FAA TECHNICAL CENTER LETTER REPORT

MODE S SENSOR COMPATIBILITY TO OUT-OF-TOLERANCE MODE S TRANSPONDERS TEST PLAN

by

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INTRODUCTION

PURPOSE. The purpose of this test activity is to quantitatively determine the effects "Out-of-Tolerance" Mode S transponders have on the performance of Mode S sensor operations and determine the compatibility of the Mode S system to the potential Mode S environment. Possible methods of rejection/compensation that may be required will be investigated.

BACKGROUND. The Federal Aviation Administration (FAA) has recently conducted tests and evaluations of the Discrete Address Beacon System (DABS), now referred to as Mode S. These test results were published in report No. FAA-RD-80-36, "Discrete Address Beacon System (DABS) Baseline Test and Evaluation", dated April 1980 (Reference 1). The Mode S system was developed to upgrade and improve the existing ATCRBS surveillance system. The Mode S system has been designed to operate within an environment of in-tolerance Beacon transponders.

Mode S baseline performance characteristics were determined, for the most part, with the system operating within an environment of in-tolerance beacon transponders. The compatibility of Mode S to operate in a Mode S environment operating outside of the "U.S. National Aviation Standard For The Discrete Address Beacon System" (Reference 2) is the intent of this test effort.

SCOPE

This test effort is not intended to be a comprehensive evaluation of all Mode S transponder characteristics. The effects of out-of-tolerance transponders on Mode S sensor performance will be limited to the transponder down link characteristics only, the Mode S performance relative to out-of-tolerance up link interrogations will not be addressed. The effects, or interference, out-of-tolerance Mode S transponders have on other Mode S transpondesrs, or vise versa, relative to Mode S sensor surveillance performance will not be characterized.

Because of the large number of Mode S transponder national standard tolerances, only those selected characteristics listed in Table 4 will be investigated. Mode S performance characteristics to in-tolerance transponders has already been investigated, therefore, this test plan will investigate transponders operating at their tolerance limits and at incremental levels outside of these limits.

DESCRIPITION OF EQUIPMENT.

The following paragraphs are presented to provide a brief descripition of the systems and equipment that will be used to support this test effort.

Mode S Sensor.

A complete descripition of the Mode S system is contained in the following: Report No. FAA-RD-80-41 (Reference 3) and Report No. FAA-ER-240-26 (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. A complete descripition is contained in Report No. Faa-NA-79-32 (Reference 5).

TRU-2 MODE S TRANSPONDER.

The TRU-2 Mode S ATC Transponder System consists of a Mode S Transponder and Mode S Control Panel. The Bendix TRU-2 system is fully compatible with the ATCRBS (Air Traffic Control Radar Beacon System) and the Mode S air traffic control services. A switch on the transponder front panel permits manual selection of either ATCRBS only, Mode S only, or normal operation. In normal operation, the TRU-2 automatically responds to either traffic control service interrogators.

The Mode S Transponder performs all functions required for a conventional ATCRBS transponder. Full Mode S capability is an extension of the basic ATCRBS conventions. This extension includes an additional receiver for dual diversity, a switching duplexer for receiver protection and antenna control, a high duty cycle transmitter to handle ELM (extended length message) replies and digital circuits to handle Mode S processing requirements. A complete descripition of the Bendix TRU-2 Mode S Transponder is contained in the following document: TRU-2 DABS/ATC Transponder System, Maintenance Manual I.B.1171A (Reference 6).

MOBILE TRANSPONDER PERFORMANCE ANALYZER.

The Mobile Transponder Performance Analyzer (MTPA) is a mobile test system that analyzes performance characteristics of various types of aircraft surveillance transponders. The MTPA has the capability of generating simulated 1090 MHZ RF transponder replies in response to ground interrogations. Characteristics of the simulated transponder replies are programmable.

A descripition of the MTPA design requirements is contained in the following: Report No. DOT-FAA-CT-81-203, "Design Requirements For An ATCRBS/DABS/ADSEL Aircraft Transponder Test System" (Reference 7).

TECHNICAL APPROACH

The investigation into the effects of "Out-of-Tolerance" Mode S transponders on Mode S sensor performance will be conducted in two stages. The first stage, "Level 1, Static Bench Tests", will be conducted to determine the Mode S sensor "Subsystem" performance as a function of specific Mode S transponder chacteristics. The second stage, "Level 2, Flight Tests" will be conducted to determine the Mode S "System" performance as a function of the same transponder characteristics using live world flight tests.

Tests will be conducted using simulated Mode S transponder replies generated by the "Mobil Transponder Performance Analyzer" (MTPA) and a special computer test program. The MTPA reply generating capabilities will enable a high volume of known transponder reply characteristics to be varied per unit of time. Mode S sensor data will be collected for each incremental change in transponder characteristic.

Tables 1 and 2 summarizes with a "TEST MATRIX" all Level 1 "Static Bench Tests". Table 3 summarizes with a Test Matrix all Level 2 "Flight Tests". Table 4 lists the specific Mode S transponder characteristics that will be investigated.

