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ANALYSIS OF THE EFFECT OF OUT-OF-TOLERANCE TRANSPONDERS ON AN EN ROUTE ATCRBS

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IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center
Annapolis, Maryland 21402



May 1976

FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, DC 20591

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16. Abstract

A test program conducted by the Lincoln Laboratory of the Massachusetts Institute of Technology on a random sample of Air Traffic Control Radar Beacon System (ATCRBS) transponders indicated that some transponders were operating with characteristics outside the specified limits prescribed by the National Aviation Standard. The Federal Aviation Administration (FAA) requested that the Electromagnetic Compatibility Analysis Center (ECAC) predict the effect on selected performance parameters of the ATCRBS caused by out-of-tolerance transponders in the environment.

The Air Route Surveillance Radar at Suitland, Maryland was selected as the location to predict the performance of the three types of transponders considered in the analysis (Military, Air Carrier, and General Aviation). The interrogator environment consisted of IFF/ATCRBS interrogators deployed within an 850 nautical-mile radius of Suitland and the aircraft transponder deployment consisted of aircraft at various azimuths, altitudes, and ranges within a 200 statute-mile radius of Suitland. For the deployed aircraft, different percentages of aircraft were designated as having out-of-tolerance transponders. The AIMS Performance Prediction Model was used to predict the performance of the Suitland interrogator for both in-tolerance and out-of-tolerance transponder characteristics for the three types of transponders analyzed.

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16. Abstract (Continued)

Deviations from the standard tolerances for transponder output power, interrogation and sidelobe suppression dead times, and for squitter rates caused predicted reductions in Common Digitizer target detection and code validation probabilities of no more than a few percentage points.

Deviations from the standard values of transponder receiver sensitivity, framing pulse spacing and reply frequency were predicted to produce a noticeable degradation in Common Digitizer performance.

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PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DoD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Assistant-Secretary of Defense for Communication, Command, Control, and Intelligence and the Chairman, Joint Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-76-C-0017, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the USA Standards Institute.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

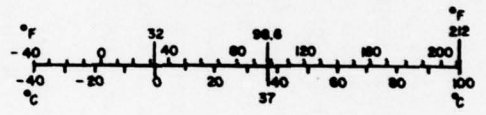
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 236, 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



FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

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SECTION 1

INTRODUCTION

BACKGROUND

The Air Traffic Control Radar Beacon System (ATCRBS) is the major source of surveillance data for air traffic control. Because of increases in air traffic, the Federal Aviation Administration (FAA) has continued to improve and develop the ATCRBS. A test program[1] was undertaken by the Lincoln Laboratory of the Massachusetts Institute of Technology to measure the operating characteristics of a random sample of ATCRBS transponders. The test program indicated that some ATCRBS transponders were operating with characteristics outside the specified limits of the National Aviation Standard.[2] The FAA has tasked the Electromagnetic Compatibility Analysis Center (ECAC) to perform a parametric analysis to determine the effect of out-of-tolerance transponders on the performance of an en route ATCRBS.

OBJECTIVE

The objective of this analysis was to predict the effect of out-of-tolerance transponders on selected ATCRBS performance parameters.

APPROACH

The AIMS Performance Prediction Model (PPM)[3] was used in this analysis. Modifications were made to the model in order to simulate the effects of variations in transponder characteristics.

The interrogator environment used in the analysis consisted of 274 IFF/ATCRBS interrogators deployed within a 850 nautical-mile radius of the ARSR Site in Suitland, Maryland. Only the minimum interrogator environment (interrogators that operate at least 8 hours per day) was considered.

---

[1]Colby, G. V., and Crocker, E. A., *Final Report, Transponder Test Program,* FAA-RD-72-30, Lincoln Laboratory, 12 April 1972.

[2]*FAA-Order 1010.5A, U.S. National Standard for the IFF MARK X (SIF) ATCRBS Characteristics.*

[3]Sutton, S. and Ehler, W., "Application of Markov Chain Theory to the Modelling of IFF/SSR Systems," *AGARD Conference Proceedings, No. 159,* NATO, November 1975.

The aircraft deployment consisted of 189 transponder-equipped aircraft deployed at various ranges, azimuths and altitudes within a 200-statute mile radius of the Suitland site. Different percentages of transponders were designated among the 189 deployed aircraft as having out-of-tolerance transponder characteristics. Three transponder types, classified as Military, Air Carrier, and General Aviation transponders, each with different features and operating characteristics, were considered in this analysis. The transponder characteristics varied in this analysis were:

1. Output power
2. Receiver sensitivity
3. Squitter rate
4. Sidelobe suppression dead time
5. Interrogation dead time
6. Reply frequency
7. Framing pulse spacing.

Values of the above parameters were inputs to the AIMS PPM. The nominal values and the values having the extreme variations from the nominal values, both high and low, taken from the measured data in Reference 1 were used.

Three transponder environments were selected for analysis. One consisted of all (100%) transponders having nominal characteristics. The other two had 100% and 20% of the transponders respectively with out-of-tolerance characteristics. Values of transponder characteristics for the latter two environments range from both the highest and lowest from the nominal.

From the AIMS PPM, the performance of the Suitland interrogator was predicted for each transponder environment (Military, Air Carrier and General Aviation) separately using transponders' nominal characteristics. This was the baseline performance. This process was repeated for the 100% and 20% out-of-tolerance environments with the parameters of each type transponder varied one at a time using various out-of-tolerance values. The effect on selected ATCRBS parameters was predicted for each case and the results were tabulated, graphed and compared with the base line performance.

SECTION 2

SYSTEM DESCRIPTION

GENERAL

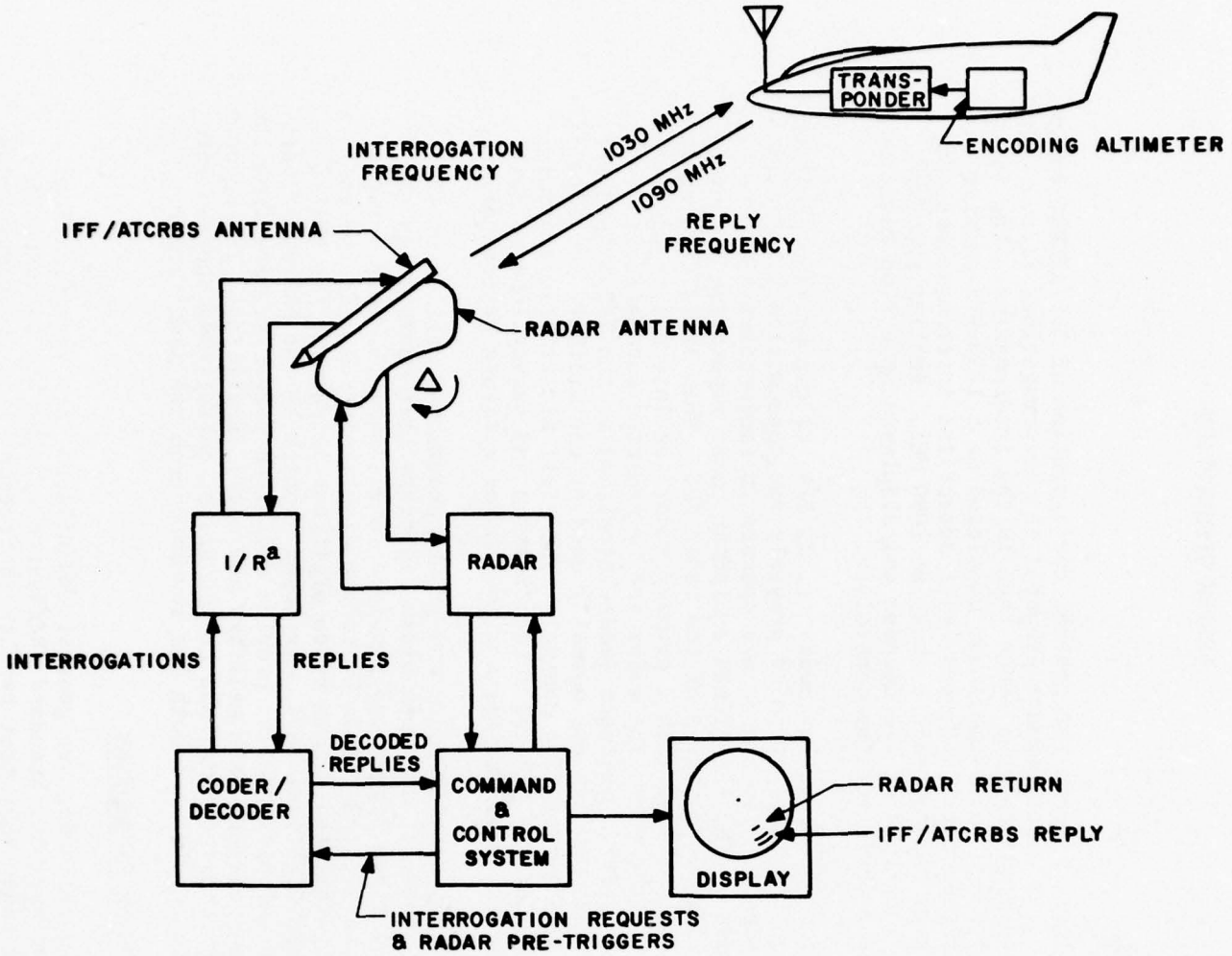
Figure 1 shows the general configuration of IFF/ATCRBS equipments. The coder/decoder prepares the interrogations (i.e., target identity requests) and sends them to the interrogator. The interrogations are pulse-amplitude modulated on a 1030-MHz carrier. Aircraft, properly equipped, will detect the interrogations, decode them, and transmit a reply at 1090 MHz. Replies received at the interrogator are decoded and displayed on a Plan Position Indicator (PPI) for the controller.

Four interrogation modes (1, 2, 3/A, C) can provide position and identity information of properly equipped military and civilian aircraft. The beacon may operate in conjunction with the primary radar. The IFF/ATCRBS equipment pulse repetition frequency (PRF) is a sub-multiple of the radar PRF. When IFF/ATCRBS equipments are not used with a primary radar, an internal trigger establishes the PRF. The modes are transmitted automatically in a given repetitive sequence (mode interlace) at the IFF/ATCRBS PRF. Modes 1, 2, and 3/A are normally used by the military for identification and air traffic control. The civil air traffic control systems use mode 3/A for identification and surveillance. Both military and civilian may use mode C for altitude determination.

In the Coder/Decoder and ground processing portion of the system, there is a beacon video digitizer that operates on the received video signal and provides range, azimuth, mode 3 reply code, and altitude (mode C) to the display system. In the enroute system, the beacon video digitizer is part of the AN/FYQ-47 Common Digitizer (CD), developed jointly by the FAA and Department of Defense (DoD) to provide digitized target reports from the enroute system to both military and civil facilities. The CD operates on both the radar and beacon video, correlating the two into a single report when both are received from the same target.

TRANSPONDER PARAMETERS

The following are general definitions and specifications from the National Standard (Reference 2), and the corresponding Lincoln Laboratory test results (Reference 1) of the transponder parameters investigated in the analysis.



[a]Interrogator/Receiver

Figure 1. General configuration of IFF/ATCRBS equipments.

Output Power (PW)

Output power is defined as the peak pulse power available at the antenna end of the transmission line of the transponder. The level is specified in Reference 2 to be between 21 dB and 27 dB above one watt (dBW) for aircraft operating above 15,000 feet and between 18.5 dBW and 27 dBW for aircraft operating below 15,000 feet.

Thirty-five of 504 general aviation transponders in the Lincoln Laboratory sample (Reference 1) had output powers deviating from specification limits, while 5 of 15 military and 23 of 27 air carrier transponders had output powers ranging from 2 to 5 dB above the specified limit.

Receiver Sensitivity (RSENS)

The receiver sensitivity is defined as the minimum trigger level for P_1 and P_3 pulses received at the input of the transponder receiver during a valid interrogation, and this level is specified in Reference 2 to be between 69 dB and 77 dB below one milliwatt (dBm).

Approximately 121 of 504 of general aviation transponders in the sample had receiver sensitivities beyond the allowable range; 4 of 15 military and 6 of 27 air carrier transponders had sensitivities 2 to 6 dB above the specified limit (Reference 1).

Squitter Rate

Other equipment installed on the aircraft may produce interference and randomly trigger the transponder to transmit false replies in the absence of legitimate interrogations. The rate of the false replies transmitted is referred to as the squitter rate and is required by Reference 2 to be under 30 squitters per second.

Only nine of the 504 general aviation transponders tested exhibited squitter in excess of the specification limit. No squitter occurred in the tests of military and air carrier transponders (Reference 1).

Sidelobe Suppression Time (SLS Time)

Sidelobe suppression time is defined as the dead time period for the inhibition of the transponder upon receipt of a sidelobe interrogation. This dead time period is specified by Reference 2 to be 35 ± 10 μs.

Approximately 48 of 504 of the general aviation transponders tested exhibited suppression times which 32 exceeded and 16 were less than specification limits. One of five of the military transponders, and one of twenty-six air carrier units were found to have suppression times shorter than the specified suppression time (Reference 1).

Dead Time

After receipt of a proper interrogation, the transponder shall not reply to any other interrogations for the duration of the reply pulse train. The dead time period shall end no later than 125 μs after the transmission of the last reply pulse of the group (Reference 2).

Thirty-two of 504 general aviation transponders in the sample had excessive dead time. Three of 15 military transponders had dead times greater than the specification. None of the 27 air carrier units exceeded the dead time specification (Reference 1).

Reply Frequency

The carrier frequency of the transponder reply signal is specified by Reference 2 to be 1090 ± 3 MHz for all types of transponders.

Fifty of 504 general aviation transponders had carrier frequencies outside the specified limits. All 27 air carrier and all except one of 15 military units tested were within the specification (Reference 1).

Reply Pulse Spacing

The reply pulse spacing is the spacing between the two leading edges of the framing pulses of the transponder reply. This spacing is specified by Reference 2 to be 20.3 ± 0.1 μs.

Thirteen of 504 general aviation transponders, two of 17 military units, and one of 28 air carrier units had out-of-tolerance framing pulse spacings (Reference 1).

SECTION 3

ENVIRONMENTAL DATA FILES AND SYSTEM MODEL

DATA FILES

ECAC Aircraft Deployment File

The aircraft deployment was obtained from radar scope photographs to simulate an environment containing aircraft deployed at various ranges, azimuths, and altitudes within a user-specified geographic area. Each aircraft was assigned a transponder with various characteristics. In this analysis, two aircraft deployment files were used.

Suitland Deployment File. This aircraft deployment file consists of 189 aircraft deployed within a 200-statute mile radius of the Suitland Air Route Surveillance Radar (ARSR), Maryland. This file was referred to as the 100% transponder environment in this analysis since the entire 189 aircraft were assumed to be equipped with transponders having nominal characteristics to obtain the base line reference predictions. Then the entire 189 aircraft were assumed to be equipped with transponders having out-of-tolerance characteristics in order to obtain predictions of their effect on selected ATCRBS parameters.

Suitland 1 Deployment File. This file contains the same numbers of aircraft at each location, however, 20% of the 189 aircraft were assumed to have transponders with out-of-tolerance characteristics while the other 80% were assumed to have nominal operating characteristics.

ECAC IFF/ATCRBS Interrogator File

This computer-stored ECAC IFF Master File contains the equipment characteristics of all the interrogators in the CONUS. The interrogator file used in this analysis was a subset of the master file and consisted of 274 IFF/ATCRBS interrogators within an 850 nautical mile radius of the Suitland ARSR. The ATCRBS interrogator located at the Suitland site was the interrogator of interest (I_o) in this analysis.

TABLE 1 shows the characteristics of the I_o. TABLE 2 shows the nominal characteristics for the general aviation, air carrier, and military transponders used in this report.

TABLE 1

DATA FOR INTERROGATOR OF INTEREST (I_o)

Site Latitude	=	38°58'08" N
Site Longitude	=	76°58'25" W
Total Height	=	365 feet
Power	=	0.8 kW
Receiver Sensitivity	=	-81 dBm
Main beam Gain/Width[a]	=	21 dB/4°
Sidelobe Gain/Width[a]	=	-7 dB/56°
Backlobe Gain/Width[a]	=	-19 dB/300°
Antenna Scan Rate	=	6 RPM
Pulse Repetition Frequency	=	355 pulse pairs per second
Sidelobe Suppression Type	=	Improved sidelobe suppression (ISLS)
Mode Interlace	=	3-3-C

[a]Three-level approximation to horizontal antenna pattern used for AIMS PPM.

SYSTEM MODEL DESCRIPTIONS

AIMS PPM

The AIMS PPM (Reference 3) is a computer simulation model which was developed to predict IFF/ATCRBS performance in a user-specified environment consisting of interrogators and transponders each with its own characteristics. Utilizing this environment as input data to the model, the performance of each transponder in the environment is evaluated and system performance can be calculated for the I_o. The basic model is constructed of 19 Transponder Models (TM's). Each TM is a state space representation of time periods of 2 μs. The probability of a signal being in a certain state is called the Steady State Probability and the probability of transitions between these states is referred to as the Transition Probability. Each TM contains various numbers of states representing transponders with different mode capabilities, decoding capabilities, and lengths of dead time. Each TM can be modified to have different mode capabilities and dead time characteristics with the additions or subtractions of decoding states, dead time states or transition path between the states. The following are the modifications to the model which were necessary in order to vary the appropriate transponder characteristics:

Transition paths were added to some transponder models in order to include the squitter rate effect on the transponder.

TABLE 2

TRANSPONDER CHARACTERISTICS USED IN THE ANALYSIS

General Aviation Transponder

Nominal Transponder Characteristics

Receiver Sensitivity	=	-69.0 dBm
Transmitter Power	=	+52.0 dBm
Mode Capability	=	3, C
SLS Capability	=	Yes
SLS Dead Time	=	35 μs
Reply Dead Time	=	35 μs
RRL Threshold[a]	=	1200 Replies/s
Antenna Gain	=	0 dBi

Air Carrier Transponder

Nominal Transponder Characteristics

Receiver Sensitivity	=	-74.0 dBm
Transmitter Power	=	+57.0 dBm
Mode Capability	=	3, C
SLS Capability	=	Yes
SLS Dead Time	=	35 μs
Reply Dead Time	=	35 μs
RRL Threshold[a]	=	1200 Replies/s
Antenna Gain	=	0 dBi
AOC Limit[b]	=	18000 pulse/s
SLS Limit	=	7500 Suppression/s

Military Transponder

Nominal Transponder Characteristics

Receiver Sensitivity	=	-78.0 dBm
Transmitter Power	=	+57.0 dBm
Mode Capability	=	1, 2, 3, C
SLS Capability	=	Yes
SLS Dead Time	=	35 μs
Reply Dead Time	=	90 μs
RRL Threshold[a]	=	1200 Replies/s
Antenna Gain	=	0 dBi
AOC Limit[b]	=	18000 Pulse/s
SLS Limit	=	5000 Suppression/s
CDC Limit[c]	=	1500 Pulse/s

[a]RRL - reply rate limit

[b]AOC - automatic overload control limit

[c]CDC - computer duty cycle limit

Figure 2 shows an example of the addition of a transition loop in one of the transponder models.

Transitions from the sidelobe suppression states to the 35-μs suppression dead time state were moved to a different state in the transponder dead time train in order to obtain a different sidelobe suppression dead time.

Dead time states were added to one transponder model to obtain longer dead time for the transponders.

No modifications to the model were required when varying the transponder output power and receiver sensitivity since these two parameters are model inputs.

In order to calculate the system performance of the I_o, the model first calculates the performance of each transponder in the environment. Taking one transponder at a time, the PPM determines the interrogators receivable by each transponder. These interrogators are then grouped in subsets according to mode interlace, and transition probability calculations are made.

After the transition probabilities are calculated, the appropriate transponder model is used to calculate the steady-state probabilities which in turn are used to predict the following transponder performance probabilities:

probability of reply
probability of garble
probability of sidelobe suppression
interrogation rates (each mode)
sidelobe suppression rates
fruit rates
interrogators receivable.

From the performance of each transponder, the I_o performance can be determined. The system performance predictions for the I_o are the fruit per second received at the I_o when the antenna main beam of the I_o is directed at each target and target detection probabilities for each target.

Digital Signal Response Computer Program (DSR)

Another ECAC computer model, DSR was used to predict the effect on the I_o receiver due to off-tuned reply signals from the transponders. The DSR model is capable of predicting the normalized response of a receiver upon receiving a pulse with specified rise time, fall time, pulse duration, and carrier frequency. The receiver can be assigned a tuned center frequency,

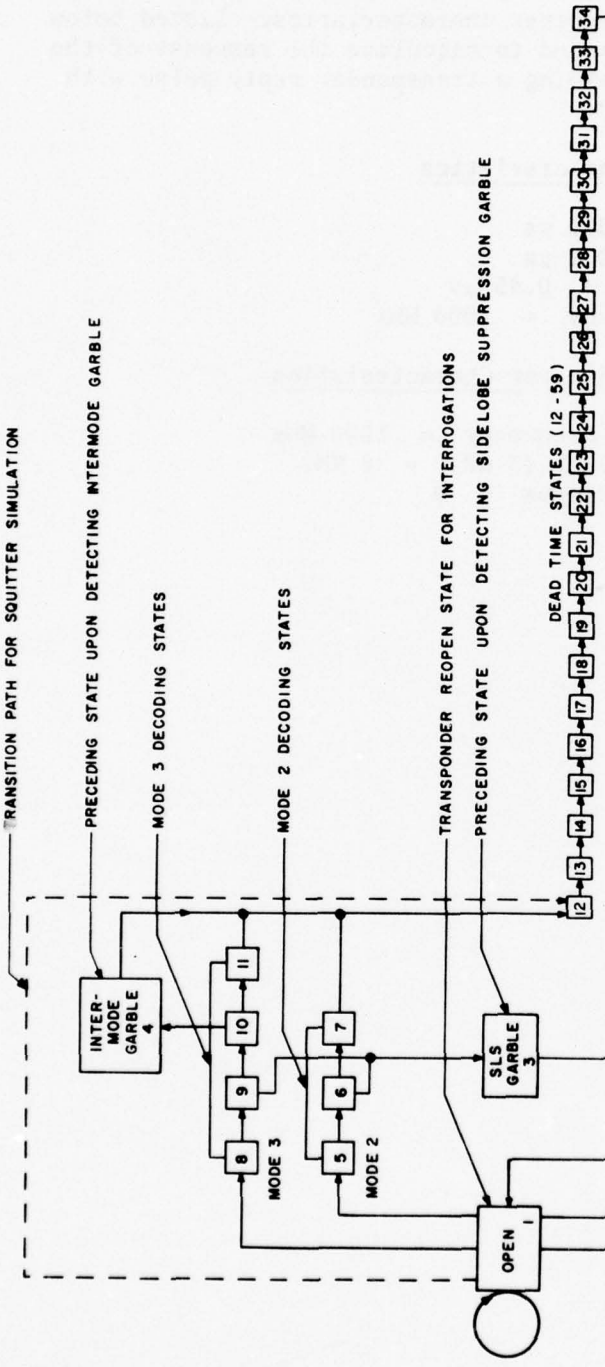


Figure 2. State representation of transponder model showing squitter simulation.

a bandwidth (BW), and a number of tuning stages. Utilizing the model, the output response can be calculated and graphed based on the input pulse and receiver characteristics. Listed below is a set of input data needed to calculate the response of the ATCRBS receiver upon receiving a transponder reply pulse with varying carrier frequency.

Reply Pulse Characteristics

Rise Time = 0.1 μs
Fall Time = 0.1 μs
Pulse Duration = 0.45 μs
Carrier Frequency = 1090 MHz

Interrogator Receiver Characteristics

Receiver Tuned Frequency = 1090 MHz
Receiver Bandwidth (3 dB) = 8 MHz
No. of Tuning Stages = 9

SECTION 4

ANALYSIS

GENERAL

The performance of the ATCRBS is ultimately evaluated in terms of the ability of the ground system to correctly detect and identify valid targets. The two predicted AIMS PPM parameters which impact the performance of the Common Digitizer (CD) are the transponder reply probability and the fruit rate received at the interrogator-of-interest. The performance of the CD is expressed in terms of three probabilities obtained through an ECAC model:

Probability of mode 3 validation
Probability of mode C validation
Probability of target detection.

In this analysis, the predicted performance of one target aircraft transponder was presented as representative of the maximum impact on CD performance due to changes in transponder characteristics.

Changes in transponder characteristics affected the ATCRBS signal environment and resulted in changes in fruit rates and transponder reply probability. Resultant fruit rates and reply probability distributions are illustrated in APPENDIX A. The average reply probability to the I_o and the CD performance were each tabulated separately following each analysis. The results obtained for the baseline deployment which consisted of 189 aircraft transponders with nominal characteristics were compared with the results obtained for two transponder environments, 100% environment or 20% environment, which represent 100% or 20% of the 189 transponders operating with out-of-tolerance characteristics in the same aircraft deployment respectively. Each graph or table is identified with transponder type, along with the transponder parameters used and the percentage of out-of-tolerance transponders in the environment.

OUTPUT POWER

General

Changes in transponder output power influenced the amount of sidelobe and backlobe fruit detected at I_o. Increasing the output power allowed the I_o to receive more asynchronous replies from distant transponders, resulting in increases in sidelobe and backlobe fruit at the I_o. Decreasing the output power lowered the number of asynchronous replies from distant transponders, thereby decreasing the total fruit rate at I_o. No change was predicted

to the system reply probability since there was no change in the ATCRBS uplink environment and interrogation density.

General Aviation Transponder

100% Transponder Environment. At a transponder output power of 44 dBm, no backlobe fruit was detected by the I_o, and no target loss was predicted by the PPM at the I_o. Changes in fruit rate for different transponder output powers are shown in Figure A-1.

