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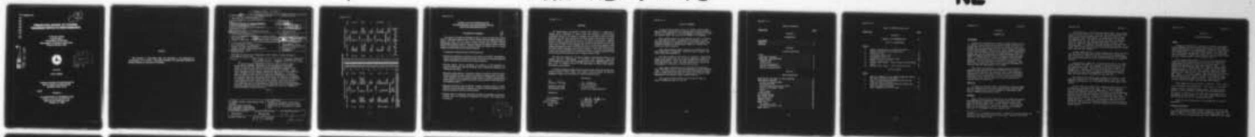

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PREDICTION MODEL OF ATCRBS TRANSIENT EFFECTS PERFORMANCE

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

June 1976

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
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16. Abstract

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A pulse-by-pulse simulation of the Air Traffic Control Radar Beacon System (ATCRBS), developed by the Transportation Systems Center of the DOT, was adapted by the Electromagnetic Compatibility Analysis Center (ECAC) for use with the UNIVAC 1110 computer. The model was made more flexible by adding the capability to use automated input information about ATCRBS and aircraft deployment. A terrain mode was added so the effects of terrain on coverage can be assessed. In addition, routines were added that simulate the effects of staggered and jittered PRF's and transponder reply codes, so that near-synchronous interference problems, broken and false targets, and other time-related anomalies can be investigated. Within the scope of this project, code-data-sampling and code-validation functions of the following digital processors have been included in the simulation: ARTS III, AN/TPX-42, and the AN/FYQ-49 common digitizer.

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METRIC CONVERSION FACTORS

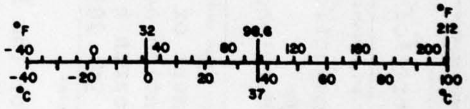
Approximate Conversions to Metric Measures

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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

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

This objective is achieved through the following services:

- **Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.**
- **Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.**
- **Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.**
- **Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.**
- **Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.**

PREFACE

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

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

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

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EXECUTIVE SUMMARY

A pulse-by-pulse model of the Air Traffic Control Radar Beacon System, devised by the Transportation Systems Center of the DOT, was modified by the Electromagnetic Compatibility Analysis Center (ECAC) for use with the UNIVAC 1110 computer.

Model modifications include adapting the model to operate with the ECAC data base, the addition of obstacle, terrain, two-path propagation, staggered and jittered PRF options, and extensive revision of the processor models to include code pulses and code validation.

These modifications permit analysis of problems such as near-synchronous interference, broken and false targets, and other time-related anomalies.

The input options of the model are flexible. Many parameters can be varied from run to run to compare the effects on ATCRBS performance. Since the model obtains most of its run data from ECAC data files, the user needs only to specify an interrogator of interest to initiate an analysis.

Very large environments can be statistically analyzed with other models such as the AIMS Performance Prediction Model (PPM). The new Transient Effects Model is designed to complement the AIMS PPM by providing the capability to analyze near-synchronous interference effects where suspected.

The Transient Effects Model will be used by ECAC to analyze ATCRBS problems for the FAA.

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SECTION 1

INTRODUCTION

BACKGROUND

As part of a continuing involvement in EMC analyses of the Air Traffic Control Radar Beacon System (ATCRBS), ECAC has developed many of the analysis capabilities needed to assist the Federal Aviation Administration (FAA) in determining how changes in spectrum management techniques may improve ATCRBS performance. Prior to the initiation of the Spectrum Management Program, the primary tool for the evaluation of ATCRBS performance was the ATCRBS IFF MARK XII System (AIMS) Performance Prediction Model (PPM).[1] The AIMS PPM is a long-term average prediction model which generates probabilistic interpretations of ATCRBS performance. The FAA tasked ECAC to develop a mathematical model which would simulate the short-term or transient phenomena associated with the performance of the ATCRBS.

The purpose of developing a Transient Effects PPM was to complement the capabilities of the AIMS PPM by providing an analysis method by which the problems such as near-synchronous interference, broken and false targets and other time-related anomalies could be investigated. Thus, a time-step simulation was needed, along with the specific routines required for a complete analysis capability.

OBJECTIVE

To develop a Transient Effects Performance Prediction Model that is compatible with the ECAC computer system and data base, and that incorporates two-path propagation, PRF-stagger, PRF-jitter, terrain and obstacle options.

APPROACH

Since a pulse-by-pulse simulation of the ATCRBS had already been devised by the Department of Transportation (DOT) Transportation Systems Center (TSC), it was decided to adapt that model to the ECAC UNIVAC 1110 computer system. ECAC would then modify it as necessary to simulate the aspects of the ATCRBS that were not programmed into the original model.

---

[1] Crawford, C. R., *Computer Simulations of ATCRBS Processing Equipment for Use with the AIMS and Transient Effects PPM's*, FAA-RD-76-102, ECAC, Annapolis, MD, January 1976.

The capabilities of the Transient Effects Model were expanded to increase its flexibility in dealing with beacon problems. The model, as originally received from TSC, operated with the input of a manually created environment of interrogators and aircraft from punched cards. The ECAC version of the model was modified to accept input from the computer-stored ECAC IFF Master File, which is constantly updated to provide the most current and best available data. In addition, aircraft deployments for many critical areas, both current and projected, can be provided directly to the model from the ECAC computer.

Another added capability is the terrain mode. Using this mode, ECAC can obtain terrain data directly from the ECAC topographic data files for any region in the Continental United States (CONUS) and evaluate the effect of earth surface aberrations on ATCRBS performance.

Along with the capability of assessing the impact of terrain on the ATCRBS, the model was expanded to include an obstacle routine option that allows the placement of obstacles around an interrogator-of-interest, simulating shielding that occurs at many ATCRBS sites. The effects of multipath propagation (ground reflections) have been also programmed into the Transient Effects PPM, utilizing routines developed for the AIMS PPM.

The inclusion of routines that simulate the effects of staggered and jittered PRF's on ATCRBS performance allows for a more complete investigation into the problem of near-synchronous interference.

Finally, ECAC has improved the original TSC simulation by the inclusion of transponder reply codes. The TSC model simulated only the framing pulses of the ATCRBS reply. This assumption limited the processor simulations, particularly since the defruiter performs its correlation techniques on a pulse-by-pulse basis. The Transient Effects PPM now includes the transponder reply codes, a pulse-by-pulse simulation of defruiter action, and code-pulse decoding functions. In addition, the code-data-sampling and code-validation functions of the following digital processors have been included in the simulation: ARTS III, AN/TPX-42, and the AN/FYQ-49 common digitizer

SECTION 2

SYSTEM DESCRIPTION

ATCRBS

Figure 1 illustrates the operation of the FAA surveillance system (ATCRBS) and the military identification system (AIMS). Uplink interrogations are transmitted on 1030 MHz. The airborne transponder detects the interrogations, decodes them and transmits a coded reply on 1090 MHz. These replies are received at the interrogator, decoded and displayed on the controller's plan position indicator (PPI) or other display device.

Four interrogation modes (1, 2, 3/A, C) are used by both ATCRBS and AIMS to obtain position and identity information from properly equipped military and civilian aircraft. The ATCRBS interrogator pulse repetition frequency (PRF) is a submultiple of the collocated radar PRF. When the ATCRBS interrogator/receiver is not used with a primary radar, an internal trigger establishes the PRF. The modes are transmitted automatically in a repetitive sequence (mode interlace) at the given PRF. Modes 1, 2, 3/A are normally used by the military for identification and air traffic control. The ATCRBS uses mode 3/A for identification and surveillance. Both military and civilian systems use mode C for altitude determination.

These modes have the form shown in Figure 2. The P_1 and P_3 pulses represent the interrogation. The P_2 pulse is the Interrogator Sidelobe Suppression (ISLS) pulse. The time spacing between P_1 and P_3 uniquely identifies the interrogation mode. The tables in Figure 2 give the pulse-spacing and amplitude requirements for valid mode 1, 2, 3/A, and C interrogations and the specifications for the interrogation pulses.

A more detailed description of the ATCRBS may be found in Reference 1.

Processor Equipment

In recent years automated digital processors have been used with this interrogator beacon system. Examples of these are the ARTS II, ARTS III, TPX-42 and the AN/FYQ-49 Common Digitizer. The ARTS III, TPX-42 and Common Digitizers were simulated in this model.

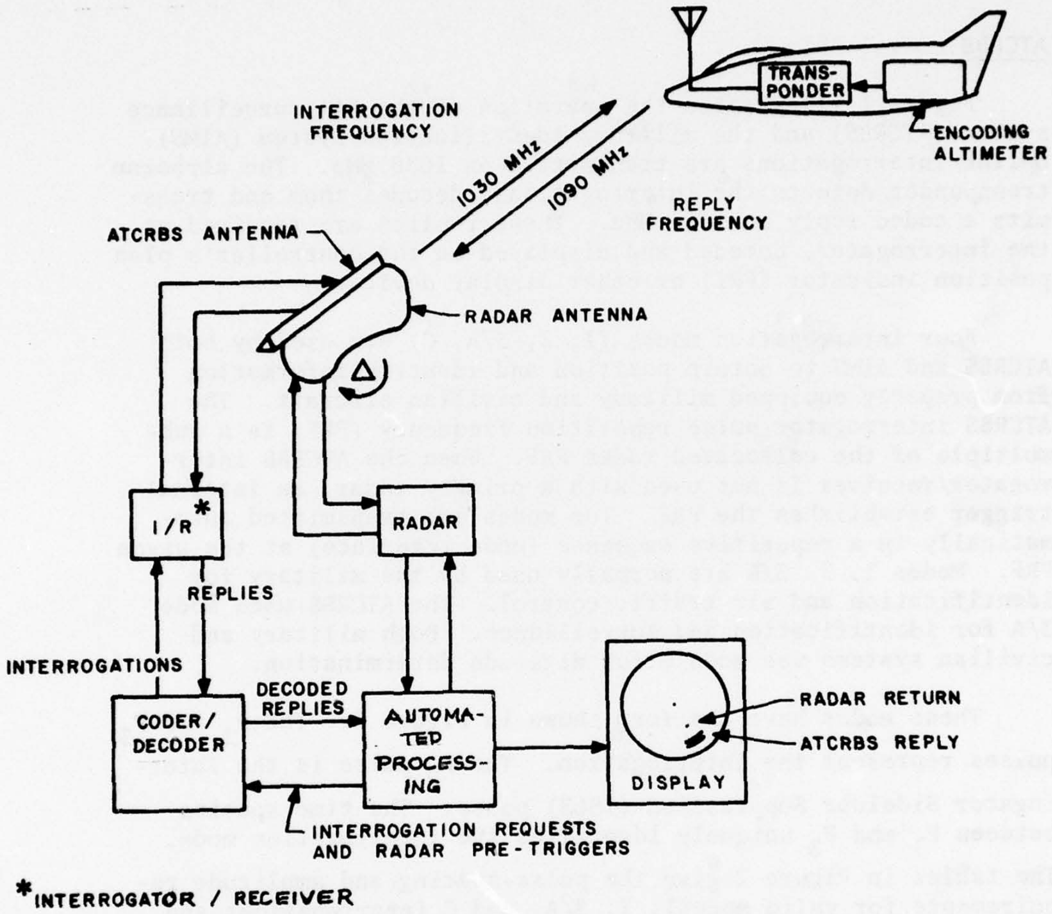
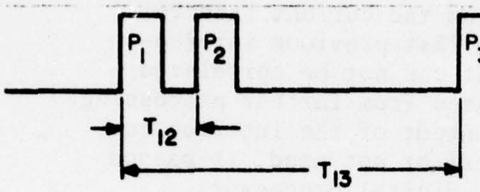


Figure 1. General configuration of ATCRBS equipments.



