FAA TECHNICAL CENTER LETTER REPORT

TEST PLAN FOR WEATHER EFFECTS UPON MODE S ACCURACY

by

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INTRODUCTION

The Federal Aviation Administration (FAA) is currently engaged in the test and evaluation (T&E) of Mode S sensors built by Texas Instruments (TI), Inc., in accordance with specifications contained in the Engineering Requirement FAA-ER-240-26, (reference 1). These sensors provide tracking of Air Traffic Control Radar Beacon System (ATCRBS) and Mode S transponder equipped aircraft.

A series of flight tests were performed in 1980 to determine the capability of the Mode S sensor in reporting the true position of ATCRBS and Mode S equipped aircraft (reference 2). The slant range and azimuthal position data reported by the sensor were compared to positional data collected concurrently by a precision range instrumentation system at the FAA Technical Center. Results indicated the sensor satisfied the ER requirements of 50 feet range jitter and 0.1 degree rms azimuth error. The flight tests were conducted in ideal weather conditions and therefore did not reflect the possible impact of adverse weather conditions. This document describes the technical approach and plans for data collection and analysis that will be followed to provide a measure of the effects weather may have upon monopulse accuracy in the Mode S sensor.

TEST OBJECTIVE

The objective of performing this (T&E) effort is to determine the effects various local weather conditions (i.e., precipitation, temperature, wind, surface conditions) may have upon the accuracy of a Mode S terminal sensor.

SCOPE OF TESTING

Testing will be restricted to the types of weather conditions occurring at the FAA Technical Center between March and July 1982. Data collection will be performed at least once each workday and as varying weather conditions dictate. Replies will be recorded from four stationary targets within 13 nm and 360 degree coverage of the sensor. The four targets, two Calibration Performance Monitor Equipments (CPME) and two Mode S transponders will be stationary to provide a known, fixed location from which replies will be solicited as input to the sensor. Each of the targets will be configured to respond in the Mode S and ATCRBS modes.

DESCRIPTION OF EQUIPMENT

The following paragraphs present a brief description of the Mode S system. Mode S transponder, and CPME used to perform the weather effects T&E on Mode S sensor accuracy.

Mode S System - The Mode S system is a cooperative surveillance and communication system for Air Traffic Control (ATC). Each Mode S equipped 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 aperature beacon antenna having sum, difference, and omni-directional patterns. Interrogations are transmitted over the sum and omni patterns and replies are received on all three patterns. The ratio of the difference-to-sum received signal amplitudes 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. The antenna boresight angle is obtained from an azimuth pulse generator to provide an angular measurement of target position from true north. The azimuth pulse generator provides 16,384 pulses per antenna revolution, thereby providing a shaft encoding angular resolution of approximately 0.022 degrees, for each azimuth unit (AU).

Range estimation 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 62.5 nanoseconds (ns), one range unit (RU).

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 data reduction and analysis (DR&A).

A detailed description of Mode S is contained in Report No. FAA-RD-80-36 (Reference 3) and Report No. FAA-RD-80-41 (Reference 4).

Calibration Performance Monitor Equipment (CPME) - The CPME is a special purpose test set required to verify Mode S sensor monopulse azimuth accuracy, to calibrate the sensor off-boresight azimuth lookup table at a given sensor site, and for checking data link integrity. Each CPME has its own discretely assigned Mode S address and is permanently installed at a surveyed location within the coverage patterns of one or more Mode S sensors. A weather proof enclosure permits the CPME to operate unattended over a wide range of environmental conditions and contain the following:

a. A modified Mode S transponder

b. A phase-locked 1090 MHz oscillator

c. A high duty cycle RF amplifier for providing high level test signals for up to 20 nm from the sensor

d. Special logic to permit the CPME to send status messages and to parrot uplink messages to the sensor

e. Self-test and diagnostic circuitry

f. Power supplies and control circuitry for operation from AC power mains.

A detailed description of the CPME is presented in Report No. FAA-RD-78-151 (Reference 5).

Mode S Transponder - The Mode S transponder was developed to the U.S. Discrete Address Beacon System (DABS) National Standard of 1978 (Reference 6) to accept and reply to interrogations from Mode S and ATCRBS ground stations. Interrogations accepted by the transponder include ATCRBS/Mode S all-call, ATCRBS only, Mode S only all-call, Mode S surveillance, and data uplinks. The transponder responds with appropriate surveillance and data downlink replies.

TECHNICAL APPROACH

The objectives and DR&A presentation planned for this T&E effort are summarized in the Test Matrix of table 1.

Tests will be conducted to determine the relative change due to weather conditions, in Mode S sensor reported range and azimuth of ATCRBS and Mode S targets. Reply data will be solicited from four stationary targets (figure 1) located as follows:

Target	Range	Azimuth	Mode S ID	ATCRBS Code
CPME #1	1.3 nm	331.9 deg	AAAAA8	7256
CPME #2	1.08 nm	67.0 deg	AAAAA9	4263 (note 1)
Mode S #1	13.0 nm	278.5 deg	FAADAB	1231
Mode S #2	0.45 nm	140.0 deg	EEEEEE	2233 (note 2)

Note: (1) CPME #2 planned to be relocated from Clementon to Bldg. 184.

(2) Mode S #2 planned to be installed in ACT-100 Lab. area as soon as antenna is available.

Within the Mode S sensor, data extraction will record on magnetic tape the replies and subsequent reports created by the sensor software. Analysis of the recorded data will be performed off-line using DR&A programs already in existence.