20% Transponder Environment. Fruit rate graphs for each case were drawn separately for the higher output power and lower output power values with different scales for clarity (Figures A-2 and A-3). The performance of the CD for both 100% and 20% environments is illustrated in TABLE 3.

Air Carrier Transponders

100% Transponder Environment. The PPM predicted that for a transponder output power level of 60 dBm, 3 dB above the specification, the total fruit rate received at the I_o increased on the average by approximately 2000 per second (See Figure A-4). Fruit rate predictions are made for the high and low transponder power levels and results were illustrated on the same graph. No target loss occurred at the I_o at a reduced power level of 46 dBm.

20% Transponder Environment. Fruit rates predicted at different transponder output power levels are shown in Figure A-5. The performance of the Common Digitizer for both the 100% and 20% environments is illustrated in TABLE 4.

Military Transponders

General. Since military aircraft transponders are equipped to have higher receiver sensitivity and output power, and are capable of replying to modes 1 and 2 in addition to modes 3/A and C, higher fruit rates were expected to be received at the I_o.

100% Transponder Environment. As the power level was increased to 59 dBm for all the transponders in the environment, the total fruit rate increased on the average approximately by 1000 to 2000 per second. Fruit rate predictions were obtained for power levels of 62 dBm and 46 dBm as illustrated in Figure A-6. No target loss occurred with the minimum output power of 46 dBm.

TABLE 3

PERFORMANCE OF THE COMMON DIGITIZER WITH GENERAL AVIATION TRANSPONDERS AT VARIOUS OUTPUT POWERS IN THE ENVIRONMENT (COMPARISON OF NOMINAL TO THE MAXIMUM CHANGE FOR A TYPICAL TARGET SELECTED FROM DEPLOYMENT)

Transponder Environment	Output Power (dbm)	Total Fruit Per Second	Reply Probability	Probability of Mode 3 Code Validation	Probability of Mode C Code Validation	Probability of Target Detection
100%	Nominal (52)	1981	99%	100%	99%	100%
100%	44	1022	99%	100%	99%	100%
	47	1153	99%	100%	99%	100%
	59	4166	99%	99%	99%	100%
	62	5148	99%	99%	99%	100%
20%	44	1515	99%	100%	99%	100%
	47	1522	99%	100%	99%	100%
	59	2273	99%	100%	99%	100%
	62	2335	99%	100%	99%	100%

TABLE 4

PERFORMANCE OF THE COMMON DIGITIZER WITH AIR CARRIER TRANSPONDERS AT VARIOUS OUTPUT POWERS IN THE ENVIRONMENT (COMPARISON OF NOMINAL TO THE MAXIMUM CHANGES FOR A TYPICAL TARGET SELECTED FROM DEPLOYMENT)

Transponder Environment	Output Power (dBm)	Total Fruit Per Second	Reply Probability	Probability of Mode 3 Code Validation	Probability of Mode C Code Validation	Probability of Target Detection
100%	Nominal (57)	6247	97%	99%	99%	100%
100%	46	1758	97%	100%	99%	100%
	60	7325	97%	99%	99%	100%
	65	10960	97%	99%	98%	100%
20%	46	5376	97%	99%	99%	100%
	60	6707	97%	99%	99%	100%
	65	7178	97%	99%	99%	100%

20% Transponder Environment. Fruit rates predicted at different transponder output levels are shown in Figure A-7. The performance of the CD for both the 100% and 20% environments is illustrated in TABLE 5.

RECEIVER SENSITIVITY

General

The impact on the fruit rate resulting from changes in receiver sensitivity was similar to varying the output power of each interrogator in the environment. The PPM showed that changes in receiver sensitivity primarily influenced the sidelobe and backlobe fruit rate at the I_o. Increased receiver sensitivity allowed each transponder to detect more asynchronous interrogations from distant interrogators in the environment and to reply to such interrogations. This caused increases in the total fruit rate at the I_o and decreases in reply probability due to the increased dead time of the transponders. Decreasing the receiver sensitivity eliminated some of the asynchronous interrogations, thereby decreasing the total fruit rate at the I_o, while increasing reply probability. As receiver sensitivity decreased below a threshold level of -69 dBm, I_o target loss was experienced due to some distant transponders which were not able to receive the I_o's main beam interrogations.

General Aviation Transponders

100% Transponder Environment. The PPM predicted increases in the total fruit rate (Figure A-8) and decreases in reply probability (Figure A-10) as the receiver sensitivity increased from -69 dB to -80 dBm, -83 dBm and -87 dBm. At receiver sensitivities higher than -83 dBm, the reply rate limiting (RRL) was triggered into effect and desensitization of some of the transponder receivers resulted. The PPM also predicted reduction of the total fruit rate (Figure A-9) and increases in the reply probability (Figure A-11) as the receiver sensitivity decreased from -69 dBm to -65 dBm, -57 dBm, and -51 dBm. At transponder receiver sensitivities lower than -69 dBm, target losses were experienced by the I_o as some distant transponders were not able to receive the I_o's interrogations.

20% Transponder Environment. Fruit rate and reply probability trends in this case were similar to those obtained for the 100% environment. Detailed fruit rate and reply probability predictions are shown in Figures A-12 through Figure A-15.

TABLE 5

PERFORMANCE OF THE COMMON DIGITIZER WITH MILITARY TRANSPONDERS AT VARIOUS OUTPUT POWERS IN THE ENVIRONMENT (COMPARISON OF NOMINAL TO THE MAXIMUM CHANGES FOR A TYPICAL TARGET SELECTED FROM DEPLOYMENT)

Transponder Environment	Output Power (dBm)	Total Fruit Per Second	Reply Probability	Probability of Mode 3 Code Validation	Probability of Mode C Code Validation	Probability of Target Detection
100%	Nominal (57)	9992	93%	99%	98%	100%
100%	46	2657	93%	100%	99%	100%
	59	10977	93%	99%	97%	99%
	62	13631	93%	98%	95%	99%
20%	46	8327	93%	99%	98%	100%
	59	10497	93%	99%	97%	99%
	62	10661	93%	99%	97%	99%

Average reply probabilities with numbers and ranges of target loss for both the 100% and 20% environment are illustrated in TABLE 6. The performance of the CD for both cases is illustrated in TABLE 7.

TABLE 6

AVERAGE REPLY PROBABILITY PREDICTIONS FOR I_o WITH GENERAL AVIATION TRANSPONDERS AT VARIOUS RECEIVER SENSITIVITIES IN THE ENVIRONMENT

Transponder Environment	Receiver Sensitivity (dBm)	Probability of Reply to I_o	Number of Targets Lost	Ranges of Target Loss (nmi)
100%	Nominal (-69)	98%	0	
100%	-51	99%	148	> 30
	-57	99%	112	> 64
	-65	99%	14	> 154
	-80	92%	0	
	-83	88%	0	
	-87	86%	0	
20%	-51	98%	30	> 30
	-57	98%	23	> 64
	-65	98%	3	> 156
	-80	97%	0	
	-83	96%	0	
	-87	95%	0	

Air Carrier Transponders

100% Transponder Environment. The PPM predicted that the fruit rate increased on the average by a factor of 2 and 3 as the receiver sensitivity varied from -74 dBm to -80 dBm and -84 dBm respectively (Figure A-16). A corresponding reduction in reply probability also occurred (Figure A-17). At a receiver sensitivity of -66 dBm, a reduction in the fruit rate with a slight increase in reply probability was noted. Also, 6 transponders which were located further than 169 nmi from the I_o were not able to receive the I_o interrogation.

20% Transponder Environment. The PPM predicted a much less severe impact on the fruit rate and reply probability as the receiver sensitivity was varied in a 20% transponder environment (Figures A-18 and A-19). The average reply probability and performance of the CD for both cases are illustrated in TABLES 8 and 9, respectively.

TABLE 7

PERFORMANCE OF THE COMMON DIGITIZER WITH GENERAL AVIATION TRANSPONDERS AT VARIOUS RECEIVER SENSITIVITIES IN THE ENVIRONMENT (COMPARISON OF NOMINAL TO THE MAXIMUM CHANGES FOR A TYPICAL TARGET SELECTED FROM DEPLOYMENT)

Transponder Environment	Receiver Sensitivity (dBm)	Total Fruit Per Second	Reply Probability	Probability of Mode 3 Code Validation	Probability of Mode C Code Validation	Probability of Target Detection
100%	Nominal (-69)	1981	99%	100%	99%	100%
100%	-51	176	Target Loss			
	-57	433	100%	100%	99%	100%
	-65	939	99%	100%	99%	100%
	-80	9057	91%	99%	98%	99%
	-83	14201	88%	97%	93%	99%
	-87	15266	84%	95%	91%	99%
20%	-51	1294	Target Loss			
	-57	1361	100%	100%	99%	100%
	-65	1575	99%	100%	99%	100%
	-80	4713	91%	99%	99%	99%
	-83	6876	88%	99%	98%	99%
	-87	7243	84%	99%	97%	99%

TABLE 8

AVERAGE REPLY PROBABILITY PREDICTIONS FOR I_o WITH AIR CARRIER TRANSPONDERS AT VARIOUS RECEIVER SENSITIVITIES IN THE ENVIRONMENT

Transponder Environment	Receiver Sensitivity (dBm)	Probability of Reply to I_o	Number of Targets Lost	Ranges of Target Loss (nmi)
100%	Nominal (-74)	96%	0	
100%	-66	98%	6	>169
	-80	92%	0	
	-84	87%	0	
20%	-66	97%	0	
	-80	95%	0	
	-84	94%	0	

TABLE 9

PERFORMANCE OF THE COMMON DIGITIZER WITH AIR CARRIER TRANSPONDERS AT VARIOUS RECEIVER SENSITIVITIES IN THE ENVIRONMENT (COMPARSON OF NOMINAL TO THE MAXIMUM CHANGES FOR A TYPICAL TARGET SELECTED FROM DEPLOYMENT)

Transponder Environment	Receiver Sensitivity (dBm)	Total Fruit Per Second	Reply Probability	Probability of Mode 3 Code Validation	Probability of Mode C Code Validation	Probability of Target Detection
100%	Nominal (-74)	6247	97%	99%	99%	100%
100%	-66	2441	99%	100%	99%	100%
	-80	14926	91%	98%	94%	99%
	-84	23539	86%	88%	83%	99%
20%	-66	5306	99%	99%	99%	100%
	-80	8817	91%	99%	98%	99%
	-84	11708	86%	98%	94%	99%

Military Transponders

General. Due to the capability of military transponders to reply to additional modes, greater variations of the fruit rate and reply probability were obtained by varying the receiver sensitivity in the military transponders.

100% Transponder Environment. Fruit rate and reply probability plots obtained for various values of receiver sensitivity are shown in Figures A-20 and A-21. At a receiver sensitivity of -66 dBm, the 6 transponders located greater than 169 nmi from the I_o were not able to receive I_o's interrogations.

20% Transponder Environment. Fruit rate and reply probability distributions for this environment are shown in Figures A-22 and A-23. Average reply probabilities and the performance of the CD are illustrated in TABLES 10 and 11, respectively.

SQUITTER RATE

General

Squitter pulses are randomly generated asynchronous interference which may trigger the transponder to send out false replies in the absence of bonafide interrogations. The probability of a false target generated by squitter pulses being displayed on the I_o radar scope is very small. But as the squitter rate increases, the transponders in the environment will generate additional false replies and also be suppressed more often, causing an increase in the system fruit rate and a decrease in reply probability. If the squitter rate is high enough to trigger the transponder to transmit replies at a rate over 1200 per second (the reply rate limit setting on transponders to prevent overloading the transmitter), the RRL (Reply Rate Limiting) circuit will be activated which results in a reduction in the receiver sensitivity of the transponder, possibly resulting in target loss as the transponder is not able to receive interrogations from the ground system.

General Aviation Transponder

General. Since no squitter pulses were present in the test of air carrier and military transponders in the survey (Reference 1), only the general aviation transponder is discussed in the analysis.

100% Transponder Environment. The PPM predicted a very slight impact on I_o performance with all transponders in the environment emitting squitters at a rate of 50/s. More effect on the fruit rate was predicted at a squitter rate of 400/s. With a squitter rate of 2000/s, all transponders experienced RRL effects causing

TABLE 10

AVERAGE REPLY PROBABILITY PREDICTIONS FOR I_O WITH MILITARY TRANSPONDERS AT VARIOUS RECEIVER SENSITIVITIES IN THE ENVIRONMENT

Transponder Environment	Receiver Sensitivity (dBm)	Probability of Reply to I_o	Number of Targets Lost	Ranges of Target Loss (nmi)
100%	Nominal (-78)	92%	0	
100%	-66	98%	6	> 169
	-81	87%	0	
	-86	79%	0	
20%	-66	93%	0	
	-81	91%	0	
	-86	89%	0	

TABLE 11

PERFORMANCE OF THE COMMON DIGITIZER WITH MILITARY TRANSPONDERS AT VARIOUS RECEIVER SENSITIVITIES IN THE ENVIRONMENT (COMPARISON OF NOMINAL TO THE MAXIMUM CHANGES FOR A TYPICAL TARGET SELECTED FROM DEPLOYMENT)

Transponder Environment	Receiver Sensitivity (dBm)	Total Fruit Per Second	Reply Probability	Probability of Mode 3 Code Validation	Probability of Mode C Code Validation	Probability of Target Detection
100%	Nominal (-78)	9992	93%	99%	98%	100%
100%	-66	2521	99%	100%	99%	100%
	-81	16992	88%	95%	91%	99%
	-86	25688	77%	75%	72%	98%
20%	-66	8209	99%	99%	99%	100%
	-81	12364	88%	98%	95%	99%
	-86	14680	77%	90%	86%	98%

reduction of receiver sensitivity and 182 transponders were desensitized out of range of the I_o. Also the fruit rate varied irregularly over the whole azimuth (See Figure A-24). The impact on the reply probability distribution due to different squitter rates is shown in Figure A-25.

20% Transponder Environment. Negligible effects on I_o performance occurred at low squitter rates. At a squitter rate of 2000/s, target loss of transponders farther than 8 nmi occurred. Fruit rate and reply probability are shown in Figures A-26 and A-27. Average reply probabilities and the performance of the CD are illustrated in TABLES 12 and 13.

SIDELOBE SUPPRESSION DEAD TIME (SLS TIME)

General

SLS dead time is often a significant factor in determining the reply probability in an ATCRBS environment. For General Aviation and Air Carrier transponders which have lower receiver sensitivity than military types, the PPM predicted no effect on the reply probability and fruit rate when varying the SLS time from 35 μs to 14 μs or 94 μs. This was due to the lower SLS detection rate these two types of transponders experienced in the environment. For the military transponders which experienced high SLS rates due to their greater sensitivity, the PPM predicted greater changes in the reply probability caused by changes in the SLS dead time setting in the transponders. Only military transponders are discussed below.

Military Transponders

100% Transponder Environment. As the SLS dead time was varied from its nominal value of 35 μs to 14 μs and 20 μs, each transponder was capable of receiving and replying to more interrogations, causing increases in reply probability and slight increases in the total fruit rate. As the SLS time was increased to 50 μs, 80 μs, or 94 μs, each transponder would be suppressed for longer periods causing a reduction in reply probability and total fruit rate. Graphs for each case are shown in Figures A-28, A-29 and A-30.

20% Transponder Environments. Negligible impact on the system fruit rate occurred for the 20% environments but changes in reply probability due to changes in SLS dead time still occurred (See Figures A-31 and A-32). The average reply probability and the Common Digitizer performance are illustrated in TABLES 14 and 15, respectively.

TABLE 12

AVERAGE REPLY PROBABILITY PREDICTIONS FOR I_o WITH GENERAL AVIATION TRANSPONDERS AT VARIOUS SQUITTER RATES IN THE ENVIRONMENT

Transponder Environment	Squitter Per Second	Probability of Reply to I_o	Number of Targets Lost	Ranges of Target Loss (nmi)
100%	Nominal 0	98%	0	
100%	50	98%	0	
	400	97%	0	
	2000	93%	182	> 8
20%	50	98%	0	
	400	98%	0	
	2000	98%	39	> 8

TABLE 13

PERFORMANCE OF THE COMMON DIGITIZER WITH GENERAL AVIATION TRANSPONDERS AT VARIOUS SQUITTER RATES IN THE ENVIRONMENT (COMPARISON OF NOMINAL TO THE MAXIMUM CHANGES FOR A TYPICAL TARGET SELECTED FROM DEPLOYMENT)

Transponder Environment	Squitter Per Second	Total Fruit Per Second	Reply Probability	Probability of Mode 3 Code Validation	Probability of Mode C Code Validation	Probability of Target Detection
100%	Nominal (0)	1981	99%	100%	99%	100%
100%	50	2570	99%	100%	99%	100%
	400	6635	98%	99%	99%	100%
	2000	292	Target Loss			
20%	50	2206	99%	100%	99%	100%
	400	3761	98%	99%	99%	100%
	2000	1392	Target Loss			

TABLE 14

AVERAGE REPLY PROBABILITY PREDICTIONS FOR I_o WITH MILITARY TRANSPONDERS AT VARIOUS SIDELOBE SUPPRESSION TIMES IN THE ENVIRONMENT

Transponder Environment	Sidelobe Suppression Time (μs)	Probability of Reply to I_o	Number of Targets Lost
100%	Nominal (35)	92%	0
100%	14	94%	0
	20	93%	0
	50	90%	0
	80	88%	0
	94	86%	0
20%	14	92%	0
	20	92%	0
	50	91%	0
	80	91%	0
	94	90%	0

TABLE 15

PERFORMANCE OF THE COMMON DIGITIZER WITH MILITARY TRANSPONDERS AT VARIOUS SIDELOBE SUPPRESSION TIMES IN THE ENVIRONMENT (COMPARISON OF NOMINAL TO THE MAXIMUM CHANGES FOR A TYPICAL TARGET SELECTED FROM DEPLOYMENT)

Transponder Environment	Sidelobe Suppression Time (μs)	Total Fruit Per Second	Reply Probability	Probability of Mode 3 Code Validation	Probability of Mode C Code Validation	Probability of Target Detection
100%	Nominal (35)	9764	93%	99%	98%	100%
100%	14	10161	95%	99%	98%	100%
	20	10061	95%	99%	98%	100%
	50	9587	92%	99%	98%	100%
	80	9156	90%	99%	98%	99%
	94	8969	88%	99%	97%	99%
20%	14	9855	95%	99%	98%	100%
	20	9832	95%	99%	98%	100%
	50	9723	92%	99%	98%	100%
	80	9624	90%	99%	97%	100%
	94	9580	88%	99%	97%	99%

DEAD TIME

General

Increases in dead time upon receipt of a valid interrogation cause decreases in reply probability and fruit rates in the system.

General Aviation Transponders

100% Transponder Environment. While increasing the dead time from 35 μs to 126 μs, 150 μs, and 200 μs, the corresponding reductions of the transponder reply probability and fruit rate were obtained for each case (See Figures A-33 and A-34).

20% Transponder Environment. Since only 20% of the transponders in the environment were assigned a longer dead time, the PPM predicted less impact on the reply probability and negligible changes on the fruit rate (See Figure A-35).

The average reply probability and the performance of the Common Digitizer for both the 100% and 20% environment are illustrated in TABLES 16 and 17, respectively.

Air Carrier Transponders

General. The results obtained for Air Carrier Transponders when varying the dead time were similar to those for General Aviation Transponders.

100% Transponder Environment. The effects on fruit rate and reply probability for various dead time settings in the transponders are shown in Figures A-36 and A-37 .

20% Transponder Environment. Effects on reply probability for various dead time settings in the transponders are shown in Figure A-38. The average reply probabilities and the Common Digitizer performance are illustrated in TABLES 18 and 19, respectively.

REPLY FREQUENCY

The amount of off-tuned frequency (Δf) determined the amount of attenuation and distortion introduced to the pulses at the output of the receiver. Figures 3 through 8 show the predicted responses of the receiver upon receiving an ATCRBS reply pulse at various off-tuned carrier frequencies as predicted by the DSR program. For a Δf up to 4 MHz, where the reply frequency is still within the receiver tuned bandwidth, very little effect was imposed on the output response of the receiver as shown in Figures 3 and 4.

TABLE 16

AVERAGE REPLY PROBABILITY PREDICTIONS FOR I_o WITH GENERAL AVIATION TRANSPONDERS AT VARIOUS DEAD TIMES IN THE ENVIRONMENT

Transponder Environment	Dead Time (μs)	Probability of Reply to I_o	Number of Targets Lost
100%	Nominal (35)	96%	0
100%	150	94%	0
	200	92%	0
20%	150	96%	0
	200	95%	0

TABLE 17

PERFORMANCE OF THE COMMON DIGITIZER WITH GENERAL AVIATION TRANSPONDERS AT VARIOUS DEAD TIMES IN THE ENVIRONMENT (COMPARISON OF NOMINAL TO THE MAXIMUM CHANGES FOR A TYPICAL TARGET SELECTED FROM DEPLOYMENT)

Transponder Environment	Dead Time (μs)	Total Fruit Per Second	Reply Probability	Probability of Mode 3 Code Validation	Probability of Mode C Code Validation	Probability of Target Detection
100%	Nominal (35)	1981	99%	100%	99%	100%
100%	126	1919	98%	100%	99%	100%
	150	1910	98%	100%	99%	100%
	200	1892	97%	100%	99%	100%
20%	126	1842	98%	100%	99%	100%
	150	1838	98%	100%	99%	100%
	200	1831	97%	100%	99%	100%

TABLE 18

AVERAGE REPLY PROBABILITY PREDICTIONS FOR I_o WITH AIR CARRIER TRANSPONDERS AT VARIOUS DEAD TIMES IN THE ENVIRONMENT

Transponder Environment	Dead Time (μs)	Probability of Reply to I_o	Number of Target Lost
100%	Nominal (35)	98%	0
100%	125	97%	0
	150	96%	0
	200	95%	0
20%	125	98%	0
	150	98%	0
	200	97%	0

TABLE 19

PERFORMANCE OF THE COMMON DIGITIZER WITH AIR CARRIER TRANSPONDERS AT VARIOUS DEAD TIMES IN THE ENVIRONMENT (COMPARISON OF NOMINAL TO THE MAXIMUM CHANGES FOR A TYPICAL TARGET SELECTED FROM DEPLOYMENT)

Transponder Environment	Dead Time (μs)	Total Fruit Per Second	Reply Probability	Probability of Mode 3 Code Validation	Probability of Mode C Code Validation	Probability of Target Dectection
100%	Nominal (35)	6247	97%	99%	99%	100%
100%	150	5932	94%	99%	99%	99%
	200	5823	93%	99%	99%	99%
20%	150	5973	94%	99%	99%	99%
	200	5953	93%	99%	99%	99%

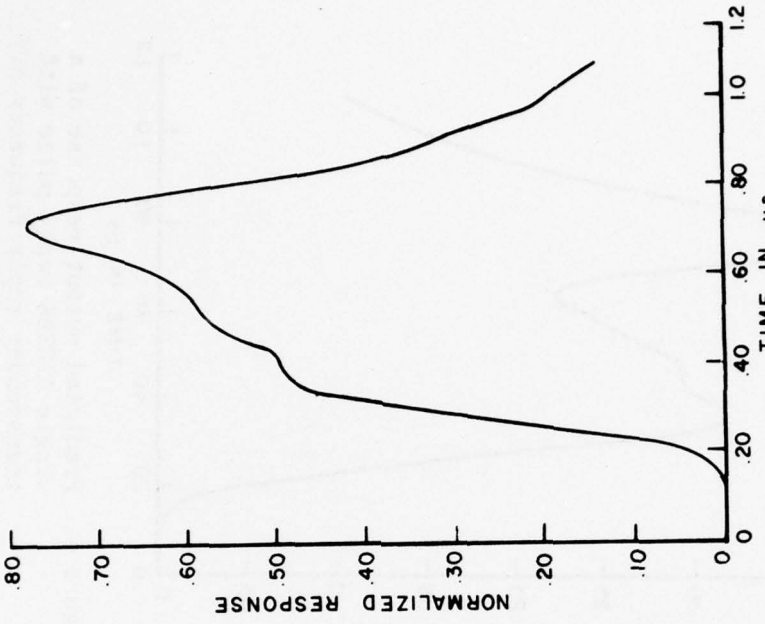


Figure 4. Predicted output response of a single ATCRBS reply pulse with transponder reply frequency off by 4 MHz.

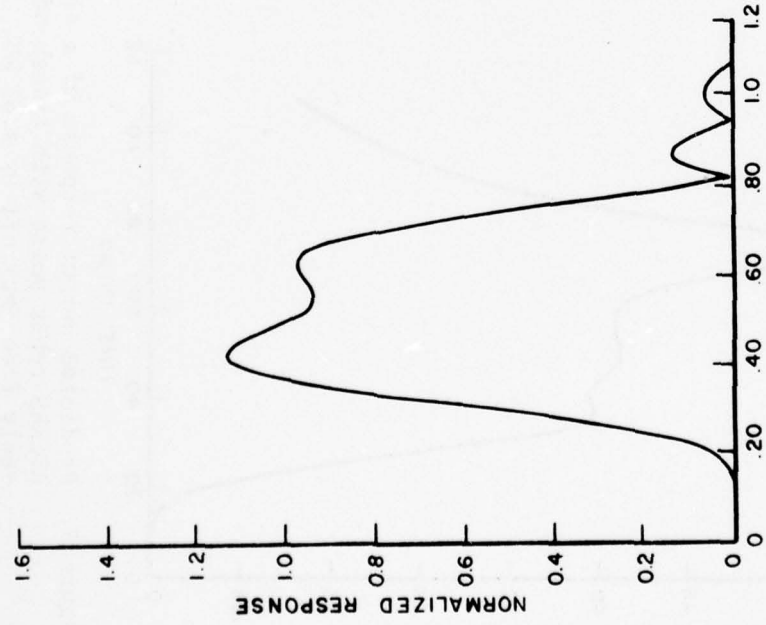


Figure 3. Predicted output response of a single ATCRBS reply pulse with transponder reply frequency on-tune.

