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THE IFF MARK X (SIF) AIR TRAFFIC CONTROL RADAR BEACON SYSTEM PERFORMANCE PREDICTION MODEL

Prepared by E. F. Freeman
of the IIT Research Institute

September 1969

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**THE IFF MARK X (SIF) AIR TRAFFIC CONTROL RADAR BEACON
SYSTEM PERFORMANCE PREDICTION MODEL**

Technical Report

No. ESD-TR-69-274

September 1969

**DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center**

**Prepared by E. F. Freeman
of the IIT Research Institute**

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North Severn
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FOREWORD

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 Director of Defense Research and Engineering and the Chairman, Joint Chiefs of Staff or their designees who jointly provide policy guidance, assign projects, and establish project 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 as part of AF Project 649E under Contract F-19628-69-C-0073 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 United States of America Standards Institute.

Users of this report are invited to submit comments which would be useful in revising or adding to this material to the Director, ECAC, North Severn, Annapolis, Maryland 21402, Attention ACV.



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ABSTRACT

The development of the IFF MARK X (SIF) Air Traffic Control Radar Beacon System Performance Prediction Model (ATCRBS PPM) is described. This model provides performance predictions of the entire system or of selected subsystems. Military, civilian, or mixed equipment deployments for any geographic location can be considered. Actual, postulated, or future interrogator and aircraft deployments can be studied to determine system or equipment effectiveness. Deployments can include an unlimited number of aircraft (transponders) operating at altitudes up to 80,000 feet and distributed over an unlimited geographical area.

KEY WORDS

AIR TRAFFIC CONTROL
RADAR BEACON
MATHEMATICAL MODEL
CALCULATION
EFFECTIVENESS
IFF

ACKNOWLEDGMENTS

The following ECAC personnel provided significant contributions to this project: R. A. Frazier, model development; Ken Geisinger, preprogramming mathematical analysis; Jim Mishoe, programming; John Lady, statistical modeling; L. Plack, statistical programming; Michael Maiuzzo, propagation model; John Carman, subprogramming; and Charles Kerr, applications. Frank L. Frisbie of the Spectrum Plans and Programs Branch, Frequency Management Division, FAA provided invaluable help.

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DD FORM 1473

GLOSSARY

A	Probability of receiving a fruit reply, given its power exceeds I_0 sensitivity (output of the GTC submodel)
A/C	Aircraft
ADC	Air Defense Command
ADP	Automatic Data Processing
AIMS	Air Traffic Control Radar Beacon System, Identification, Friend or Foe, MARK XII System
Amplitude Sensitivity of model	Combined effect of: Interrogator power output, interrogator antenna gain, propagation paths, transponder antenna gain, transponder receiver sensitivity for the interrogation link, transponder power output, transponder antenna gain, propagation path loss, interrogation antenna gain, and interrogator receiver sensitivity for the reply link
AOC	Automatic Overload Control
ARADCOM	Army Air Defense Command
ARTCC	Air Route Traffic Control Center
ARTS	Advanced Radar Traffic Control System
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
B	Fruit reduction factor due to receiver dead time, in percent
BLW	Backlobe width of antenna
CD	Common digitizer (radar video data processor)

GLOSSARY (Continued)

C-E	Communications-electronics
CFAR	Constant false alarm rate
DD 1374	Used to collect environmental data on fixed and nontactical mobile C-E equipment
Deadtime submodel	Computes RR , f_{ri} , f_{rn} , and RR'' , which considers the period of time a T_j receiver is shut down due to the decoding of valid or SLS interrogations
Decoded signal	Signal accepted by the decoder as valid
DI	Expected number of valid IPS from a single I/R detected by the transponder
DME	Distance measuring equipment
ΔGB	Mainbeam antenna gain minus backlobe gain (dB)
ΔGS	Mainbeam antenna gain minus sidelobe gain (dB)
ΔL	Minimum increase required of transponder sensitivity to eliminate a portion of detected interrogations (dB)
EIR	Effective interrogation rate (of I_k)
EMC	Electromagnetic Compatibility
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FPS	Total average fruit replies per scan
f_{ri}	Unwanted fruit replies received by I_0 from many transponders in the environment
f_{rn}	Rate of T_j replies to valid I_0 interrogators

GLOSSARY (Continued)

Fruit	Nonsynchronous IFF/SIF replies
GTC	Gain Time Control
GTC Function	Automatically varies I_o receiver sensitivity as a function of time, resulting in a decrease in the number of fruit replies received
ICAO	International Civil Aviation Organization
IFF	Identification, Friend or Foe
IFR	Instrument Flight Regulations
IRF	Interrogation Rate
I_k	RBS Interrogator/responsor
Interrogator	Radar beacon transmitter-receiver transmitting discrete radio signals that repetitiously request all transponders, on the mode being used, to reply
I_o	Victim or desired ATCRBS interrogator responsor
IPS	Interrogations per second
IPS_k	Number of IPS emitted by I_k
I/R	Interrogator/responsor
IRAC	Interdepartment Radio Advisory Committee
IRS	Interrogation rate for SLS for a particular interrogator detected by the transponder
ISLS	Interrogator Sidelobe Suppression
IISLS	Improved Interrogator Sidelobe Suppression

GLOSSARY (Continued)

KA, K _s , K	Interpolation factors used for adjusting the rate of interrogations (TDI) received when they exceed the threshold rate of a nondiscriminatory transponder
L	Transponder threshold adjusted due to RRL or SLS action (dBm)
L _t	Transponder threshold (dBm)
MBW	Mainbeam width of I/R antenna
Modem	Modulator demodulator
MTI	Moving target indicator
NAFEC	National Aviation Facilities Experimental Center
NAS	National Airspace System
N _j	An integer ≥ 1 corresponding to the number of essentially similar transponders located about the same geographic position
OIR	Over-interrogation ratio
PI _O	Power level of a signal from T _j in the I _O receiver
PPI	Plan Position Indicator
PPM	Performance Prediction Model
PRF	Pulse repetition frequency
PRRL	Probability of reply rate limit
RAPPI	Random access plan-position indicator
RBS	Radar beacon system
RPM	Scan rate of antenna in revolutions per minute

GLOSSARY (Continued)

RR	Round reliability (the ratio of replies to I_0 from the transponder in question to the total number of interrogations from I_0)
RR'	Countdown due to RRL
RR''	Countdown due to deadtime, as calculated in the deadtime submodel
RRL	Reply Rate Limit or Limiting
R/T SCSE	Ray-Trace correction to the smooth curve, smooth earth model
RSLs	Responser sidelobe suppression
SCSE	Smooth curve, smooth earth (propagation path loss)
SIF	Selective Identification Feature
SLS	Sidelobe Suppression
SLSSW	Switch that indicates to the program whether or not the check for SLS change of threshold has been accomplished SLSSW = 0 -- NO 1 -- YES
SLW	Sidelobe width of I/R antenna
SM	Statute miles
SPI	Special position identification
SSR	Secondary surveillance radar
S_R	Receiver Sensitivity in dBm
STC	Sensitivity time control

GLOSSARY (Continued)

TACAN	Tactical Air Navigation
TBLFR	Average number of fruit replies received on I_0 backlobe per scan
TDI	Total average of detected interrogations per second received by the transponder for all I_k
TH	Threshold
Threshold averaging submodel	After transponder threshold has been increased by L to cut out some interrogations due to over-interrogation, a tolerance level is placed around critical threshold setting so that interrogations of a power level that fall within that tolerance are accepted proportionally
T_j	RBS transponder
TMBFR	Average number of fruit replies received on I_0 mainbeam per scan
TN_j	Total number of T_j s, the power levels of which at I_0 exceeded the I_0 threshold
Transponder	Radar beacon receiver transmitter that receives radio signals from an interrogator and automatically replies with a specific reply pulse or pulse group
TSI	Expected total number of SLS IPS from all interrogators detected by the transponder
TSLFR	Average number of fruit replies received on I_0 sidelobe per scan
TX	Indicator for transponder type TX = 1 -- discriminatory = 2 -- non discriminatory

GLOSSARY (Continued)

W_k Probability that signal power received from I_k exceeds L

$W(K,L)$ Propability that power from I_k exceeds the sensitivity level L at the transponder under consideration,

or,

Interrogation beamwidth (MBW, MBW + SLW, 360)

360

(good only for scanning interrogators)

$\leftarrow$ In an equation it means that quantity is replaced by another quantity; for example, $A \leftarrow B$ means A is replaced by B

SECTION 1

INTRODUCTION

OBJECTIVES

The Electromagnetic Compatibility Analysis Center (ECAC) was tasked to develop a model that would predict the performance of the Air Traffic Control Radar Beacon System (ATCRBS) in its electromagnetic environment. This task resulted from the combination of separate but related tasks received from the Navy and the FAA.

A second objective of the project was validation of the model by predicting ATCRBS performance in a monitored environment situation.

PROJECT BACKGROUND

ECAC received separate tasks from the Navy and the FAA that were sufficiently related to justify their integration into a common analysis. The Navy tasked ECAC to analyze mutual interference and interactions between TACAN and IFF equipment. The objective of this task was to provide a validated basis for establishing IFF/TACAN compatible channel assignment plans that would permit handling the maximum amount of air traffic in various operational areas (see Reference 1). The FAA tasked ECAC to predict and analyze interference conditions that might compromise ATCRBS, a vital part of the evolving National Airspace System (NAS).

Because both TACAN and IFF operate in the same environment and use a common frequency range (960 to 1215 MHz), ECAC combined both tasks into a single project. ECAC prepared a project package that was approved by the Communication Electronics Directorate (J-6) of the Joint Chiefs of Staff and the Office of Director of Defense Research and Engineering (ODDRE) in March 1967. Due to the complex nature of the overall ATCRBS IFF/TACAN problem, the project package was expanded into a detailed project plan (see Reference 2).

This report describes the IFF MARK X (SIF) ATCRBS Performance Prediction Model (ATCRBS PPM). The validation of this model will be reported in a future ECAC report. Mutual interference and interactions between IFF and TACAN systems are reported in other ECAC reports.

APPROACH

A model was developed that accounted for the interrogator and transponder operating characteristics and for designated deployments of the equipments. The model was automated for use on the UNIVAC 1108 computer. Sample environments were processed for which equipment output observations had been made. The model is available for prediction of performance of planned deployments of ATCRBS.

SIGNIFICANT FEATURES OF THE MODEL

The ATCRBS PPM was developed with several variations to meet the needs of equipment and systems performance analysis. These variations are: average derived performance predictions, Monte-Carlo derived performance predictions, and a method of deriving performance prediction samples for statistical analysis. The significant features of these variations are:

1. The average derived performance prediction may be considered for an initial analysis of equipment and system performance. It provides average total detected interrogations per second, valid replies per second, round reliability (for each transponder at the output of the desired interrogator receiver), reply rate limit indicator, average transponder sidelobe suppressions per second, mainbeam, sidelobe, and backlobe fruit per second at each transponder, and average fruit per scan at any selected interrogator.
2. Distributions, means, and variances of transponder performance are determined by selecting a transponder and its combination of interrogators and producing an output distribution of transponder performance by Monte-Carlo sampling of possible combinations of antenna orientations.
3. A probability of reply rate limiting (RRL) at the transponder is provided by determining the probability of simultaneous interrogator antenna illumination of the transponder, the total interrogation rate per second, and comparing this rate with the interrogation rate limit.
4. Samples of transponder and interrogator performance are provided to attain distributions, means, and variances of selected outputs. Samples are generated by establishing initial interrogator antenna orientations with respect to the selected interrogator and then stepping these antennas through one scan of the interrogator. The number of steps per scan is determined by the mainbeam width of the selected interrogator. Fruit density per antenna beamwidth per scan is the prime output. Random deployment of aircraft can be considered also. Instant performance predictions at ATCRBS can be provided.
5. Aircraft and interrogator deployments and equipment parameters can be varied independently to provide forecasts as well as real-world situations of ATCRBS performance.

6. Distributions of equipment performance parameters can be considered.
7. The effects of aircraft horizontal and vertical antenna patterns on transponder performance can be determined.
8. ATCRBS performance distributions can be developed for specific geographical locations, as desired.
9. An unlimited number of transponders can be considered.
10. Two hundred interrogators per transponder can be considered.
11. Transponders can be deployed from 10 to 80,000 feet in altitude.
12. Ground interrogator deployments can be distributed over any tactical area, as required.
13. Airborne interrogators can be deployed.
14. Interrogator SLS and Transponder SLS may be either fully or partially deployed.
15. Polar plots of interrogator deployments can be provided.
16. Polar plots of aircraft deployments can be provided.
17. Polar or Cartesian displays of performance predictions can be provided as computer-generated outputs.
18. A full or partial computer printout of all inputs, calculations, and outputs can be provided.
19. The effects of RSLS on fruit rates can be predicted.
20. AIMS performance predictions can be developed for various tactical environments.
21. Polar or Cartesian displays of fruit density per mainbeam beamwidth can be provided.
22. Sector scanning can be assessed.
23. Effects of the sidelobe suppression limit on system performance can be determined.
24. Modifications to the performance prediction model can be considered to meet specific needs of the user.

SECTION 2

CONCLUSIONS

1. Applications of the model demonstrated correlation between predicted and measured performance. For example, predicted values of fruit per scan at Tyndall AFB, Florida, and Total Detected Interrogations (TDI) at the test aircraft fall within a one-sigma limit of the measured-data means.

2. The model demonstrates that the ATCRBS is very sensitive to small changes of system parameters, such as transmitter power output, receiver sensitivity, aircraft deployment, interrogator deployment, and transponder deadtime. Since this sensitivity exists, caution should be exercised when introducing heuristic changes into the system.

3. Since the ratio of values of peak fruit per scan to average values of fruit per scan can be as much as 5 to 1, it is necessary to consider the peak values as well as average values in establishing ATCRBS effectiveness.

4. It is also necessary to consider fruit density per mainbeam width as well as average and peak values of fruit per scan. Fruit density may exceed data limits of processors such as the common digitizer while the average fruit per scan is within acceptable limits. A fruit density of 800 per degree can occur while average fruit per scan is as little as 100,000 per 360 degrees.

5. Interrogation sidelobe suppression (ISLS) can reduce fruit per scan by as much as 6 to 1. Results of several model applications indicate the range of this ratio can be from a minimum of 2 to 1 to a maximum of 6 to 1.

6. Interrogation receiver sidelobe suppression (RSLS) can reduce fruit per scan to an expected ratio of 10 to 1. For example, if a 100 percent effective RSLS device is installed, then all received sidelobe and backlobe fruit is eliminated. The ratio of mainbeam fruit to sidelobe and backlobe fruit extracted from several model applications ranges from a minimum of 1.4 to 1 to a maximum of 30 to 1.

7. A 50 percent reduction in transponder reply rate limiting can increase round reliability as much as 2 percent and reduce fruit per scan as much as 30 percent.

8. Application of the model to the environment centered at Tyndall AFB illustrates limitations of power reduction techniques in reducing fruit. In this specific case a reduction in overall system mean power of 50 percent reduced fruit per scan by 2 percent, while an increase in overall system power by 100 percent increased the fruit per scan by 50 percent.

SECTION 3

SYSTEM DESCRIPTION

ATCRBS employs a radar beacon interrogator paired to a surveillance radar. The beacon interrogator has its own transmitter and receiver and either shares the surveillance radar's antenna or uses a separate antenna that is mechanically coupled to the surveillance antenna. Figure 3-1 is a block diagram of the Air Traffic Control Radar Beacon System. A quarter wave monopole blade antenna is used with the aircraft transponder. The transponder replies can be displayed along with radar video on the surveillance radar's PPI. The interrogator transmits at a frequency of 1030 MHz with a pulse-repetition rate less than or equal to 450 Hz (see Reference 3). A future system is planned in which independent operation for some interrogators will be possible.

The interrogation signal consists of two 0.8 microsecond pulses separated by 8 microseconds for mode 3/A and by 21 microseconds for mode C, disregarding SLS (see Figure 3-2). These pulses are generated by the pulse-pair generator. The transponder replies with a coded pulse train. The spacing between the first and the last pulse (each of 0.45 microsecond duration) of the coded reply is fixed at 20.3 microseconds. These bracket pulses from the reply, which has either 6 or 12 information-pulse positions, spaced 2.9 or 1.45 microseconds apart, respectively (see Figure 3-3). Information pulses in any of the 6 or 12 possible positions means that there are either 64 (2^6) or 4096 (2^{12}) possible codes. Reply codes are normally selected by the pilot. Decoding equipment at the interrogator receiver determines which code was received. The ground decoder in the present ATCRBS is designed so that all transponder-equipped aircraft transmitting a particular code, selected by the ground controller, are displayed. Identification is initiated by the controller by means of the normal communication channel. One of the objectives of the NAS Enroute Stage A is to automate ATCRBS information (see Figure 3-4 and Reference 4).

The National Airspace System is a future air traffic control system that will provide automation for every facility, terminal, and enroute interrogator, where automation is warranted. These facilities will be connected by data transmission links, and the entire system will be a nationwide, real-time, automated ATC system.

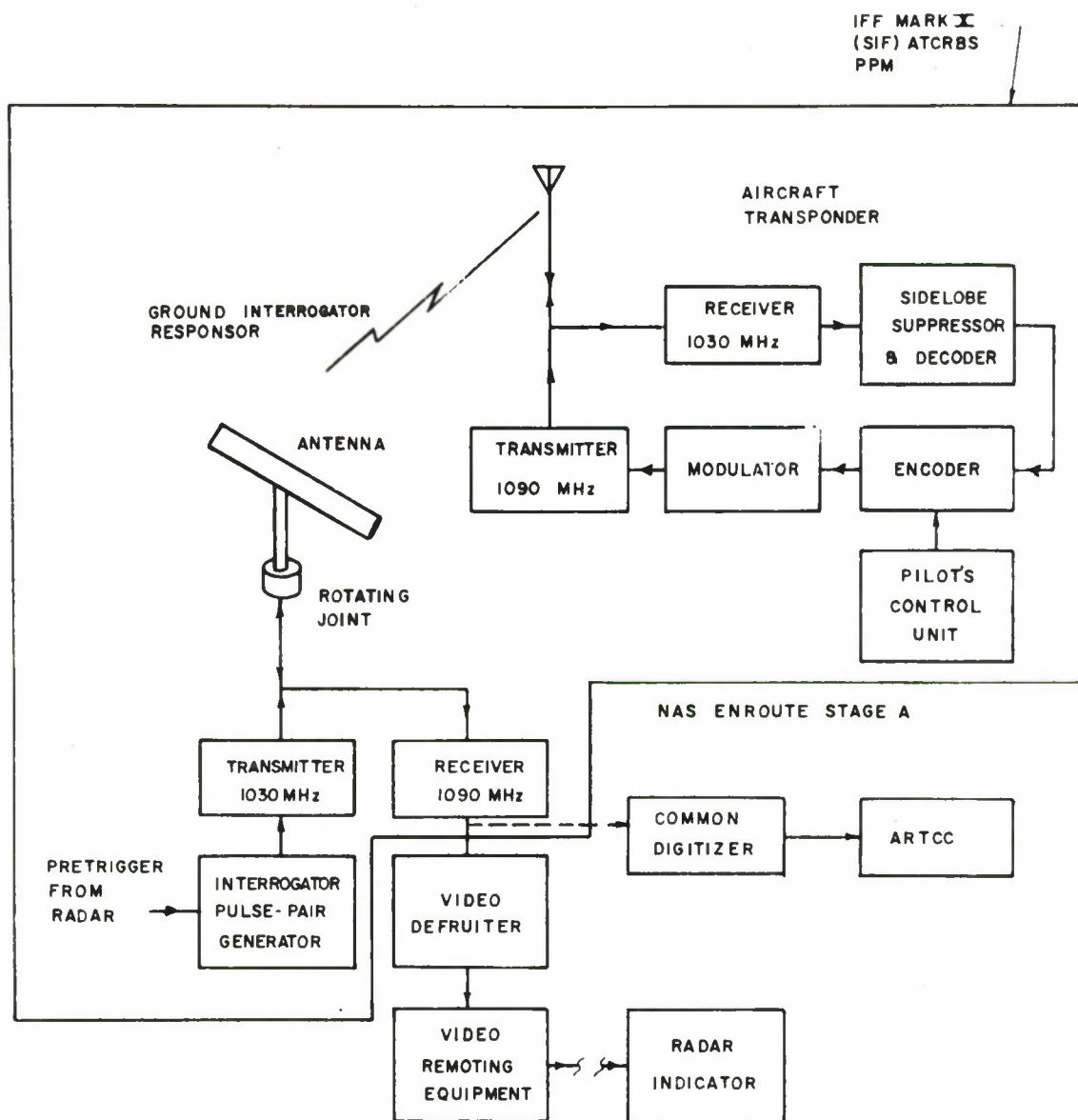


Figure 3-1. IFF MARK X (SIF) ATCRBS Block Diagram

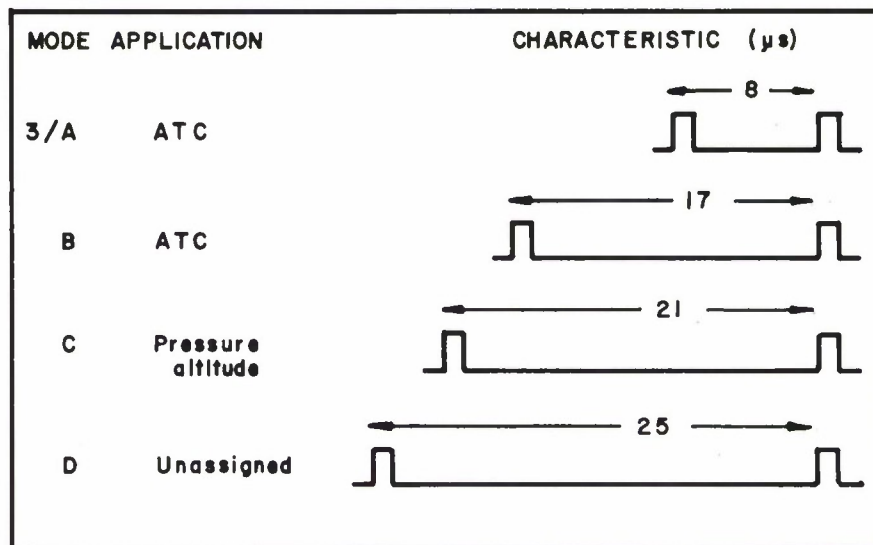


Figure 3-2. ATCRBS Interrogation Modes

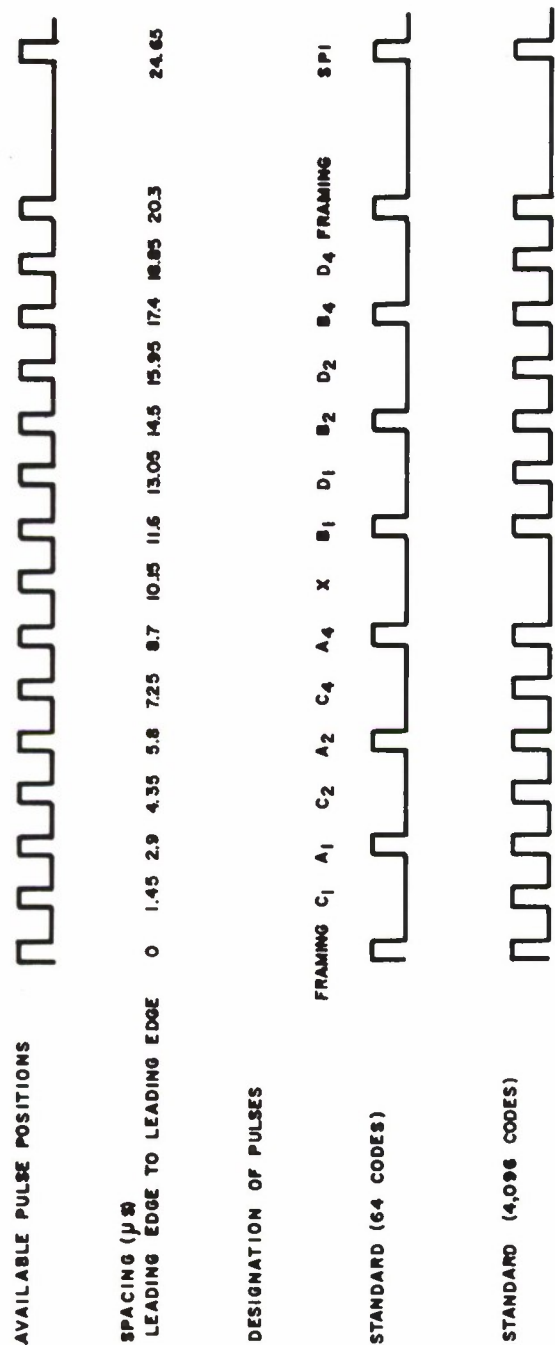


Figure 3-3. ATCRBS Transponder Reply Codes

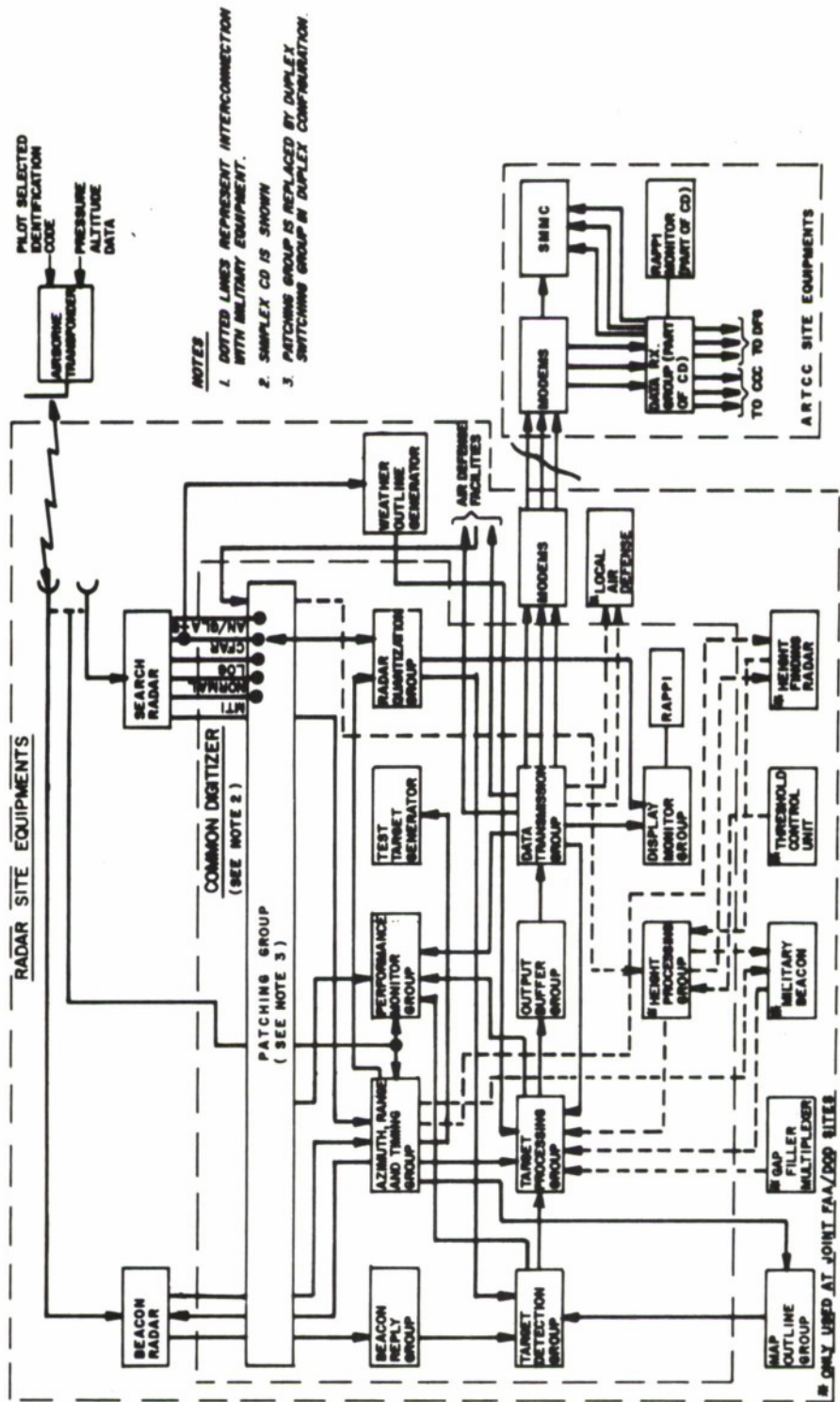


Figure 3-4. Radar Data Acquisition and Transfer Subsystem

Automation of NAS enroute interrogator service is being carried out in stages, the first of which is Enroute Stage A. This system is evolving through the introduction of various levels of automation into the present manual system. The significant features of the Enroute Stage A system will be:

1. Automation features for easy transfer and accurate processing and updating of flight information.
2. Automatic display of altitude or flight level information with aircraft position.
3. Automation aids for establishing and maintaining radar identification of aircraft in the system.
4. A computer processing capability to serve as the basis for implementation of subsequent automation improvements in ATC.

The ATCRBS is sometimes called a secondary surveillance radar (SSR) to distinguish it from the primary radar, which does not require cooperating targets. When used for general identification of military targets a beacon system is known as Identification, Friend or Foe (IFF).

One of the major limitations of ATCRBS is interference from other interrogators, especially in regions of high traffic density. Due to its nature, a transponder might be queried by any mode-compatible interrogator within range, and its replies might be received by any receiver.

A large part of the interference problem is a result of the interrogator antenna sidelobes. An aircraft transponder at long range receives only mainbeam interrogations. At short ranges, the transponder may receive many sidelobe interrogations.

Excessive ATCRBS transponder replies entering the interrogator by means of the sidelobes may be reduced partly by sensitivity time control (STC) or gain time control (GTC). STC or GTC are automatic programs of receiver gain in which the receiver is desensitized for replies from transponders at short ranges and then gradually increased in sensitivity with range (or sweep time). The effect of STC is to decrease the chance of the reception of nearby strong signals in the antenna sidelobes, without discriminating against weak signals at longer ranges. Although STC offers some relief from excessive replies, it is not a perfect solution to the interference problem at the interrogating receivers. Excessive replies by the beacon transponder can also be prevented by the suppression of the antenna sidelobe interrogations, using an omnidirectional antenna in conjunction with the directive interrogating antenna, and the addition of sidelobe suppression (SLS) circuits in the airborne transponders.

SIDELOBE SUPPRESSION SYSTEM

The SLS system adopted as a standard by the FAA and the military is a three pulse system that prevents the airborne transponder from being interrogated by ground station antenna sidelobes. In operation, the ground station transmits three pulses instead of the conventional two pulses. The three-pulse system can be used with either the directional/omnidirectional SLS technique or the sum-difference technique.

In the directional/omnidirectional antenna system, the first and third pulses (P_1 and P_3) are transmitted by the directional antenna. The second pulse (P_2) is transmitted by the omnidirectional antenna. The aircraft transponder compares the relative amplitudes of P_1 and P_2 . If P_1 is not at least 9 dB greater in amplitude than P_2 , a suppressor gate is generated in the transponder and the third pulse (P_3) is suppressed. Therefore, the transponder will not reply. Figure 3-5 shows that the only area where P_1 will be 9 dB greater than P_2 is between points A and B in the mainbeam of the directional antenna.

When the sum-difference SLS system (military) is used, P_1 and P_3 are transmitted by the sum patterns and P_2 is transmitted by the difference pattern. Figure 3-6 shows that the only area where P_1 is at least 9 dB greater than P_2 is between points C and D.

Beacon replies to interrogations by the directive antenna sidelobes are virtually eliminated in this system as long as the vertical lobe structure of the omnidirectional antenna matches that of the directional antenna.

SLS is also an effective method for reducing interrogations caused by reflections. If the direct signal radiated from the interrogator is strong enough to be detected, the transponder will generate a reply. Any vertical conducting surface in the immediate vicinity of the interrogator antenna might reflect the mainbeam signal and cause interrogation and reply of airborne transponders; this might result in the display of spurious transponder signals at incorrect azimuths and ranges. The problem is most severe at terminal facilities where the primary radar and beacon antennas are mounted on low towers and airport buildings, hangars, and fences cause strong reflections. The long-range radar sites with high antenna towers are bothered by fewer reflections.

