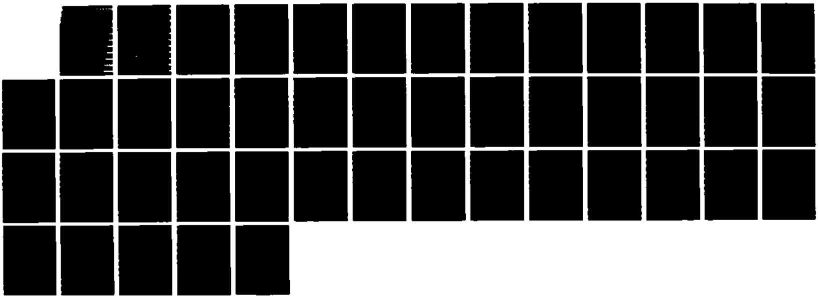
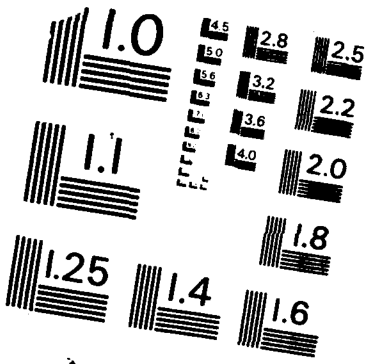
AD-A170 824 A COMPARISON OF THE EFFECTS OF TWO TRAFFIC ALERT AND COLLISION AVOIDANCE..(U) ELECTROMAGNETIC COMPATIBILITY ANALYSIS CENTER ANNAPOLIS MD T O'GRADY ET AL. APR 86 1/1

UNCLASSIFIED ECAC-CR-86-027 DOT/FAA/PM-86/8 F/G 17/7 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DOT/FAA/PM-86/8

Program Engineering
and Maintenance Service
Washington, D.C. 20591

A Comparison of the Effects of Two Traffic Alert and Collision Avoidance Systems (TCAS III and TCAS II) on the Performance of the Air Traffic Control Radar Beacon System

IIT Research Institute
Under Contract to
Department of Defense
Electromagnetic Compatibility
Analysis Center
Annapolis, Maryland 21401

April 1986
Final Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/PM-86/8	ADA170824	

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
A Comparison of the Effects of Two Traffic Alert and Collision Avoidance Systems (TCAS III and TCAS II) on the Performance of the Air Traffic Control Radar Beacon System	5. Report Date: April 1986 6. Performing Organization Code: P0328
7. Author(s): T. O'Grady, D. Katz, C. Corse	8. Performing Organization Report No.: ECAC-CR-86-027
9. Performing Organization Name and Address: DoD Electromagnetic Compatibility Analysis Center, North Severn, Annapolis, MD 21402	10. Work Unit No. (TRAIS) 11. Contract or Grant No.: F-19628-85-C-0071, CDRL # 10M
12. Sponsoring Agency Name and Address: US Department of Transportation, Federal Aviation Administration, Program Engineering & Maintenance Service, Washington, DC 20591	13. Type of Report and Period Covered: FINAL - 5/84 to 3/86 14. Sponsoring Agency Code: APM-330

15. Supplementary Notes

IIT Research Institute, under contract to DoD.

16. Abstract

An analysis was performed to predict the effects of the Traffic Alert and Collision Avoidance System (TCAS III) on the performance of the Air Traffic Control Radar Beacon System (ATCRBS) in the Los Angeles Basin. This was accomplished by comparing the effects of TCAS III and TCAS II operations on airborne transponder and ground-based ATCRBS interrogator performance in the same hypothetical peak Los Angeles Basin aircraft deployment.

17. Key Words	18. Distribution Statement
ATCRBS, Los Angeles Basin, Mode S, TCAS, TCAS II, TCAS III	This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	52	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DOT/FAA/PM-86/8

PREFACE

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

This report was prepared for the Program Engineering and Maintenance Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WA1-175, as part of AF Project 649E under Contract F-19628-85-C-0071, 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 Standards Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the USA Standards Institute.