TABLE 1. TEST MATRIX FOR DETERMINING WEATHER EFFECTS

UPON MODE S ACCURACY

OBJECTIVES	DR&A PRESENTATION	INTERPRETATION
Determine long term Mode S sensor stability for reported range and azimuth of four fixed targets in ATCRBS and Mode S operational modes	Chronological plots of: mean and standard deviation for a. range errors b. azimuth errors Percent detection	Identify the Magnitude and cause of long term variations in Mode S reported range and azimuth values of test targets.
Determine the effect of weather on the range and azimuthal accuracy of a Mode S sensor for: ATCRBS operation Mode S operation	Plots of mean and standard deviation for: a. Target monopulse number versus off-boresight azimuth b. Target azimuth error versus off-boresight azimuth c. Range and azimuth errors as a function of: temperature dew point winds visibility barometric pressure surface conditions precipitation level	Identify the weather parameters which affect Mode S sensor accuracy

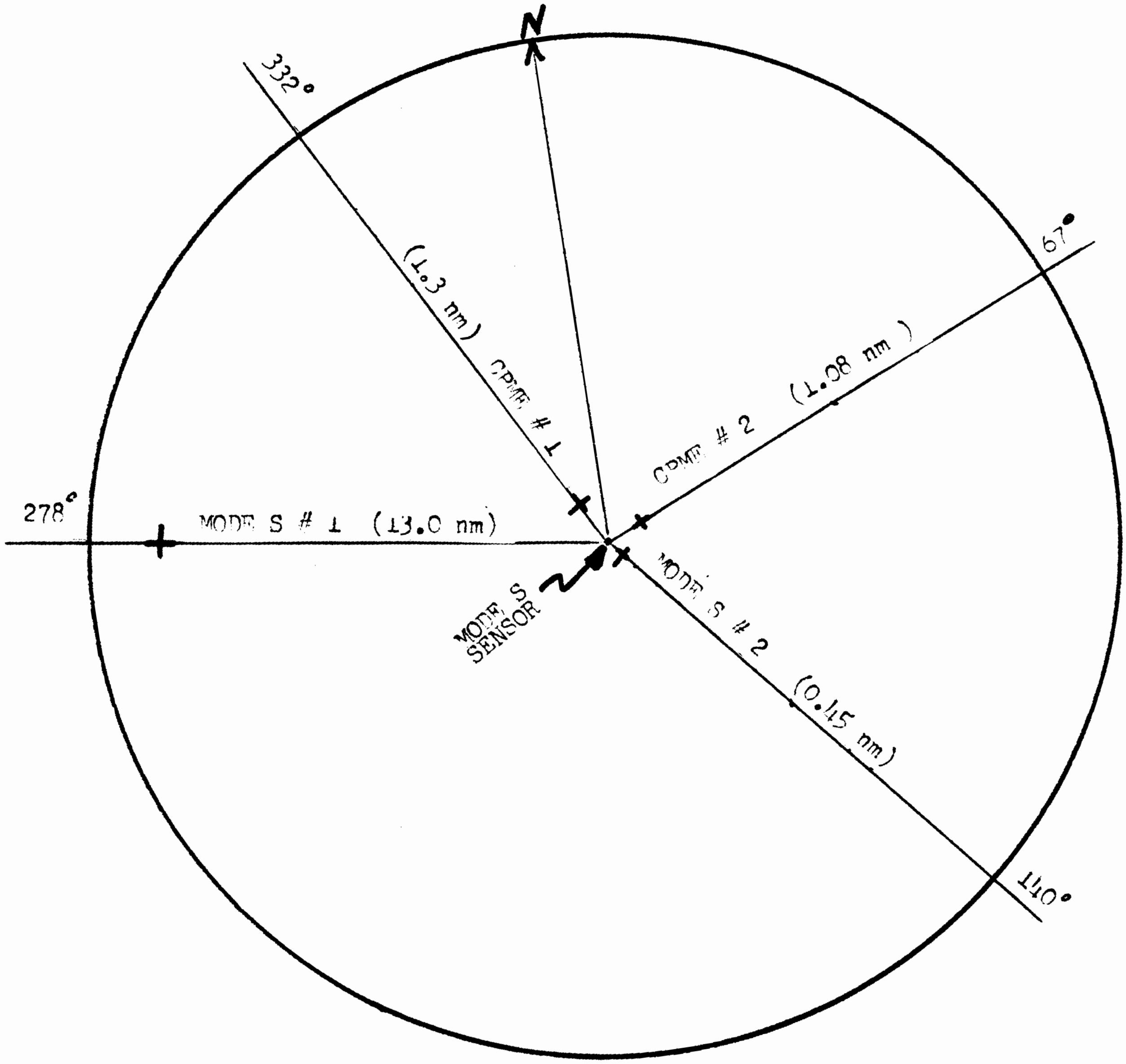

Figure 1. STATIONARY TARGET ORIENTATION RELATIVE TO MODE S SENSOR

Each workday, a series of tests will be performed at the terminal sensor to establish a chronological record of sensor accuracy as a result of varying weather conditions and long term drift characteristics of the sensor. The same tests will be conducted on an as-needed basis dependent upon the occurrence of varying weather conditions during the day (i.e., thunderstorms, rain, snow). The tests to be conducted daily for each test target will consist of four specific sequences:

1. Determine the sensor range and azimuth accuracy (RAA) as a function of 2 consecutive scans.

2. Determine the azimuth mean error and standard deviation of replies received (RAATPD) as a function of 200 scans at a high (1800) PRF.

3. Determine the RF carrier frequency of target replies to ascertain the amount of azimuth error attributable to variations in the reply frequency of a transponder as noted in Report No. FAA-CT-100-5LR (Reference 7).

4. Determine the mean and standard deviation of range and azimuth errors as derived from the reports generated by the sensor, from several hundred scans of normal operation.

Each time the above sequence of data are collected, current weather information will be requested of the National Weather Service for later correlation to range and azimuth accuracy data. The atmospheric and surface weather effects will be analyzed in an effort to identify individual contributors in degrading system accuracy.

DATA COLLECTION PLAN

Data collection will commence with initiation of the RAA diagnostics program to give a preliminary (2 scan) indication of the magnitude of changes to be expected that day from CPME #1.