In the sidelobe areas, the reception of P_1 , which is radiated by the antenna sidelobe, causes transponder suppression because P_2 , which is radiated by the omnidirectional antenna, is received at an equal or stronger signal level. Any reflection of the mainbeam signals (P_1 and P_3) must occur slightly later because the reflected path is longer than the direct path taken by the sidelobe signal. The transponder SLS action of 35 microseconds (deadtime) starts at reception of P_2 and prevents a transponder reply to the reflected interrogation pulses.

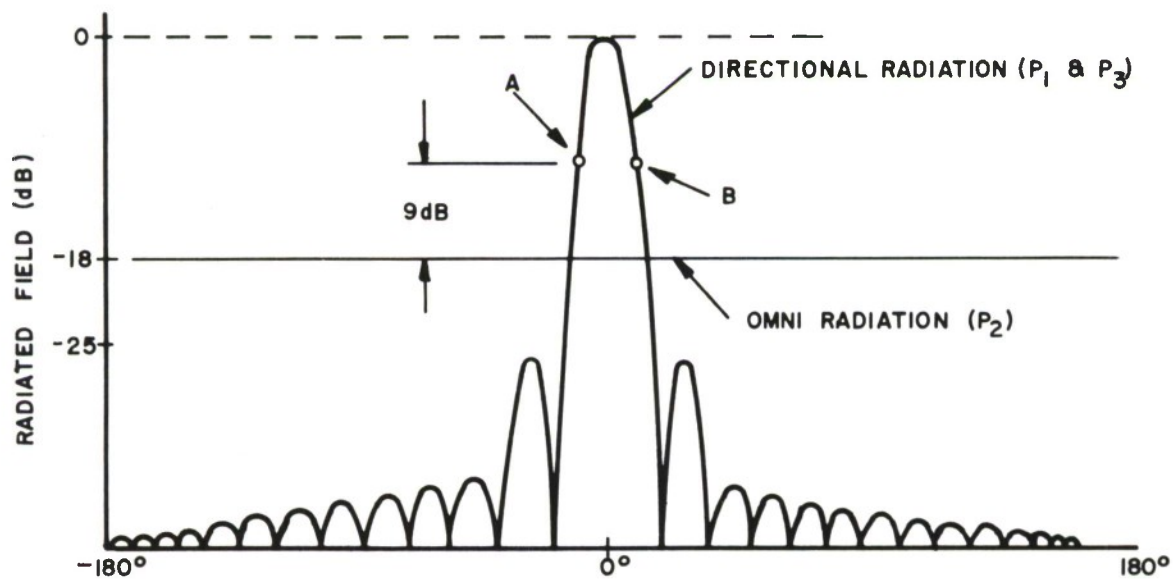
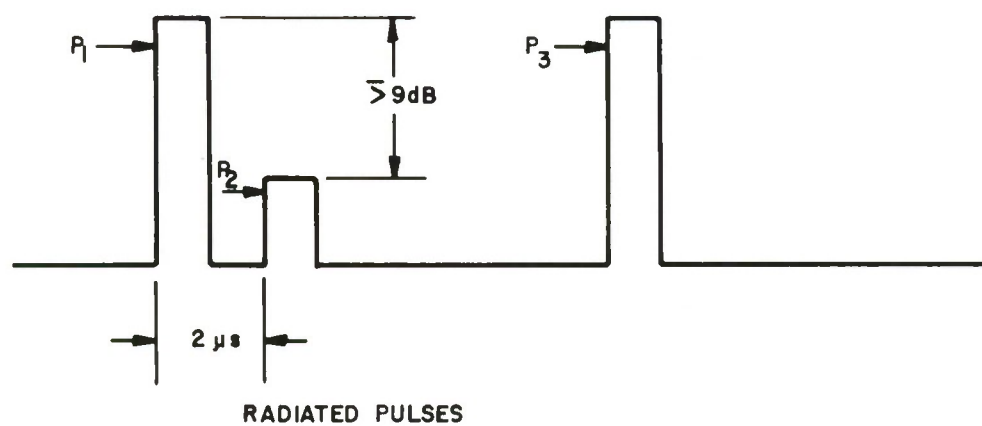


Figure 3-5. Directional/Omnidirectional Antenna Pulse Transmission

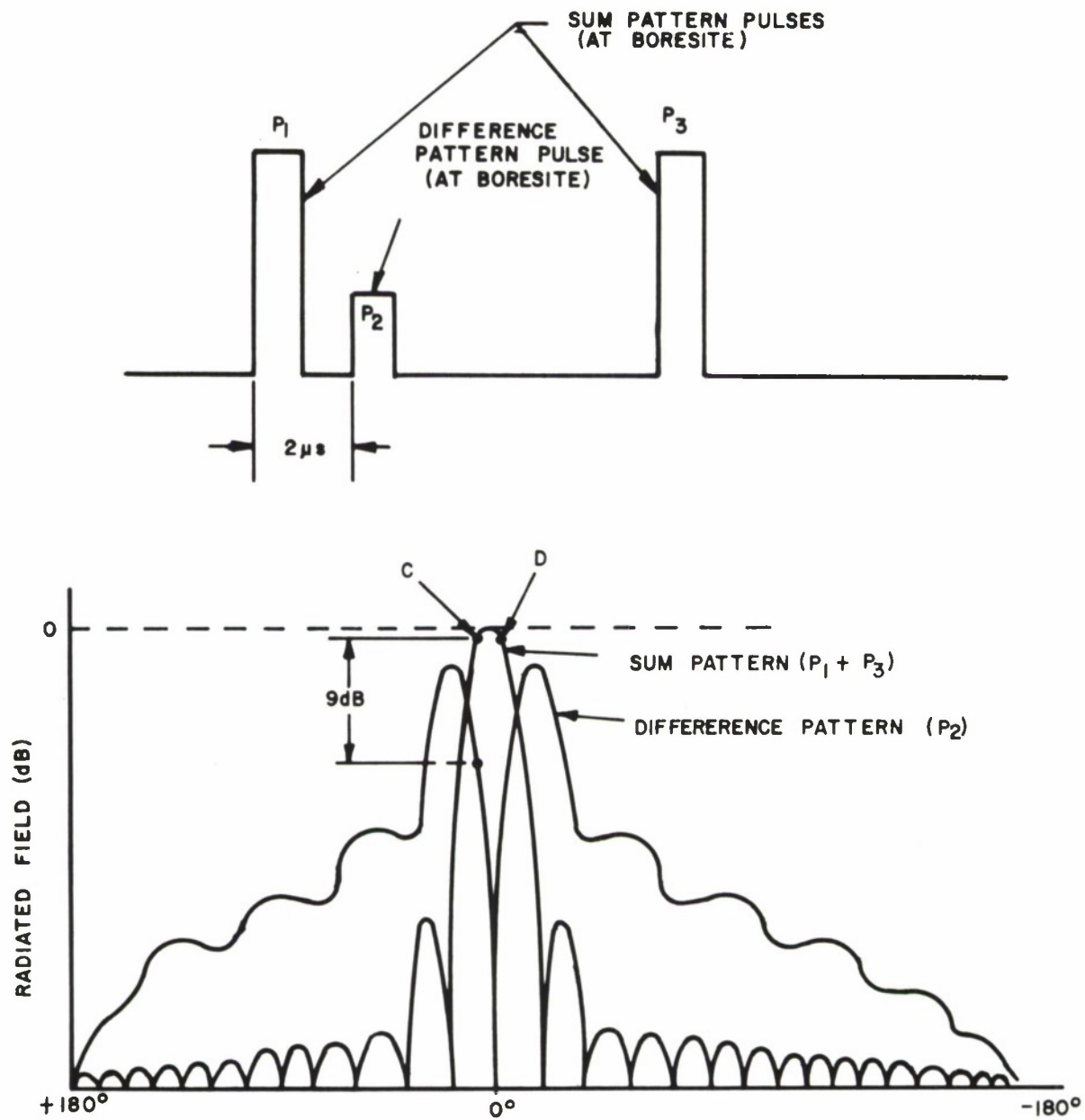


Figure 3-6. Sum-Difference SLS Pulse Transmission

However, if the sidelobe signal level of P_1 is too weak to be detected by the transponder, then the reception of only P_2 cannot start the transponder suppression action. The transponder, therefore, is unprotected from reflections that initiate undesirable replies.

At locations where all reflections are not effectively suppressed by transponder SLS action, an improved SLS technique may be used. To assure transponder suppression in the sidelobe areas, P_1 is radiated simultaneously by both the directional and omnidirectional antennas. This technique requires an additional SLS diode switch and appropriate circuitry.

Responsor Sidelobe Suppression

Responsor sidelobe suppression (RSLS) is a processing technique that rejects sidelobe and backlobe received replies while accepting mainbeam received replies.

REPLY RATE LIMITING

The RRL circuit provides a means of preventing the transponder from being overloaded by replying to excessive interrogations. The function of this circuit is to reduce the transponder receiver sensitivity as the average number of replies increases, keeping the number of replies per second within a preset range. RRL favors strong signals and denies service to weak signals.

DEFRUITING

If a beacon transponder is in the range of interrogating transmitters at different sites, it might be interrogated by all and its replies received by all. At any interrogator, the replies due to its own interrogations will appear at the same position on the display (assuming negligible movement of the transponder over the interrogation period). However, replies that are initiated by interrogations from other transmitters will be unsynchronized with the receiver display sweep circuits and will not appear at the same position on the display at each interrogation; in a beacon system this form of interference, which results from unsynchronized replies, is called fruit (see Figure 3-7). A recirculating-delay-line integrator, storage-tube integrator, or digital techniques can enhance synchronous replies and filter out (defruit) asynchronous ones.

AUTOMATIC OVERLOAD CONTROL

Automatic overload control (AOC) is a transponder transmitter overload protection circuit that is code-content dependent. Control of the total number of pulses transmitted per unit time is provided to protect the transmitter against overload damage when the top limit of its duty cycle is reached.

BRACKET DECODING

Bracket decoding is the technique used to separate individual replies. The replies transmitted from the aircraft are bracketed by framing pulses with code pulses in between. Therefore, bracket decoding circuitry is designed to recognize only information contained between pulses that have correct spacing.

CAUSES OF BEACON SYSTEM DEGRADATION

Replies from several aircraft might be received at approximately the same time. This reception can cause a garbled condition in which some code pulses are accepted erroneously by all bracket decoders.

Garbling lowers beacon system performance by causing possible loss of valid code information. Replies may also be lost for other reasons: For example, the action of the RRL circuit reduces transponder sensitivity and results in a reduction on the number of replies; another cause of reduced replies is the finite time (deadtime) required after a reply is made before the transponder can accept a new query. Deadtime is between 35 to 125 microseconds in a typical transponder. Automatic overload control (AOC) will also cause deadtime in the transponder if more than a predetermined number of pulses per second are required. Aircraft maneuvers can also cause lost replies; the orientation of the transponder antenna can be such that it fails to receive the interrogation signal (aircraft structural shielding). SLS deadtime and intersystem suppressions pulses also contribute to performance degradation.

ROUND RELIABILITY

Round reliability is shown in Figure 3-7 as the ratio of valid interrogations transmitted from a desired interrogator to the valid replies received at the same interrogator from a specific transponder.

FAA ATCRBS IMPLEMENTATION PROGRAM

The FAA plans extensive use of ATCRBS in the contiguous United States ATC NAS. ATCRBS is supplemented by primary radar, procedural radar identification, and voice position reports for aircraft not equipped with transponders. When the NAS enroute stage A aircraft identification has been implemented, radar track acquisition and maintenance and transfer of radar identification between controlled jurisdictions will become largely automatic for aircraft equipped with transponders with Mode A 4096 code capability.

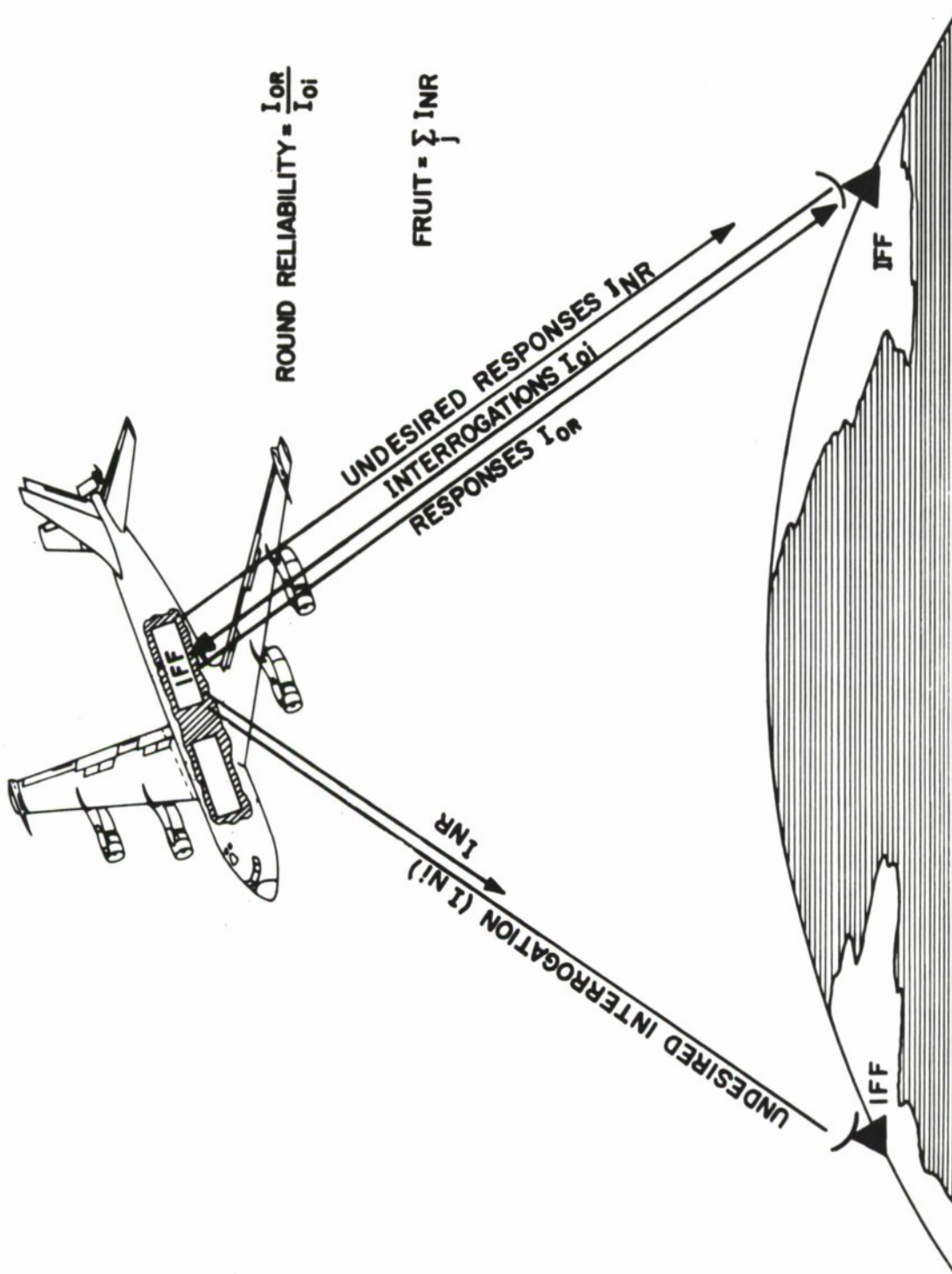


Figure 3-7. Valid Interrogations and Fruit for ATCRBS

Approximately 20 Air Route Traffic Control Centers (ARTCCs) will be employed in a system providing discrete aircraft identification and three dimensional position data. Each ATCRBS facility will interrogate on at least Mode A and Mode C, and each will employ a three pulse SLS control interrogation.

This tracking capability is included in the more sophisticated automatic data processing systems with provision for automatic track acquisition and maintenance using discrete and nondiscrete ATCRBS codes. Radar data identification problems will be reduced at facilities so equipped, and ATCRBS-transmitted pressure-altitude data might be of help in the tracking function. More important, this capability will ensure that data displayed to the controller is filtered so that he receives only that of direct concern to him; this allows numerical presentation of altitude or flight level. In the contemplated advance systems, this data also will be used for automatically predicting ATC conflicts in the third dimension.

The NAS Stage A systems will use digitizers at remote radar sites to convert primary data and radar beacon video data to digital form for transmission on 2400 bit-per-second circuits for input to ADP systems. Both primary radar and radar beacon data are digitized.

The digitizer was designed to achieve optimum compromise among the probabilities of detection, false target declaration, target splits, code validation, and azimuthal position accuracy. These probabilities are functions of round reliability, fruit, run length, sliding window size, leading edge criteria, and trailing edge criteria (see Reference 4).

All ATC terminal interrogators and all enroute interrogators not used jointly by Air Defense will use modes 3/A and C. All Air Defense ATC interrogators will use modes 2, 3/A, and C. Satisfying both Air Defense and ATC requirements within three modes allows use of one common interrogator.

In addition to the NAS enroute system, the FAA has also initiated a terminal area automation program. Approximately 62 terminals will have the Advanced Radar Traffic Control Systems (ARTS-III) by 1973. These systems are modular in concept; the basic system will incorporate only beacon tracking, but is designed to allow expansion that will include primary radar tracking with multiple radar inputs.

MILITARY ATCRBS IMPLEMENTATION PROGRAM

AIMS is an acronym formed from ATCRBS IFF MARK XII Systems and reflects the many diverse configurations of these systems.

The objectives of the AIMS program are standardization of essential system characteristics, generally improved IFF equipments, common specifications for equipment procurement, a tridepartment coordinated time-phased implementation plan, a minimum number of equipment models (commonality), a coordinated development program that eliminates duplication, and maximum use of the existing facilities and resources of all military services.

Four interrogation modes are currently used between military aircraft and military and civil ground stations. Modes 1, 2, and 3 are used by the military; Mode A is for civil aviation. Military Mode 3 and civil Mode A are identical. Reference 3 designated these modes, referred to as Mode 3/A, be used for common air traffic control. Mode 3/A currently is limited in application due to the relatively few codes (64) provided. Under the DOD AIMS Program, Mode 3/A will be expanded to 4096 codes, and new Modes 4 and C will be provided. This will provide discrete identity on Mode 3/A, altitude reporting on Mode C, and Mark XII capability in Mode 4 (see TABLE 3-1).

TABLE 3-1
INTERROGATION MODES

Use	Modes	Interim System		Future AIMS System
Military	1	32 Codes	Navy Tac NORAD	No Change
	2	4096 Codes	Navy Tac NORAD ADC	No Change
	4	Not Used		MARK XII
Civil	3/A	64 Codes	Common Air Traffic Control	4096 Codes
	B	Not Used		No Change
	C	Not Used		Altitude Reporting
	D	Not Used		No Change

SECTION 4

SIMULATION MODELING OF THE ATCRBS

In modeling ATCRBS it is necessary to estimate operational degradation to ATCRBS due to interference interactions between various elements of the system. Transponders receive interrogations from many interrogator-responders (I/Rs). Because the transponders are limited in their reply-rate capability, they may be unable to reply to every interrogation. An I/R may receive many replies it did not elicit.

SYSTEM MODEL PROGRAM

ATCRBS PPM consists of a number of FORTRAN IV computer programs that estimate the performance of the RBS. Performance degradation due to intrasystem electromagnetic interference is considered. This program includes mathematical models of various system components and the data processing structure required to take information about a particular problem situation and process it through these models. Details of the computer input format are included in Reference 11.

COMPUTER PROGRAM CAPABILITIES

The capability of analyzing the performance of any deployment of ground and airborne RBS equipments is a primary model requirement. Two aspects of the problem are:

1. How do the many interrogators affect the ability of each transponder (T_j) to reply to an interrogation from one particular interrogator, I_o ?
2. How do the replies to interrogations from other interrogators interfere with the ability of I_o to detect desired replies?

The quantity predicted to answer the first question is the round reliability of the transponder. This quantity is the ratio of replies to the victim interrogator, I_o , from the transponder in question, T_j , to the total number of interrogations from I_o . Both I_o and T_j are summed over a period of time during which I_o is intentionally interrogating T_j .

The quantity predicted to answer the second question is the fruit rate, the average number of fruit replies per second actually detected by I_o .

Initial conditions are that a particular deployment of transponders, interrogators, and their important characteristics are specified. The interrogators in the area and their important characteristics may be obtained from the ECAC data base. The instantaneous mean values of fruit rate and round reliability depend on a particular set of orientations of the rotating antennas of the nearby I/Rs. The expected value of the output parameters are calculated based on the probability of occurrence of each quantized gain level of each interfering I/R. A three level antenna pattern consisting of mainbeam, sidelobe, and backlobe is used.

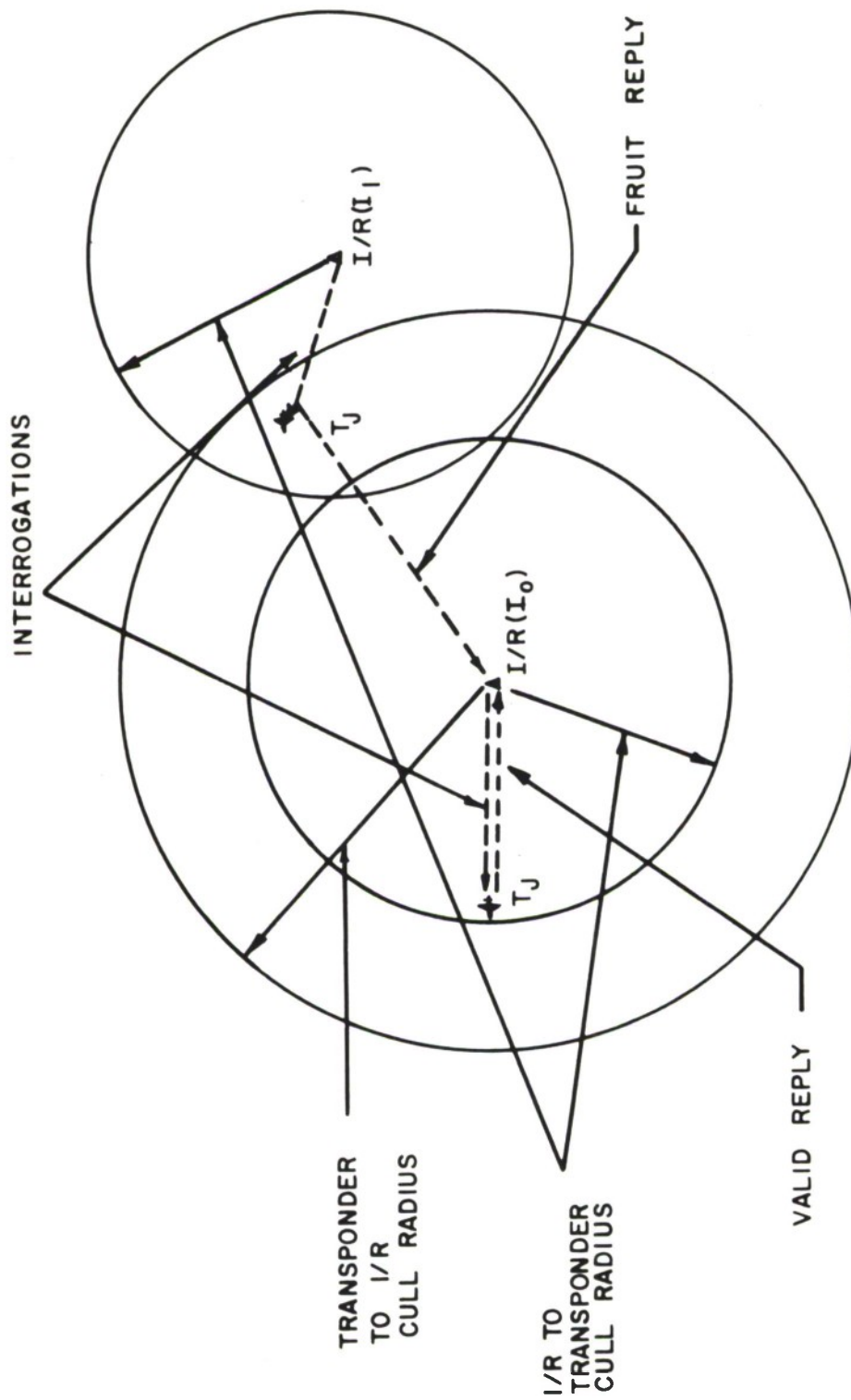
A simplified problem deployment is shown in Figure 4-1. The victim, $I/R(I_0)$, one interferer, $I/R(I_1)$, and two transponders are deployed. There is a distance from an I/R beyond which the interrogations cannot be detected by transponder T_j . In the computer program this is a function of the characteristics of the particular I/R and transponder, but for illustrative purposes this is shown as a fixed I/R-to-transponder cull radius.

Likewise, there is a distance from a transponder beyond which replies cannot be detected by an I/R. This is also a function of the equipment parameters, but is represented in Figure 4-1 as a transponder-to-I/R cull radius. The generation of fruit replies depends on the geometry of the deployment and on how I_0 receives fruit replies from transponders it cannot interrogate, as well as from those that it can interrogate.

COMPUTER PROCESSING

The basic components in the computer model are shown in Figure 4-2. The first step is construction of a magnetic tape information file about I/Rs in the problem area. This information is obtained from the user or the ECAC data base file that contains records of electronic equipment in the area.

The next step is to determine where possible interference links might occur; the processor performs this function. The deployment of transponders and their individual parameters is supplied on punched cards. The result is a magnetic tape file that contains a list of transponders, each followed by a list of I/Rs that can be detected by that transponder. As shown in Figure 4-3, this list may or may not contain I_0 .



IFF SYSTEM MODEL PROBLEM TO PREDICT:

1. TOTAL FRUIT AT I_0
2. ROUND RELIABILITY AT EACH TRANSPONDER

Figure 4-1. Simplified ATCRBS Transponder/Interrogator Deployment

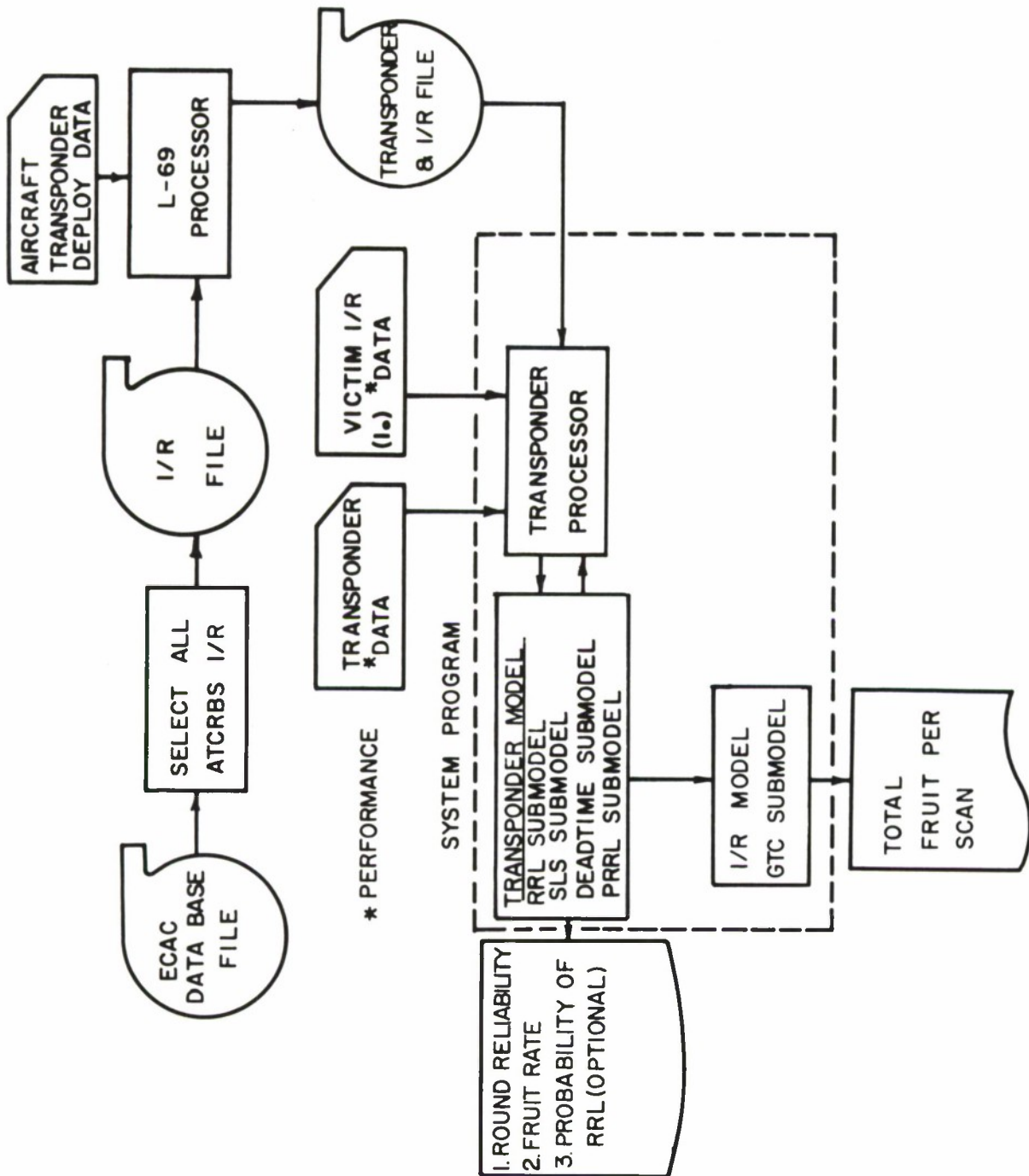


Figure 4-2. MARK X (SIF) ATCRBS Computer Processing

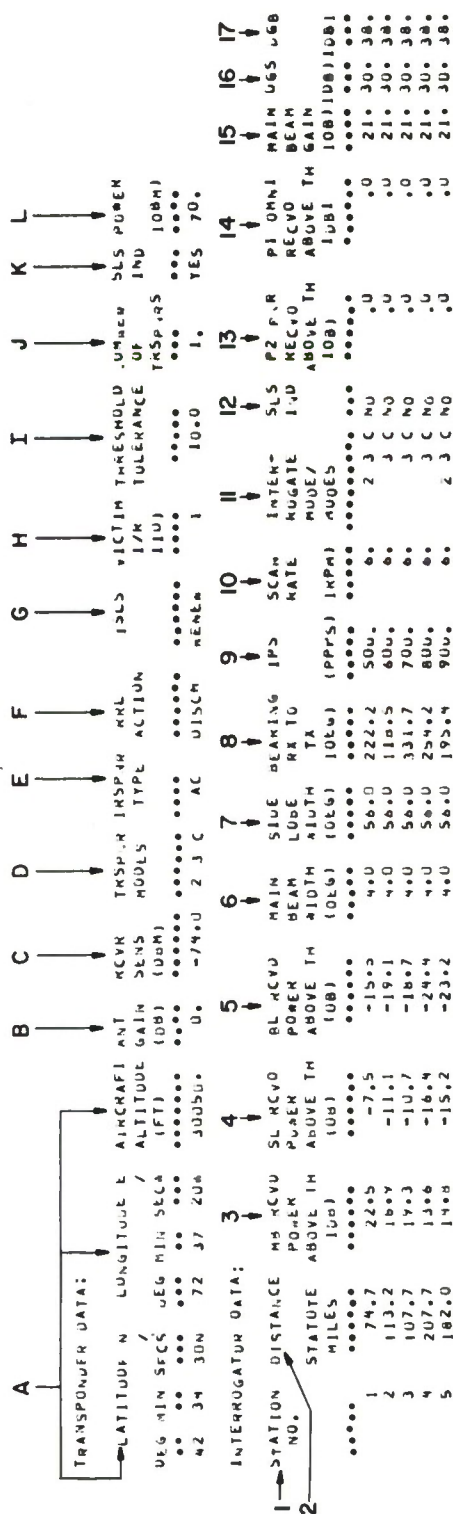


Figure 4-3. Transponder/Interrogator Data

TRANSPONDER/INTERROGATOR OUTPUT DATA

TRANSPONDER DATA (Refer to Figure 4-3)

- A. Latitude, longitude, and altitude of aircraft
- B. Antenna gain (dB)
- C. Receiver sensitivity (dBm)
- D. Transponder modes - mode detection capability
- E. Transponder type - military, aircarrier, general aviation
- F. Type of RRL - discriminatory, nondiscriminatory
- G. Interrogator sidelobe suppression (ISLS) status - operational status, renewable, nonrenewable.
- H. Victim interrogator/receiver identification
- I. Threshold tolerance (dB) - value selected by user
- J. Number of transponders - no limitation to be considered at any location
- K. Transponder SLS indication - type of suppression - no, yes, improved
- L. Transponder power output (dBm)

INTERROGATOR DATA (Refer to Figure 4-3)

- 1. Station number - A specific number assigned to the project IFF file
- 2. Slant range distance (statute miles) from the transponder to the interrogator

3. Mainbeam power above receiver sensitivity at transponder (dB)
4. Sidelobe power above receiver sensitivity at transponder (dB)
5. Backlobe power above receiver sensitivity at transponder (dB)
6. Mainbeam width (degrees)
7. Sidelobe width (degrees)
8. Bearing of transponder from interrogator (degrees from true North)
9. Interrogations per second (IPS) for each ground interrogator
10. Scan rate (rpm)
11. Interrogation modes; five may be listed (1, 2, 3/A, 4, C) and interlaced
12. SLS indication; three types of information can be inserted (improved , no, yes)
13. P_2 power received above threshold at the transponder. This is valid only when the interrogator is equipped with SLS.
14. P_1 omnipower received above threshold (improved ISLS only)
15. Mainbeam gain (dB)
16. Difference between mainbeam and sidelobe gain
17. Difference between mainbeam and backlobe gain

NOTE: Backlobe width is the difference between mainbeam plus sidelobe and 360° and is not listed as a separate output.