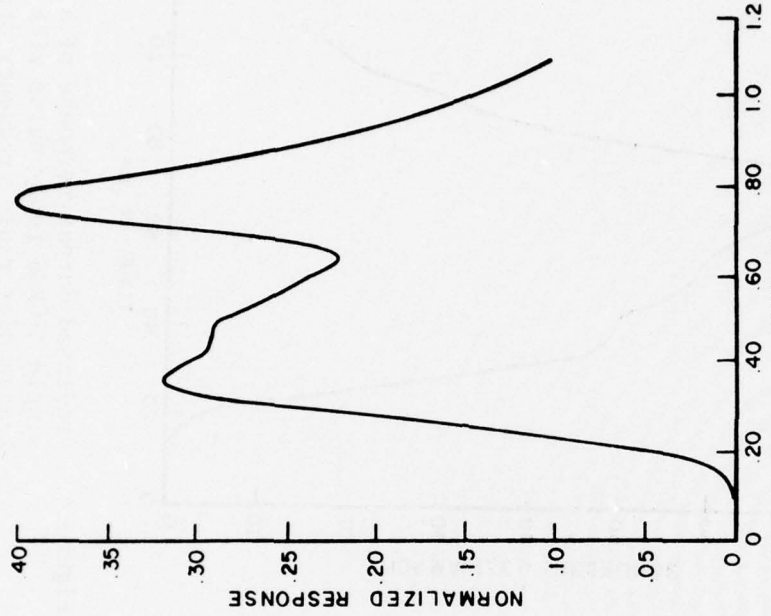


Figure 6. Predicted output response of a single ATCRBS reply pulse with transponder reply frequency off by 5 MHz.

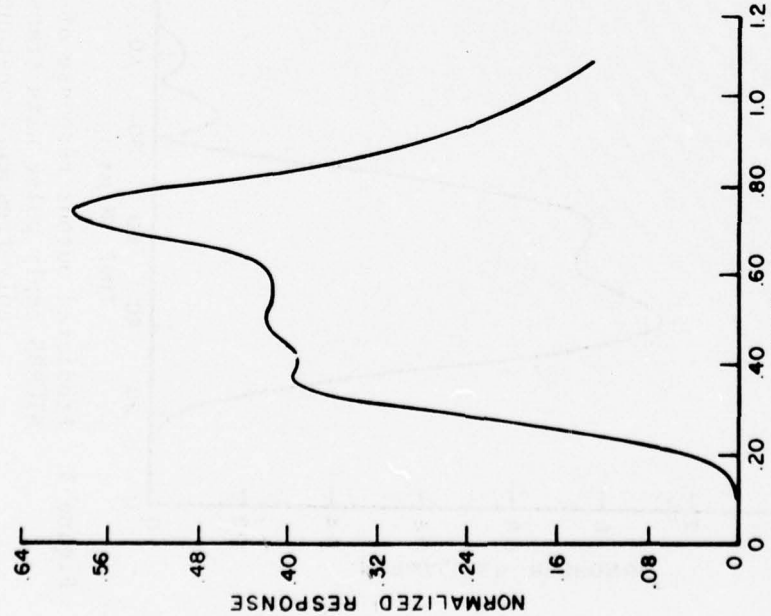


Figure 5. Predicted output response of a single ATCRBS reply pulse with transponder reply frequency off by 4.63 MHz.

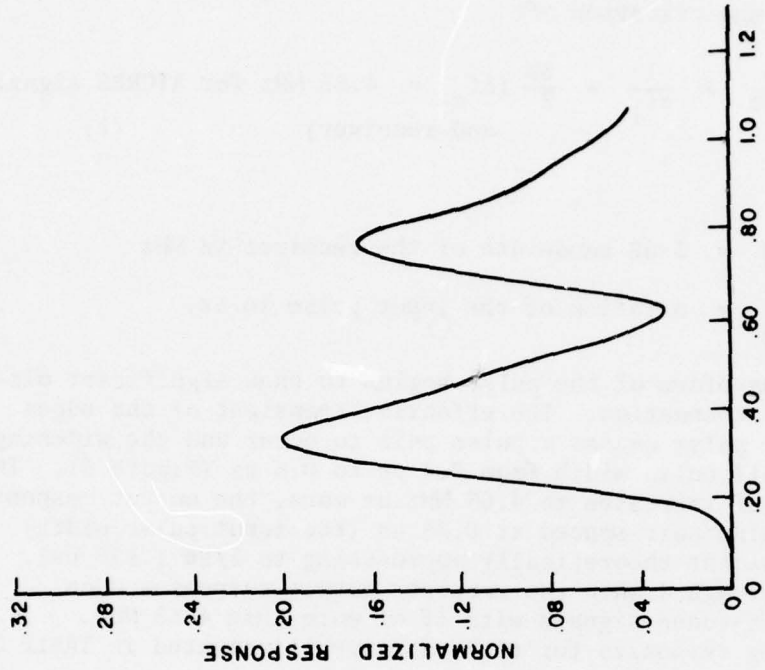


Figure 8. Predicted output response of a single ATCRBS reply pulse with transponder reply frequency off by 6 MHz.

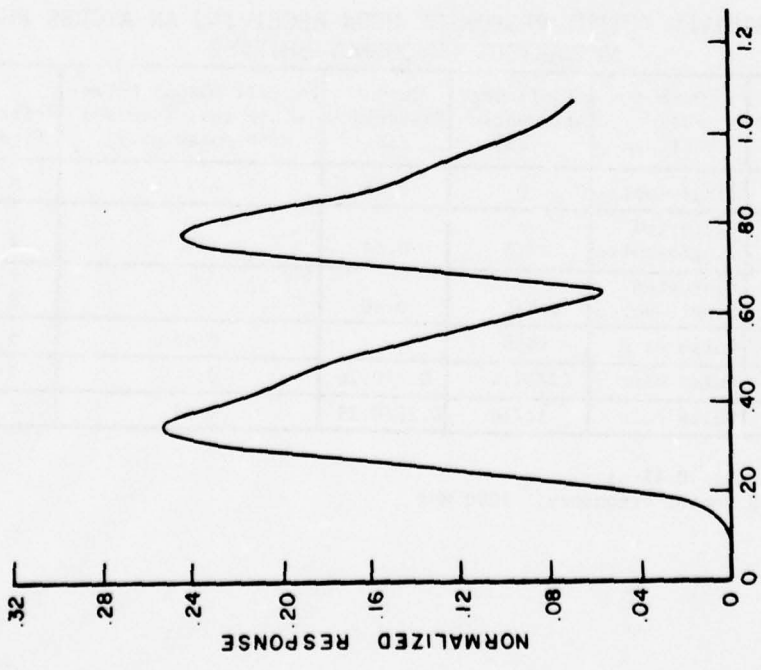


Figure 7. Predicted output response of a single ATCRBS reply pulse with transponder reply frequency off by 5.5 MHz.

As the reply frequency is tuned further off the receiver bandwidth, approaching the criterion of:

$$\Delta f_c = \frac{1}{\pi \tau_i} + \frac{BW}{2} \quad (\Delta f_c = 4.63 \text{ MHz for ATCRBS signal and receiver}) \qquad (1)$$

where

BW = 3-dB bandwidth of the receiver in MHz

τ_i = duration of the input pulse in μs,

the output waveform of the pulse begins to show significant distortion and attenuation. The effective transient of the edges of the input pulse causes a pulse pair to occur and the widening of the overall pulse width from 0.4 μs to 0.6 μs (Figure 5). In general, as Δf increases to 4.63 MHz or more, the output response becomes a pulse pair spaced at 0.45 μs (the input pulse width) with pulse widths theoretically approaching to 1/BW (.125 μs). Figures 6 through 8 show the receiver output responses upon receiving off-tuned signals with Δf of more than 4.63 MHz. The resulting responses for each case are illustrated in TABLE 20.

TABLE 20

PREDICTED RECEIVER OUTPUT RESPONSES UPON RECEIVING AN ATCRBS PULSE AT VARIOUS FREQUENCY SHIFTS[a]

Amount of Frequency Shift (Δf) (MHz)	Output Pulse Waveform	Amplitude Attenuation (dB)	Output Pulsewidth (μs)	Overall Output Pulse-width (μs) (occured with pulse pair)	Refer to Figure
On-Tune	Single-pulse	0	0.46	- -	3
4	Distorted Single-pulse	2.3	0.54	- -	4
4.63	Distorted Single-pulse	4.4/8	0.60	- -	5
5	Pulse Pair	10/8	- -	0.66	6
5.5	Pulse Pair	12/12.4	0.3/0.26	0.7	7
6	Pulse Pair	14/16	0.25/0.25	0.64	8

[a]Input Pulsewidth: 0.45 μs
Receiver Tuned Center Frequency: 1090 MHz

The present CD is set to accept an input signal pulse width from 0.35 to 0.621 μs.[4] The predicted receiver output responses which contain widened pulses shown in Figures 6 through 8 will degrade CD performance.

Upon receiving an off-tuned reply from the transponder, two types of interference may be imposed on the Common Digitizer depending on the amount of off-tune frequency:

1. Attenuation of the received signal pulses may cause the CD to fail to detect the reply.
2. Distortion of the received signal pulses which are present in two forms, widening of the pulse and the appearance of pulse pairs, may cause the CD to improperly decode the reply signal.

REPLY FRAMING PULSE SPACING

Because the success of the decoding and information extraction process of an ATCRBS beacon is predicated upon the detection of the F1 and F2 framing pulse pair, the pulse spacing between F1 and F2 is a major factor in determining the performance of the CD in the en route system. The specification on the framing pulse spacing is 20.3 ± 0.1 μs in the National Standard. But due to the off-tolerance of the framing pulse spacings of some airborne transponders, the tolerance of the CD at selected sites has been reset to accept the reply pulse spacing up to 20.3 ± 0.3 μs.[5]

From the Lincoln Laboratory test results, only 1 of the 504 general aviation transponders under the test program had reply pulse spacing exceeding 20.3 ± 0.3 μs. Any transponders emitting brackets spaced by more than 20.6 μs or less than 20.0 μs would not be detected by the CD.

Reference 1 states that 16 of the transponders tested did not meet the National Standard framing pulse tolerance of ± .1 μs. Of the 16 units not meeting the specification, 13 were general aviation transponders.

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[4]Technical Manual, *Transmitting Set, Coordinate Data*, AN/FYQ-49, February 1972.

[5]Discussion with C. A. Gobs, FAA, Leesburg ARTCC, October 1975.

SECTION 5

RESULTS

RESULTS

Receiver Sensitivity

Varying the receiver sensitivity of three types of transponders affected selected ATCRBS performance parameters the most. Predicted changes are shown in TABLE 21.

TABLE 21

EFFECT OF RECEIVER SENSITIVITY VARIATIONS ON SYSTEM PERFORMANCE

General Aviation Transponders

Environment[a]	Receiver Sensitivity (dBm)	Fruit[b] Rate	Reply[c] Probability	Common Digitizer Probabilities: Code Validations Mode 3	Common Digitizer Probabilities: Code Validations Mode C	Common Digitizer Probabilities: Target Detection	No. of Targets Lost at Low Receiver Sensitivity
100%	Nominal (-69)	1981	99%	100%	99%	100%	-
100%	-57	433	100%	100%	99%	100%	112
	-87	15266	84%	95%	91%	99%	-
20%	-57	1361	100%	100%	99%	100%	23
	-87	7243	84%	99%	97%	99%	-

Air Carrier Transponders

100%	Nominal (-74)	6247	97%	99%	99%	100%	-
100%	-66	2441	99%	100%	99%	100%	6
	-84	23539	86%	88%	83%	99%	-
20%	-66	5306	99%	99%	99%	100%	0
	-84	11708	86%	98%	94%	99%	-

Military Transponders

100%	Nominal (-78)	9992	93%	99%	98%	100%	-
100%	-66	2521	99%	100%	99%	100%	6
	-86	25688	77%	75%	72%	98%	-
20%	-66	8209	99%	99%	99%	100%	0
	-86	14680	77%	90%	86%	98%	-

[a] Indicates percentage of transponders in sample with indicated characteristics

[b] Received at the victim interrogator (Suitland ARSR)

[c] For a representative transponder within the sample.

At a receiver sensitivity of -57 dBm, target loss occurred for general aviation transponders located farther than 64 nmi from the I_o. At a receiver sensitivity of -66 dBm, target loss occured for air carrier and military transponders located farther than 169 nmi from the I_o.

Interrogation Dead Time

Increasing the dead time of the two types of transponders caused changes in system performance as shown in TABLE 22.

TABLE 22

EFFECT OF DEAD TIME VARIATIONS ON SYSTEM PERFORMANCE

General Aviation Transponders

Environment	Dead Time (μs)	Fruit Rate	Reply Probability	CD Probabilities		
				Code Validations Mode 3	Mode C	Target Detection
100%	Nominal (35)	1981	99%	100%	99%	100%
100%	150	1910	98%	100%	99%	100%
	200	1892	97%	100%	99%	100%
20%	150	1838	98%	100%	99%	100%
	200	1831	97%	100%	99%	100%

Air Carrier Transponders

100%	Nominal (35)	6247	97%	99%	99%	100%
100%	150	5932	94%	99%	99%	99%
	200	5823	93%	99%	99%	99%
20%	150	5973	94%	99%	99%	99%
	200	5953	93%	99%	99%	99%

Output Power

Varying the output power of the three types of transponders resulted in changes in system performance as shown in TABLE 23. No target loss within the 200-statute mile radius from the interrogator was predicted with the transponder output power lowered to 44 dBm.

Sidelobe Suppression Dead Time

Varying the sidelobe suppression time from 35 μs to 14 μs and 94 μs produced no predicted impact on system performance for general aviation or air carrier transponders. Varying the sidelobe suppression time for military transponders caused predicted changes on system preformance as shown in TABLE 24.

TABLE 23

EFFECT OF OUTPUT POWER VARIATIONS ON SYSTEM PERFORMANCE

General Aviation Transponders

Environment	Output Power (dBm)	Fruit Rate	Reply Probability	CD Probabilities		
				Code Validations Mode 3	Mode C	Target Detection
100%	Nominal (52)	1981	99%	100%	99%	100%
100%	44	1022	99%	100%	99%	100%
	62	5148	99%	99%	99%	100%
20%	44	1515	99%	100%	99%	100%
	62	2335	99%	100%	99%	100%

Air Carrier Transponders

100%	Nominal (57)	6247	97%	99%	99%	100%
100%	46	1758	97%	100%	99%	100%
	65	10960	97%	99%	98%	100%
20%	46	5376	97%	99%	99%	100%
	65	7178	97%	99%	99%	100%

Military Transponders

100%	Nominal (57)	9992	93%	99%	98%	100%
100%	46	2657	93%	100%	99%	100%
	62	13631	93%	98%	95%	99%
20%	46	8327	93%	99%	98%	100%
	62	10661	93%	99%	97%	99%

TABLE 24

EFFECT OF SIDELOBE SUPPRESSION TIME VARIATIONS ON SYSTEM PERFORMANCE (MILITARY TRANSPONDERS)

Environment	Sidelobe Suppression Time (μs)	Fruit Rate	Reply Probability	CD Probabilities Code Validations Mode 3	Mode C	Target Detection
100%	Nominal (35)	9764	93%	99%	98%	100%
100%	14	10161	95%	99%	98%	100%
	94	8969	88%	99%	97%	99%
20%	14	9855	95%	99%	98%	100%
	94	9580	88%	99%	97%	99%

Squitter Rate

The predicted impact on system performance with squitter pulses introduced in the general aviation transponder environment is shown in TABLE 25.

TABLE 25

EFFECT OF SQUITTER RATE VARIATIONS ON SYSTEM PERFORMANCE (GENERAL AVIATION TRANSPONDERS)

Environment	Squitter Rate	Fruit Rate	Reply Probability	CD Probabilities Code Validations Mode 3	Mode C	Target Detection
100%	Nominal (0)	1981	99%	100%	99%	100%
100%	50	2570	99%	100%	99%	100%
	400	6635	98%	99%	99%	100%
20%	50	2206	99%	100%	99%	100%
	400	3761	98%	99%	99%	100%

Framing Pulse Spacing

The Suitland Common Digitizer will not decode transponder replies with framing pulse spacings greater than 20.3 ± 0.3 μs.

Reply Frequency

Transponders detuned by more than 4.63 MHz may introduce distortion and attenuation into the reply pulses at the output of the receiver. This can impede the decoding process of the Common Digitizer.

CONCLUSIONS

1. Deviations from the standard tolerances for transponder output power, interrogation and sidelobe suppression dead times, and for squitter rates caused predicted reductions in Common Digitizer target detection and code validation probabilities of no more than a few percentage points.

2. Deviations from the standard values of transponder receiver sensitivity, framing pulse spacing and reply frequency were predicted to produce a noticeable degradation in Common Digitizer performance.

APPENDIX A

FRUIT AND REPLY PROBABILITY DISTRIBUTION PLOTS

FRUIT RATE GRAPHS

These graphs show the changes in the total fruit per second received at the I_o as the antenna scans through various bearing angles.

REPLY PROBABILITY GRAPHS

These bar graphs show the changes in the reply probability distribution of the total 189 transponders in the deployment. In both plots, the symbol a/c stands for aircraft.

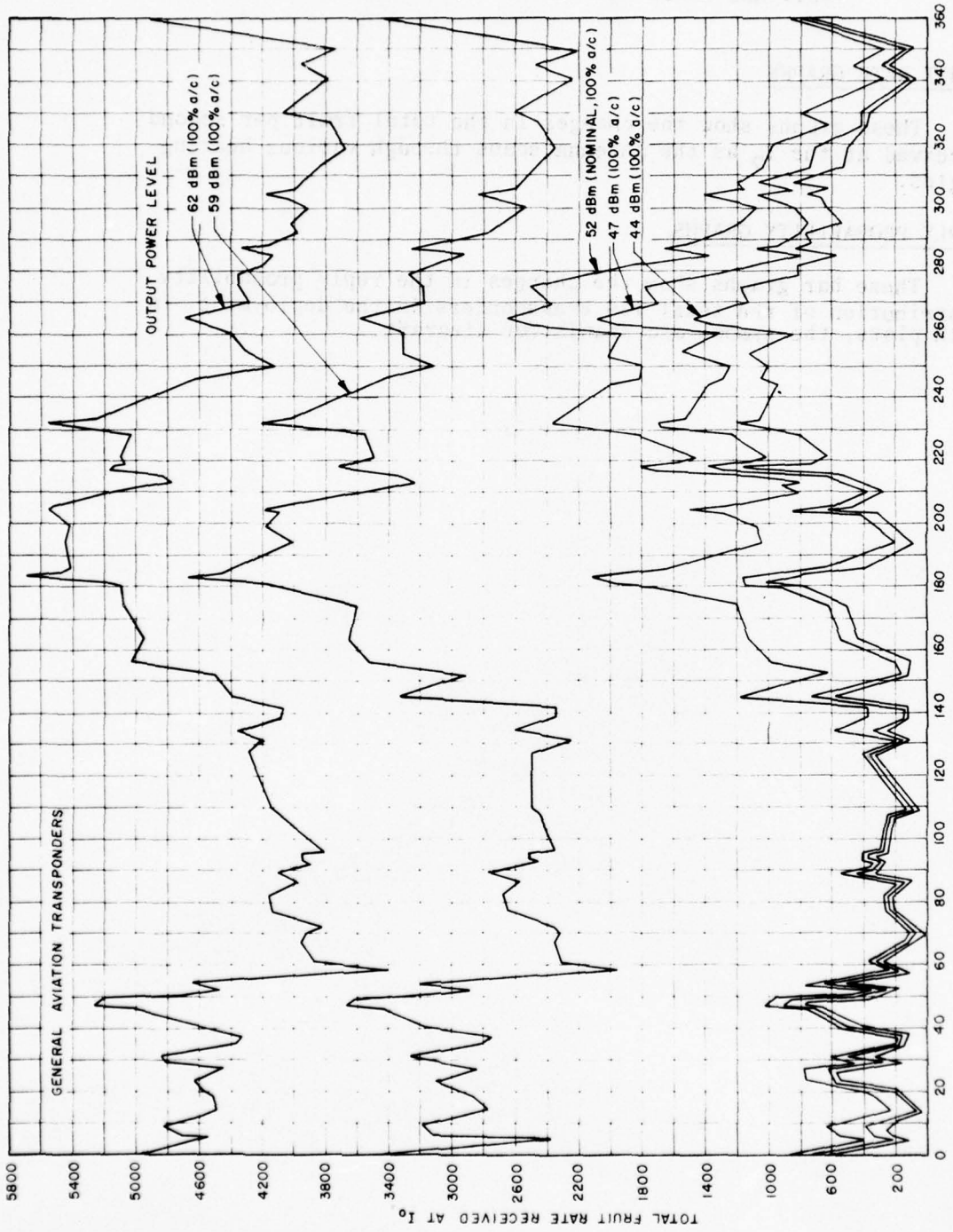


Figure A-1. Comparison of predicted fruit rates at different output power levels for general aviation transponder type (100% environment).

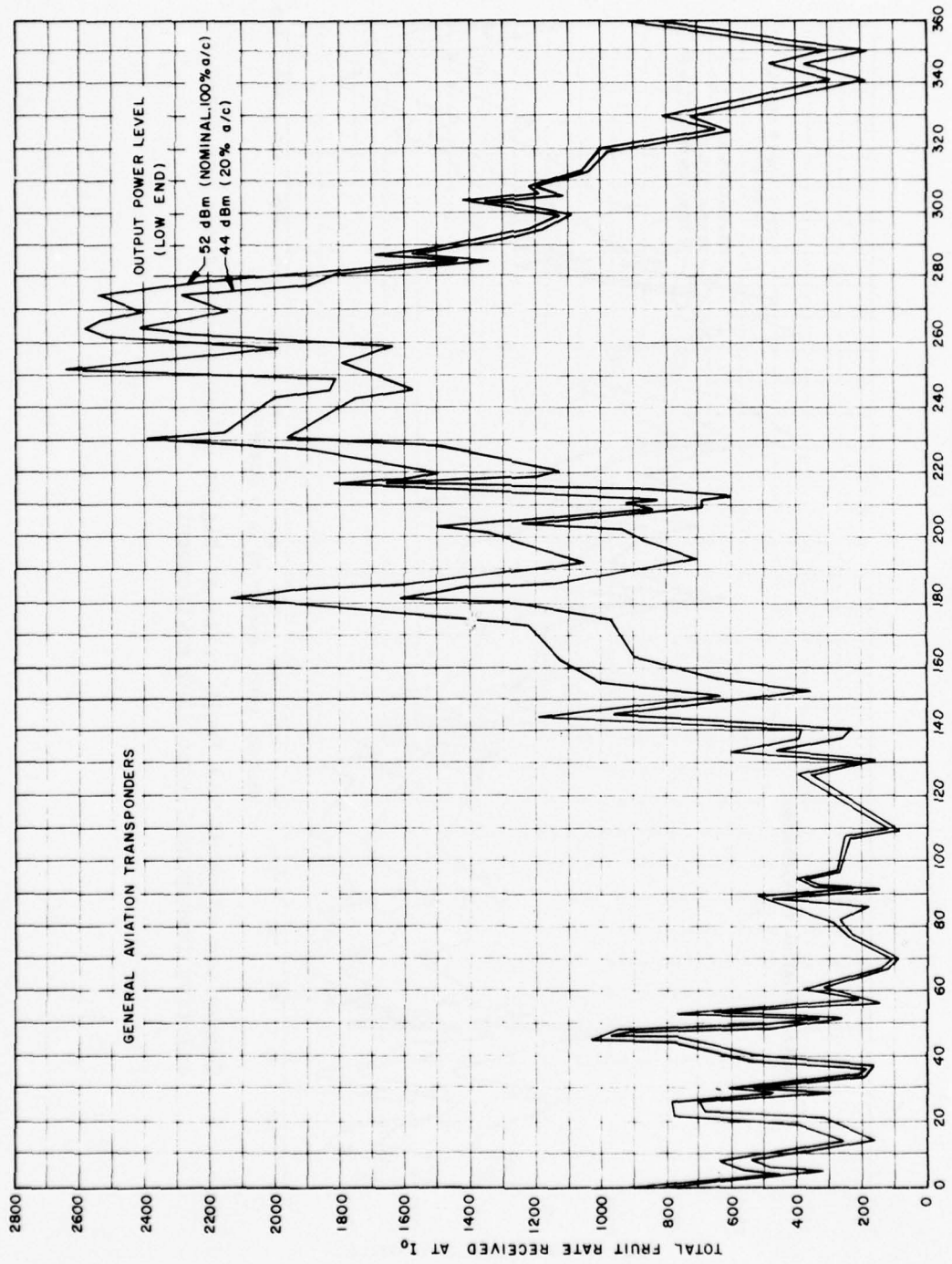


Figure A-2. Comparison of predicted fruit rates at lower output power levels for general aviation transponder type (20% environment).