The next step will record reply data from each of the stationary targets for a minimum of 200 scans using the RAATPD program. This program is similar to the RAA diagnostic except a larger data sample is collected and written onto magnetic tape for off-line analysis. RAATPD functions by scheduling a high number of interrogations of a subject target for the period of time it is illuminated by the sensor's antenna beam. The resulting monopulse value of each reply is then used by the sensor to derive azimuth of the target via the sensor monopulse look-up table. RAATPD computes the difference between the derived bearing of the target and the actual bearing in AU's. The end result is a series of azimuth differences (errors), in AU's, between the subject target's location based on the monopulse value, and its actual location. Also, during running of the RAATPD program, the reply frequency of each subject transponder will be measured and recorded using the test setup of figure 2.

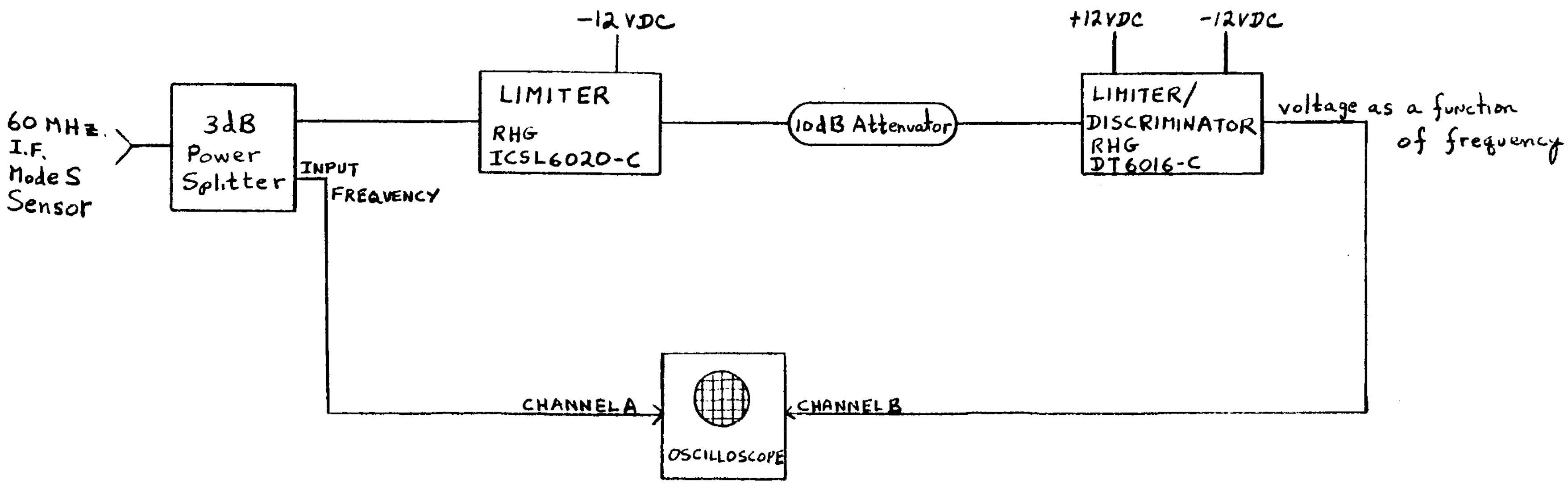

Figure 2. Test Setup for Transponder Reply Frequency Measurement

Data collection will continue by initiating the Mode S sensor data extraction program to collect reply and report data at a normal interrogation rate. The software track system parameter (FRENMX) controlling the types of interrogations scheduled by the Mode S sensor will be modified to enable the two Mode S transponders to reply in the Mode S and ATCRBS modes each scan. Data will be collected concurrently for both modes of operation using software release 9.0

The local weather conditions as monitored by the National Weather Service will be recorded during Mode S sensor data extraction. The following weather parameters will be noted:

1. Temperature
2. Dew point
3. Winds (bearing and speed)
4. Barometric pressure
5. Visibility
6. Precipitation (in past 24 hr. period)
7. Sky covering
8. Surface condition

DATA ANALYSIS PLAN

The Mode S sensor data, recorded during the data collection phase, will be analyzed using existing software programs that run on a Digital Equipment Corporation PDP-11/40 or PDP-11/45 minicomputer.

First, data analysis will be initiated on the target reports generated by the sensor. The end result of this analysis will be a chronological plot of the following performance parameters for both ATCRBS and Mode S operation of the four test targets:

1. Mean range error and standard deviation
2. Mean azimuth error and standard deviation
3. Percent detection

Figures 3, 4, and 5 depict sample presentations of the expected data. These plots will serve as a basis for detecting variations in the sensor reported position of the test targets as a result of long term drifts or weather conditions. At the conclusion of all data analysis the distribution of these range and azimuth errors will be plotted on a histogram similar to the examples of figures 6 and 7.