This file, along with additional data on transponders and I_O , constitutes the ATCRBS program input. The program contains three major subprograms:

1. The transponder processor computes the average interrogation rate for each I/R based on interrogation mode interlace and on the probability that antenna orientation will be such that the I/R will interrogate the transponder (see Figure 4-4). I_O is handled separately.

2. The Transponder Model predicts the action of each transponder under these input conditions. All inputs to the transponder from interference I/Rs are treated statistically. The basic outputs are round reliability and fruit rate (see Figure 4-5). The computations made from the three cases are:

- a. I_O interrogating on its mainbeam
- b. I_O interrogating on its sidelobe (unintentional)
- c. I_O interrogating on its backlobe (unintentional)

3. The I_O Model predicts the average total fruit replies per scan received by I_O from the transponders. This average is computed by calculating separately the total fruit rate received on I_O 's mainbeam, sidelobe, and backlobe and by summing the products of each total multiplied by the probability of that particular orientation of the I_O antenna (see Figure 4-6).

ECAC DATA BASE FILE

The ECAC environmental data base collection covers the use of C-E equipment by civilian, military, and government organizations in the contiguous United States; by the U.S. military in Alaska, Canada, Europe, Hawaii, and Puerto Rico; by civil and U.S. military organizations on Okinawa; and by Allied Forces in the Federal Republic of Germany. The primary data collected for each equipment consists of at least: location coordinates, operating frequency, operating schedule, power output, modulation, equipment nomenclature, antenna height and orientation, site elevation, organizational unit designation, and equipment function (see TABLE 4-1).

ENVIRONMENTAL PROCESSING

Environmental processing is the preparation of model inputs; these inputs are obtained from the ECAC data base. The data are in a tape file (E File) with one record for each I/R in the problem environment. The standard E File record contains such information as the equipment location, sensitivity, power output, antenna mainbeam gain, beamwidth, and antenna scan rate. The ATCRBS PPM requires that these records be expanded with special items such as SLS indicator (yes, no), sidelobe width, sidelobe gain, backlobe gain, interrogation rate, and interrogation modes.

TRANSPONDERS
AND INTERROGATORS

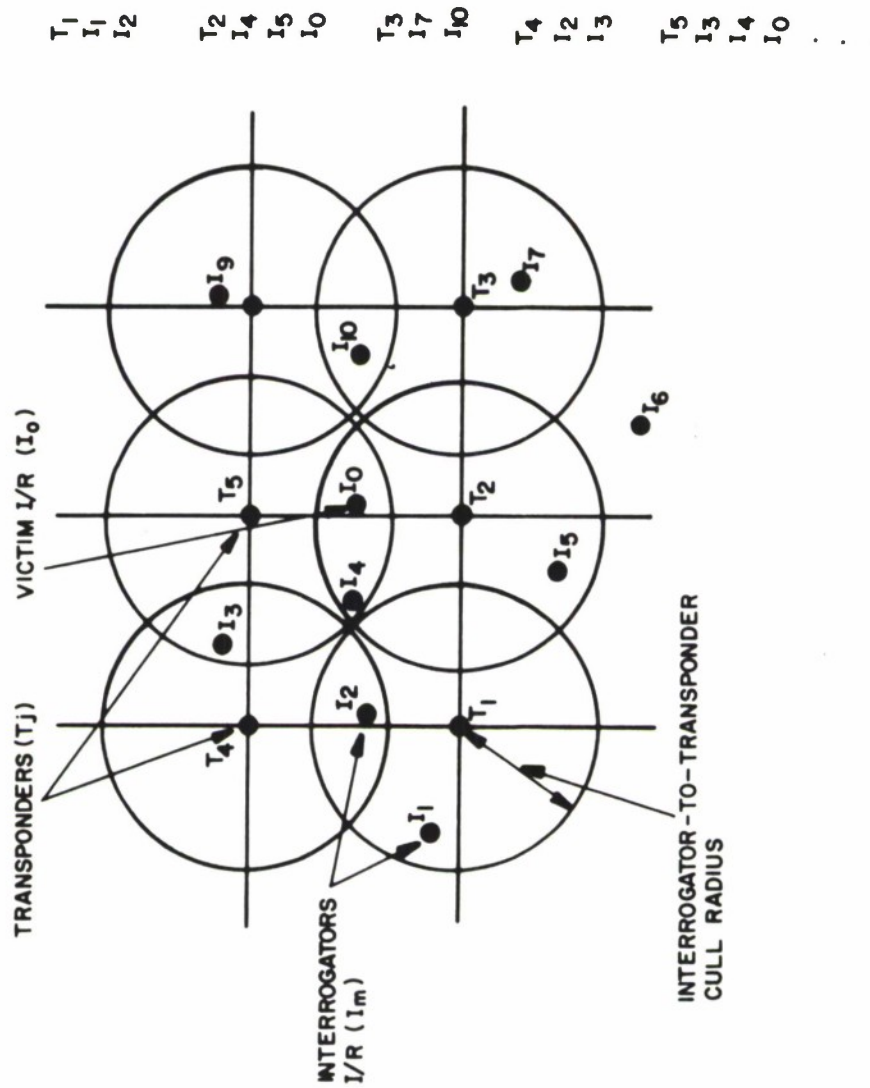


Figure 4-4. Processor Function

A. —
B. —
C. —
D. —
E. —
F. —
G. —
H. —
I. —
J. —
K. —
L. —
M. —
N. —

OUTPUTS: 1(0) INTERROGATING MAIN BEAM
TOTAL AVE DETECTED INTERROGATIONS(TDI)= 560.59
TOTAL AVE SUPPRESSIONS(TSI)= 127.50
FINAL THRESHOLD= -74.00 KE = .000
RRL-MODE COMPATIBILITY(RR')= 1.000
SYNCHRONOUS REPLY RATE= 382.098
COUNTDOWN(RR')= .980
ROUND RELIABILITY= .980
MAIN BEAM FRUIT RATE= 160.612 (RRL)
OVER-INTERROGATION RATE= .45
PROBABILITY OF AOC= .00000
NUMBER OF ITERATIONS= 0
SIDE LOBE FRUIT RATE= 166.992
BACK LOBE FRUIT RATE= 166.992

O. —

Figure 4-5. Transponder Model Computer Output

TRANSPONDER MODEL OUTPUT DATA (Refer to Figure 4-5)

- A. *Victim ATCRBS I/R
- B. Average number of detected interrogations per second received by the transponder from all interrogators (TDI)
- C. Expected total number of SLS interrogations per second from all interrogators detected by the transponder.
- D. Transponder threshold when operating in the given environment (dBm)
- E. Countdown due to RRL, $OSRR \leq 1$
- F. Rate of T_j replies to valid I_O interrogations
- G. Countdown due to deadtime, as calculated in the deadtime submodel
- H. Ratio of valid replies to valid interrogations (I_O)
- I. *Average rate of fruit replies transmitted during I_O mainbeam interrogation time
- J. TDI divided by RRL threshold (meaningless unless greater than 1)
- K. Probability that RRL will occur
- L. Number of times RRL/Threshold has been changed
- M. *Average rate of fruit replies transmitted during I_O sidelobe interrogation time.
- N. *Average rate of fruit replies transmitted during I_O backlobe interrogation time
- O. Threshold Averaging (see Equation 5-25)

* I_O was validly interrogating during this time interval.

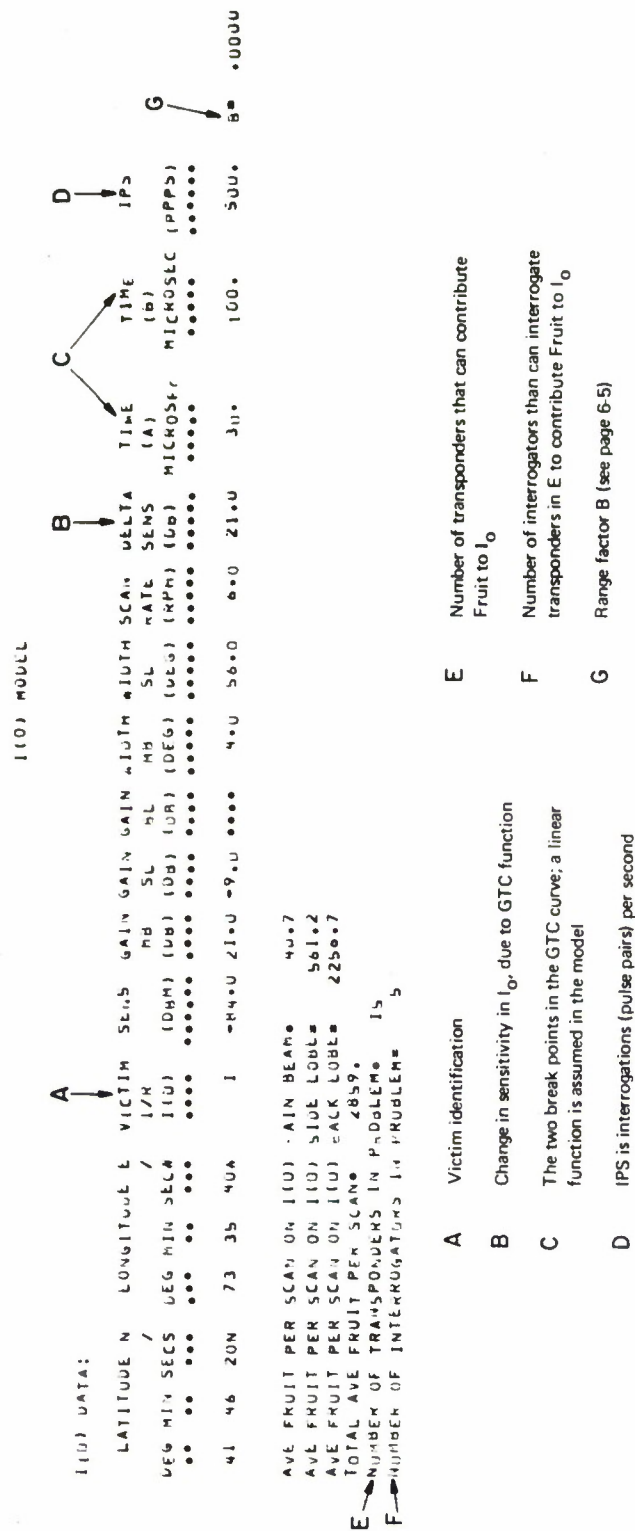


Figure 4-6. Interrogator Model Output

TABLE 4-1
ECAC AUTOMATED ENVIRONMENTAL DATA BASE

Environmental Collections Authorized							
CONUS civil, military government U.S. Military in Canada U.S. Military & FAA in Hawaii U.S. Military in Panama			U.S. Military in Puerto Rico U.S. Military & FAA in Alaska Civil & U.S. Military on Okinawa U.S. Military in Europe				
Status by Sources							
Major Parameters	Data Sources	DOD FAA	NASA USCG	FCC Data from OEP	IRAC Data from OEP	FCC License Pvt., CATV, Western Union, & Independent Microwave	AT&T, GT&E Co., Files on Common Carrier Microwave
Location	Fixed systems	Nearest second of arc Benchmark used in some cases. Air navigation aids known exactly.		Nearest second of arc if the information is given. If not given, the coordinates of approximate center of state and a circular mobile cell of sufficient radius to encompass whole state is assigned.	Same as FCC data from OEP. Also some US&P or CONUS	Nearest second of arc (data always given)	Nearest second of arc (data always given)
	Mobile with a fixed base station	Location of base station to nearest second of arc and area of operation. Benchmark used in some cases		20 mile radius assumed. When the source does not give location, ECAC assigns to roughly center of state and a radius of operation encompassing same	Same as FCC data from OEP. Also some US&P or CONUS	Same as DD 1374	No equipment
	Mobile without fixed base station	Reported geographic area described by a circle, square or rectangle		Cell assigned by state or CONUS indicator	Cell assigned by state, CONUS or US&P indicator	No equipment	No equipment
	Communication	Spot frequency reported to accuracy conformable with channelization practice. Some report band limits as well. A few report only band limits		Spot frequency reported to accuracy conformable with channelization practice	Same as FCC data from OEP	Same FCC data from OEP	Same as FCC data from OEP
Operating frequency	Radar	Usually the lesser of tuning range capability and band authorization on spot frequency is stated. (ARADCOM & ADC spot frequency reliable)		Midpoint of authorized band for police radars, otherwise the lower limit of the authorized band is stated.	Lower endpoint of the band authorized is stated	No radars	No radars
Power output and bandwidth		Nominal values		Authorized	Authorized	Authorized	Nominal values
Receiver sensitivity and bandwidth		Nominal sensitivity to desired signal		No receiver data available from source	Only receiver location available from source in some cases. Not used in ECAC data base	Nominal values for CATV & Pvt. microwaves. No broadcast entertainment receivers in source	Nominal Sensitivity to desired signal
Quantity of equipment		Actual value		Maximum number authorized	None given in source data. Entered in ECAC record	Always 1	Always 1
Antenna orientation	Height	Nearest foot		None given in source	None given in source	Same as DD 1374	Same as DD 1374
	Site elevation	Nearest foot					
	Polarization	Nominal					
	Direction	Nearest degree					
	Motion	Nominal					
Exclusions							
CONUS tactical and training frequency use CONUS military flying training activity Communication satellites and ground stations CONUS amateur & Citizens				AEC tracking and instrumentation system Radio telescope Equipment related to proving ground activities used less than six months Some experimental equipment operated by DOD contractors			
Special Inclusions							
CONUS distress, calling, guard frequencies							

ECAC's L-69 Processor is a computer program used in many applications requiring manipulation of data in the E File. For ATCRBS the Power-Distance Cull Mode of the L-69 Processor is used to operate on an E File containing only ATCRBS I/R records and on a set of data cards representing ATCRBS transponders. ATCRBS transponders can be deployed at the user altitude to a position accuracy of 1 second in latitude and longitude and 1 foot in altitude.

The L-69 program was designed to allow the user to perform various preanalysis processing of the E File. This processing allows the user to reduce the size of the environment by application of various selected cull criteria.

L-69 Power-Distance Cull Selection Mode

In this mode, the program selects all transmitters from an input environment that are either within a specific distance or produce a signal power density above a specified level at any of a number of receiving locations specified in terms of latitude, longitude, and antenna height.

Each record in the input environment file is examined with respect to each geographic power-distance-cull specification presented to the program. If an E File record represents an equipment located within the cull distance and produces a power density greater than the threshold specified, a copy of this record will be made on the output file. Otherwise, the record will be dropped.

This program relies only on information concerning power output and mainbeam antenna gain. The power density is calculated using

$$P_{\text{dBm/m}^2} = P_t + G_t - 10 \log_{10} 4\pi - 20 \log_{10} \gamma + R \quad (4-1)$$

where

P_t = Power output (dBm),

G_t = Antenna gain (dB),

γ = Slant range (meters),

R = Additional path loss in the diffraction region (dB)

Propagation Loss

Equation 4-1 includes free-space propagation loss and "R" the additional loss associated with the diffraction region. The factor "R" is automatically calculated and added to free space loss by the program. Details of the method of determining diffraction region path loss, distance to the radio horizon and corrections to the radio horizon distance due to the National Bureau of Standards Exponential Reference Atmosphere can be found in Reference 10.

SECTION 5

MATHEMATICAL MODELING OF THE ATCRBS TRANSPONDER

The most complicated part of the ATCRBS PPM Computer Program is the transponder model. Figure 5-1 is an abbreviated flow diagram.

One of the major problems is calculation of the exact input conditions. The situation is complicated by the actions of two transponder circuits that adjust the sensitivity of the receiver to keep the number of replies elicited within equipment or system design limits. These circuits are the Reply-rate Limiting (RRL) and the sidelobe suppression (SLS) control circuits.

REPLY--RATE LIMITING

The first step is to determine the input, exclusive of limiting. Previous processing has prepared a list of I/Rs that can interrogate transponder T_j on their mainbeams with the transponder set to its most sensitive setting, L_t .

The mean effective interrogation rate for each I/R is calculated by determining the portion of beamwidth during which the I/R signal is above sensitivity setting L . In some cases, SLS pulse-coding eliminates all nonmainbeam interrogations, regardless of power level. All interrogations other than SLS will be valid and will be subject to RRL.

The model calculates the average interrogation rate per second of each interference interrogator. This rate is a function of power level, antenna gains, beamwidth, mode compatibility, and interrogation rate. The model does not calculate the I_o interrogation rate in the same manner; it assumes one of three conditions for I_o 's interrogation rate, IRF (I_o):

1. I_o is interrogating with its full IRF (I_o).
2. I_o is interrogating with a suppression rate equal to IRF (I_o).
3. I_o is not powerful enough to interrogate on the beam in which T_j is assumed to be.

The model calculates RR, fruit rate, and other parameters, assuming I_o is interrogating first on mainbeam, then on sidelobe, then on backlobe. On mainbeam either assumption (1) or (3) above is possible. On sidelobe and backlobe (1) or (3) is possible if either I_o or T_j is not SLS-equipped; 2 or 3 is possible if both I_o and T_j are SLS-equipped.

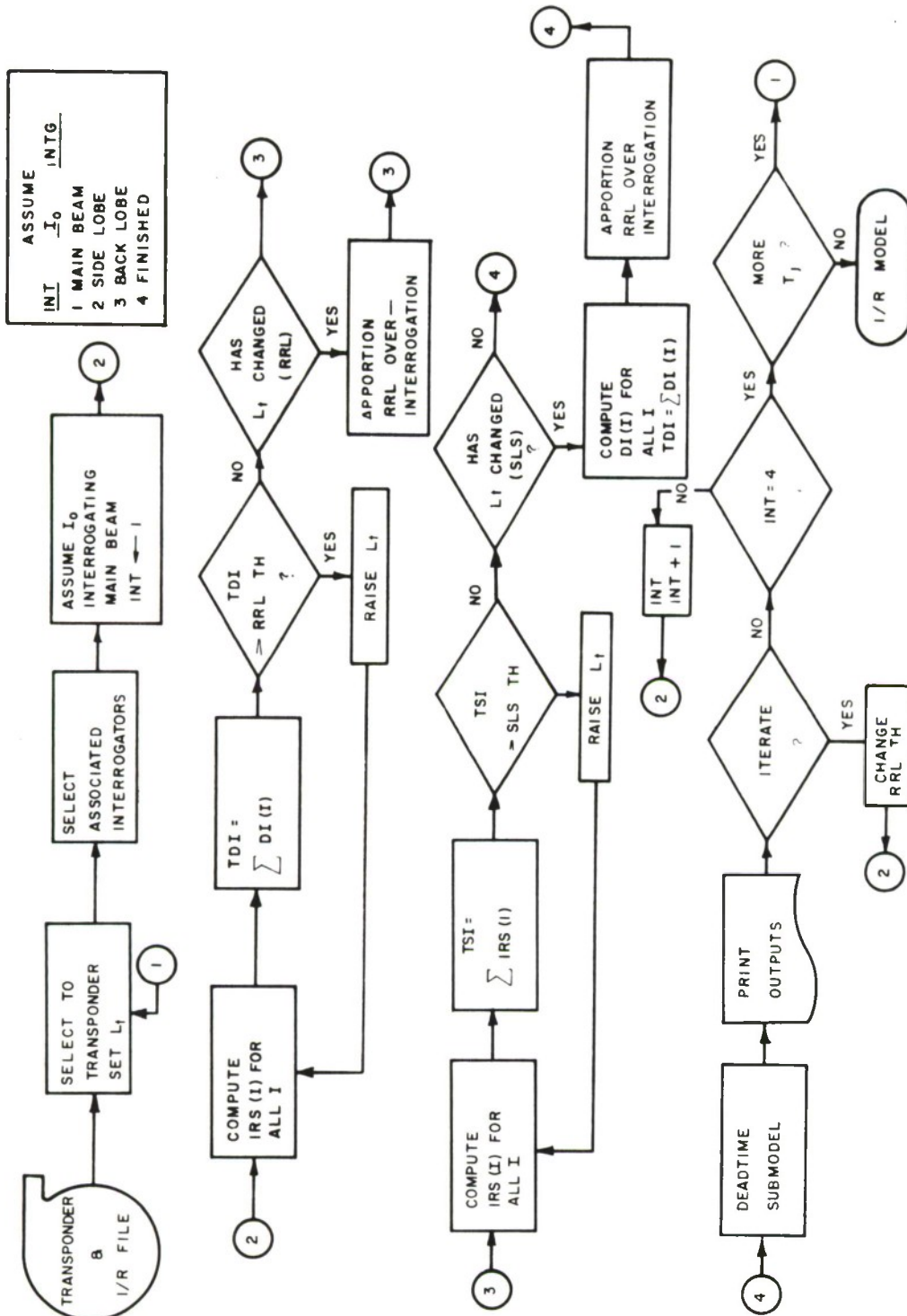


Figure 5-1. IFF Transponder Model, Abbreviated Flow Diagram

TABLE 5-1 illustrates reply rate limiting. The numbers were chosen for ease of calculation rather than realism. Three interference I/Rs, I_1 , I_2 , I_3 , as well as I_0 , can interrogate the transponder. TABLE 5-1 gives assumed values for the power received at the transponder (mainbeam) (P_r), mainbeam and sidelobe antenna pattern widths (MBW and SLW), the difference between antenna gain in the mainbeam and antenna gain in the sidelobe of the I/R (ΔGS), and the difference between antenna gain in the mainbeam and antenna gain in the backlobe of the I/R (ΔGB).

In this example the signal from I_1 is -75 dBm at the transponder, when the transponder is in I_1 's mainbeam. However, when the transponder is in I_1 's sidelobe, the signal from I_1 is -85 dBm, and when it is in I_1 's backlobe the signal is -109 dBm. With a transponder sensitivity of -90 dBm and I_1 's implied backlobe width of 315 degrees, I_1 's signal will be strong enough to be detected only one-eighth of the time [$(360 - 315)/360 = 1/8$].

Figure 5-2 shows the functional relation between transponder threshold setting L and the number of interrogations detected. This figure shows for each I/R the number of degrees the antenna covers for each of the three quantization levels of antenna gain. Each gain level corresponds to a particular power value received by the transponder (shown on the vertical scale). Because each I/R antenna is rotating with constant rpm, the amount of beamwidth corresponding to a particular value of received power is proportional to the probability of that value of received power being experienced. I_0 is not treated in this statistical manner. Its probability is either 1.0 (interrogating) or 0.0 (not interrogating).

Figure 5-2 represents a cumulative probability distribution function for power received at the transponder for each I/R in turn. Only values of received power greater than L_t , transponder sensitivity, are of interest. Figure 5-2 shows that I_1 has a probability of 0.125 of exceeding L_t , while the probabilities for I_2 and I_3 are 1.00 and 0.50, respectively.

$DI(k, L_t)$, the expected number of valid interrogations per second received from I_k at threshold L_t is given by

$$DI(k, L_t) = W(k, L_t) \times EIR(k) \quad (5-1)$$

where

$$W(k, L_t) = \text{The probability that the power received for } I_k \text{ exceeds threshold } L_t,$$

$$EIR(k) = \text{The effective interrogation rate of } I_k$$

$EIR(k)$ is given by

TABLE 5-1
SAMPLE PROBLEM DATA

I/R	P (in dBm)	MBW (in degrees)	SLW (in degrees)	Δ GS (in dB)	Δ GB (in dB)	IPS	(NTM) Modes
I ₀	-81	72	108	17	27	80	1
I ₁	-75	10	35	10	34	360	1,C
I ₂	-45	20	70	24	34	400	1,3/A
I ₃	-63	72	108	17	27	500	1,2
Notes							
$L_t = -90$ dBm T_j Modes: 1,3/A,C (NCM) RRL threshold = 600 interrogations/second. (This was selected for ease of calculation.)							

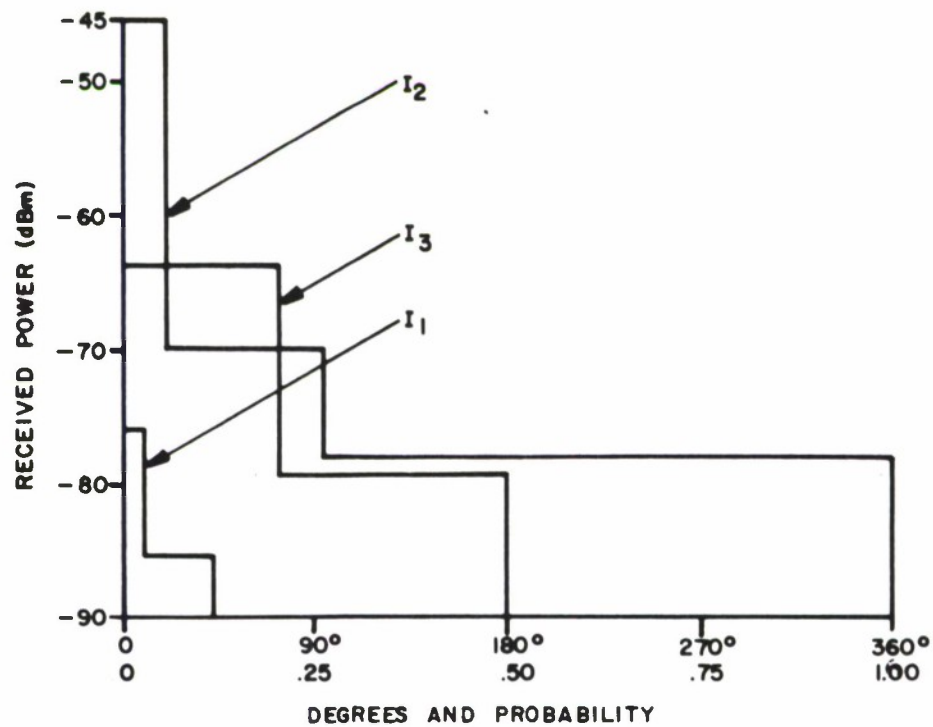


Figure 5-2. RRL Computation of Received Power for a Quantized Three-level Antenna Pattern

$$EIR(k) = IRF(k) \frac{NCM}{NTM} \quad (5-2)$$

where :

IRF(k)	=	The number of interrogations per second emitted by I_k ,
NTM	=	The number of interrogations in the sequence (of interlaced interrogation modes that are employed by many I/Rs) for example: 1, 2, 2, 3/A, 1, 2, 2, 3/A.... NTM = 4) of 4_k
NCM	=	The number of interrogation modes in the interrogation sequence of I_k in common with the modes to which the transponder will respond.

If both the transponder and the interrogator are equipped with SLS, then $W(k,L)$ is computed using only the mainbeam width because only those interrogations will be detected, regardless of power level. Assuming this is not the case in the sample problem, then

$$DI(0,L_t) = 80 \times 1.0 = 80 \quad (5-3)$$

$$DI(1,L_t) = 360 \times (45/360) = 45 \quad (5-4)$$

$$DI(2,L_t) = 400 \times 1.00 = 400 \quad (5-5)$$

$$DI(3,L_t) = 500 \times (180/360) \times 1/2 = 125 \quad (5-6)$$

The duration of an interrogation is so small that only a negligible number of simultaneous arrivals of interrogations is expected in a second. Therefore, the average total number of detected interrogations per second will be essentially

$$TDI(L) = \sum_k DI(k,L) \quad (5-7)$$

The sum is taken over all I/Rs in the list that could interrogate the transponder in question. In the sample problem, $TDI(L_t) = 650$, which is larger than the assumed RRL threshold. Thus, the RRL limit is exceeded by even the expected number of interrogations. A measure of the degree of over-interrogation is provided by the Over-Interrogation Ratio (OIR), which is the number of interrogations detected at setting L_t , divided by the RRL threshold.

In our example this ratio has a value of 1.083. With regard to the manner in which over-interrogation is handled, there are two types of transponder: discriminatory and nondiscriminatory.

1. *Nondiscriminatory RRL Action* Assume the transponder is of the nondiscriminatory type. When interrogation rate $TDI(L_t)$ exceeds RRL, the transponder randomly blanks out a sufficient number of interrogations so that only a number equal to RRL is accepted. This is modelled by reducing the contribution for each I/R ($\bar{k}$) proportionally.

$$\bar{k} = 600/650 = 0.9231 \quad (5-8)$$

$$DI(O) = DI(O, L_t) \times \bar{k} = 74 \quad (5-9)$$

$$DI(1) = DI(1, L_t) \times \bar{k} = 42 \quad (5-10)$$

$$DI(2) = DI(2, L_t) \times \bar{k} = 369 \quad (5-11)$$

$$DI(3) = DI(3, L_t) \times \bar{k} = 115 \quad (5-12)$$

$$TDI = \Sigma TDI(k) = 600 \quad (5-13)$$

2. *Discriminatory RRL Action* The discriminatory transponder eliminates lower-powered interrogations by first decreasing the sensitivity from initial setting L_t to some new level, L .

Each time $W(k, L)$ is computed, a power increment, $\Delta L(k)$, is computed; this is the amount of power increase required to effect a change in the value of $W(k, L)$, predicted on a step-function model for antenna gain. These values are examined to find the minimum amount to raise transponder threshold L to produce a new value of $TDI(L)$.

The threshold setting is then adjusted to a new value; that is,

$$L \leftarrow L + \Delta L + 0.1 \text{ dB} \quad (5-14)$$

where

$\leftarrow$ indicates *is replaced by*

The additional 0.1 is included to ensure a new value will actually be computed. The raising of value L above its original setting, L_t , is discriminatory RRL action.

In this example, the new L becomes -85. This results in

$$DI(0,-85) = 80 \quad (5-15)$$

$$DI(1,-85) = 10 \quad (5-16)$$

$$DI(2,-85) = 400 \quad (5-17)$$

$$DI(3,-85) = 125 \quad (5-18)$$

$$TDI(-85) = 615 \quad (5-19)$$

which is still above the RRL threshold. The process is repeated until the over-interrogation no longer occurs. The new L becomes -81 dB, resulting in :

$$DI(0,-81) = 0 \quad (5-20)$$

$$DI(1,-81) = 10 \quad (5-21)$$

$$DI(2,-81) = 400 \quad (5-22)$$

$$DI(3,-81) = 125 \quad (5-23)$$

$$TDI(-81) = 535 \quad (5-24)$$

In fact, the value of TDI should be brought back to 600. One way to do this would be to restore some of the interrogations taken from the last I/R to have its contribution reduced. In reality, however, the interrogations from an I/R do not arrive at three distinct power levels. Moreover, there are certain inherent uncertainties in the computation of these power levels. Therefore, to cut out interrogations from one I/R and not from another for which the power level is predicted to be only slightly higher would be unrealistic and arbitrary. Thus, a tolerance level, ϵ , specified as an input parameter, is placed around the critical threshold setting. The interrogations whose power levels fall within that tolerance are accepted proportionally; this is particularly important if I_0 is among those affected.