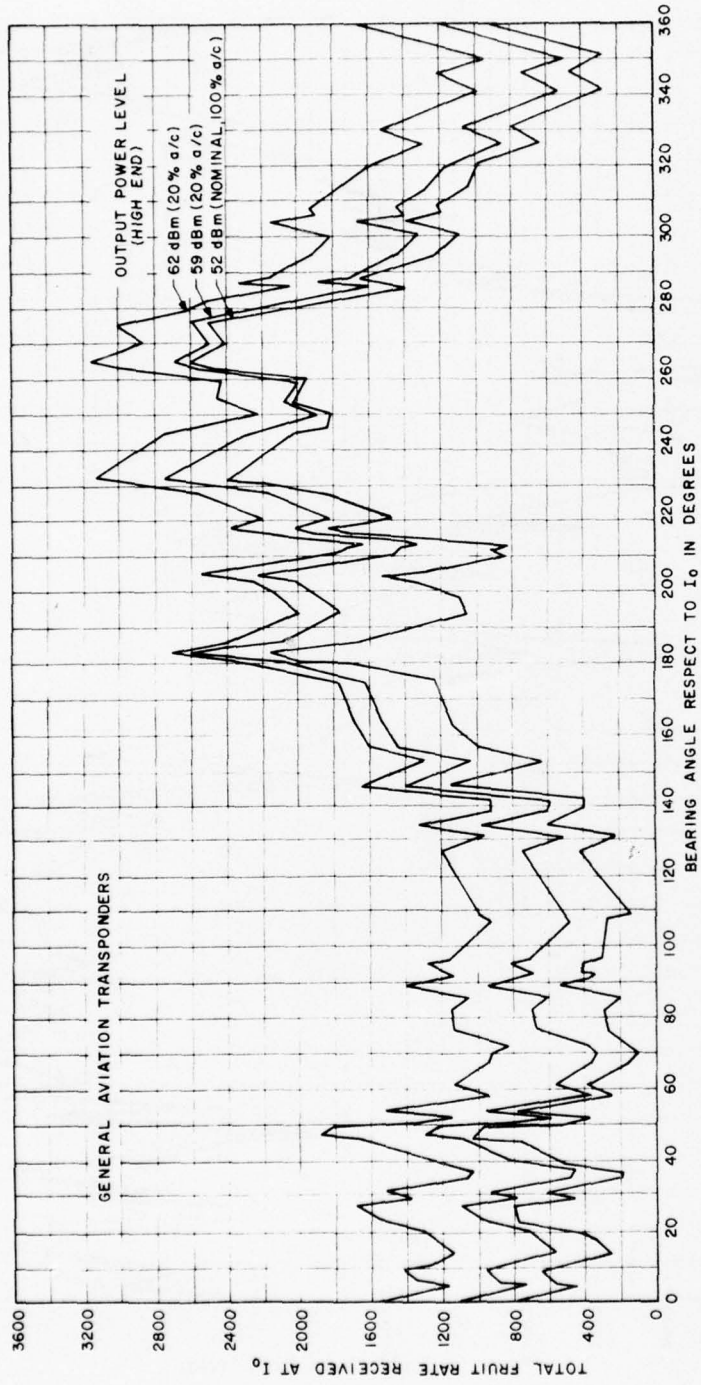


Figure A-3. Comparison of predicted fruit rates at higher output power levels for general aviation transponder type (20% environment).

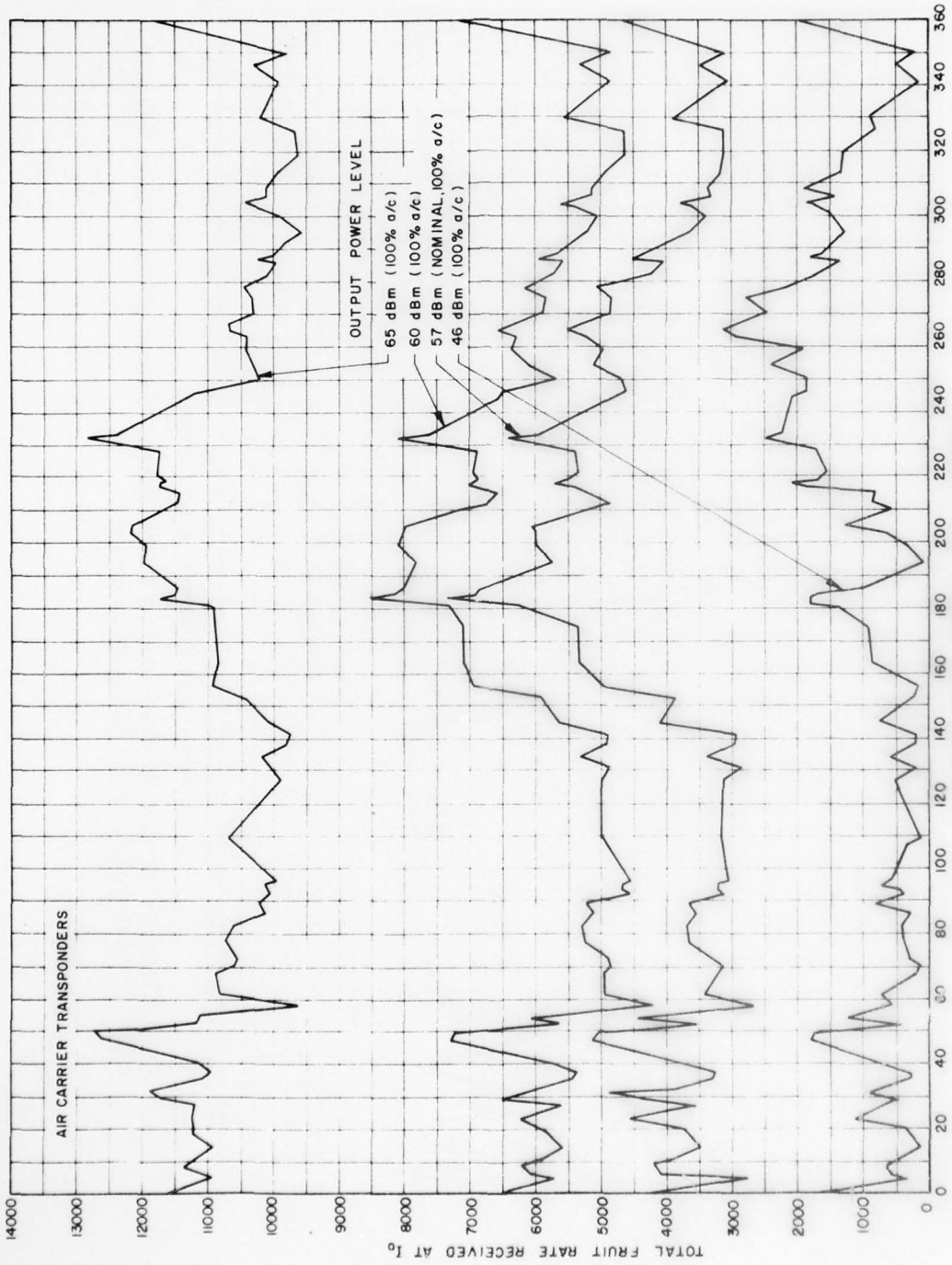


Figure A-4. Comparison of predicted fruit rates at different output power levels for air carrier transponder type (100% environment).

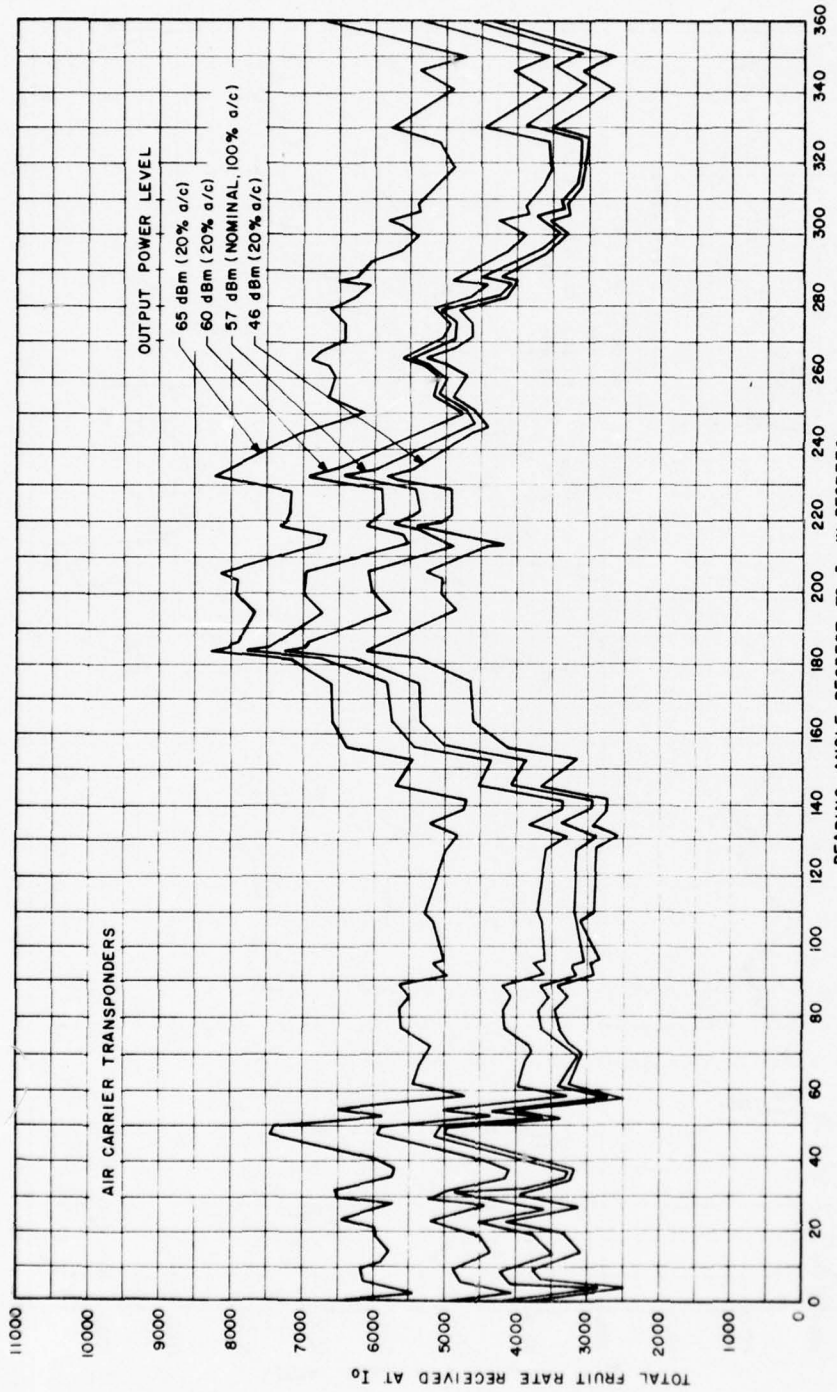


Figure A-5. Comparison of predicted fruit rates at different output power levels for air carrier transponder type (20% environment).

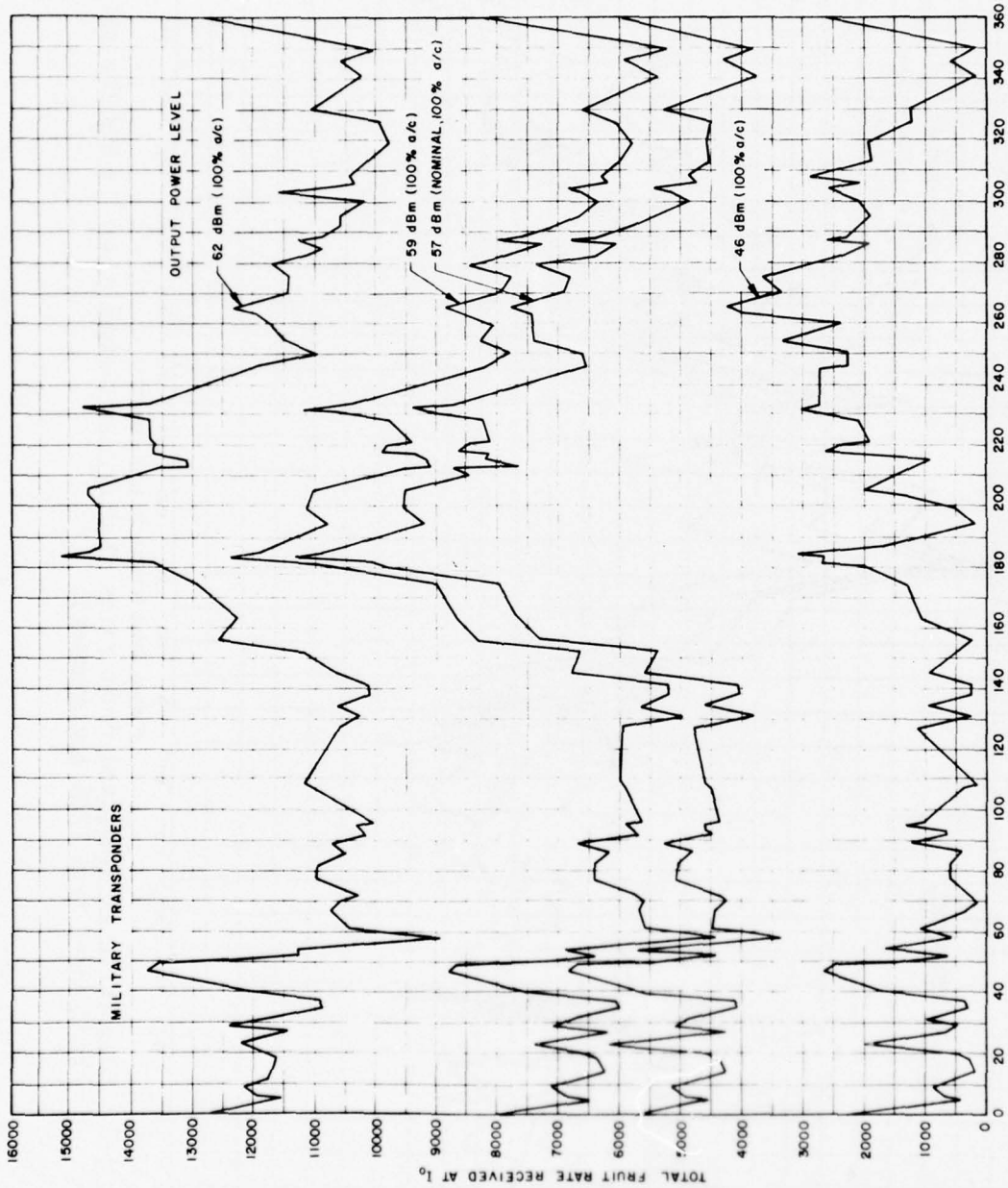


Figure A-6. Comparison of predicted fruit rates at different output power levels for military transponder type (100% environment).

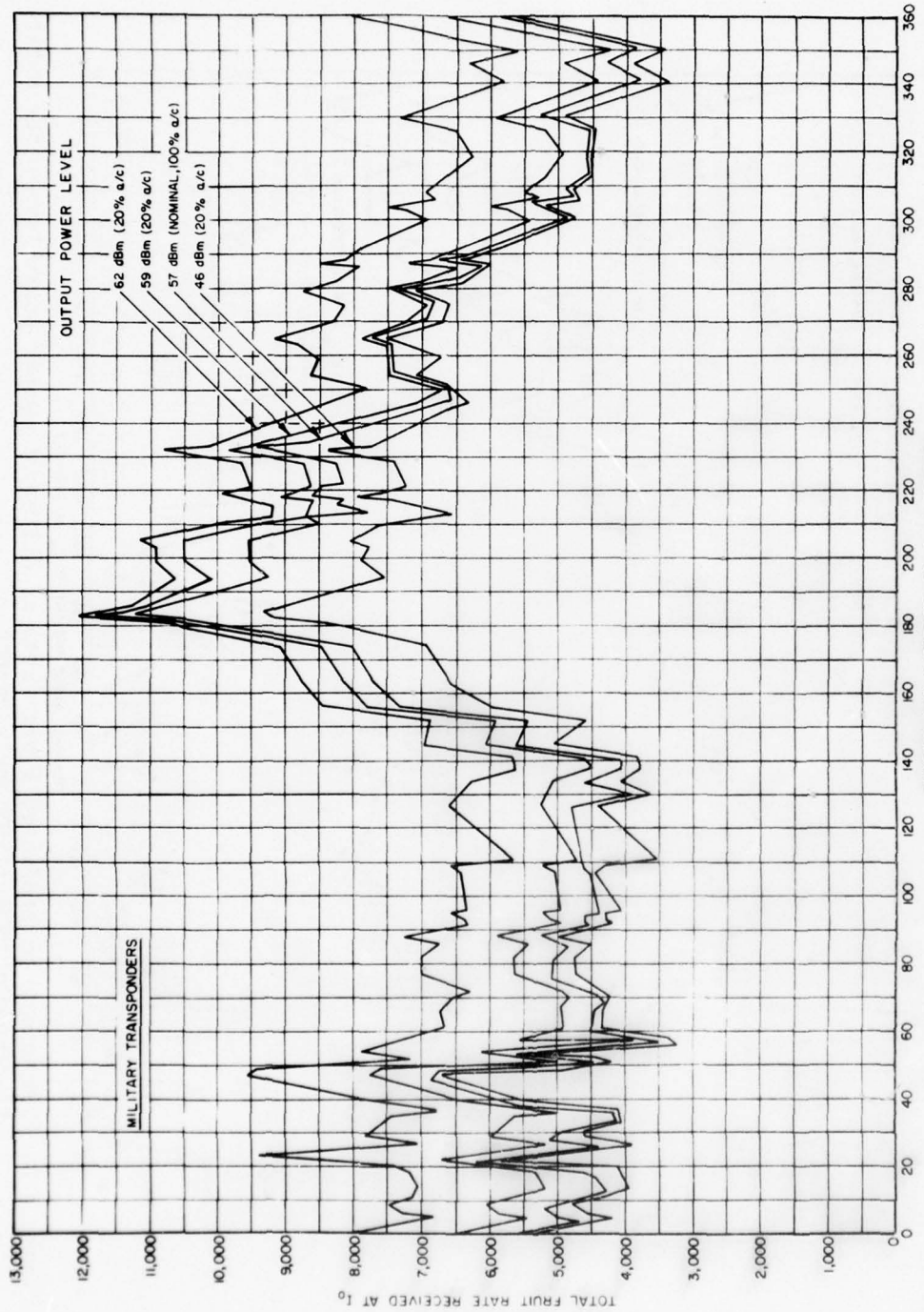


Figure A-7. Comparison of predicted fruit rates at different output power levels for military transponder type (20% environment).

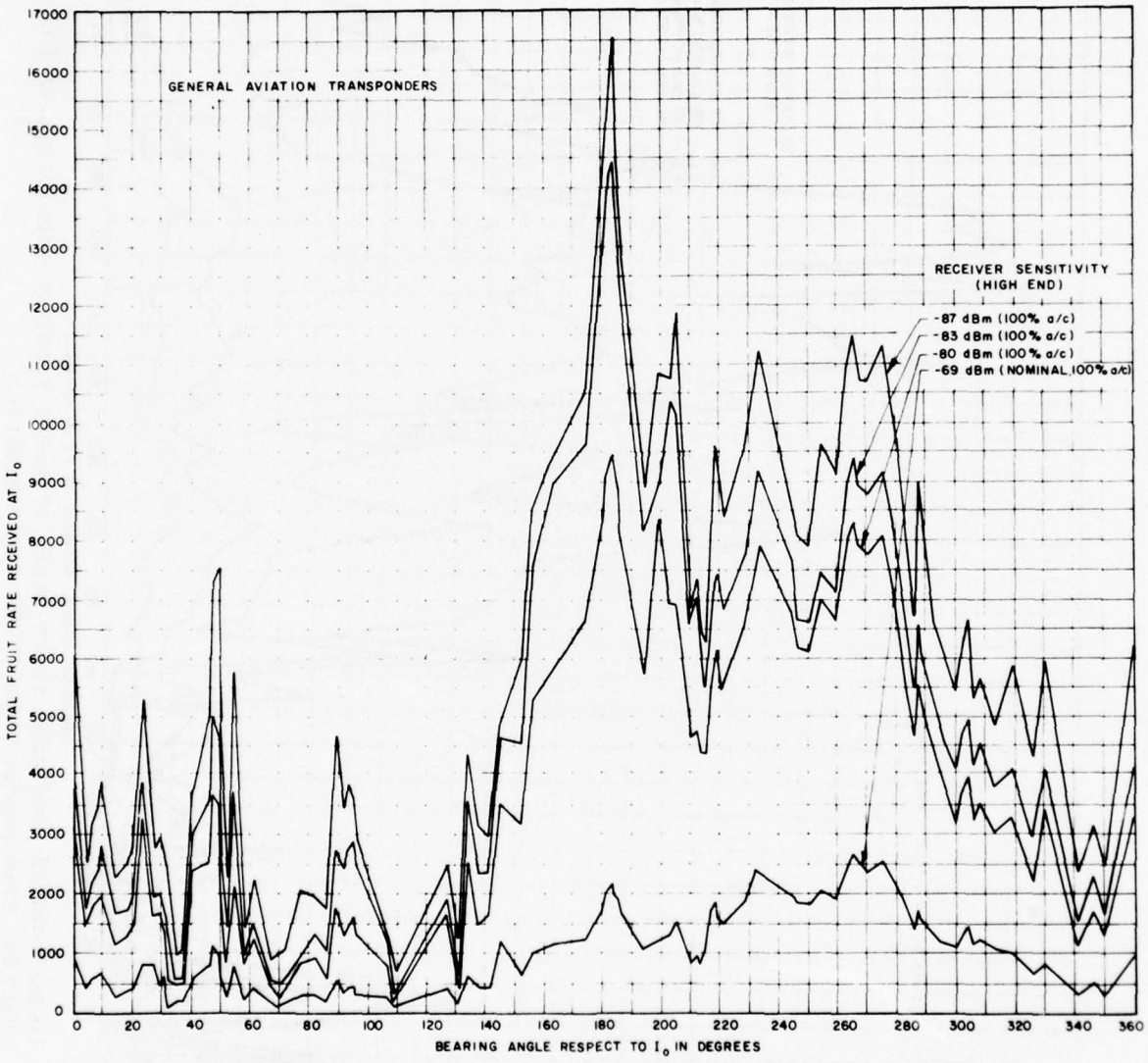


Figure A-8. Comparison of predicted fruit rates at higher receiver sensitivities for general aviation transponder type (100% environment).

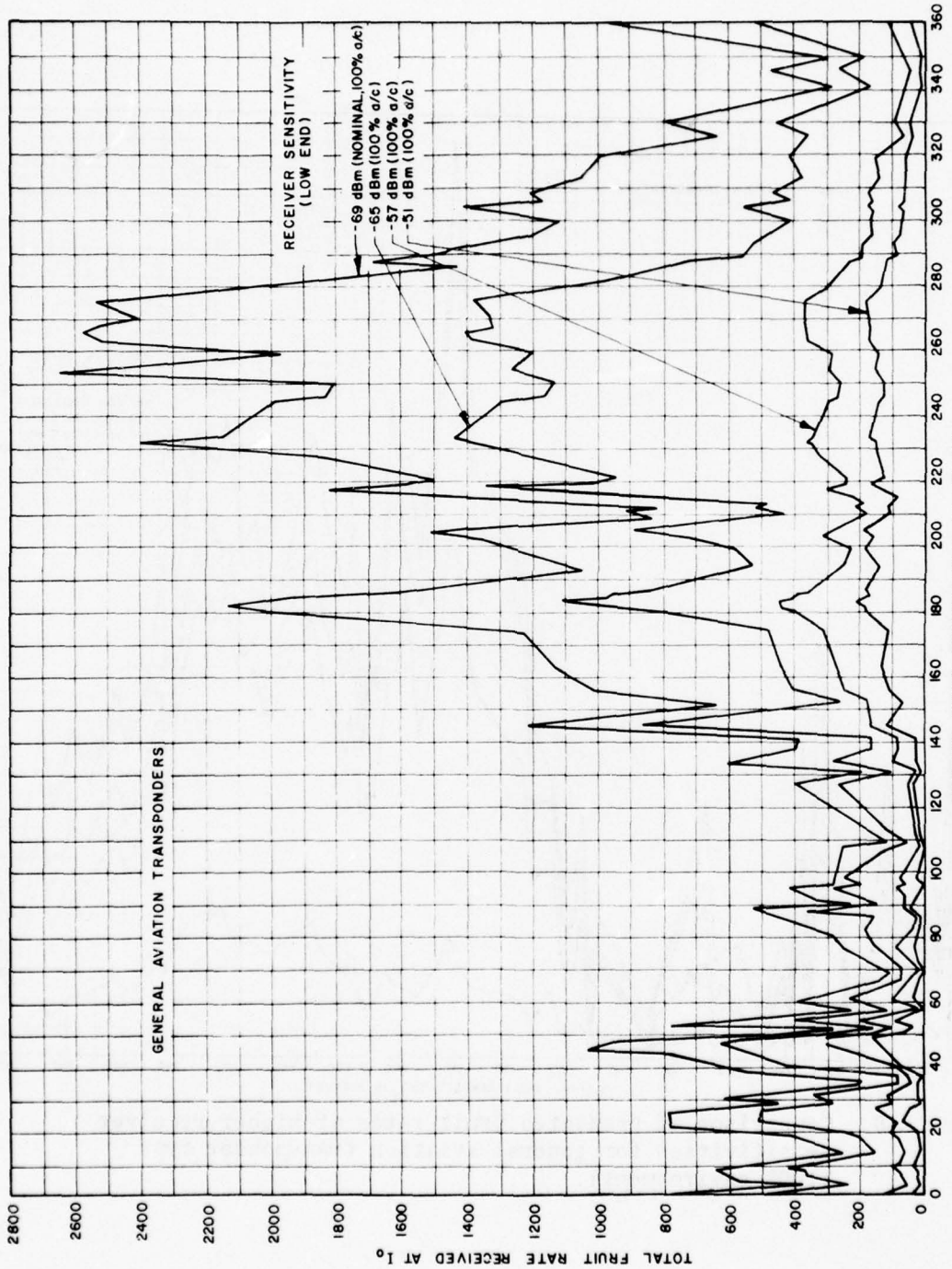


Figure A-9. Comparison of predicted fruit rates at lower receiver sensitivities for general aviation transponder type (100% environment).

