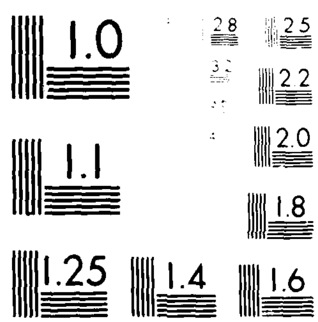
AD-A111 733 FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER ATL--ETC F/G 17/7
COMPARISON BETWEEN THE SURVEILLANCE PERFORMANCES OF THE AIR TRA--ETC(U)
JAN 82 W SWANSEEN
UNCLASSIFIED FAA/CT-81-29 FAA/RD-81-32 NL

1 OF 1
AD A
111733

END
DATE
FILMED
04-82
DTIC



MICROCOPY RESOLUTION TEST CHART

(12)

Report No. DOT/FAA/RD-81/32
DOT/FAA/CT-81/29

AD A111733

COMPARISON BETWEEN THE SURVEILLANCE PERFORMANCES OF THE AIR TRAFFIC CONTROL RADAR BEACON SYSTEM MODE OF THE MODE S AND THE AUTOMATED RADAR TERMINAL SYSTEM

William Swanseen

FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER
Atlantic City Airport, New Jersey 08405

INTERIM REPORT

JANUARY 1982

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D. C. 20590

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/RD-81/32		

4. Title and Subtitle	5. Report Date
COMPARISON BETWEEN THE SURVEILLANCE PERFORMANCES OF THE AIR TRAFFIC CONTROL RADAR BEACON SYSTEM MODE OF THE MODE S AND THE AUTOMATED RADAR TERMINAL SYSTEM	January 1982
	6. Performing Organization Code: ACT-100
	8. Performing Organization Report No.: DOT/FAA/CT-81/29
7. Author(s): William Swanseen	
9. Performing Organization Name and Address: Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.: 034-241-510
	13. Type of Report and Period Covered: Interim Report June - September 1980
12. Sponsoring Agency Name and Address: U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590	
	14. Sponsoring Agency Code: ARD-230

15. Supplementary Notes

16. Abstract

A test and evaluation was conducted at the Federal Aviation Administration Technical Center to compare the surveillance performance and the range and azimuth accuracy of the Air Traffic Control Radar Beacon System (ATCRBS) mode of the Mode S (formerly the Discrete Address Beacon System (DABS)) to that achieved with the existing Automated Radar Terminal System (ARTS) III. Targets of opportunity and ATCRBS-equipped Technical Center test aircraft were used in this evaluation. The 5-foot ATCRBS antenna at the Technical Center Mode S terminal sensor was used to collect data at both the Mode S and the ARTS III sensors. Data reduction and analysis tools developed by the Technical Center were used to determine sensor performance characteristics and to highlight areas for further analysis.

It was concluded that the ATCRBS mode of the Mode S sensor provided improved blip scan ratio, Mode A code, and altitude reliability performance when compared to the ARTS III. The Mode S sensor also provided better range and azimuth accuracy than the ARTS III.

17. Key Words	18. Distribution Statement
Mode S Range and Azimuth Accuracy Air Traffic Control Radar Beacon System Discrete Address Beacon System Automated Radar Terminal System	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	21	

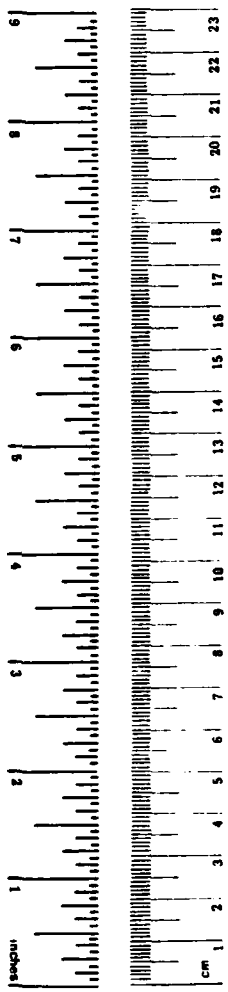
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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

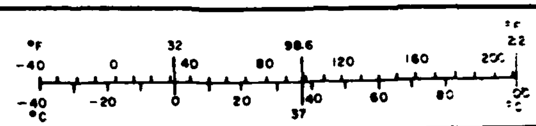


TABLE OF CONTENTS

A

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

PURPOSE.

The purpose of this test and evaluation (T&E) activity was to compare the surveillance performance of the Air Traffic Control Radar Beacon System (ATCRBS) mode of the Mode S (formerly the Discrete Address Beacon System (DABS)) to that achieved with the Automated Radar Terminal System (ARTS) III. Two different dissemination options of the Mode S sensor were compared to the ARTS III. The first was dissemination after target-to-track correlation had been performed. The second was dissemination of uncorrelated and correlated beacon reports.

The surveillance performance characteristics compared between the two systems were accomplished using targets of opportunity. Comparison of range and azimuth accuracy were achieved using Technical Center test aircraft.

BACKGROUND.

Limited data were collected during the Mode S baseline T&E effort comparing performance of the Mode S and the ARTS III. These data were presented in "Discrete Address Beacon System (DABS) Baseline Test and Evaluation," Report No. FAA-RD-80-36, dated April 1980. During the baseline T&E, the ATCRBS and Mode S facilities used for data comparison were separated by approximately 1 mile. The terminal facility for automation and surveillance testing (TFAST) provided inputs for the ARTS III. The TFAST employed an experimental 4-foot open array antenna which was located on a 70-foot tower. The Mode S sensor data were collected using a 5-foot ATCRBS antenna positioned on a 20-foot tower.

The data collected for this report were obtained using the Technical Center Mode S sensor, with a 5-foot ATCRBS antenna. The output of the radiofrequency (RF) portion of the sensor was alternatively switched between the Mode S and ARTS III.

SYSTEM DESCRIPTION.

MODE S THEORY OF OPERATION. Mode S is a cooperative surveillance and communications system for air traffic control. Each aircraft is assigned a discrete address or unique code which permits data link communications to or from a particular aircraft. The data link operates integrally with Mode S surveillance interrogations and replies.

The Mode S sensor has two modes of operation: the ATCRBS mode and the Mode S mode. The Mode S uses the available processing time (channel) first for ATCRBS functions and then for Mode S functions. Mode S employs monopulse direction finding, a technique using a rotating fan beam antenna with a sum pattern and a difference pattern. The ratio of the phase and amplitudes of the signals received on the difference and sum patterns is used to determine the off-boresight angle of the target; i.e., the angular difference between the target position and the antenna pointing angle.