This method adopted for doing this is the RRL Threshold Averaging k_E (or Apportioning) Model:

$$k_E = \frac{RRL - TDI(L - 2\epsilon)}{TDI(L) - TDI(L - 2\epsilon)} \quad (5-25)$$

where

L = The first threshold setting that eliminates over-interrogation.

Thus, if in the sample problem $\epsilon = 5$ dB, $TDI(-91) = 650$,

$$k_E = \frac{600 - TDI(-91)}{TDI(-81) - TDI(-91)} = \frac{600 - 650}{535 - 650} = \frac{50}{115} = \frac{10}{23} \quad (5-26)$$

This computation is used to obtain the estimated detected interrogations received from the i^{th} interrogator $EDI(i)$ by

$$EDI(i) \leftarrow DI(i, L - 2\epsilon) + (1 - k_E) + k_E DI(i, L),$$

which produces in the sample problem

$$EDI(0) = 45^* \quad (5-27)$$

$$EDI(1) = 30^* \quad (5-28)$$

$$EDI(2) = 400 \quad (5-29)$$

$$EDI(3) = 125 \quad (5-30)$$

$$TDI = 600 \quad (5-31)$$

* Only those interrogators whose power levels fell within L and $L - 2\epsilon$ were affected.

SLS LIMITING IN DISCRIMINATORY TRANSPONDERS

If both the I/R and the transponder are equipped with SLS, then only intentional (mainbeam) interrogations will be recognized as valid and considered in RRL. There is also a limit to the rate at which SLS interrogations can be handled by the transponder. Whenever the SLS interrogation rate exceeds this threshold, sensitivity level L_t is decreased until SLS interrogations are less than the threshold. This situation is over-suppression or SLS limiting.

The rate for SLS interrogations is computed for each I/R and denotes $IRS(i)$ for the i^{th} I/R. This is done in one of two ways, depending on whether the I/R is equipped with normal or improved SLS. In either case only nonmainbeam interrogations that exceed L are

considered, and all modes are accepted by the transponder. If the I/R is not SLS equipped, $IRS(i) = 0$.

The total SLS interrogation rate in the transponder is taken to be:

$$TSI(L) = \sum_i IRS(i) \quad (5-32)$$

This neglects the unlikely possibility of overlapping interrogations. If $TSI(L)$ exceeds the SLS limit, L is raised by increments, ΔL , calculated in the process, until $TSI(L)$ falls just below the threshold. If L is changed by this process, then the ordinary interrogation rates, $DI(i, L)$, must be recalculated based on the new value of L . Conversely, if over-interrogation occurs, the suppression rate is calculated using the new threshold determined by the RRL submodel. The highest threshold calculated to limit either over-interrogation or over-suppression is used for both.

SLS LIMITING IN NONDISCRIMINATORY TRANSPONDERS

In the case of nondiscriminatory transponders, the value of $TSI(L_t)$ is calculated and checked against the SLS threshold. The value of $TDI(L_t)$ is calculated and checked against the RRL threshold. If either threshold is exceeded, then all interrogations and suppressions are reduced proportionally by the same factor that brings both within their acceptable levels.

DEADTIME CALCULATIONS

When a transponder receives and decodes a valid interrogation or suppression signal, it shuts down its receiver for a period of time referred to as the deadtime, which can also be caused by suppressions from TACAN/DME. Deadtime must be considered in estimating the RR of the transponder:

$$RR = \frac{\text{replies to legitimate } I_o \text{ interrogations}}{\text{legitimate } I_o \text{ interrogations}} = \frac{f_{rn}}{f_{in}} \quad (5-33)$$

taken over some appropriate period of time during which I_o is intentionally interrogating T_j (that is, T_j is in the mainbeam of I_o). The following definitions apply:

- f_{in} = Interrogation rate of I_o (valid interrogations only)
- f_{rn} = Rate of T_j replies to valid I_o interrogations
- f_{il} = Sum of all valid interrogations except those from I_o

fr_1 = Rate at which T_j is replying to the f_{i1} interrogations (that is, fruit rate)

fi_2 = Rate at which SLS interrogations are being received from all sources (including I_0 if applicable)

T_1 = Deadtime generated by the reply to a valid interrogation

T_2 = Deadtime generated by the reception of an SLS interrogation

a = Total TACAN/DME deadtime (user input) per second

RR' = Countdown due to RRL

RR'' = Countdown due to deadtime

Countdown is the rate of replies after consideration of the process (with either deadtime or RRL) to the rate of replies before consideration of the process. RR is equal to

$$RR' \times RR'' \quad (5-34)$$

where RR' is computed by going through the RRL process with I_0 , deliberately interrogating T_j on mainbeam and keeping track of how many I_0 interrogations, if any, are lost. When I_0 is not deliberately interrogating T_j , RR has no meaning and hence RR' and RR'' are not calculated.

The calculation of how deadtime affects RR and f_{ri} is made in either of two ways, depending on whether T_j contains a renewable or nonrenewable SLS circuit. For renewable circuits:

$$RR'' = [e^{fi_2 T_2 + (fi_1 T_1 + a)(1 - fin T_1)} e^{-fi_2 T_2}]^{-1} \quad (5-35)$$

$$fr_1 = fi_1 [1 - frn T_1] [e^{fi_2 T_2 + fi_1 T_1 + a}]^{-1} \quad (5-36)$$

For nonrenewable circuits:

$$RR'' = [1 + (fi_2 T_2 + a + fi_1 T_1)(1 - fin T_1)]^{-1} \quad (5-37)$$

$$fr_1 = fi_1 [1 - frn T_1] [1 + fi_1 T_1 + a + fi_2 T_2]^{-1} \quad (5-38)$$

Renewable transponders will accept SLS during deadtime generated by a previous SLS; nonrenewable circuits must recover from an SLS before the next SLS will be accepted.

So far two circuits within the transponder have been investigated: The RRL-SLS limiting circuits and the deadtime circuits. It was assumed that the transponder counted the rate of interrogations (SLS) in the RRL-SLS circuits and adjusted receiver sensitivity to keep these rates below a specified limit. (In the nondiscriminatory circuit the receiver is shut down randomly for fractions of a second to accomplish the same thing.) It was then assumed that the deadtime submodel received the output of the RRL-SLS submodels and determined the reply rates (both to I_o interrogations and to fruit interrogations). This is correct except: The RRL-SLS submodel does limit interrogations, but it does so to limit the transmitter reply rate ($frn + fri$) to a specified limit. An iterative feedback loop between the output of the deadtime submodel and the input of the RRL-SLS submodel is necessary; this is accomplished by assuming an initial interrogation limit, calculating the reply rate, and then updating the interrogation limit, if necessary. The beginning of the iteration process is the decision block "ITERATE?" shown in Figure 5-1.

An optional output is the probability that at any instant the rate of interrogations will exceed the RRL limit. This is called PRRL and is a separate subroutine.

SECTION 6

MATHEMATICAL MODELING OF ATCRBS INTERROGATION

The victim interrogator, I_O , is affected by intrasystem interference that takes the form of fruit replies transmitted by T_j and received by I_O . Figure 6-1 is a simplified flow diagram of the model.

INTRODUCTION

The I/R antenna is assumed to be rotating with a three level pattern. Thus, the fraction of the fruit replies from each transponder that will be detected by I_O depends on the power level of the reply at I_O and the proportion of time I_O 's antenna gain allows the reply to be detected.

The fruit rate received from all transponders is processed, summed separately, and combined in proportion to the probability of occurrence of each I_O gain level. Processing the received fruit is a matter of eliminating a fraction of them as a function of I_O antenna gain circuitry.

RECEIVED POWER CULL

The first step in processing each T_j is calculation of the power level of the signal from T_j in the I_O receiver.

This is estimated by

$$P_r = P_T + L_p + G_T + G_I + S \quad (6-1)$$

where

S = Minimum threshold of I_O 's receiver (-dBm). This occurs when the GTC function is at its maximum gain.

P_r = Power received at the receiver of I_O (normalized to S by the equation) (dB).

P_T = Transmitter power from transponder T_j (dBm).

L_p = Propagation path loss from T_j to I_O , (dB).

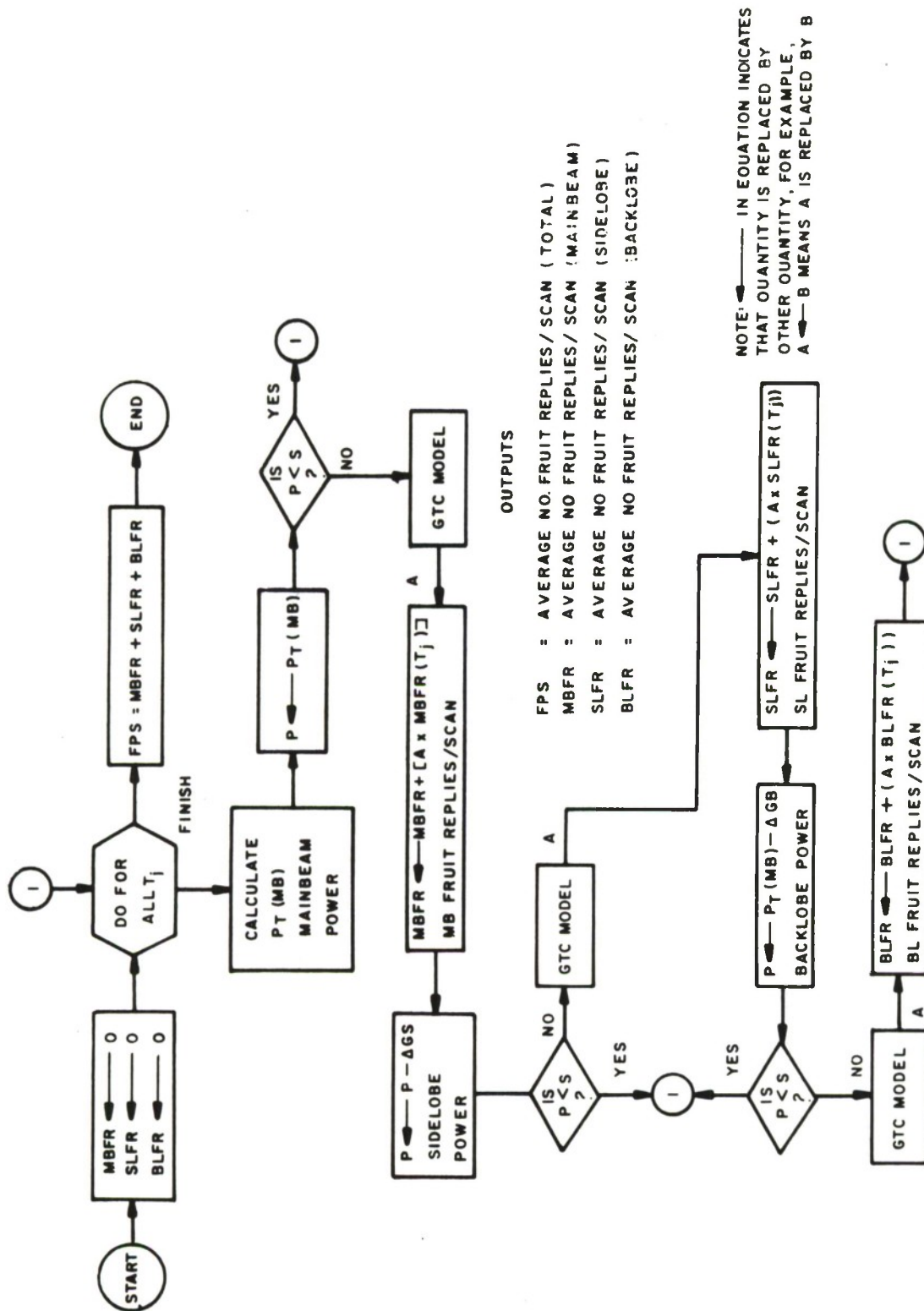


Figure 6-1. I_O Model, Simplified Flow Diagram

G_T = Gain of the transponder antenna (assumed to be omnidirectional) (dB).

G_I = Gain of the I_O receiver antenna (dB).

The three values of P_r depend on which of the three values of G_I is assumed. These values are noted as P_r (MB), P_r (SL), and P_r (BL) for the mainbeam, sidelobe, and backlobe, respectively. Any replies for which $P_r < 0$ are ignored.

GAIN TIME CONTROL (GTC)

The GTC function in the receiver automatically varies receiver sensitivity as a function of time. The GTC parameters in this description meet the requirements of equipment procurement specifications; however, user-specified values can be considered. From $t = 0$ at the interrogation trigger to approximately $t = 15$ microseconds, the sensitivity is at its minimum with a value of Δ (dB) below threshold. The sensitivity then increases to its maximum value, S , and remains at S until the end of interrogation period T at which T equals $1/IPS$, where IPS is the interrogation rate (per second) of I_O . The GTC circuit is designed to increase the receiver gain by 6 dB for every octave increase in time, beginning at $t = 15$ microseconds and continuing to some time, $t \leq T$, where it levels off at S .

Because there is a one-to-one correspondence between time t and distance d (for synchronous replies only), the received synchronous replies from a closing aircraft will remain at approximately a constant level equal to the power received from T_j when it was approximately 20 miles away. Thus, the probability of saturating I_O 's receiver is reduced. However, fruit replies from a given transponder are received randomly with respect to time. Thus, they are equally likely to be received at I_O during any equally long time segment from $t = 0$ to T . The probability that they exceed the receiver threshold will vary from 0 to 1. For each power level P_r , the following analysis must be made:

Let A equal the probability of receiving a fruit reply, given that its power P_r is greater than 0.

From the preceding discussion,

If $P_r \geq \Delta S$, then $A = 1$,

If $P_r < 0$, then $A = 0$,

If $0 \leq P_r < \Delta S$, then $0 < A < 1$.

The receiver sensitivity curve approximates Figure 6-2. In the model the curve is approximated by a straight line (dotted in Figure 6-2) between maximum threshold, ΔS , and minimum threshold, 0 dB. All power is normalized to S.

Let

- a = Time at which the GTC function begins to change,
- b = Time at which the GTC function reaches maximum gain,
- ΔS = Change in threshold due to GTC.

The equation of the linear approximation of the curve is

$$Th = \frac{(b - t)\Delta S}{b - a}; \quad a \leq t < b \quad (6-2)$$

A is the probability that threshold TH is below P_r when a fruit pulse is received. Because fruit from any given transponder, T_i is received randomly in time, the probability that the threshold is below P_r is equal to the fraction of time that the threshold is below P_r .

Therefore

$$A = 1 - \frac{t'}{t} \quad \text{when } 0 \leq P_r \leq \Delta S \quad (6-3)$$

$$= 1 \quad \text{when } P_r > \Delta S \quad (6-4)$$

where t' is the solution when P_r equals Th , which is

$$t' = b - \frac{P_r}{\Delta S} (b - a) \quad (6-5)$$

so that A is 1 when P_r equals ΔS and, when $0 \leq P_r \leq \Delta S$,

$$A = \frac{1}{t} \left[t - b + \frac{P_r}{\Delta S} (b - a) \right] \quad (6-6)$$

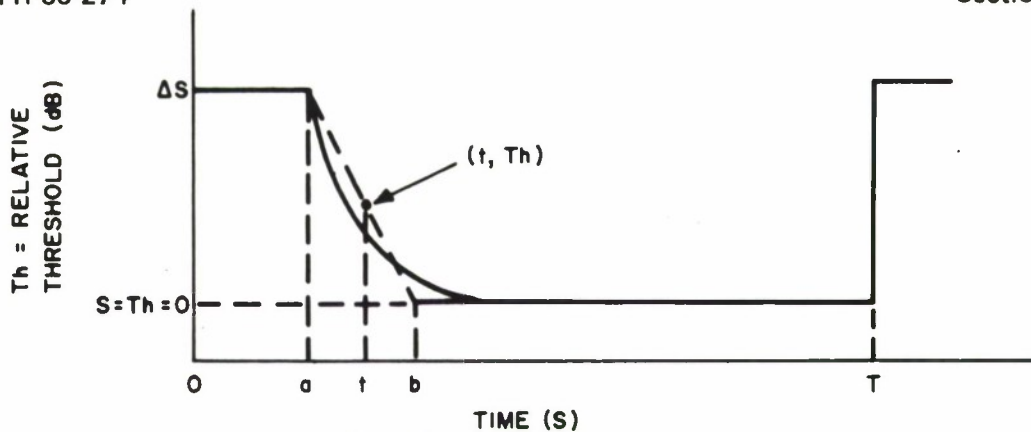


Figure 6-2. GTC Submodel

RANGE FACTOR B

The propagation time for interrogation and reply cannot be longer than $T = 1/\text{PRF}$. Some interrogators interrogate to shorter distances than the possible maximum distance. This lesser range is accomplished by shutting down the receiver for that part of the interpulse period that is not of interest. The following method is used to adjust the fruit rate due to the receiver shutdown:

Let $R_{\max} = 1/(10.7 \times 10^{-6} \times \text{PRF})$, maximum interrogation range in statute miles, limited by PRF.

R_1 = maximum range out to which the interrogator is interested. (statute miles)

T_1 = $10.7 \times 10^{-6} R_1$ (time the receiver is on to receive replies from targets out to R_1)

T_d = $T - T_1$ (time during each interpulse period that the interrogator receiver is shut down)

$B = \frac{T - T_1}{T} = 1 - \frac{T_1}{T}$ (percent of time that the interrogator is dead. This is also the percent reduction in fruit received by I_0 from the case where $T_d = 0$.)

Now $T_1 = 10.7 \times 10^{-6} R_1$

$T = \frac{1}{\text{PRF}} = 10.7 \times 10^{-6} R_{\max}$

Thus $\frac{T_1}{T} = \frac{R_1}{R_{\max}}$

$$\text{Then } B = \frac{R_{\max} - R_1}{R_{\max}}$$

Let FRL_j = Fruit rate from transponder j received by I_0 's antenna lobe L (Mainbeam, sidelobe, or backlobe).

A_j = Probability of receiving FRL_j as a function of GTC and range factor B .

$$\text{Then } A_j = A - B$$

SUMMATION OF FRUIT

FPS, the total average number of fruit replies detected per scan of the I_0 antenna can be calculated by

$$FPS = MBFR + SLFR + BLFR \quad (6-7)$$

where

MBFR, SLFR, and BLFR = the total average number of fruit replies detected per scan on I_0 's mainbeam, sidelobe, and backlobe, respectively.

If the possibility of overlapping fruit replies is ignored, then for example

$$MBFR = \sum_j \frac{A \times MBFR_j \times MBW \times N_j}{6 \times SR} \quad (6-8)$$

where

$MBFR_j$ = The average mainbeam fruit rate (replies per second) of T_j .

N_j is an integer greater than or equal to 1, corresponding to the number of essentially similar transponders located at about the same position. This feature allows the user to specify that a transponder actually represents a number of similar transponders, thus eliminating redundant calculations where a value $N_j > 1$ is appropriate.

MBW = the mainbeam width of I_0 in degrees.

SR = the scan rate of the I_0 antenna in scans per minute (rpm)

The sum is taken over all transponders not culled out on the basis of power. A is the GTC factor calculated for that T_j and the assumption of I_0 mainbeam gain. Similar computations are made for SLFR and BLFR.

MONTE-CARLO SIMULATION VERSION

The average version of the ATCRBS PPM is designed to estimate average values for RR and fruit rates. It is also desirable to have the capability to obtain an output distribution of these values based on the range of possible inputs to the transponder model that are based on combinations of interrogator antenna orientations.

The transponder output is not a linear function of its input; in fact, the output is limited to a certain reply rate. Therefore, the Monte-Carlo derived mean output is not exactly the same as the output from the averaging method used in the model. The Monte-Carlo output may be slightly less than the values predicted by this process because at instants of peak input the reply rate limit may be exceeded. The limiting process is modeled in the computer program and will be encountered whenever the average input conditions would force this action. This long-term average method should produce results reasonably close to the Monte-Carlo outputs.

The simulation technique consists of running through the transponder model many times for each transponder and its environment of interrogators. On each run a complete set of antenna orientations is selected randomly. Each orientation consists of a random choice of mainbeam, sidelobe, or backlobe gain for that interrogator based on the original beamwidths associated with each gain level. The Monte-Carlo version has the additional advantage of providing a representative distribution of output values. Mean and standard deviation of the fruit rate and RR are also computed. Figure 6-3 is a flow diagram showing modifications to the long-term average model for Monte Carlo simulation, and for computing the means and variances of the output distributions. Figure 6-4 is a flow diagram for computing a random orientation for any given interrogator.

Due to the extensive calculations required, it is more practical to use the long-term average model on deployments. A study based on handling a few transponders by means of the Monte-Carlo simulation might provide guidance in establishing a proper interpretation of outputs from the long-term average model.

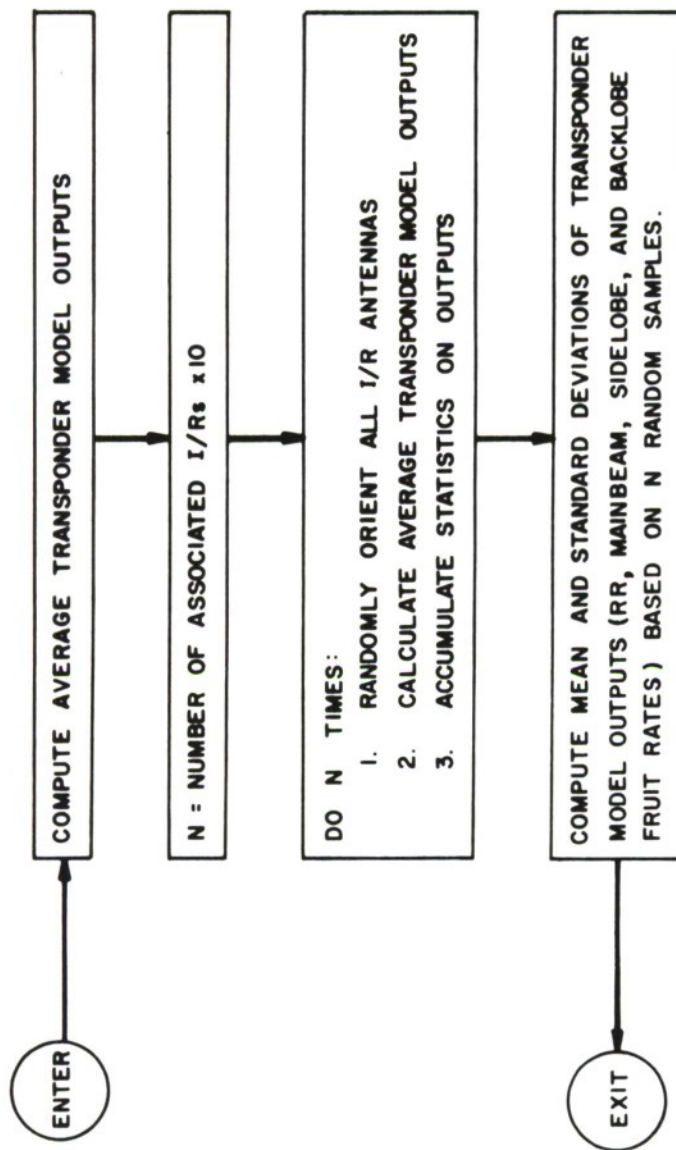
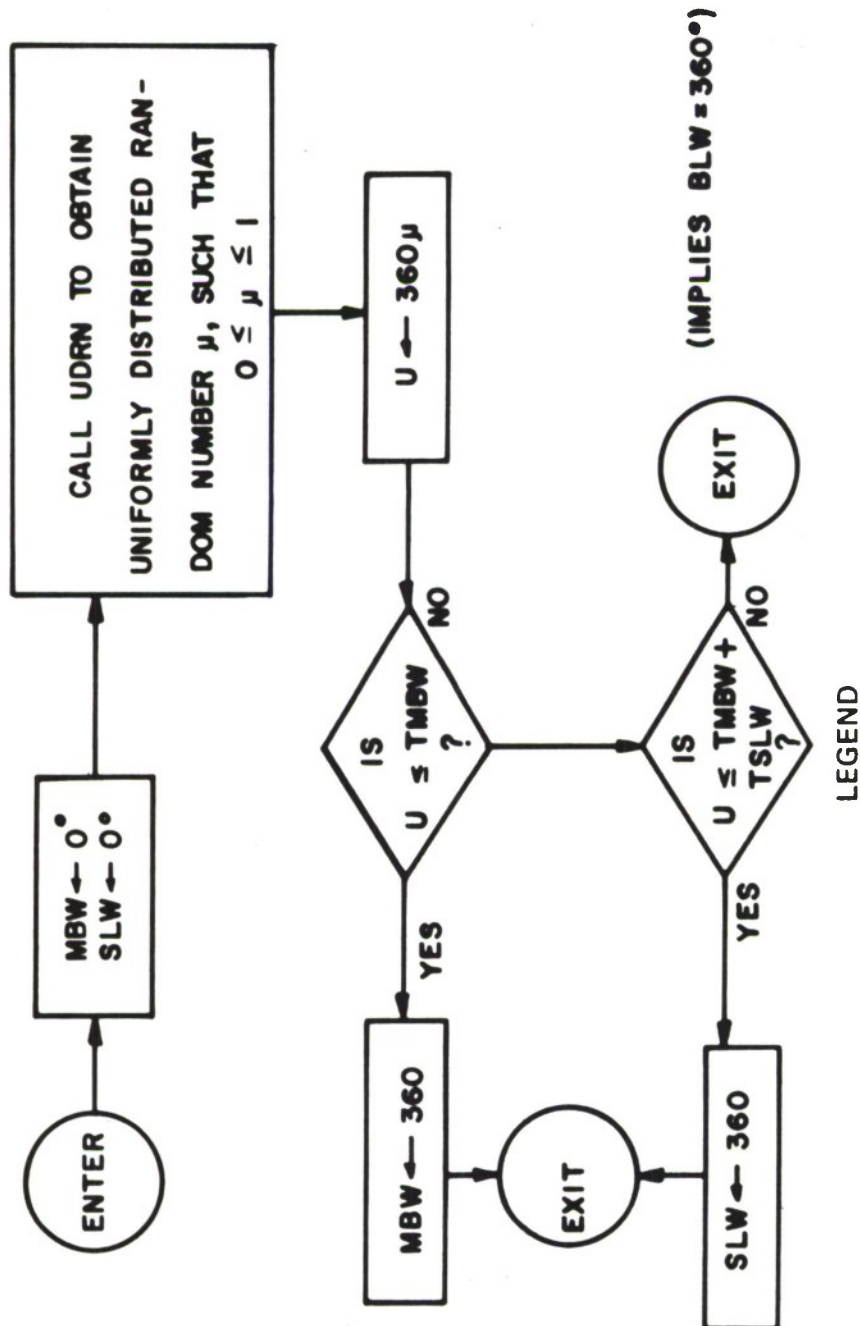


Figure 6-3. Monte-Carlo Version



LEGEND

- MBW** = Randomly generated mainbeam width (0° or 360°)
- SLW** = Randomly generated sidelobe width (0° or 360°)
- BLW** = 360 - MBW - SLW = backlobe width
- TMBW** = True mainbeam width
- TSLW** = True sidelobe width
- TBLW** = True backlobe width = 360 - TMBW - TSLW
- UDRN** = Uniform Distribution Random Number Generator

Figure 6-4. Random Orientation Computation, Flow Diagram

STEP-SCANNING VERSION

The Step-Scanning ATCRBS PPM version differs from the Long-Term Average ATCRBS in several ways. First, it computes fruit values per sector from a random rotating I/R environment. Provisions were made to allow 30 separate random calculations, the results of which are summed. The final computed output tables are mean and standard deviation values of fruit per sector. An option allows the user to plot (in polar and Cartesian coordinates) the mean value table.

A second difference is the limitation placed on the size of the I/R environment that can be considered. This limitation is necessary because the model stores all needed I/R parameters in the core memory of the computer being used. This storage allows faster access to data (nanoseconds versus milliseconds) and is necessary to the recalculation process, which requires multiple accesses to the same data.

CLASSES OF INTERROGATIONS

Three classes of interrogations are considered in the ATCRBS simulation model:

1. Interrogations without sidelobe suppressions
2. Interrogations with sidelobe suppressions
3. Interrogations with improved sidelobe suppressions

Antenna patterns for normal, SLS, and ISLS interrogations are shown in Figure 6-5.

The model will accept transponders that are not equipped with the three pulse SLS.

PROBABILITY OF RRL ACTION P (RRL)

This subsection describes a method of solving the probability of RRL action, P (RRL), using inputs from the transponder model (see Figure 6-6). The two parameters used are the duty cycle and effective interrogation rate (EIR) of each listed station. The ratio of the effective antenna pattern per antenna scan is the interrogation duty cycle (IDC) in this calculation; that is, $\frac{4^\circ}{360^\circ} = 0.011$.

PROCEDURE

The procedure to be used is:

1. From the transponder model, list all stations with associated EIR and IDC.

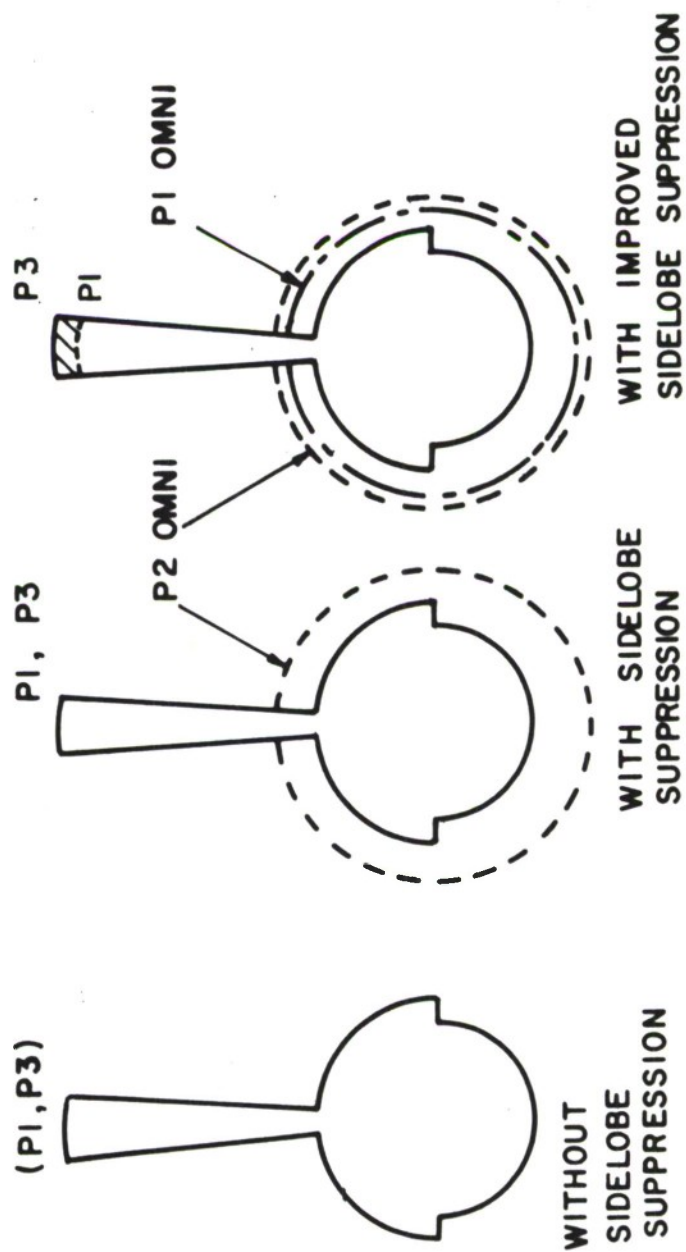


Figure 6-5. IFF Interrogation Classes

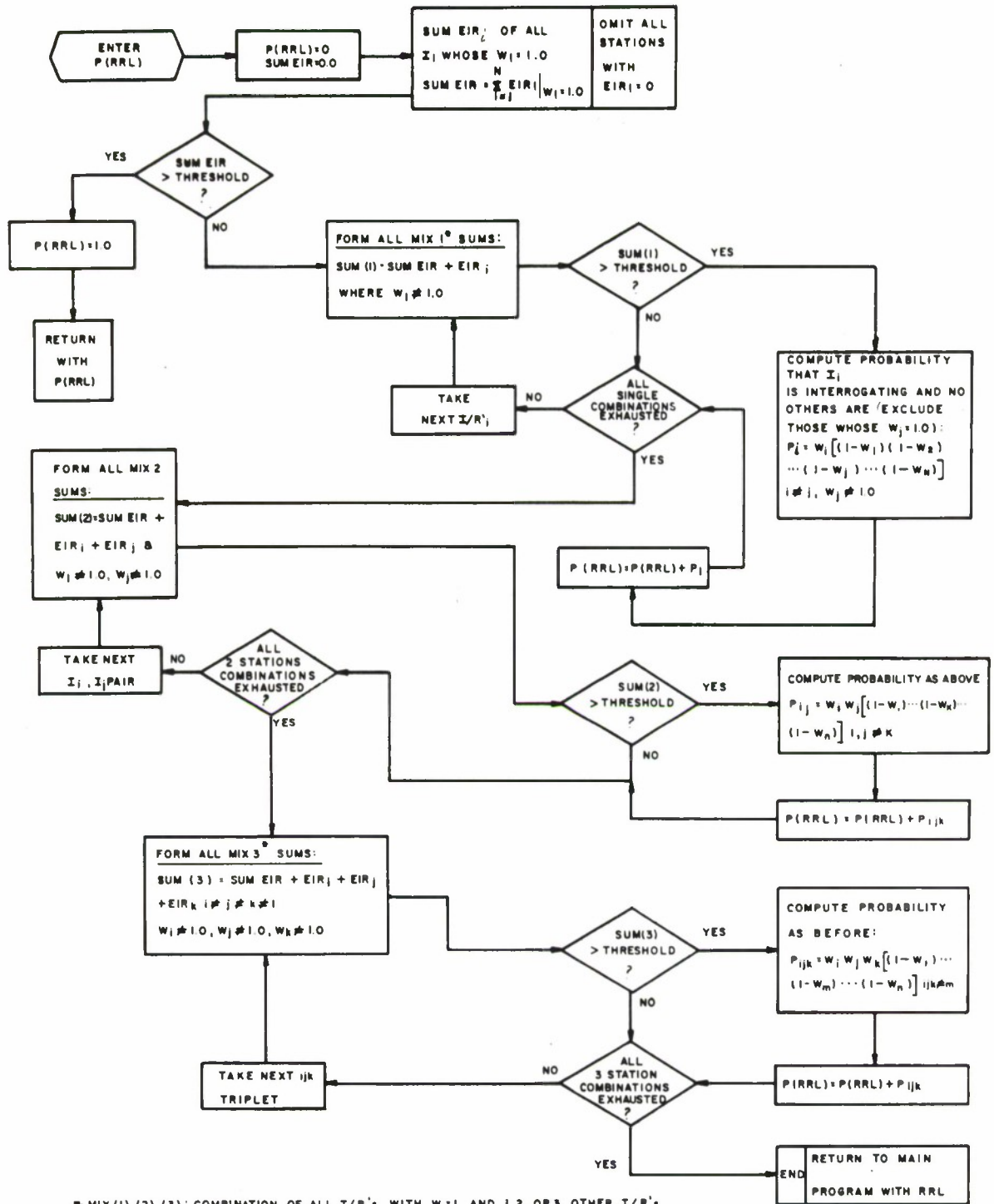


Figure 6-6. Probability of RRL, Simplified Flow Diagram

2. From this list, select all stations with an IDC of 1, and sum their EIRs in mainbeam, sidelobe, and interrogations.

3. If this sum is greater than RRL, the $P(RRL)$ is equal to 1 and the problem is complete.

4. If the sum is less than RRL, the $P(RRL)$ is computed by compiling a list of stations, the combined EIRs of which are all greater than the RRL threshold. This list is formed by including all stations with an IDC of 1 in every combination. The number of stations in each combination will be limited to the number of stations with an IDC of 1, plus, at the most, three other stations.