The test configuration shown in Figure 1 will be implemented to determine Mode S sensor performance relative to various transponder characteristics. Mode S interrogations will be decoded by the TRU-2 transponder receiver circuitry. The decoded interrogation signial will be used to control the PDP-11/34 computer via the reply processor. The computer will control the MTPA Programmable Waveform Generator and Variable Attenuator. The output of the waveform generator will pulse the TRU-2 pulse amplitude modulator which in turn will generate the desired RF transponder reply. The transponder output reply will be detected and processed by the Mode S sensor.

Level 1, Static Bench Tests.

The Mode S sensor, located at the FAA Technical Center approximately one-half mile from the test laboratory, will be used to elicit Mode S replies from the MTPA in a real world, live environment. The static tests will be conducted primarily to determine Mode S subsystem performance and compatibility relative to specific Mode S transponder tolerances. These static tests will provide an indication prior to conducting Level 2 flight tests of which critical transponder characteristics should be investigated to determine the effects on overall Mode S system performance and compatibility.

The Mode S subsystem that will be addressed is the "Mode S Reply Processor". To support the Level 1 static testing, a Mode S TRU-2, transponder operating in the "Mode S Only Mode" will decode the Mode S "All-Call and Roll-Call" interrogations and enable the MTPA to respond with the appropriate reply.

The first static tests to be conducted will primarily be concerned with collecting a significant quanitity of Mode S sensor "Reply" and "Report" baseline data with the MTPA providing transponder replies within the National Standard Tolerances (Reference 2). These data will be statistically analyzed to provide the baseline performance data necessary to characterize Mode S subsystem performance and compatibility to subsequent out-of-tolerance Mode S transponders tests.

Mode S subsystem compatibility as a function of Mode S transponder characteristics will be determined by defining the following eight critical elements in Mode S "Reply Report Processing".

1. Round Reliability
2. Message Bit Reliability and Confidence
3. Message Decoding with Error Detection and Correction
4. Monopulse Estimate
5. Range and Azimuth Estimate
6. Failure Codes
7. Re-interrogations
8. Splits (Range & Azimuth)

These critical elements are defined in Appendix A.

Following the baseline characterization of the Mode S Reply Processor subsystem, tests will be conducted to determine sensor performance and compatibility relative to the Mode S transponder operating at: maximum and minimum allowable tolerances, and then out-of-tolerance. Possible combinations of near and out of tolerance limits may be investigated.

Mode S data will be recorded on magnetic tape by the Mode S sensor "Data Extraction System". These data will consist of recording both "Replies" and "Reports" in a live world environment. To limit the MTPA from replying to interrogations other than those generated by the Mode S sensor, a narrow beamwidth dish antenna will be pointed at the Mode S sensor. The data collected at the Mode S sensor will be limited to a specific range and azimuth window to reduce the number of replies and reports recorded by the data extraction system in the live environment.

Analysis of the data collected will be accomplished by the use of existing computer data reduction programs. These programs will aid in the determination of Mode S sensor performance and compatibility in terms of it's capability to process transponder replies operating at, other than in-tolerance characteristics.

Level 2, Flight Test Performance.

The second stage of testing, "Level 2, Flight Tests" will be conducted to determine the Mode S system surveillance performance as a function of specific Mode S transponder characteristics using live world flight tests. To support the Level 2 testing, the Mode S TRU-2/MTPA test configuration used during Level 1, static testing, will be installed in a selected test aircraft. Flight tests will be flown to determine Mode S surveillance tracking performance and reliability relative to the transponder operating just within tolerances. Following these tests, sensor performance and compatibility will be determined when operating with transponders that are operating at out-of-tolerance limits.

The test aircraft will fly in Mode S coverage zones along pre-established flight paths. These flight paths will be designed to enable the determination of the critical elements listed as a function of such variables as range, altitude, and maneuver condition (e.g., straight line radials, orbitals with slow turn rates and high turn rates). The specifics of the test flights are listed in Table 5.

Mode S system compatibility as a function of Mode S transponder characteristics will be determined by defining the following six critical elements in Mode S Surveillance Tracking Performance, Reliability and Confidence:

1. Blip Scan Ratio
2. Track Acquisition
3. Continuity and Firmness
4. Positional Accuracy
5. Splits and Swaps
6. Message Reliability and Confidence

These critical elements are defined in Appendix A.

Tests will be conducted to determine the target position reporting accuracy of the Mode S sensor. To support these tests, the FAA Technical Center's Nike-Hercules precision radar tracking system will operate in conjuction with the Mode S sensor to provide independent measurement data. The range and azimuth of the test aircraft as detected by the Mode S sensor will be compared to the range and azimuth position of the test aircraft determined by the precision radar tracking system.

Transponder reply data will be collected using the Mode S data extraction system. Surveillance track data will be collected in addition to reply and report data. Data will be collected for various transponder tolerances. The specific test transponder characteristics varied will be determined after the analysis of the data collected during the Level 1, static tests. There is no apparent reason to conduct expensive flight testing of a Mode S transponder operating at a particular tolerance characteristic that did not indicate Mode S degradation during the static subsystem compatibility testing. Hopefully, the static testing will have provided enough statistical data to be selective in the transponder characeristics chosen to determine overall Mode S sensor performance and compatibility relative to other than in-tolerance transponder characteristics.

Processing of the Mode S surveillance data will be accomplished by using several existing computer data reduction and analysis programs.