Robert Clarke

ROBERT CLARKE
Project Manager, IITRI

Stuart Kennison

STUART M. KENNISON
Director of Research
Contractor Operations

Approved by:

DAVID J. ESSES, Col, USAF
Director

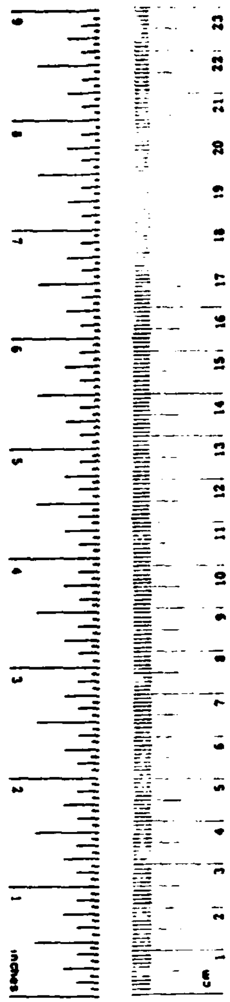
RICHARD A. JEDLICKA, Lt Col, USAF
Air Force Deputy Director

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

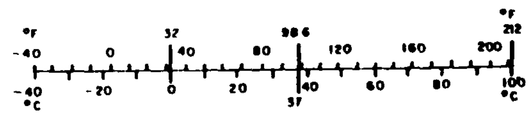
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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



EXECUTIVE SUMMARY

The Traffic Alert and Collision Avoidance System (TCAS III) analyzed in this report was developed to provide a collision-avoidance function for TCAS III-equipped aircraft in air traffic environments populated with both Air Traffic Control Radar Beacon System (ATCRBS) and Mode S (referred to previously as the Discrete Address Beacon System (DABS)) transponder-equipped aircraft. TCAS III-equipped aircraft perform the Collision Avoidance System (CAS) tracking function by actively interrogating other aircraft in the local airspace. The Federal Aviation Administration (FAA) requested that the Electromagnetic Compatibility Analysis Center (ECAC) investigate the effect of these TCAS III-related emissions on ground-based Air Traffic Control (ATC) system performance.

For this analysis, TCAS III operation was modeled in accordance with the current TCAS III design used by the Bendix Corporation in their engineering model. This design does not include an interference limiting capability as does the TCAS II design. An analytical model was developed by ECAC to predict the rate at which TCAS III-related signals arrive at all transponders in a peak hypothetical air traffic deployment for the Los Angeles Basin. This TCAS III signal environment was merged with the ground-based ATC signal environment to develop the composite TCAS III/ATC signal environment. (The ground-based ATC signal environment was predicted using the DABS/ATCRBS/AIMS Performance Prediction Model (PPM).) This composite TCAS III/ATC signal environment was then compared with a composite TCAS II/ATC signal environment in an identical air traffic deployment. Based on this comparison, it is predicted that TCAS III operations, relative to TCAS II operations, will have the following effects:

1. Decrease the average ATCRBS interrogation rate by 7.3%
2. Decrease the average ATCRBS side lobe suppression rate by 13.5%
3. Increase the average ATCRBS transponder reply efficiency by 0.7%
4. Increase the average Mode S transponder reply efficiency (TCAS III-equipped aircraft) by 0.3%
5. Increase the average Mode S transponder reply efficiency (non-TCAS III-equipped aircraft) by 0.3%
6. Decrease the Long Beach interrogator ATCRBS fruit rate by 6.8%.

Since interrogation rates, suppression rates, fruit rates, and transponder reply efficiences are indicative of ground-based ATC performance, it is predicted that TCAS III operations will reduce the target detection and mode validation efficiency of ground-based ATCRBS less than that predicted for TCAS II operations. (For the Long Beach ATCRBS interrogator, TCAS II operations will reduce Mode A and Mode C validation efficiencies by 0.3% and 0.7%, respectively, but will not reduce target detection efficiency.)