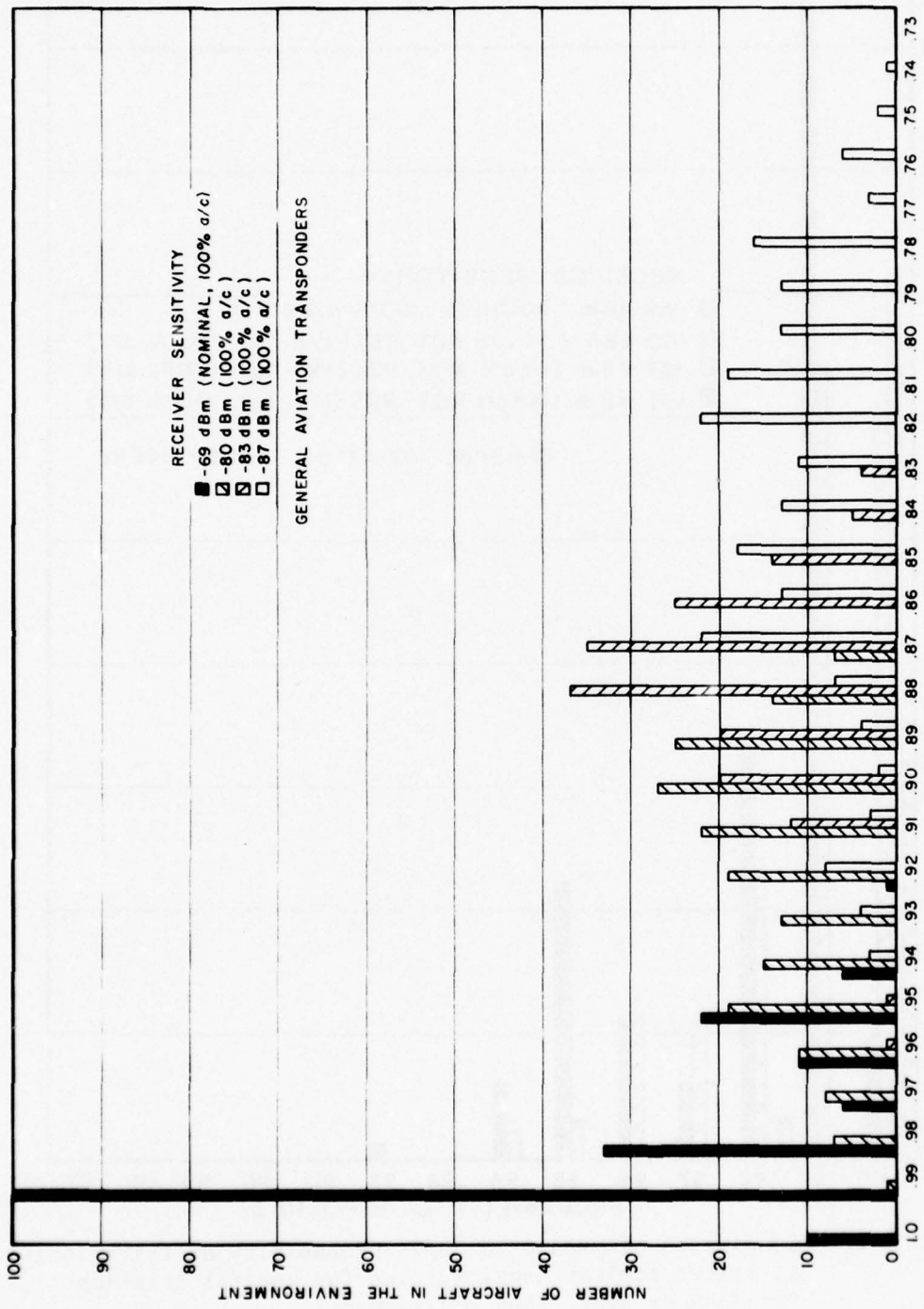


Figure A-10. Comparison of predicted reply probability distributions at higher receiver sensitivities for general aviation transponder type (100% environment).

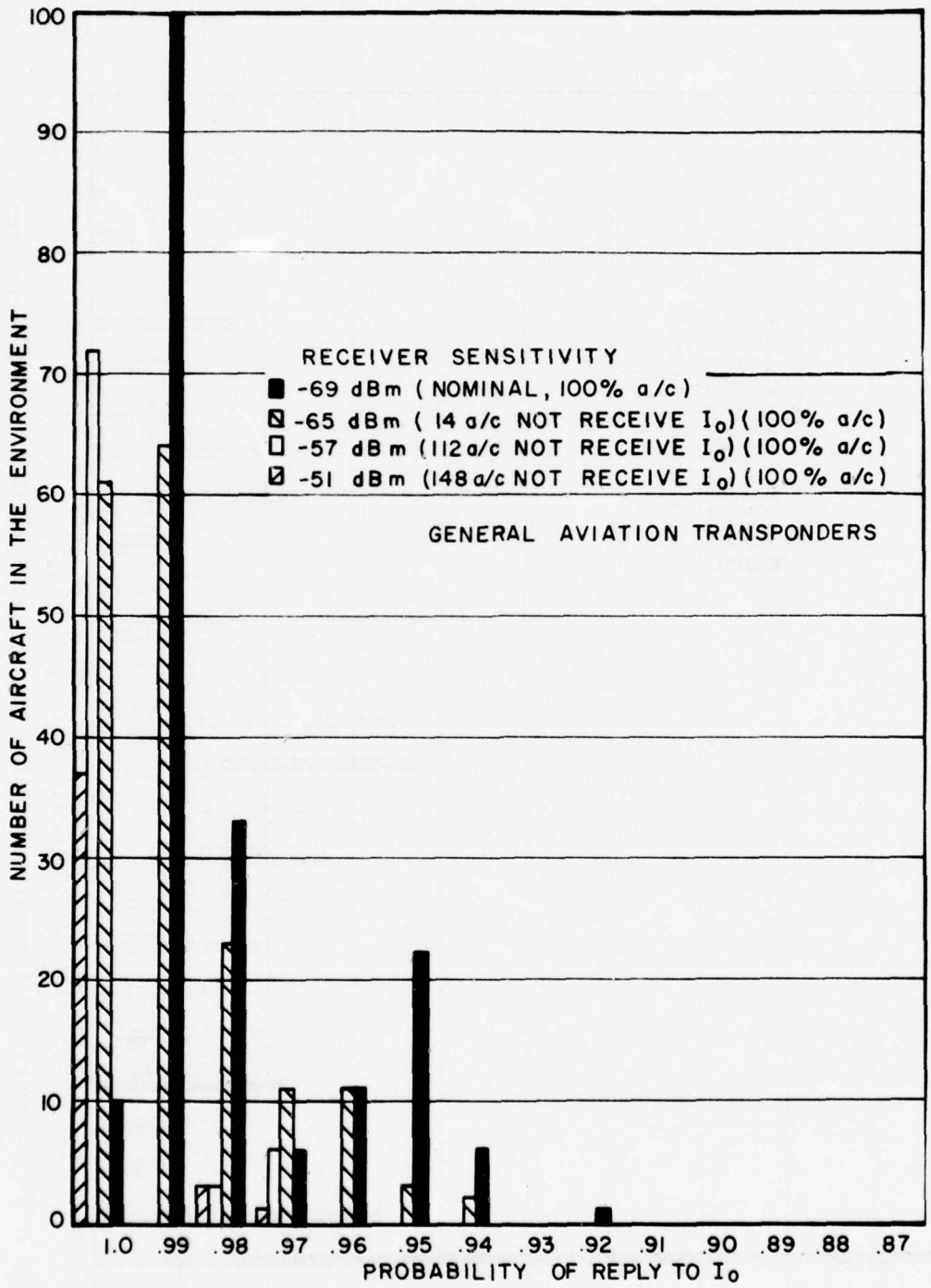


Figure A-11. Comparison of predicted reply probability distributions at lower receiver sensitivities for general aviation transponder type (100% environment).

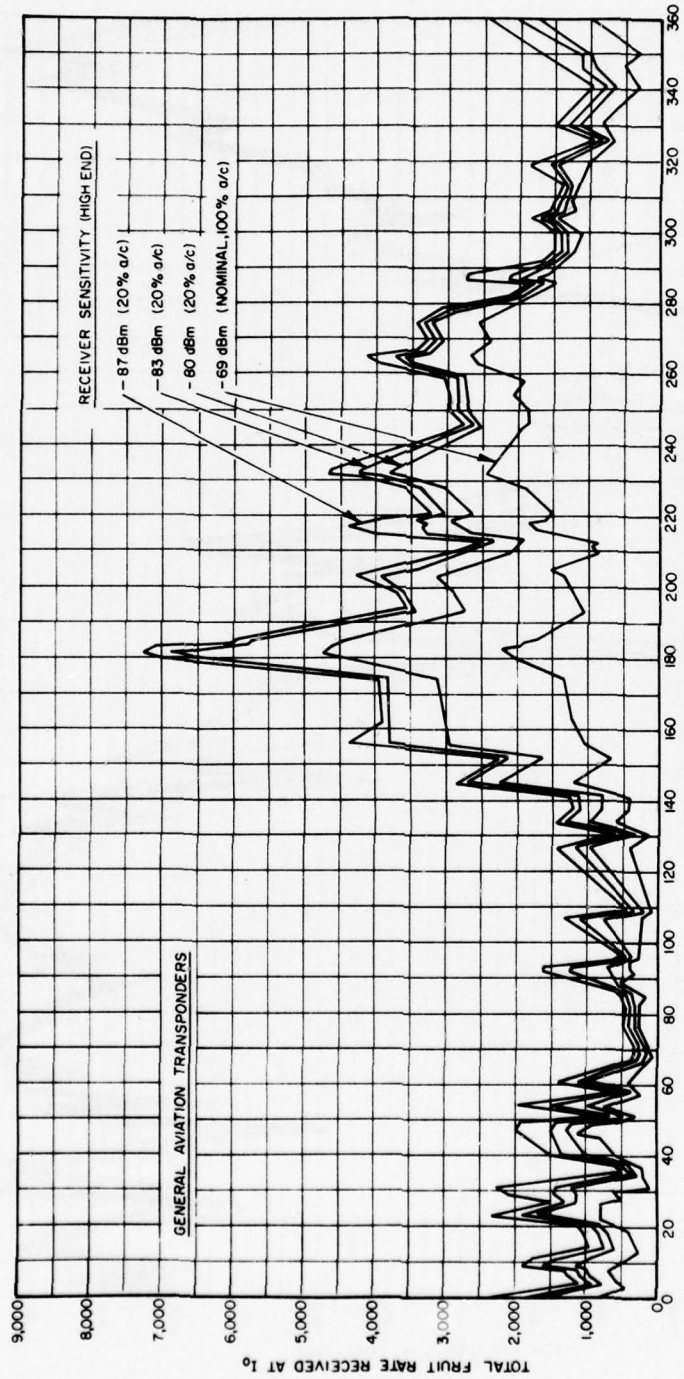


Figure A-12. Comparison of predicted fruit rates at higher receiver sensitivities for general aviation transponder type (20% environment).

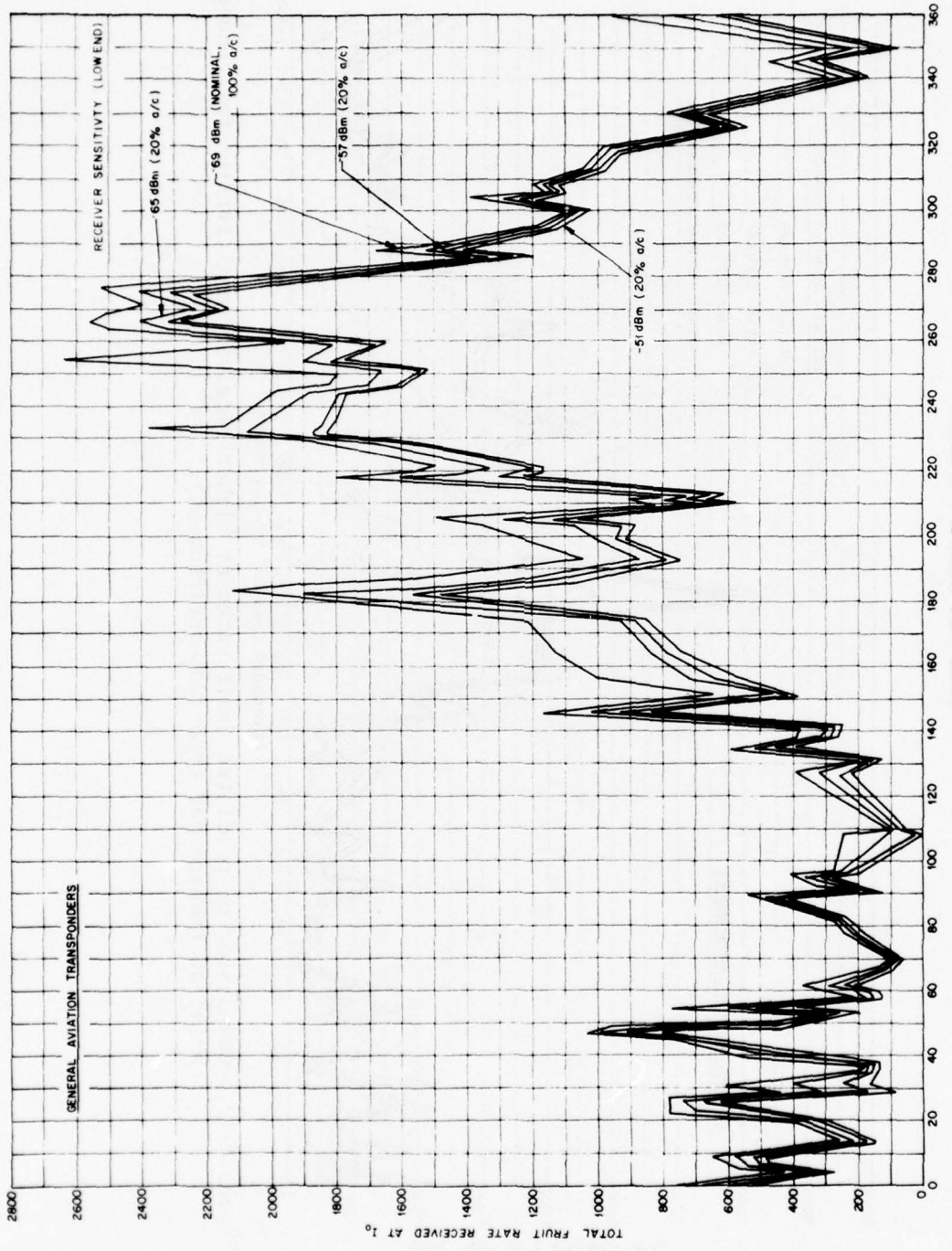


Figure A-13. Comparison of predicted fruit rates at lower receiver sensitivities for general aviation transponder type (20% environment).

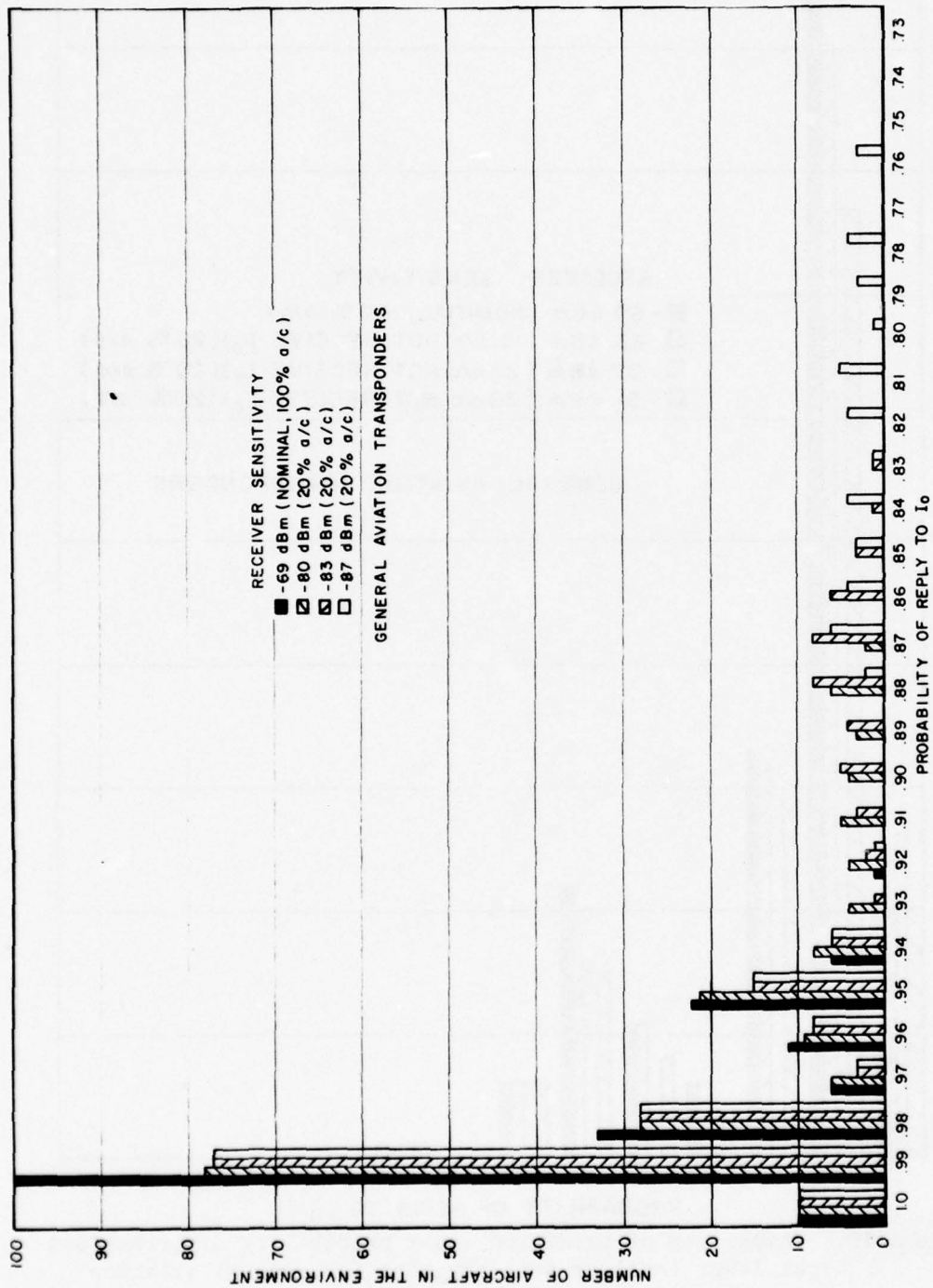


Figure A-14. Comparison of predicted reply probability distributions at higher receiver sensitivities for general aviation transponder type (20% environment).

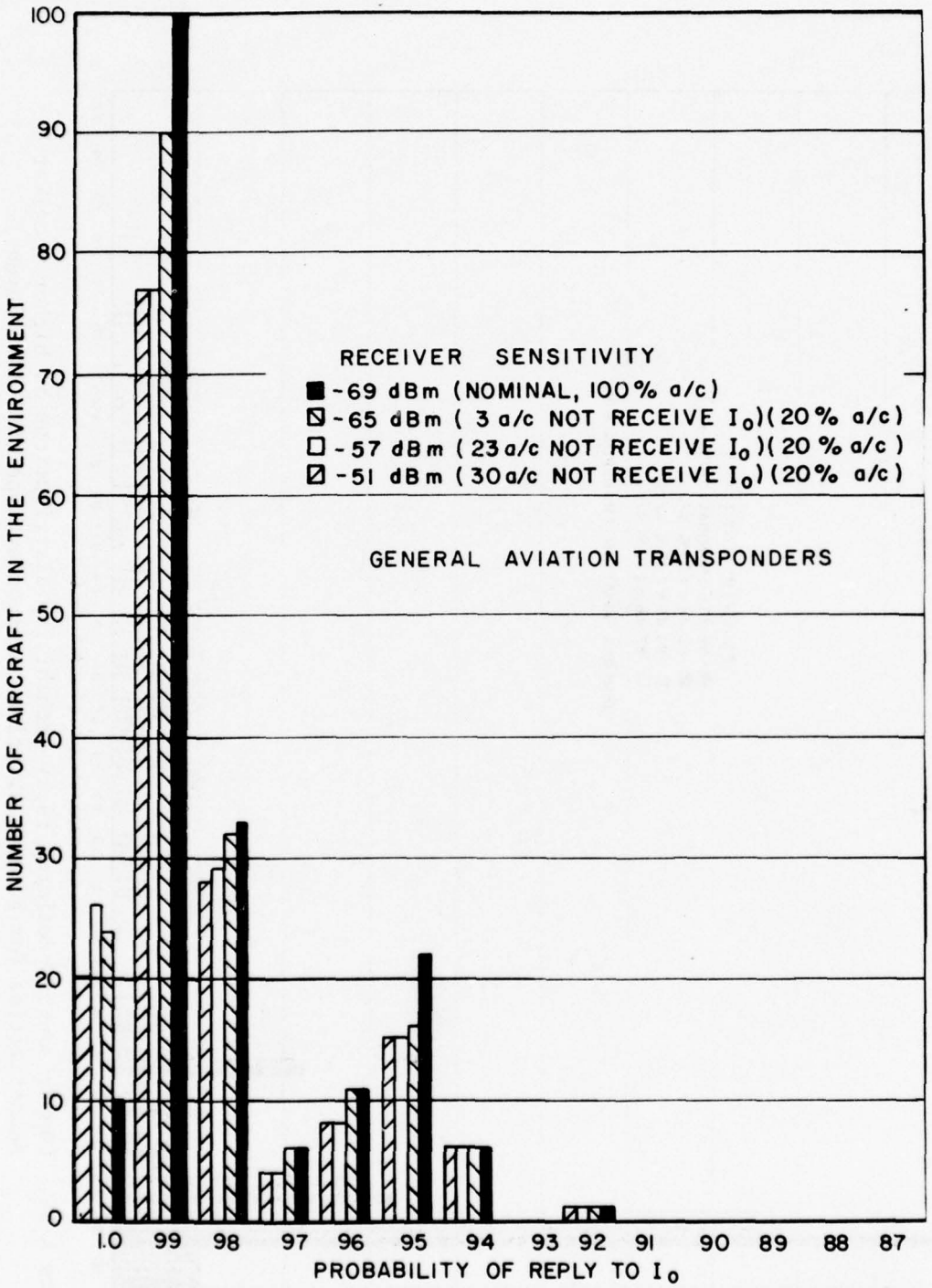


Figure A-15. Comparison of predicted reply probability distributions at lower receiver sensitivities for general aviation transponder type (20% environment).

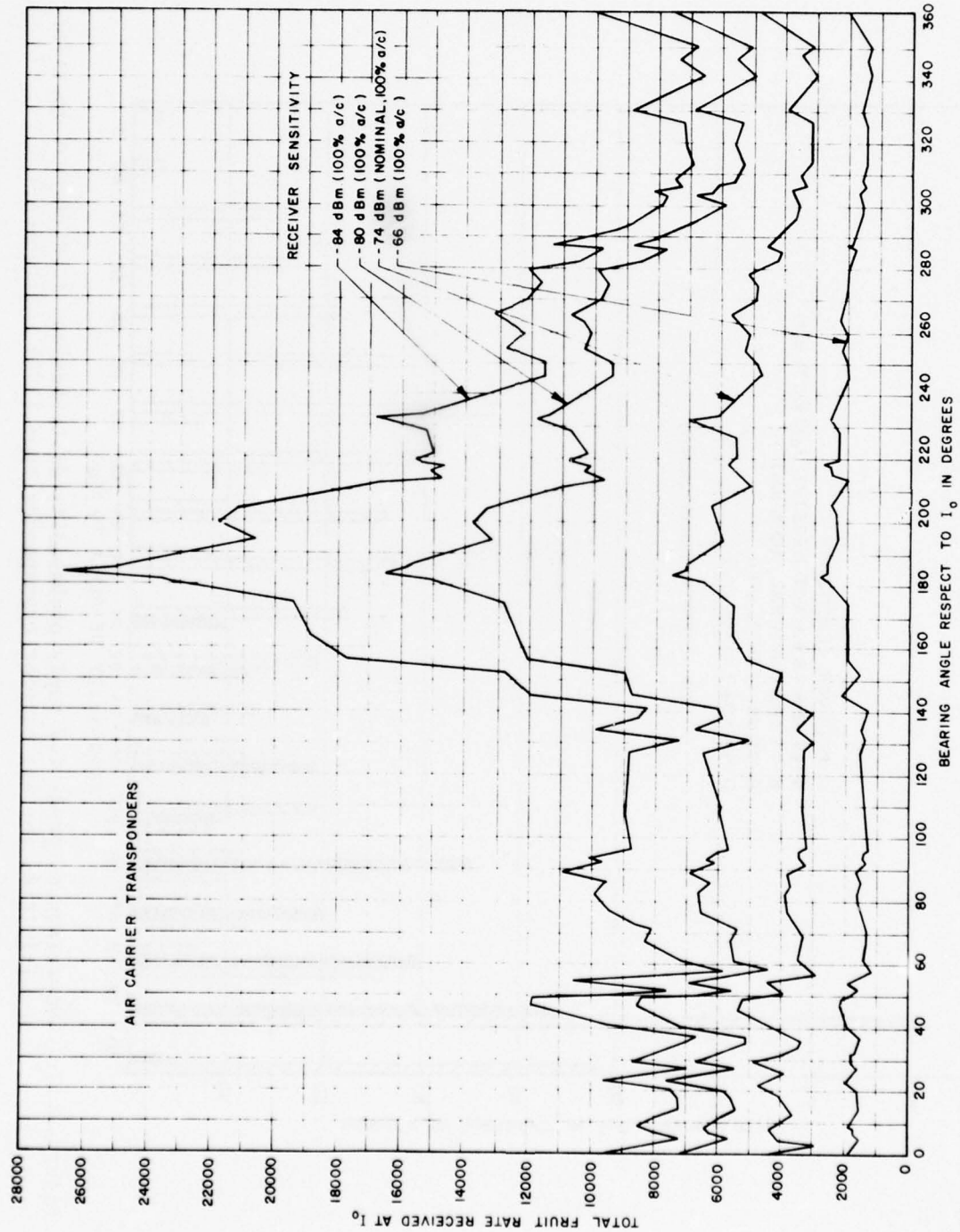


Figure A-16. Comparison of predicted fruit rates at different receiver sensitivities for air carrier transponder type (100% environment).