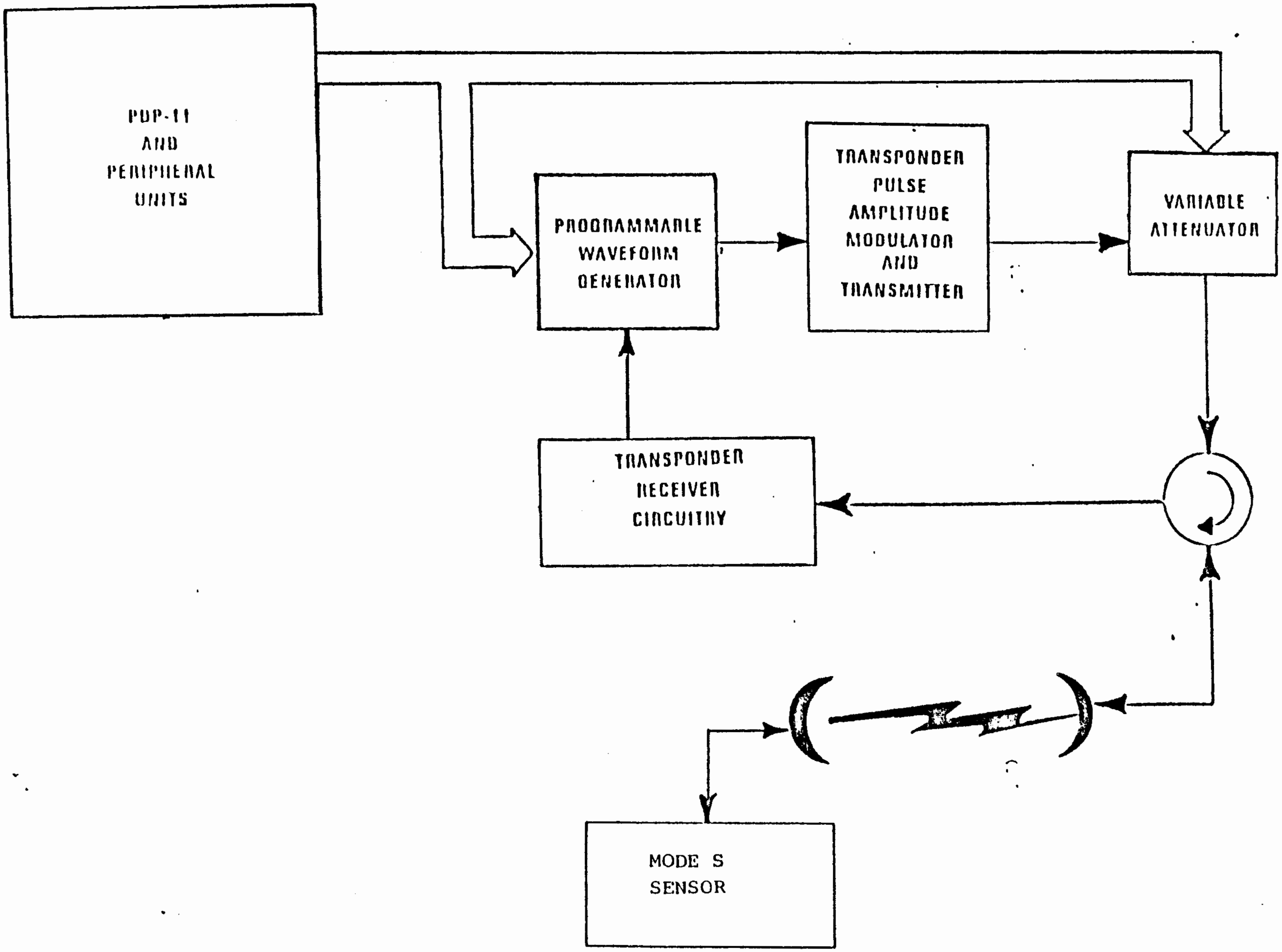

PDP-11
AND
PERIPHERAL
UNITS
PROGRAMMABLE
WAVEFORM
GENERATOR
TRANSPONDER
PULSE
AMPLITUDE
MODULATOR
AND
TRANSMITTER
VARIABLE
ATTENUATOR
TRANSPONDER
RECEIVER
CIRCUITRY
MODE S
SENSOR

FIGURE 1

TEST	SPECIFIC OBJECTIVE	DR&A	INTERPRETATION
LEVEL 1 (L1)	"STATIC BENCH TESTS" Determine the Mode S subsystem Reply and Report performance as a function of specfic Mode S transponder characteristics.	Statistics, Plots, Tables, Graphs, etc	Determine if there are any unique "Out-of-Tolerance" Mode S transponder characteristics that induce signifigant Mode S deviations in: target detection, positional accuracy, and code identity/altitude reliability & confidence.
PHASE 1 (L1.1)	"BASELINE PERFORMANCE" Determine a baseline of performance for the Mode S Reply Processor by determining the following 8 critical elements in Reply processing relative to in-tolerance transponder characteristics: Round Reliability, Message Bit Reliability & Confidence, Message Decoding with Error Correction, Monopulse Estimate, Range & Azimuth Estimate, Failure Codes, Reinterrogations & Splits.	Statistical table that defines the following: 1. Round Reliability 2. Message Reliability /Confidence 3. Message Decoding 4. Monopulse Value 5. Range & Azimuth Estimate 6. Failure Code 7. Reinterrogations 8. Splits	Evaluate a signifigant quantity of baseline data and determine that the statistical data computed defines the necessary subsystem performance characteristics. Establish that a satisfactory level of performance was attained in "Reply" processing relative to the critical elements in Mode S Reply Processing.