Reliable and improved ATCRBS surveillance data derived from Mode S are obtained with a nominal 5 hits per target contrasted to today's ATCRBS which requires 16 to 30 hits per target. A Mode S period is defined as the time interval between the end of an ATCRBS listening period and the next ATCRBS interrogation. The Mode S period is used to perform Mode S surveillance and data link communications.

Mode S mode surveillance interrogations are scheduled in range order. In each antenna beam dwell, the Mode S sensor first interrogates the Mode S transponder-equipped aircraft farthest from it. It computes the expected arrival time of the reply and plans the interrogation of the next farthest aircraft so that the replies will arrive at the sensor in sequence, but not overlapped. It continues interrogating succeeding aircraft at decreasing ranges and schedules a corresponding listening period to receive replies from each aircraft interrogated. It repeats this procedure, interrogating all targets in line-of-sight during one roll-call schedule. Only aircraft on the sensor's roll-call list can be discretely interrogated. To acquire targets not yet on the sensor's roll-call list, Mode S transmits, when in the ATCRBS mode, an ATCRBS/Mode S all-call interrogation, which is similar to today's corresponding ATCRBS interrogation with an additional pulse (P4). An ATCRBS transponder is unaffected by the presence of the P4 pulse and responds with a normal ATCRBS reply. Mode S transponders recognize the interrogation as a Mode S all-call interrogation and respond with a Mode S all-call reply containing its discrete address. After determining the position and velocity of a Mode S transponder-equipped aircraft, the sensor places the target on its roll-call list. On a subsequent discrete interrogation, the Mode S transponder can be locked out from replying to all-call interrogations, thereby eliminating unwanted replies. In the ATCRBS mode, Mode S transmits a P2 suppression pulse on the omnidirectional antenna each time there is an ATCRBS/all-call interrogation to suppress ATCRBS transponders outside of the antenna main beam. In the Mode S mode, each discrete interrogation consists of a preamble of P1-P2 suppression pulse pairs to suppress ATCRBS transponders that are in the antenna main beam when the particular Mode S target is being interrogated. This intentional suppression (nominally 35 microseconds) is to prevent unwanted ATCRBS replies from being triggered by a discrete interrogation. Each Mode S reply consists of a 4-pulse preamble which is designed to make the Mode S reply easily distinguishable from an ATCRBS reply. Mode S replies can be 56 or 112 microseconds long, whereas an ATCRBS reply is nominally 20.3 microseconds.

To perform many of its functions, the Mode S incorporates a distributed computer architecture. This architecture features the multiple use of common modules such as computers, memory couplers, data buses, and modems. The application of redundancy at the module level supports the high reliability requirements of the Mode S. Common backup (as standby units) is provided on-line for each module type such that failure recovery, in general, can be accomplished at the local level without major perturbation to the remainder of the system. All communications between computers is through global memory such that each computer with its tasks becomes an independent subsystem. If a computer fails, its tasks can be switched automatically to another computer with minimum interference with the rest of the system.

The major changes in system operation between baseline testing and the Mode S (ATCRBS mode) ARTS III testing are related to the number of ATCRBS replies per report. During baseline testing, a relatively narrow receive beam width (2.4°) was used. This resulted in an average of approximately 3.8 ATCRBS replies per report. Operation of the sensor was modified with Mode S software release 7.2 to allow for an effective beam width of 3.4°. The average number of replies per report is approximately 5.3 for the current system. The higher values of replies per report are required to support the necessary level of high confidence Mode 3/A code and altitude data.

ARTS III THEORY OF OPERATION. The ARTS III converts beacon video derived from the Air Traffic Control Beacon Interrogator (ATCBI) into digital target reports. These reports are passed on to the ARTS III tracker and provide positional data, altitude, target identity, and velocity to the air traffic controller.

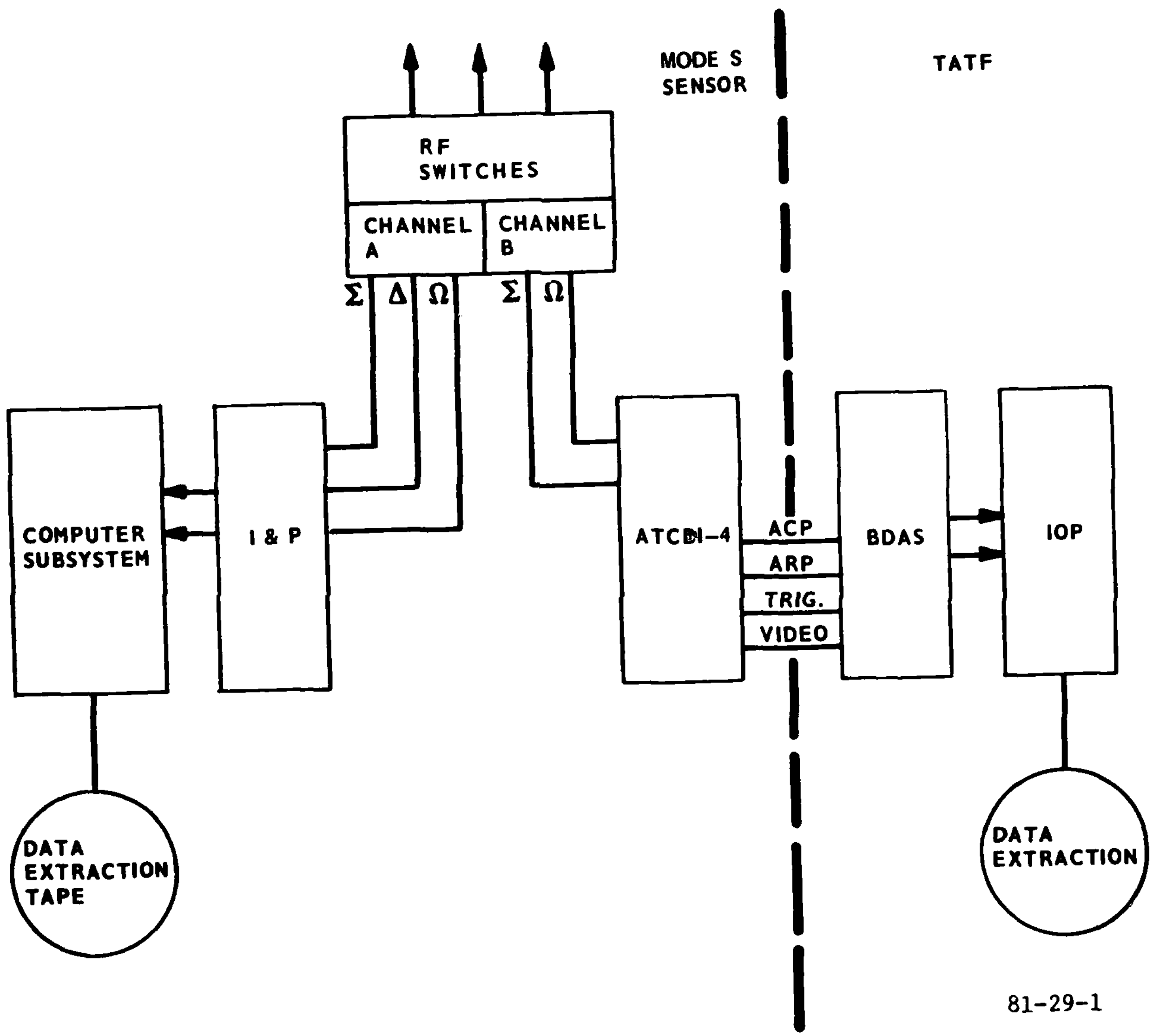
The modular design of the ARTS III system allows for a number of system configurations. The configuration under test was comprised of an ATCBI-4, Beacon Data Acquisition System (BDAS), an input output processor (IOP), a display, and a 7-track tape recorder.