TABLE OF CONTENTS

Subsection | Page

SECTION 1
INTRODUCTION

SECTION 2
SYSTEM DESCRIPTION

SECTION 3
ANALYSIS DESCRIPTION

TABLE OF CONTENTS (Continued)

Subsection | Page

SECTION 4

ANALYSIS RESULTS

SECTION 5

LIST OF ILLUSTRATIONS

Figure

TABLE OF CONTENTS (Continued)

Table | Page

LIST OF TABLES

SECTION 1
INTRODUCTION

BACKGROUND

During the past several years, the Electromagnetic Compatibility Analysis Center (ECAC) has supported the Federal Aviation Administration (FAA) by predicting the effects of various airborne Collision Avoidance Systems (CAS) on the existing FAA Air Traffic Control Radar Beacon System (ATCRBS) and the planned Mode S system (previously called Discrete Address Beacon System (DABS)).[1,2] In FY81, ECAC investigated the effects of an omnidirectional version of the Traffic Alert and Collision Avoidance System (TCAS) on ATCRBS and Mode S system performance in a hypothetical Los Angeles Basin air traffic deployment and in subsets of that deployment.[3,4] For those air traffic deployments, it was predicted that TCAS activity would not significantly degrade ATCRBS or Mode S ATC system performance; however, the design included interference-limiting constraints resulting in undesired reductions in the protection volume of TCAS-equipped aircraft that were operating in densely populated airspace.

---

[1]Theberge, Norman, The Impact of a Proposed Active BCAS on ATCRBS Performance in the Washington, DC, 1981 Environment, FAA-RD-77-140, Washington, DC, September 1977, ADA 048589.

[2]Gettier, C., et al., Analysis of Elements of Three Airborne Beacon Based Collision Avoidance Systems, FAA-RD-79-123, FAA, Washington, DC, May 1979, ADA 082026.

[3]Hildenberger, Mark, User's Manual for the Los Angeles Basin Standard Traffic Model Card Deck/Character Tape Version, FAA-RD-73-89, FAA, Washington, DC, May 1973, ADA 768846.

[4]Patrick, G., and Keech, T., Impact of an Omnidirectional Traffic Alert and Collision Avoidance System on the Air Traffic Control Radar Beacon System and the Discrete Address Beacon System, FAA/RD-81/106, FAA, Washington, DC, November 1981, ADA 116170.

To maximize the protection area for TCAS-equipped aircraft operating in future high-density environments, the FAA proposed a new TCAS design. This design includes a directional scanning antenna, improved Mode S tracking algorithms, a modified whisper-shout (w/s) sequence (to maintain surveillance of ATCRBS-equipped aircraft), and associated revisions to the interference-limiting algorithm.[5] The design was chosen to reduce the extent of interference limiting and thus allow TCAS-equipped aircraft to successfully perform the collision avoidance function in congested airspace (0.3 aircraft per square nmi) and also to reduce the potential for interference with ground-based ATC systems.

Two types of TCAS units, TCAS I and TCAS II, were proposed and developed by the FAA. TCAS I, designed for use in general-aviation aircraft, identifies nearby ATCRBS and Mode S aircraft by periodically eliciting replies using an ATCRBS interrogation format. TCAS II, designed for use in commercial aircraft, provides TCAS II-equipped aircraft with vertical evasive maneuver capability to increase vertical separation from threatening aircraft. This was accomplished with the use of improved antennas capable of omnidirectional Mode S surveillance and limited directional ATCRBS surveillance.

To investigate the effects of TCAS I and TCAS II operations on ATCRBS and Mode S ATC performance, ECAC was requested to perform a simulation analysis similar to the FY81 Los Angeles Basin study (Reference 4). The TCAS Signal Environment Model (SEM)[6] was developed by ECAC to predict the time-average rates at which TCAS signals are received at transponders in a given

---

[5] Radio Technical Commission for Aeronautics, Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, RTCA/DO-185, Washington, DC, September 1983.

[6] Gilchrist, C., et al., Traffic Alert and Collision Avoidance System Signal Environment Model (TCAS SEM) Programmer's Reference Manual, DOT/FAA/PM-85/22, FAA, Washington, DC, July 1985.

deployment. These rates were then used in the DABS/ATCRBS/AIMS[a] Performance Prediction Model (PPM)[7] to merge the TCAS signal environment with signals generated by ground-based ATC systems. These models predicted that the electromagnetic effects of TCAS I and TCAS II operations did not significantly reduce the performance of ATCRBS and Mode S ATC systems; however, in some instances the TCAS surveillance volume still had to be reduced when the systems were operating in very densely populated airspace.[8]

Under the FAA sponsorship, the Bendix Corporation developed an enhanced version of TCAS II (TCAS III) that employs directional antennas to acquire accurate three-dimensional tracks of all ATCRBS- and Mode S-transponder-equipped aircraft. The use of top- and bottom-mounted directional antennas for aircraft surveillance along with improved tracking algorithms provide TCAS III-equipped aircraft with vertical and horizontal evasive maneuver capability in addition to reducing the number of interrogations required to accurately track aircraft within the surveillance volume. TCAS III is designed to operate in traffic densities as high as 0.4[9] aircraft per square nmi.