TABLE 1. Level 1, Phase 1, TEST MATRIX.

TEST	SPECIFIC OBJECTIVE	DR&A PRESENTATION	INTERPRETATION
PHASE 2	"OUT-OF TOLERANCE LIMITS"		
(L1.2)	Determine the performance of the Mode S sensor Reply Processor as a function of transponder characteristic at maximum/minimum limits or out-of-tolerance limits	Plots defining the critical elements in "Reply" and "Report processing relative to defined Mode S "Out-of Tolerance"	Identify any significant deviation of performance relative to the baseline data.
TEST 1 (L1.2.1) " .1a " .1b " .1c " .1d " .1e " .1f	"Round Reliability" as a function of transponder: a. Frequency b. Pulse Spacing c. Pulse Shape d. Reply Delay e. Reply Power f. Receiver Sensitivity	Plots of the percent of scans a reply was detected divided by total number scans, for each incremental change in the test transponder characteristic.	Establish the susecptibility of the Mode S Reply Processor relative to the critical elements defined when the transponder is operated at other than normal reply characteristics
TEST 2 (Li.2.2) " .2a " .2b " .2c	"Message Bit Reliability and Confidence as a function transponder: a. Frequency b. Pulse spacing c. Pulse Shape	Plot of number of correct messages devided by the number of messages that were detected.	
TEST 3 (Li.2.3) " .3a " .3b " .3c	"Message Decoding (Error Detection & Correction)" as a function transponder: a. Frequency b. Pulse spacing c. Pulse Shape	Plot of number of incorrect replies devided by the number of replies that were corrected.	
TEST 4 (L1.2.4) " .4a " .4b " .4c	"Reply Monopulse Value"as a function of transponder: a. Frequency b. Pulse Spacing c. Pulse Shape	Plot of deviation relative to baseline mean in AU's.	
TEST 5 (Li.2.5) " .5a " .5b " .5c " .5d	"Range/Azimuth Estimate" as a function of transponder: a. Frequency b. Pulse Spacing c. Pulse Shape d. Reply Delay	Plots of range and azimuth deviation relative to baseline mean in Ru's & Au's	
TEST 6 (L1.2.6)	"Failure Codes" as a function of all Transponder characteristics	The number of occurrences relative to characteristic	
TEST 7 (L1.2.7)	"Reinterrogations" as a function of all Transponder characteristics	Same as Test L1.2.6	
TEST 8 (L1.2.8)	"Splits (Rng/Az)" as a function of all Transponder characteristics	Same as Test L1.2.6	

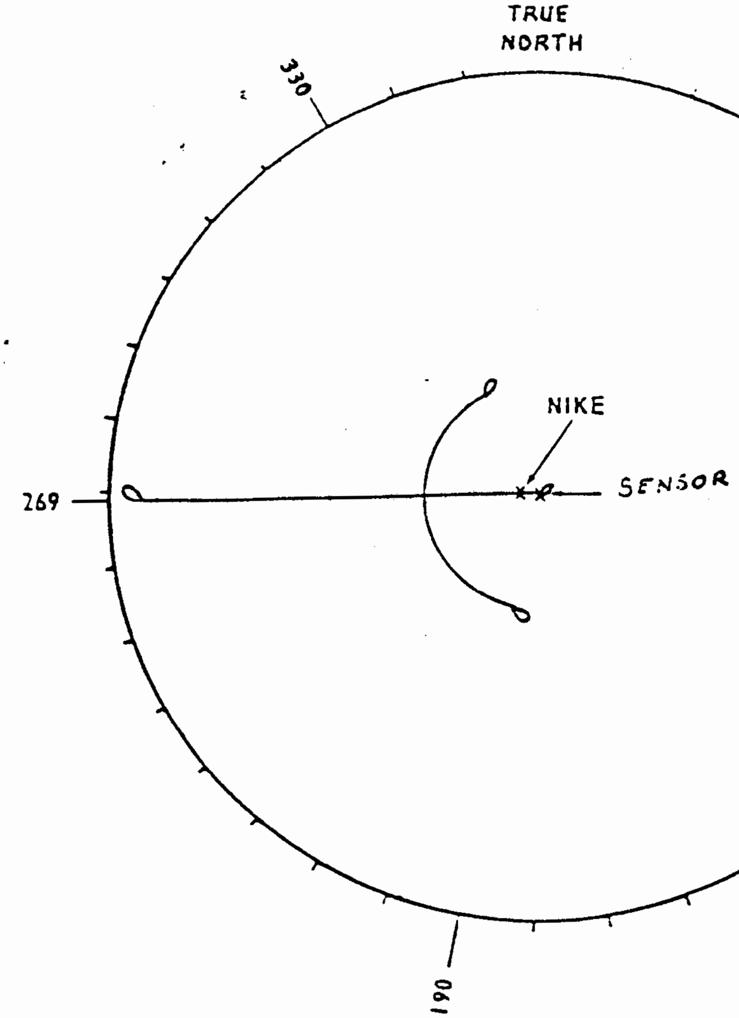
TABLE 2. Level 1, PHASE 2, TEST MATRIX.