The ATCBI-4 was used to provide system timing, main and side-lobe interrogations, and a receiver for aircraft replies. The ATCBI-4 quantizes the raw receiver video and provides this output to an MX-8757/UPX defruiter. The defruiter output is transmitted over land lines to the BDAS, a hardwired beacon processor that performs (on a sweep basis) azimuth decoding, mode trigger recognition, bracket detection, Mode 3/A code and altitude code pulse recognition, and garble sensing. The BDAS transfers the aforementioned data to the IOP for processing. The IOP is a general purpose computer which has a 16-bit interface with the BDAS. The IOP accepts azimuth, reply, and status words from the BDAS. The IOP performs target detection, target tracking, display functions, and keyboard input functions. The software resident in the IOP was adapted from the basic ARTS III version 15 operational software. Patches for the scan rate and pulse repetition frequency (PRF) were made to allow operation with the ATCBI-4 and the 5-foot ATCRBS antenna.

DISCUSSION

TEST CONFIGURATION.

The test configuration for the Mode S and ARTS III testing is shown in figure 1. It can be seen from the figure that in the Mode S mode, the RF channel switches were set to channel A. This allowed the Mode S sensor to operate in its normal configuration. When operating with the ARTS III, the Mode S sensor was paused, and the channel change unit was activated, switching the ATCRBS 5-foot antenna from Mode S to the ATCBI-4 ARTS III. The channel B inputs are normally terminated at the Mode S sensor since a redundant interrogator and processor (I&P) was not required for the engineering models. The ATCBI-4 video is sent to a defruiter and line driver before being sent over land lines to the ARTS III located at the terminal automation test facility (TATF). Table 1 contains information describing the operating characteristics of both systems. The Mode S sensor was designed to operate at a significantly lower ATCRBS interrogation rate than the ATCBI-4 ARTS III to allow time for discrete interrogations of Mode S-equipped aircraft. The Mode S sensor uses a monopulse technique which allows for a precise target azimuth estimate with only four or five replies per ATCRBS report. The Mode S sensor also operates with a 6-period jitter. Five ATCRBS interrogations are sent at a rate of 133.3 per second (7.5-millisecond interrogation interval), then one interrogation is sent at a rate of 106.7 PRF (9.37 milliseconds). This sequence is then cyclically repeated resulting in an average PRF of 128. The ARTS III



81-29-1

FIGURE 1. TEST CONFIGURATION

TABLE 1. OPERATING CHARACTERISTICS

	Mode S (ATCRBS Mode)	ARTS III
Average PRF	128	310
Jitter	6 periods jitter 5 periods 133.3 1 period 106.7	none
Scan Time	4.71 seconds	4.71 seconds
Power at Rotary Joint		
Main	300 watts	300 watts
SLS	300 watts	300 watts
Receive Beam Width	3.4°	No RSLS

was maintained at a constant 310 PRF. The Center's Mode S sensor was operated in the jitter mode because of the proximity of the Clementon Mode S sensor, which was also operating with the same assigned PRF. The Mode S sensor also used received side-lobe suppression (RSLS), a technique used to limit the receive beam width to 3.4°. The ATCBI-4 ARTS III does not use RSLS.

TEST APPROACH.

Comparison of data between the ATCRBS mode of Mode S and the ARTS III was divided into two distinct categories for data collection and analysis:

1. Surveillance performance

2. Range and azimuth accuracy

Surveillance performance was characterized by processing targets of opportunity within the Technical Center terminal coverage area. Data collection was run over a 6-week period during the summer of 1980. The data were collected during random time periods between 9 a.m. and 4:30 p.m. Data collection was achieved by alternately recording information either at the Mode S sensor or the ARTS III facility. Each data recording was for a duration of 15 minutes. The RF switching of the 5-foot ATCRBS antenna from one system to the other was usually accomplished within 2 minutes. This procedure insured that the data collected for both systems were from a similar population of aircraft and transponders. The data for many of these 15-minute samples were then statistically analyzed to test for any significant differences in surveillance performance between the two systems. The surveillance characteristics analyzed for the two systems included blip scan ratio (BSR), Mode 3/A code reliability, altitude reliability, and extra (false or split) targets.

In anticipation of the engineering requirement FAA-ER-240-26 and amendment 3, specification change 17, the Mode S sensor ATCRBS mode data were compared to the ARTS III for the two extreme disseminations allowed for a noncorrelating user. These two options as referenced in FAA-ER-240-26, paragraph 3.4.6.14.1, were:

1. No dissemination of uncorrelated beacon data.

2. Dissemination of all uncorrelated and correlated beacon targets.

Since these options will be available as a site-selectable parameter, it was necessary to compare the Mode S and the ARTS III for both configurations.

Range and azimuth accuracy of the ATCRBS mode of the Mode S and ARTS III was determined using Technical Center aircraft flying predetermined radial and orbital flightpaths while being tracked by the Technical Center Nike-Hercules precision tracking facility. Identical radials and orbits were flown while data were recorded on each of the systems under test. The range and azimuth position of the test aircraft as detected by both the Mode S (ATCRBS mode) and the ARTS was compared to the Nike-Hercules position to establish positional accuracy of the system under test.

DATA COLLECTION.

Data collection at the Mode S sensor was accomplished by recording the replies and reports generated from the ATCRBS targets of opportunity or test aircraft on the Mode S data extraction tape. Mode S software release 7.2 was used in the Mode S. Multisite load tape 316N12 along with site adaptation cassettes A-115 and N-120 was used to load the sensor. Data extraction requirements were determined using cassette DX6.

