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JOINT U.S./U.S.S.R. MODE S COMPATIBILITY TEST PROGRAM

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et al.

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for the U.S./U.S.S.R. Air Traffic
Control (05.0402) Subgroup

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16. Abstract

This document describes the joint tests conducted at the Federal Aviation Administration (FAA) Technical Center to determine the compatibility of a Union of Soviet Socialist Republics (U.S.S.R.) designed transponder with the United States (U.S.) Mode S system. A U.S. transponder was included in these tests for convenient comparison of results. Both bench tests and flight tests were conducted to ascertain compatibility to the U.S. Discrete Address Beacon System (DABS) National Standard of 1978. Radial and orbital flight profiles were used to gather statistical data to draw conclusions about the transponder's performance in conjunction with the Mode S system. Both the methods of conducting these tests and the results obtained are described.

It was concluded that the U.S.S.R. Mode S transponder operated successfully and is compatible with the U.S. Mode S system. Moreover, the test results confirmed that the performance of both the U.S. and the U.S.S.R. transponders were comparable.

Test data results are contained in volume 2.

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INTRODUCTION

PURPOSE.

The purpose of the joint United States (U.S.)/Union of Soviet Socialist Republics (U.S.S.R) Compatibility Test Program was to determine the compatibility of the U.S.S.R. Mode S transponder with the United States Mode S system. This compatibility would be demonstrated by conformance of selected parameters to the U.S. Discrete Address Beacon System (DABS) National Standard of 1978 (reference 1) and performance comparable to that of a U.S. Mode S transponder.

BACKGROUND.

Under the auspices of the U.S./U.S.S.R Agreement for Cooperation in the Field of Transportation of June 19, 1973 (reference 2), U.S. and U.S.S.R. civil aviation officials have been jointly meeting to discuss common matters of air traffic control since June of 1975. As these discussions progressed, a significant portion of the dialogues centered on Mode S secondary surveillance (formerly entitled Discrete Address Beacon System (DABS)). Mode S is a secondary surveillance system designed to provide improved surveillance and communications, yet remain compatible with the current Air Traffic Control Radar Beacon System (ATCRBS). Owing to this mutual interest and the international concern for a common approach, a joint U.S./U.S.S.R Mode S Working Group was established in June 1979. The first meeting of this Working Group was held November 5 through 13, 1979 in Washington, D.C. During these initial discussions, it was agreed that the U.S.S.R. would develop a Mode S transponder in accordance with the U.S. DABS National Standard and that this transponder would be tested at the Federal Aviation Administration (FAA) Technical Center using a U.S. Mode S ground sensor, transponder, and other related facilities. The principal aim of this activity would be to demonstrate the compatibility of the Soviet transponder with the U.S. Mode S system.

Subsequent meetings of the Working Group finalized arrangements for this joint endeavor and formalized a test plan (reference 3).

This report describes the joint program and presents the results of the tests.

DESCRIPTION OF EQUIPMENT.

U.S.S.R. TRANSPONDER ASSEMBLY. The U.S.S.R. experimental transponder assembly, as shown in figure 1, incorporates the transponder itself and a control panel. The transponder consists of two distinct units mounted on a common shock-absorbing frame. One unit is a transceiver device, and the other unit is a device for processing discrete interrogations and replies. The control panel includes terminals for connecting +28 volts direct current, an antenna connector, and switches for control of transponder operating modes. The control panel switches make provision for the following modes of operation:

1. Power ON/OFF. For +28 volts direct current.

2. STANDBY mode. The transponder is energized but does not radiate.

3. Mode AC. The transponder replies include the identification number and altitude information requested by ATCRBS Mode A and Mode C interrogations, respectively.

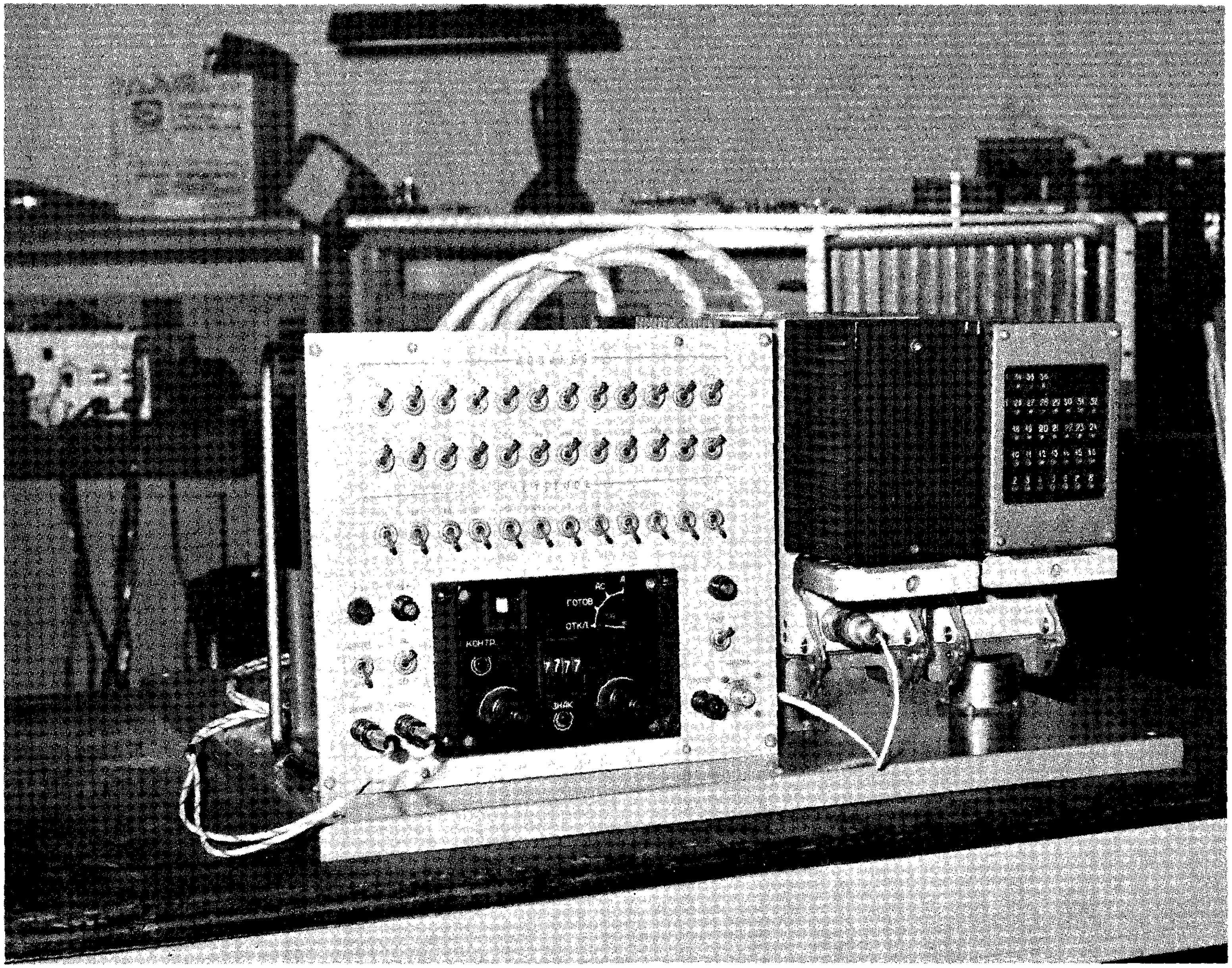

FIGURE 1. U.S.S.R. TRANSPONDER ASSEMBLY

4. Mode A. The transponder replies include the identification number requested by an ATCRBS Mode A interrogation, but do not include altitude information when requested by an ATCRBS Mode C interrogation.

5. Mode S Only. Set by switching on the LOCKOUT switch to exclude ATCRBS replies.

6. ATCRBS Only. Set by switching off the Mode S switch.

7. Mode S Address. Any Mode S discrete address can be selected via switches.

8. ATCRBS Identification. Any ATCRBS identification number can be selected.

9. Altitude. Any flight altitude can be selected for both ATCRBS and Mode S replies.

10. SPI Pulse. SPI pulse transmission in ATCRBS replies can be accomplished by pressing the SIGN button.

11. CHECK. When this button is depressed a diagnostic check is performed on the transponder

The U.S.S.R. transponder has been developed in compliance with the U.S. DABS National Standard of 1978 ensuring operation with both Mode S and ATCRBS sensors. Interrogations received by the transponder include ATCRBS/Mode S all-call, Mode S surveillance, ATCRBS only, Mode S only all-call, and data uplinks (Comm-A). The transponder will respond with appropriate surveillance and downlink (Comm-B) replies.

U.S. TRANSPONDER ASSEMBLY. The U.S. transponder was developed to the U.S. DABS National Standard of 1978 to accept and reply to interrogations from Mode S and ATCRBS ground stations. Interrogations accepted by the transponder include ATCRBS/Mode S all-call, Mode S surveillance, ATCRBS only, Mode S only all-call, and data uplinks (Comm-A). The transponder will respond with appropriate surveillance and downlink (Comm-B) replies. The transponder assembly consists of the transponder itself and an associated control panel. The U.S. transponder assembly is depicted in figure 2.