5. The $P(RRL)$ is equal to the sum of the probabilities associated with each combination. The individual probability of any one combination is equal to the product of the IDC of the listed stations and 1 minus the IDC of all stations not listed.

6. The culls formed are necessary because, for example, only 20 stations would require more than 1,000,000 combinations. The first cull is to include in every combination the stations with IDC of 1. This is allowable because, when computing the associated probability, the product of 1 minus the IDC of all other stations is taken. Therefore, to eliminate one of these stations is equivalent to forming a combination with a probability of 0. The second cull is to limit the combinations to the number of stations with an IDC of 1 plus three.

For example, if in a problem containing 20 stations there are two stations with an IDC of 1, all combinations of five or fewer stations whose combined PRF is greater than 1300 are formed; this would be about 20,000 combinations, compared to 1,000,000 taking all possible combinations. This procedure appears justified because most stations with IDC less than 1 have around 0.007. Therefore, this procedure eliminates only those probabilities of the order of 10^{-6} .

TABLE 6-1 shows that the line probability of stations 1, 2, 3, 7, and 10 interrogating at the same time that stations 4, 5, 6, and 8 are not interrogating (station 9 dropped because $EIR_9 = 0$) is the produce of the probabilities of occurrence; for example, $P(RRL)_{1, 2, 3, 7, 10} \equiv P(RRL)_{23} = \frac{10}{11}$ for $j = 1$

$$IDC = W_i$$

$$P_j = P_1 \cdot P_2 \cdot \dots \cdot P_{10} = w_1 \cdot w_2 \cdot w_3 \cdot (1-w_4) \cdot (1-w_5) \cdot$$
(6-9)

$$(1-w_6) \cdot w_7 \cdot (1-w_8) \cdot w_{10} \quad (\text{ie: } 1+2+3+7+10 = 23 \text{ subscript})$$

TABLE 6-1
SAMPLE PROBABILITY OF RRL INPUT DATA

i Station Number	EIR _i Effective Interrogation Rate	IDC W _i
1	360	0.004
2	125	0.010
3	325	1.000
4	275	0.026
5	376	0.002
6	102	0.011
7	273	1.000
8	400	0.005
9	0	0.001
10	306	1.000

Computed Values

$$\Sigma \text{EIR}_i (w_i = 1) = 904 \quad [i = 3, 7, 10]$$

Item 9 not used ($\text{EIR}_9 = 0$)

All combinations include stations 3, 7 and 10;
Stations 1, 2, 4, 5, 6, and 9 drop out on single
combinations pass because $\text{EIR} + \text{EIR}_i \leq \text{threshold}$

Threshold = 1300

where

$P_i = w_i$ for all stations in the mix,

$= (1-w_i)$ for all others.

$$P(RRL)_{23} = 0.00003825 \quad (6-10)$$

All conditions having been met, the next combination is checked, computed, and added to total $P(RRL)$. When all $P_i(RRL)$'s are added, the total is $P(RRL)$, the probability that the transponder will encounter an interrogation rate greater than its limit. (See TABLE 6-2).

TABLE 6-2
P(RRL) (TOTAL = 0.00554066)

Combination	P ₍₁₎	P ₍₂₎	P ₍₃₎	P ₍₄₎	P ₍₅₎	P ₍₆₎	P ₍₇₎	P ₍₈₎	P ₍₁₀₎	P(RRL)
3,7,10,8	0.996	0.990	1	0.974	0.998	0.989	1	0.005	1	0.00473969
1,2	0.004	0.010	1	0.974	0.998	0.989	1	0.995	1	0.00003825
1,4	0.004	0.990	1	0.026	0.998	0.989	1	0.995	1	0.00010110
1,5	0.004	0.990	1	0.974	0.002	0.989	1	0.995	1	0.00000758
1,6	0.004	0.990	1	0.974	0.998	0.011	1	0.995	1	0.00004212
1,8	0.004	0.990	1	0.974	0.998	0.989	1	0.005	1	0.00001903
2,4	0.996	0.010	1	0.026	0.998	0.989	1	0.995	1	0.00025431
2,5	0.996	0.010	1	0.974	0.002	0.989	1	0.995	1	0.00001908
2,8	0.996	0.010	1	0.974	0.998	0.989	1	0.005	1	0.00004787
4,5	0.996	0.990	1	0.026	0.002	0.989	1	0.995	1	0.00005044
4,8	0.996	0.990	1	0.026	0.998	0.989	1	0.005	1	0.00012652
5,6	0.996	0.990	1	0.974	0.002	0.011	1	0.995	1	0.00002101
5,8	0.996	0.990	1	0.974	0.002	0.989	1	0.005	1	0.00000949
6,8	0.996	0.990	1	0.974	0.998	0.011	1	0.005	1	0.00005271
1,2,4	0.004	0.010	1	0.026	0.998	0.989	1	0.995	1	0.00000100
1,2,5	0.004	0.010	1	0.974	0.002	0.989	1	0.995	1	0.00000005
1,2,6	0.004	0.010	1	0.974	0.998	0.011	1	0.995	1	0.00000041
1,2,8	0.004	0.010	1	0.974	0.998	0.989	1	0.005	1	0.00000019
1,4,5	0.004	0.990	1	0.026	0.002	0.989	1	0.995	1	0.00000018
1,4,6	0.004	0.990	1	0.026	0.998	0.011	1	0.995	1	0.00000112
1,4,8	0.004	0.990	1	0.026	0.998	0.989	1	0.005	1	0.00000050
1,5,6	0.004	0.990	1	0.974	0.002	0.011	1	0.995	1	0.00000007
1,5,8	0.004	0.990	1	0.974	0.002	0.989	1	0.005	1	0.00000003
1,6,8	0.004	0.990	1	0.974	0.998	0.011	1	0.005	1	0.00000021
2,4,5	0.996	0.010	1	0.026	0.002	0.989	1	0.995	1	0.00000049
2,4,6	0.996	0.010	1	0.026	0.998	0.011	1	0.995	1	0.00000282
2,4,8	0.996	0.010	1	0.026	0.998	0.989	1	0.005	1	0.00000127
2,5,6	0.996	0.010	1	0.974	0.002	0.011	1	0.995	1	0.00000020
2,5,8	0.996	0.010	1	0.974	0.002	0.989	1	0.005	1	0.00000009
2,6,8	0.996	0.010	1	0.974	0.998	0.011	1	0.005	1	0.00000053
4,5,6	0.996	0.990	1	0.026	0.002	0.011	1	0.995	1	0.00000055
4,5,8	0.996	0.990	1	0.026	0.002	0.989	1	0.005	1	0.00000025
4,6,8	0.996	0.990	1	0.026	0.998	0.011	1	0.005	1	0.00000140
5,6,8	0.996	0.990	1	0.974	0.002	0.011	1	0.005	1	0.00000010

SECTION 7

ATCRBS PPM APPLICATIONS

Initial validation of the ATCRBS PPM has been carried out using data supplied by the FAA for the Tyndall and Valdosta long-range radars. Aircraft deployments were obtained from these radars. The aircraft deployments occurred at 1145 hours, 12 January 1968, and are shown in Figure 7-1. The interrogator ground environment was obtained from the ECAC environmental data base.

The FAA reported a fruit per scan value of approximately 90,000 for the Tyndall interrogator. The ATCRBS PPM predicted 103,055 fruit per scan without SLS; with SLS and all other conditions unchanged, the predicted average fruit per scan was 14,678.

MONTE-CARLO VERSUS LONG-TERM AVERAGE PREDICTIONS

Comparison of model versions was desirable to determine if a significant difference would result in performance predictions. Thus, two sets of transponders and their combinations of interrogators were selected. The average option was used to determine transponder performance, as was the Monte-Carlo option, for comparison. More than 350 samples were generated for each option to obtain means and variances of transponder performance. The results of this comparison are listed in TABLE 7-1. The differences obtained are not considered to be significant, thus establishing some confidence in the long-term average model version.

MEASURED VALUES VERSUS LONG-TERM AVERAGE PREDICTIONS

A comparison between model predictions and field measurements was made by duplicating field recordings of transponder performance. Measured data were provided by Code SEACI/SENY, Wright-Patterson AFB, Dayton, Ohio. These tests were conducted on 20 July 1966. A C-131 IFF testbed aircraft flew from Jacksonville, Florida, to Savannah, Georgia, at altitudes between 9,000 and 13,000 feet. The aircraft instrumentation simultaneously counted the total replies generated by the aircraft transponder to the interrogations from the ground environment. The ATCRBS PPM was used to predict the total average replies generated by a transponder at 10,000 feet altitude and at 10 mile intervals between Jacksonville, Florida, and Savannah, Georgia (see Figure 7-2). The results of predicted and measured transponder replies are shown in Figures 7-3 and 7-4 for actual and simulated flights between Jacksonville and Savannah. Figure 7-3 contains predictions of the total reply rate of a transponder with receiver sensitivities of -80 and -70 dBm; the measured results are effectively bracketed by the predicted results.

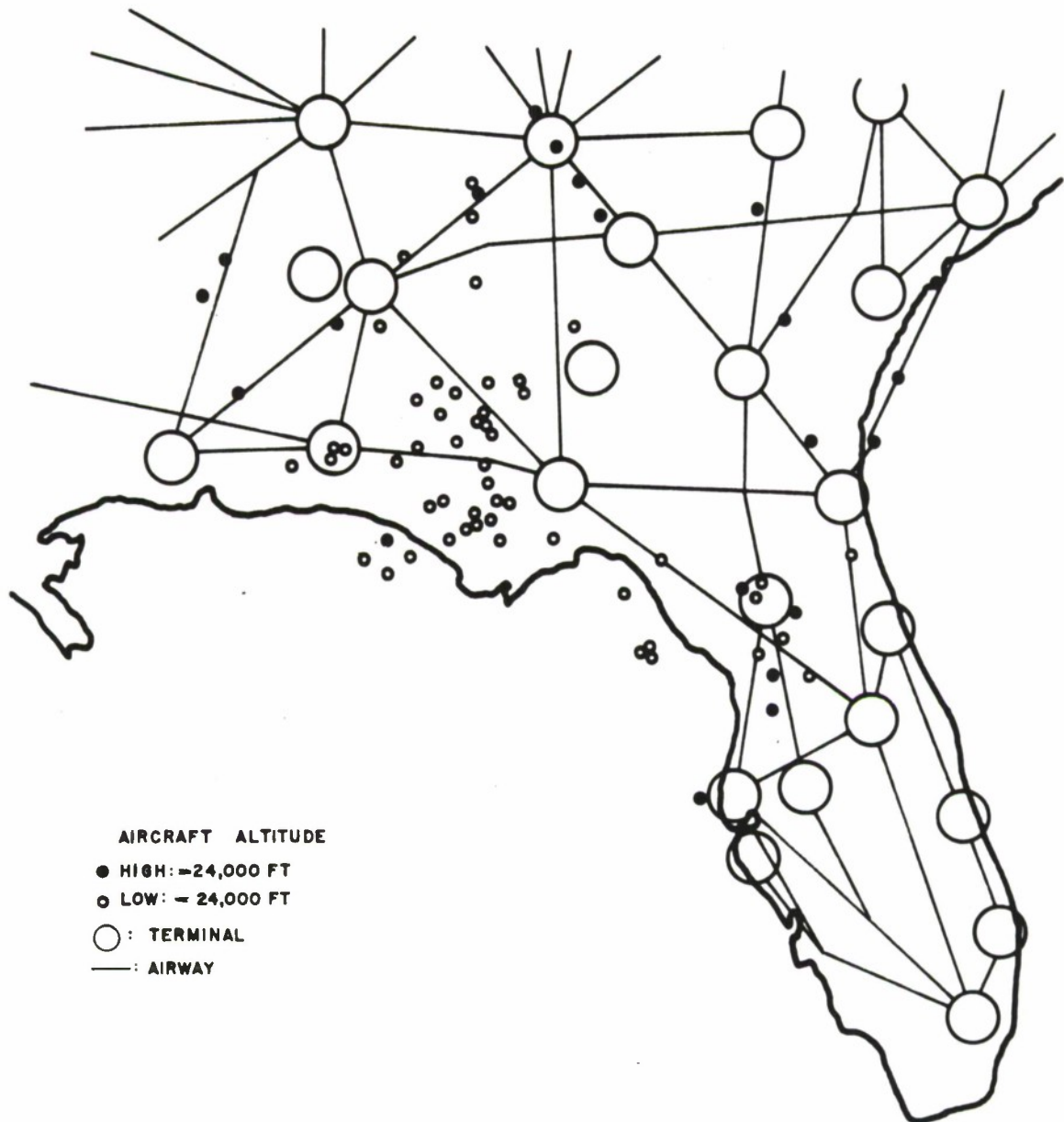


Figure 7-1. Aircraft Deployment, 12 January 1968

TABLE 7-1
MODEL COMPARISONS

Sample	Average Derived	Monte-Carlo Derived	Difference
Mainbeam Fruit	374.5/sec	388.2/sec	+13.7
Mainbeam Fruit	404.3/sec	395.5/sec	-8.8
Round Reliability	0.963	0.961	-0.002
Round Reliability	0.960	0.960	---

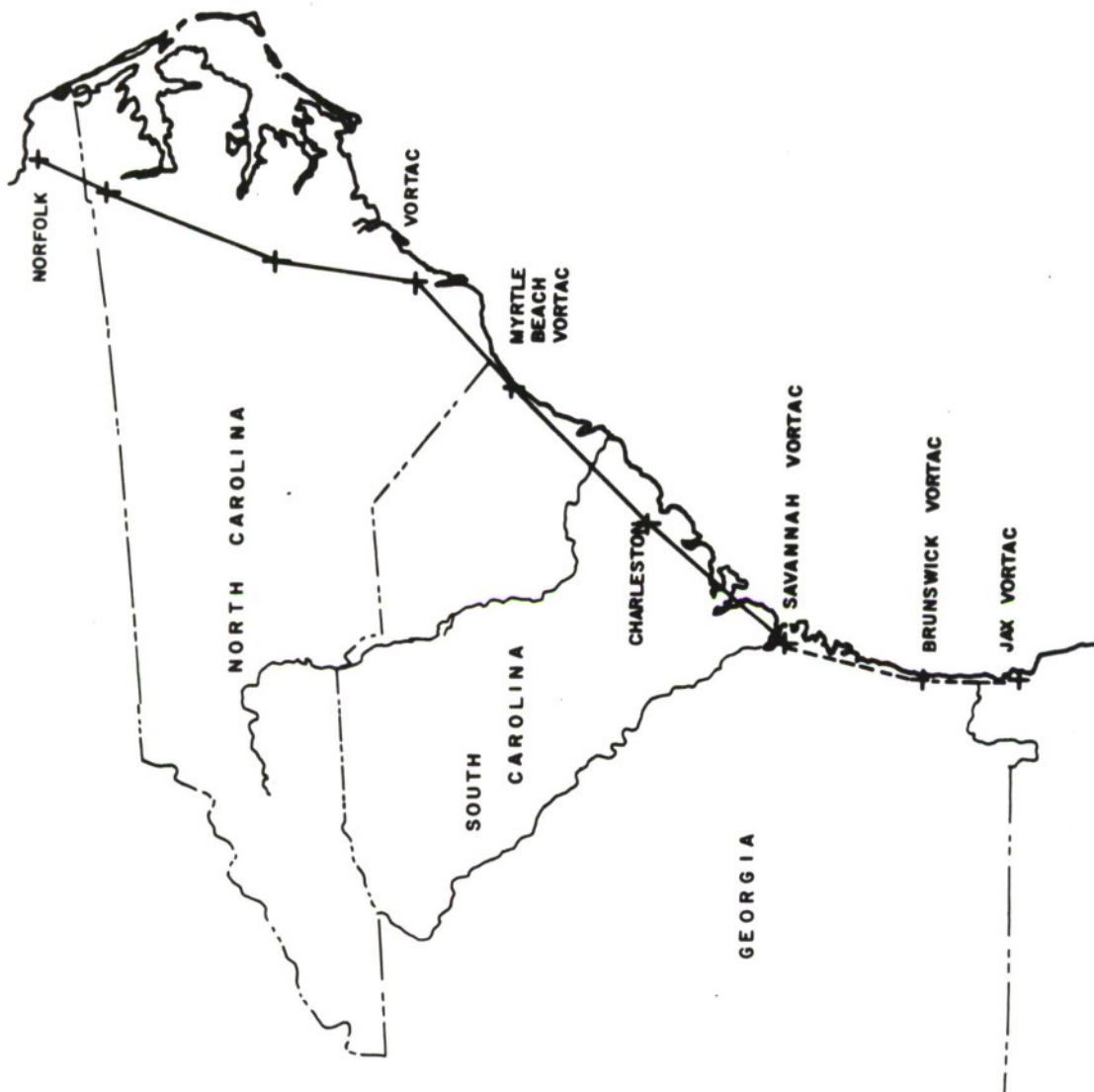


Figure 7-2. Aircraft Flight Path

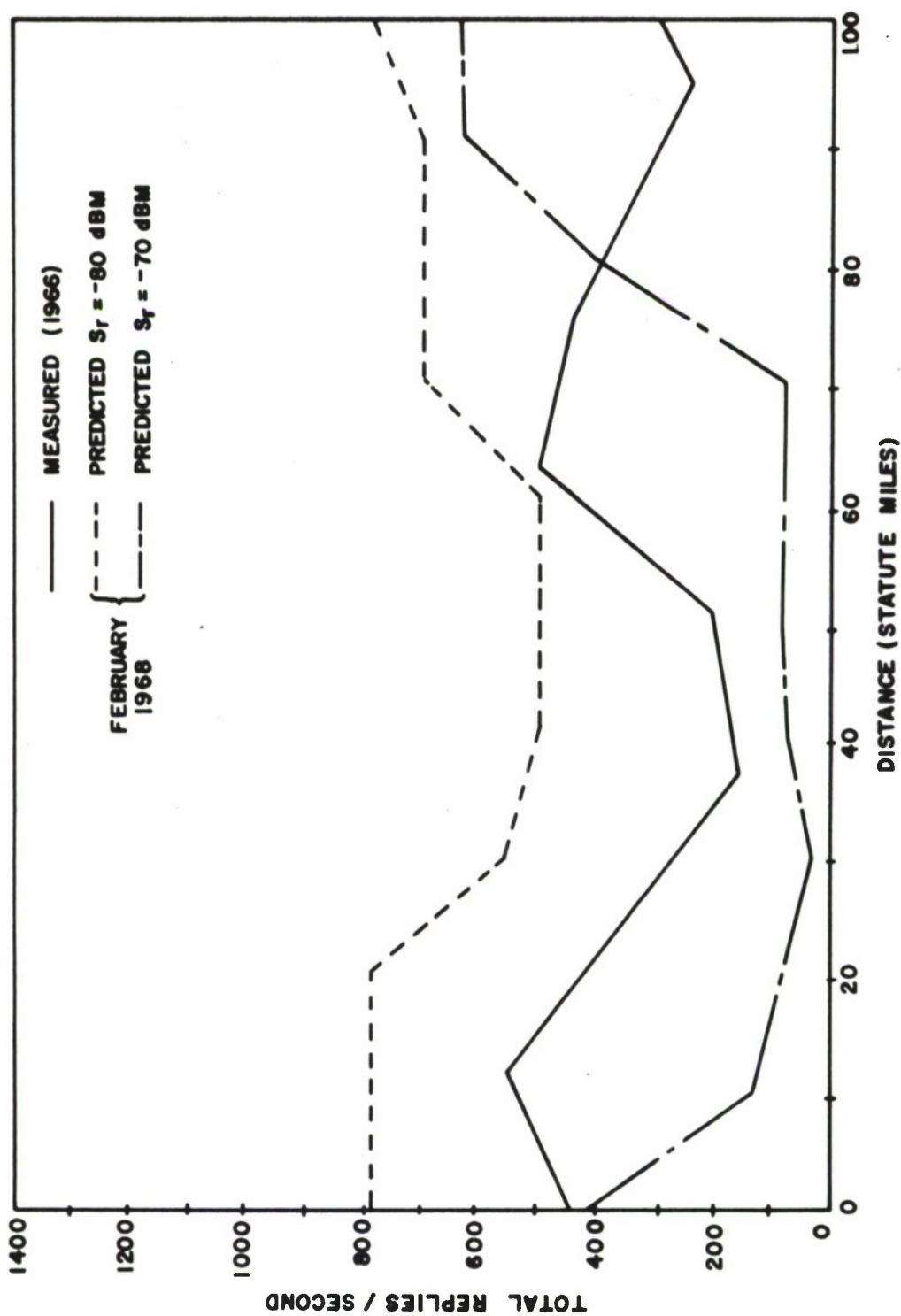


Figure 7-3. Comparison of Measured and Predicted IFF Transponder Performance
(Receiver Sensitivities of -80 and -70 dBm)

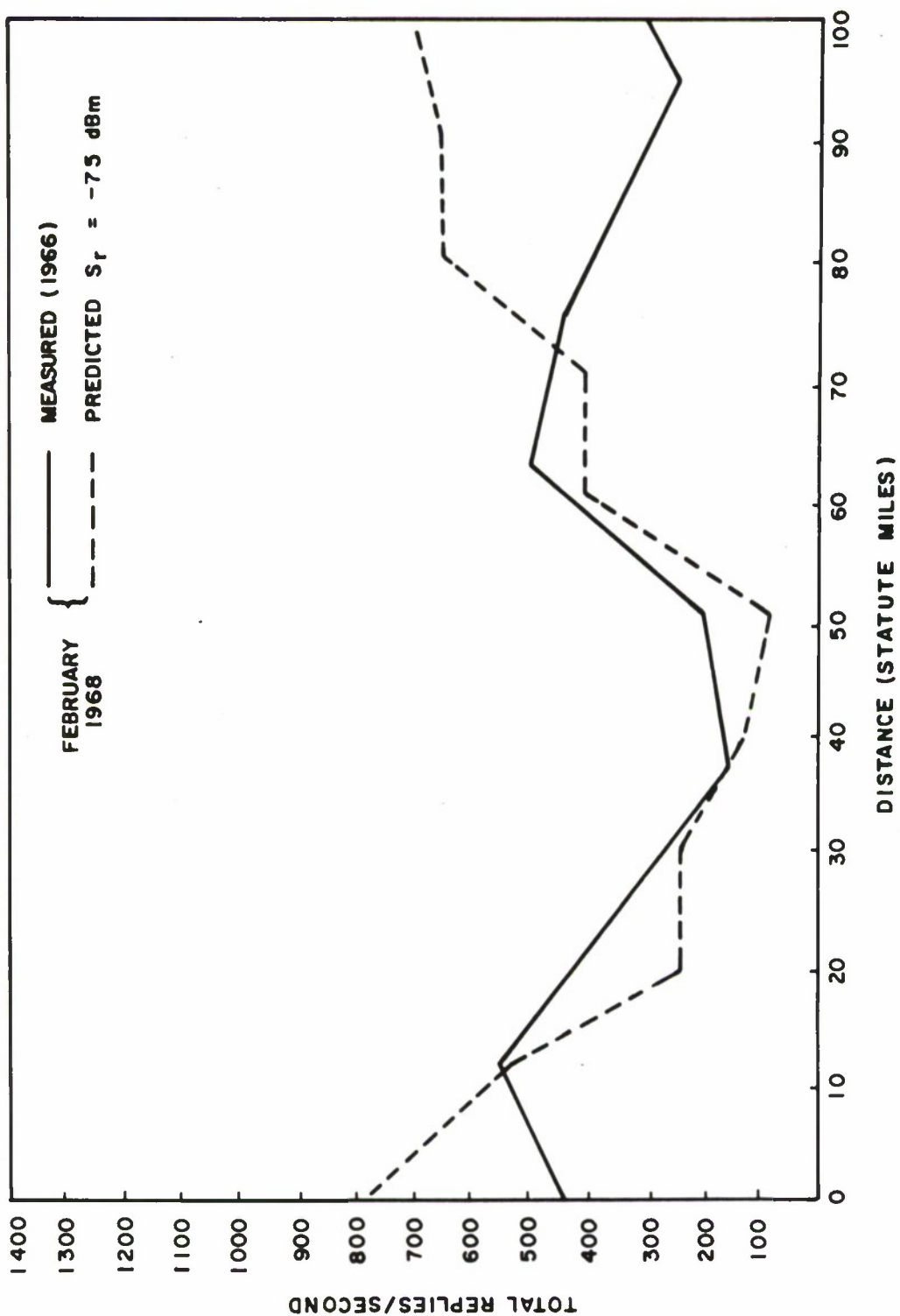


Figure 7-4. Comparison of Measured and Predicted IFF Transponder Performance
(Receiver Sensitivity of -75 dBm)

In Figure 7-4 the simulated transponder receiver sensitivity was adjusted to -75 dBm, and the total average replies were predicted, with all other parameters unchanged. Measured total replies and predicted average total replies between 10 and 75 statute miles are within close agreement. The differences between measured and predicted values at Jacksonville and Savannah can be reduced by turning off one of the two interrogators collocated at Jacksonville and one of the two interrogators collocated at Savannah. Removal of these interrogators causes measured and predicted values to be in close agreement over the complete flight path (see Figure 7-5). The FAA advised that it is reasonable to assume that these interrogators were not transmitting during the flight test period.

Figure 7-6 is a fruit distribution prediction (fruit density per MBW) for one scan of the Tyndall AFB ATCRBS generated by the step-scanning model. Input factors were 429 aircraft and 144 ground-based interrogators. The aircraft distribution is the FAA estimate of peak-minute traffic for 1968 within 360 nautical miles of the Tyndall AFB (see Reference 8). The 144 interrogators are the estimated minimum required for FAA Instrument Flight Regulations (IFR) within 720 nautical miles of Tyndall. The total fruit per scan for this single sample is 41,060. Figure 7-6 illustrates the dynamics of fruit distribution.

Average performance predictions for the Tyndall AFB ATCRBS are shown in Figure 7-7. Input factors were 429 aircraft within 360 statute miles of Tyndall for 1968, corrected to 1975 and 1980 (see Reference 8). The two interrogator environments obtained from the ECAC data base consisted of the 144 minimum interrogators required for IFR within 720 nautical miles of Tyndall AFB, and all 186 interrogators located within 720 nautical miles of Tyndall. ATCRBS receiver sensitivity was measured as -90 dBm. This value was used in the model. SLS-equipped interrogators are identified in Figure 7-7 as Y or N, respectively, Y indicates SLS is operational, N indicates it is not. The numbers after the Y or N are the number of interrogators that remain in the problem (power distance cull) from the original 144 or 186. Figure 7-8 is a repeat of this situation with ATCRBS receiver sensitivity set at -84 dBm. (From Figure 7-7, for 200 aircraft and a receiver sensitivity of -90 dBm, the average fruit per scan is 200,000; from Figure 7-8, with a receiver sensitivity of -84 dBm, the average fruit per scan is 100,000, demonstrating one aspect of amplitude sensitivity of ATCRBS and the ATCRBS PPM).

Figure 7-9 presents average fruit per scan predictions for the same conditions as Figure 7-7, except the sensitivity of the Tyndall ATCRBS was varied from -90 to -66 dBm. In all cases the environment is SLS-equipped. The number of aircraft and interrogators involved in the problem decreases as the sensitivity decreases, as expected.