Due to this added complexity in the TCAS design and to further investigate the effects of TCAS III operation on ATCRBS and Mode S performance, ECAC was requested to perform a statistical analysis to predict the effects of TCAS III operations on ATC system performance.

---

[a]The Discrete Address Beacon System (DABS) was renamed Mode S after the completion of the development of the DABS/ATCRBS/AIMS PPM.

[7]Crawford, C. R., and Ehler, C. W., The DABS/ATCRBS/AIMS Performance Prediction Model, FAA-RD-79-88, FAA, Washington, DC, November 1979, ADA 089440.

[8]Patrick, G., et al., The Impact of a Traffic Alert and Collision Avoidance System on the Air Traffic Control Radar Beacon System and Mode S System in the Los Angeles Basin, DOT/FAA/PM-84/30, FAA, Washington, DC, May 1985.

[9]Enhanced TCAS II System Summary, BCD-TR-098, Bendix Communications Division, Baltimore, MD, April 1984, p. 4.

OBJECTIVE

The objective of this effort was to predict the effects of TCAS III operations on ground-based ATCRBS performance in a Los Angeles Basin environment.

APPROACH

An analytical model was developed to simulate TCAS III operations[10] and to predict the rate at which TCAS III signals arrive at transponders in a Los Angeles basin air traffic deployment. The TCAS III arrival rates were combined with ground-based ATC signal rates to determine the composite rates at all transponders in the deployment. (Ground-based ATC rates were predicted using the DABS/ATCRBS/AIMS PPM.) The composite signal rates were then used in conjunction with the attendant receiver/processor response to estimate the reply efficiency and reply rate of each transponder. The estimated reply rate of each transponder in conjunction with the reply rate and fruit rate[a] predicted by the FY84 TCAS II simulation analysis (Reference 8) was used to predict the fruit rate at the Long Beach ATCRBS interrogator receiver due to TCAS III/ATC operations. The estimated average transponder reply efficiency and the received fruit rate with TCAS III/ATC operations were then compared with the corresponding values predicted for TCAS II/ATC operations. The differentials in these performance parameters were then used in conjunction with the associated receiver/processor performance (target detection and mode validation efficiencies) from the TCAS II analysis to estimate the effects of TCAS III on Long Beach ATCRBS performance.

The interrogator deployment used in this analysis was developed from the ATCRBS/IFF data base at ECAC and, as specified by the FAA, consisted of all

---

[a]Fruit rate is defined as the rate at which unelicited replies are received at the interrogator-of-interest per second.

[10]Enhanced TCAS II Computer Program Documentation, Bendix Communication Division, Volume 1, Parts I through III, (no date), pp. 3.1-3.65.

interrogators within 500 nmi of Los Angeles. This deployment consisted of 61 ATCRBS interrogators and was derived from a total ATC system population of 140 interrogators. Due to terrain shielding and power limitations, 79 interrogators were eliminated.

The peak hypothesized Los Angeles basin air traffic deployment used in this analysis consists of 743 aircraft within 60 nmi of Los Angeles with a maximum density within 5 nmi about any TCAS III-equipped aircraft of 0.534 aircraft per square nmi. In this deployment, 25% of the aircraft are Mode S-equipped (44% of these are TCAS III-equipped) with the remaining 75% being ATCRBS-equipped.