MODE S TRANSPONDER TESTER. The Mode S transponder bench tester simulates ATCRBS and Mode S interrogations and measures performance from the elicited replies. The tester provides a binary display which indicates that the transponder did, or did not meet selected DABS National Standard requirements. In addition, the tester generated under software control, a repetitive series of interrogations which were monitored on an oscilloscope along with the transponder's replies. Figure 3 is a functional block diagram of the transponder tester. The Mode S transponder tester is shown pictorially in figure 4.

MODE S SYSTEM. The Mode S system is a cooperative surveillance and communication system for air traffic control. The system used in these tests consists of the Mode S sensor and transponder. Each Mode S aircraft is assigned a unique discrete address which accepts a surveillance interrogation and provides a reply protocol that inherently supports data link ground/air communications. The Mode S ground sensor employs a monopulse direction finding technique using a 5-foot vertical

FIGURE 2. U.S. TRANSPONDER ASSEMBLY

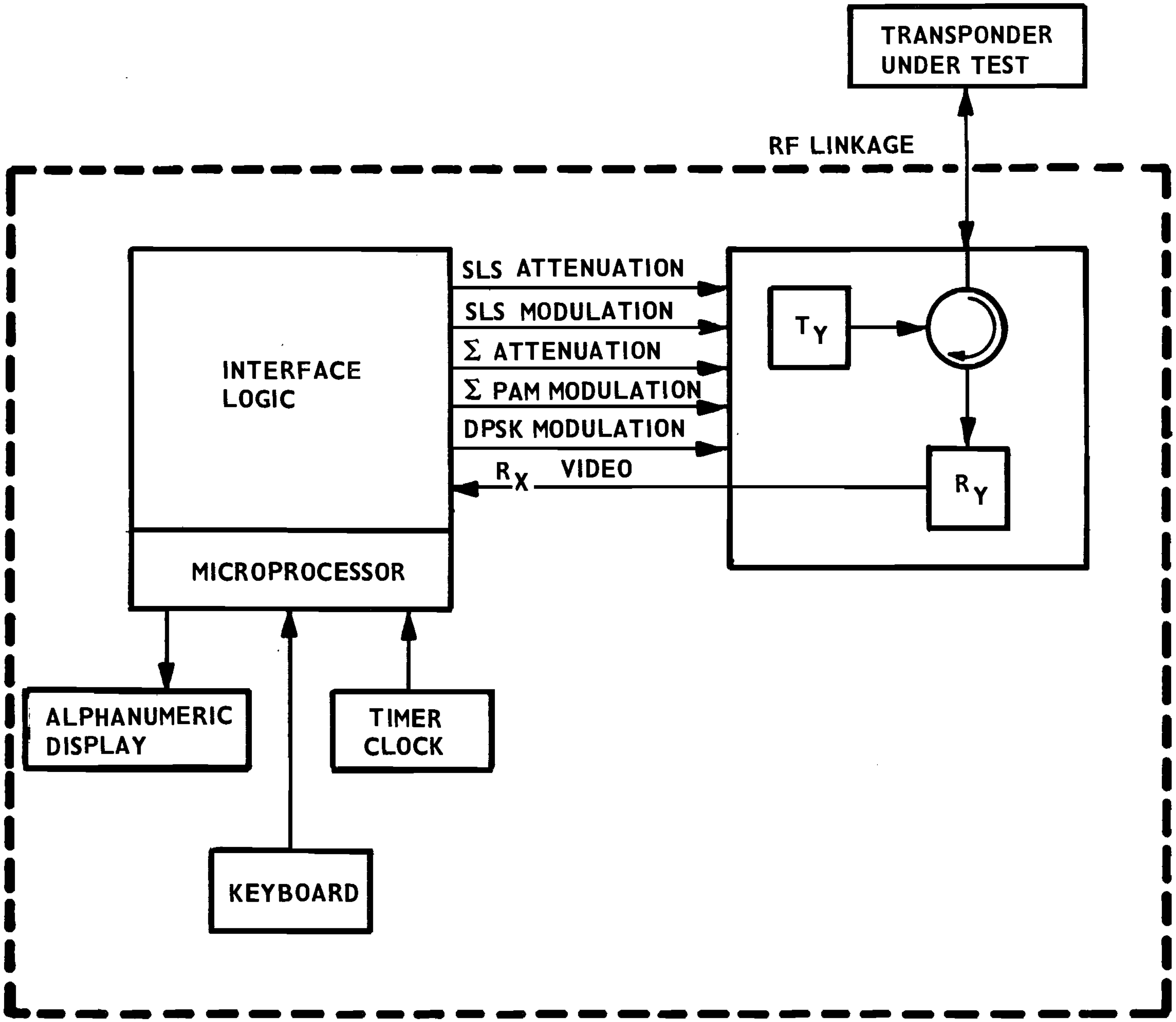

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FIGURE 3. MODE S TRANSPONDER TESTER FUNCTIONAL BLOCK DIAGRAM

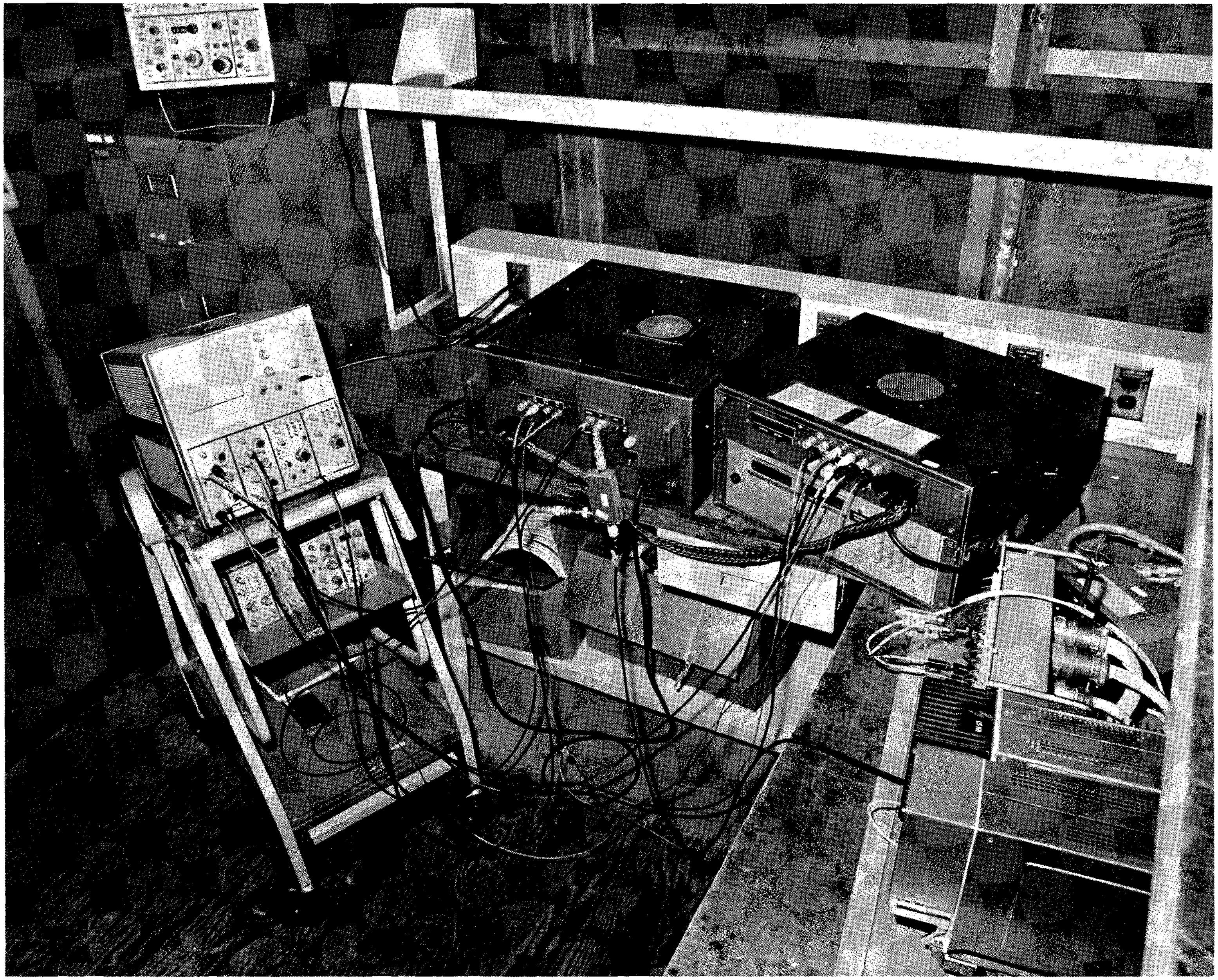


FIGURE 4. MODE S TRANSPONDER TESTER PICTORIAL

aperature beacon antenna having sum, difference, and omni-directional patterns; replies are received on all three patterns. The ratio of the difference-to-sum received amplitudes gives the off-boresight azimuth; this in conjunction with the antenna boresight value from an azimuth pulse generator, provides an angular measurement of target position from true north. The azimuth pulse generator provides 16,384 pulses per antenna revolution; this provides a shaft encoding angular resolution of 0.022°.

