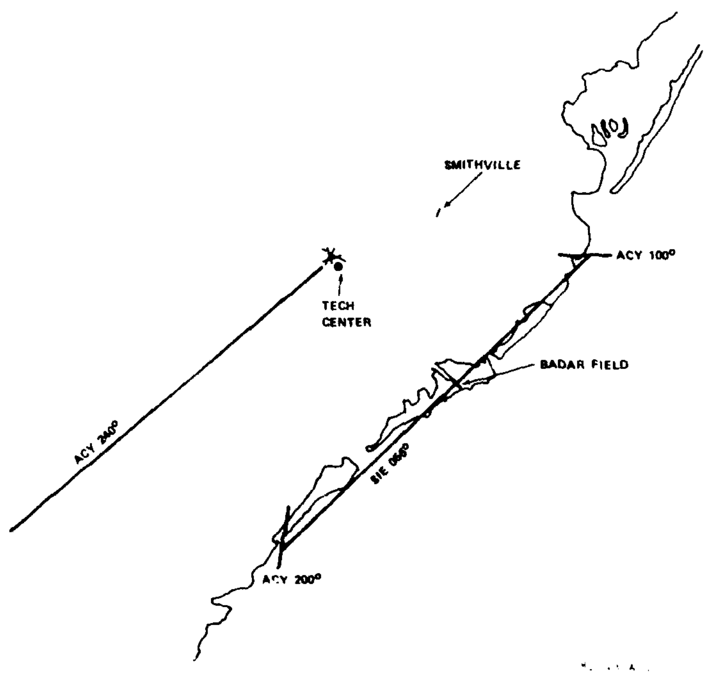

FIGURE A-1. LOCAL AND SATELLITE AIRPORTS

AD-A125 930 MODE S BASELINE RADAR TRACKING(U) FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER ATLANTIC CITY NJ E F MANCUS ET AL. NOV 82 DOT/FAA/CT-82/43

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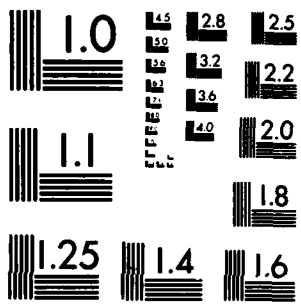

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LOW ALTITUDE RADIAL.

For the low altitude radial the aircraft, a Cessna 172, initiated the flight over the Atlantic City (ACY) Airport on a 240° heading and an altitude of 1,000 feet. The aircraft proceeded outbound at an indicated airspeed of 110 knots for 24 nautical miles (340° radial of Sea Isle (SIE)) and reversed course to ACY.

S-TURN FLIGHT PATTERNS.

For the S-turn flight patterns, the aircraft proceeded to the ACY 200°/SIE 055° and climbed to an altitude of 3,000 feet. At this location the aircraft proceeded outbound at an indicated airspeed of 110 knots on the SIE 055° to the ACY 100° (20 nautical miles) making S-turns, and reversed course to the ACY 200°, again repeating S-turns. This flightpath was directly over the Atlantic City/Absecon Island providing ground clutter.

TANGETIAL FLIGHT PATTERNS.

For the tangential flight patterns, the aircraft initiates the flight at the ACY 200°/SIE 055° at an altitude of 3,000 feet. At this location the aircraft proceeded outbound at an indicated airspeed of 120 knots on the SIE 055° radial to the ACY 100° and reversed course to the ACY 200°. Again, this flightpath was directly over the Atlantic City/Absecon Island to provide ground clutter.

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