The ARTS software was a copy of the Denver A-015 software adapted for a 310-PRF and a 4.71-second scan rate. ATCRBS replies and reports were extracted via the data extraction tape recorder.

SURVEILLANCE PERFORMANCE TESTS. The actual data collection runs consisted of alternating ARTS III and Mode S data collection periods. Each ARTS III period was approximately 15 minutes long. The start of the Mode S sample was always less than 3 minutes after the stop of the ARTS III run. The time from "ARTS III STOP" to "MODE S START" was less than 1 minute for most of the data collection runs.

ACCURACY COMPARISON TESTS. The accuracy test flights were run serially. First, the Technical Center test aircraft flew a 270° radial at 9,000 feet from the sensor zenith cone out to a range of 50 nautical miles (nmi) and then returned along the 270° radial. During the first radial flight, the ARTS III was tracking the test aircraft. Next, an identical radial was flown while the Mode S sensor tracked the aircraft.

In a similar manner, two orbits were flown at a range of 13 nmi and an altitude of 9,000 feet. The orbit transversed was from 190° to 340° and back. During both the radial and orbital flights, the Technical Center Nike-Hercules precision tracking facility was used to track and collect positional information on the aircraft. The altitude and azimuths selected for the test flights were determined to maximize Nike-Hercules track accuracy based on the geographical location of the Nike-

Hercules and the Mode S sensor antenna. At the completion of each test, data extraction tapes from the Mode S, ARTS III, and Nike-Hercules facilities were retained for subsequent processing on the Honeywell 66/60 computer.

DATA REDUCTION.

The data reduction and analysis (DR&A) programs developed by FAA Technical Center personnel were used to process data contained on the Mode S, ARTS III, and Nike-Hercules data extraction tapes. Two analysis programs were used to analyze the sensor's data — the live environment analysis program and the range and azimuth accuracy program. Other computer programs were used for listing specific types of data when deemed necessary. The live environment analysis program outputs surveillance performance statistics. The inputs to the program are target reports for each scan of the antenna. The program processes each aircraft report per scan and builds a track on each target that has a report for at least two consecutive scans. Totals on the number of reports detected are accumulated. The range and elevation angle limits imposed on data analysis were selected to insure that the aircraft included were within a normal operating range for a terminal sensor and within the main vertical beam of the ATCRBS 5-foot antenna. The azimuth coverage from 120° to 145° was deleted to eliminate multiple discrete codes caused by reflections from the Technical Center hangar. The filtering parameters used were ranges from 4 to 45 nmi, all azimuths except for those of known reflectors, and elevation angles from 0.5° to 30°. The track must also have had at least 10 reports associated with it and must have had a Mode C altitude established for the track.

The data for each run was filtered by scan number. A start and a stop scan for each run was specified such that each run was approximately 100 scans. The actual sample size for an individual test run may vary slightly with each pass of the analysis tracker. Therefore, the correlated only data may have a different sample size than the correlated plus uncorrelated data because of the start scan and stop scan criteria used in the filtering process. These variations in sample size are on the order of 1 to 2 percent.

The beacon BSR performance measurement is computed by dividing the number of beacon reports per track by the number of scans the aircraft was present, times 100. This measurement is summed for all aircraft over a given input scan interval.

$$\text{BSR} = \frac{\text{Number of reports}}{\text{Number of scans under track}} \times 100$$

The data reduction and analysis program used to calculate BSR was subject to introducing minor processing errors (estimated at 1 to 2 percent) due to reply garbling, asynchronous replies, reply reflections and the geometry of the aircraft involved. By analyzing many sample runs these errors tend to offset one another, making the contributions to the mean values from these errors relatively minor.

Some additional calculated performance measurements are defined as follows:

$$\text{Mode 3/A reliability} = \frac{\text{Number of targets detected with correct Mode 3/A code}}{\text{Total number of times target detected with correct or incorrect code}} \times 100$$

Altitude reliability is defined in a similar manner.

$$\text{Altitude reliability} = \frac{\text{Number of targets with correct Mode C and all high confidence bits set}}{\text{Total number of times target detected with either correct or incorrect Mode C code}} \times 100$$

Extra reports per scan = Number of reports each scan which did not correlate to the DR&A tracker. These usually result from split or false (fruit reflected) reports.

TEST RESULTS AND ANALYSIS

SURVEILLANCE PERFORMANCE.

Test results for 24 Mode S (ATCRBS mode) and ARTS III data sets are presented in tables 2 and 3. Table 2 summarizes comparative performance for the blip scan ratio, Mode 3/A code reliability, altitude reliability, and false targets per scan. Table 2 compares data for the ATCRBS mode of Mode S for data disseminated following target-to-track correlation to that obtained with the ARTS III. Table 3 contains exactly the same input data but compares Mode S sensor performance using uncorrelated beacon reports with the ARTS III data. These data include ATCRBS-equipped aircraft only which were within the following filter limits:

Range: 4 to 45 nmi
Azimuth: 0° to 120° and 145° to 360°
Elevation angle: 0.5° to 30.0°

These same filters were applied to both the Mode S and the ARTS III data. Both sets of data were analyzed using the same algorithms. Each test in table 2 compares the performance of the Mode S sensor ATCRBS mode and the ARTS III for a 100-scan sample. The sample size for each test is included in table 2. The sample size is the total number of aircraft reports which were within the filter limits over the 100 scans of data used for each test. At the bottom of each column of data in table 2 is the mean value of the 24 test samples.

As previously noted in the Data Reduction section, the analysis tracker used to compile the BSR, Mode 3/A code reliability, and the altitude reliability data is only accurate to approximately 1 to 2 percent. This performance was verified by examining the variation in the sample size data for the Mode S data contained in tables 2 and 3. These independent passes of the two sets of Mode S data should result in the correlating data sample size being approximately the same or slightly