The Mode S sensor contains a real-time clock which is synchronized with the National Bureau of Standards (NBS) coordinated universal time transmissions (radio identification, WWVB).

Range estimation by the Mode S sensor is derived from the measurement of elapsed time between a reference interrogation pulse and a reference reply pulse. Timing for this estimation is provided by the sensor real-time clock in increments of 0.0625 microseconds (μs) (one range unit). Interrogation and reply times are stored and compared giving an estimate of two-way range in range units. This value includes transponder delays and cable delays, and is converted to one-way range for insertion into the target report.

The Mode S sensor also contains a data extraction subsystem capable of extracting data from the operating system in real-time and recording that data on magnetic tape for subsequent off-line reduction and analysis.

An exterior view of the Mode S sensor is shown in figure 5. A detailed description of Mode S is contained in report No. FAA-RD-80-41 (reference 4).

NIKE-HERCULES TRACKING RADAR SYSTEM. The Nike-Hercules is a modified precision military instrumentation radar. Positional data recorded by the Nike data extraction system includes a time-of-day entry that is synchronized to WWVB. Positional reports are recorded at a rate of 10 per second in a latitude-longitude format. The theoretical error budget for the Nike tracking system is shown in table 1. A complete description of the capabilities of the Nike is contained in the following: report No. FAA-NA-79-32 (reference 5), "Calibration Procedure: Nike-Hercules Instrumentation Radar" (reference 6), and a letter entitled "Nike Coverage Limitations for Data Quality" (reference 7).

TABLE 1. THEORETICAL ERROR BUDGET FOR THE NIKE-HERCULES TRACKING SYSTEM

	Theoretical Bias Error*	Theoretical Random Error*
Azimuth	0.25 milliradians (0.014°)	0.15 milliradians (0.008°)
Elevation	0.25 milliradians (0.014°)	0.15 milliradians (0.008°)
Range	6 meters (19.6 feet)	3 meters (9.8 feet)

*These error figures were originally obtained via calculation and have been verified experimentally by past tests. However, they have not been experimentally verified for all space.

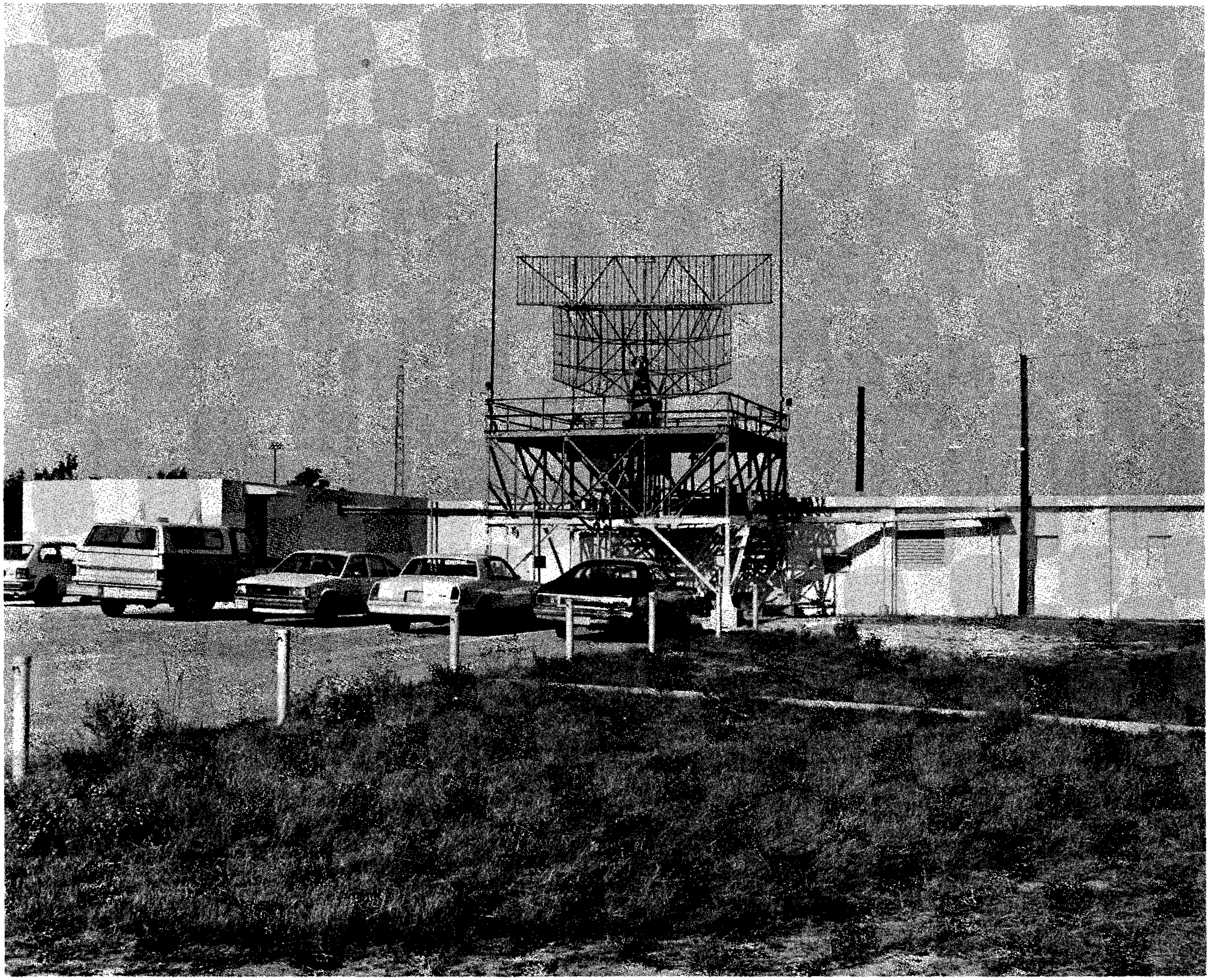


FIGURE 5. MODE S SENSOR EXTERIOR VIEW

METHODOLOGY

GENERAL.

The U.S.S.R. and U.S. Mode S transponders were subjected to bench and flight tests to determine their compatibility with the U.S. Mode S system.

BENCH TESTING.

The U.S.S.R. and U.S. transponders were subjected to a series of bench tests using the Mode S transponder tester. Table 2 lists the parameters measured during these tests. Satisfactory results were required before proceeding with flight testing.

TABLE 2. BENCH TEST PARAMETERS

Sensitivity (Minimum Triggering Level)
Power Output (Framing Pulses)
ATCRBS Framing Pulse Spacing
ATCRBS Mode 3A Code (Ident)
Reply Delay and Jitter
Reply Rate Limit
Mode S Identity
ATCRBS/Mode S All-Call
Mode S Only All-Call
Mode S Roll-Call and Lock-Outs
ATCRBS Lock-Out
Side-Lobe Suppression (Limited)
Reply Frequency

FLIGHT TESTING.

During the joint U.S.S.R and U.S. transponder flight tests, an assessment was made of the parameters presented in table 3.

The obtained data was analyzed on the basis of the information contained in:

- Plot track diagrams for each run;
- Histograms showing the distribution of azimuth and range errors;
- Magnetic tape data extraction listings containing the information for each scan.

Each flight was also observed on a monitoring indicator located at the Mode S sensor.

TABLE 3. FLIGHT TEST PARAMETERS

1. Percent detection (blip scan ratio) = $\frac{\text{Number of times target was detected}}{\text{Number of scans target is being analyzed}}$

2. Altitude reliability = $\frac{\text{Number of times target was detected with correct altitude code}}{\text{Number of times target was detected}}$

3. Mode S interrogation rate = $\frac{\text{Number of roll-call interrogations}}{\text{Number of scans target is being analyzed}}$

4. Range error = Mode S sensor target range (minus) Nike target range.

5. Azimuth accuracy = Mode S sensor target azimuth (minus) Nike target azimuth.

AIRCRAFT INSTRUMENTATION. Upon completion of the bench tests, the Soviet transponder was mounted in a Technical Center Convair 580 aircraft (N-91) (see figure 6). Also on the aircraft were a U.S. Mode S transponder and an x-band transponder for use with the Nike-Hercules tracking system. The U.S. transponder was included in these tests for convenient comparison of results. Each transponder used a separate microwave antenna mounted on the aircraft. Both the U.S. and Soviet transponders use the type of antenna shown in figure 7. Figure 8 depicts the x-band antenna for use with Nike.

TEST CONFIGURATION. Both Mode S transponders were flight tested in an environment which contained normal ATCRBS targets, a stationary Mode S transponder located 13.04 nautical miles (24.15 kilometers) southwest of the Technical Center sensor, and the calibration performance monitoring equipment (CPME). Data were collected by the sensor in the discrete mode for comparison of aircraft positional data obtained concurrently by the Nike. The test configuration is depicted in figure 9.

The Mode S sensor recorded target reports from the two transponders to provide aircraft positional data. Each target report was time-tagged by the sensor clock to provide a means of correlating target reports with the Nike tracking data. The Nike data are taken as the absolute reference for this report.