The performance of ATCRBS is presented in terms of the estimated values of interrogation and suppression rates at airborne transponders, transponder reply efficiency, and the fruit rate at the Long Beach ATCRBS interrogator. For this analysis, transponder reply efficiency is defined as one minus the percentage of transponder dead time where dead time is defined as the time the transponder receiver/processor is occupied with receiving and processing interrogations and suppressions and generating replies. The interrogation and suppression rates are defined as the number of each of these types of signals received per second at each aircraft. These system parameters were used as a basis to deduce the effect of TCAS III operations on ground-based ATCRBS performance in terms of target detection and mode validation efficiency.

REPORT ORGANIZATION

The remainder of this report is organized as follows:

1. Section 2 provides a brief description of the operational characteristics of the ATCRBS and Mode S systems used in this analysis and a summary of the operational and technical characteristics for the current TCAS III design. This is followed by a brief description of the significant differences between the TCAS III and TCAS II systems.

2. Section 3 outlines the approach used in predicting TCAS III signal activity and describes the aircraft deployment and transponder operational characteristics used in this analysis.

3. The results of this analysis are given in Section 4, which includes the effect of TCAS III operations on airborne transponder and Long Beach ATCRBS interrogator performance.

4. Section 5 summarizes the results discussed in Section 4 and includes the conclusions drawn from these results.

SECTION 2
SYSTEM DESCRIPTION

ATCRBS

The Air Traffic Control Radar Beacon System (ATCRBS) is presently used by the FAA as a means of surveillance for ATC. The ATCRBS interrogator is a secondary surveillance radar (SSR) that transmits interrogations (1030 MHz) and receives replies (1090 MHz) from transponder-equipped civilian and military aircraft.

The two modes of interrogations, Modes A and C, used by the ATCRBS interrogator provide aircraft identity and altitude information, respectively. Interrogations can be from either ground-based ATC sites, airborne interrogators, or TCAS-equipped aircraft. The mode of the interrogation is uniquely determined by the separation between two of the three pulses (P_1, P_3) which form the interrogation (see Figure 2-1). The third pulse (P_2) allows for sidelobe suppression and is referred to as the interrogator sidelobe suppression (SLS) pulse. This pulse occurs 2 μs after the leading edge of the first pulse and is transmitted via an omnidirectional antenna or the difference pattern of an interrogator antenna. If the SLS pulse received by the transponder is at least 9 dB below the interrogation P_1 pulse, the transponder processes the interrogation. These modes are transmitted automatically in a given sequence (mode interlace) in accordance with the requirements of each ATC site.

When an interrogation is detected, the transponder suppresses each mode decoder for a time period not to exceed 35 μs for civilian transponders. During this dead time, the transponder prepares and transmits a reply. All replies have a similar format and consist of two framing pulses separated by 20.3 μs from leading edge to leading edge. Up to twelve information pulses can be inserted between the framing pulses. The time required to process and transmit the reply is approximately 23 μs. When an SLS pulse is detected with the proper relative amplitude, the transponder is suppressed for 35 ± 10μs.

The interrogator receives replies created in response to its own mainbeam interrogations. Unwanted replies or other random signals entering the receiver may interfere with the detection of valid replies. This interference can be reduced by SLS so that the transponder replies only to mainbeam interrogations, as described earlier. Replies received at the interrogator are processed, correlated, and displayed on a plan position indicator for observation by the controller.

MODE S

The Mode S Beacon System is a combined SSR system and ground-air-ground data link system capable of providing aircraft surveillance and communications and is capable of common-channel interoperation with ATCRBS.

The fundamental difference between Mode S and ATCRBS lies in the manner in which aircraft are selected to respond to an interrogation. In ATCRBS, the selection is spatial, i.e., all aircraft within the mainbeam of the interrogator respond. In Mode S, each aircraft is assigned a unique address code. Selection is then accomplished by including the aircraft's address code in the interrogation, thus ensuring that a specific aircraft will respond to the interrogation.

The Mode S sensor range orders interrogations to Mode S aircraft in such a way that valid replies do not overlap. In order to be discretely interrogated in this manner, an aircraft must be on a sensor's roll-call file, i.e., the sensor must know its address and approximate location. To establish targets not already on a sensor's roll-call file, each sensor transmits all-call interrogations that contain a specified reply probability for all Mode S-equipped aircraft receiving the interrogation. Upon receipt of an all-call interrogation the transponder executes a stochastic process in which a reply decision is made in accordance with the specified reply probability. Depending upon the outcome of the stochastic process, the transponder may respond with its unique address. This random occurrence of replies allows the

Mode S sensor to acquire closely spaced aircraft whose replies would otherwise be synchronously garbled.