TABLE 2. MODE S (ATCRBS MODE) CORRELATED BEACON REPORTS COMPARED WITH ARTS III REPORTS

Test No.	Sample Size		Beacon Blip Scan Ratio (%)		Mode 3/A Code Reliability (%)		Altitude Reliability (%)		Extra Targets Per Scan (%)	
	Mode S	ARTS	Mode S	ARTS	Mode S	ARTS	Mode S	ARTS	Mode S	ARTS
1	2,401	2,333	99.1	97.1	98.6	97.1	94.2	92.7	0.46	1.10
2	2,016	1,617	99.6	97.7	99.7	97.2	97.5	94.5	0.30	0.90
3	2,369	2,061	99.3	97.3	99.6	99.2	97.9	96.6	0.20	0.40
4	1,544	1,544	99.9	98.2	99.9	97.9	98.6	94.3	0.52	0.50
5	3,138	2,180	98.8	97.4	99.8	97.2	96.0	89.6	0.31	1.50
6	2,818	1,593	99.4	97.6	99.6	98.4	97.5	89.1	0.29	1.40
7	2,055	2,680	97.4	94.8	99.2	97.9	95.3	90.3	0.55	1.80
8	1,947	1,753	99.0	96.9	99.8	97.2	94.5	91.6	0.62	1.40
9	2,117	2,256	99.0	94.9	99.5	97.1	95.8	87.8	0.71	2.20
10	1,916	1,644	97.5	96.2	99.7	98.2	97.0	89.9	0.69	1.70
11	2,155	1,910	98.5	97.4	99.0	97.6	95.9	89.0	0.44	1.50
12	2,691	1,141	98.8	96.6	99.6	96.3	97.0	87.6	0.41	2.10
13	3,227	1,966	98.8	95.4	99.7	97.4	95.6	88.9	0.61	2.20
14	2,160	1,807	98.0	98.3	99.2	98.5	92.6	85.6	0.34	2.00
15	1,976	2,438	99.5	94.9	99.6	98.6	97.2	92.6	0.33	2.20
16	1,487	2,011	99.7	98.7	99.6	98.9	98.3	93.6	0.61	0.80
17	2,559	2,071	97.8	96.9	99.7	98.6	95.2	86.3	0.66	1.00
18	2,004	1,554	99.5	97.7	99.5	98.5	97.5	91.4	0.41	2.17
19	1,710	2,715	99.1	96.3	99.2	98.1	89.8	91.8	0.41	1.10
20	3,138	2,731	98.8	94.8	99.8	97.6	96.0	87.2	0.31	1.76
21	2,813	2,007	99.4	96.4	99.6	96.4	97.5	89.3	0.29	1.26
22	2,488	2,514	98.7	97.7	99.8	96.8	97.7	86.9	0.41	1.45
23	2,429	2,984	97.1	92.8	99.3	97.2	96.5	89.5	0.47	1.24
24	1,679	2,457	97.3	95.3	99.9	98.1	97.7	91.9	0.71	1.21
Mean Value for 24 Data Samples			98.7	96.3	99.6	97.8	96.2	90.3	0.48	1.45

TABLE 3. MODE S (ATCRBS MODE) CORRELATED AND UNCORRELATED BEACON REPORTS COMPARED WITH ARTS III REPORTS

Test No.	Sample Size		Beacon Blip Scan Ratio (%)		Mode 3/A Code Reliability (%)		Altitude Reliability (%)		Extra Targets Per Scan (%)	
	Mode S	ARTS	Mode S	ARTS	Mode S	ARTS	Mode S	ARTS	Mode S	ARTS
1	2,446	2,333	99.5	97.1	97.2	97.1	93.8	92.7	2.34	1.10
2	1,979	1,617	99.6	97.7	99.5	97.2	97.4	94.5	1.92	0.90
3	2,370	2,061	99.4	97.3	99.0	99.2	97.9	96.6	1.61	0.40
4	1,547	1,544	99.9	98.2	99.6	97.9	98.6	94.3	1.68	0.50
5	3,202	2,180	99.5	97.4	98.9	97.2	97.9	89.6	2.26	1.50
6	2,791	1,593	99.2	97.6	99.0	98.4	97.1	89.1	2.20	1.40
7	2,086	2,680	97.1	94.8	98.2	97.9	95.5	90.3	2.48	1.80
8	1,945	1,753	98.4	96.9	98.4	97.2	94.4	91.6	2.41	1.40
9	2,164	2,256	98.6	94.9	98.7	97.1	95.5	87.8	2.23	2.20
10	1,995	1,644	96.6	96.2	97.9	98.2	96.5	89.9	2.33	1.70
11	2,209	1,910	98.6	97.4	98.0	97.6	95.8	89.0	2.09	1.50
12	2,727	1,141	98.9	96.6	99.6	96.3	97.6	87.6	2.17	2.10
13	3,316	1,966	99.0	95.4	99.4	97.4	95.8	88.9	1.91	2.20
14	2,201	1,807	98.0	98.3	97.8	98.5	91.9	85.6	2.64	2.00
15	2,037	2,438	98.5	94.9	98.5	98.6	96.6	92.6	2.12	2.20
16	1,492	2,011	99.0	98.7	99.5	98.9	98.4	93.6	2.41	0.80
17	2,571	2,071	97.9	96.9	96.8	98.6	95.1	86.3	2.17	1.00
18	2,016	1,554	98.8	97.7	98.9	98.5	97.3	91.4	1.75	2.17
19	1,687	2,715	99.4	96.3	98.4	98.1	92.6	91.8	1.80	1.10
20	3,192	2,731	98.9	94.8	99.5	97.6	96.0	87.2	1.94	1.76
21	2,789	2,007	99.2	96.4	99.3	96.4	97.5	89.3	1.72	1.26
22	2,521	2,514	98.9	97.7	98.9	96.8	97.4	86.9	1.98	1.45
23	2,526	2,984	95.3	92.8	97.9	97.2	96.3	89.5	2.03	1.24
24	1,763	2,457	94.9	95.3	99.5	98.1	96.3	91.9	2.02	1.21
Mean Value for 24 Data Samples			98.5	96.3	98.8	97.8	96.2	90.3	2.08	1.45

less than the correlated plus uncorrelated data sample size. Examination of the 24 sets of Modes S data samples in tables 2 and 3 confirms the fact that the error in sample size is approximately 1 to 2 percent.

The comparison of Mode S and ARTS BSR contained in table 2, therefore, indicates the operation of the two systems is essentially the same. The Mode 3/A code reliability data also indicates approximately equal performance of the Mode S and ARTS sensors. A slight increase in the Mode S performance was anticipated since the Mode S tracker is used to update the Mode 3/A codes of correlated reports in some cases.

The Mode S altitude reliability data is 6 percent greater than the ARTS reliability. The ARTS altitude reliability is relatively low (90 percent) and is, in part, due to the interlace ratio used during this testing.

The last two columns in table 2 compare the number of extra targets per scan for the Mode S (ATCRBS mode) and the ARTS III. Since table 2 contains data after target-to-track correlation has been performed (normal dissemination to a non-correlating user), the percent of extra targets per scan for Mode S (ATCRBS mode) is lower than for the ARTS III report data. The data from table 2, therefore, demonstrate the advantages of delaying dissemination until after target-to-track correlation:

1. Greater Mode 3/A code reliability.

2. Lower rate of extra targets.

Table 3 contains the performance values determined for data disseminated to the Systems Support Facility (SSF) (a correlating user which receives both correlated and uncorrelated beacon reports). The ARTS III data from table 2 are included for comparison.