FLIGHT PROFILES. Approximate flight profiles are depicted in figure 10. Six flights were conducted to gather enough statistical data to draw conclusions about the transponder's in flight performance. Three radial flights (figure 10, flight types 1 and 2) for testing azimuth accuracy were conducted on a 269° true azimuth radial that aligns the sensor and Nike. Two flights ranged from 5 to 35 nautical miles (9 to 65 kilometers) at an elevation of 10,000 feet (3,048 meters). The third ranged from 7 to 50 nautical miles (13 to 93 kilometers) at an elevation of 15,000 feet (4,572 meters). Three orbital flights (figure 10, flight types 3, 4, and 5) to test range accuracy were conducted along a 140° arc, from 190° to 330° true north azimuth. The first two were both conducted at a slant range of 13 nautical miles (24 kilometers) and at elevations of 6,000 feet (1,829 meters) and 12,000 feet (3,658 meters), respectively. The third flight was conducted at a slant range of 16 nautical miles (30 kilometers) and an elevation of 12,500 feet (3,810 meters).

FIGURE 6. CONVAIR 580 AIRCRAFT (N-91)

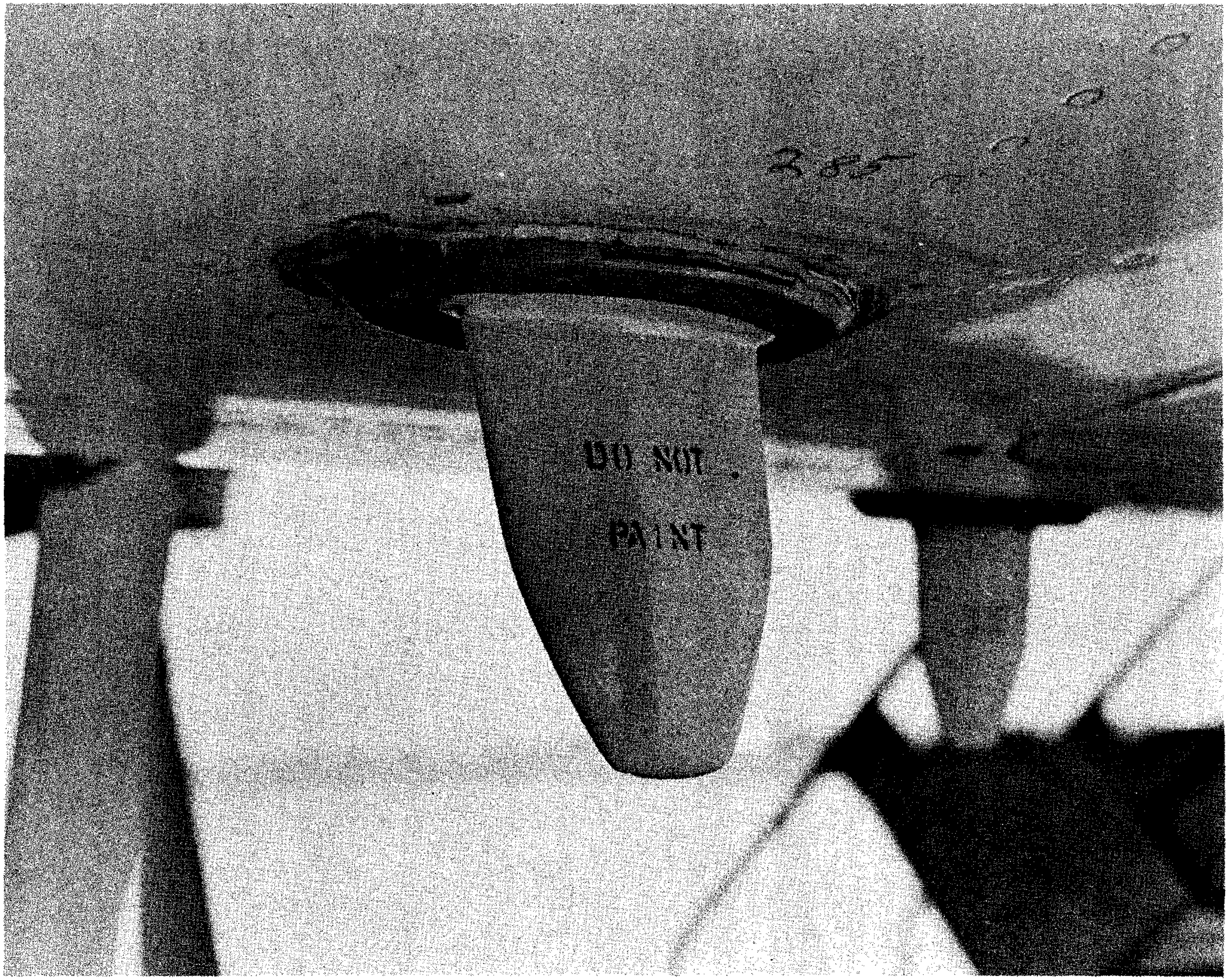


FIGURE 7. U.S./U.S.S.R. TRANSPONDER ANTENNA

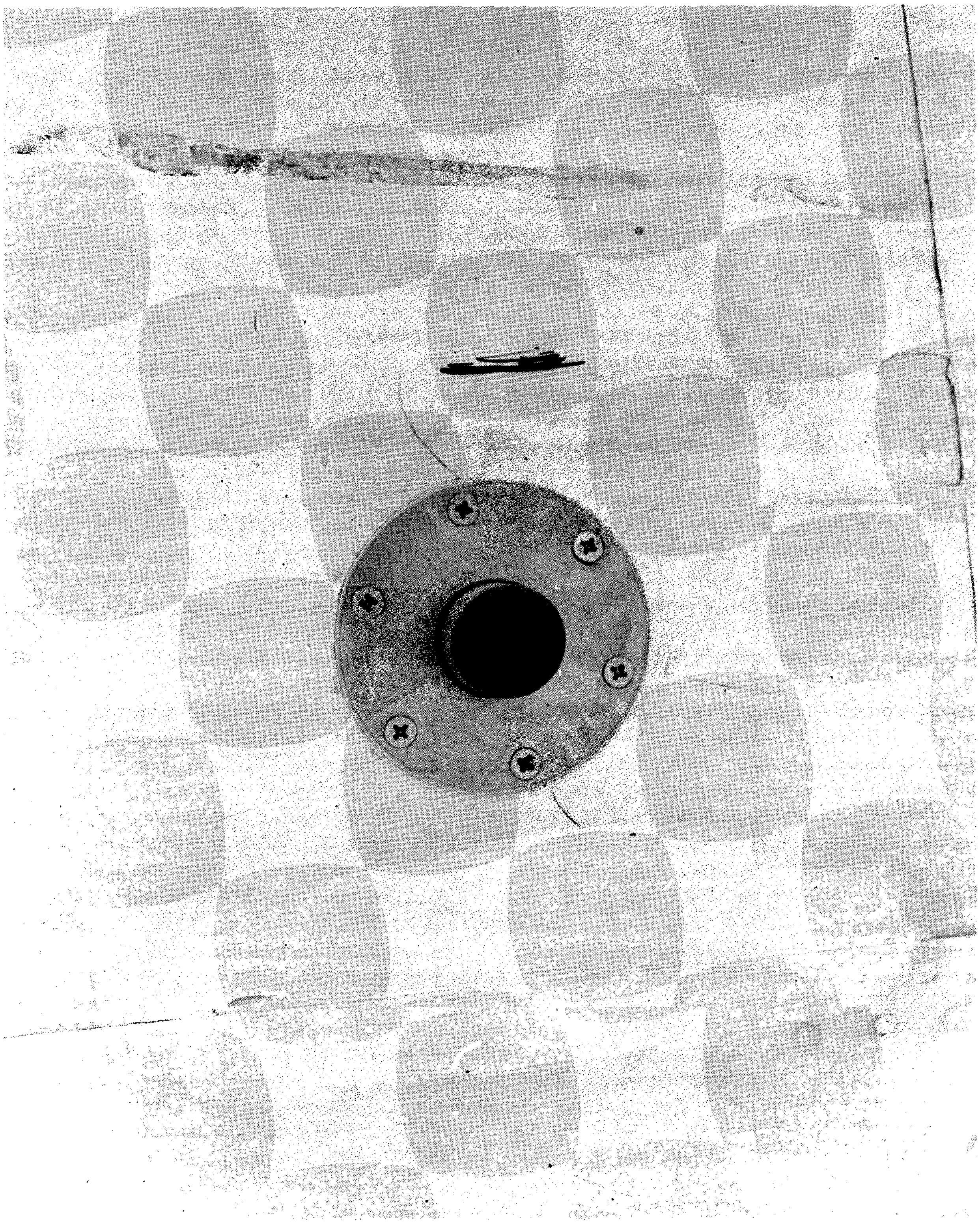


FIGURE 8. X-BAND TRANSPONDER ANTENNA

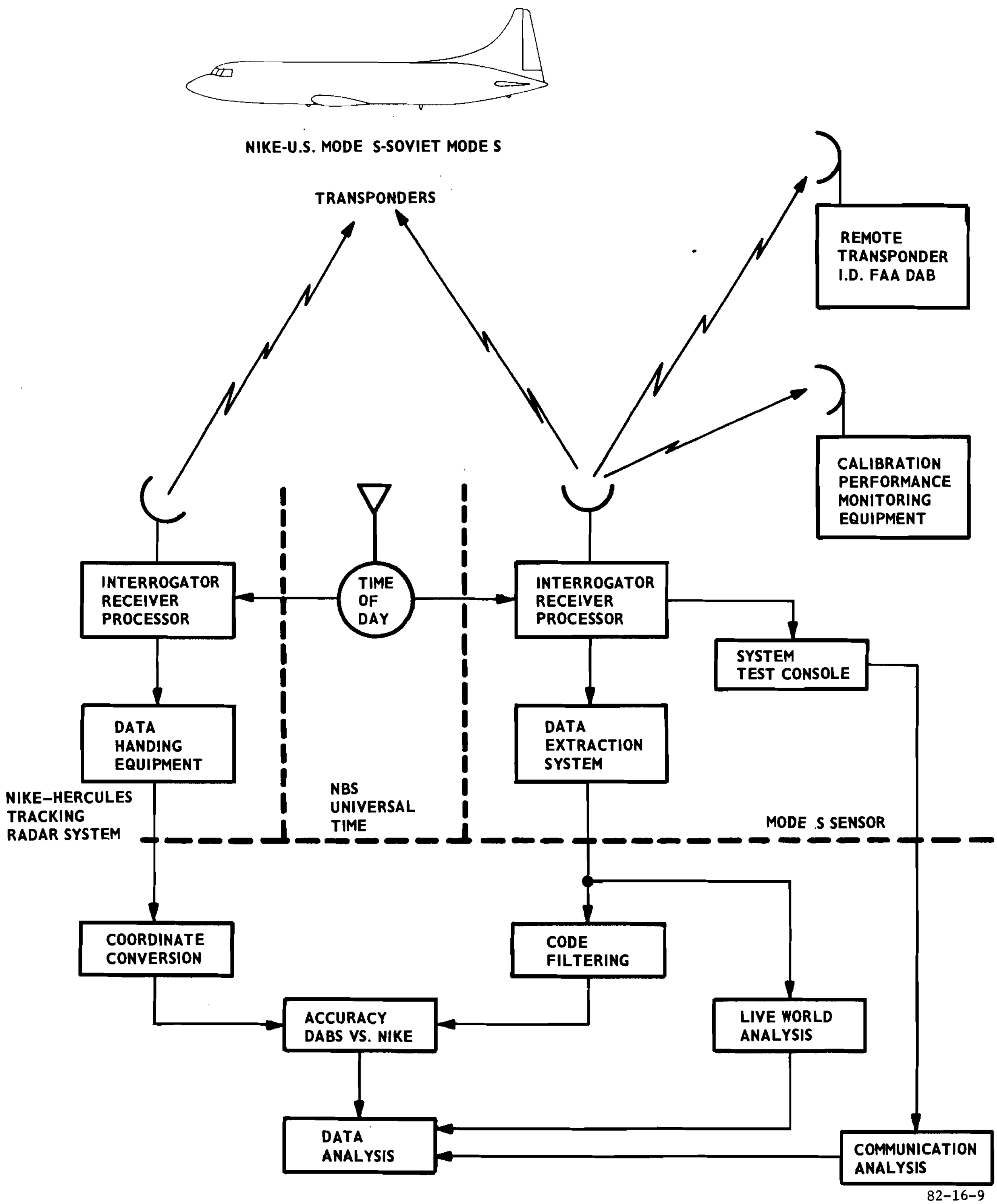
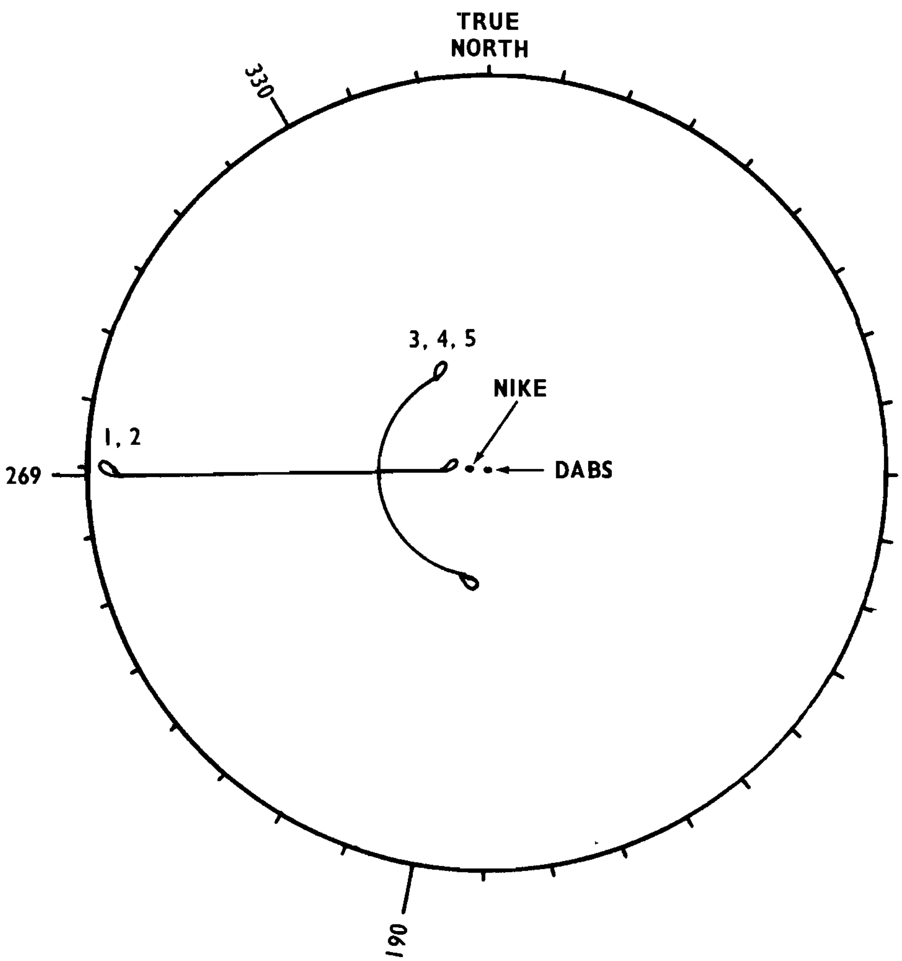


FIGURE 9. TEST CONFIGURATION



FLIGHT TYPE	DESCRIPTION
1	269 DEGREE RADIAL, 5 TO 35 NAUTICAL MILES (9 TO 65 KILOMETERS), AT 10,000 FEET (3048 METERS)
2	269 DEGREE RADIAL, 7 TO 50 NAUTICAL MILES (13 TO 93 KILOMETERS), AT 15,000 FEET (4572 METERS)
3	140 DEGREE ARC, 190 TO 330 DEGREES, 13 NAUTICAL MILES (24 KILOMETERS) AT 6,000 FEET (1829 METERS)
4	140 DEGREE ARC, 190 TO 330 DEGREES, 13 NAUTICAL MILES (24 KILOMETERS) AT 12,000 FEET (3658 METERS)