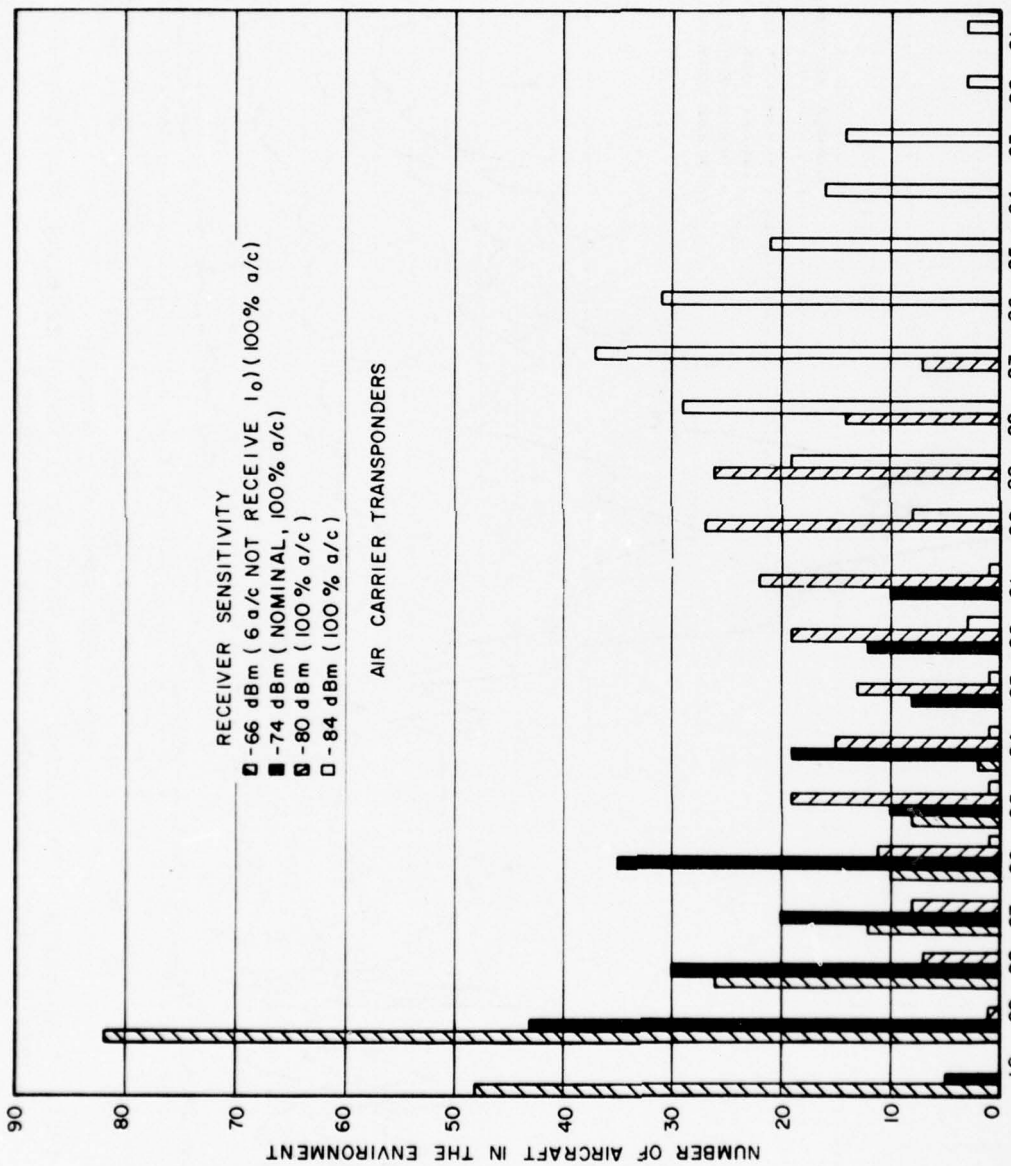


Figure A-17. Comparison of predicted reply probability distributions at different receiver sensitivities for air carrier transponder type (100% environment).

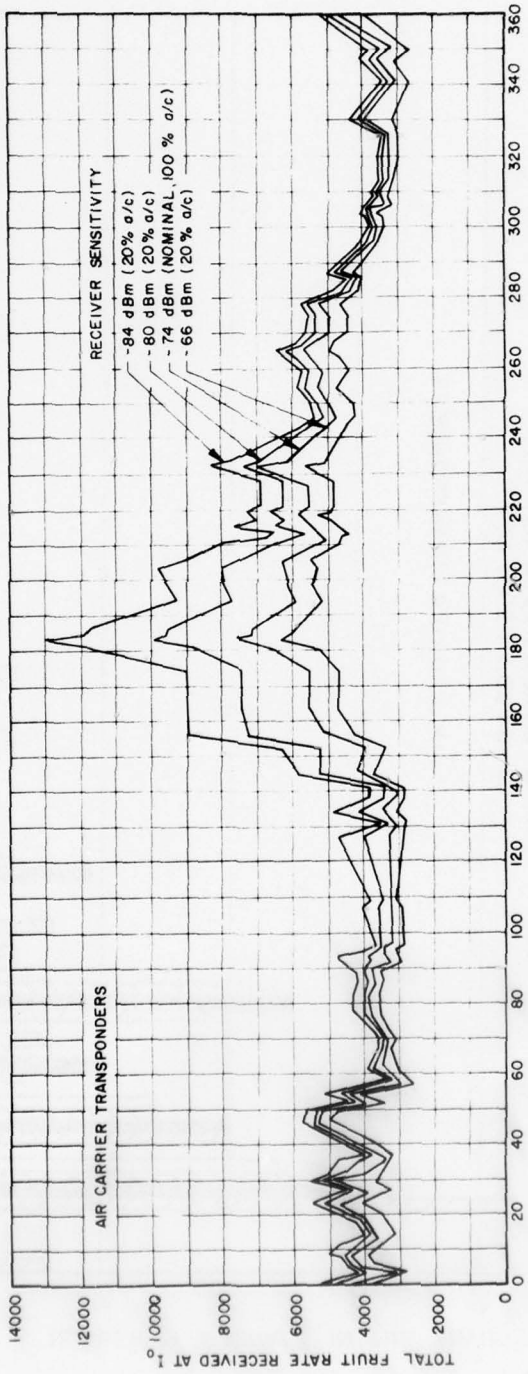


Figure A-18. Comparison of predicted fruit rates at different receiver sensitivities for air carrier transponder type (20% environment).

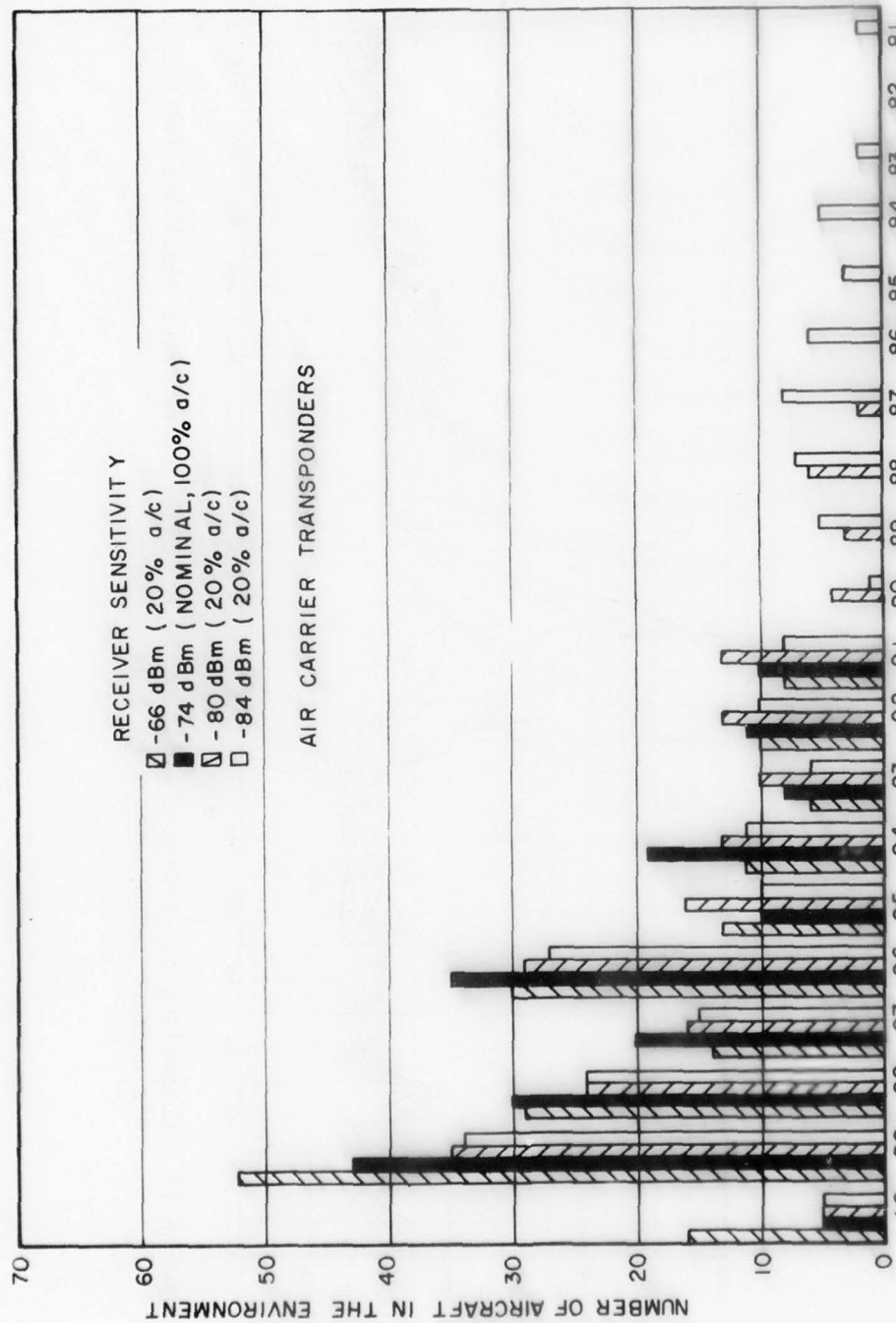


Figure A-19. Comparison of predicted reply probability distributions at different receiver sensitivities for air carrier transponder type (20% environment).

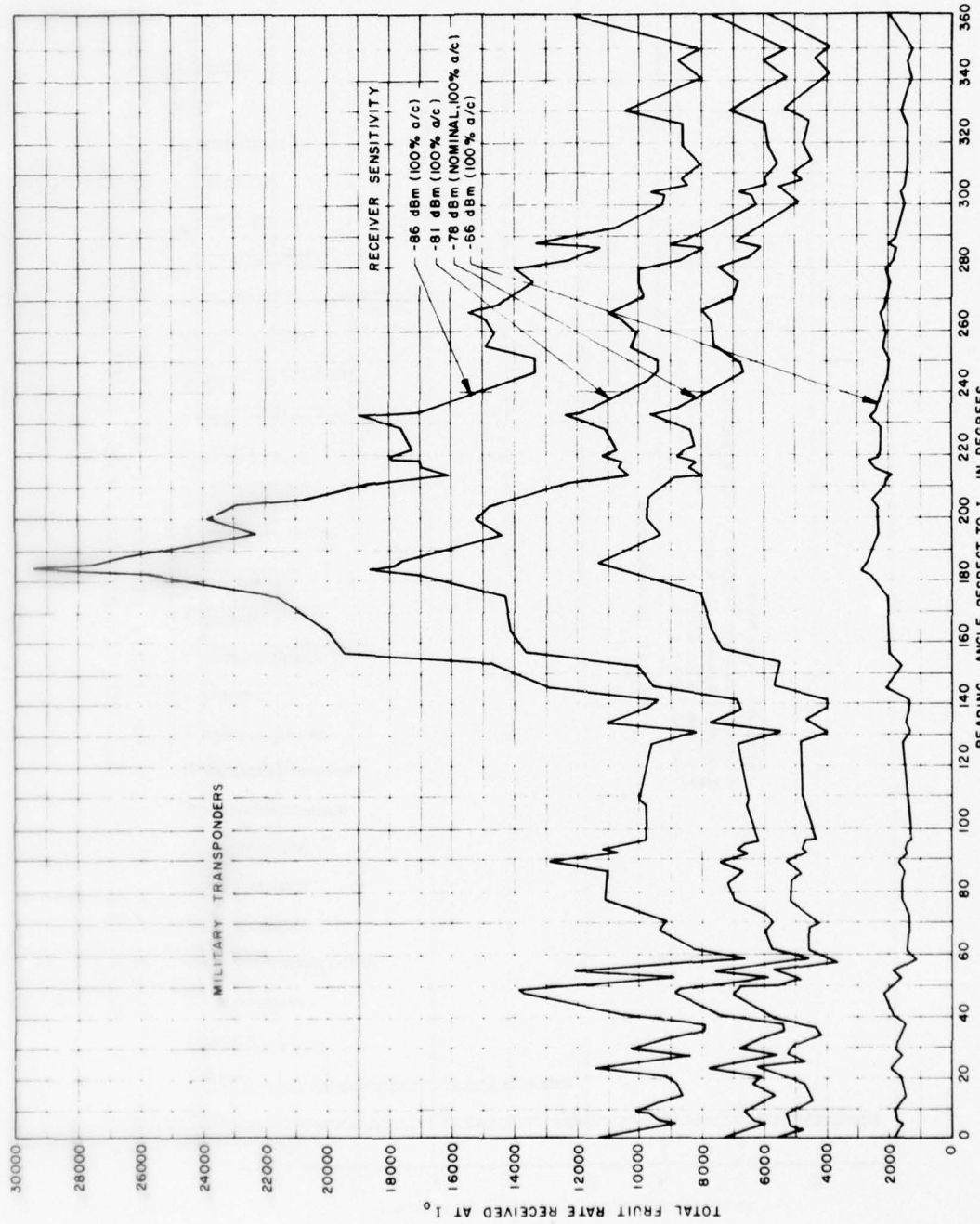


Figure A-20. Comparison of predicted fruit rates at different receiver sensitivities for military transponder type (100% environment).

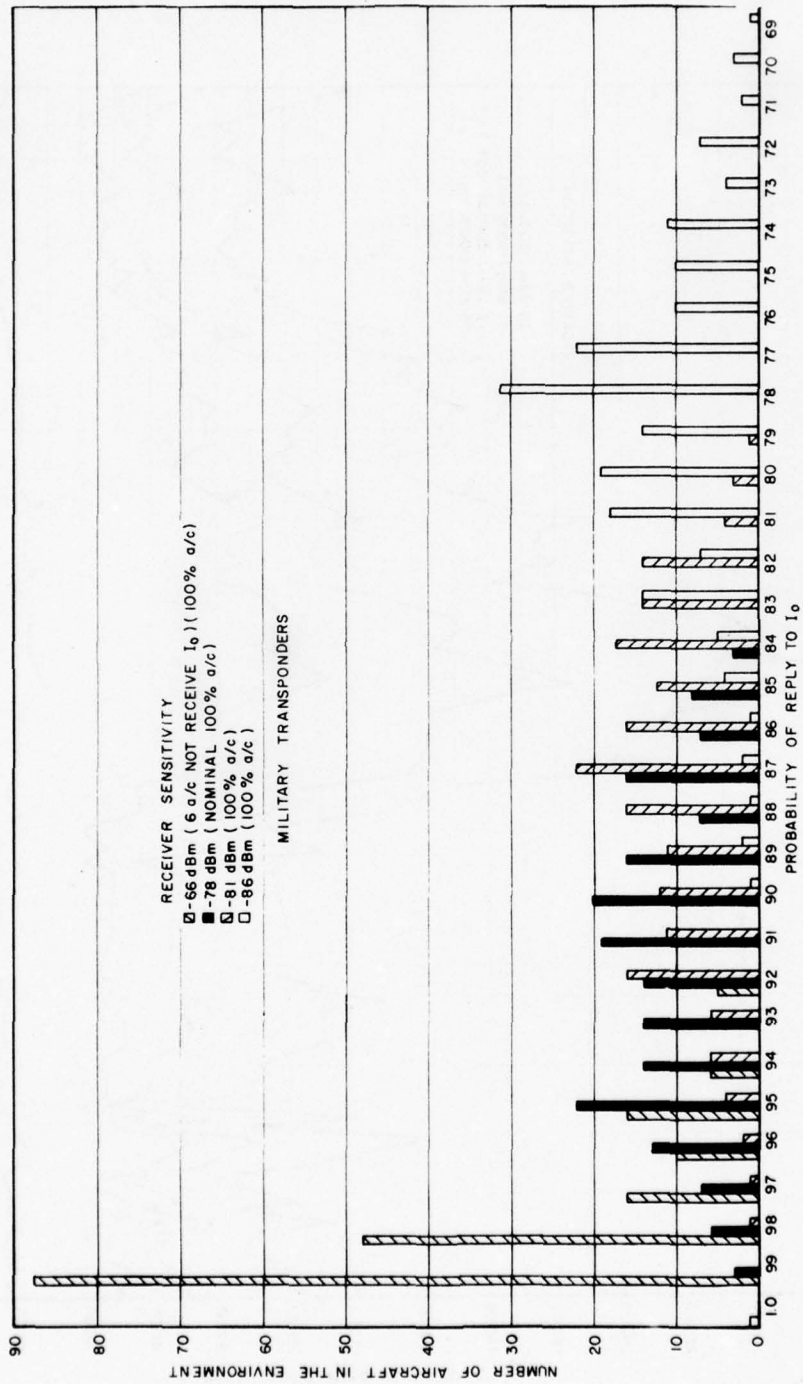


Figure A-21. Comparison of predicted reply probability distributions at different receiver sensitivities for military transponder type (100% environment).

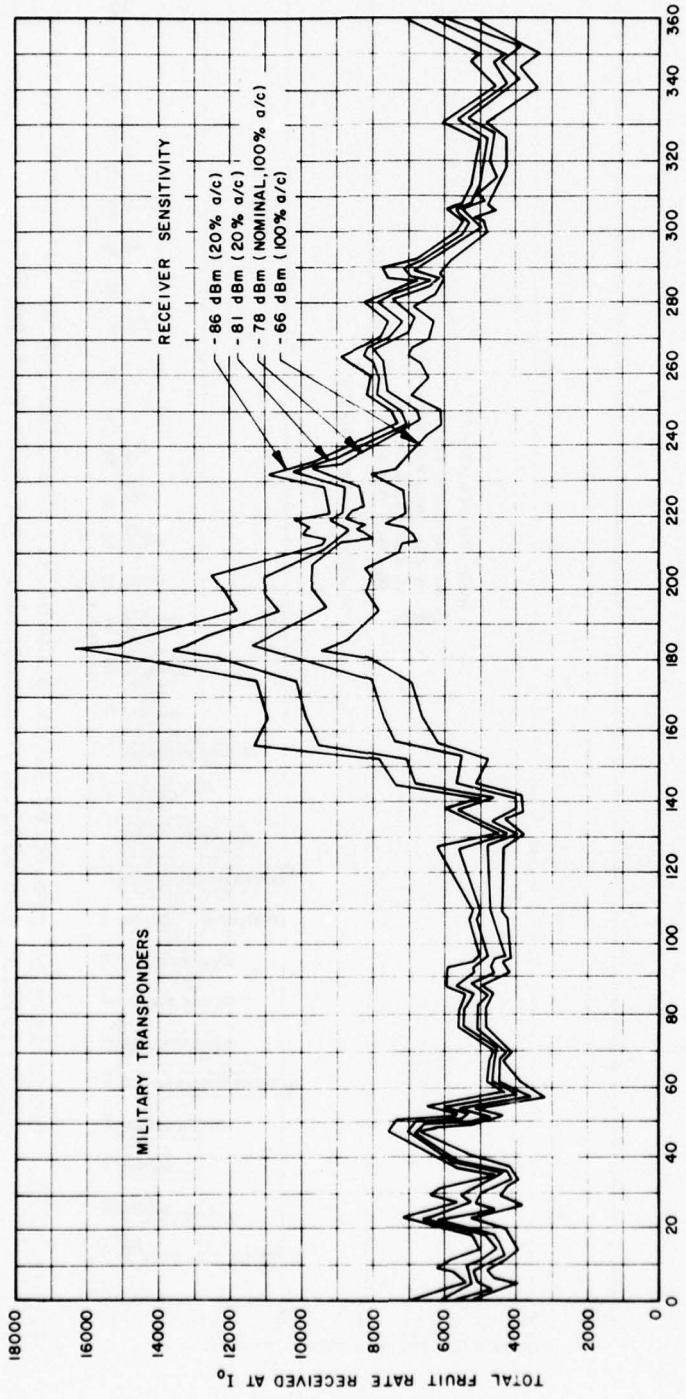


Figure A-22. Comparison of predicted fruit rates at different receiver sensitivities for military transponder type (20% environment).

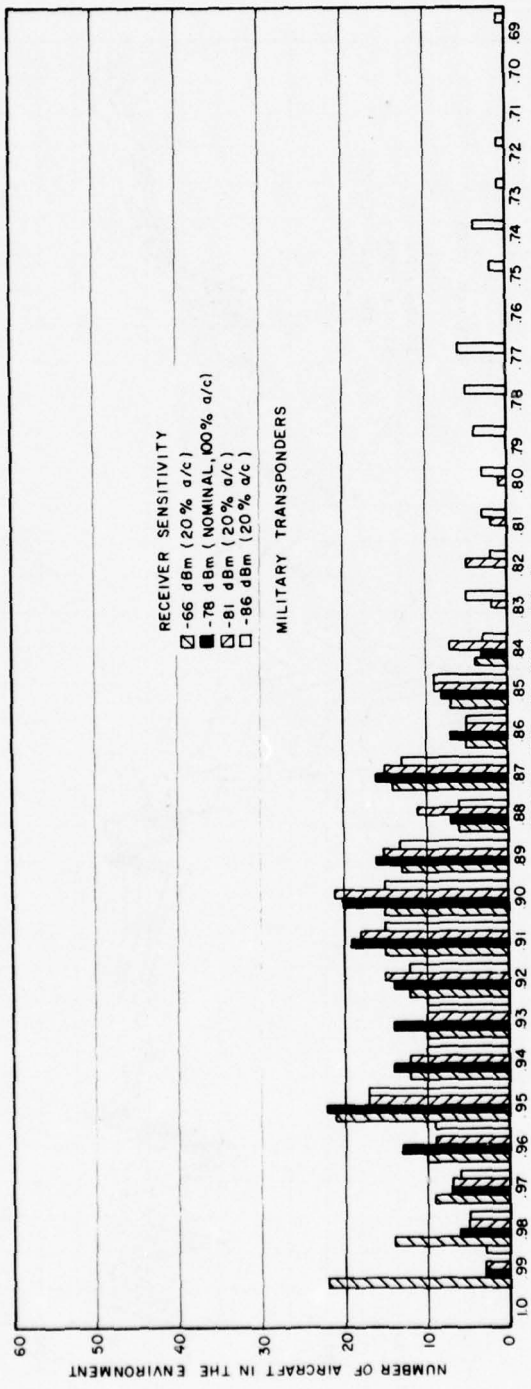


Figure A-23. Comparison of predicted reply probability distribution at different receiver sensitivities for military transponder type (20% environment).