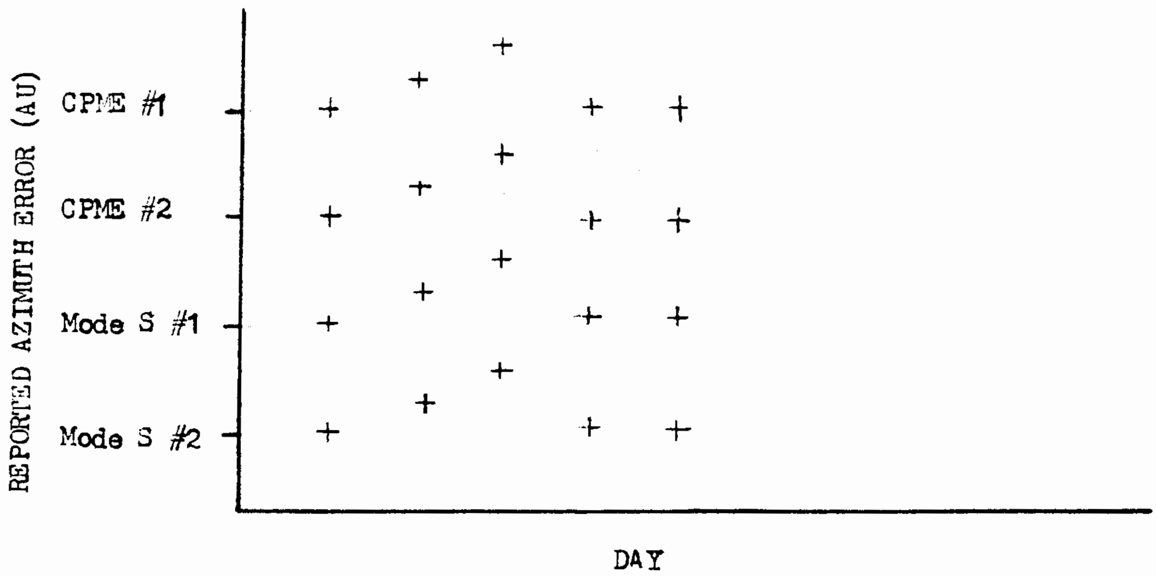

Figure 4. CHRONOLOGICAL PLOT OF REPORTED MEAN AZIMUTH ERROR AND STANDARD DEVIATION

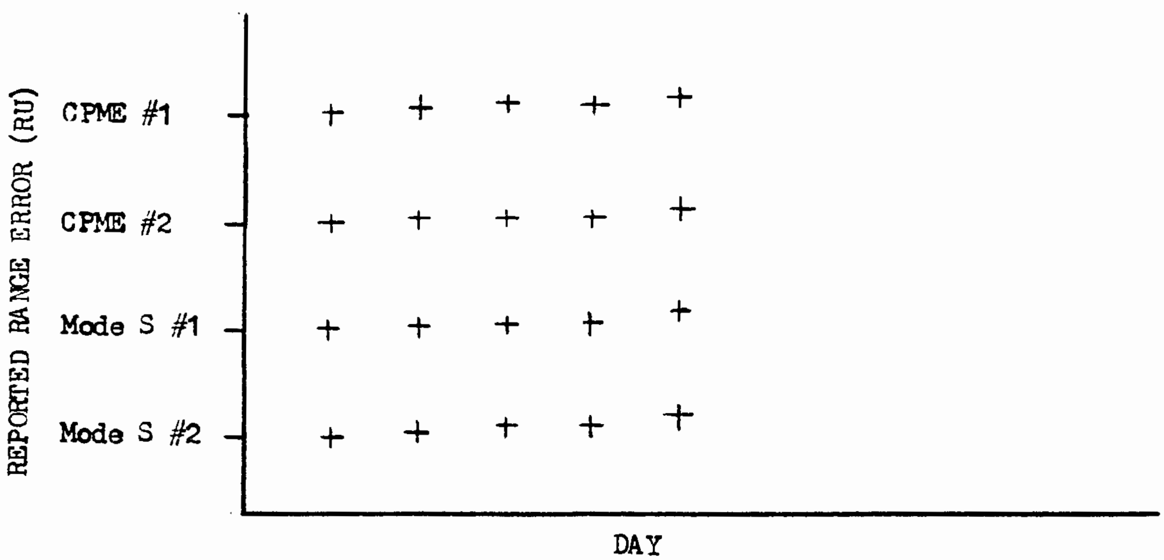

Figure 3. CHRONOLOGICAL PLOT OF REPORTED MEAN RANGE ERROR AND STANDARD DEVIATION

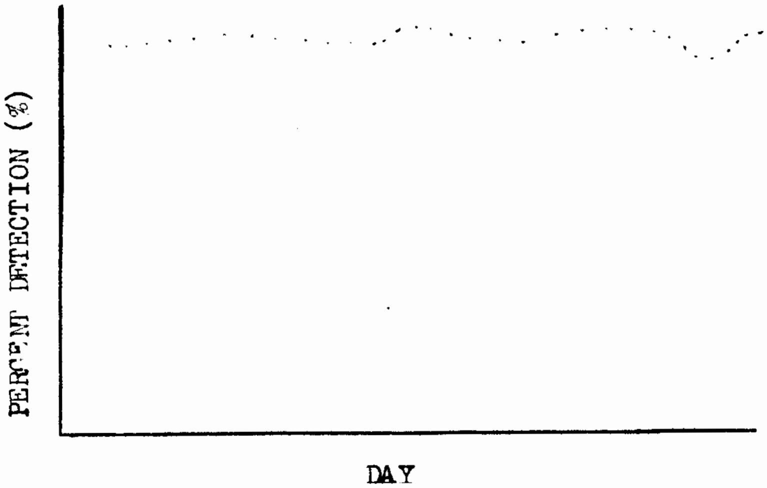

Figure 5. CHRONOLOGICAL PLOT OF PERCENT DETECTION

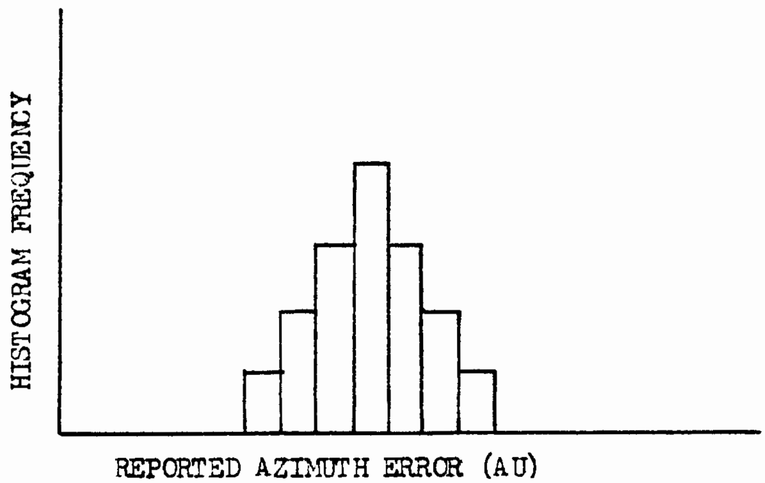

Figure 6. HISTOGRAM OF AZIMUTH MEAN ERROR DISTRIBUTION

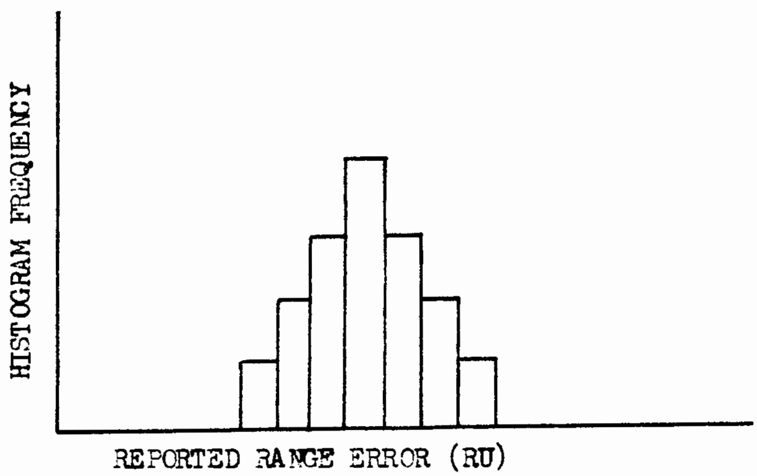

Figure 7. HISTOGRAM OF MEAN RANGE ERROR DISTRIBUTION

The mean and standard deviation of range and azimuth errors for each target will also be plotted as a function of the weather parameters being monitored. These plots (figure 8) would attempt to identify specific weather parameters affecting Mode S accuracy.

Variations in the chronological plots of target range and azimuth errors will be further analyzed at the reply level of sensor performance. The replies will be analyzed from data collected via the RAATPD program by generating plots of:

(1) Monopulse number versus off-boresight azimuth

   (a) mean

   (b) standard deviation

(2) Azimuth error versus off-boresight azimuth

   (a) mean

   (b) standard deviation

Samples of the expected plots are presented in figures 9, 10, 11, and 12. Separate plots will be generated for each test target depicting the monopulse number and azimuth error as a function of where the reply is received in the antenna beam.

TEST SCHEDULE

1.	Complete Release 9.0 software modifications to allow ATCRBS and Mode S interrogations of Mode S transponder	2/82
2.	Complete software modifications of RAATPD program to allow selection of individual test targets for interrogation in ATCRBS mode only	2/82
3.	Complete installation of CPME #2	2/82
4.	Complete installation of Mode S #2	2/82
5.	Data Collection	

Start	ASAP (Dependent upon availability of sensor following the testing of phase/amplitude monopulse receivers and calibration of sensor after radar/beacon antenna is replaced).
Complete	July 1982