5	140 DEGREE ARC, 190 TO 330 DEGREES, 16 NAUTICAL MILES (30 KILOMETERS) AT 12,500 FEET (3810 METERS)

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FIGURE 10. FLIGHT PROFILES

QUALITY CONTROL. The following efforts were made to minimize or eliminate errors:

1. Flight Profiles — All flight profiles were selected so as not to exceed the error budget of the Nike-Hercules tracking system.

2. Sensor — The sensor was operated in a single site configuration to minimize interference.

3. Instrumentation Delays — Delays responsible for range or azimuth errors were addressed in the following areas:

a. Transponders — The Mode S data extraction subsystem adjusts the slant range of a target by the nominal transponder delay times specified in the DABS National Standard. However, since the actual delay often differs from the nominal delay, all transponder turnaround times were measured prior to testing, and modifications were made to the data reduction software to account for such differences.

b. Cabling — The cabling length which connects the transponder to it's antenna was measured and it's equivalent cable delay calculated and accounted for in the data reduction software.

c. Antenna — The distances between the transponder antenna and the Nike reference antenna were measured and accounted for in the data reduction software. The relative positions of the three different antennas were also accounted for in the data reduction software. Figure 11 depicts the positions of these antennas on the aircraft. All instrumentation corrections are summarized in table 4.

4. Data — Sensor data were collected from the transponders with the aircraft located at a surveyed fixed ground point (No. 132). Data were also collected for the sensor's CPME to supply a check on the accuracy of the sensor.