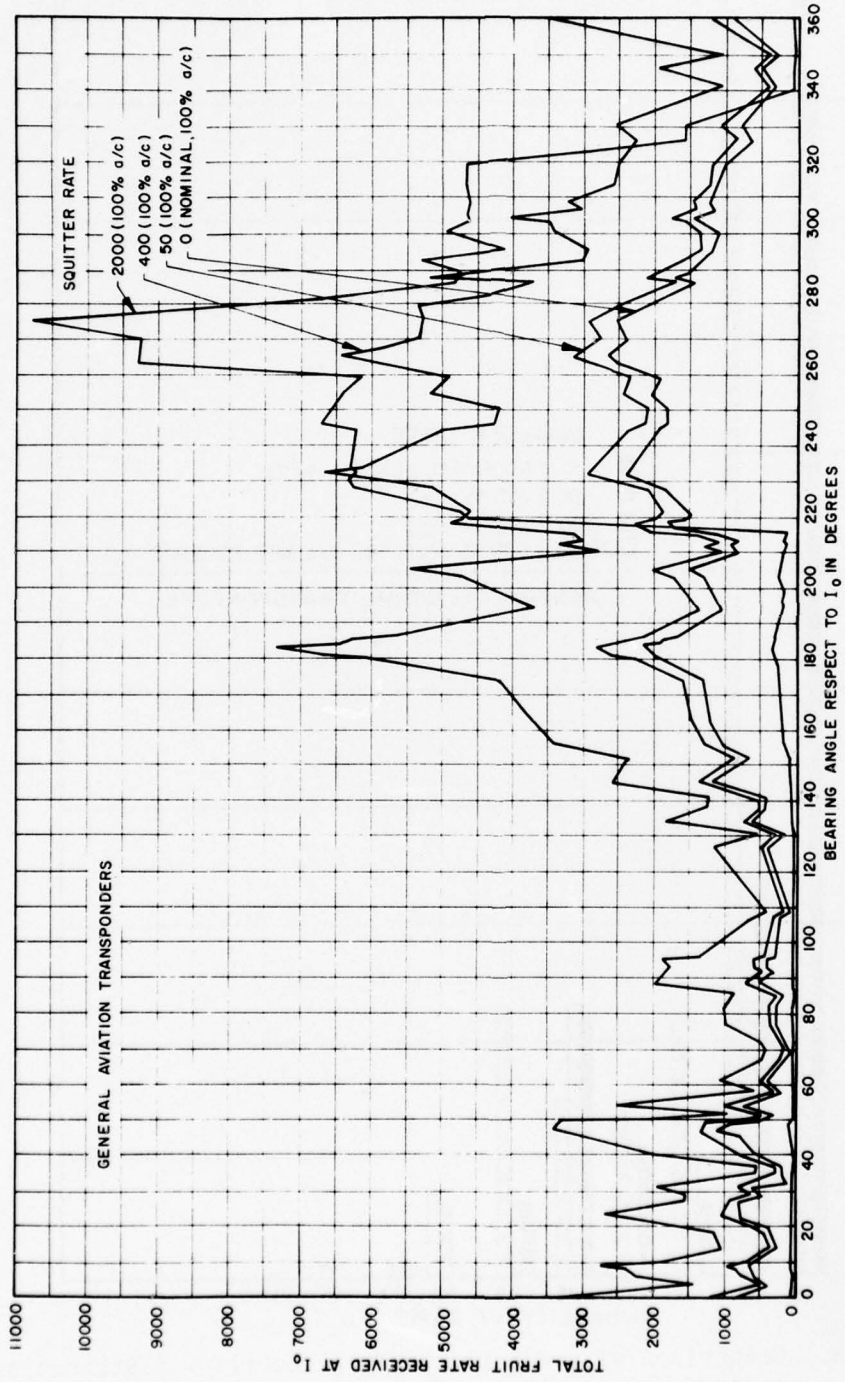


Figure A-24. Comparison of predicted fruit rates at different squitter rates for general aviation transponder type (100% environment).

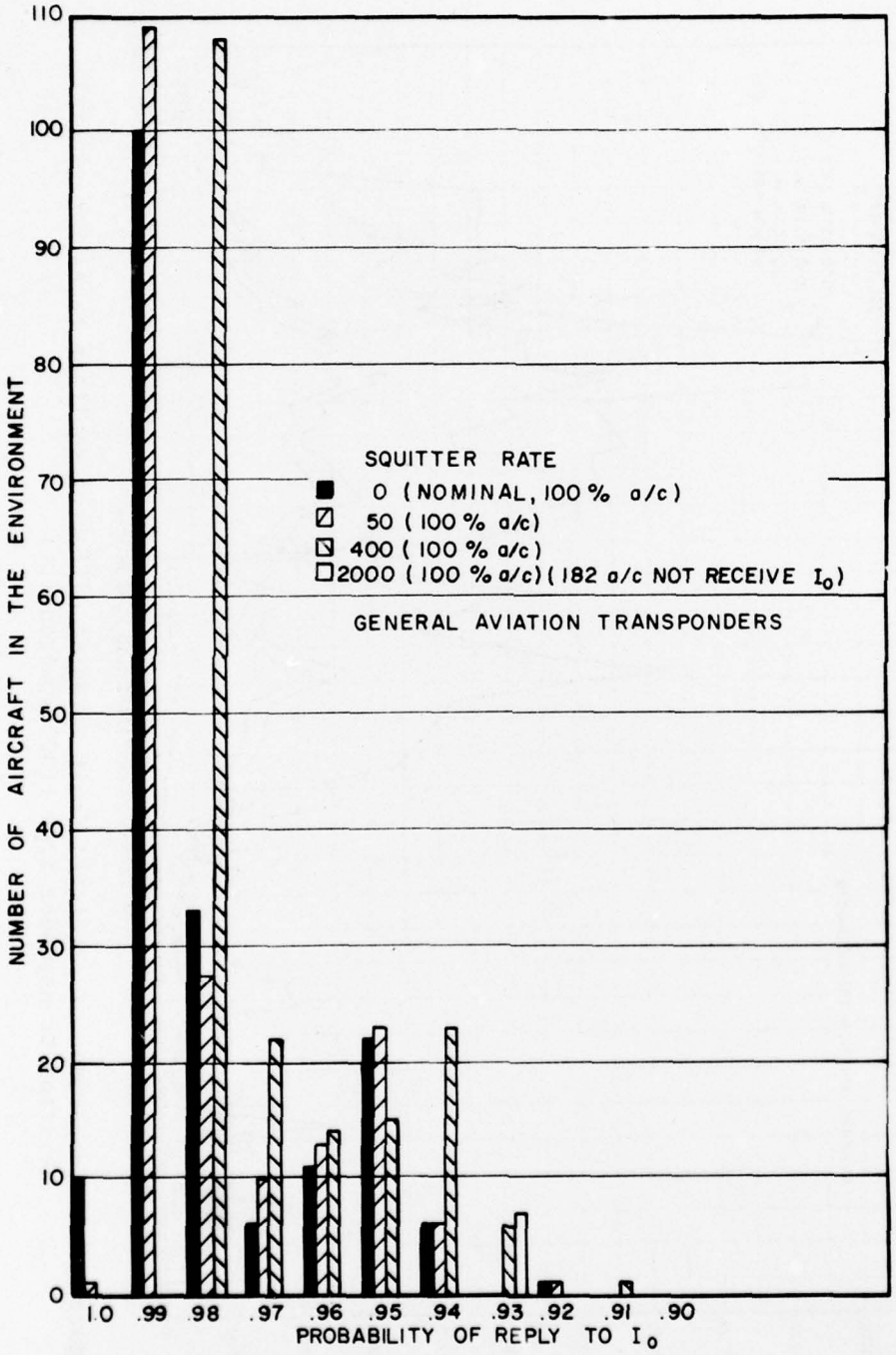


Figure A-25. Comparison of predicted reply probability distributions at different squitter rates for general aviation transponder type (100% environment).

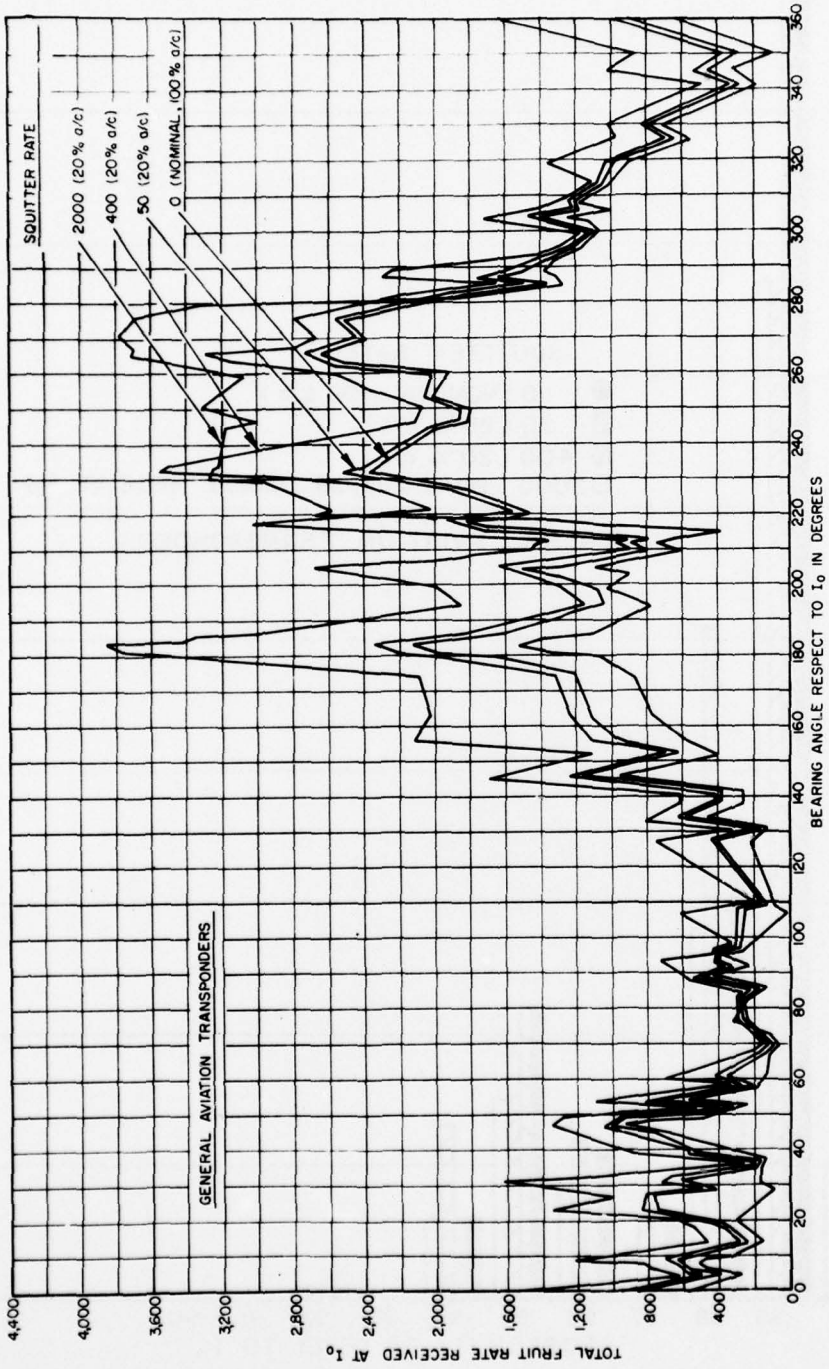


Figure A-26. Comparison of predicted fruit rates at different squitter rates for general aviation transponder type (20% environment).

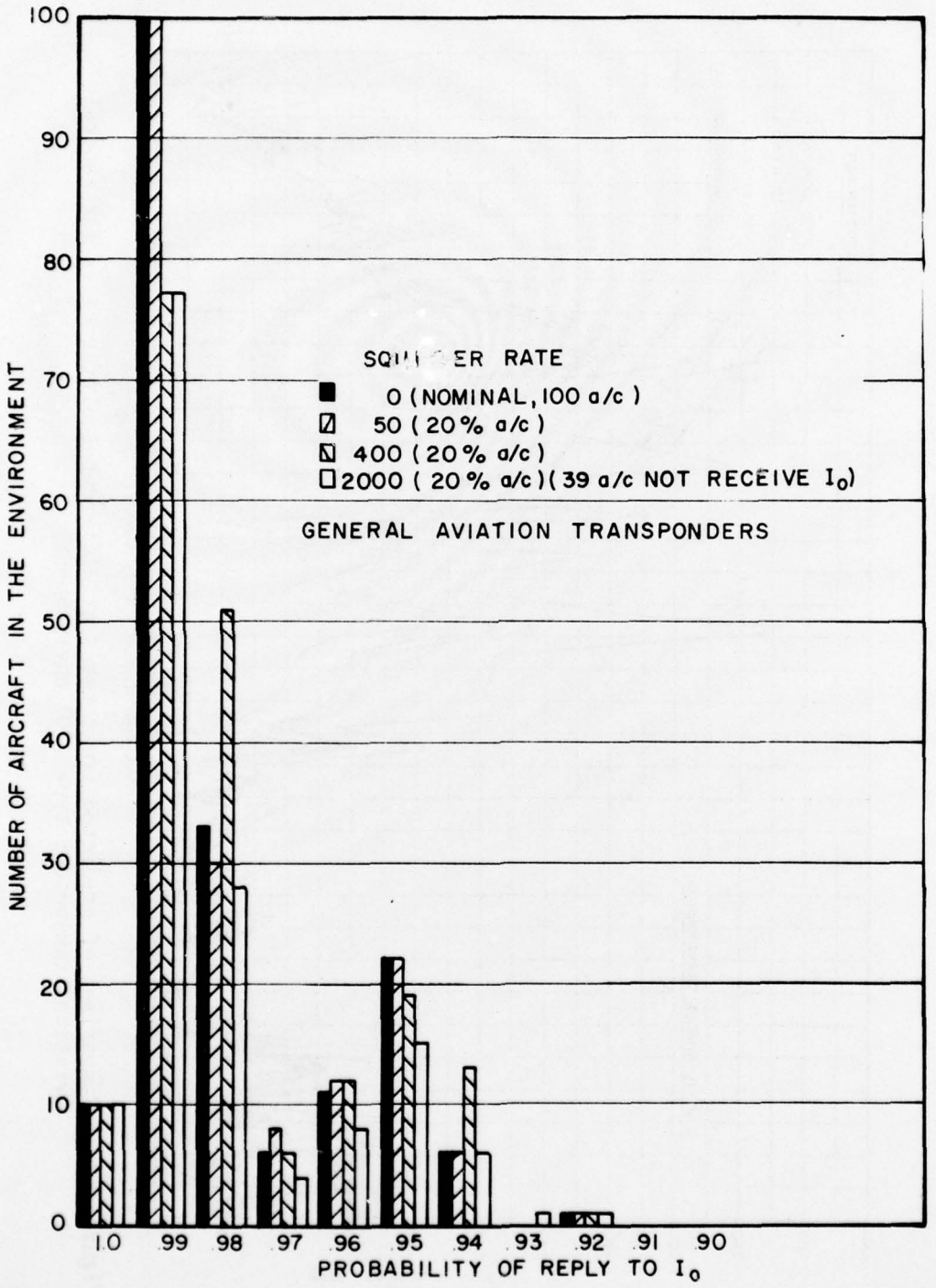


Figure A-27. Comparison of predicted reply probability distributions at different squitter rates for general aviation transponder type (20% environment).

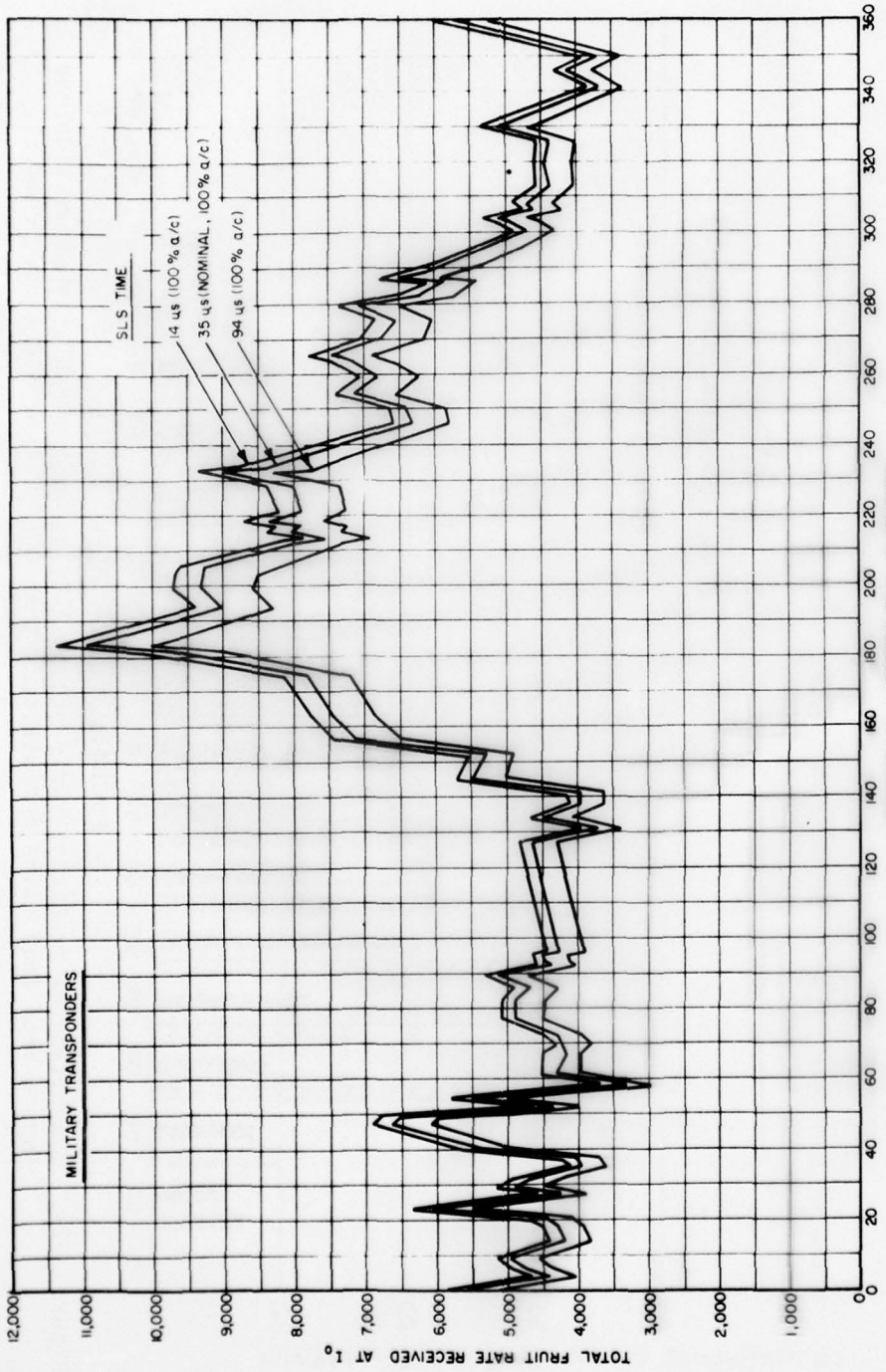


Figure A-28. Comparison of predicted fruit rates at different lengths of sidelobe suppression dead times for military transponder type (100% environment).

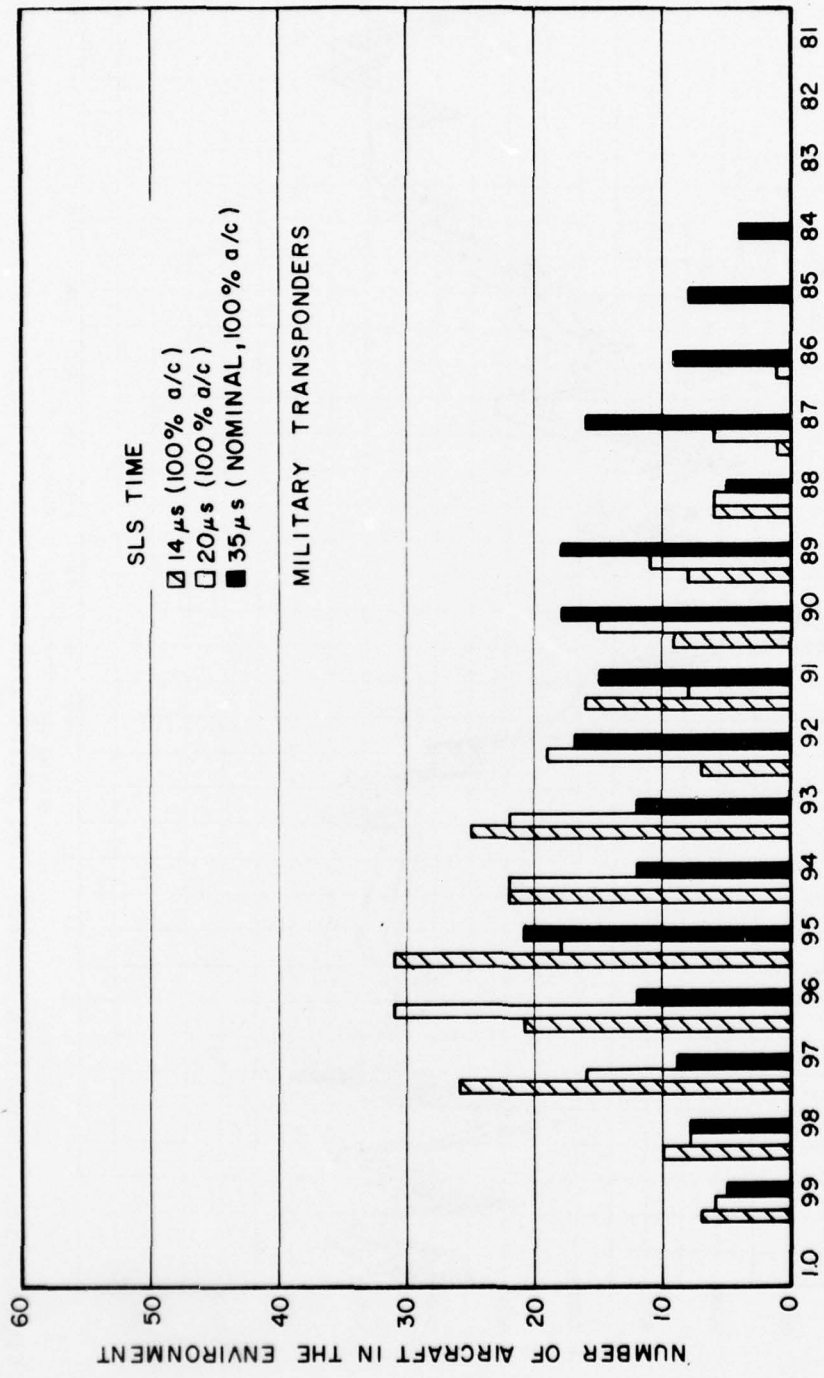


Figure A-29. Comparison of predicted reply probability distributions at shorter sidelobe suppression dead times for military transponder type (100% environment).

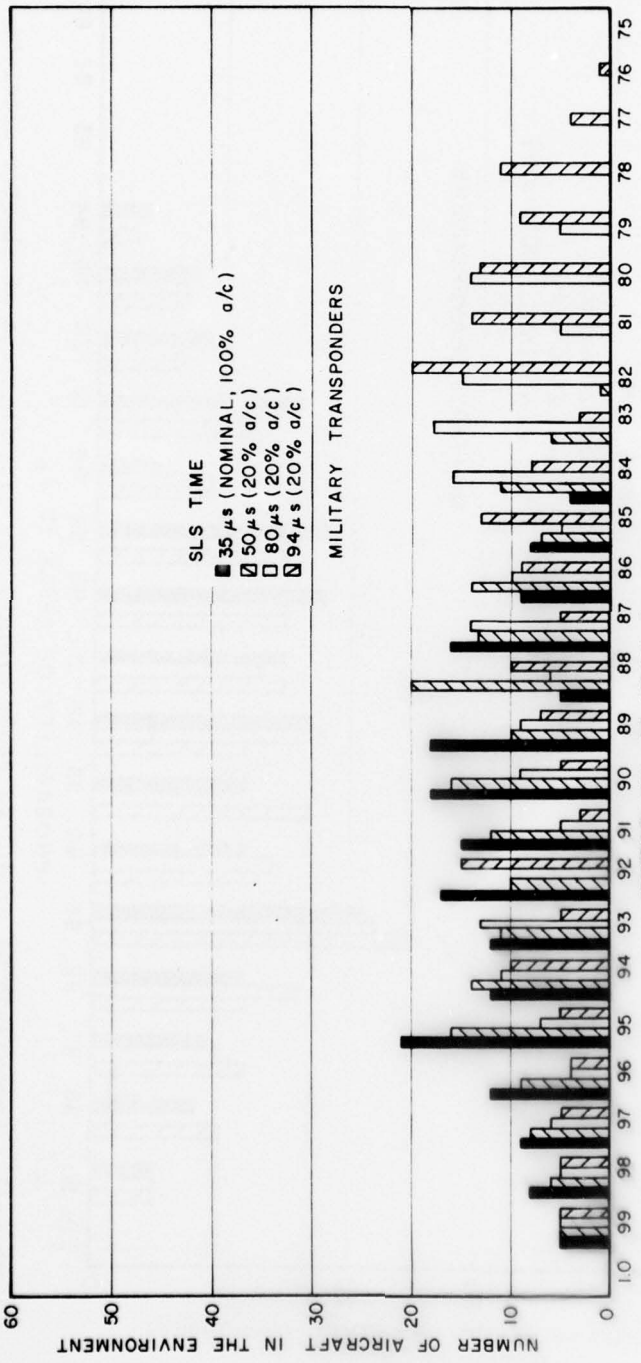


Figure A-30. Comparison of predicted reply probability distributions at longer sidelobe suppression dead times for military transponder type (100% environment).

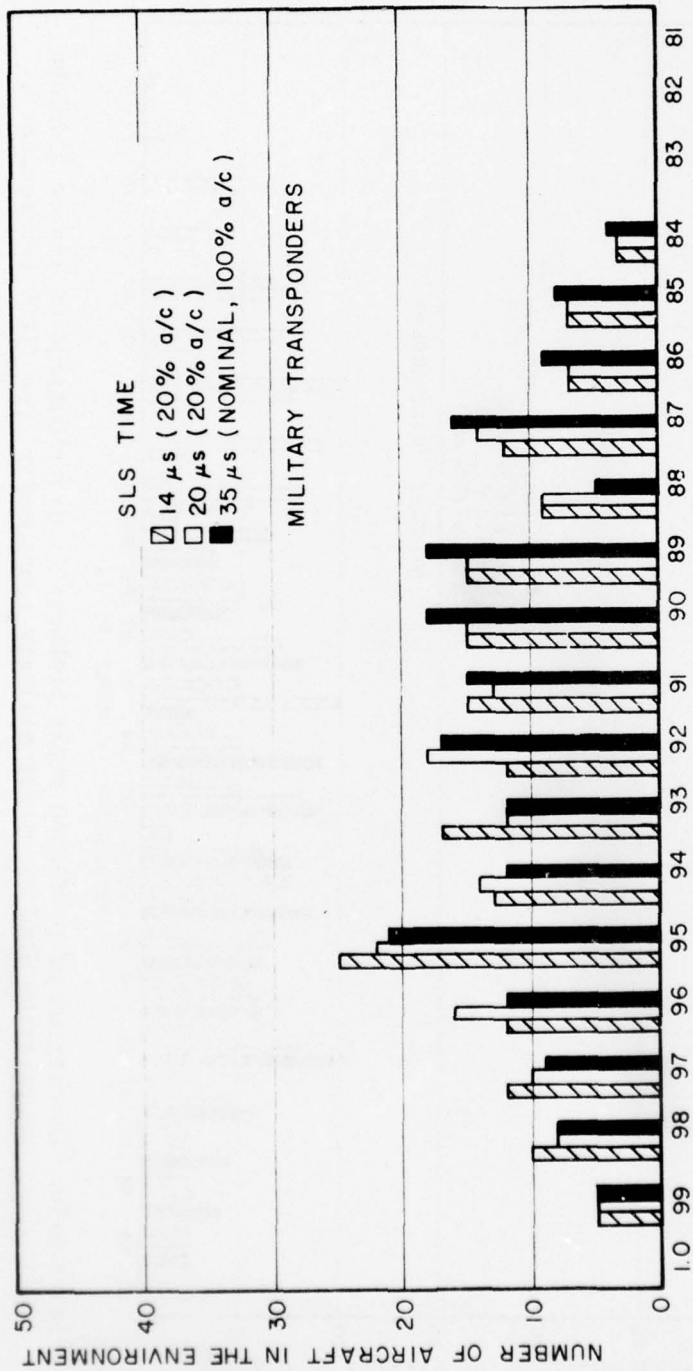


Figure A-31. Comparison of predicted reply probability distributions at shorter sidelobe suppression dead times for military transponder type (20% environment).