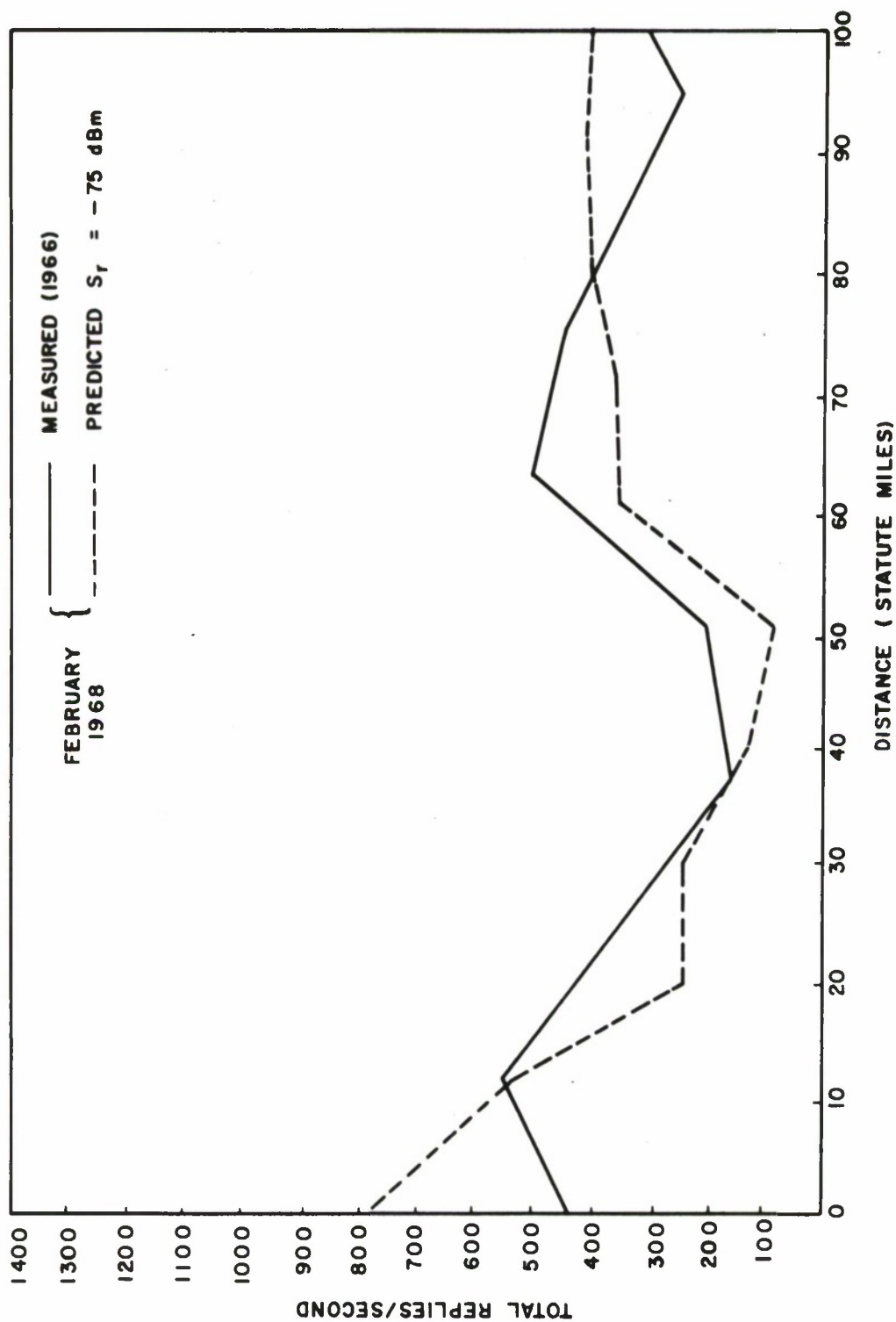


Figure 7-5. Comparison of Measured and Predicted IFF Transponder Performance for a Reduced Environment (Receiver Sensitivity of -75 dBm)

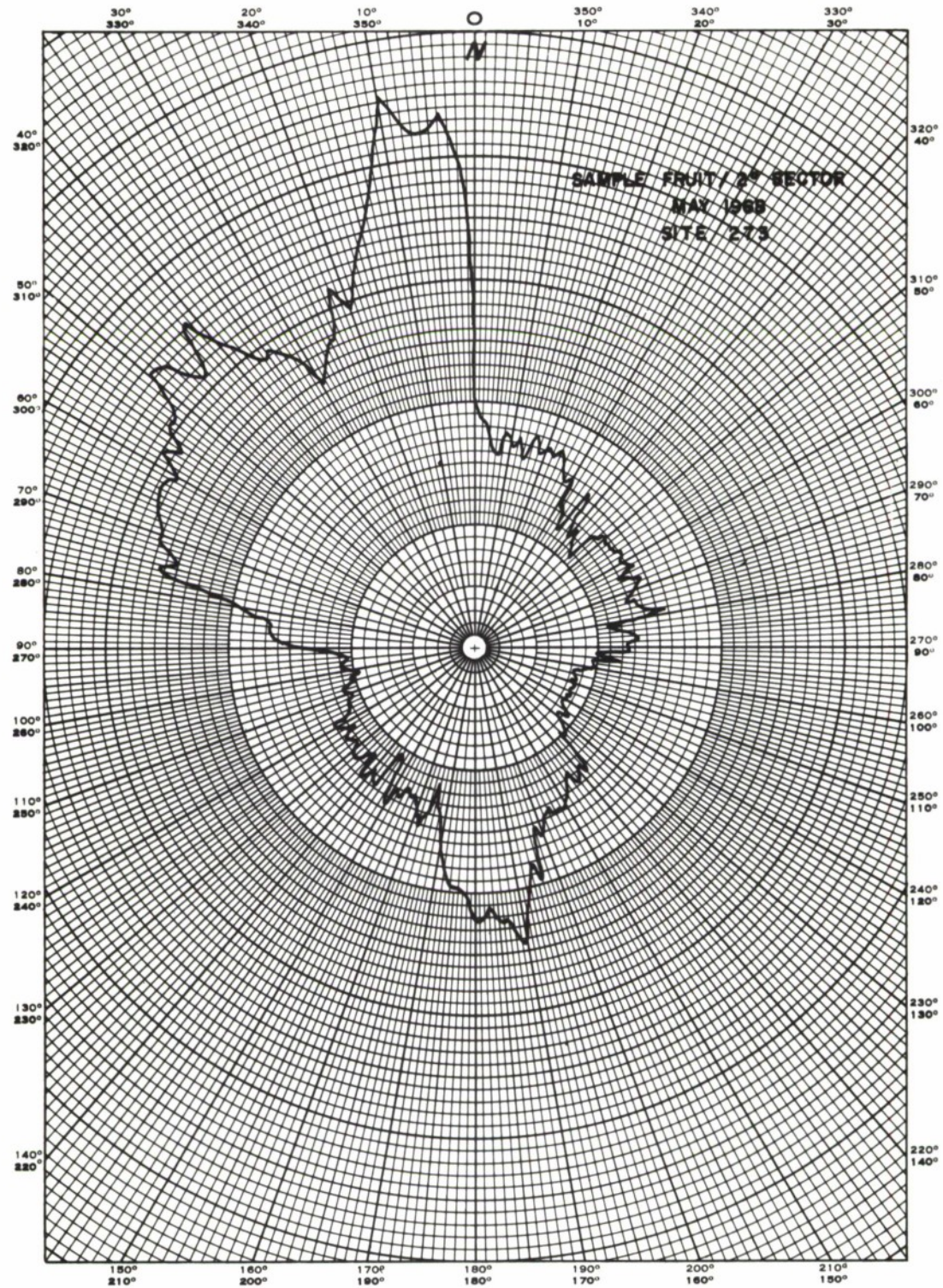


Figure 7-6. Distribution of Fruit

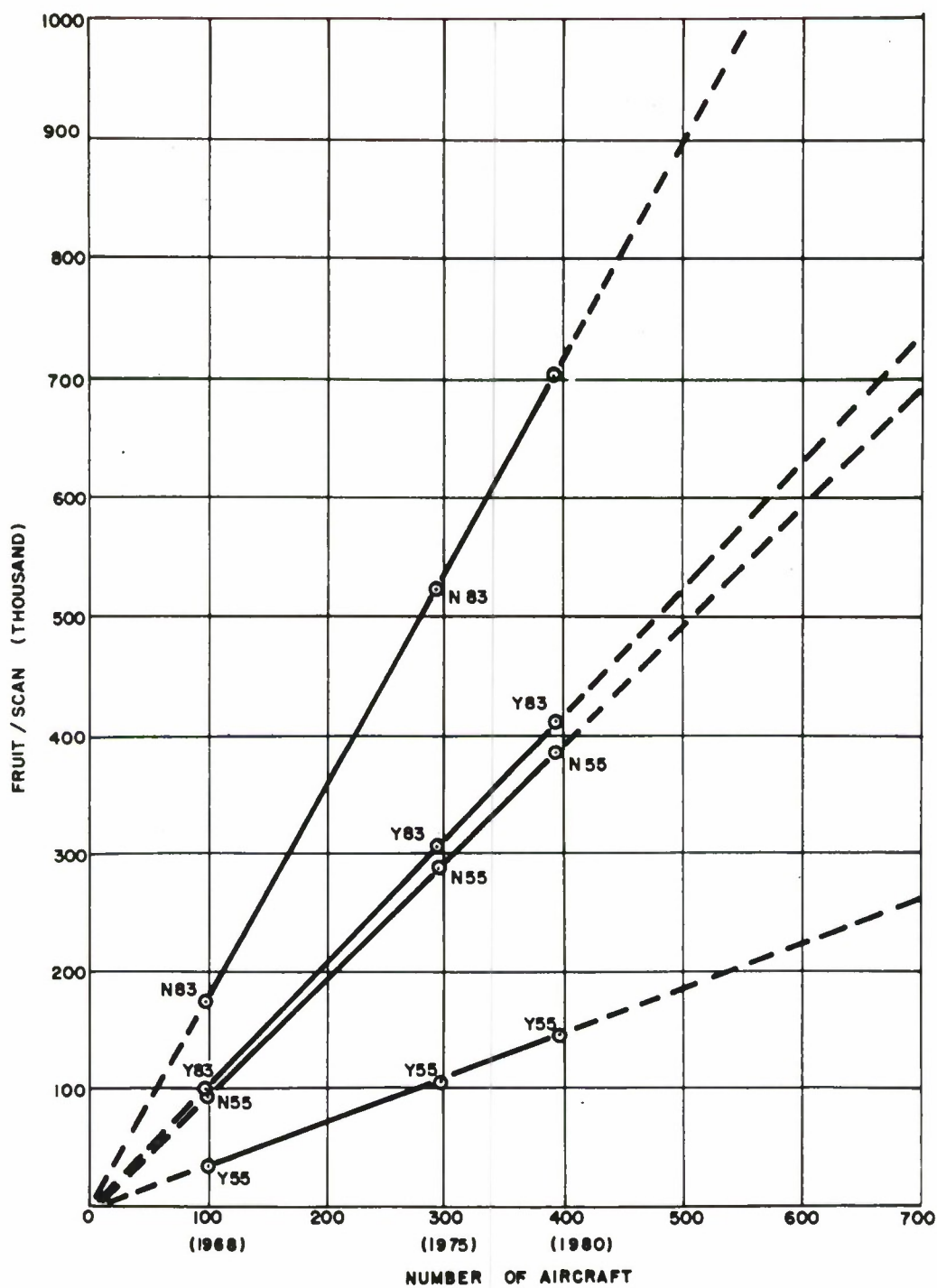


Figure 7-7. Tyndall AFB ATCRBS Performance Prediction Receiver
Sensitivity -90 dBm, October 1968

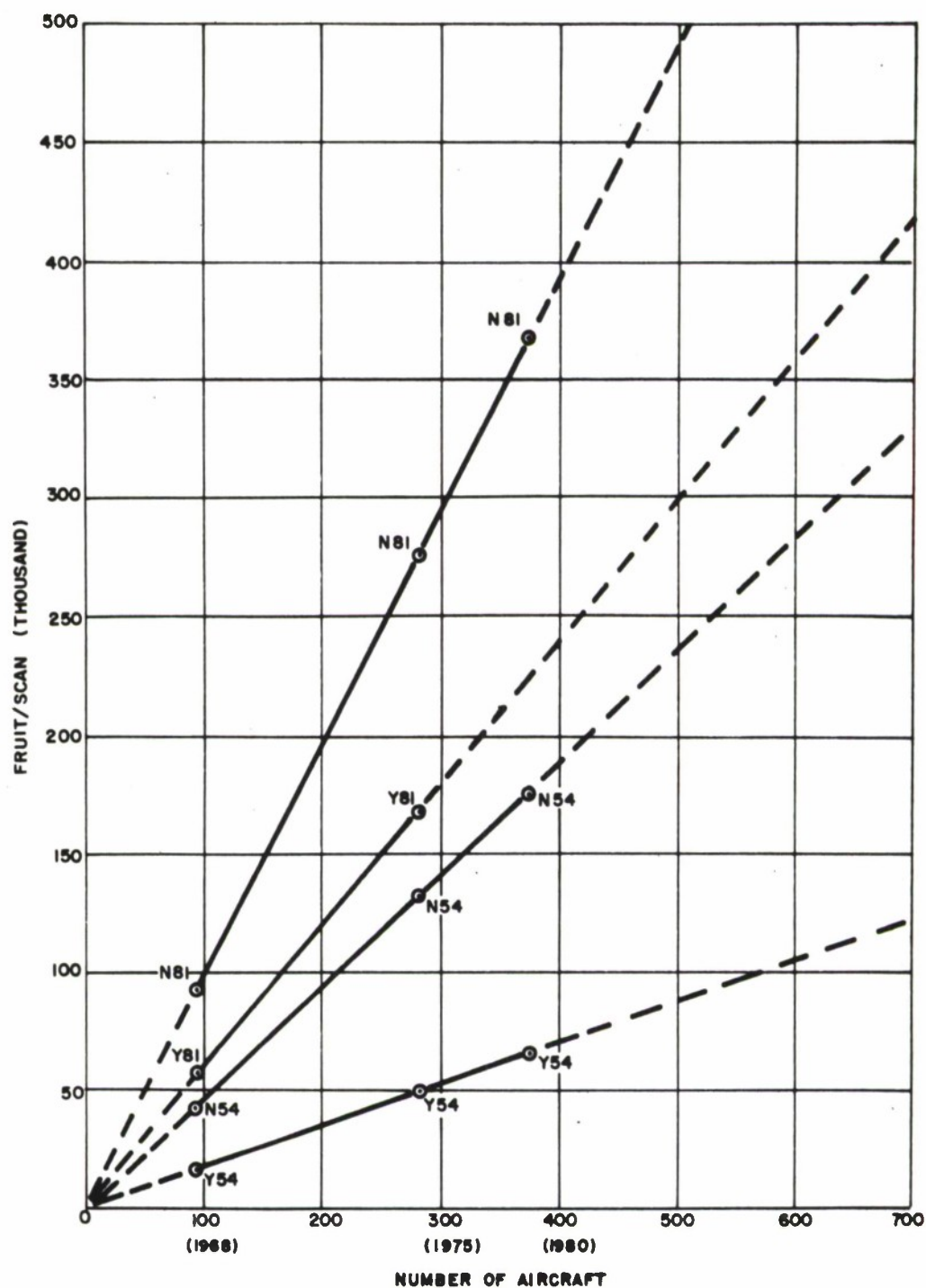


Figure 7-8. Tyndall AFB ATCRBS Performance Prediction Receiver Sensitivity -84 dBm, October 1968

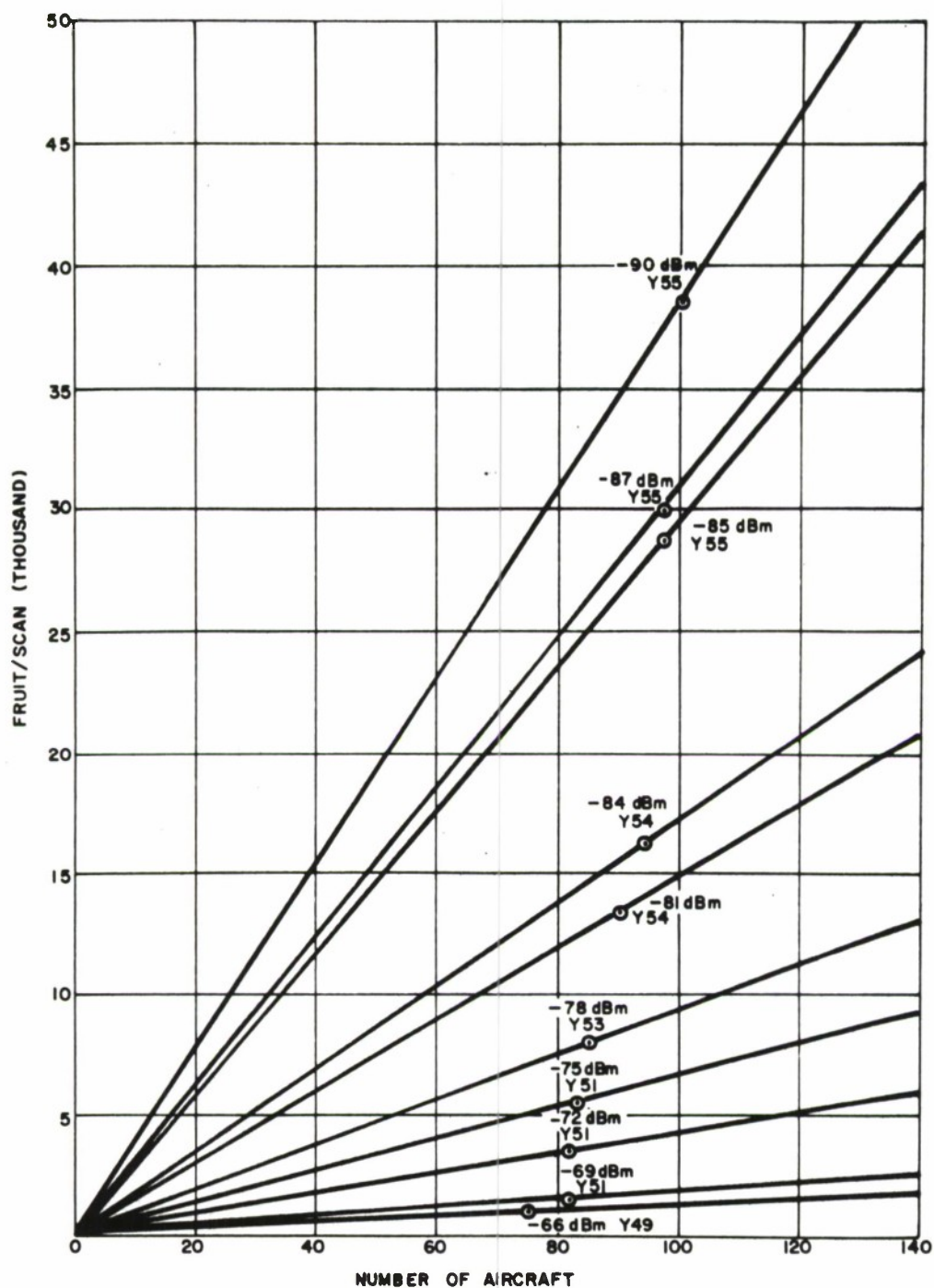


Figure 7-9. Tyndall AFB ATCRBS Performance Prediction - October 1968

For Figures 7-7 through 7-9, military aircraft transponders operated in the model with a sensitivity of -75 dBm, air carriers with -74 dBm, and general aviation with -70 dBm. All aircraft antenna gains were set at 0 dB.

Figure 7-10 is a combined display of the ATCRBS average fruit per scan predictions versus the number of aircraft deployed within range of the Tyndall AFB ATCRBS. The minimum IFR and maximum interrogator environment are represented. The number of false targets versus fruit per scan and the probability of code validation versus fruit per scan is also presented (see Reference 9). For 200 aircraft, 200,000 fruit per scan are predicted if the maximum number of interrogators are operating; 200,000 fruit per scan would produce 20 false aircraft per scan and the probability of code validation would be 0.73 per scan.

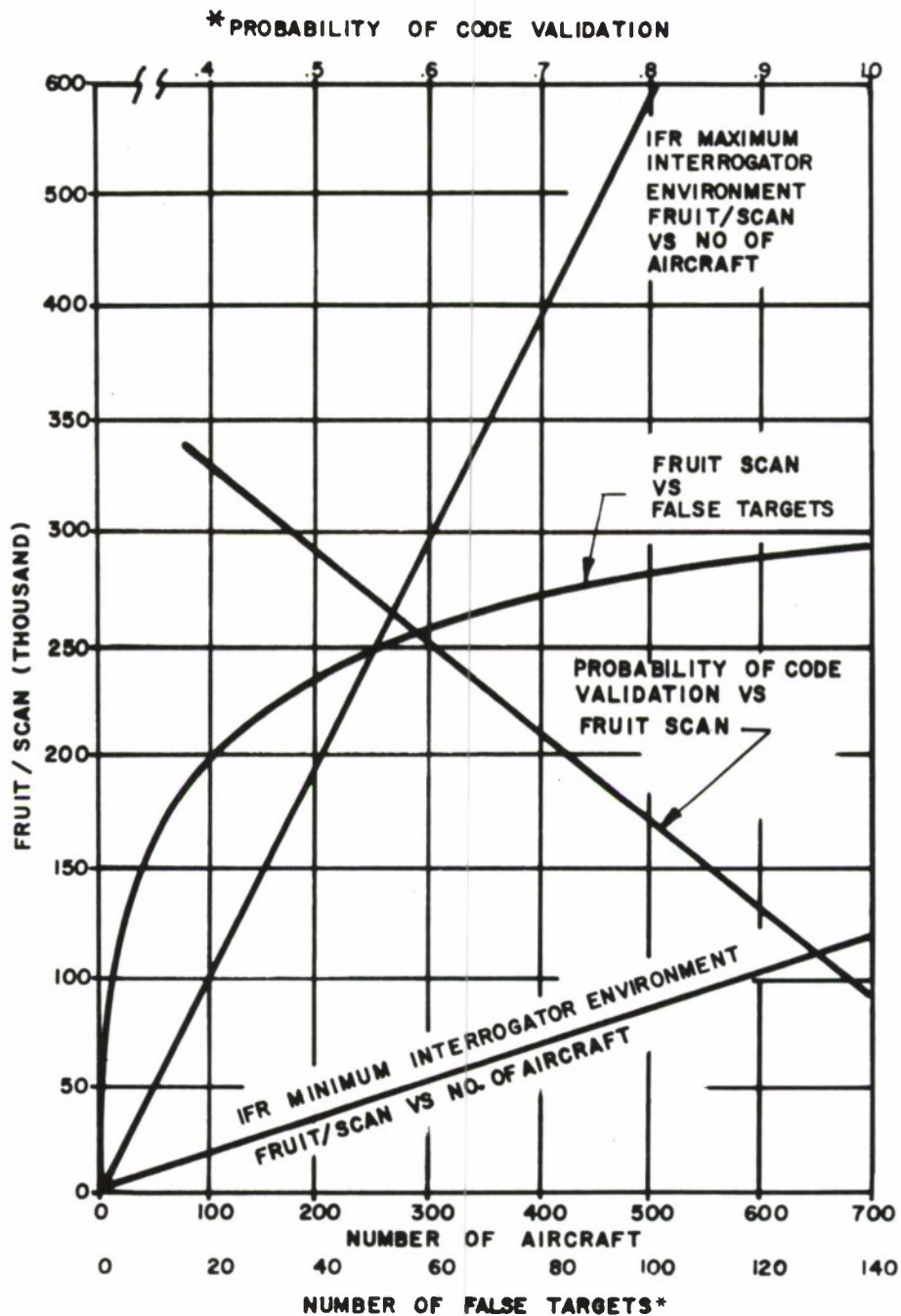
TYNDALL AFB FIELD TESTS

Field tests, conducted at Tyndall AFB from 28 July to 2 August 1968, obtained measured performances of ATCRBS. In one test the test aircraft, FAA Gulfstream N477, was flown at 5000 feet northeast from Tyndall AFB. Two transponders were installed in the aircraft. Top antennas were used. The transponder reply rate per second was recorded continuously. The measured data of Figure 7-11 were compiled from this test. At the distances from Tyndall displayed in the figure, the mean and standard deviations of the transponder measured replies per second were determined from samples of measured data. The sensitivity of the RCA was less than the TRU-1; this was confirmed by the results.

Predicted and measured reply rates per second are shown in Figure 7-12. The measured mean and standard deviation reply rate per second is in close agreement with the predicted transponder performance. Two transponder receiver sensitivities, -74 and -70 dBm, were used in the model, and the aircraft antenna gain was set at 0 dB.

Continuous recordings of fruit and valid replies per scan were obtained at the Tyndall AFB ATCRBS as part of the field tests. Fruit and valid replies of approximately 1000 scans per test period were available. Fruit histograms of measured data were obtained and mean and standard deviations determined. The fruit histograms are shown in Figures 7-13, 7-14, and 7-15 for 28 July, 30 July, and 1 August 1968, respectively. The mean and standard deviations of fruit per scan for each test period is contained in TABLE 7-2. Records of beacon-equipped aircraft within range of the Tyndall AFB ATCRBS per scan were also obtained, and their mean and standard deviations are also shown in TABLE 7-2. The relatively large variations in measured data show graphically the dynamics of system performance.

A comparison of measured and predicted performance is shown in Figure 7-16. The measured mean and standard deviations of fruit per scan and aircraft per scan were obtained from TABLE 7-2.



*Data supplied by FAA (Reference 8 and 9)

Figure 7-10. Tyndall AFB ATCRBS Performance Predictions
at the Output of the Radar Video Data Processor

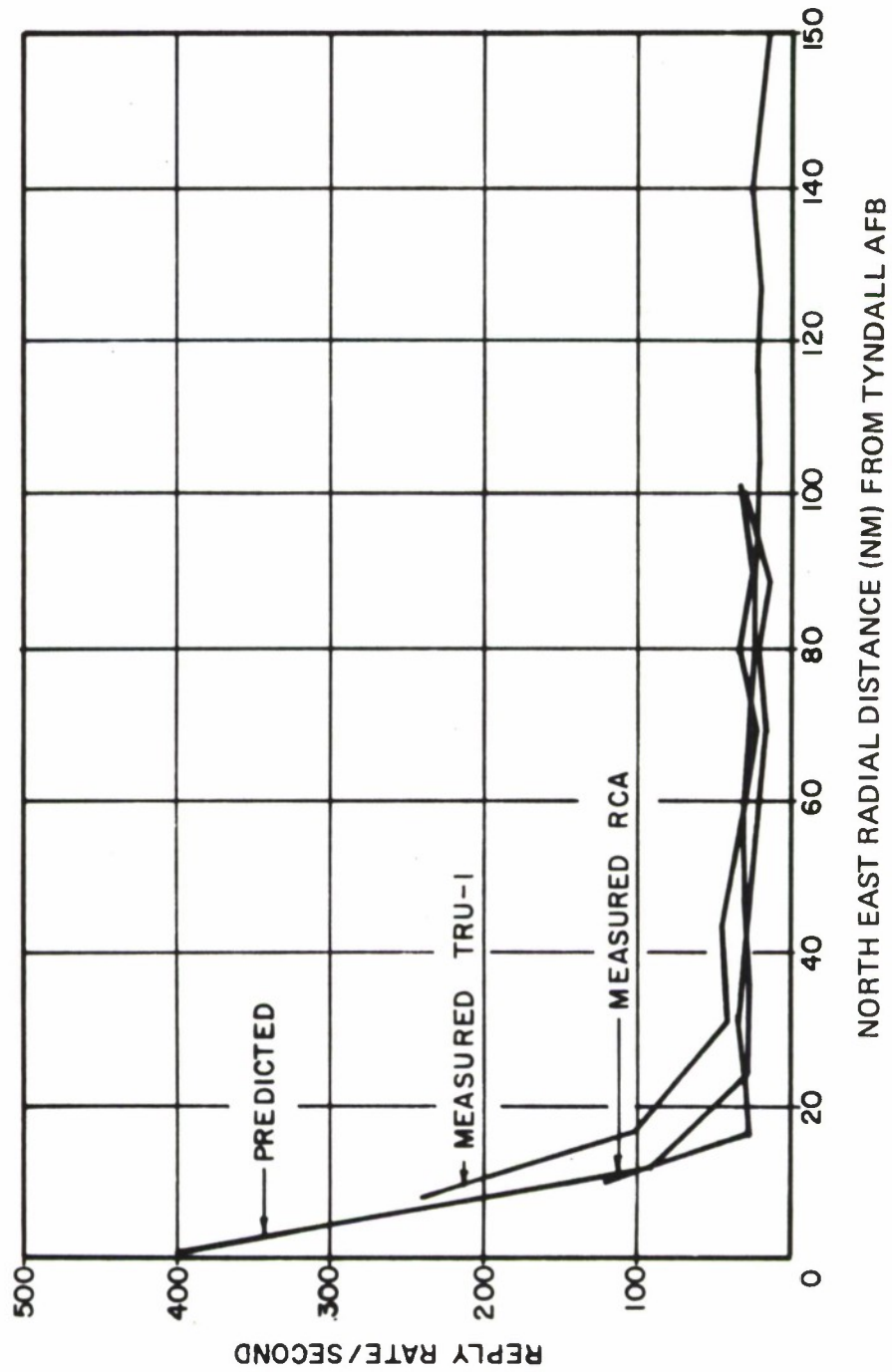


Figure 7-11. Predicted and Measured Transponder Performance

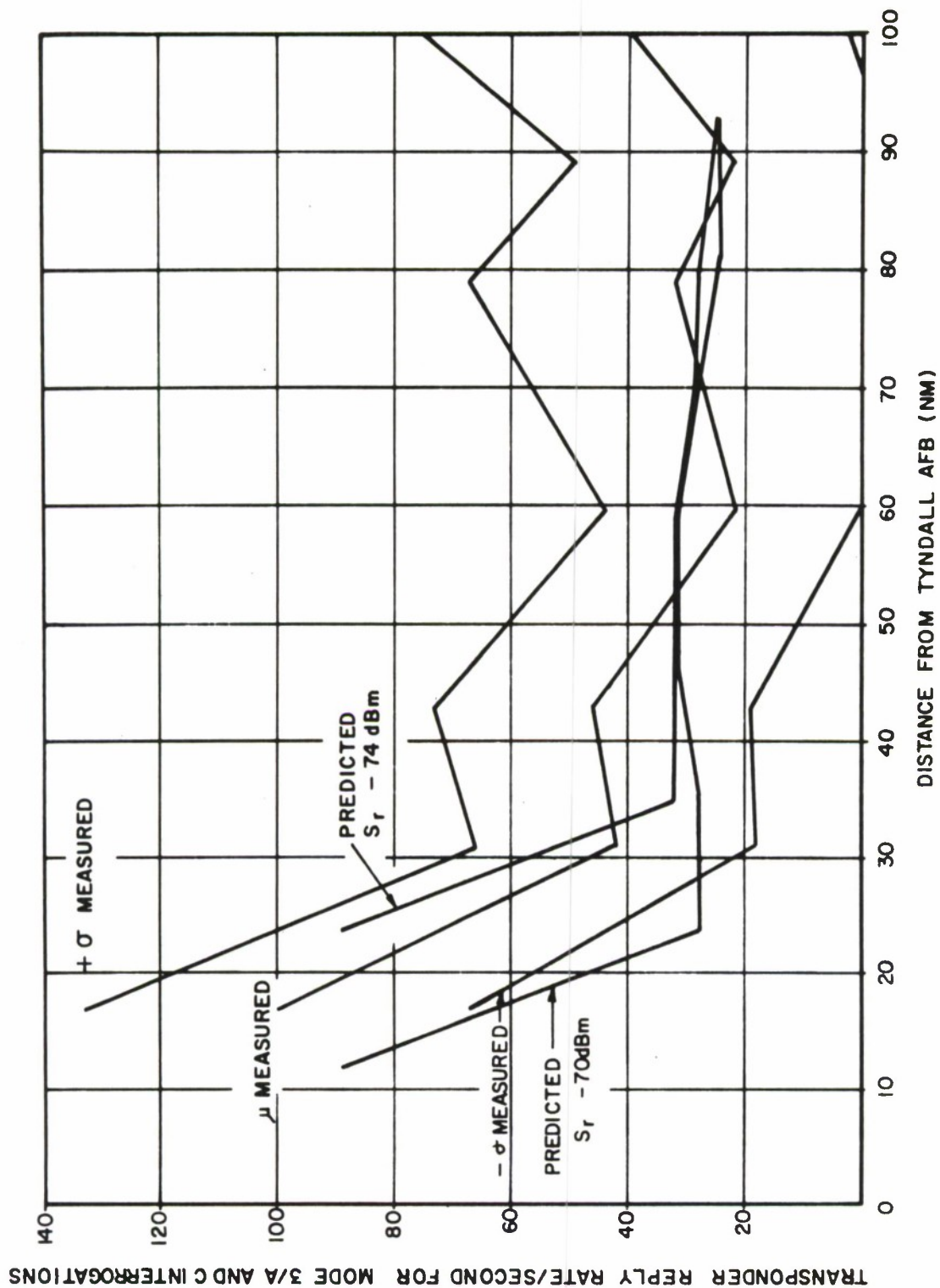


Figure 7-12. Predicted and Measured TRU-1 Transponder Reply Rate/Sec Test Aircraft at 5000 Feet Heading NE Actual Ground Environment, August 1968, Tyndall AFB