TABLE 4. INSTRUMENTATION CORRECTIONS

	U.S.S.R.		U.S.	
Transponder Delays	Roll-Call Mode	All-Call Mode	Roll-Call Mode	All-Call Mode
Nominal	128.00 μs	129.50 μs	128.00 μs	129.50 μs
Actual	127.96 μs	129.48 μs	128.04 μs	129.88 μs
Correction	-0.04 μs	-0.02 μs	+0.04 μs	+0.38 μs
Cable Delays (Calculated)	0.144		0.005	
Antenna Position Relative to Nike Antenna	23 ft. 9 in (7.24 m)		46 ft. 8 in. (14.22 m)	

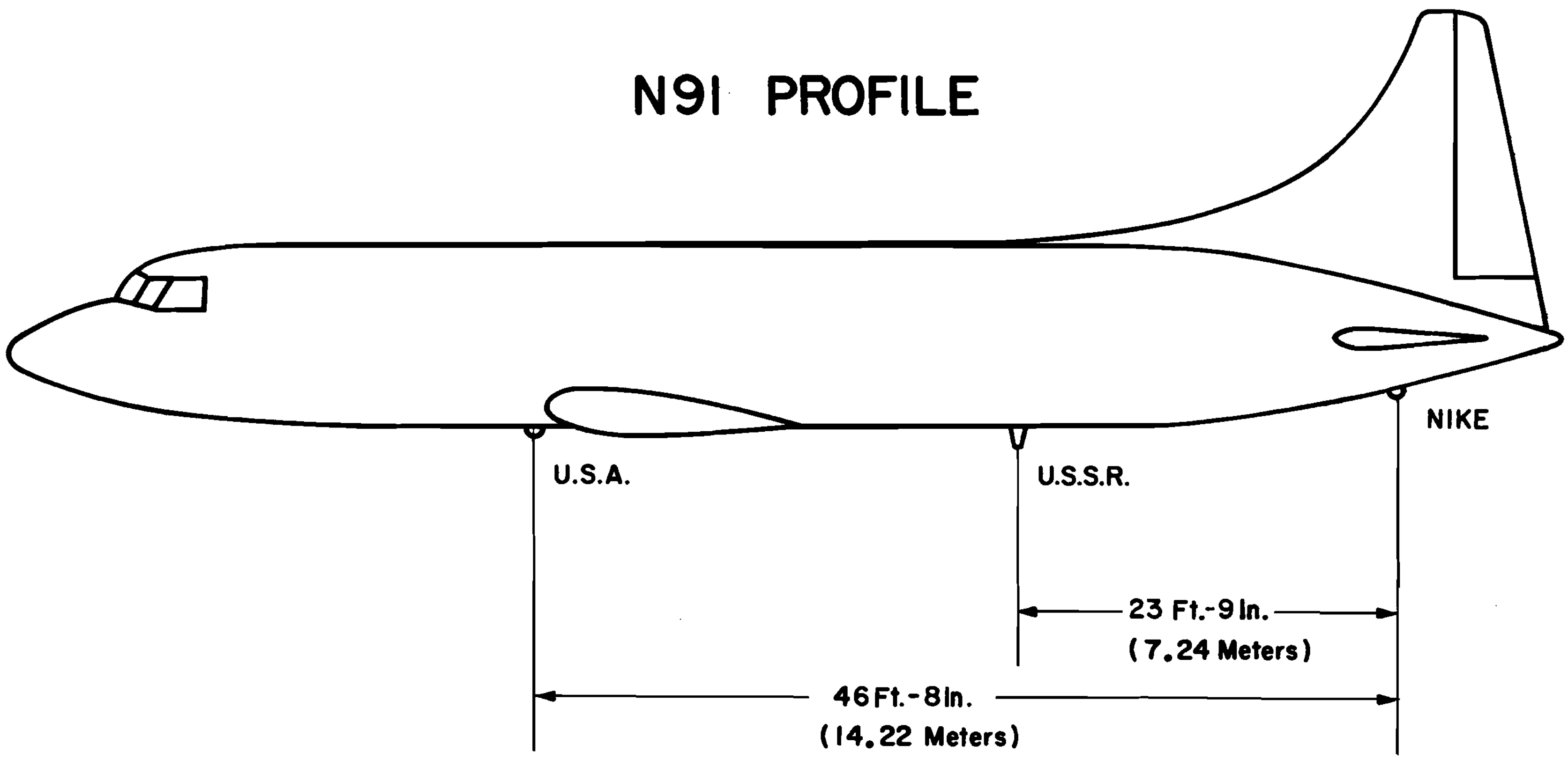

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FIGURE 11. AIRCRAFT ANTENNA POSITIONS

DATA REDUCTION. All data reductions were performed using a Digital Equipment Corporation PDP-11/40 and a Honeywell 66/60 computer. The specific programs that were run and the functions that they perform follow:

1. Report Plot — After each flight, the Mode S sensor data for the Soviet and U.S. transponders were plotted on the PDP-11/40 to provide a visual check of the flight.

2. Live World Analysis — This program processes the sensor data extraction tape and provides transponder reply performance listings.

3. Filter — This program processes the Mode S sensor data extraction tape and filters for the Mode S codes pertinent to each test. The output produces a second tape for input into the accuracy program.

4. Coordinate Conversion — This program coordinate converts the latitude-longitude format of the Nike data extraction tape to the location of the sensor.

5. Accuracy — This program takes aircraft target reports from the filter program tape output and compares them to the Nike data using time-of-day as a correlating function. Mode S system data are recorded to a precision of 1/16 of a second. Nike data are recorded to a precision of 1/10 of a second. Nike data are converted to sensor coordinates prior to comparison. Accuracy information is also provided on the CPME on a 30-scan average at half-hour intervals. These data provide a quality control check on the sensor's range and azimuth measurement performance during tha flight test runs.

RESULTS

BENCH TESTS.

The U.S. and the U.S.S.R. transponders were bench tested before and after flight testing. Tables 5 and 6 list the results obtained before flight testing. (Note: The Soviet transponder had no Mode S lock-out capability, and ATCRBS lock-out was obtained through a manually operated switch. This is in accordance with the original test plan.)

FLIGHT TESTS.

A total of six flight tests were conducted from October 8 through 16. Flight time was approximately 2 hours per flight for a total of 12 hours. Results of all flights are summarized in tables 7 through 12. The data in these tables represent the flight profiles previously described, exclusive of any turns.

Tables 7 and 8 enumerate the combined surveillance and accuracy results for the Soviet and U.S. transponders, respectively. Table 9 lists the sample sizes for the data presented in tables 7 and 8. Tables 10 and 11 are combined summaries categorized under flight altitudes for the Soviet and U.S. transponders, respectively. Table 12, similar to table 9, lists the sample size of the data presented in tables 10 and 11.

TABLE 5. U.S.S.R. TRANSPONDER BENCH TEST RESULTS

Model No. not applicable Serial No. 801

Sensitivity (Minimum Triggering Level) -72 dBm

Power Output (Framing Pulses) F1 51 dBm F2 51 dBm

ATCRBS Framing Pulse Spacing 20.29 μs

ATCRBS Mode 3A Code and Indent Spacing to F1

A1	2.90 μs	A2	5.81 μs	A4	8.70 μs		
B1	11.60 μs	B2	14.50 μs	B4	17.40 μs		
C1	1.47 μs	C2	4.35 μs	C4	7.25 μs		
D1	13.05 μs	D2	15.95 μs	D4	18.85 μs	ID	24.66 μs

Replay Delay Jitter	P3 - F1	3.43 μs
	Jitter	±0.08 μs
Roll-Call Sync Phase Reversal	- Preamble 1	127.96 μs
	Jitter	±0.03 μs
	P3 - Preamble 1	129.48 μs
	Jitter	0.03 μs
Reply Rate Limit		1250 PRF
ATCRBS/Mode S All-Call		7FFFFF Hexadecimal I.D.
Mode S Only All-Call		7FFFFF Hexadecimal I.D.

Mode S Roll-Call

Surveillance Identity	OK
Surveillance Altitude	OK
Surveillance ATCRBS Lock-Out	OK
Surveillance Mode S Lock-Out	not applicable
Comm-A	Reply

SLS (Limited)

MTL	+50 dBm	P1 = P2 = P3	Suppress
MTL	+50 dBm	P1 = P2, P2 = 9 dB down	Reply

Reply Frequency 1092.6 MHz

Note: dB = Decibel
dBm = Decibels above 1 milliwatt
I.D. = Identification
MHz = Megahertz
PRF = Pulse repetition frequency

TABLE 6. U.S. TRANSPONDER BENCH TEST RESULTS

Model No. TRU-2 Serial No. 1018

Sensitivity (Minimum Triggering Level) -72 dBm

Power Output (Framing Pulses) F1 51 dBm F2 51 dBm

ATCRBS Framing Pulse Spacing 20.28 μs

ATCRBS Mode 3A Code and Indent Spacing to F1

A1	2.89 μs	A2	5.78 μs	A4	8.68 μs		
B1	11.69 μs	B2	14.48 μs	B4	17.38 μs		
C1	1.43 μs	C2	4.34 μs	C4	7.23 μs		
D1	13.03 μs	D2	15.93 μs	D4	18.83 μs	ID	24.64 μs

Replay Delay Jitter	P3 - F1	3.09 μs
	Jitter	±0.03 μs
Roll-Call Sync Phase Reversal	- Preamble 1	128.04 μs
	Jitter	±0.03 μs
	P3 - Preamble 1	129.88 μs
	Jitter	0.03 μs
Reply Rate Limit		1250 PRF
ATCRBS/Mode S All-Call		001400 Hexadecimal I.D.
Mode S Only All-Call		001400 Hexadecimal I.D.