The Mode 3/A code reliability for the Mode S (ATCRBS mode) data in table 3 is slightly lower than the corresponding data in table 2. The slight improvement in Mode S/ATCRBS Mode 3/A code data disseminated after correlation is due to the fact that target-to-track correlation has occurred, and low confidence incorrect Mode 3/A codes have been corrected by the tracker before dissemination. The altitude reliability for both sets of Mode S (ATCRBS mode) data is equal. The tracker does not update the altitude field of a Mode S (ATCRBS mode) beacon report as is accomplished for the mode 3/A code for correlated reports. Therefore, performance for both sets of data was expected to be the same.

The final two columns in table 3 compare Mode S and ARTS III performance for extra targets per scan. This comparison indicates that the ARTS III data were better than the Mode S data. Extra targets per scan include all targets which did not correlate to the DRA tracker. Examples of this type of target report are split reports and fruit reports. A careful examination of the extra report data revealed that the increase in the Mode S sensor extra reports was due to excessive target splitting. The target splits were caused by the generation of extra reports during reply-to-reply correlation. These reports resulted from the rule of not merging replies which differ in any high confidence code bits. An example of this problem is when a target report of code 1200 is being built from its Mode 3/A replies and initiates a target report with code 1200 and all high confidence bits set. If on the edge of the beam it receives a reply which correlates in range and azimuth but has a code of 0200 with all high confidence bits set, the difference in the high confidence A1 bit (first bit of the ATCRBS code) will force a new target report to be generated. Replies which drop a single bit (normally replies on the beam edges) are common enough to contribute approximately a 1-percent split rate in the Mode S sensor. This phenomenon is strongly correlated to the receive beam width used in the Mode S.

The ARTS III also detects replies with missing code pulses near the edge of the beam. The ARTS III, however, uses a consecutive hit, miss counter for target detection. All replies at the target range (1/16 nmi quantization interval) are used for target detection regardless of the code of the reply. Therefore, replies with incorrect codes near the antenna beam edges do not create split target reports in the ARTS III.

In Mode S, the split target rate is a function of the effective receiver beam width. This beam width was increased from the originally delivered value of 2.4° to 3.4° to increase the number of ATCRBS replies per report from 3.8 to 5.3. This increase in the number of ATCRBS replies per report increases the Mode 3/A code and altitude reliabilities. An adverse effect of increasing the beam width is the creation of split target reports. These reports are normally eliminated by the target-to-track correlation logic before dissemination. The current Mode S software implementation, however, allows dissemination to correlating users before target-to-track correlation is performed. The false targets sent to a correlating user are normally assigned a surveillance file number of 0. The current software implementation does, however, eliminate most of the false reports before dissemination to a noncorrelating user.

A partial solution for the extra targets per scan from the Mode S sensor will be the inclusion of the proper ATCRBS fruit rejection logic in the sensor. FAA-ER-240-26 did not include several of the cases for eliminating multiple beacon reports. The ER has already been updated with the necessary changes. These changes should eliminate some, but not necessarily all, of the Mode S extra targets. The modified ATCRBS fruit rejection logic must be inserted into the surveillance code prior to the time of target report dissemination to eliminate the extra targets being sent to the air traffic control users.

REPORT ACCURACY.

The mean range and azimuth errors of the Mode S (ATCRBS mode) and ARTS III sensors are presented in table 4. The table contains four rows, each of which represents a single flight segment. The four flight segments compared between the two systems were:

1. Outbound radial flight
2. Inbound radial flight
3. Clockwise orbit flight
4. Counterclockwise orbit flight

The range and azimuth errors were determined by subtracting the Nike-Hercules reported position of the aircraft from the position reported by either the Mode S sensor or the ARTS III. The mean error (range and azimuth) represented in the table has been adjusted by subtracting the following bias errors:

1. Range and azimuth bias determined by comparing the reported position of a fixed transponder with the surveyed position of the transponder.

2. Cable and transponder delays associated with the aircraft installation in the Technical Center's Aero Commander, N-50.

The same technique for eliminating bias errors was used for both the Mode S sensor and ARTS III data. The data analyzed for range and azimuth accuracy were limited to those areas of the predetermined flightpath where Nike-Hercules provided optimal track accuracy considering the geographical location of the Nike-Hercules and the Mode S antenna. The data sets for Mode S and ARTS III were adjusted to include the same number of samples for corresponding flight segments.

Table 4 indicates that the azimuth errors of the Mode S (ATCRBS mode) are far fewer, as expected, than those of the ARTS III. The Mode S mean azimuth error is more than an order of magnitude better than the ARTS III for three of the four flight segments. Of even greater significance, is the difference in the standard deviation of the azimuth errors when the two systems are compared. The Mode S standard deviation which ranges from 0.018° to 0.041° is between 5 and 20 times smaller than the corresponding ARTS III data. These results were obtained with the Mode S sensor operating at PRF and RSLS thresholds, which allowed approximately 5.3 ATCRBS replies per report. The ARTS III was operating with an average of 15 replies per report.

The reasons for the improvement in the Mode S azimuth reporting when compared to the ARTS III are as follows:

1. The ARTS III uses a 12 bit (4096 azimuth unit) antenna shaft encoder. This results in a precision of 0.088°. The ARTS III also uses a sequential hit, miss counter to determine target detection and azimuth center marking. This technique is subject to additional errors which are dependent on the azimuth distribution of the replies (hits and misses) which form the target report.

2. The Mode S uses a 14 bit (16384 azimuth unit) antenna shaft encoder. The use of the 14 bit encoder increases the precision of the measurement of the antenna pointing direction to 0.022°. In addition, the Mode S utilizes a monopulse, off-boresight angle correction technique. The technique allows for a precise measurement of the off-boresight angle of each received reply, and enhances the proper azimuth detection of the target. Certain interference conditions and quantization effects in the monopulse A/D converter limits the final accuracy determination for Mode S targets to be slightly greater than the 0.022°.

Standard "F" and "T" statistical tests were run comparing the Mode S azimuth accuracy to the accuracy of the ARTS III. The Mode S azimuth accuracy was determined to be significantly better (at the 95 percent confidence level) than the ARTS III for each of the four flight segments tested.