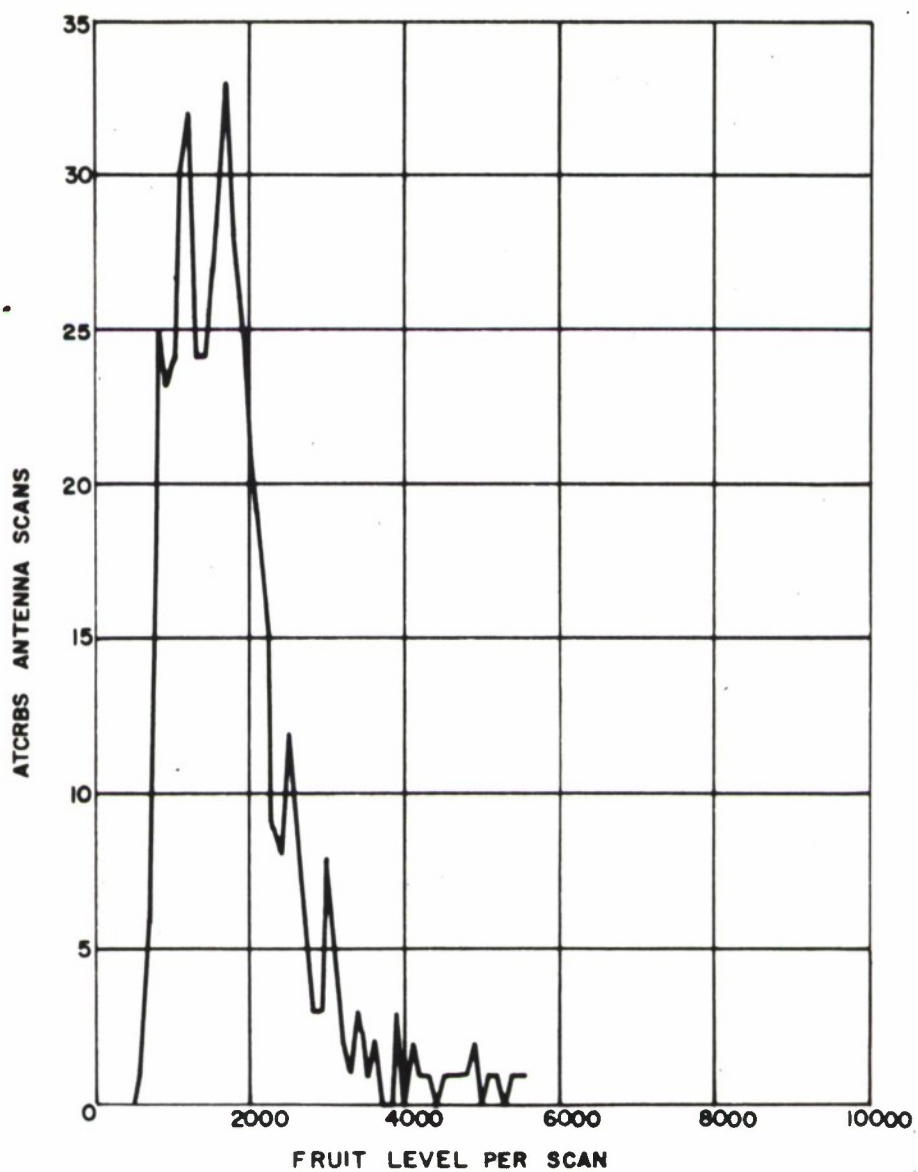


Figure 7-13. Fruit Histogram, Tyndall AFB, 28 July 1968

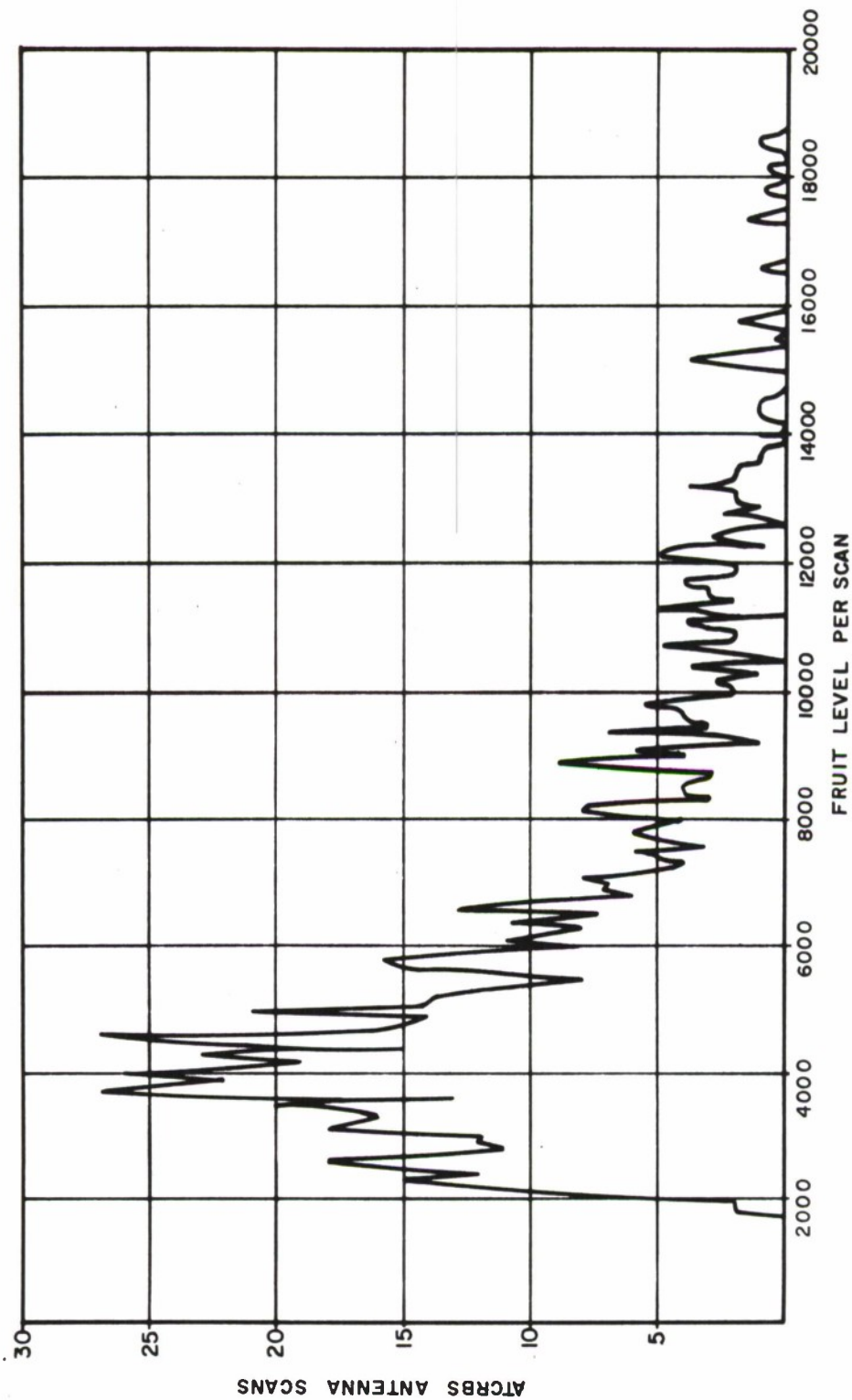


Figure 7-14. Fruit Histograms Tyndall AFB, Measured 30 July 1968

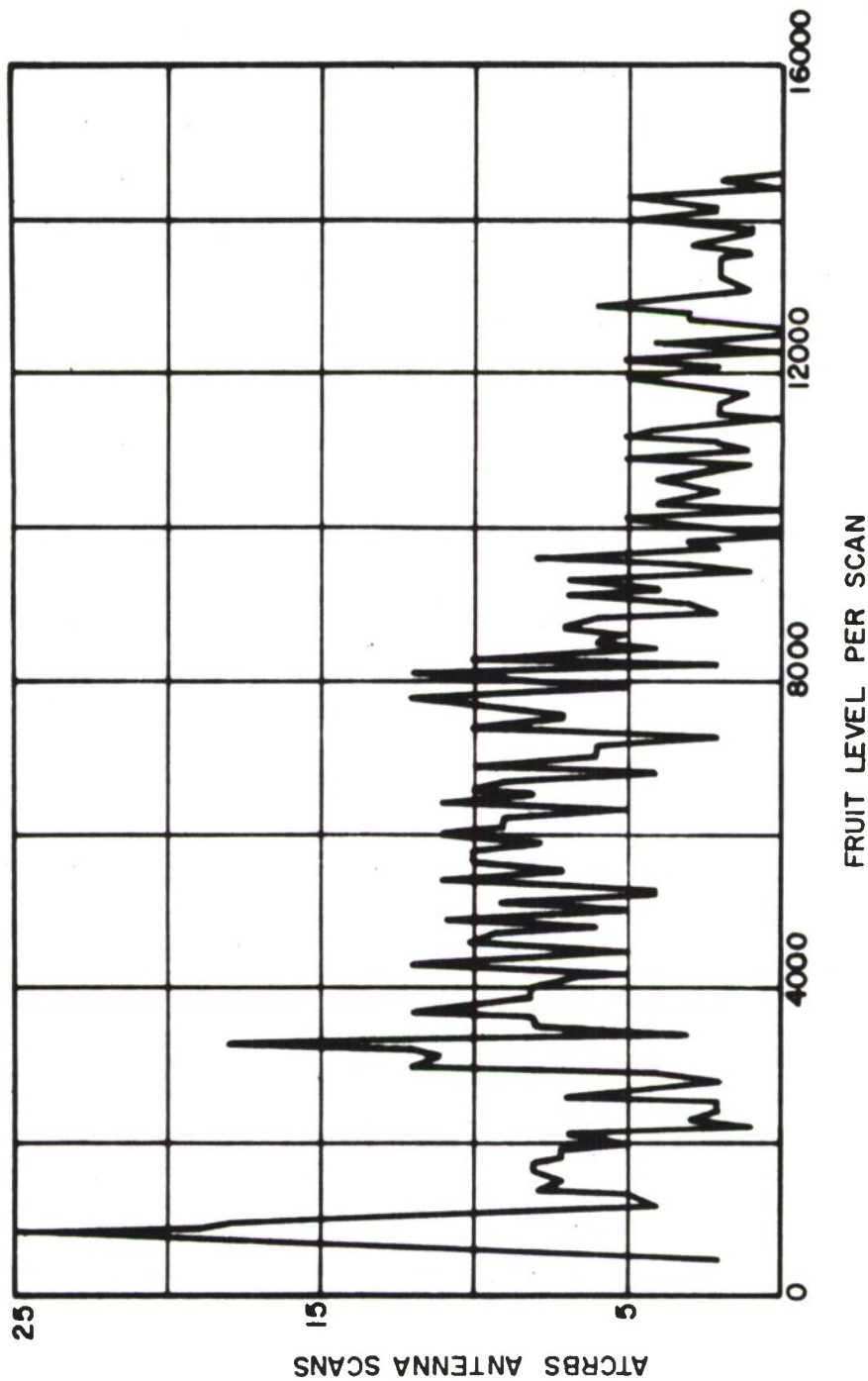


Figure 7-15. Fruit Histogram, Tyndall AFB, 1 August 1968

TABLE 7-2
MEAN AND STANDARD DEVIATIONS, TYNDALL AFB

Date	Fruit/scan		Aircraft/scan	
	μ	σ	μ	σ
28 July 68	1719	± 836	26.6	± 6.3
30 July 68	5800	± 3129	69.7	± 10.5
31 July 68	4381	± 1738		
1 Aug 68	6115	± 4070	56.6	± 12.4
2 Aug 68	5820	± 1874		

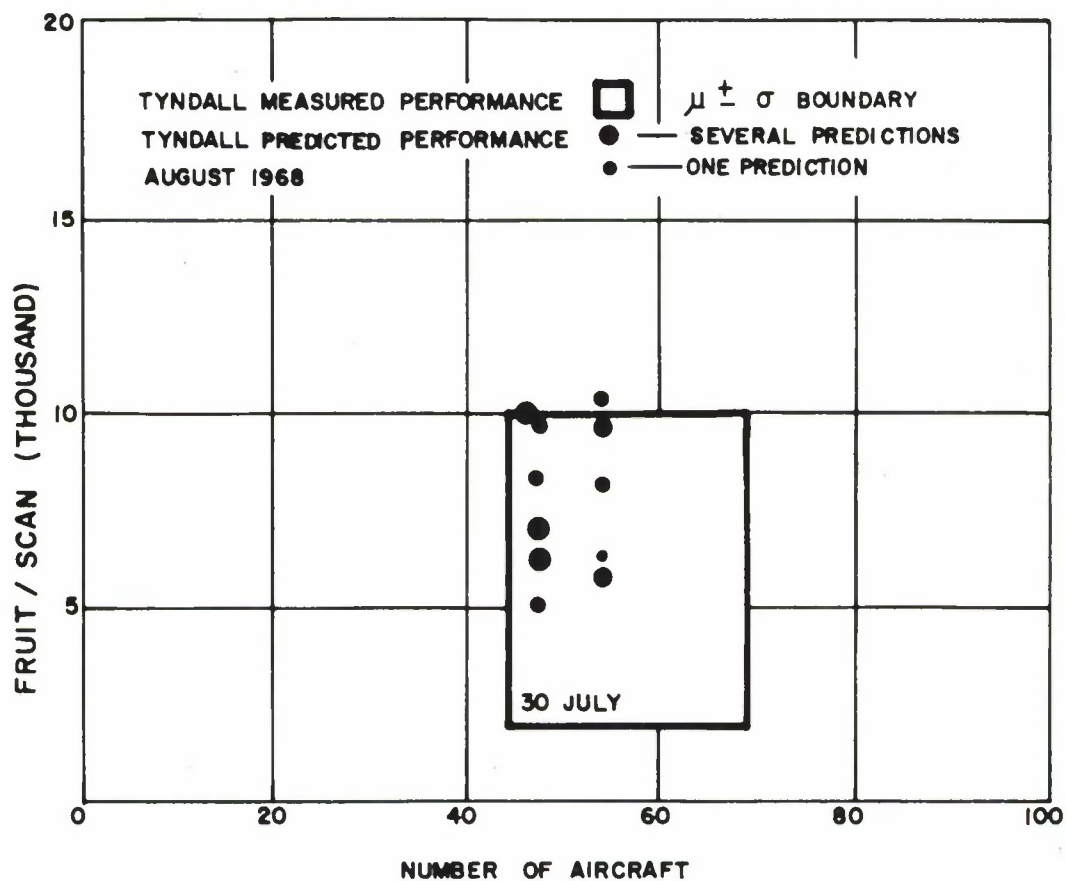


Figure 7-16. Measured Versus Predicted Performance

Predicted performances listed in TABLE 7-3 are for two selected aircraft deployments on 30 July 1968 (see Figures 7-17 and 7-18) and the actual interrogator environment as of 30 July 1968. To obtain a wide range of performance predictions, several values of interrogator receiver sensitivity and aircraft transponder receiver sensitivities were considered. Using these values in the model, the predicted performance was compared with measured performance. Receiver sensitivities greater than -90 dBm for the Tyndall interrogator and transponder sensitivities greater than -74 dBm were considered excessive. Very few aircraft were equipped with Mode C capability during the test period. Performance predictions excluding Mode C and excessive sensitivities are plotted on Figure 7-16. The predictions fall within the $(\mu \pm \sigma)$ measured area of performance.

Figure 7-19 shows how the ATCRBS PPM might be applied to a specific geographical location (Tyndall AFB) to establish the expected system performance after reducing the power output of all ground interrogators. The aircraft deployments used are shown in Figures 7-17 and 7-18. The ground interrogator environment used was that as of 30 July 1968 (extracted from the ECAC data base). Transponder receiver sensitivity was held constant at -70 dBm. A two step procedure was used:

1. Determine the fruit per scan for each aircraft deployment for I_0 receiver sensitivities of -84 and -90 dBm. For this condition, the fruit per scan at I_0 was referenced to a 0 dB system amplitude.
2. Demonstrate fruit-per-scan sensitivity to interrogator transmitter power outputs. Fruit per scan predictions were obtained for:
 - a. Aircraft deployments versus the above
 - b. Interrogator deployment versus the above, except that each interrogator transmitter power output was reduced in 3 dB steps and then increased in 3 dB steps above and below initial conditions.

The resulting fruit per scan was plotted in Figure 7-19.

No change in system performance would occur if the 0 dB reference were located at the knee of the performance curve, as shown, for system power output reduction of approximately 6 dB for the 54 aircraft deployment. A 3 dB reduction in system power output for the deployment of 47 aircraft indicates a predicted 35 percent reduction in average fruit per scan. Reductions in system power output of each interrogator did not reduce the number of aircraft detected by the Tyndall AFB ATCRBS (see Figures 7-20 through 7-23).

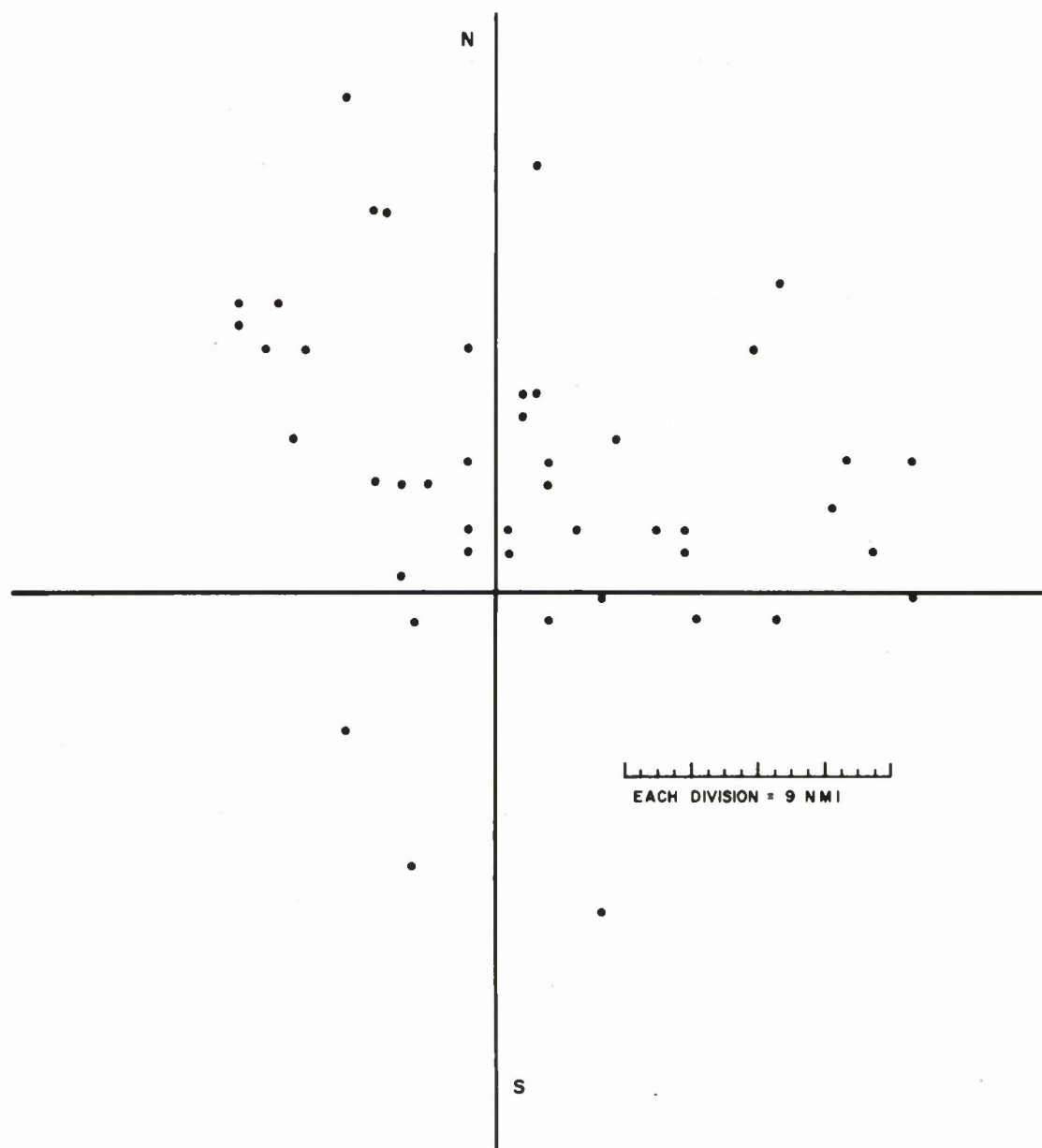


Figure 7-17. Aircraft Deployment Centered at Tyndall AFB, 30 July 1968
(Time - 13:30:31)

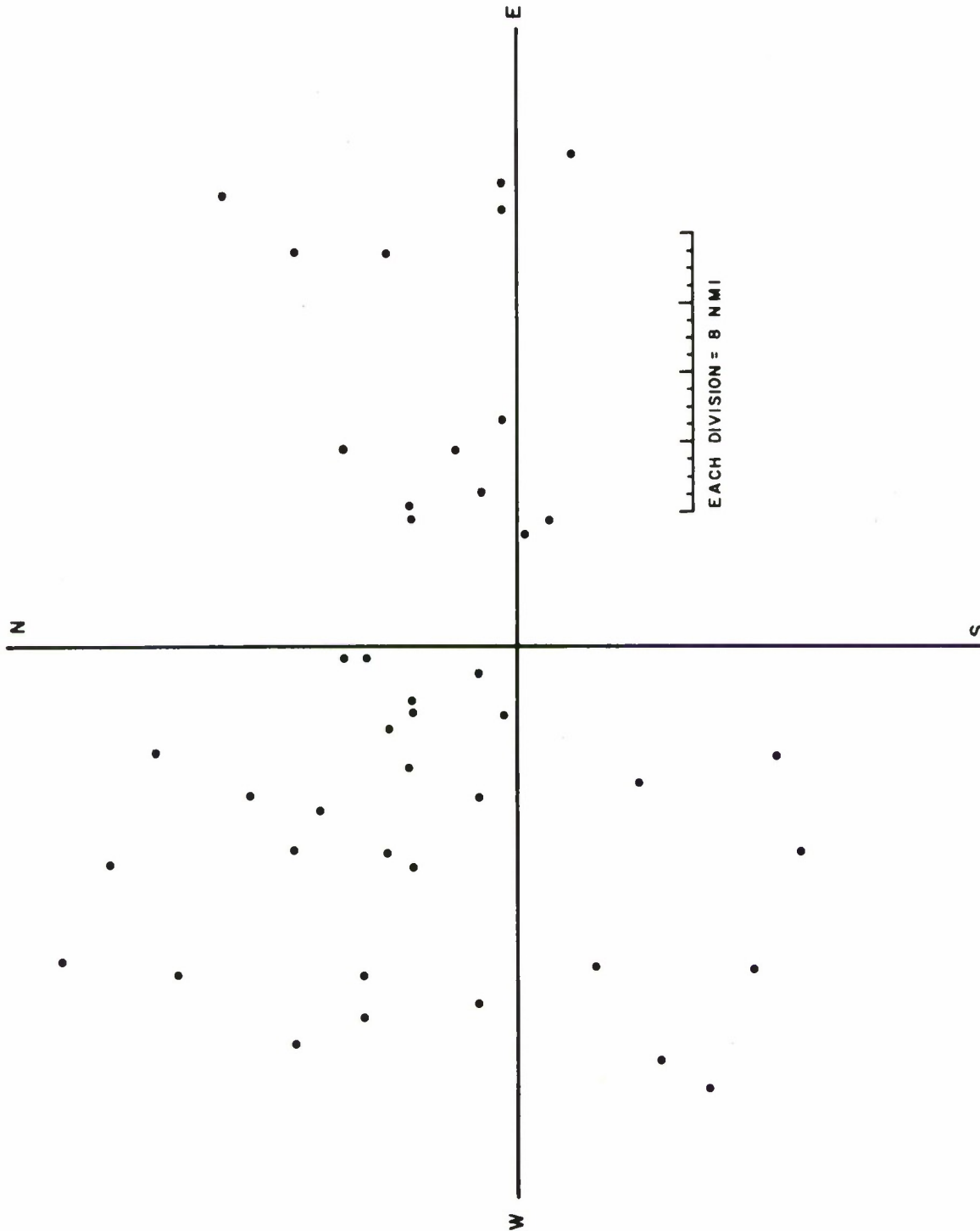


Figure 7-18. Aircraft Deployment Centered at Tyndall AFB, 30 July 1968
(Time - 13:45:00)

TABLE 7-3
PREDICTIONS OF THE TYNDALL AFB
ATCRBS FRUIT PER SCAN, JULY 1968

L_t (in dBm)	I_{o_s} (in dBm)	Number of Aircraft	Number of Interrogators	Average Fruit/Scan	Mode
-70	-90	47	51	7860	3/A
-70	-84	46	51	5183	3/A
-70	-84	54	50	5981	3/A
-70	-90	54	50	9962	3/A
-74	-84	54	50	11355	3/A
-74	-84	54	50	13929	3/A C
-74	-90	54	50	20576	3/A
-74	-84	47	48	17336	2/A C
-74	-90	54	50	20290	3/A C
-74	-90	47	48	22354	3/A C
-77	-90	47	48	24993	3/A
-73	-90	47	48	17454	3/A
-67	-90	47	48	9703	3/A
-64	-90	47	48	9704	3/A
-61	-90	47	48	8369	3/A
-77	-84	54	50	15563	3/A
-73	-84	54	50	9980	3/A
-67	-84	54	50	5983	3/A
-64	-84	54	54	5985	3/A
-61	-84	54	50	5897	3/A
-61	-84	47	48	5038	3/A
-64	-84	47	48	6333	3/A
-67	-84	47	48	6332	3/A
-73	-84	47	48	13939	3/A
-77	-84	47	48	19352	3/A
-77	-90	54	50	20386	3/A
-73	-90	54	50	14633	3/A
-67	-90	54	50	9963	3/A
-64	-90	54	50	9966	3/A
-61	-90	54	50	9860	3/A
-74	-87	53	54	17648	3/A C
-70	-87	53	50	11655	3/A C
-67	-87	53	50	11658	3/A C
-64	-87	53	50	11661	3/A C
-74	-87	54	50	14229	3/A C
-70	-87	54	50	8216	3/A C
-67	-87	54	50	8217	3/A C
-64	-87	54	50	8220	3/A
-74	-87	46	48	19155	3/A C
-70	-87	46	48	10260	3/A C
-67	-87	46	48	10264	3/A C
-64	-87	46	48	10265	3/A C
-74	-87	47	48	16802	3/A
-70	-87	47	48	7884	3/A
-67	-87	47	48	7886	3/A
-64	-87	47	48	7887	3/A

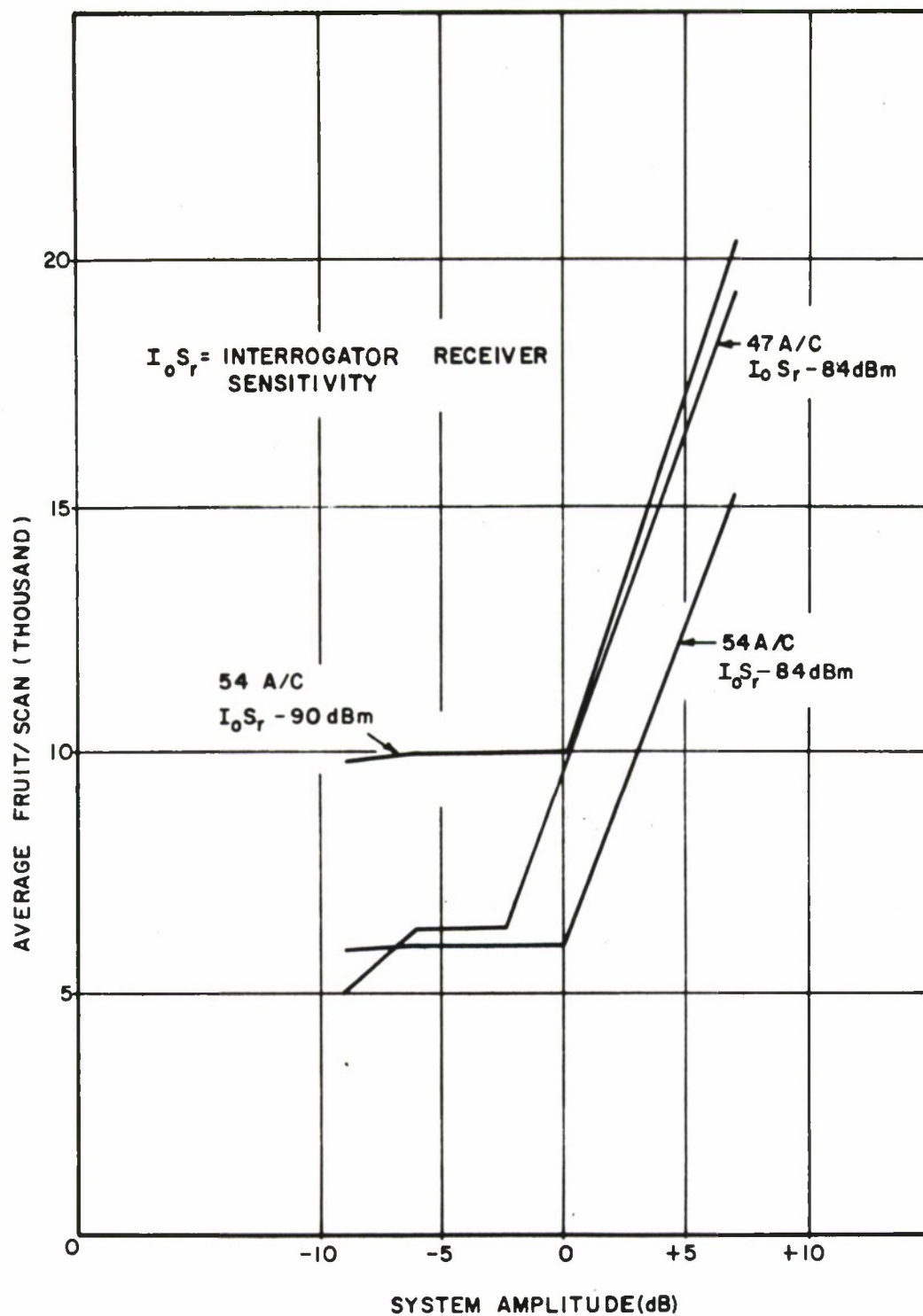


Figure 7-19. Tyndall AFB ATCRBS Predicted Performance Versus Power Reduction for Two Aircraft Deployment, October 1968

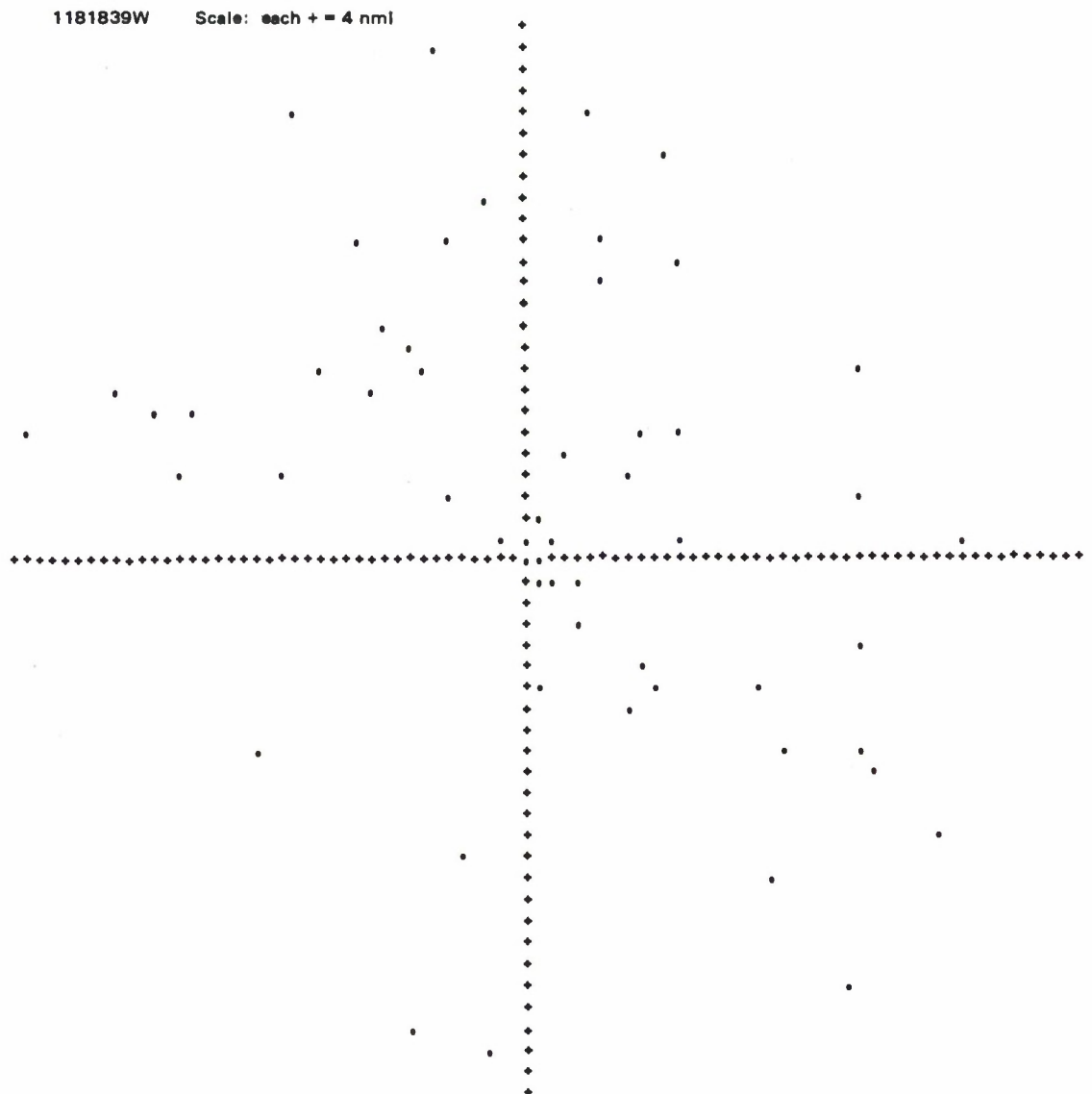


Figure 7-20. Actual Aircraft Deployment for Scan One of the Tyndall Air Route Surveillance Radar