Mode S Roll-Call

Surveillance Identity	OK
Surveillance Altitude	OK
Surveillance ATCRBS Lock-Out	OK
Surveillance Mode S Lock-Out	OK
Comm-A	Reply

SLS (Limited)

MTL	+50 dBm	P1 = P2 = P3	Suppress
MTL	+50 dBm	P1 = P2, P2 = 9 dB down	Reply

Reply Frequency 1089.4 MHz

Note: dB = Decibel
dBm = Decibels above 1 milliwatt
I.D. = Identification
MHz = Megahertz
PRF = Pulse repetition frequency

TABLE 7. FLIGHT SUMMARY FOR SOVIET MODE S TRANSPONDER

DATE	FLIGHT TYPE ALTITUDE (ft)	PERCENT DETECTION (%)	ALTITUDE RELIABILITY (%)	INTERROGATION RATE	RANGE ERROR (ft)		AZIMUTH ERROR (deg)	
					MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
8 OCTOBER 1981	Radial 10,000 (3,048m)	99.99	99.99	1.45	-52.5 ft (-16.0 m)	27.7 ft (8.4 m)	-.054°	.048°
9 OCTOBER 1981	Radial 15,000 (4,572m)	-	-	-	-58.6 ft (-17.9 m)	31.2 ft (9.5 m)	-.083°	.043°
9 OCTOBER 1981	Orbital 12,000 (3,658m)	99.99	99.75	-	-58.1 ft (-17.7 m)	21.7 ft (6.6 m)	-.070°	.050°
13 OCTOBER 1981	Radial 10,000 (3,048m)	99.99	99.99	1.36	-62.1 ft (-18.9 m)	29.6 ft (9.0 m)	-.096°	.055°
	Radial 10,000 (3,048m)	99.99	99.99	1.46	-53.1 ft (-16.2 m)	29.8 ft (9.1 m)	-.099°	.059°
	Radial 15,000 (4,572m)	98.98	99.99	1.59	-53.7 ft (-16.4 m)	32.4 ft (9.9 m)	-.082°	.054°
14 OCTOBER 1981	Orbital 6,000 (1,829m)	99.99	99.99	1.28	-63.6 ft (-19.4 m)	20.6 ft (6.3 m)	-.081°	.056°
	Orbital 6,000 (1,829m)	99.99	99.99	1.43	-	-	-	-
16 OCTOBER 1981	Orbital 12,500 (3,810m)	99.99	99.99	1.31	-55.9 ft (-17.0 m)	21.1 ft (6.4 m)	-.101°	.050°
	Orbital 12,500 (3,810m)	99.99	99.99	1.29	-	-	-	-

TABLE 8. FLIGHT SUMMARY FOR U.S. MODE S TRANSPONDER

DATE	FLIGHT TYPE ALTITUDE (ft)	PERCENT DETECTION (%)	ALTITUDE RELIABILITY (%)	INTERROGATION RATE	RANGE ERROR (ft)		AZIMUTH ERROR (deg)	
					MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
8 OCTOBER 1981	Radial 10,000 (3,048m)	99.57	99.99	1.46	48.6 ft (14.8 m)	30.4 ft (9.3 m)	0.002°	0.050°
9 OCTOBER 1981	Radial 15,000 (4,572m)	-	-	-	48.6 ft (14.82 m)	30.4 ft (9.26 m)	-0.037°	0.043°
9 OCTOBER 1981	Orbital 12,000 (3,658m)	99.75	99.99	-	30.4 ft (9.3 m)	30.4 ft (9.3 m)	-0.017°	0.044°
13 OCTOBER 1981	Radial 10,000 (3,048m)	99.99	99.99	1.37	36.5 ft (11.5 m)	30.4 ft (9.3 m)	-0.044°	0.052°
	Radial 10,000 (3,048m)	99.99	99.99	1.43	42.5 ft (13.0 m)	24.3 ft (7.4 m)	-0.057°	0.053°
	Radial 15,000 (4,572m)	99.99	99.99	1.27	42.53 ft (13.0 m)	30.4 ft (9.3 m)	-0.042°	0.052°
14 OCTOBER 1981	Orbital 6,000 (1,829m)	-	-	-	-	-	-	-
	Orbital 6,000 (1,829m)	-	-	-	-	-	-	-
16 OCTOBER 1981	Orbital 12,500 (3,810m)	99.99	99.99	1.44	30.4 ft (9.3 m)	24.3 ft (7.4 m)	-0.038°	0.040°
	Orbital 12,500 (3,810m)	99.99	99.99	1.46	-	-	-	-

TABLE 9. SAMPLE SIZES FOR SOVIET AND U.S. TRANSPONDER FLIGHT TESTS

DATE	FLIGHT TYPE ALTITUDE (ft)	PERCENT DETECTION (%)	ALTITUDE RELIABILITY (%)	INTERROGATION RATE	RANGE ERROR (ft)		AZIMUTH ERROR (deg)	
					MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
8 OCTOBER 1981	Radial 10,000 (3,048m)	234	234	243	214	214	214	214
9 OCTOBER 1981	Radial 15,000 (4,572m)	-	-	-	437	437	437	437
9 OCTOBER 1981	Orbital 12,000 (3,658m)	413	413	-	407	407	407	407
13 OCTOBER 1981	Radial 10,000 (3,048m)	165	165	164	154	154	154	154
	Radial 10,000 (3,048m)	152	152	151	133	133	133	133
	Radial 15,000 (4,572m)	218	218	223	182	182	182	182
14 OCTOBER 1981	Orbital 6,000 (1,829m)	215	215	211	200	200	200	200
	Orbital 6,000 (1,829m)	105	105	103	-	-	-	-
16 OCTOBER 1981	Orbital 12,500 (3,810m)	222	222	218	205	205	205	205
	Orbital 12,500 (3,810m)	247	247	238	-	-	-	-

TABLE 10. COMBINED FLIGHT SUMMARY BY ALTITUDE FOR SOVIET MODE S TRANSPONDER

ALTITUDE	PERCENT DETECTION	ALTITUDE RELIABILITY	INTERROGATION RATE	RANGE ERROR		AZIMUTH ERROR	
				MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
6,000 ft (1829 m)	99.99	99.99	1.35	-63.6 ft (-19.4 m)	20.6 ft (6.3 m)	-.081°	.056°
10,000 ft (3048 m)	99.99	99.99	1.43	-55.6 ft (-16.9 m)	28.6 ft (8.8 m)	-.083°	.053°
12,000 ft (3658 m)	99.99	99.87	1.30	-57.4 ft (-17.5 m)	21.5 ft (6.5 m)	-.080°	.050°
15,000 ft (4572 m)	98.14	99.99	1.59	-57.2 ft (-17.4 m)	31.6 ft (9.6 m)	-.082°	.047°

TABLE 11. COMBINED FLIGHT SUMMARY BY ALTITUDE FOR U.S. MODE S TRANSPONDER

ALTITUDE	PERCENT DETECTION	ALTITUDE RELIABILITY	INTERROGATION RATE	RANGE ERROR		AZIMUTH ERROR	
				MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
6,000 ft (1829 m)	-	-	-	-	-	-	-
10,000 ft (3048 m)	99.81	99.99	1.42	43.3 ft (13.2 m)	28.8 ft (8.8 m)	-0.028°	0.051
12,000 ft (3658 m)	99.87	99.99	1.45	30.4 ft (9.3 m)	28.4 ft (8.6 m)	-0.024	0.043
15,000 ft (4572 m)	99.99	99.99	1.27	46.8 ft (14.3 m)	30.4 ft (9.3 m)	-0.038	0.046

TABLE 12. IDENTICAL SAMPLE SIZES FOR SOVIET AND U.S. TRANSONDERS BY ALTITUDE

ALTITUDE	PERCENT DETECTION	ALTITUDE RELIABILITY	INTERROGATION RATE	RANGE ERROR		AZIMUTH ERROR	
				MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
6,000 ft (1828 m)	320	320	314	200	200	200	200
10,000 ft (3048 m)	551	551	558	501	501	501	501
12,000 ft (3658 m)	882	882	456	612	612	612	612
15,000 ft (4472 m)	218	218	223	619	619	619	619

Data omissions in the tables are attributable to one of four reasons. In the case of the surveillance data, unrepeatable anomalies occurred which rendered the data inadequate or the data were unavailable due to a recording error. In the case of the range and azimuth accuracy data, either the sample size of the data was inadequate for analysis, or the Nike-Hercules tracking data were unavailable. The U.S. transponder data for the October 14 orbital are unavailable because this flight was conducted with the transponder power intentionally turned off. The statistical analysis and results of these tests were derived from the data which are contained in volume 2 of this report and from output listings of the Live World Analysis Program. Volume 2 consists of:

1. Plots of individual flightpaths organized according to the date and flight type of tables 7 and 8.

2. A sample of the Mode S system data extraction tape listing with an explanation of the designations used.

3. Histograms of azimuth and range errors.

4. Plots for radial flights showing the mean and standard deviation of errors in finding azimuth and range dependent on slant range and elevation.