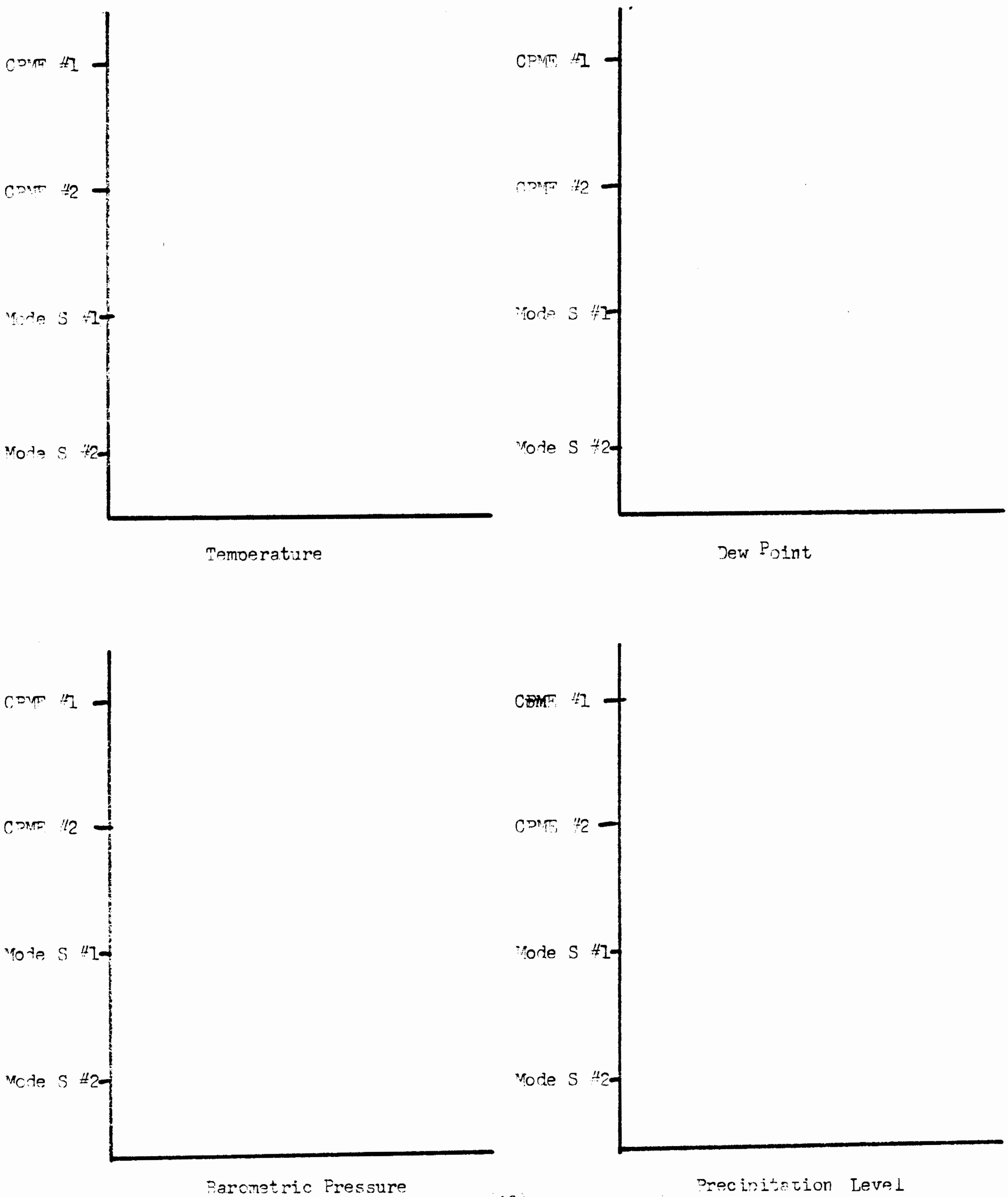

Figure 8. SAMPLE LAYOUT OF ERROR PLOTS VERSUS WEATHER PARAMETERS

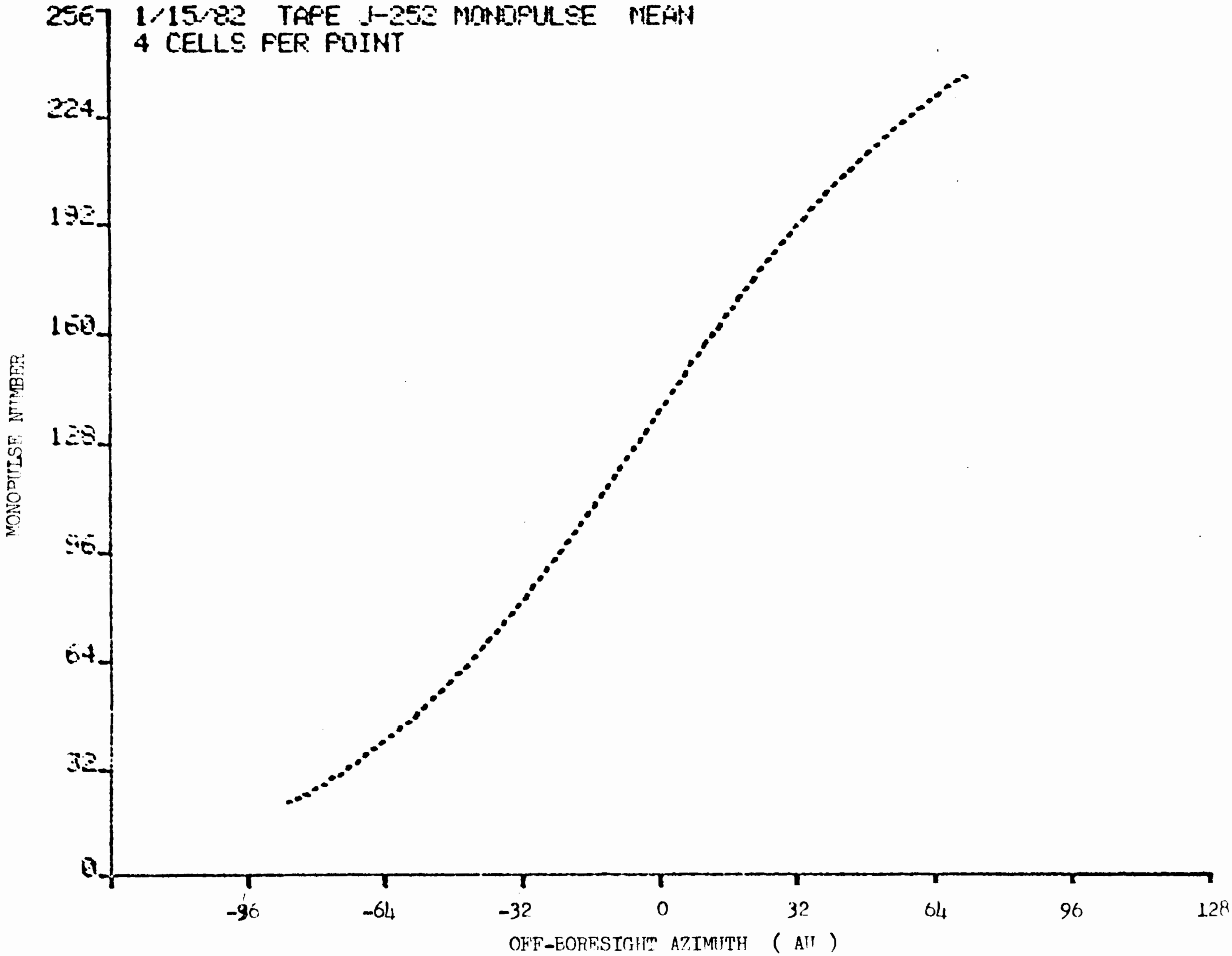

Figure 9. MEAN MONOPULSE NUMBER VERSUS OFF*BORESIGHT AZIMUTH

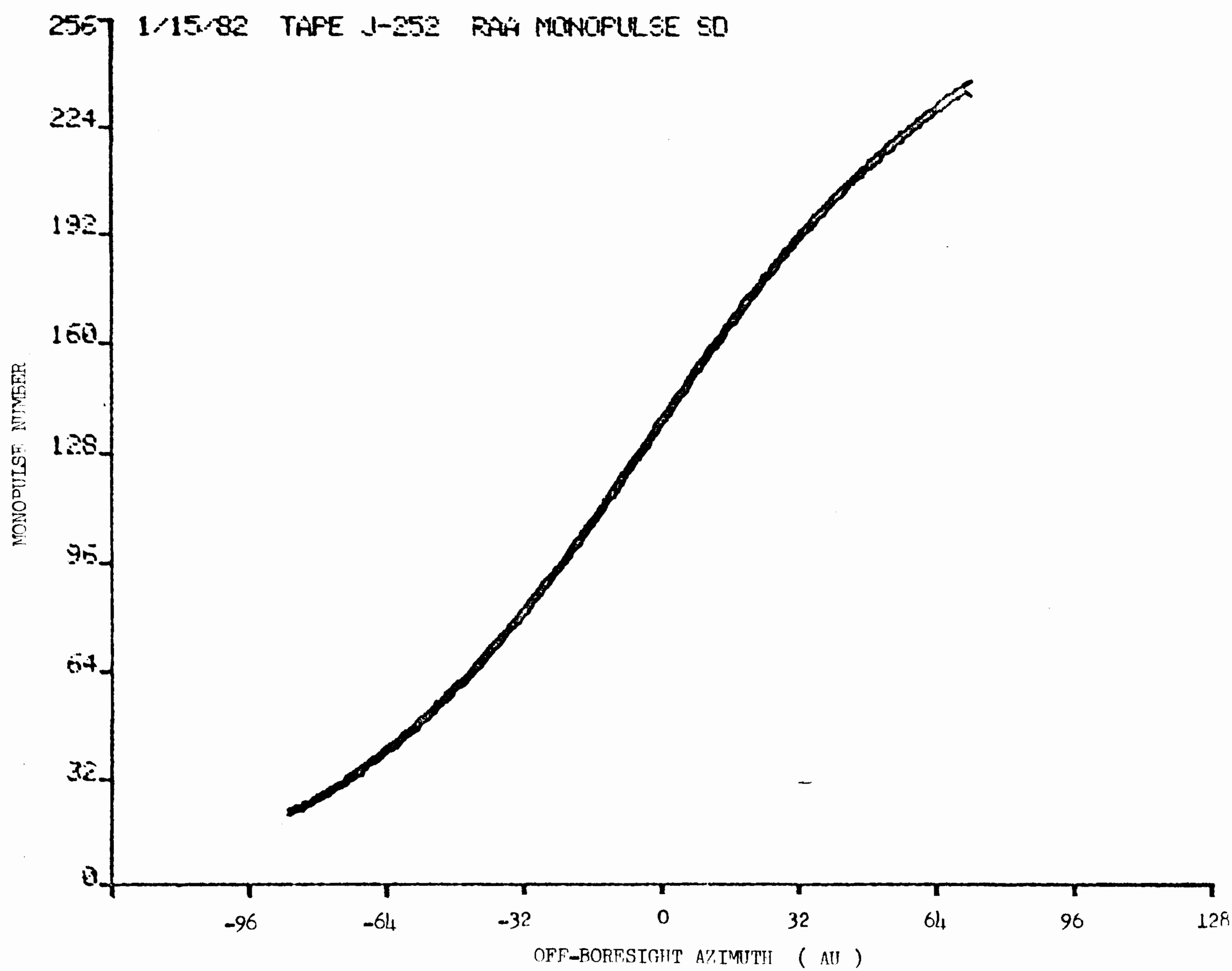

Figure 10. MONOPULSE STANDARD DEVIATION VERSUS OFF-BORESIGHT AZIMUTH

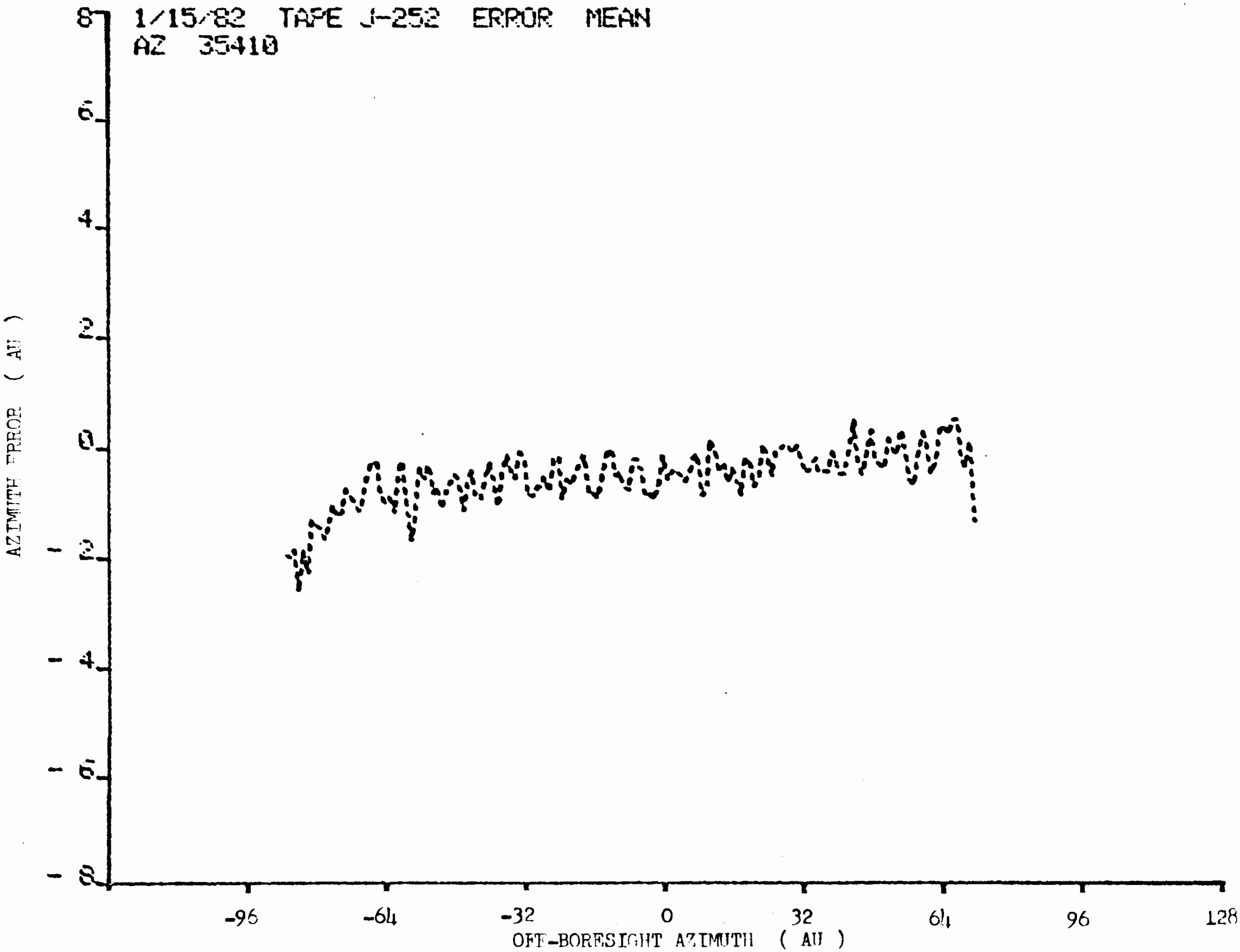

Figure 11. MEAN AZIMUTH ERROR VERSUS OFF-BORESIGHT AZIMUTH