TEST	SPECIFIC OBJECTIVE	DR&A	INTERPRETATION
LEVEL 2 (L2)	"FLIGHT TEST PERFORMANCE" Determine the Mode S "System" surveillance performance as a function of specific Mode S transponder characteristics using live world flight tests. The specific transponder characteristics to be tested will be determined after analysis of Level 1, Static Tests.	Statistics, Plots AND Tables.	Determine if there will be any measurable compromise relative to the present Mode S surveillance tracking capabilities to "Out-of-Tolerance" Mode S transponders after the implementation of the Mode S Sensors in an operational environment.
PHASE 1 (L1.2)	"OUT-OF-TOLERANCE LIMITS" Determine the sensor's Surveillance Tracking Performance, Reliability and Confidence as a function of specific transponder characteristics operating at maximum/minimum and out-of tolerance limits.	Plots to define surveillance performance	Establish a level of performance that can be expected from Mode S surveillance tracking and reliability relative to specific Out-of-Tolerance Mode S transponder limits.
TEST 1 (L1.1.1)	"Track Blip Scan Ratio" as a function of selected transponder characteristic	Tests 1 through 6 will be defined using both plots and tables of statistics for each flight tested transponder tolerence.	
TEST 2 (L2.1.2)	"Track Acquisition" (same as Test 1)		
TEST 3 (L2.1.3)	"Continuity & Firmness" (same as Test 1)		
Test 4 (L2.1.4)	"Positional Accuracy" (same as Test 1)		
Test 5 (L2.1.5)	"Splits & Swaps" (same as Test 1)		
TEST 6 (L2.1.6)	"Message Reliability & Confidence" (same as Test 1)		

Table 3. Level 2, Phase 1, Test Matrix.

TEST PHASE	1	2		
MODE S TRANSPONDER CHARACTERISTIC	BASELINE TOLERANCES	MINIMUM MAXIMUM TOLERANCES	OUT OF TOLERANCE	INCREMENTAL CHANGES OF:
FREQUENCY MHZ >1500 FT. ALT.	1090 " "	1087 & 1093 1089 & 1091	<1087 to 1082 >1093 to 1098	1.0 MHZ.
PULSE SPACING (USEC.)				
A. PREAMBLE PULSES	1, 3.5, 4.5 (relative to first pulse)	+ 0.05 - 0.05	>0.05 <0.05	25 NSEC.
B. DATA PULSES	(multiples of 0.5usec.)	+ 0.05 - 0.05	>0.05 <-0.05	25 NSEC.
PULSE SHAPE				
A. PULSE WIDTH (USEC.)	0.5 1.0	0.45 & 0.55 0.95 & 1.05	<0.45 >0.55 >0.95 >1.05	25 NSEC.
B. AMPLITUDE VARATION DB	NONE	+ 2.0 DB - 2.0 DB	<-2.0 to -4.0 >2.0 to +4.0	1.0 DB.
REPLY DELAY (USEC.)				
A. 1st preamble pulse to P6 sync O reversal	128	127.75 128.25	<127.75 >128.25	25 NSEC.
B. 1st to P4	128	127.5 128.5	<127.5 >128.5	50 NSEC.
SENSITIVITY (DBM)				
A. 90% Detect	-74.0	-71.0 -77.0	<90.0%	1.0 DB.
B. 99% Detect	MTL + 3.0 DB. and -24.0 DBm	-68 to -74 99% @ -24.0	<99.0%	1.0 DB.
C. 10% Detect	-81.0	10% @ -81.0	>10.0%	1.0 DB.
REPLY POWER (DBw.)				
A. >1500 FT	> 21.0 DB	21.0 & 27.0	<21.0 to 18.0 >27.0 to 30.0	1.0 DB.
B. <1500 FT	> 18.5	18.5 & 27.0	<18.5 to 12.0 >27.0 to 30.0	1.0 DB.

TABLE 4. Mode S TRANSPONDER CHARACTERISTICS.



FLIGHT TYPE	DESCRIPTION
Radials	Inbound and outbound flights along a 269 degree true azimuth radial at; 1. an altitude of 2,500 feet and ranging from 0 to 50 nautical miles. 2. an altitude of 5,000 feet and ranging from 0 to 60 nautical miles. 3. an altitude of 15,000 feet and ranging from 0 to 60 nautical miles.
Orbitals	Clockwise and counter clockwise flights along a 140 degree arc at; 1. an altitude of 2,500 feet and a range of 5 nautical miles. 2. an altitude of 6,000 feet and a range of 13 nautical miles. 3. an altitude of 12,000 feet and a range of 13 nautical miles.

Table 5

DATA COLLECTION PLAN

The test sequence will be chacterized by an orderly progression from the separate evaluation of the Mode S sensor Reply Processor subsystem to assessments of overall Mode S surveillance system performance and compatibility to "Out-of-Tolerance Mode S transponders.