5. Plots showing the mean and standard deviations of errors in finding azimuth and range dependent on slant range, azimuth, and elevation for orbital flights.

Initial flight tests revealed a high reinterrogation rate for the Soviet transponder. The cause of this reinterrogation was due to the Soviet transponder not having an altitude/identity bit to indicate whether altitude or ATCRBS identity code data were being returned to the sensor. The absence of this altitude/identity bit was in accordance with the U.S. DABS National Standard of 1978. Therefore, the current sensor software utilizing the altitude/identity protocol was disabled to accommodate the Soviet transponder in all flight tests.

The measured mean range errors for both transponders were within the expected accuracy of the Mode S sensor. The mean range errors extended from -63.5 feet (-19.4 meters) to -52.5 feet (-16.0 meters) for the Soviet transponder, and +30.4 feet (9.3 meters) to +48.6 feet (14.8 meters) for the U.S. transponder. No significant differences were noted when the standard deviations of both data sets were compared. There are various sources which could result in the differences measured in mean range errors. Three such sources are:

1. The difference in transponder antenna cable lengths used for the two transponders. The difference in antenna cable length results in different signal strengths at the input of the two transponders. Because the transponder delay time is affected by input signal strength, a relative error results. A similar relative error could occur in the reply.

2. Time delays in cables were calculated on the basis of cable length measurements only.

3. The measurement technique used to determine transponder delay time and jitter.

In spite of these error sources, the accuracies measured for both transponders are consistent with results obtained from previously conducted U.S transponder range accuracy tests.

Upon initial inspection, the mean azimuth errors of the Soviet transponder appear to be greater than those for the U.S. transponder. This difference is attributable to the differances in the reply frequencies of the Soviet and U.S. transponders. Referring to tables 5 and 6, the reply frequency for the Soviet transponder is 1092.6 megahertz (MHz), while the reply frequency for the U.S. transponder is 1089.4 MHz. As illustrated in figure 12 of report No. FAA-CT-81-100-J-LR (reference 8), differences from 1090 MHz in the reply frequency of a transponder induce azimuth errors. For example, at a reply frequency of 1093 MHz and an off-boresight azimuth of 1.2° applicable to these test runs, an azimuth error of approximately -0.066° is introduced. When this error is taken into consideration, the data for the Soviet and U.S. transponders are in closer agreement and range from a corrected mean azimuth error of -0.035° to 0.012° for the Soviet transponder, and a mean of -0.057° to 0.002° for the U.S. transponder. A comparison of the standard deviations for both data sets showed no significant differences. These observed mean azimuth error differences are considered negligible and within the specified accuracy of the Mode S sensor.

Analysis of the results presented in tables 7 and 8 shows that the percent detection and altitude reliability for the U.S.S.R. and U.S. transponders were equivalent and were both usually 99.99 percent. In the case of percent detection, the minimum value was 98.14 percent for the Soviet transponder and 99.57 percent for the U.S. transponder. The minimum value for altitude reliability for the Soviet transponder was 99.75 percent. It should be noted that a listed value of 99.99 percent actually represents 100 percent due to data reduction software not providing for rounding of numbers. Percent detection and reliability figures should be evaluated in conjunction with the sample sizes from which they were derived.

The number of interrogations per scan ranged from 1.28 to 1.59 for the Soviet transponder and from 1.27 to 1.46 for the U.S. transponder. The highest values were observed for flights involving a large number of maneuvers. These maneuvers necessitated an increased number of interrogations for tracking.

CONCLUSIONS

The bench tests results demonstrated that the parameters measured for the Union of Soviet Socialist Republics (U.S.S.R.) transponder complied with the requirements of the United States (U.S.) Discrete Address Beacon System (DABS) National Standard of 1978. Results of the analysis of flight test data affirmed that the U.S.S.R. Mode S transponder, when operating with the U.S. Mode S system, provided range and azimuth accuracies, and percent detection and interrogator reply rates that were comparable with those of the U.S. transponder and consistent with the results of previously conducted U.S. Mode S transponder tests. It is, therefore, concluded that the U.S.S.R. Mode S transponder is compatible with the U.S. Mode S system.

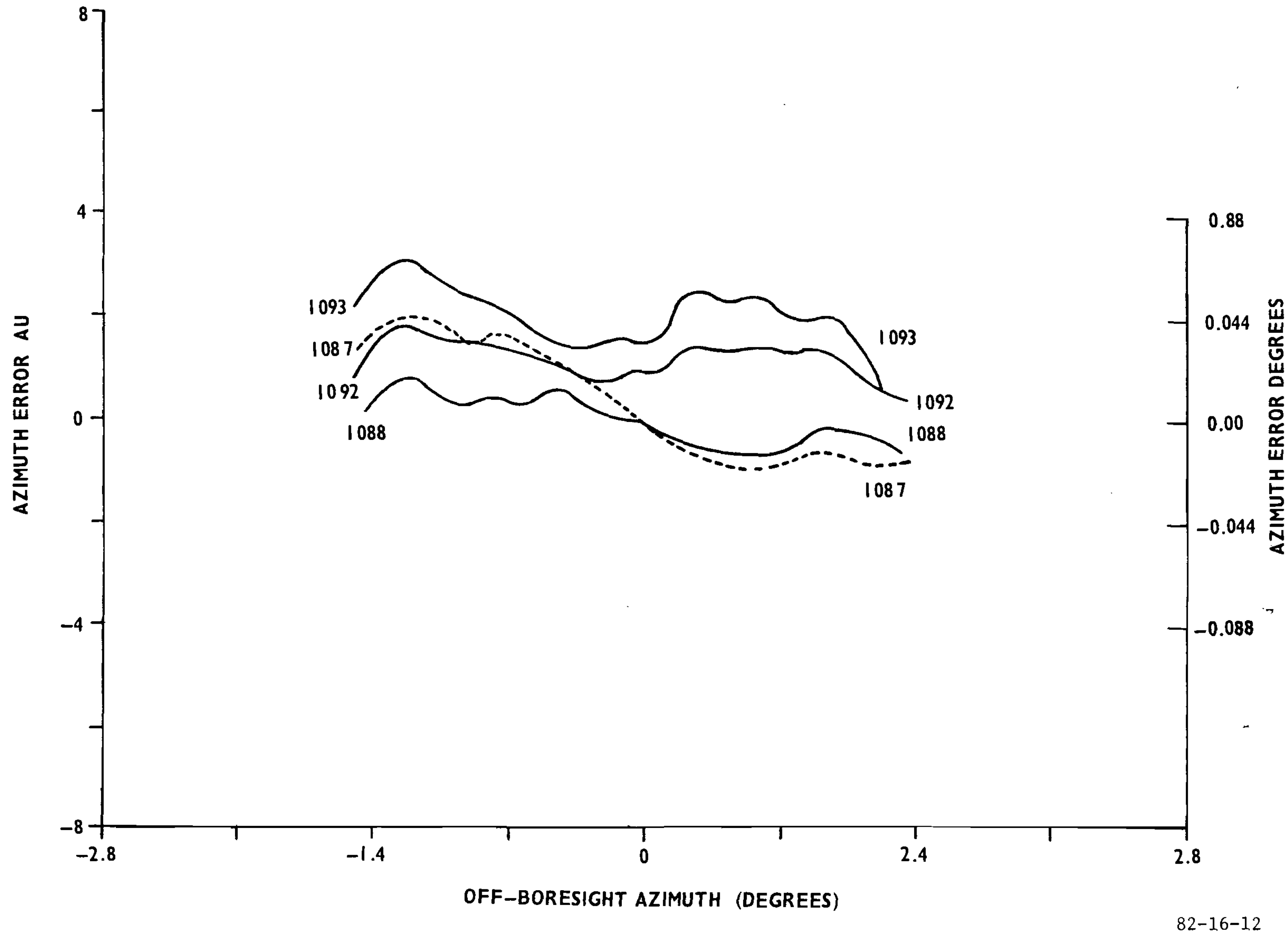

FIGURE 12. AZIMUTH ERROR CORRECTIONS FOR DIFFERENT TRANSPONDER REPLY FREQUENCIES

REFERENCES

1. U.S. National Aviation Standard for the Discrete Address Beacon System, March, 1978.

2. Joint U.S./U.S.S.R. Agreement for Cooperation in the Field of Transportation, June 19, 1973.

3. Joint U.S./U.S.S.R. Plan for Testing the Compatibility of the U.S.S.R. Transponder with the U.S. Discrete Address Beacon System (DABS), May 1, 1981.

4. Orlando, V. A., and Drouilhet, P. R., Discrete Address Beacon System Functional Description, FAA-RD-80-41, April 1980.

5. Luciani, V. J., NAFEC Range Instrumentation Systems, FAA-NA-79-32, February 1980.

6. Purcell, P. R., Calibration Procedure: Nike-Hercules Instrumentation Radar, Nike System Procedure N81-2, July 1981.

7. Purcell, P. R., Nike Coverage Limitations for Data Quality, Information Letter, July 23, 1981.

8. Alimenti, R. J., and Fox, D. P., DABS Open Array Error Measurements, CT-81-100-5-LR, July 1981.