There are three basic signal formats used by Mode S for surveillance of ATCRBS and Mode S-equipped aircraft and data link communication with Mode S-equipped aircraft:

1. ATCRBS/Mode S all-call interrogation
2. ATCRBS only all-call interrogation
3. Mode S interrogation.

The ATCRBS/Mode S and ATCRBS only all-call interrogations are similar to the corresponding ATCRBS interrogations but have an additional pulse P_4 following P_3 to suppress Mode S transponders (see Figure 2-1).

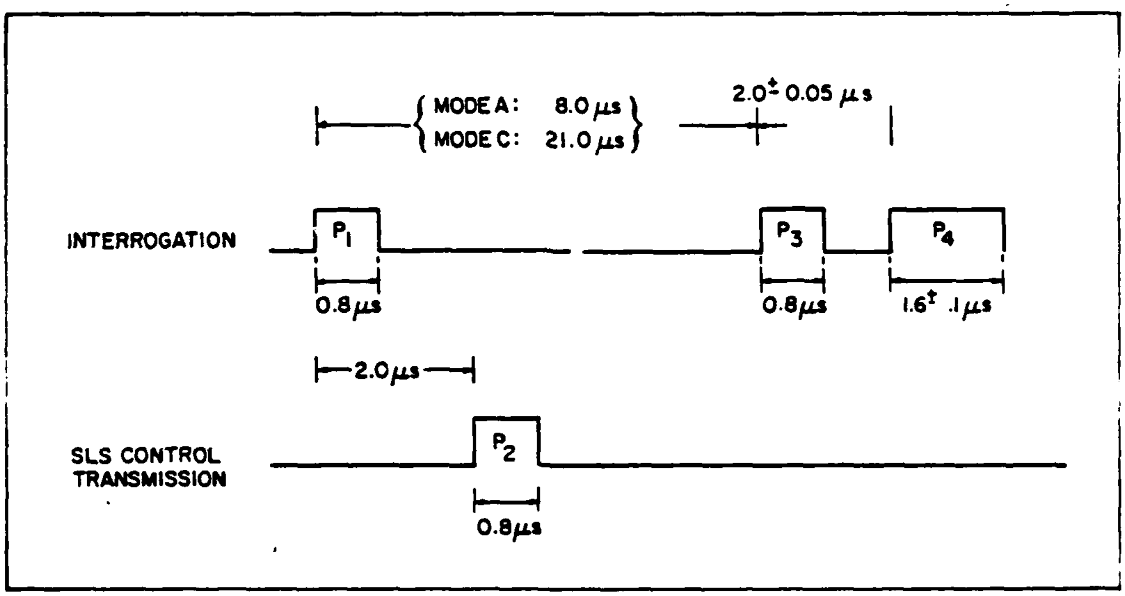


Figure 2-1. ATCRBS/Mode S all-call interrogation format.

The Mode S interrogation is formed by three pulses, P_1, P_2, and P_6 (see Figure 2-2). Pulses P_1 and P_2 are spaced 2 μs apart and form the preamble of the interrogation. The preamble initiates a sidelobe suppression in an ATCRBS transponder for 35 μs to keep the transponder from issuing a spurious reply due to P_6. P_6 contains the data of the Mode S interrogation and is either 16.25 or 30.25 μs long. The Mode S reply signal format consists of two pairs of 0.5 μs pulses followed by either 56 or 112 μs data block depending on the amount of information transmitted.