PULSE SPACING CRITERIA FOR SIF MODES 1, 2, 3/A, C		
MODE	T_{13} (μs)	T_{12} (μs)
1	3 ± 0.1	2 ± 0.15
2	5 ± 0.2	
3/A	8 ± 0.2	
C	21 ± 0.2	↓

PULSE SPECIFICATIONS	
WIDTH	0.8 ± 0.1 μs
RISE TIME	0.05 TO 0.1 μs
FALL TIME	0.05 TO 0.2 μs

PULSE AMPLITUDE CRITERIA FOR VALID INTERROGATION

1) $P_1 > P_2 + 9\,dB$

2) $P_3 = P_1 \pm 1\,dB$

PULSE AMPLITUDE CRITERIA FOR SIDELOBE INTERROGATION

$P_2 \geq P_1$

Figure 2. ATCRBS interrogation characteristics.

Replies received by the interrogator receiver may be defruited prior to further processing. The defruiter attempts to correlate the timing of replies from the current interrogation with replies received from the last previous interrogation of the same mode. Replies that can not be correlated are regarded as fruit and are eliminated from further processing. The output of the defruiter, or the output of the interrogator receiver if the defruiter is turned off or not used, is passed to the decoder unit and/or one of the digital processors.

The decoder operates in one of two modes. In the first, a pulse sequence is passed to the display each time a pair of bracket pulses (the transponder reply) is detected. In this mode, when a pulse is received, the decoder requires another pulse 20.3 μs later to complete the bracket pair.

The decoder can also be set to detect certain code pulses and display only the target aircraft which respond with that particular code. In this case, after a pair of framing pulses have been detected 20.3 μs apart, the pulse positions between the framing pulses are checked for the presence of code pulses. The decoder is used primarily as backup for the digital processors.

Terminal ASR/beacon systems use ARTS III, AN/TPX-42, and ARTS II processors with a built-in decoder that receives beacon video input from the Air Traffic Control Beacon Interrogator. En route ARSR/beacon systems employ common digitizer processors. The common digitizer does not use a defruited input. A defruiter is used with the ARTS III, ARTS II and the AN/TPX-42. An analog decoder is used as backup for the en route system and also for the terminal system.

Each processor applies a unique algorithm to the sequence of target hits and misses. When its detection criteria are met a digital target report is prepared and positioned on the controller's display at the target location.

Each processor, in addition to detecting targets, performs code-validation functions. In the common digitizer the Target Processing Group performs this function for modes 2, 3/A, and C. Consecutive replies in the same mode are compared, and if the code data bits match and no garble flags are associated with either return, the code is validated. This process continues until the code is validated or the target disappears.

The AN/TPX-42 validates by comparing consecutive replies to interrogations of the same mode and displays a code validation number, reflecting the level of confidence in a reported code, in the target report.

The ARTS III begins code validation as soon as the combination of hits and misses satisfies its statistical detection algorithm and the target leading-edge flag has been set. Validation is done on both modes 3/A and C. Like the AN/TPX-42, the ARTS III also produces a code validation number.

OPERATIONAL CONSIDERATIONS

Staggered PRF

The time interval between successive interrogations is referred to as the interrogator pulse repetition period (PRP). Its reciprocal is the interrogator pulse repetition frequency (PRF). The interrogator processing equipment correlates incoming replies using the interrogator output pulses as a reference.

If there are other interrogators operating at the same PRF, replies from aircraft triggered by the interferer's interrogations will correlate with the victim's PRP and produce false targets. To resolve this problem the FAA atempts to keep PRF's separated in frequency for a given area. However, even at different frequencies, the time of transmission of interrogations from two interrogators can overlap and transponder lockout or improper reply correlation can occur. To overcome problems of this type, an increasing number of staggered PRF schemes are being used. The staggered PRF interrogator varies the time between interrogations in predetermined steps. This technique was originally used in the primary radar system to eliminate second-time-around targets.

Jittered PRF

The jittered PRF interrogator was introduced prior to the staggered PRF. It also varies the time between transmissions but it does so randomly by adding a small time increment of up to three microseconds. Although not as successful as staggered PRF in eliminating the problems mentioned above, it is easier to implement and is currently in use at some installations.

Two-Path Propagation

Ground-reflected signals are the cause of at least two problems, depending on the time lag between the direct and reflected signals. In the case of airborne interrogators, the path length difference may be considerable and garbled replies or false targets may result. In the more common situation of a ground interrogator installation, the interrogator antenna may be less than 100 feet above the surface. Under these conditions, the path length difference between the reflected and direct signal will be small and lobing results, causing the target to fade in and out as its range changes.

Terrain Considerations

Performance of the interrogator system is affected by line-of-sight blockage due to terrain. ECAC's data base has information extracted from topographical maps that can be used to determine line-of-sight blockage due to terrain.

Obstacle Considerations

Population growth, industrial growth, and other factors have resulted in the erection of buildings in the areas close to most major airports. These new buildings are a source of system degradation due to blockage of surveillance areas.

SECTION 3

MODEL DESCRIPTION

ADAPTING THE TSC MODEL TO ECAC OPERATION

The program as received from TSC was written for optimized run time on a CDC 6600 computer with a very large core. The ECAC system uses a UNIVAC 1100 computer with 64,000 words of core. In order to conserve core space and provide for the routine running of moderatley large environments, the program was divided into segments that could be sequentially processed in the same core area. Approximately 24,000 words of core were saved by segmenting the following initialization functions:

1. Computation of the mathematical tables used in the main program.
2. Initialization of switches and values obtained from the run data parameter cards.
3. Selection of the interrogators from the on-line IFF files and preparation of interrogator arrays from the data in the IFF files.
4. Selection of aircraft from the aircraft on-line files and preparation of aircraft arrays.

After the initialization is completed, the segmented area is occupied with information required for the simulation run. The original model used three arrays to store uplink P_1 pulse and P_2 pulse powers and azimuth angle from each interrogator to each aircraft transponder in the environment. Additional core space was saved by creating a subroutine that eliminated the need for these large arrays.

The normal operating limit of 50 interrogators and 50 aircraft can be enlarged by going to an extended-core option. It is expected that smaller environments will be more commonly used in investigations at the detailed level this program is designed to address. Additionally, an option of the program allows very large fruit environments to be simulated by the random insertion of fruit pulses into the reply stream at the input to the receiver model. This is done by assuming an incoming fruit rate with a Poisson distribution of arrival times. The associated mean fruit rate can be obtained by simulating the larger environments with ECAC's probabilistic AIMS model.

BASIC MODEL OPERATION

The model operation is referenced to one interrogator called the interrogator of interest. The basic time step of the model is one PRP of the interrogator of interest. This is called the simulation cycle.

During a simulation cycle the positions of the aircraft and the positions of interrogator antennas are assumed to be fixed. These positions may be updated at the start of each new simulation cycle. The general flow of events listed below is depicted in Figure 3 and described in more detail in the following discussion.

1. Uplink Interrogations
2. Transponder Processing
3. Downlink Reply and Receiver Model
4. Receiver Processing
5. Output
6. System Update.

Uplink Interrogator Model

The Uplink Interrogator Model computes the amplitude and time of arrival of all pulses transmitted during the current simulation cycle. The effect of all interrogators on one transponder at a time is computed. The program cycles through all transponders.

The time of arrival of pulses is computed in the following manner as each interrogator is passed by each transponder:

1. The time of transmission of the P_3 pulse is used as a reference. It is equal to the time of transmission of the last P_3 pulse plus the pulse repetition period (PRP) of the associated interrogator.
2. The slant range is computed and converted to propagation time and added to the time of transmission of P_3 to derive time of arrival of the next P_3.
3. The time of arrival of P_1 is found by looking at the current interrogation mode and subtracting the appropriate number of microseconds from the time of arrival of P_3 (8 μs for mode A, 21 μs for mode C, etc).
4. If the interrogator has a sidelobe suppression pulse (P_2), its time of arrival will be equal to the time of arrival of the P_1 pulse plus 2 μs.

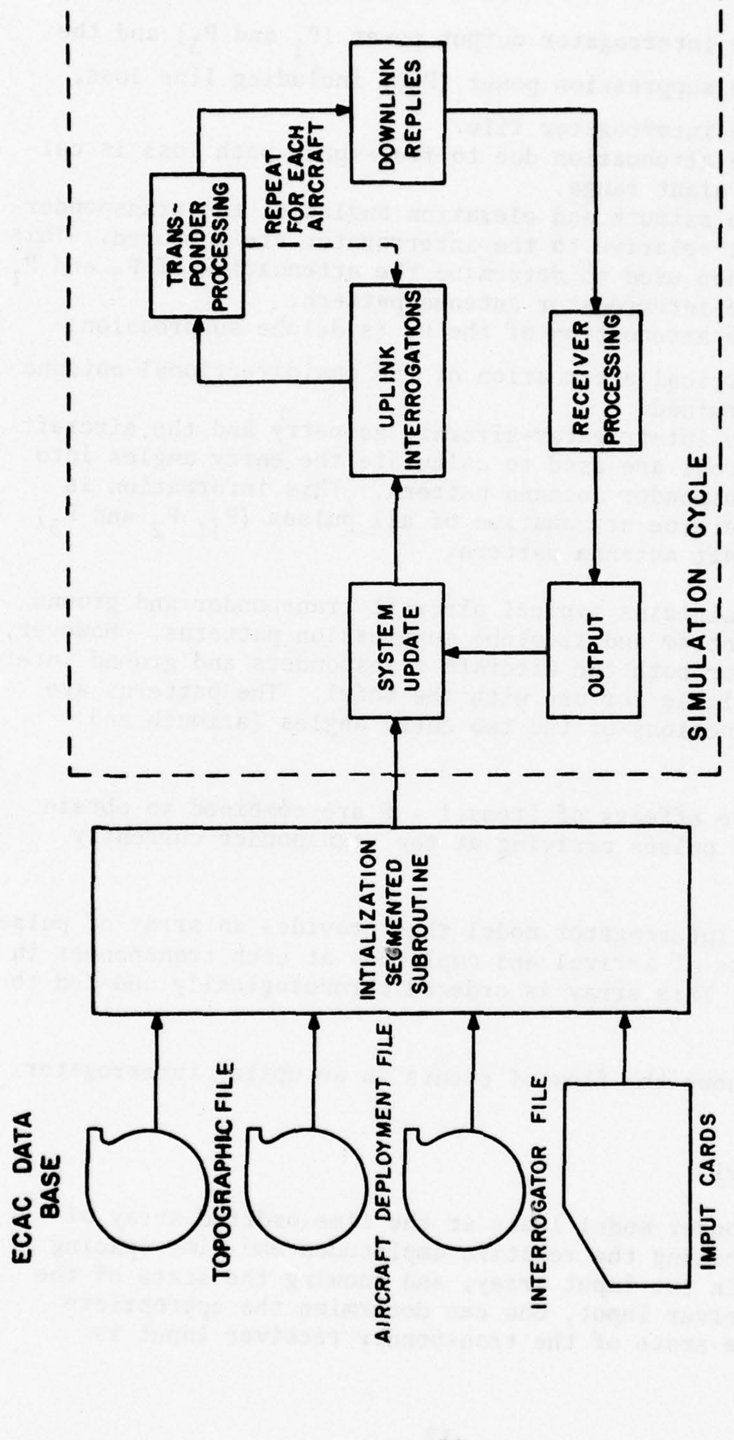


Figure 3. Simulation flow.