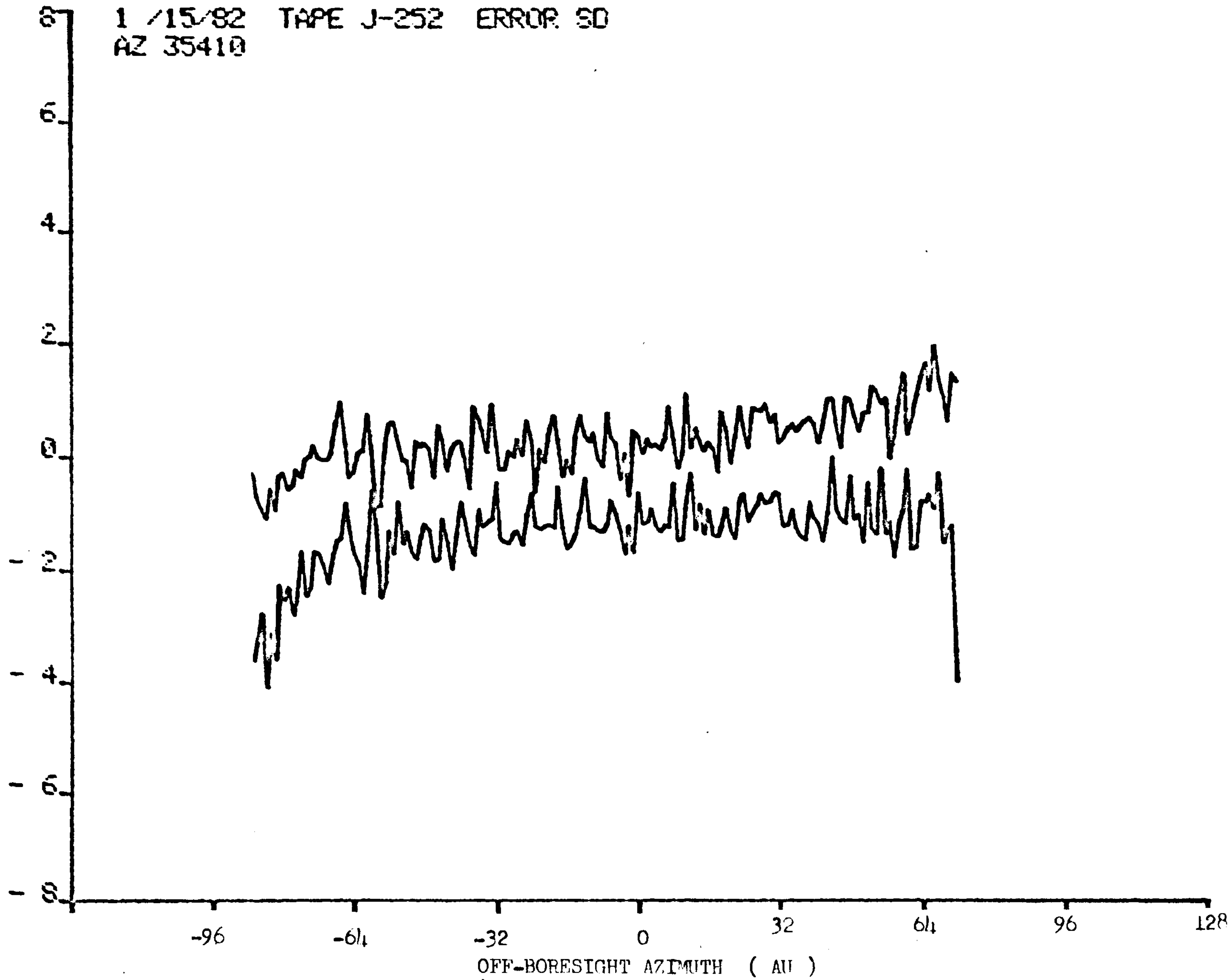

Figure 12. AZIMUTH ERROR STANDARD DEVIATION VERSUS OFF-BORESIGHT AZIMUTH

6. Data analysis complete: September 1982

7. Letter Report October 1982 (due in Mode S Program office 10/5/82)

REFERENCES

1. Federal Aviation Administration, Discrete Address Beacon System - Phase II, Engineering Requirement, FAA-ER-240-26, November 1, 1974.

2. Discrete Address Beacon System (DABS) System Accuracy, FAA-RD-81-90

3. Discrete Address Beacon System (DABS) Baseline Test and Evaluation, FAA-RD-80-36, April 1980.

4. Discrete Address Beacon System Functional Description, FAA-RD-80-41, April 1980.

5. The DABS Calibration Performance Monitoring Equipment, FAA-RD-78-151, March 1979.

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

7. DABS Open Array Error Measurements, FAA-CT-100-5-LR, July 1981.