Tables 1 and 2 of the "Test Matrix" define all Static Bench Tests test number. For classification purposes, tests are labled sequentially, starting with L1 for Level 1, L1.1 for the first "Phase" of testing in Level 1, and L1.1.1 for the first "Test" in Level 1, Phase 1. The following is an example of the above:

```
Level   Phase   Test
  |       |       |
  --->Lx. x. x <--
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Table 3 of the "Test Matrix" defines all tests to be conducted in Level 2, "Flight Test Performance".

Though the objectives are grouped under headings labeled "Tests", it is not implied that a separate test mission will be conducted for each individual test. In general, a given test mission will fulfill the objectives of a group of tests.

L1. LEVEL I "STATIC BENCH TESTS", Test Matrix Tables 1 and 2.

The main objective of Level 1, "Static Bench Tests" is to determine the MODE S sensor's subsystem "Reply" and "Report" performance as a function of specfic Mode S transponder characteristics.

This section provides detailed planning information for each phase of testing within Level 1. Mode S sensor compatibility testing is arranged in the following way; first, a basic set of prerequisites for all the Level 1 tests are listed. These prerequisite activities should be completed and the results known before scheduling the Mode S sensor. The Level 1 static tests defined in the test matrix are divided into 2 test phases. The purpose of each test phase is to determine Mode S subsystem compatibility as a function of specific Mode S transponder characteristics. These transponder characteristics are listed in Table 4.

Mode S sensor reply and report live environment data will be recorded on magnetic tape by the sensor's data extraction system. Data collection will be limited to the geographic location of the test transponder located in the Technical Centers laboratory. The information recorded by the data extraction software will be used as inputs to the various computer data reduction programs.

PREREQUISITES

Activities which must be completed and the results of these activities known prior to beginning Mode S compatibility performance tests to "Out-of-Tolerance" Mode S transponders.

1. The performance of the test transponder has been verified to operate within "U.S. National Aviation Standards for Mode S Transponders".

2. All special test instrumentation, equipment, and etc, have been checked out and verified.

3. Satisfactory and reliable performance of the test transponder has been demonstrated when modified to an "out-of-tolerance" condition. This predominately pertains to the test configurations and characteristic.

L1.1 PHASE 1 "BASELINE PERFORMANCE", Test Matrix Table 1.

The objective of Phase 1 testing is to determine a baseline of performance for the Mode S Reply Processor as a function of in-tolerance Mode S test transponder characteristics.

Performance will be compared to the performance attained during subsequent test phases to determine the effects different Mode S transponder characteristics have on overall Mode S sensor subsystem performance.

The following eight critical elements in Mode S Reply and Report processing relative to transponder characteristic will be defined: (1) Round Reliability, (2) Message Bit Reliability and Confidence, (3) Message Decoding with Error Detection and Correction, (4) Monopulse Estimate, (5) Range and Azimuth Estimate, (6) Failure Codes, (7) Re-interrogations, and (8) Splits (Rng/Az).

The data necessary to statistically define the critical elements in Mode S reply processing performance will be obtained by the Mode S sensor eliciting replies from the test transponder located in the Technical Center's laboratory. Both Mode S Reply and Report data will be collected over a 2,000-scan interval. These data will be recorded on magnetic tape by the Mode S data extraction system. The reply and report data will be analyzed to compute the Mode S subsystem performance.

L1.2 PHASE 2 "OUT-OF-TOLERANCE PERFORMANCE", Test Matrix Table 2.

The purpose of Phase 2 testing is to determine the performance of the Mode S Reply Processor as a function of Mode S transponder characteristics operating at specific maximum and minimum limits, and out-of-tolerance limits. These limits are defined in Table 4, Test Phase 2. Also included in this table are the incremental changes to transponder characteristics that will be investigated to define Mode S compatibility.

The data necessary to statistically define the critical elements in Mode S reply report processing performance will be obtained by the Mode S sensor eliciting replies from the TRU-2/MTPA configuration located in the Technical Center's laboratory. Approximately 300-scans of "Reply" and "Report" data will be collected for each incremental change in transponder characteristic. These data will be recorded on magnetic tape by the Mode S data extraction system. The data will be analyzed to compute the Mode S subsystem performance to maximum/minium tolerance limits and out-of-tolerance limits.

Test Phase 2, will determine the performance for each critical element defined in Phase 1, "Baseline Performance" but for Mode S transponders operating at the characteristics listed in Table 4, Phase 2.

L1.2.1 Test 1, "Round Reliability".

The objective of this test is to determine the "Round Reliability of the Mode S Reply Processor as a function of transponder:
a) Frequency, b) Pulse Spacing, c) Pulse Shape, d) Delay, e) Power, and f) Receiver Sensitivity.

L1.2.1a Round reliability vs. transponder frequency.
L1.2.1b " " pulse spacing
L1.2.1c " " pulse shape.
L1.2.1d " " delay.
L1.2.1e " " power.
L1.2.1f " " receiver sensitivity.