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The amplitude of the arriving pulses is computed as follows:

1. The interrogator output power (P_1 and P_3) and the relative sidelobe suppression power (P_2), including line loss, are read from the interrogator file.

2. The attenuation due to free-space path loss is calculated from the slant range.

3. The azimuth and elevation angles of the transponder-equipped aircraft relative to the interrogator are computed. This information is then used to determine the attenuation of P_3 and P_1 pulses due to the interrogator antenna pattern.

4. The attenuation of the P_2 (sidelobe suppression) pulse, due to vertical attenuation of the omnidirectional antenna pattern, is determined.

5. The interrogator-aircraft geometry and the aircraft pitch, yaw, and roll are used to calculate the entry angles into the aircraft transponder antenna pattern. This information is then used to determine attenuation of all pulses (P_1, P_2 and P_3) due to the aircraft antenna pattern.

The model maintains typical aircraft transponder and ground interrogator mainbeam and sidelobe suppression patterns. However, other patterns for both the aircraft transponders and ground interrogator are available for use with the model. The patterns are maintained as functions of the two entry angles (azimuth and elevation).

6. The effects of items 1 - 5 are combined to obtain the amplitude of pulses arriving at the transponder currently under study.

The uplink interrogator model thus provides an array of pulses specified by time of arrival and amplitude at each transponder in the simulation. This array is ordered chronologically and fed to the transponder.

Figure 4 shows the flow of events in an uplink interrogator model.

Transponder Model

The transponder model looks at the time-ordered array of pulses. By examining the relative amplitudes and time spacing between pulses in the input array, and knowing the state of the transponder receiver input, one can determine the appropriate response and the state of the transponder receiver input is updated.

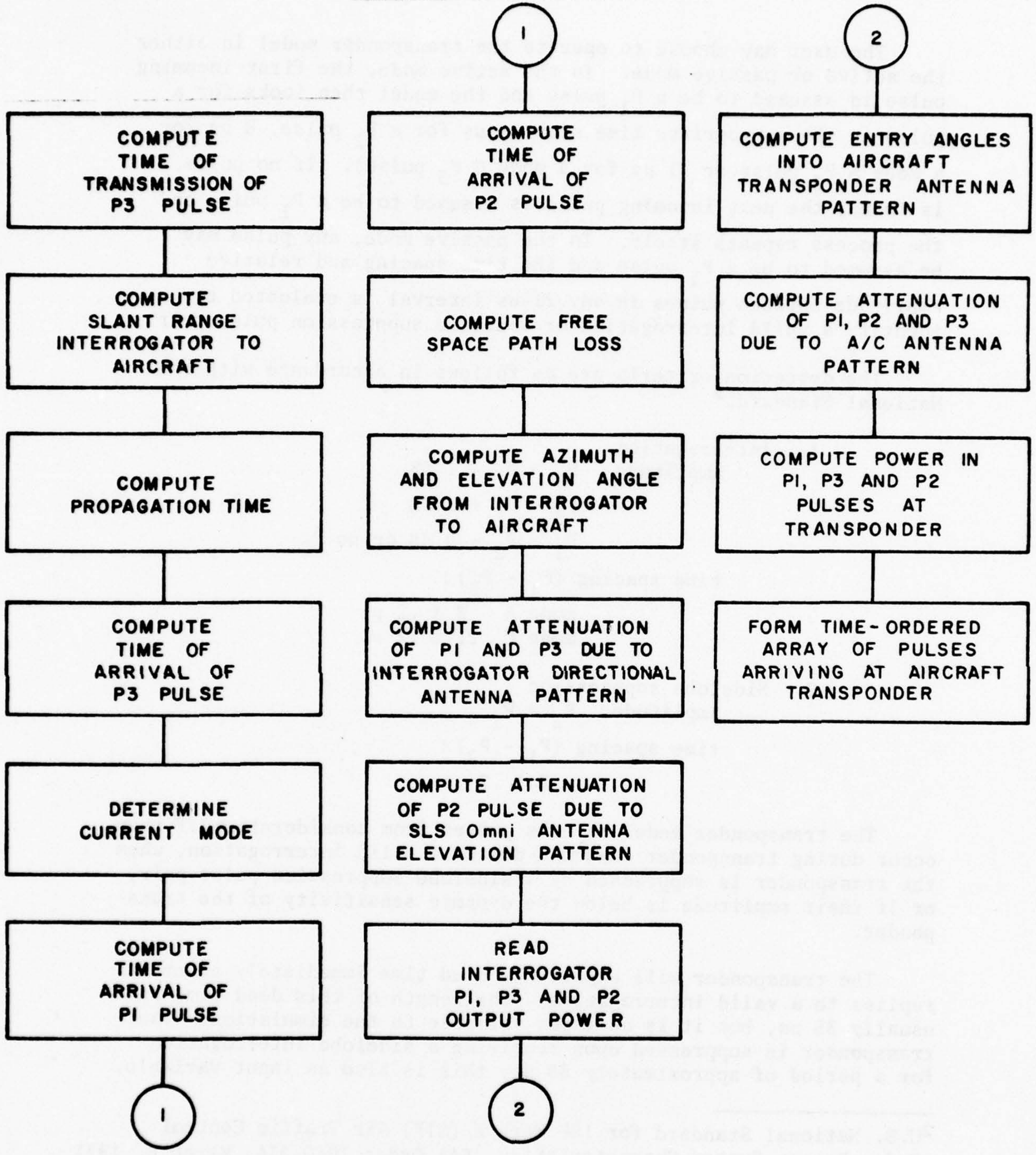

Figure 4. Interrogator model flow.

The user may choose to operate the transponder model in either the active or passive mode. In the active mode, the first incoming pulse is assumed to be a P_1 pulse and the model then looks for a pulse in the appropriate time slot (2 μs for a P_2 pulse, 8 μs for a mode A P_3 pulse or 21 μs for a mode C P_3 pulse). If no pulse is found, the next incoming pulse is assumed to be a P_1 pulse and the process repeats itself. In the passive mode, any pulse may be assumed to be a P_1 pulse and the time spacing and relative amplitude between pulses in any 21-μs interval is evaluated to identify a valid interrogation or sidelobe suppression pulse pair.

The detection criteria are as follows in accordance with the National Standard.[2]

1. Interrogation
   amplitude: $P_3 > P_1 - 1$ dB
   $P_3 < P_1 + 3$ dB
   $P_1 > P_2 + 9$ dB or no P_2
   time spacing ($P_1 - P_3$):
   mode A 8 ± .2 μs
   mode C 21 ± .2 μs
2. Sidelobe suppression
   amplitude: $P_2 > P_1$
   time spacing ($P_1 - P_2$):
   2 ± .2 μs

The transponder model rejects pulses from consideration if they occur during transponder dead time due to a valid interrogation, when the transponder is suppressed by a sidelobe suppression pulse pair, or if their amplitude is below the dynamic sensitivity of the transponder.

The transponder will experience dead time immediately after it replies to a valid interrogation. The length of this dead time is usually 35 μs, but it is an input variable to the simulation. The transponder is suppressed upon receiving a sidelobe interrogation for a period of approximately 35 μs; this is also an input variable.

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[2] U.S. National Standard for IFF Mark X (SIF) Air Traffic Control Radar Beacon System Characteristics, FAA Order 1010.51A, March 8, 1971

The nominal transponder receiver sensitivity is an input variable, usually set at -71 dBm. This is the sensitivity when none of the desensitization mechanisms are affecting the transponder. Two types of desensitization are modeled in accordance with the National Standard (Reference 2). They are echo suppression and reply-rate desensitization.

Echo suppression occurs upon receipt of any pulse at the transponder receiver input. The receiver input is desensitized to within a value between 0 and 9 dB (as specified by an input variable) of the desensitizing pulse. Usually 5 dB is specified. Recovery from echo suppression desensitization is linear during the ensuing 15 μs. Reply rate limit desensitization occurs such that the number of replies per second is kept at or below a preset limit of 1200 replies per second (variable).

The transponder model also gathers data that is used to compute the following output statistics from each transponder:

1. Rate of interrogation
2. Rate of reply
3. Rate of valid uplink SLS P_1 - P_2 suppression pulse pairs
4. Rate of suppression (transponder will be suppressed if a pulse pair is identified as a valid P_1 - P_2 and the transponder is not already in dead time or suppressed)
5. Reply probability
6. Suppression probability
7. Minimum and maximum interrogation rate
8. Minimum and maximum reply rate
9. Minimum and maximum uplink SLS rate
10. Minimum and maximum suppression rate.

Figure 5 shows the flow of the transponder model.

Downlink Reply and Receiver Model

The downlink reply and receiver model determines which of the replies generated by the transponder model will actually be received at the interrogator of interest. The model will pass pulses of suitable amplitude on to the receiver processing routines.