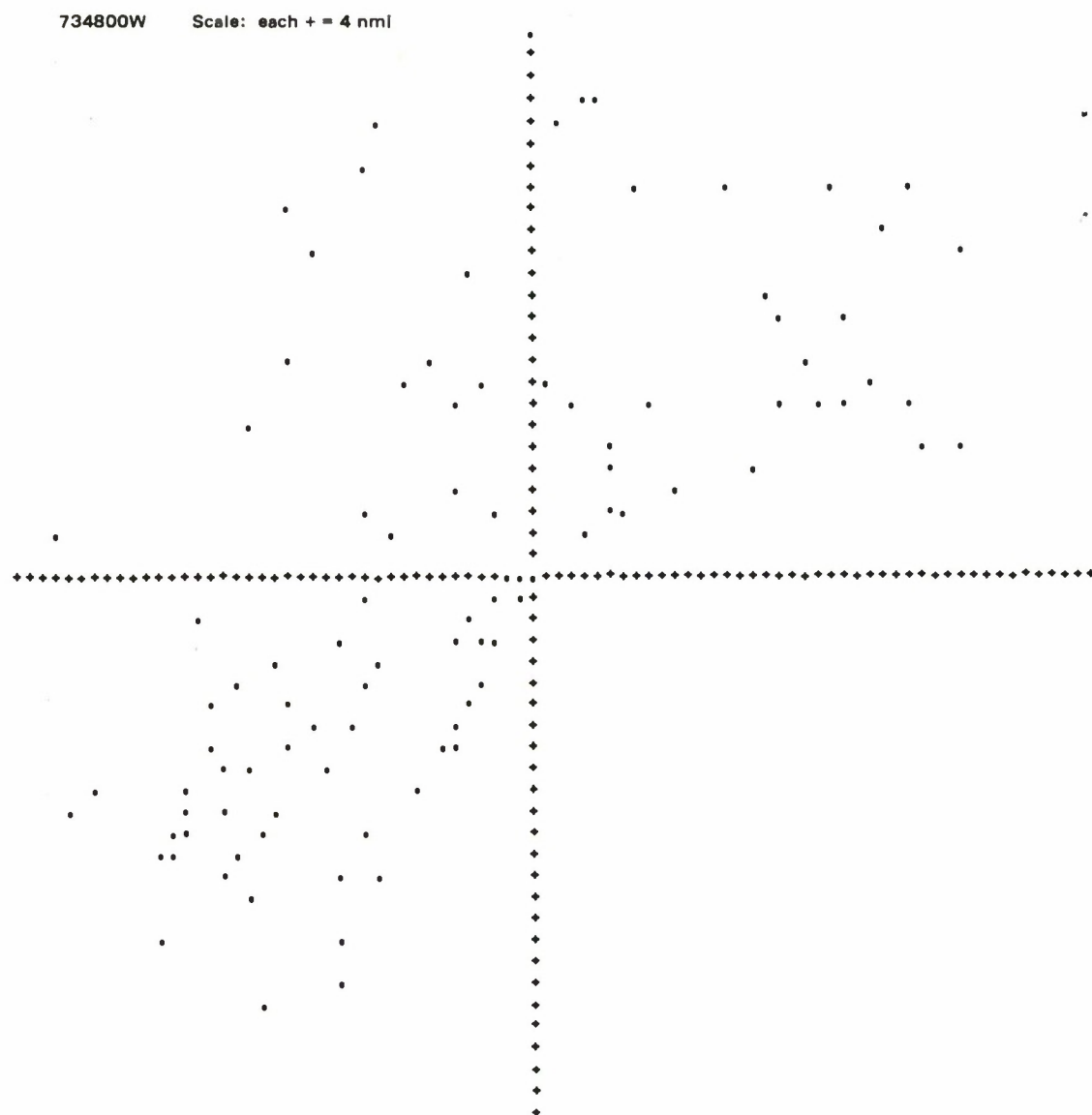


Figure 7-21. Actual Aircraft Deployment for Scan Two of the Tyndall Air Route Surveillance Radar

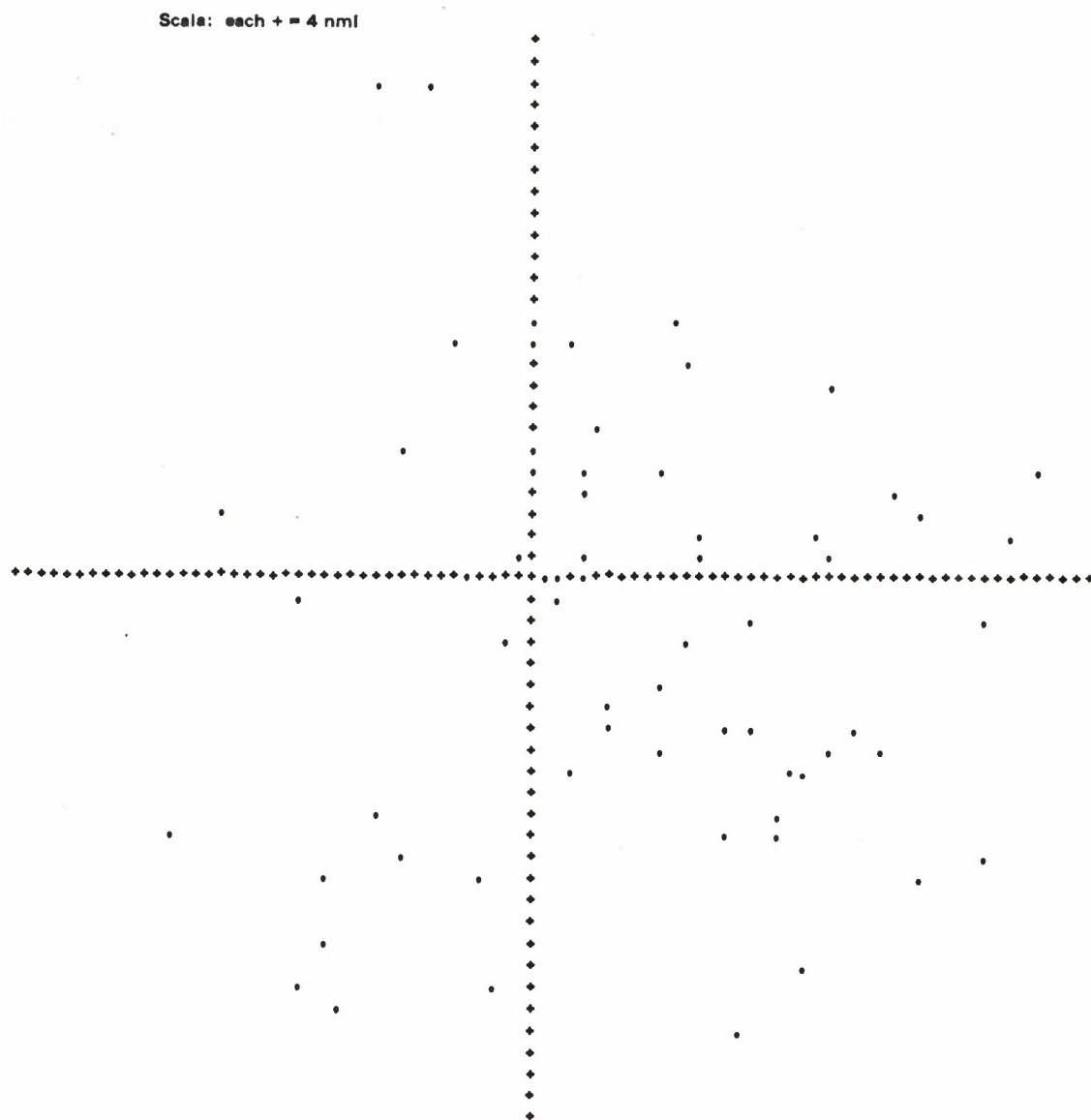


Figure 7-22. Actual Aircraft Deployment for Scan Three of the Tyndall Air Route Surveillance Radar

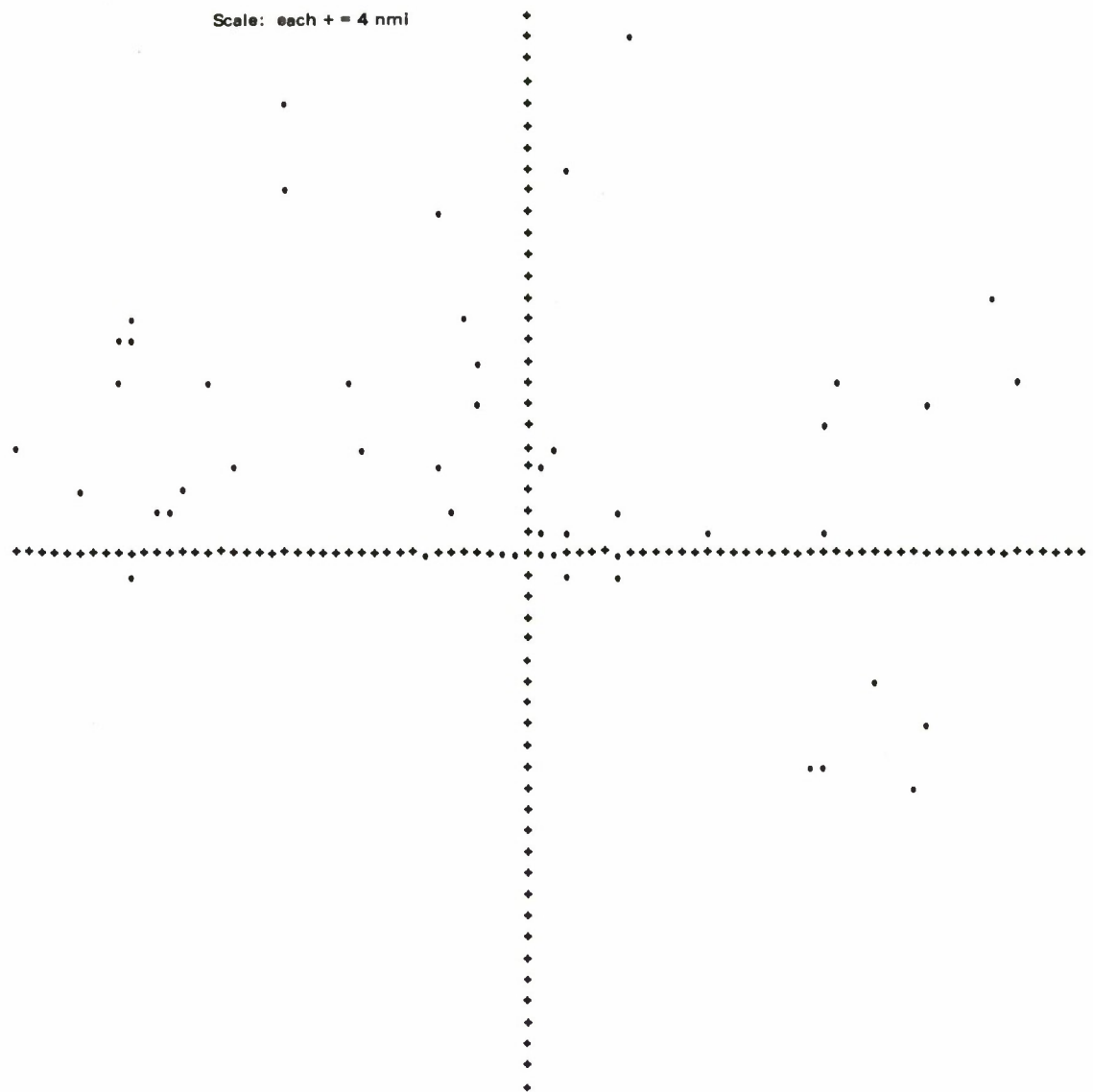


Figure 7-23. Actual Aircraft Deployment for Scan Four of the Tyndall Air Route Surveillance Radar

The IFF MARK X (SIF)/ATCRBS PPM was exercised using a statistically derived deployment of aircraft (Peak Minute 1968) by the FAA (Reference 8). Included in the deployment were 429 transponder-equipped aircraft located within 360 nautical miles of the Tyndall AFB, Florida, long-range radar. There were 162 air-carrier, 144 military, and 123 general aviation types of aircraft.

All ground interrogators within a 720 nautical mile radius of Tyndall AFB that are listed in the ECAC E File were considered. The I/R at Tyndall AFB was considered the victim interrogator (I_0) for this exercise. A total of 127 interrogators were included in the calculations.

The transponder characteristics used for this exercise are listed in TABLE 7-4.

All transponders were assumed to have discriminatory RRL action.

Interrogator characteristics were as listed in the E File, but were updated to reflect the latest information. Each interrogator responder station was contacted and its normal operational mode was determined. These mode were used in the exercise. Antenna characteristics of each station were assumed to be:

<u>Bandwidth</u>		<u>Gain</u>
Mainbeam	4°	as reported
Sidelobe	56°	9 dB below mainbeam
Backlobe	300°	17 dB below mainbeam

Two complete exercises were performed using the above data. The first exercise assumed a normal RRL of 1200 replies per second for all transponders. The second exercise used an RRL of 500 replies per second. The effects of this parameter change on fruit and round reliability are shown below:

	<u>RRL = 1200</u>	<u>RRL = 500</u>
Total Fruit/scan	109,730	93,228
Round Reliability (mean value)	.853	.855

A significant reduction (15 percent) in fruit was experienced by I_0 with an insignificant change in round reliability.

The total predicted Tyndall AFB fruit per scan of 109,730 would result in four false targets per scan and a probability of code validation of 0.98 at the output of the common digitizer (Reference 9). This performance is predicted for the 1968 peak minute traffic period.

TABLE 7-4
TRANSPONDER CHARACTERISTICS

Type of Transponder	Sensitivity (in dBm)	Mode	Reply Rate Limit (Replies/second)	Sidelobe Suppression
Military	-75	23C	1200 & 500	Yes
Civil aircarrier	-74	3C	1200 & 500	Yes
General aviation	-70	3C	1200 & 500	Yes

APPLICATION OF THE ATCRBS MODEL TO THE JFK TERMINAL

The DOT/FAA Air Traffic Control Advisory Committee requested estimates of performance of the John F. Kennedy (JFK) New York Terminal interrogator-responder in the 1968 and 1980 air traffic environments (see Reference 11).

The following is the explanation of how the ATCRBS model was used at JFK terminal.

Assumptions

The following assumptions were made about the model application:

1. The ATCRBS interrogators' antenna patterns are represented in the ATCRBS model by three-level, one-dimensional, synthesized patterns. It is assumed that this is an adequate representation of the actual pattern.
2. Interrogator deployments and characteristics are as listed in the ECAC fixed environmental E-file with FAA proposed additions for 1980.
3. Air traffic deployments were furnished by FAA and represent peak-minute traffic samples, statistically derived, in the areas of interest.
4. Median or mean values of certain equipment parameters were assumed. These values include, for both transponder and interrogators, sensitivity, output power and antenna characteristics.

5. The equipment characteristics and deployments used in this analysis are given under the headings Major Interrogator Characteristics and Air Traffic Environment.

Limitations

The following are the limitations imposed on the model's application at JFK:

1. Interrogation garbling and transponder-code garbling are not included in the existing model.
2. Airborne and shipboard interrogators, and industrial test facilities are not considered in this analysis.
3. Time-on factors for maximum and minimum interrogator environments are not considered in this report, however, maximum and minimum fruit predictions provide a range of expected limits for consideration in future system design parameters.

Interrogator Environment

The ground-interrogator environment was established by selecting from the ECAC environment file all equipments operating on 1030 MHz within a 720 nautical-mile radius of John F. Kennedy Airport. Within this area, maximum and minimum environments were established. The maximum environment uses all interrogators in the area except test equipments, radar bomb scoring sites and ship and airborne interrogators. The minimum environment includes only FAA air route surveillance radars (ARSRSs) Air Force radar approach control and Navy radar air traffic control centers (RAPCONs and RATCCs), FAA Terminals (ASRSs) and Air Defense Command facilities.

For the 1980 time frame, additions were made to the current minimum and maximum ground environments to include 16 proposed FAA terminal-interrogator sites and 9 existing Canadian sites.

Major Interrogator Characteristics

These characteristics are explained in the list that follows:

1. Antenna characteristics used in the ATCRBS model are synthesized with a three-level pattern. The major characteristics assumed for this exercise are:

<u>Antenna Beamwidth</u>	<u>Antenna Gain</u>
Mainbeam 4°	As in the "E" File
Sidelobe 60°	28 dB below mainbeam
Backlobe 296°	40 dB below mainbeam

NOTE

Certain military interrogators which use integral feed antennas were assumed to have a mainbeam width of 6°. These are primarily associated with those equipments found only in the maximum environment

2. Interrogation Modes in 1968 are:

	<u>Mode Interlace</u>		
Army Air Defense Command (ARADCOM)	1	2	3
USAF Air Defense Command (ADC)	3	3	2
FAA	3	or 33C*	
All others	3	only	

For 1980:

All ADC and Joint Use	3	3	2	C
All FAA	3	3	C	
ARADCOM	1	2	3	
All Other Military	3	3	C	

3. Interrogator-responder receiver sensitivity (JFK) is -90 dBm.

4. FAA and ADC interrogators are sidelobe suppressed, except that JFK, Newark, New Jersey, and Washington National terminal facilities have improved sidelobe suppression. All others are not sidelobe-suppression equipped.

5. The GTC characteristics of an interrogator are synthesized in the transponder model by a linear relationship. The major characteristics used in this analysis are a 35 dB dynamic range and a linear gain variation between $T_0 + 15\mu s$ and $T_0 + 300\mu s$.

6. All other characteristics are as reported in the ECAC environment file.

*Interlace 33C is used at those sites equipped for mode C within 720 nautical miles of JFK.

Air Traffic Environment

The primary air traffic environment for this analysis was provided by FAA. It consists of all aircraft airborne within a 360 nautical mile radius of JFK during a peak minute on a busy day. Traffic counts are:

Air Carrier IFR	242	VFR	96
General Aviation IFR	80	VFR	56
Military IFR	<u>124</u>	VFR	<u>19</u>
	446		171
Total	617		

All 617 aircraft are considered to be transponder equipped and capable of accepting sidelobe suppressed interrogations. The following considerations apply to aircraft of each fleet.

1. For transponder operating modes, air carrier aircraft use 3C; military aircraft use 1, 2, and 3; general aviation uses 3C.
2. The transponder characteristics are given as:

Power output, 500W
 Sensitivity, -74 dBm
 Antenna Gain, 0 dB
 Reply Rate Limit Threshold, 1200/sec
 Discriminatory Reply Rate Limit Action —
 when transponder is overinterrogated it
 adjusts its sensitivity to eliminate the
 weaker interrogations.

Other characteristics are essentially as given in the FAA and ICAO specifications.

For the 1980 aircraft environment a growth factor of ten times the present (1968) number of aircraft was used. The total aircraft deployment within 360 nautical miles of JFK is then 6170 aircraft.

A second aircraft deployment developed by ECAC was also applied to the ATCRBS model. The total number of aircraft in this deployment was 637, for 1968, and was scaled by a factor of ten for the 1980 environment. Equipment characteristics were essentially the same as for the FAA deployment. The deployment was derived using FAA statistics; and deploying aircraft along airways, in holding patterns, and on departure and approach paths.

RESULTS OF ANALYSIS

The results of the application of the model to JFK terminal facilities are reported in this subsection.

ATCRBS Model Outputs

A summary of the transponder-model results for the 1968 environment is presented in TABLE 7-5. This table compares average fruit replies per scan for the JFK terminal facility; the ASR, as a function of ground environment, interrogator antenna sidelobe and backlobe levels, and the transponder reply-rate limit. The table is divided into eight parts. In each part only one parameter change is analyzed for both maximum and minimum environments. The data for each part was obtained by using the following basic parameter inputs to the ATCRBS transponder model.

1. For part 1 of the table, the inputs are: The 1968 environment, the transponder RRL threshold at 1200 replies per second, and the sidelobe and backlobe levels at -28 and -40 dB or -25 and -37 dB relative to mainbeam gain.
2. For part 2, the inputs are: The 1968 environment, and the transponder RRL threshold at 600 replies per second.
3. For part 3, the inputs are: The 1980 environment, interrogator sidelobe suppression operating only on FAA and ADC equipments, and the RRL threshold at 1200 replies per second.
4. For part 4, the inputs are the same as part 3, except that all interrogators are equipped with sidelobe suppression.
5. For part 5, the inputs are: The 1980 environment, the RRL threshold level at 1200 replies per second, and the transponder dead time increased to $300\ \mu\text{s}$.
6. For part 6, the inputs are: The 1980 environment (from an ECAC-derived traffic sample), and the RRL threshold at 1200 replies per second.
7. For part 7, the parameters are the same as part 4, except all interrogators are SLS-equipped.
8. For part 8, the inputs are: The 1980 environment (from an FAA traffic sample); predictions are for the JFK ARSR (long-range radar).

DISCUSSION OF THE RESULTS

A number of significant results may be deduced from TABLE 7-5. The most evident result is the large difference in fruit per scan between the comparable maximum and minimum environment cases. For example, in the 1980 environment the increase in total fruit per scan from minimum to maximum interrogator nonsidelobe-suppressed (SLS) environments varies between 470 and 720 percent. For a totally sidelobe-suppressed environment, the increase is still a significant 80 percent (61,400 to 111,000 fruit replies/scan).

KEY TO TABLE 7-5

ENVIRONMENT

Maximum	-	Maximum ground interrogator environment for 1968 or 1980 as defined under the heading <u>Interrogator Environment</u> .
Minimum	-	Minimum ground interrogator environment for 1968 or 1980 as defined under the heading <u>Interrogator Environment</u> .
Δ SL	-	Difference in dB between interrogator mainbeam and sidelobe gain used in the prediction.
Δ BL	-	Difference in dB between interrogator mainbeam gain and backlobe gain used in the prediction.
No. of A/C	-	Number of aircraft contributing to the fruit received at JFK.
No. of I/R	-	Number of interrogators which interrogate the aircraft which contribute fruit to JFK.
T Fruit	-	Total fruit replies received per scan by JFK.
MB Fruit	-	Fruit replies per scan received on JFK mainbeam.
SL Fruit	-	Fruit replies per scan received on JFK sidelobes.
BL Fruit	-	Fruit replies per scan received on JFK backlobes.

TABLE 7-5
JFK TRANSPONDER MODEL OUTPUTS

PART 1								
Summary of 1968 results using RRL threshold = 1200 replies/sec								
Environment	Δ SL	Δ BL	No. of A/S	No. of I/R	T Fruit	M8 Fruit	SL Fruit	8L Fruit
Maximum	-28	-40	217	180	63000	1900	24400	36700
Minimum	-28	-40	217	79	9150	410	4040	4700
Maximum	-25	-37	217	180	78320	2090	30120	46110
Minimum	-25	-37	217	79	17400	566	6684	10150
PART 2								
Summary of 1968 results using RRL threshold = 600 replies/sec.								
Maximum	-28	-40	217	180	32860	810	13290	18760
Minimum	-28	-40	217	79	9120	400	4030	4690
PART 3								
Summary of 1980 results using RRL threshold = 1200 replies/sec and a traffic multiplication factor of ten.*								
Maximum	-28	-40	2170	187	631500	19500	244000	368000
Minimum	-28	-40	2170	86	87800	3900	38300	46600
Maximum	-25	-37	2170	187	782400	20900	301000	461000
Minimum	-25	-37	2170	86	166400	5320	63600	97500
PART 4								
Summary of 1980 results with RRL = 1200 replies/sec and a traffic multiplication factor of ten* and all interrogators equipped with sidelobe suppression.								
Maximum	-28	-40	2170	187	111000	4800	45900	60300
Minimum	-28	-40	2170	86	61400	2500	24600	34300
PART 5								
1980 environment with RRL threshold = 1200 replies/sec and traffic multiplication factor of ten.* Transponder deadtime increased to 300 μ sec from the nominal 100 μ sec								
Minimum	-28	-40	2170	86	84700	3500	36900	44300
PART 6								
1980 environment with ECAC derived traffic sample RRL threshold = 1200 replies/sec								
Maximum	-28	-40	2590	208	821000	20000	287000	514000
Minimum	-28	-40	2430	96	88600	3900	41300	43400
PART 7								
Same as Part 6, but all interrogators SLS equipped								
Maximum	-28	-40	2590	208	100500	4500	42300	53700
PART 8								
1980 environment RRL = 1200 predictions for JFK Long Range Radar								
Maximum	-28	-40	2160	187	2,530,000	78000	975000	1,470,000
Minimum	-28	-40	2160	86	351000	15600	153000	183000

*For an aircraft environment growth factor of 20, multiply the fruit values in PART 3 and 4 by 2.

The effects of interrogator sidelobe suppression are also evident when the total fruit/scan for 100 percent SLS and minimum SLS environments are compared. In the 1980 maximum environment, addition of interrogator sidelobe suppression to all interrogators reduces fruit/scan by 82 percent (631,500 to 111,000). For the minimum environment, the results are not so dramatic because the greater percentage of interrogators are SLS-equipped. The fruit reduction is still approximately 30 percent (87,800 to 61,400).

An additional dramatic reduction in fruit may be demonstrated if it is assumed that a JFK interrogator is equipped with receiver sidelobe suppression (RSLs). A 100-percent-effective RSLs device would remove the entire fruit contribution from sidelobe and backlobes. The remaining fruit would be only that received on mainbeam. For example, in the 1980 maximum environment, the fruit per scan would be reduced from 631,500 to 19,500 (>95 percent) by a 100 percent effective RSLs device. For the 1980 maximum environment with all interrogators sidelobe suppressed, the reduction in fruit by RSLs would also be approximately 95 percent.

Other significant factors investigated in this study of the production of fruit are the interrogator antenna characteristics. A 3 dB increase in sidelobe and backlobe levels for all interrogators in the problem produced a 90 percent increase in fruit per scan received at JFK for a minimum 1980 interrogator environment. This same antenna change for maximum environment produced only a 24 percent increase in fruit. Significantly, for the maximum environment, the number of aircraft which are being overinterrogated places a limit on the fruit increase due to a degraded antenna system.

Other results may be deduced from the data. Although not as dramatic as those previously mentioned, they are significant in that their cumulative benefit may produce a dramatic result. These results are listed below.

1. Reduction of RRL from 1200 to 600 replies/sec can reduce fruit by significant amounts. The percentage reduction in fruit and corresponding change in round reliability is a function of the number of interrogators and aircraft in the problem and the geometry of their deployment. For JFK-terminal minimum 1968 environment, the total fruit/scan will decrease 30 percent for an RRL change from 1200 to 600 replies/scan.

2. Round reliability can also be calculated. Although not shown in TABLE 7-5 round reliability for the 1968 minimum environment was calculated. For a 1200-reply/sec RRL threshold, the mean value of the long-term-average round reliability (RR) was 0.88. Reduction of the RRL threshold to 600 replies per second increased the mean value of RR to 0.90. These values of round reliability are only for the JFK terminal facility.

3. Increase in transponder deadtime from the nominal 100 μ s to 300 μ s can reduce fruit. In the example given in Part 5 of TABLE 7-5 the fruit decreased from 87,800 to 84,700 for the 1980 minimum environment.

4. A second aircraft deployment developed by ECAC using FAA statistics (see Reference 8) gave significantly different values of fruit/scan and number of aircraft contributing to the fruit. Comparison of Parts 1 and 6 of TABLE 7-5 provide an interesting insight to the dynamics of aircraft deployment. The 1980 ECAC deployment included a total of 6370 aircraft compared to the 6170 for the 1980 FAA traffic. For the 1980 maximum environment — ECAC traffic — the total fruit was 821,000. The number of aircraft contributors was 2170 and 2590 respectively. As a matter of comparison the fruit increased 33 percent and the number of contributing aircraft increased approximately 20 percent. The increase in fruit can probably be attributed to a large number of aircraft being more heavily interrogated.

5. Part 7 of TABLE 7-5 indicates effects of all SLS interrogator environment in the ECAC traffic sample. Comparison of part 7 with part 6 (all-SLS FAA traffic) again shows the effect of traffic deployments.

A number of variables that were investigated and not reported in TABLE 7-5 deserve mention. These variables are the effect of responder sensitivity, number of aircraft being over-interrogated, and the fruit replies at the JFK long-range radar (ARSR). A brief discussion of these variables is given below:

1. Decreasing the sensitivity of the JFK receiver by 3 dB (-90 to -87 dBm) reduced the total fruit/scan by approximately 25 percent (63,000 to 47,000) for the 1968 maximum environment.

2. The number of aircraft which will be overinterrogated by the 1980 maximum ground environment, with antenna sidelobes at -28 dB and backlobes at -40 dB, 100 percent of the time (the probability of overinterrogation is 100 percent) is 1310 out of the 6170 aircraft deployed. The majority of these aircraft are operating in the corridor between Washington, D.C. and New York City. For the minimum ground environment, no aircraft are overinterrogated 100 percent of the time. For probabilities of overinterrogation of less than 100 percent these numbers will increase.

3. Part 8 of TABLE 7-5 gives values of total fruit replies/scan for the JFK ARSR (long range radar). The significant factor which may be deduced from these values of fruit is the reduction, 86 percent, due to use of a minimum ground environment.

4. An increase in the GTC dynamic range from 35 to 50 dB reduced fruit 1 percent for the 1980 maximum environment.

ATCRBS performance predictions for the New York ARTCC are in process and will be reported at a later date. Validation of the model based on field measurements is continuing. Many model improvements are in process to simplify its application. From this application of the ATCRBS model to JFK terminal, the following conclusions have been drawn: A tenfold increase in the 1968 air traffic environment produces a proportionate increase in the beacon fruit rate. A 99 percent reduction in fruit replies can be obtained by:

1. Limiting the beacon-interrogator environment to air traffic control and Air Defense Command functions
2. Provide ISLS for all installations in the area
3. Equipping the JFK interrogator with RSLS.

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13. ABSTRACT ABSTRACT The development of the IFF MARK X (SIF) Air Traffic Control Radar Beacon System Performance Prediction Model (ATCRBS PPM) is described. This model provides performance predictions of the entire system or of selected subsystems. Military, civilian, or mixed equipment deployments for any geographic location can be considered. Actual, postulated, or future interrogator and aircraft deployments can be studied to determine system or equipment effectiveness. Deployments can include an unlimited number of aircraft (transponders) operating at altitudes up to 80,000 feet and distributed over an unlimited geographical area. KEY WORDS AIR TRAFFIC CONTROL RADAR BEACON MATHEMATICAL MODEL CALCULATION EFFECTIVENESS IFF			