The remaining seven tests will not require additionl data collection. Data collected during the "Round Reliability" tests will also define the remaining tests.

L1.2.2 Test 2, "Message Bit Reliability and Confidence"

L1.2.2a Message Bit Reliability and Cofidence vs. tansponder frequency.
L1.2.2b " " pulse spacing.
L1.2.2c " " pulse shape.

L1.2.3 Test 3, "Message Decoding with Error Detection and Correction"".

L1.2.3a Reply Code vs. frequency.
L1.2.3b " " pulse spacing.
L1.2.3c " " pulse shape.

L1.2.4 Test 4, "Monopulse Value".

L1.2.4a Reply Monopulse Value vs. frequency.
L1.2.4b " " pulse spacing.
L1.2.4c " " pulse shape.

L1.2.5 Test 5, "Range and Azimuth Estimates*".

L1.2.5a Range & Azimuth Estimate vs. transponder frequency.
L1.2.5b " " pulse spacing.
L1.2.5c " " pulse shape.
L1.2.5d " " delay.

L1.2.6 Test 6, "Failure Codes".

L1.2.6a-6f Failure Codes vs. all transponder characteristics.

L1.2.7 Test 7, "Re-interrogations".

L1.2.7a-7f Reinterrogations vs. all transponder characteristics.

L1.2.8 Test 8, "Splits (Rng/Az)".

L1.2.8a-8f Splits vs. all transponder characteristics.

DATA COLLECTION PLAN.

L2. LEVEL 2 "FLIGHT TEST PERFORMANCE", Test Matrix Table 3.

The main objective of Level 2 tests is to determine the MODE S sensor's surveillance performance as a function of specfic Mode S transponder characteristics using live world flight tests.

The flight tests will be conducted using the Technical Center's Nike tracking system and the Mode S system. The test aircraft will be equipped with the MTPA/TRU-2 Mode S transponder used during the Level 1, Static Bench Tests. This configuration will be operated in the "ATCRBS Only" mode. The flight plan for the tests will be composed of radial flights, and orbitial flights. The specifics of the flight plan are listed in Table 5.

To minimize flight time, only those transponder characteristics that indicated degradation to "Reply and/or Report" processing will be investigated relative to Mode S surveillance performance.

L2.1 PHASE 1 Test.

The purpose of Phase 1 testing is to determine the Mode S sensor Surveillance Tracking Performance, Reliability, and Confidence as a function of specific test transponder characteristics operating at maximum/minimum allowable limits, and out-of-tolerance limits using live world flight tests.

The following six critical elements in Mode S surveillance performance will be defined for each flight test: (1) Track Blip-Scan-Ratio, (2) Track Acquisition, (3) Tracking Continuity and Firmness, (4) Track Position Accuracy, (5) Track Splits and Swaps, and (6) Message Reliability and Confidence.

L2.1.1 Test 1, "Track Blip Scan Ratio".

L2.1.2 Test 2, "Track Acquisition".

L2.1.3 Test 3, "Continunity and Firmness".

L2.1.4 Test 4, "Positional Accuracy".

L2.1.5 Test 5, "Splits and Swaps".

L2.1.6 Test 6, "Message Reliability and Confidence".

The data necessary to statistically define the critical elements in Mode S surveillance performance will be obtained by the Mode S sensor eliciting replies from the test transponder located in the test aircraft. Selected transponder characteristics will be varied and data will be collected for each incremental change. Data will be recorded simultaneously on magnetic tape by both the Mode S sensor and Nike-Hercules system. The data will be analyzed to compute the Mode S subsystem performance to maximum/minimum tolerance limits and out-of-tolerance limits.

DATA REDUCTION AND ANALYSIS

Data reduction and analysis will be accomplished, wherever possible, using automated data reduction techniques. Software from previous testing efforts is available for processing the Mode S sensor and Nike Hercules data extracion tapes. This software will be run on the Honeywell 66/60 and Digital Equipment Corporation (DEC) PDP-11 computers. Any remaining analysis will be performed manually by inspecion of data listings dumped from magnetic tape, or, through the development of new data reduction tools.

Software currently available on the PDP-11 computer includes all the Mode S data reduction software developed for the Mode S baseline testing. This software can list, plot, and provide statistics on selected parameters from the sensor DEX tape on both the reply and report level. It will be used extensively in the data reduction effort.

Software curently available on the Honeywell 66/60 computer includes the Live World Analysis program and the Accuracy Analysis program. The Live World Analysis program uses the sensor DEX tape, and can be used to analyze surveillance processing on the report level. The program acts like a tracker and provides data on blip scan ratio, Id reliability, Id confidence and the average number of interrogations per scan for each test. The Accuracy Analysis program utilizes the sensor and Nike DEX tapes. The program coordinate converts the Nike range, azimuth and altitude to the sensor's coordinates and calculates the range, azimuth and altitude mean errors, plus standard deviations.

The data presentation in the final report will be organized into four major areas. The first will be tables listing the baseline performance data collected under Level 1, Phase 1, as per table 1, of the test matrix. This baseline performance data will provide the means for comparison analysis in all subsequent presentations. The second area of the presentation will consist of plots depicting the eight critical test elements under Mode S Reply Processor Performance (Level 1, Phase 2), as per table 2 of the test matrix. Each test element will be plotted versus a particular transponder function, as that function is varied across its out of tolerance values. These values and the incremental changes to be used are listed in table 4, columns 4 and 5. An example would be a plot of Round Reliability versus Frequency as Frequency is varied from 1082 MHz to 1098 MHz, in steps of 1 MHz. The final area of the data presentation will present the results of the level 2, phase 1, categories 1 and 2 testing. Since this analysis depends on the results of level 1, phase 2, testing, it is difficult to predict exactly how it will be presented. However, it can be said that it will be similar to the presentations in areas two and three described above.