The calculations for pulse power are simplified on the downlink since the signal paths are the same as on the uplink and many calculations have already been made. Some of the parameter values calculated for the uplink routine are stored for use by

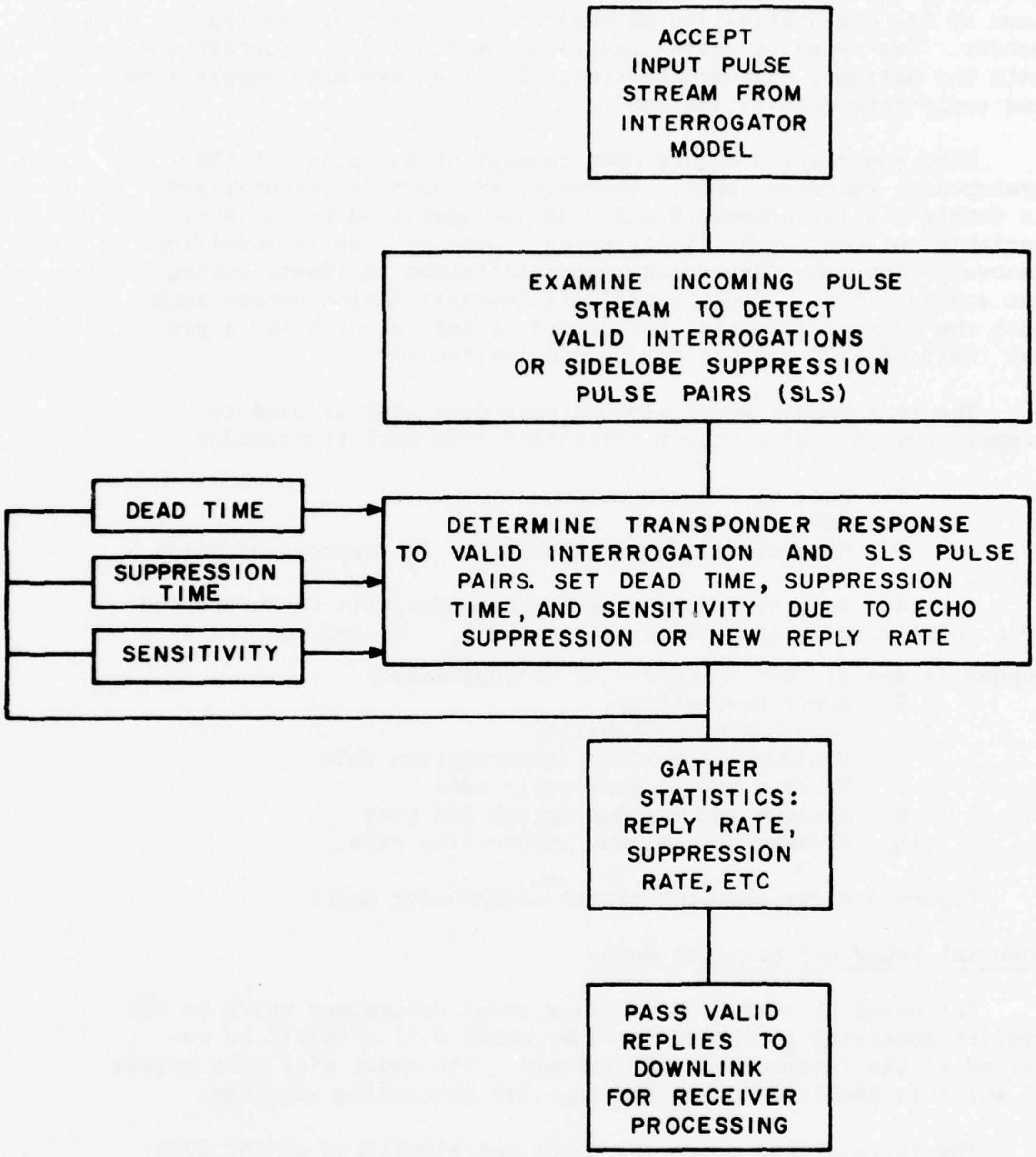

Figure 5. Transponder model flow.

the downlink routine. These are the propagation time, free-space loss, and attenuation due to antenna gains.

The original TSC model was concerned with only the F_1 and F_2 framing pulses. ECAC added an option that includes the coding pulses for each aircraft.

The method for determining which pulses are received and their time of arrival is outlined as follows:

1. The attenuation due to free space path loss and antenna gains, stored from the uplink calculation, are retrieved.
2. The attenuation in the omnidirectional sidelobe suppression (SLS) antenna pattern due to elevation angle is computed.
3. The power output of the transponder is combined with 1 & 2 to determine the received power at the directional antenna and at the omnidirectional SLS antenna.
4. If the interrogator of interest employs receiver sidelobe suppression (RSLS), the power level received by the directional antenna is compared with that received by the omni antenna. If the power level received on the directional antenna is not greater than that received on the omnidirectional antenna by some preset level, (nominally 12 dB) the reply will be rejected.
5. The times of arrival of the pulses are determined from the time of transmission of F_1, the propagation-time and the relative location of the code pulse to F_1.
6. The receiver sensitivity at the time of arrival is determined. It is a function of the nominal receiver sensitivity, an input variable, and the current effect of the sensitivity time control (STC).
7. The received pulse power is then compared to the current receiver sensitivity to determine if it will be received.
8. Pulses that are received at power levels greater than current sensitivity are held in an array until all pulses received during the current simulation cycle are processed.
9. The array is time-ordered and passed on to the processor models.

Figure 6 shows the flow of events in the downlink reply and receiver model.

Processing Equipment Models

The original TSC model did not include transponder reply code pulses, but considered only the F_1 and F_2 framing pulses of the

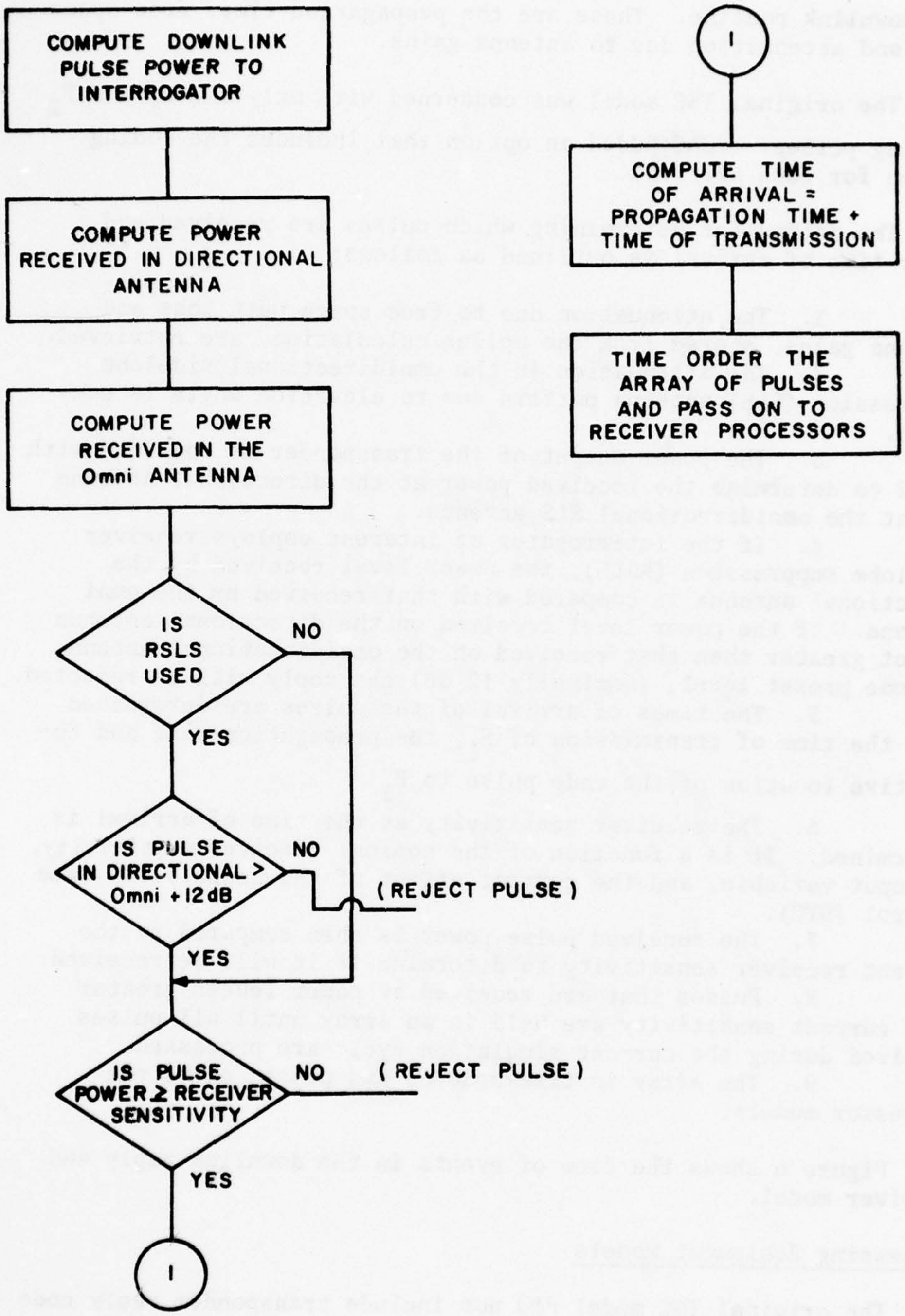

Figure 6. Downlink reply and receiver model.

ATCRBS reply. Modifications to the defruiter, decoder, and digital processors were required to simulate operation on a pulse-by-pulse basis rather than a reply-by-reply basis.

Processor equipment models were developed for use with this model under a separate task. A detailed report on these models and an extensive system description has been prepared.[1]

The primary significance of this work is the addition of code-pulse processing to the reply-processing schemes of the original TSC model.

A brief description of the operation of these equipments is included here for completeness.

Defruiter Model. The modified defruiter correlates on a pulse-by-pulse basis. Differences in elapsed time between an incoming pulse and pulses received on the last interrogation of the same mode are calculated. If this time difference lies within the acceptance gate, the pulses pass out of the defruiter to the decoder. Those that are not passed on are counted as fruit pulses and this information is later used in the output.

Decoder Model. The decoder looks for a 20.3-μs (± a specified tolerance) spacing in the pulses passing out of the defruiter. This spacing indicates a bracket pair has been received. Once a bracket pair is identified, the DECODE subroutine is called to look at the intervening pulses and determine if they fall into code-pulse positions. The code is then returned to the main program and can be displayed on output.

AN/FYQ-47 Common Digitizer Model. The model of the Common Digitizer (CD) used with the Transient Effects PPM has the same structure as the original TSC simulation except for one modification and one additional routine. The modification consists of a reprogrammed sliding-window function of the Common Digitizer (CD) for compatibility with the ECAC computer, requiring a limited amount of core storage. The additional routine necessary to complete the simulation of the beacon processor portion of the CD was a model of the code-validation functions. Also included is a simulation of the garble conditions required as an input to the code-validation subroutine. The input and output variables are listed in TABLE 1.