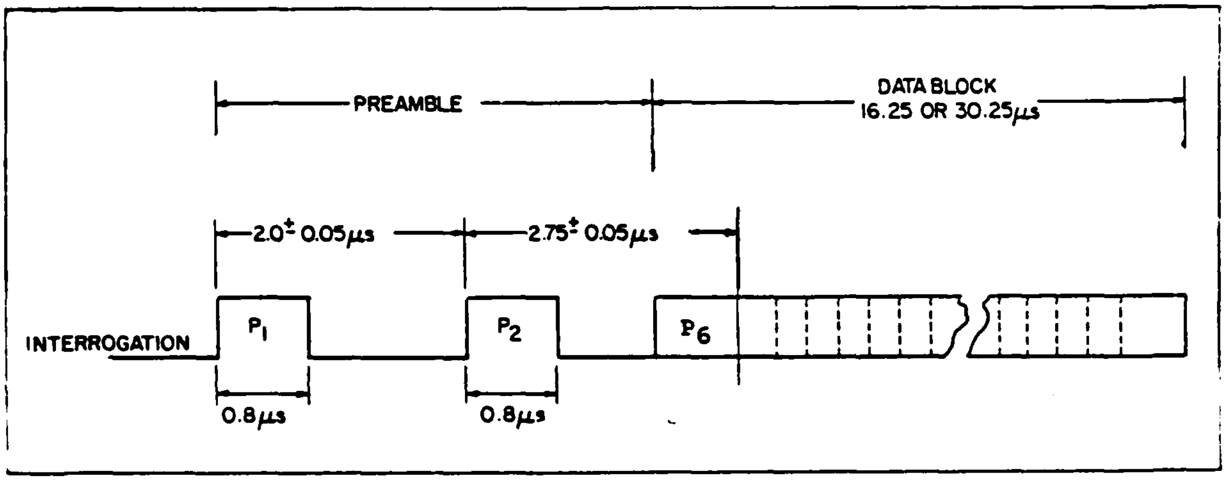


Figure 2-2. Mode S interrogation format.

Transponders are subjected to a variety of signal formats from ATCRBS interrogators, Mode S interrogators, and TCAS interrogators. The reaction of a transponder receiver/processor and transmitter to each type of signal is, in general, different for Mode S and ATCRBS transponders. TABLE 2-1 lists the different types of signals that may be received at transponders and the resultant receiver/processor and transmitter action.[11,12]

---

[11]"US National Aviation Standard for the Discrete Address Beacon System (DABS)," Department of Transportation, FAA, Washington, DC, December 1980.

[12]"US National Standard for IFF Mark X (SIF)/Air Traffic Control Radar Beacon System Characteristics," Agency Order 1010.51, FAA, Washington, DC, March 1971.

TABLE 2-1

TRANSPONDER INTERROGATION PROCESSING AND DEAD TIMES

Transmission Type	Transponder Type	Receiver Dead Time (μs)	Transmitter Action
ATCRBS Interrogation	ATCRBS	60	Reply
ATCRBS-Only Interrogation[a]	ATCRBS	60	Reply
ATCRBS-Suppression	ATCRBS	35	Suppression
Mode S Interrogation (All-Call and Roll-Call)	ATCRBS	35	Suppression
ATCRBS Interrogation	Mode S	60	Reply
ATCRBS-Only Interrogation	Mode S	24	Suppression
ATCRBS Suppression	Mode S	35	Suppression
Mode S Interrogation (at transponder address)	Mode S	192 (short reply) 248 (long reply)	Reply
Mode S Interrogation (not at transponder address)	Mode S	20 (short interro.) 32 (long interro.)	Suppression Suppression
Mode S All-Call Interrogation	Mode S	128	Reply

[a]ATCRBS-only interrogations are transmitted by Mode S sensors and TCAS III interrogators.

TCAS III

TCAS III is an airborne system that is designed to use existing ATCRBS and Mode S signal formats to perform the collision-avoidance function. TCAS III tracks ATCRBS-equipped aircraft in its vicinity with a w/s interrogation sequence. TCAS III tracks Mode S-equipped aircraft by listening for Mode S transmissions (squitters) to determine if any aircraft is a potential threat (i.e., within the potential collision altitude window). If so, TCAS III will discretely interrogate the aircraft to obtain range and bearing in order to determine if the establishment of a track is required. The surveillance of both ATCRBS- and Mode S-equipped aircraft is performed over an approximate one-second interrogation scheduling interval (see Figure 2-3). TABLE 2-2 gives the TCAS III interrogator characteristics.