REFERENCES

1. Discrete Address Beacon System (DABS) Baseline Test and Evaluation, Report No. FAA-RD-80-36, April 1980.

2. U.S. National Aviation Standard For The Discrete Address Beacon System, Appendix 1 to Order 6365.1.

3. Discrete Address Beacon System Functional Descripition, Report No. FAA-RD-80-41, April 1980.

4. Discrete Address Beacon System (DABS) Sensor Engineering Requirement, Report No. FAA-ER-240-26, July 1980.

5. NAFEC Range Instrumentation Systems, Report No. FAA-NA-79-32, February 1980.

6. TRU-2 DABS/ATC Transponder System, Maintenance Manual I.B.1171A.

7. Design Requirements For An ATCRBS/DABS/ADSEL Aircraft Transponder Test System, Report No. DOT-FAA-CT-81-203, July 1981.

APPENDIX A

CRITICAL ELEMENTS OF MODE S REPLY PROCESSING

ROUND RELIABILITY:
Round Reliability is the percentage of replies received from an aircraft compared to the number of interrogations directed to the aircraft.

MESSAGE BIT RELIABILITY & CONFIDENCE:
message bit reliability and confidence is the number of times a Mode S rerply with the correct message is detected by the message bit processor, divided by the total number of times the Mode S reply was detected with the correct or incorrect message. The message bit processor produces a sequence of information bit decisions and a corresponding sequence of confidence bits, prior to error detection and correction.

MESSAGE DECODING with ERROR CORRECTION:
The function of message decoding is to check the bit decisions for errors by means of a parity check, and if errors are detected, to then use the confidence bit sequence to attempt to locate a burst error pattern spanning up to 24 bit decisions that would correct the message.

MONOPULSE VALUE:
The monopulse value for the Mode S reply is formed as the average of fifteen acceptable samples which correlate with a monopulse reference derived using two acceptable, monopulse samples.

RANGE ESTIMATE:
Target range for a Roll Call reply is computed from the expected range delay, D1 (from the target record), the measured range correction, D2 (from the Mode S Reply Processor), the transponder turnaround delay (Roll Call = 132 uS.), and by any other system delay D5.

$$\text{True Range} = D1+D2-(132uS-D5)$$

Target range for an All Call reply is computed form the measured range, D3 (from the Mode S Rely Processor), the transponder turnaround delay (All Call = 129.5 uS), and any other system delay D4.

$$\text{True Range} = D3-(129.5uS+D4)$$

AZIMUTH ESTIMATE:
The reply azimuth estimate for the reply is calculated in terms of the antenna boresight azimuth and the monopulse average for the reply. The monopulse average is first used to calculate an index into a look up table. If the index is within the beamwidth of the main antenna lobe, the index provides a value from the table which is the off boresight angle of the reply. This off boresight angle is added to the antenna boresight azimuth to give the final reply azimuth estimate.

FAILURE CODES:
A two bit field in the Mode S roll call target report that indicates the following:

00 - valid reply
01 - no preamble (same as no reply detected)
10 - no reply decode (same as error correction not possible)
11 - no monopulse estimate

REINTERROGATIONS:
If a roll call reply report is not detected within the scheduled period, a reinterrogation will occur while in the antenna main beam.

SPLITS: (RANGE AND AZIMUTH):
Splits are the generation of two reports from one transponders replies. Splits can result from code or azimuth declaration erors in the reply processor caused by delay variations or environmental effects. Azimuth splits are often caused when the transponder frequency, amplitude of elevation angle is unusual, thus producing reply characteristics which do not match the monopulse calibration of the Mode S sensor.

CRITICAL ELEMENTS OF MODE S SURVEILLANCE TRACKING PERFORMANCE.

SURVEILLANCE BLIP SCAN RATIO:
The number of times the surveillance file for a track is updated, divided by the sum of the number of updates, plus the number of coasts.

ACQUISITION:
Acquisition is when a declared target report from reply correlation does not correlate with any existing tracks, but does correlate with a report from the previous scan, and a new track is initiated.

CONTINUITY:
Continuity is an indication of how well a target remains on track. The targets track life or track history in terms of its firmness and surveillance file number is how continuity is measured.

FIRMNESS:
Firmness is a number associated with a track ranging from a minimum value of one, set at track initiation, to some maximum allowable limits. Each scan in which there is no report which correlates with a track, the track is coasted and its firmness increased until it reaches the maximum limit and dropped.

SWAPS:
Swaps are the existence of two surveillance file numbers for one aircraft and/or one surveillance file number for two aircraft. Swaps are a function of aircraft flight patterns.

POSITION ACCURACY:
Position accuracy will be defined in terms of a distribution of the range and azimuth errors of the test target as compared to the range and azimuth inputs from an independent source. This independent source will be the Nike Hercules tracking system.