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[1] Crawford, C. Randall, *Computer Simulations of ATCRBS Processing Equipment for Use with the AIMS and Transient Effects Performance Prediction Models*, ECAC-PR-75-062, or FAA-RD-76-102, January 1976

TABLE 1

AN/FYQ-47 COMMON DIGITIZER MODEL/TRANSIENT EFFECTS PPM INPUT AND OUTPUT VARIABLES

Inputs
Window Length
Target Leading Edge Threshold
Target Trailing Edge Threshold
Reply Ranges
Reply Codes
Garble Status
Outputs
Target Start Azimuth
Target Stop Azimuth
Corrected Center Azimuth
Target Range
Reported Code
Code Validation Status

The CD model operates as follows:

1. *Preparatory to entering the statistical detector routine,* bracket and code pulse detection are accomplished in a manner similar to that discussed above for the decoder model.
2. Garble detection is simulated as follows: if a bracket pair is detected which overlaps or falls in the pulse position of a previously detected bracket pair, both replies are flagged as garbled.
3. The interrogation mode is checked. If the mode is not 3A, control is transferred to the code validation routine. If the mode is 3/A, statistical detection is continued.
4. Azimuth degrees are converted to azimuth change pulses (ACP's).
5. If there are no replies at the current azimuth, the contents of the sliding window are shifted back in the memory, and a zero is placed in the first window slot. This is done for all range bins. The window consists of a series of ones and zeros in the 11 right-most bits of a computer word. Updates are made in the right-most bit. This configuration helps conserve available core storage.
6. A similar process is followed for a hit: a one is entered in the right-most bit, and the contents of the window are shifted left.

7. The window count is compared against target-start and target-stop thresholds.

8. If target start occurs, the leading-edge flag is set and the start azimuth is recorded.

9. If target end occurs, and the leading-edge flag has been set, target-end azimuth is recorded.

10. After the target ends, the center azimuth is computed as follows:

a. The target start and stop azimuths are averaged.

b. A bias is subtracted:

BIAS = [(ITL-1) + (IWNL + 1-ITL - ITT)/2.]
ITL = target leading-edge threshold
IWNL = window length
ITT = target trailing edge threshold

Bias is converted to ACP's before correcting the azimuth.

11. Range is calculated by finding the correct range bin for the reply, and setting a flag in the half of the range bin in which the reply exists to obtain 1/8-nmi accuracy.

12. After processing all replies, the remaining range bins are updated with zeros.

13. Code validation processes are simulated in the CD model for modes 2, 3, and C. Validation for modes 2 and C is done automatically, switching past the statistical detection routine. The following steps are taken:

a. The target record is checked to see if the mode has already been validated.

b. If not, the code of the incoming reply is compared with the code received on the last interrogation of that mode, if a reply was received.

c. If these codes match, and the garble flags of both replies are set to zero, the code for that mode is validated.

d. The code validation information is added to the target report printout.

14. The leading-edge flag is reset to zero, and a target report is printed including:

a. Range bin (nmi)
b. Start azimuth (ACP's, degrees)
c. Center azimuth (ACP's, degrees)
d. End azimuth (ACP's, degrees)
e. Code validation information

ARTS III Processor Model. The only substantial changes made to original simulation of ARTS III beacon processor were the inclusion of garble-sensing and code-validation routines. The inputs to the ARTS simulation and the performance outputs are listed in TABLE 2. The operation of the model is as follows:

1. The incoming array of reply pulses is examined for pulse spacings of 20.3 (± 0.1 or 0.2) μs. The intervening pulses in the array are checked to determine if they occur in code pulse positions of the reply.
2. When a 20.3-μs bracket pair is detected that overlaps a previously detected pair, the model determines whether code-pulse positions have been entered by the overlapping reply. If so, both replies are flagged as garbled.
3. The ARTS routine first checks the mode of interrogation. If not mode A or C, the number of replies is set to zero. Otherwise, processing continues normally.
4. The maximum number of in-process targets is limited to 45. Target records are kept in an old-target register, and, when updated, the result is stored in a new-target register.
5. If a reply is received that begins a new target, a target record is created at the reply range, and the hit, sweep, and "sumh" counts are set equal to one. Also, the miss count and leading-edge flags are set to zero. The new target is then transferred to the old-target register.
6. On each interrogation, the incoming reply ranges are compared with the range recorded in the old-target register. If the incoming range is within ± 1/16 nmi of the record range, the reply is recorded as a hit. All existing targets which do not receive a hit are updated with a miss. When a hit is received, the miss count is set to zero, the "sumh" count is incremented by the interrogation number, and the interrogation count is incremented.
7. After each update, the target-detection thresholds are compared with the appropriate counts. If the leading-edge flag is still zero, the hit count is checked against the target-start threshold and the miss count is checked. The flag is set if the specified number of replies for leading-edge declaration has been received before a specified number of consecutive misses.
8. If the leading-edge flag has been set and a miss is received, the number of consecutive misses in the register is checked against the target-end threshold to determine if the trailing edge has been reached.
9. Before a target is declared, the total number of hits is compared with a minimum-run-length threshold.
10. The run length of the target is also compared against another threshold which, if exceeded, causes a strong-target azimuth confidence label to be included in the target report.

TABLE 2

ARTS III PROCESSOR MODEL/TRANSIENT EFFECTS PPM
INPUT AND OUTPUT VARIABLES

Inputs
Target Detection Parameters Reply Ranges Reply Codes Garble Status
Outputs
Target Range Corrected Center Azimuth Sweep Count Hit Count Sum Count Strong Target Label Reported Code Code Validation Number

11. The number of interrogation sweeps over which a target continues is compared with a ringaround threshold which, if reached before target end, causes the target to be declared a ringaround, i.e. the target does not end, creating a circle on a PPI. The record is then deleted from the register.

12. Code validation is performed for both mode A and mode C.

13. A validation number for each mode is contained in the target report. For mode A, the code bits and garble status of consecutive replies from that mode are compared and a corresponding validation number is assigned. Validation level zero is assigned if all replies have garble tags, level one if one reply is ungarbled, level two if one is ungarbled and the decoded code bits match, and level three if consecutive ungarbled replies with matching codes are received.

14. Mode C validation levels are checked in the same manner, with validation level zero meaning no mode C replies received. Level one is assigned if all replies are garbled and level two if a single reply is ungarbled. Level three is assigned for two consecutive ungarbled replies occurring with identical codes.

15. The output from the ARTS III simulation consists of the following:

a. Range
b. Center azimuth

c. Sweep count
d. Hit count
e. Sumh count
f. Strong target azimuth confidence lable, if reached
g. Mode A code validation number and code
h. Mode C code validation number and code.

AN/TPX-42 Processor Model. The simulation of the AN/TPX-42 processor is similar to the ARTS III simulation in that, in both processors, the reply ranges are merged with an in-process target array in which incoming ranges are compared with the record range of the most recent reply. The Common Digitizer compares incoming reply ranges with the recorded range at the time of declaration of target leading edge. The TPX-42 employs a sliding-window detector similar to that of the CD, as opposed to the more complex algorithm used by the ARTS III processor.

The model of the TPX-42 used with the Transient Effects PPM is the same as the one included in the TSC simulation, with the exception of the following:

1. The sliding window function is programmed differently.
2. Simulation of the Reply Detection Unit includes code pulse recognition.
3. Code validation functions are simulated.

A list of input and output variables is provided in TABLE 3.

The flow of the TPX-42 computer model is as follows:

1. The incoming-reply pulse array is analyzed for pulses arriving with a spacing of 20.3 ± 0.15 μs. Each time that interval is sensed, the intervening pulses are tested to determine which pulses are located in code pulse positions as measured in 1.45 μs intervals (± 0.1 μs) from the first framing pulse.
2. If two other pulses in the array are found to be 20.3 ± 0.15 μs apart, and they are detected before the occurence of the second framing pulse of the first bracket pair detected, the model switches to the garble-sensing routine. A garble flag is set for both of these replies if the second reply overlaps a pulse position of the first. The garble flags and reply codes are used later in the program for code validation purposes.
3. All replies are processed by the TPX-42, regardless of the interrogation mode. A maximum of 20 replies can be processed on one interrogation.

TABLE 3

AN/TPX-42 PROCESSOR MODEL/TRANSIENT EFFECTS PPM
INPUT AND OUTPUT VARIABLES

Inputs
Window Length
Target Leading Edge Threshold
Target Trailing Edge Threshold
Reply Ranges
Reply Codes
Garble Status
Outputs
Target Start Azimuth
Target Stop Azimuth
Corrected Center Azimuth
Target Range
Reported Code
Code Validation Number

4. When the first reply in the array is processed, and no target records exist in the register, a new record is inserted. The range (nmi) and azimuth (ACP's) of the reply is recorded, and a "one" is inserted into the first bit in the sliding window.

5. As replies are received on subsequent interrogations, the reply ranges stored in the reply array are compared with the recorded ranges in the existing target register. If a reply range is within the range tolerance (usually ± 1/16 nmi) of an existing record range, the reply is entered as a hit in the sliding window. For any targets for which no replies exist on a given interrogation, a zero will be inserted into the window.

6. After the receipt of a valid hit, the mode of interrogation is checked. If a mode 3/A interrogation had been transmitted, the confidence count is increased by one.

7. After receipt of a hit, the number of "ones" in the sliding window is compared with the target leading-edge threshold to determine if target start has been achieved. If a miss has occurred, the program checks to determine if the number of "ones" in the sliding window has been reduced to the value of the target trailing-edge threshold. If trailing edge is detected, and the leading-edge flag had been previously set, the target will be detected if the mode 3/A confidence-count threshold has been reached.

8. The center azimuth of a detected target is calculated by adding the number of ACP's at leading and trailing edge, dividing by two, and subtracting a bias value. The target range is the value of the last recorded reply range.

9. Code validation is accomplished by using information from the routine that performs code-pulse recognition and garble sensing. Validation numbers are calculated by comparing the codes and garble status of consecutive mode 3/A or mode C replies. Numbers are assigned corresponding to the following conditions: level zero when no replies are received on that mode, level one when only garbled codes are reported, level two when one non-garbled reply is received, and level three when two consecutive non-garbled replies with identical codes are received on the indicated mode.

10. A target report from the TPX-42 computer model consists of the following:

a. Range
b. Start azimuth
c. Stop azimuth
d. Center azimuth
e. Confidence check (number of 3/A replies)
f. Code validation number and reported code.

Output

An output is provided from any simulation cycle in which one or more target hits occur. A single line of output, consisting of time, azimuth angle, mode and range of each target, occurs for any simulation cycle resulting in a target hit. A complete discussion on model outputs is given in the section MODEL OUTPUT.

System Update

During a simulation cycle, all positions are assumed to be fixed. Since a simulation cycle is typically 2500 μs, this is a reasonable assumption. At the start of each new simulation cycle, all the interrogator antennas are rotated in azimuth by an amount proportional to the rotation rates. The position of aircraft may be changed at the start of each simulation cycle; however, since very little motion takes place during one simulation cycle, aircraft position may be updated after a specified number of simulation cycles.

2-PATH OPTION

The two-path option in this model evaluates ground-reflected signals associated with the interrogator of interest. If the time lag between the direct signal and the reflected signal is great enough, false targets or garbled replies will be created and recognized by the model. In most cases the time lag will be small (on the order of a wavelength) and the model will simulate the lobing effects.