The range errors associated with the Mode S and ARTS III are presented in table 4. Since the least significant bit of the ARTS III range is 1/16 of an nmi (380 feet), the expected deviation in the range data due to quantization effects was 110 feet. The Nike-Hercules tracking system used as a reference for this evaluation is subject to a 3-meter (10-foot) theoretical random error. The values for the ARTS III standard deviation from table 4 ranged from 128 to 136 feet for the four test flights. These values were very close to the expected deviation values.

TABLE 4. COMPARISON OF MODE S (ATCRBS MODE) AND ARTS III ACCURACY

Azimuth Errors (Degrees)

	Mode S (ATCRBS Mode)			ARTS III		
	Sample Size	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation
Outbound Radial	78	0.003	0.041	78	0.049	0.198
Inbound Radial	137	-0.004	0.029	121	0.072	0.255
Clockwise Orbit	147	-0.004	0.025	149	0.117	0.238
Counterclockwise Orbit	41	0.028	0.018	39	-0.098	0.312

Range Errors (Feet)

	Mode S (ATCRBS Mode)			ARTS III		
	Sample Size	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation
Outbound Radial	78	69	27	78	11	128
Inbound Radial	137	87	33	121	-126	121
Clockwise Orbit	147	67	27	149	-4	134
Counterclockwise Orbit	41	70	26	39	-70	136

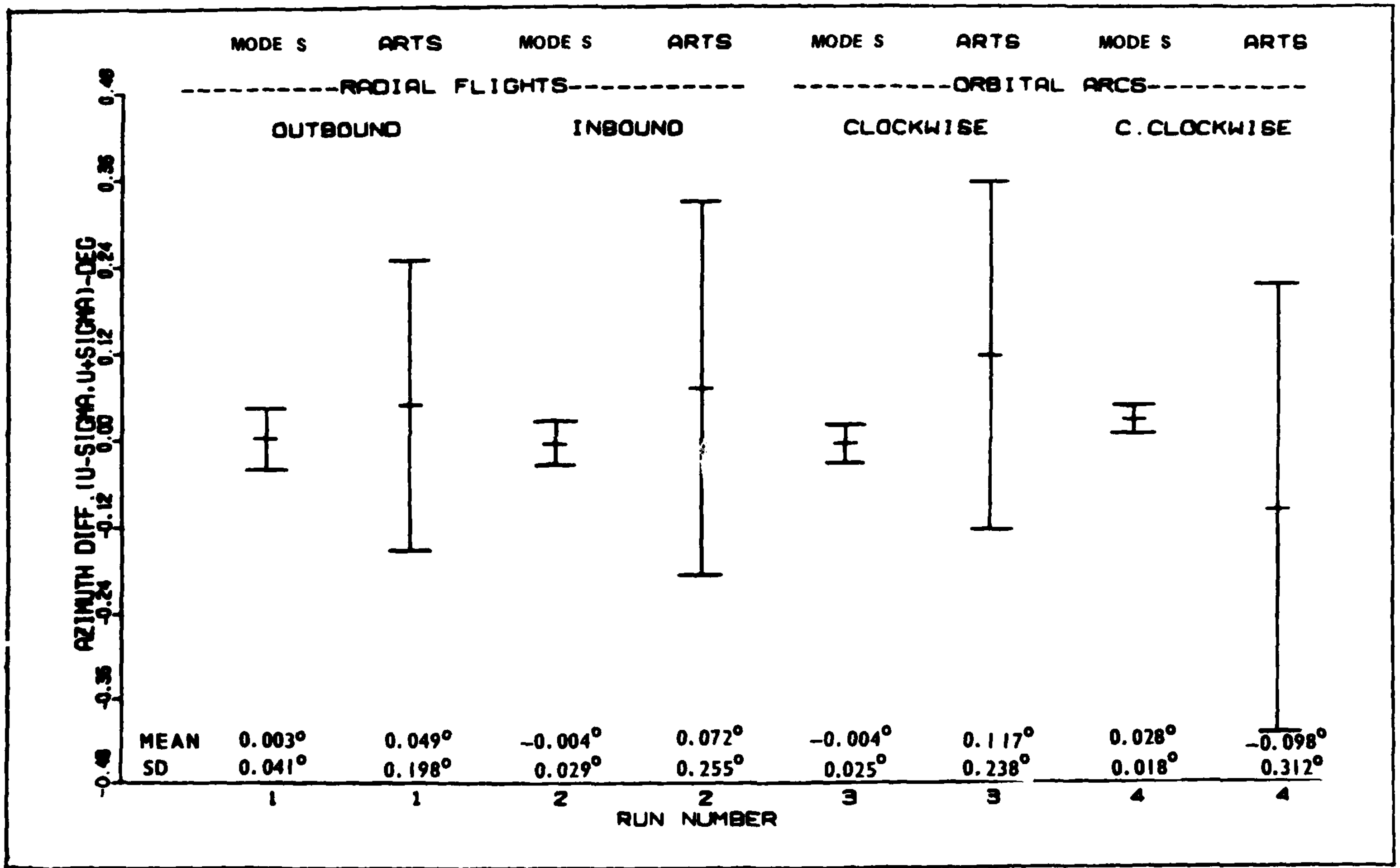
The least significant bit of the Mode S reported position is 60 feet. The expected deviation in data due to quantization is 17.3 feet. The Nike-Hercules tracking system errors were the same as mentioned above for the ARTS III data, 10 feet. It can be seen from table 4 that the standard deviation of the Mode S range errors varies from 26 to 33 feet. These values are very close to the expected variations in the data. The standard deviation of the range error for the Mode S is approximately four times less than the ARTS III data.

The data from table 4 are depicted in graphic form in figures 2 and 3. Figure 2 plots the mean and standard deviation of the azimuth errors for the four flight segments for both the Mode S and ARTS III. Figure 3 is a similar plot of range errors. In figures 2 and 3 the horizontal line for each run indicates the mean error, while the vertical line indicates the spread (standard deviation) of the data for that particular run.

The data presented in this report were not intended to completely characterize the accuracy of the Mode S system. A complete description of the Mode S accuracy is contained in a report, DOT/FAA/CT-81/67, entitled "DABS System Accuracy."