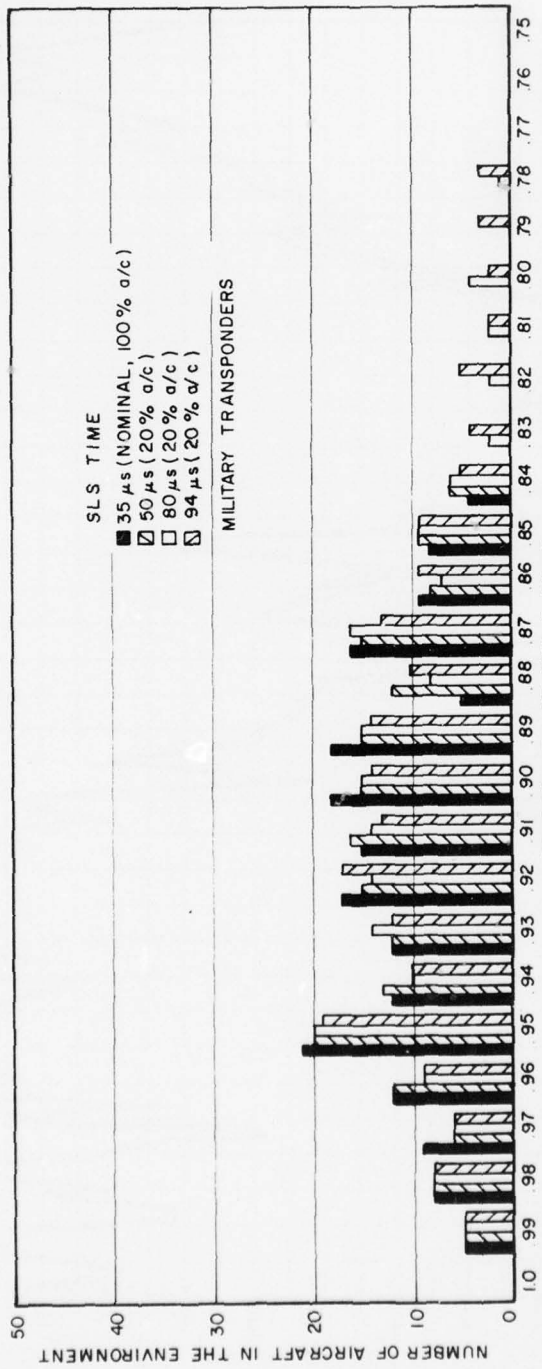


Figure A-32. Comparison of predicted reply probability distributions at longer sidelobe suppression dead times for military transponder type (20% environment).

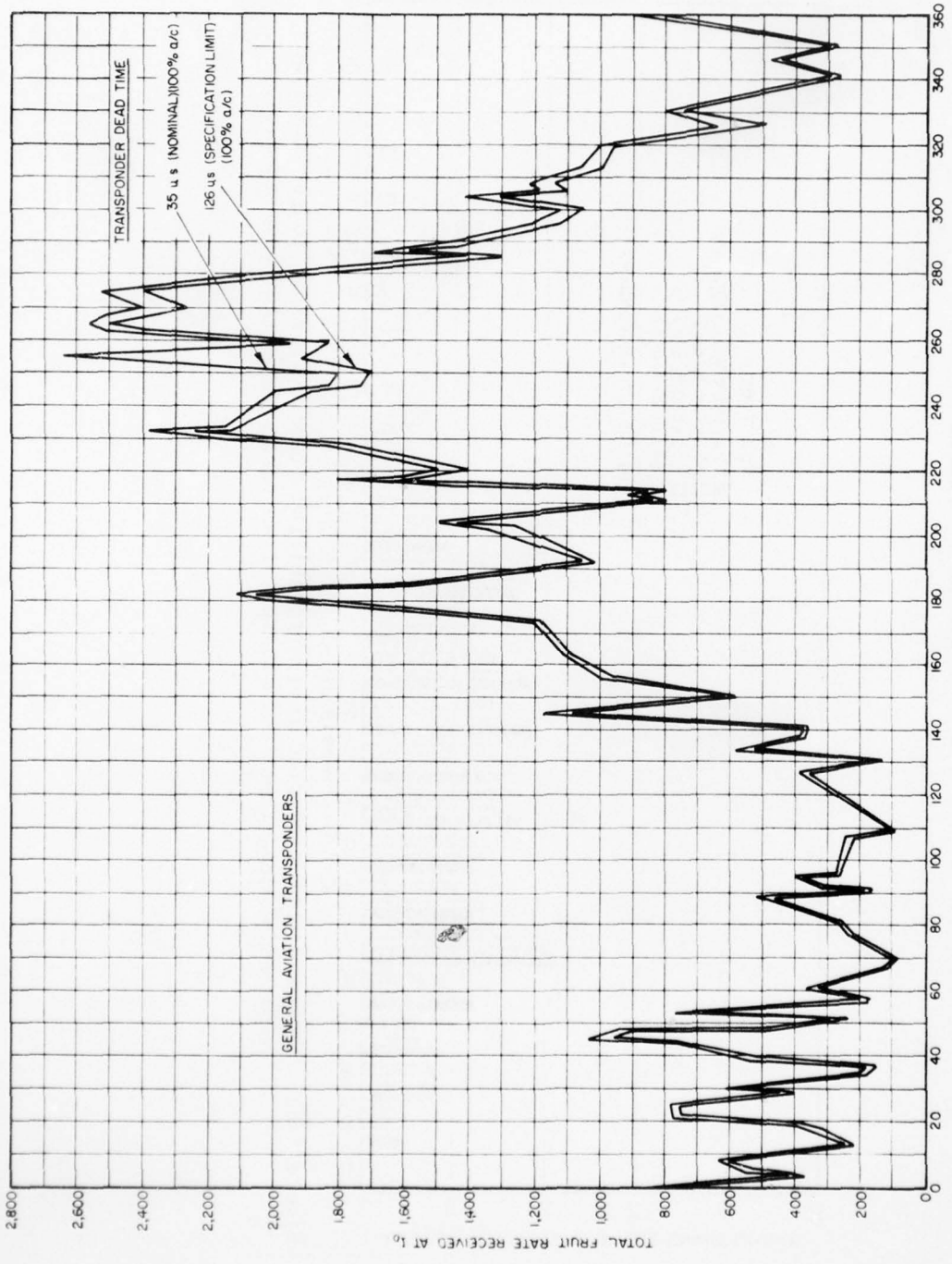


Figure A-33. Comparison of predicted fruit rates at longer dead time for general aviation transponder type (100% environment).

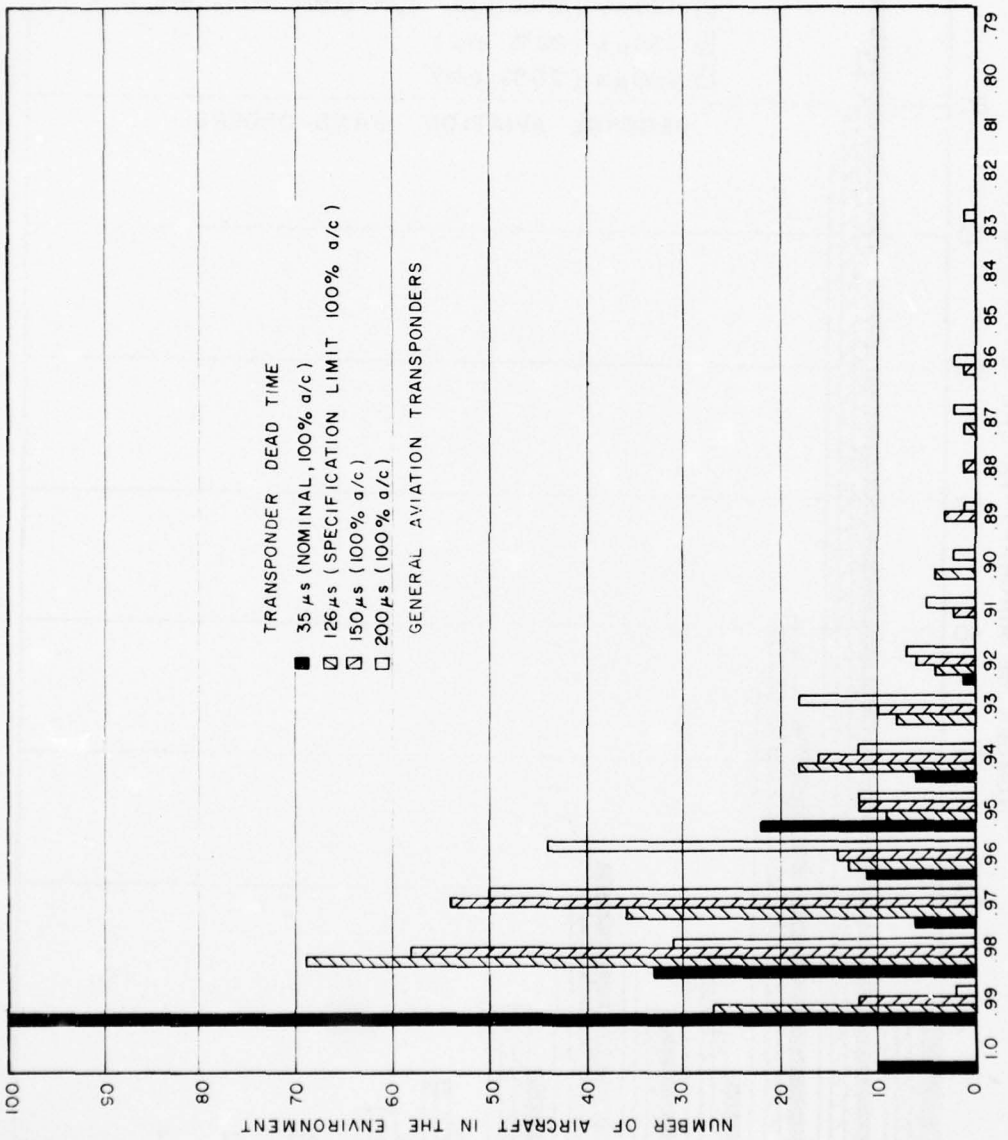


Figure A-34. Comparison of predicted reply probability distributions at different lengths of dead times for general aviation transponder type (100% environment).

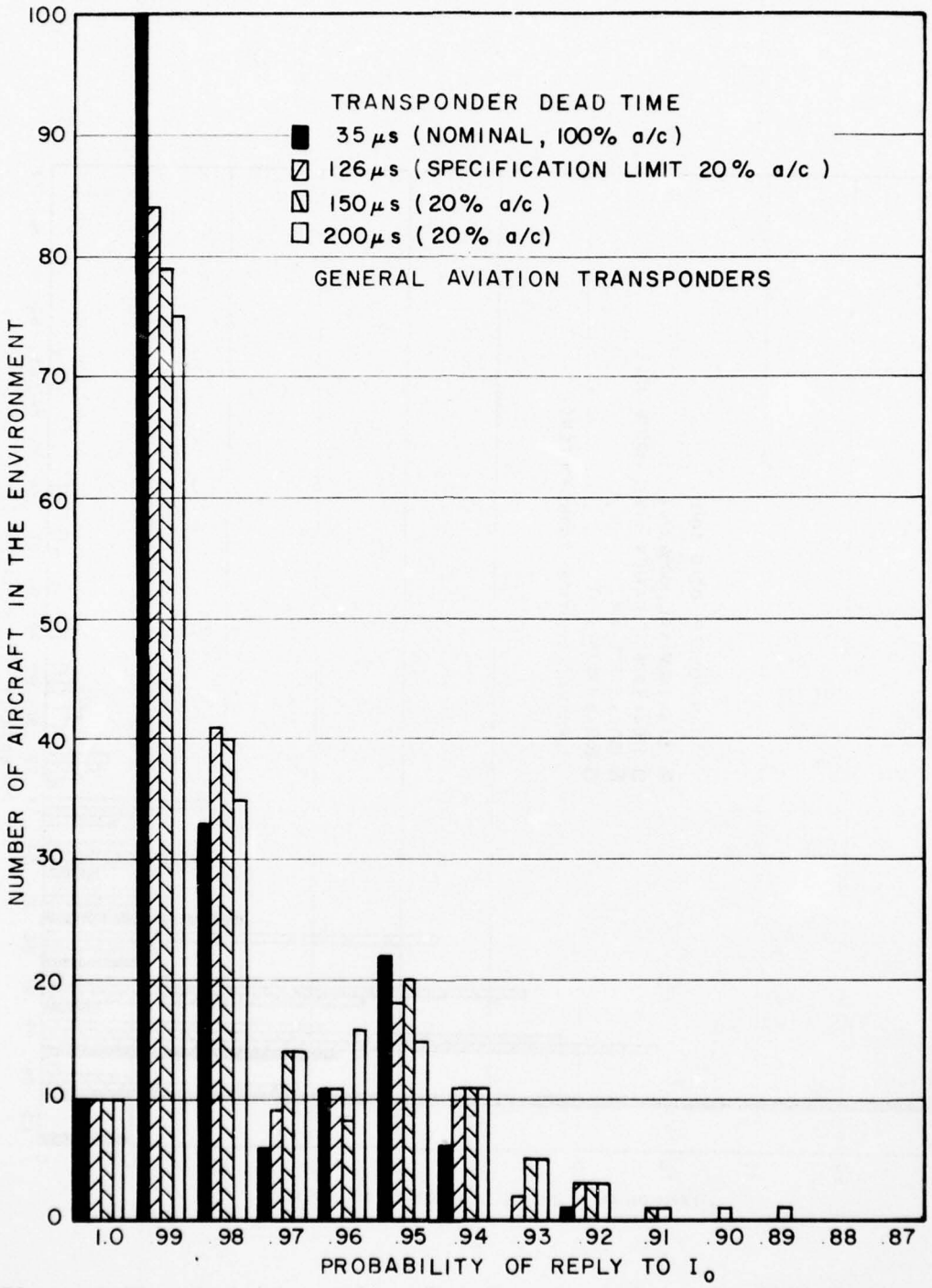


Figure A-35. Comparison of predicted reply probability distributions at different lengths of dead times for general aviation transponder type (20% environment).

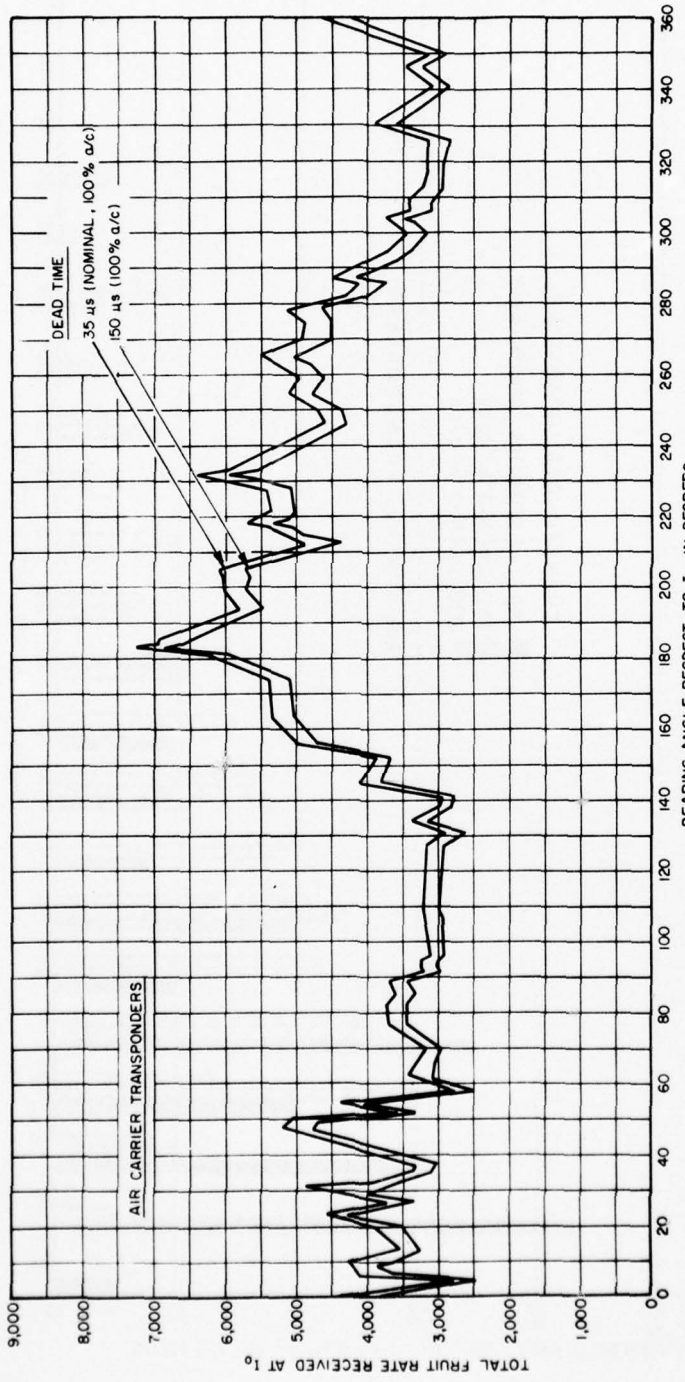


Figure A-36. Comparison of predicted fruit rates at longer dead time for air carrier transponder type (100% environment).

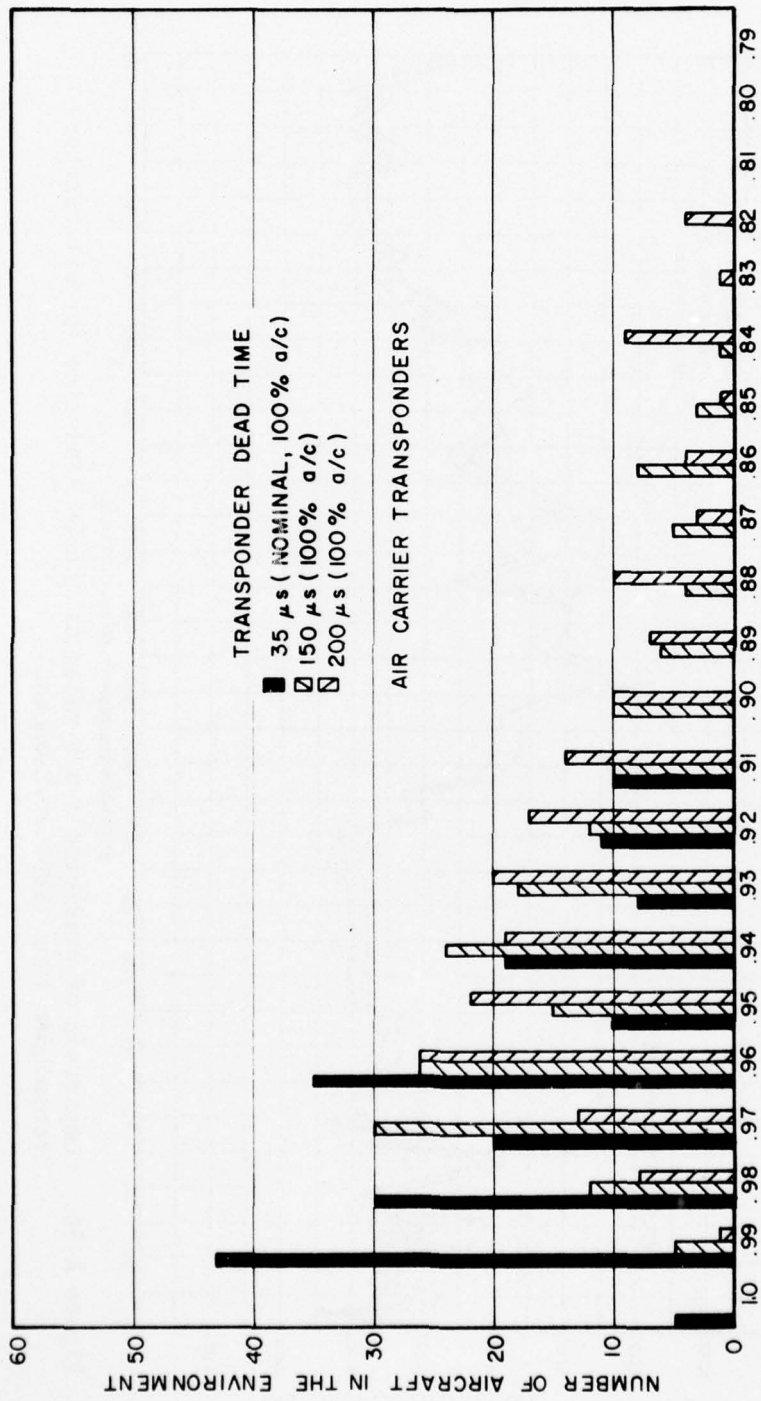


Figure A-37. Comparison of predicted reply probability distributions at different lengths of dead times for air carrier transponder type (100% environment).

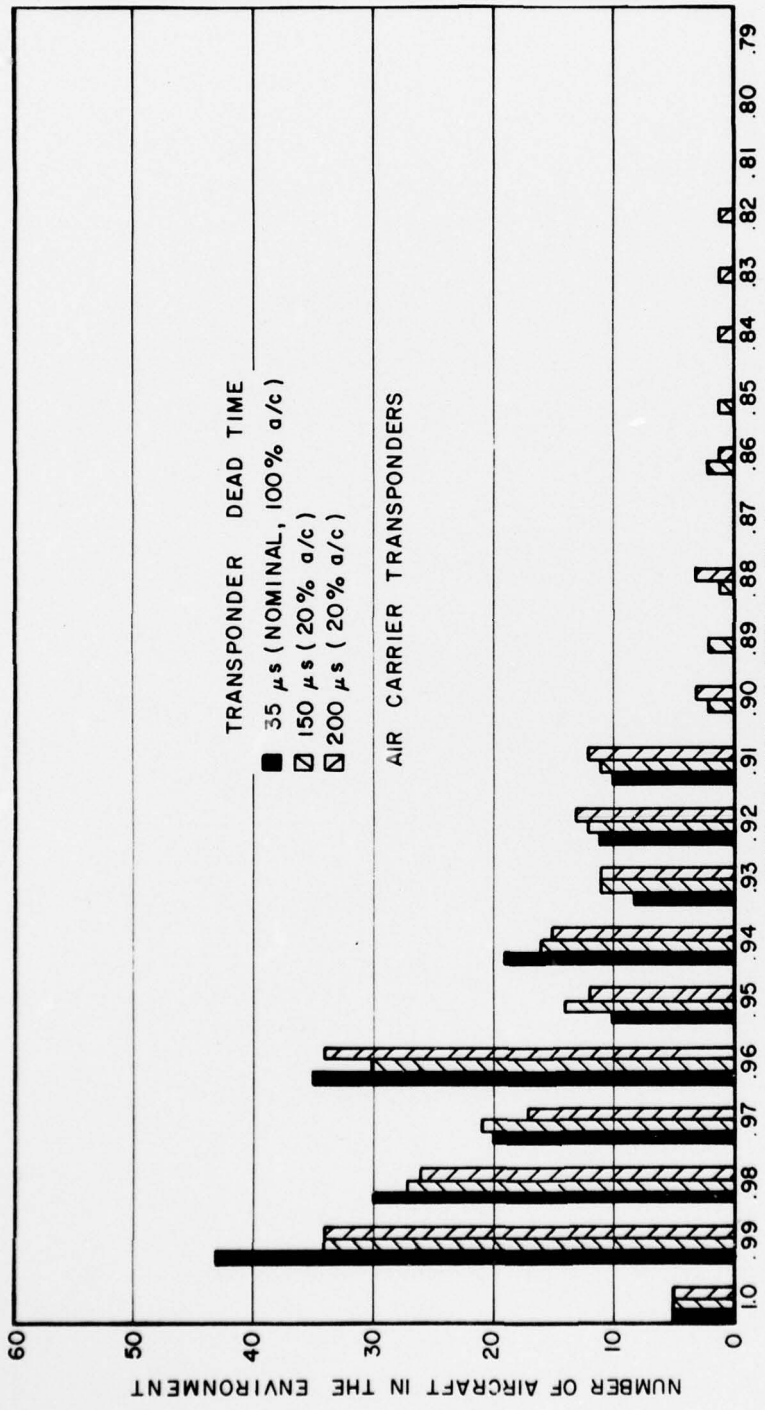


Figure A-38. Comparison of predicted reply probability distributions at different lengths of dead times for air carrier transponder type (20% environment).

- End of Report -