The method of computing the magnitude of the earth-reflected signal is as follows:

1. The angle θ between the horizontal and the reflected wave at the point of reflection is computed from the interrogator-aircraft geometry.
2. The decibel value of the smooth-earth reflection factor is computed. This factor is based on the theoretically derived specular reflection coefficient at the smooth surface of a homogenous earth with specific values for relative permittivity and electrical conductivity, and the reflection angle.
3. A modification of the smooth-earth specular reflection coefficient that accounts for surface roughness is included in the model. The technique utilized[4] begins with the roughness factor, Δh, as an input variable. Using the Rayleigh roughness criterion, the end result is the specular adjustment factor in dB.

When either the surface roughness or the reflection angle θ become large enough, diffuse reflection results in a stronger signal than does specular reflection. The diffuse reflection factor, DIFF (in dB), is calculated using the following equation from Reference 1:

$$\mathrm{DIFF} = 20 \log \left(\frac{1}{\sqrt{\sin\theta}} \right)$$

When diffuse reflection is the dominant mode, the diffuse reflection factor is combined with the additional free-space loss attributed to the longer reflected path with respect to the direct path. This combined result is referred to as roughness factor A (RFNSA). When specular reflection is the dominant mode, the specular-adjustment factor is combined with the smooth-earth reflection factor. The combined result is referred to as roughness factor B (RFNSB). A mode selection scheme for choosing between specular and diffuse reflection is described in Reference [3]

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[3] Longley, A. G., and Rice, P. L., *Prediction of Tropospheric Radio Transmission Loss Over Irregular Terrain, A Computer Method - 1968*, ESSA Technical Report ERL 79-ITS67, Boulder, Colorado, July 1968.

Another reference[4] provides similar calculations for the specular adjustment factor and the diffuse reflection factor, but it makes no mention of mode selection. Therefore, the most conservative approach was chosen (least attenuation of the reflected wave) by adding together the numeric values of roughness factors A and B in phase and expressing the resultant as a composite roughness factor in decibels. Guidelines for determination of the roughness factor, Δh, as an input variable have been extracted from Reference 4 and are listed below:

Estimates of Δh

Type of Terrain	Δh in feet
Water or very smooth plains	0-15
Smooth plains	15-65
Slightly rolling plains	65-130
Rolling plains	130-260
Hills	260-490
Mountains	490-980
Rugged mountains	980-2300
Extremely rugged mountains	>2300

4. The reflected signal enters the aircraft and interrogator antenna patterns at angles different than the direct signal. To obtain actual power levels at a ground or airborne receiver the new angles are calculated and the antenna pattern attenuation is combined with the above power calculation to obtain reflected signal power.

The above procedure must be applied to both the uplink and downlink paths. Since these paths are the same, the combined attenuation of the uplink propagation loss (including multipath effects) and the antenna gain patterns is stored and used in the downlink calculation to reduce computation time. Once the amplitude of the reflected pulse is computed, the delay time, which is simply the difference in path length divided by the speed of light, is computed to determine if there is pulse overlap or if the width is .8 μs (P_1, P_2, P_3), and on the downlink whether the pulse width is .45 μs (reply). At delay times greater than these there is a distinct set of pulses. The structure of the original TSC model allows for insertion of these pulses into the input pulse stream of the transponder on uplink, at which point processing continues

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[4] Beckman, P., and Spizzichino, A., *The Scattering of Electromagnetic Waves From Rough Surfaces*, The MacMillan Company, 1963.

in the normal fashion. On the downlink, additional reply pulses are entered into the ground receiver input pulse stream and normal processing continues. When the time lags cause overlapping pulses, a subroutine is called to combine the pulses and find a resultant power level. Normal processing is then continued with a modified pulse level.

PRF STAGGER OPTION

There are increasing numbers of interrogators in high-volume interrogator-aircraft environments that benefit from the use of staggered PRF schemes. The staggered PRF is a useful tool in overcoming near-synchronous interference problems.

The original TSC model operated on a simulation cycle equal to the pulse repetition period of the interrogator of interest, and assumed a fixed PRF. Modifications, as the following steps indicate, were made to allow a staggered PRF to be used, in which case the simulation cycle varies from pulse to pulse.

1. One input card with the following information is required for each interrogator with a staggered PRF:

    a. ID number of the interrogator as it appears in the input files

    b. number of steps in the staggered pattern (up to eight)

    c. the PRF's in the staggered pattern (arranged as they occur).

2. A flag is associated with each interrogator. It is set to 1 if the interrogator has a staggered PRF. If not, it is set to 0. A counter is created for each staggered interrogator to keep track of the current PRF.
3. When the program requires the next time of transmission of an interrogator's P_3 pulse, the flag value is read.
4. If the flag value is 0, the time of transmission is calculated using the PRF as read from the data file where: time of transmission = time of last transmission + 1/PRF.
5. If the flag is set to 1, the counter associated with the current interrogator is read. The counter value is incremented by 1.
6. The value found in 5 is used as an index to read the current PRF from the PRF array associated with the current interrogator. If the last PRF in the array is read, the counter is reset to 1.

7. The PRF value found in 6 is used to determine the time of transmission of the next P_3 pulse: time of transmission = last time of transmission + 1/PRF.

8. Time of transmission of P_1 and P_2 are referenced to P_3 in the usual manner.

In investigating changes required for this option it was discovered that the original model of the ground receiver could not identify second-time-around targets. Calculations of range were based on the time of reply, referenced to the last interrogation. The model did not check the time of reply to see if it would actually occur prior to the time of transmission of the next interrogation. The model was changed to include this check. If the time of reply is placed in the next simulation cycle, the reply is saved, referenced to the next interrogation, and processed during the next simulation cycle. The targets associated with replies processed in this array will now appear as second-time-around targets close to the interrogator of interest.

The user may call the stagger option by adding one card to the input deck specifying the interrogator file ID, the number of stagger steps, and the staggered PRF's.

PRF JITTER OPTION

The PRF jitter option changes the pulse repetition rate from interrogation to interrogation by adding 0, 3.6 and 7.2 μs to the PRP. The time interval added normally follows the standard FAA five-step sequence: 0, 7.2, 0, 3.6, 3.6. Other sequences are readily simulated.

TERRAIN OPTION

The user may call a model option to investigate the terrain between any interrogator and aircraft in the input environment. If the path between an interrogator and an aircraft is blocked due to terrain, a large value of attenuation is entered into the uplink calculation, effectively removing the transmission path. The routine functions for each aircraft relative to the interrogator of interest are as follows:

1. A subroutine named TERCUL is called using the latitude, longitude and altitude of the aircraft and interrogator of the pair under study as input.

2. TERCUL in turn calls the required subroutines, which extract topographical data from the ECAC Topographical data base files.

3. The topographical data is used to construct a terrain profile along the line between the interrogator and aircraft.

4. Next the elevation angle between the interrogator and aircraft is computed.

5. Elevation angles between the interrogator and terrain elevations along the profile are computed.

6. The computed terrain elevation angles are compared to the aircraft elevation angle found in step 4. If a terrain elevation angle is greater than the aircraft elevation angle, the line-of-sight path between interrogator and aircraft is blocked.

7. An array is maintained that is dimensioned by the number of aircraft and the number of interrogators. When line-of-sight is blocked, a 1 is entered and when the line-of-sight is clear a 0 is entered.

8. This array is passed to the main program and consulted as processing of the uplink pulse powers is made. If the path is blocked, a corresponding level of uplink attenuation is entered into this calculation.

9. Normal processing then continues.

The ECAC topographic file consists of a grid of ground elevations extracted from topographic maps and stored in compressed form on mass storage. The data is used to construct topographic profiles between interrogator and aircraft. The model uses 30-second data.

OBSTACLE OPTION

The obstacle option allows the user to specify up to 50 obstacles around the interrogator of interest. These are specified by an elevation angle to the top of the obstacle from the interrogator of interest, an azimuth-start angle and an azimuth-stop angle. Blocked transmission paths are then found in the following manner:

1. The azimuth and elevation angles to the aircraft are computed.

2. The elevation angle to each obstacle is compared with the elevation angle of the aircraft.

3. If none of the obstacles have elevation angles greater than the aircraft elevation angle, line-of-sight conditions exist and normal processing continues.

4. If an obstacle has an elevation angle greater than the aircraft elevation angle, a test is made to determine if the aircraft azimuth angle lies within the obstacle start-stop azimuth angles.

5. If the conditions in 4 are met, the line-of-sight is blocked and a corresponding level of attenuation is entered into the uplink path.

6. Normal processing then continues.

MODEL INPUT

A typical set of run data cards is shown in Figure 7. The five basic run cards specify the following:

START - interrogator of interest, simulation run time and ground receiver variables

RANGE - radius around interrogator of interest of aircraft and interrogator selection from the data files

RANDOM - seed for random number generator used when random initial interrogator azimuth angles or random start times are desired

TNSPDR - transponder parameters

SWITCH - switches for choice of model options

TABLE 4 defines the card abbreviations.

A major modification to the original TSC model was the replacement of card inputs for interrogators and aircraft deployments with inputs provided directly from the ECAC data base.

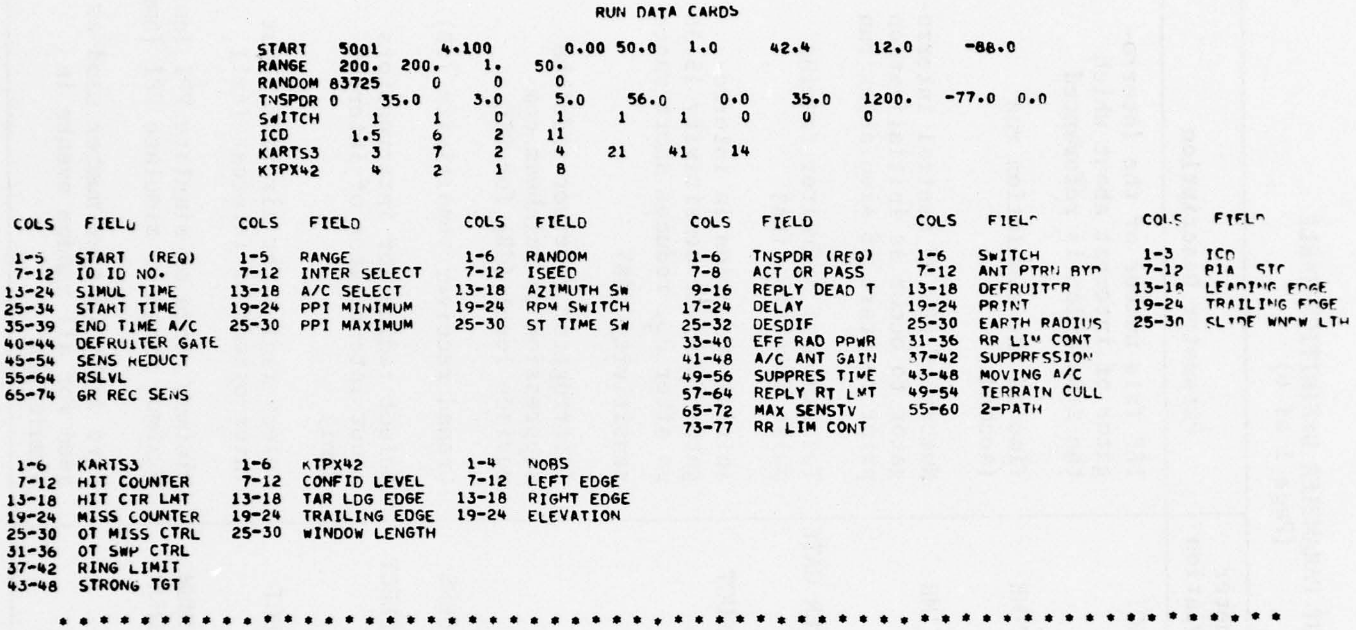
Interrogator Files

Interrogator environments are culled from data in ECAC's IFF/ATCRBS Data Base. Using the ID number of the interrogator of interest, the model determines its latitude and longitude. Using this information, the data base files are automatically searched to extract the information on all interrogators within a specified select radius around the interrogator of interest. The selected interrogators, along with the aircraft information extracted from the aircraft deployment files, form the total working environment for the specified run.