MODE S/ARTS ACCURACY COMPARISONS AIRCRAFT N-50

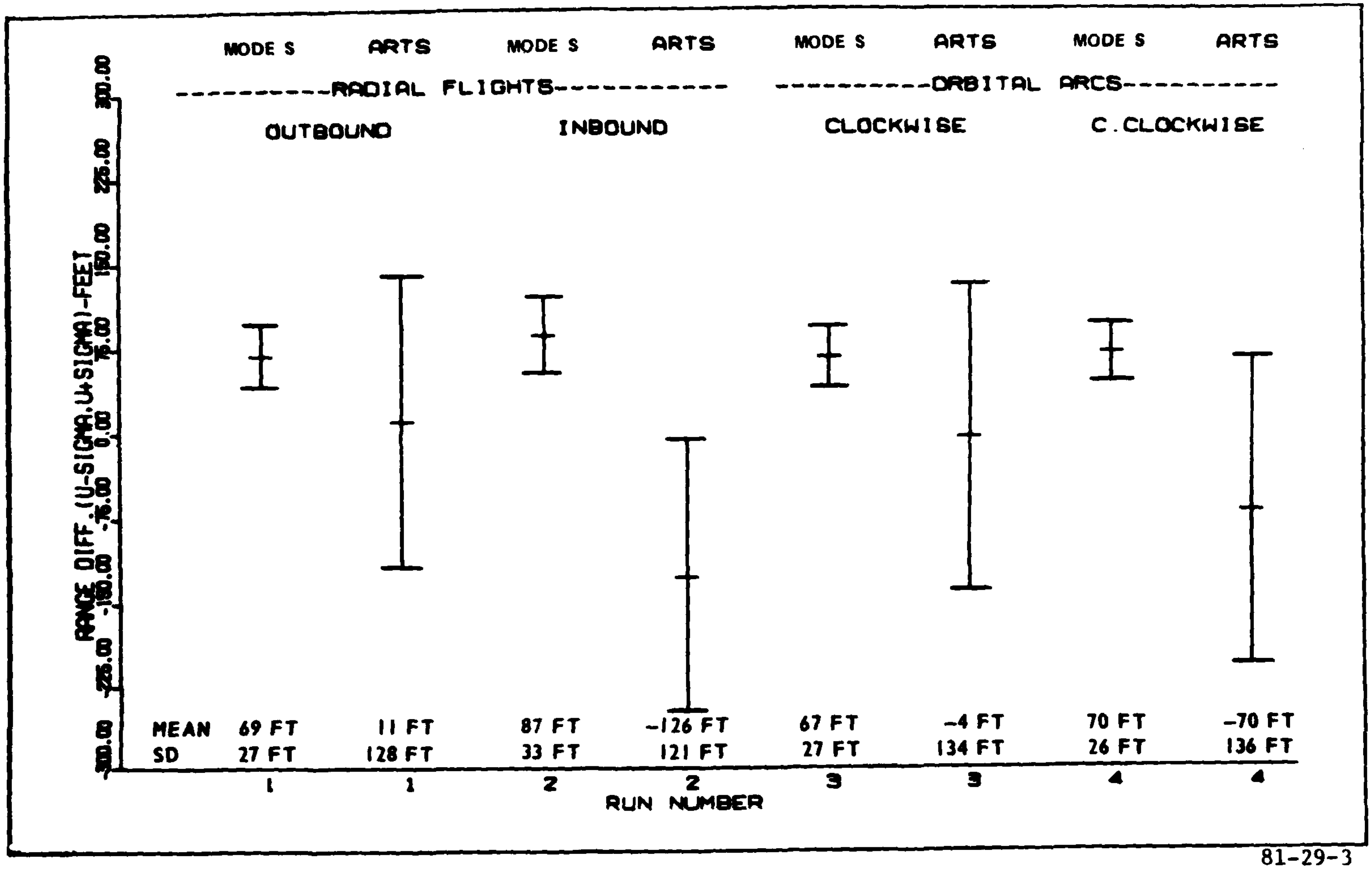
SHIP TRANSPONDER NO.63 TRU-1 CODE: 4276



81-29-2

FIGURE 2. MODE S (ATCRBS MODE) ARTS III AZIMUTH ACCURACY COMPARISON

MODE S/ARTS ACCURACY COMPARISONS AIRCRAFT N-50
SHIP TRANSPONDER NO.63 TRU-1 CODE: 4276



81-29-3

FIGURE 3. MODE S (ATCRBS MODE) ARTS III RANGE ACCURACY COMPARISON

SUMMARY OF RESULTS

The surveillance performance for the ATCRBS mode of the Mode S sensor and the ARTS III can be summarized as follows:

SURVEILLANCE PERFORMANCE.

1. The BSR and Mode 3/A code reliability using either of the Mode S dissemination options is equal to the performance achieved using the ARTS III. The ATCRBS mode of Mode S achieved this performance while receiving only 5 replies per report, the ARTS III system utilizes 15 to 18 replies per report.

2. An improvement in altitude reliability was noted for either Mode S dissemination as compared to ARTS III. A contribution to the difference in performance was the mode interface ratio used for the two systems.

3. The number of extra targets (split and false) per scan for Mode S/ATCRBS targets disseminated after target-to-track correlation had been performed was 0.7 percent per scan less than the number of extra targets per scan for the ARTS III.

4. The number of extra targets (split and false) per scan for the Mode S sensor when ATCRBS targets were disseminated before target-to-track correlation was completed was 0.4 percent per scan more than the corresponding ARTS III data.

REPORT ACCURACY.

1. The mean range bias for the Mode S sensor ATCRBS mode was +74 feet. The standard deviation of the range error for this mode was 29 feet. The mean range bias for the ARTS III was -46 feet. The standard deviation of the range error for the ARTS III was 129 feet.

2. The mean azimuth bias for the Mode S was +0.006°. The standard deviation of the azimuth errors for the Mode S was 0.029°. The mean azimuth bias of the ARTS III was 0.035°, and the standard deviation of the azimuth errors for ARTS III was 0.243°.

CONCLUSIONS

1. The Air Traffic Control Radar Beacon System (ATCRBS) mode of the Mode S (formerly the Discrete Address Beacon System (DABS)) exhibited similar performance when compared to an Automated Radar Terminal System (ARTS) III in the following surveillance areas: blip scan ratio and mode 3/A code reliability. This performance was achieved by the Mode S sensor while operating with a reduced pulse repetition frequency (128 per second) which average five replies per target report.

2. Mode S (ATCRBS mode) sensor performance for both Mode 3/A code reliability and the percent of extra targets per scan is improved when dissemination is delayed until target-to-track correlation has been performed.

3. For users receiving uncorrelated beacon reports, the Mode S (ATCRBS mode) disseminated more false or extra targets per scan than the ARTS III.

4. The Mode S (ATCRBS mode) provides greater range and azimuth accuracy than the ARTS III.

RECOMMENDATION

1. It is recommended that the modified Air Traffic Control Radar Beacon System (ATCRBS) fruit rejection logic described in FAA-ER-240-26A be inserted into the surveillance code prior to the time of target report dissemination to eliminate the extra targets being sent to the air traffic control users.

4-8