ECAC's IFF/ATCRBS Data Base files are constantly updated by the FAA. Thus the most up-to-date information is always available.

Each interrogator record in the file contains the following information:

1. IFF/ATCRBS file identification number
2. ECAC identification
3. Security classification (S, C, U)



```
                                     RUN DATA CARDS

                   START   5001       4.100       0.00 50.0   1.0     42.4     12.0     -88.0
                   RANGE   200.  200.    1.    50.
                   RANDOM 83725     0     0     0
                   TNSPDR 0    35.0    3.0     5.0    56.0     0.0     35.0    1200.   -77.0  0.0
                   SWITCH     1     1     0     1     1     1     0     0     0
                   ICD      1.5     6     2    11
                   KARTS3     3     7     2     4    21    41    14
                   KTPX42     4     2     1     8

COLS   FIELD            COLS   FIELD           COLS   FIELD          COLS   FIELD            COLS   FIELD            COLS   FIELD

 1-5   START  (REQ)      1-5   RANGE            1-6   RANDOM          1-6   TNSPDR (REQ)      1-6   SWITCH            1-3   ICD
 7-12  IO ID NO.         7-12  INTER SELECT     7-12  ISEED           7-8   ACT OR PASS       7-12  ANT PTRN BYP      7-12  PIA  STC
13-24  SIMUL TIME       13-18  A/C SELECT      13-18  AZIMUTH SW      9-16  REPLY DEAD T     13-18  DEFRUITER        13-18  LEADING EDGE
25-34  START TIME       19-24  PPI MINIMUM     19-24  RPM SWITCH     17-24  DELAY            19-24  PRINT            19-24  TRAILING EDGE
35-39  END TIME A/C     25-30  PPI MAXIMUM     25-30  ST TIME SW     25-32  DESDIF           25-30  EARTH RADIUS     25-30  SLIDE WNDW LTH
40-44  DEFRUITER GATE                                                33-40  EFF RAD PPWR     31-36  RR LIM CONT
45-54  SENS REDUCT                                                   41-48  A/C ANT GAIN     37-42  SUPPRESSION
55-64  RSLVL                                                         49-56  SUPPRES TIME     43-48  MOVING A/C
65-74  GR REC SENS                                                   57-64  REPLY RT LMT     49-54  TERRAIN CULL
                                                                     65-72  MAX SENSTV       55-60  2-PATH
                                                                     73-77  RR LIM CONT

 1-6   KARTS3            1-6   KTPX42           1-4   NOBS
 7-12  HIT COUNTER       7-12  CONFID LEVEL     7-12  LEFT EDGE
13-18  HIT CTR LMT      13-18  TAR LDG EDGE    13-18  RIGHT EDGE
19-24  MISS COUNTER     19-24  TRAILING EDGE   19-24  ELEVATION
25-30  OT MISS CTRL     25-30  WINDOW LENGTH
31-36  OT SWP CTRL
37-42  RING LIMIT
43-48  STRONG TGT

    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Figure 7. Typical run data card set.

TABLE 4

INPUT PARAMETER DEFINITION TABLE
(Page 1 of 6)

Card ID	Parameter Abbreviation	Parameter Description
START	IO ID NO.	IFF file number of the interrogator of interest about which the simulation is referenced
	SIMUL TIME	Time of the simulation run (seconds)
	START TIME	Number of PRP of central interrogator to occur as initialization prior to start of simulation run
	DEFRUITER GATE	Tolerance of defruiter framing pulse detection (μs)
	SENS REDUCT	Initial reduction in interrogator receiver sensitivity 15.36 μs after P_3, reduces short range sensitivity (dB)
	RSLVL	Interrogator receiver sidelobe suppression to mainbeam comparison level (dB) for STC
	GR REC SENS	Ground receiver sensitivity (dB)
RANGE	INTER SELECT	Select radius for interrogators about interrogator of interest (nmi)
	A/C SELECT	Select radius for aircraft about interrogator of interest (nmi)
	PPI MINIMUM	Minimum range of simulate PPI (nmi)
	PPI MAXIMUM	Maximum range of simulate PPI (nmi)
RANDOM	ISEED	Five digit integer number used as seed for all random events in simulation

TABLE 4

(Page 2 of 6)

Card ID	Parameter Abbreviation	Parameter Description
	AZIMUTH SW	Switch for random assignment of interrogator initial azimuths 0 = off 1 = on
	RPM SWITCH	Switch for random bias of interrogator rotation rates 0 = off 1 = on
RANDOM	ST TIME SW	Switch for random occurrance of first pulse of interrogation 0 = off 1 = on
TRNSPDR	ACT OR PAS	= 0 for passive transponder = 1 for active transponder
	REPLY DEAD T	Transponder dead time after reply (μs)
	DELAY	Time delay in transponder for processing reply (usually 3 μs)
	DESDIF	Transponder desensitization difference (dB)
	EFF RAD PPWR	Transponder effective radiated peak power (dBm)
	A/C ANT GAIN	Transponder antenna gain (dB)
	SUPPRES TIME	Transponder suppression time (μs)
	REPLY RT LMT	Reply rate limit (replies per sec)

TABLE 4

(Page 3 of 6)

Card ID	Parameter Abbreviation	Parameter Description
	MAX SENSTV	Nominal sensitivity [without any reduction (dB)]
	RR LIM CONT	Reply rate limit cutoff dB
SWITCH	ANT PTRN BYP	Aircraft antenna bypass switch 1 = on 0 = off (assume 0 dBi omni)
	DEFRUITER	Ground receiver defruiter 1 = on 0 = off
	PRINT	
	EARTH RADIUS	4/3 earth option 1 = on 0 = off
	RR LIM CONT	Switch indicating if reply rate limit counts suppressions as well as interrogations
	MOVING A/C	Moving aircraft switch 1 = moving 0 = stationary
	TERRAIN CULL	Terrain blockage switch 1 = terrain inspected for blocked transmission 0 = terrain not considered
SWITCH	2-PATH	Two path option switch 1 = 2-path on 0 = 2-path off

TABLE 4

(Page 4 of 6)

Card ID	Parameter Abbreviation	Parameter Description
ICD	ICD	Common digitizer is on if this card is in the run deck
	LEADING EDGE	Number of successive hits required to define leading edge of target
	TRAILING EDGE	Number of successive misses required to define trailing edge of target
	SLIDE NNDW LTH	Number of successive hits required to declare a target
KARTS3	KARTS3	ARTS III is on if this card is in the run deck
	HIT COUNTER	No. of hits required prior to a specified number of misses to set target leading edge flag
	HIT CTR LMT	Minimum hit required to declare target
	MISS COUNTER	Specified number of misses associated with setting target leading edge flag
	OT MISS CTRL	Old target status check
	OT HIT CTRL	Minimum number of sweeps used for target validity
	RING LIMIT	Number of hits on target required to declare ring around

TABLE 4

(Page 5 of 6)

Card ID	Parameter Abbreviation	Parameter Description
	STRONG TARGET	Number of hits required to declare high quality target
KTPX42	KTPX42	TPX42 processor is on if this card is included in the run deck
	CONFID LEVEL	Number of hits that must be received on a primary mode to declare valid target
	TAR LDG EDGE	Number of hits in the window required to set target leading edge flag
KTPX42	TRAILING EDGE	Number of hits in the window is reduced to this number to declare trailing edge after target has been declared
	WINDOW LENGTH	Length of sliding window (number of excessive hits *and* misses)
NOBS	NOBS LEFT EDGE RIGHT EDGE	One card is required for each obstacle to be placed about the interrogator of interest start and stop (left and right) angle in degrees is specified for the obstacle 0 degrees is North
	ELEVATION	Elevation angle above horizontal
STAG	STAG	One card is required for each stagger PRF interrogator in the model
	ID	ID no. of staggered PRF interrogator

TABLE 4

(Page 6 of 6)

Card ID	Parameter Abbreviation	Parameter Description
	NSTS	Number of steps in stagger pattern up to 8
	NPRF1 : NPRF8	PRF's used in staggered pattern as they occur
JITT	JITT	One card required for each interrogator with jittered PRF
	ID	ID no. of jittered PRF interrogator

4. Latitude and longitude (degrees, minutes, seconds)
5. Site elevation (feet above mean sea level)
6. City/military-base name
7. State
8. Antenna equipment nomenclature
9. Antenna height (feet)
10. Antenna scan rate (rpm)
11. Antenna mainbeam gain (dBi)[a]
12. Antenna horizontal mainbeam width (degrees)[a]
13. Antenna sidelobe gain (dBi)[a]
14. Antenna horizontal sidelobe width (degrees)[a]
15. Antenna backlobe gain (dBi)[a]
16. I/R equipment nomenclature
17. Sidelobe suppression indicator (conventional, improved, no SLS, RSLS)
18. Mode interlace
19. Transmitter output power (peak kW)
20. Receiver sensitivity (dBm)
21. Pulse repetition frequency (pulse pairs per second)
22. Operating agency (USAF, FAA, etc.)
23. Unit or division of operating agency
24. Environment indicator (MIN: operates at least 8 hours daily; included in normal or minimum environment. MAX: limited operation; included in maximum I/R environment only).

Aircraft Deployment Files

ECAC has constructed aircraft deployment files for many areas in the continental U.S. from photographs of ATCRBS replies on radar plan position indicator (PPI) scopes and digital target report listings. Latitude, longitude and aircraft altitude are currently in this file and provision is made in the model to accept aircraft speed, heading, pitch, yaw and roll data. The information on transponder reply codes used with the modified processor subroutines is currently entered separately via card deck.

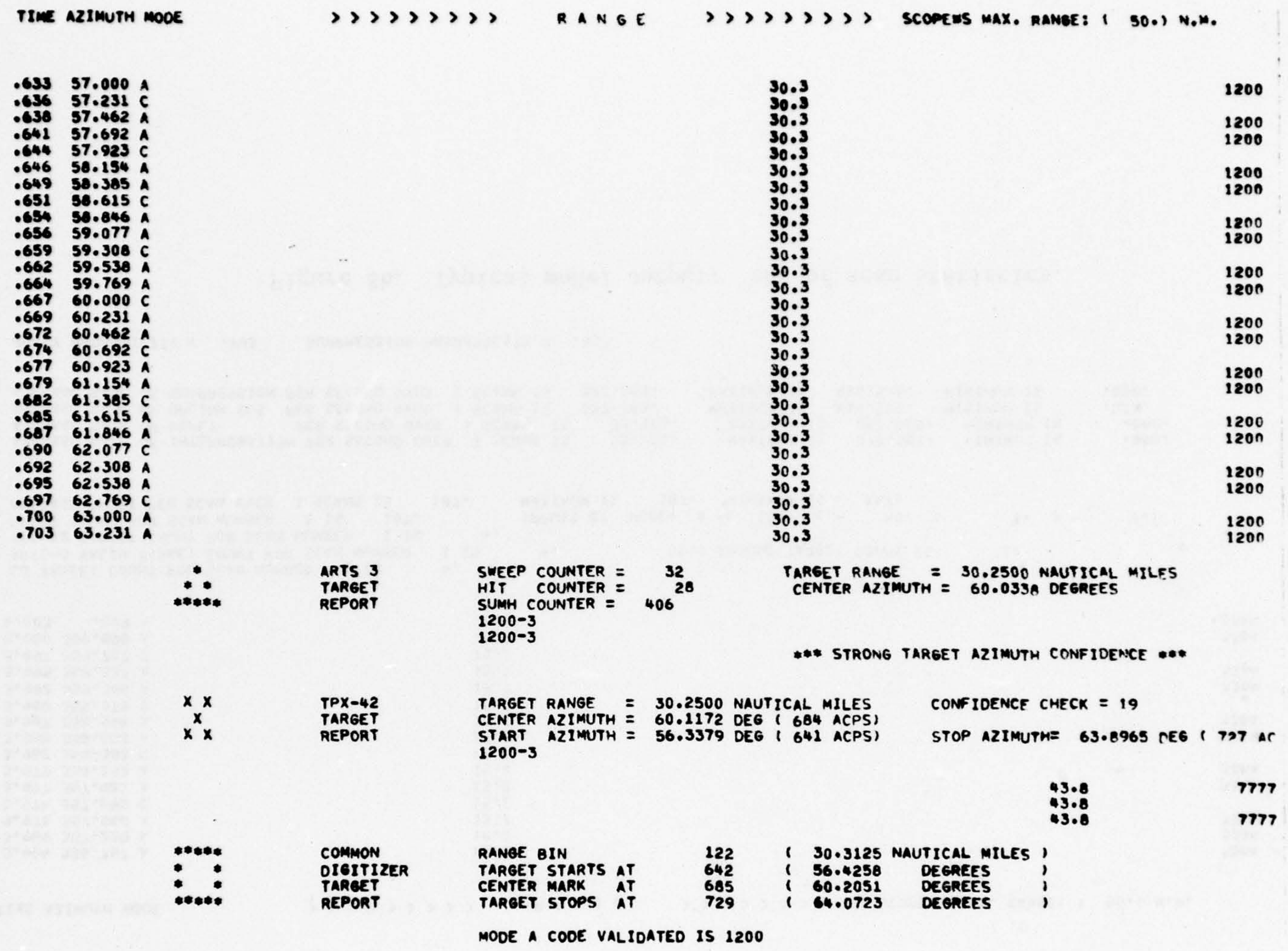
Other transponder characteristics are described on the TRNSPDR input card.

MODEL OUTPUT

Figures 8a and 8b are typical pages of model output. Each pulse repetition period of the interrogator of interest that produces one or more target hits, as identified by the decoder, will show up as a single line of output. This line will print out, reading from

---

[a] Three-level approximation of horizontal pattern.



```
TIME AZIMUTH MODE          >>>>>>>>>>    R A N G E    >>>>>>>>>>  SCOPE*S MAX. RANGE: ( 50.) N.M.

.633  57.000 A                                        30.3                                          1200
.636  57.231 C                                        30.3
.638  57.462 A                                        30.3                                          1200
.641  57.692 A                                        30.3                                          1200
.644  57.923 C                                        30.3
.646  58.154 A                                        30.3                                          1200
.649  58.385 A                                        30.3                                          1200
.651  58.615 C                                        30.3
.654  58.846 A                                        30.3                                          1200
.656  59.077 A                                        30.3                                          1200
.659  59.308 C                                        30.3
.662  59.538 A                                        30.3                                          1200
.664  59.769 A                                        30.3                                          1200
.667  60.000 C                                        30.3
.669  60.231 A                                        30.3                                          1200
.672  60.462 A                                        30.3                                          1200
.674  60.692 C                                        30.3
.677  60.923 A                                        30.3                                          1200
.679  61.154 A                                        30.3                                          1200
.682  61.385 C                                        30.3
.685  61.615 A                                        30.3                                          1200
.687  61.846 A                                        30.3                                          1200
.690  62.077 C                                        30.3
.692  62.308 A                                        30.3                                          1200
.695  62.538 A                                        30.3                                          1200
.697  62.769 C                                        30.3
.700  63.000 A                                        30.3                                          1200
.703  63.231 A                                        30.3                                          1200
             *        ARTS 3       SWEEP COUNTER =     32      TARGET RANGE    =  30.2500 NAUTICAL MILES
            * *       TARGET       HIT   COUNTER =     28       CENTER AZIMUTH =  60.0338 DEGREES
           *****      REPORT       SUMH COUNTER =   406
                                   1200-3
                                   1200-3
                                                                *** STRONG TARGET AZIMUTH CONFIDENCE ***

            X X       TPX-42       TARGET RANGE   =  30.2500 NAUTICAL MILES      CONFIDENCE CHECK = 19
             X        TARGET       CENTER AZIMUTH =  60.1172 DEG ( 684 ACPS)
            X X       REPORT       START  AZIMUTH =  56.3379 DEG ( 641 ACPS)      STOP AZIMUTH=  63.8965 DEG ( 727 AC
                                   1200-3

                                                                                    43.8            7777
                                                                                    43.8
                                                                                    43.8            7777

           *****      COMMON       RANGE BIN              122      (  30.3125 NAUTICAL MILES )
           *   *      DIGITIZER    TARGET STARTS AT       642      (  56.4258    DEGREES     )
           *   *      TARGET       CENTER MARK   AT       685      (  60.2051    DEGREES     )
           *****      REPORT       TARGET STOPS  AT       729      (  64.0723    DEGREES     )

                                   MODE A CODE VALIDATED IS 1200
```

Figure 8a. Typical model output: single target with processor reports.

```
TIME AZIMUTH MODE              >>>>>>>>>>     R A N G E     >>>>>>>>>>   SCOPE=S MAX. RANGE: (  50.) N.M.

3.964 356.767 A                        15.2                                                            3364
3.969 357.229 A                        15.2                                                            3364
3.972 357.460 A                        15.2                                                            3364
3.974 357.690 C                        15.2
3.977 357.921 A                        15.2                                                            3364
3.979 358.152 A                        15.2                                                            3364
3.982 358.383 C                        15.2
3.985 358.613 A                        15.2                                                            3364
3.987 358.844 A                        15.2                                                            3364
3.990 359.075 C                        15.2
3.992 359.306 A                        15.2                                                            3364
3.995 359.537 A                        15.2                                                            3364
3.997 359.767 C                        15.2
4.000 359.998 A                        15.2                                                            3364
4.003    .229 A                        15.2                                                            3364

 CD TARGET COUNT FOR SCAN NUMBER    1 IS       4.
 ARTS-3 VALID TARGET COUNT FOR SCAN NUMBER   1 IS      4.          RING AROUND TARGET COUNT IS       0.
 TPX-42 TARGET COUNT FOR SCAN NUMBER   1 IS       4.
 FRUIT COUNT FOR SCAN NUMBER   1 IS    187.          (FRUIT BY  MODE, A -   107, C -    80, 1 -     0, 2 -     0.)
 AVERAGE FRUIT PER SCAN OVER  1 SCANS IS    187.     MAXIMUM IS    187,   MINIMUM IS    187.


 AVERAGE RATE OF INTERROGATION PER SECOND OVER  1 SCANS IS     35.250.     MAXIMUM IS   370.500,   MINIMUM IS      .000.
 AVERAGE RATE OF REPLY         PER SECOND OVER  1 SCANS  IS    35.000.     MAXIMUM IS   351.000,   MINIMUM IS      .000.
 AVERAGE RATE OF UPLINK SLS  PER SECOND OVER  1 SCANS IS   337.763.     MAXIMUM IS  410.526,   MINIMUM IS      .000.
 AVERAGE RATE OF SUPPRESSION PER SECOND OVER  1 SCANS IS   323.263.     MAXIMUM IS  410.526,   MINIMUM IS      .000.

 REPLY PROBABILITY =  .993     SUPPRESSION PROBABILITY =  .957
```

Figure 8b. Typical model output: end of scan statistics.

left to right, the current time, the angular position of the interrogator of interest in degrees, the mode of the interrogation, and any target replies received during the current simulation cycle. Targets are described by range, in nautical miles from the interrogator of interest, and by azimuth.

After a complete 360 degree rotation of the interrogator of interest, the following statistics are printed:

1. Running target counts for the CD, TPX-42, and ARTS III processors
2. Fruit count for each 360° rotation by mode of interrogation
3. Average, maximum, and minimum fruit per 360° rotation to date
4. Average, maximum, and minimum interrogation, reply, uplink SLS, and suppression rates for each aircraft
5. Reply and suppression probabilities for each aircraft.

The three processors will produce output at any time during the run when their respective detection criteria are met. Processor output for each target detected consists of the following:

CD

Range bin (nmi)
Start azimuth (ACP's, degrees)
Center azimuth (ACP's, degrees)
End azimuth (ACP's, degrees)
Code validation information

ARTS III

Range
Center azimuth
Sweep count
Hit count
Sumh count
Strong target azimuth confidence label, if reached
Mode A code validation number and code
Mode C code validation number and code

TPX-42

Range
Start azimuth
Stop azimuth
Center azimuth
Confidence check (number of 3/A replies)
Code validation number and reported code.

SECTION 4

SUMMARY

A Transient Effects PPM has been developed to allow ECAC to simulate short-term ATCRBS performance at a pulse-by-pulse level.

The model includes options to simulate terrain and obstacle blocking, staggered and jittered PRF's, and two-path propagation.

The first application of the Transient Effects PPM will be to examine the performance of the terminal beacon at Washington National Airport and the enroute interrogator at JFK, New York, with the objective of analyzing time-related effects such as broken and missed targets and PRF changes. This work will be reported under Detailed Analysis Task 20-b.1 of the ATCRBS Spectrum Management Program (reference report FAA-RD-77-89).

RECOMMENDATION

The FAA may wish to consider further work in this area at some later time to augment the transient effects performance prediction model with a simulation of the ARTS II processor.