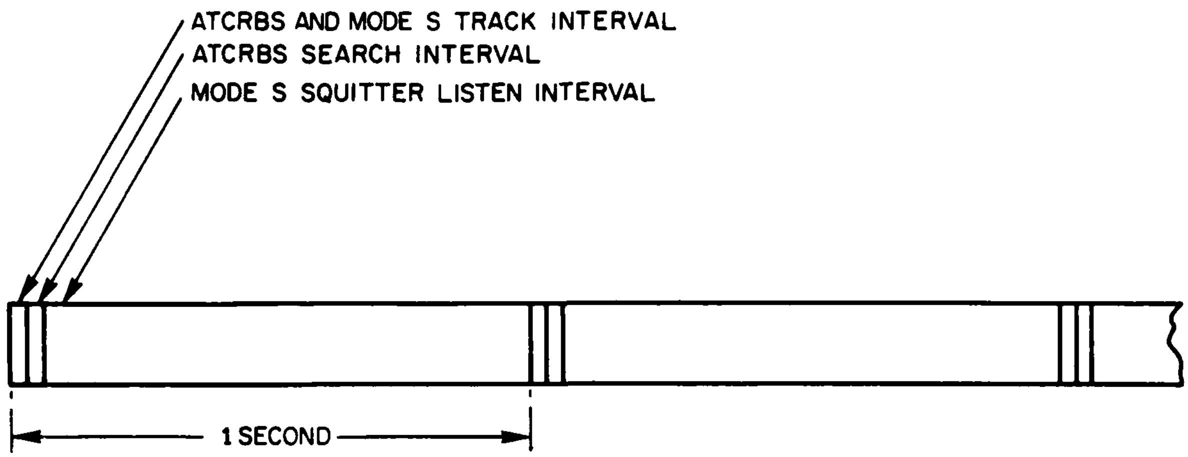


Figure 2-3. TCAS III surveillance timing.

TABLE 2-2

TCAS III CHARACTERISTICS

Transmit Power[a]	26.2 dBw
Receiver Sensitivity (MTL[b])[a] (1090 MHz Channel)	-77.0 dBm
Cable Loss	3 dB
Peak Antenna Gain (directional in azimuth)[c]	4.2 dBi (Mode S) -0.8 dBi (ATCRBS)

[a]Transmitter power and receiver sensitivity were statistically assigned using a normal distribution with a standard deviation of 0.5 dB.

[b]Minimum triggering level (90% decode level).

[c]A sum and difference antenna system is used to sharpen the 64° 3 dB beamwidth used for Mode S transmissions to the 22.5° beamwidth used for ATCRBS transmissions.

The TCAS III-equipped aircraft carries a Mode S air traffic control transponder which performs the functions of existing ATCRBS (Modes A and C) transponders and provides Mode S air-to-air communications for coordinating the resolution of encounters between TCAS III- and TCAS II-equipped aircraft. The Mode S transponder is also used for communications with the ground-based Mode S sensor for surveillance and air-to-ground data link purposes.

Surveillance Capability

TCAS III uses directional antennas to accurately measure bearing and range for both Mode S and ATCRBS targets within its surveillance volume. The directional antenna is capable of producing an interrogation beam used for ATCRBS tracking and searching of 22.5 degrees and for Mode S tracking of 64.0 degrees. This beam can be electronically steered around the TCAS III-equipped aircraft in increments of 5.625 degrees yielding 64 individual beam positions. During ATCRBS searching, however, only 32 beam positions on each antenna are searched (even beams on the top and odd beams on the bottom). In addition, the directional antennas provide Mode S-squitter listening on a 64-degree beam which can also be electronically steered to any one of 12 beam positions (6 each for top and bottom antennas). For ATCRBS track and search, the surveillance range (for processing replies) is a function of bearing with a maximum range of 16.6 nmi fore and 8.0 nmi aft. Mode S tracking is omnidirectional with a maximum surveillance range of 20 nmi (Figure 2-4). For all interrogations transmitted through the bottom antenna, however (unless the target was initially acquired through the top antenna), power is attenuated to limit the surveillance range to 4 nmi and reduce the effects of multi-path on the acquisition of new targets. Both ATCRBS and Mode S surveillance volumes are limited to a relative altitude difference of 7000 feet.

ATCRBS Track and Search Routine

As previously stated, TCAS III performs its interrogation scheduling during an interval of approximately one second and begins the interval with

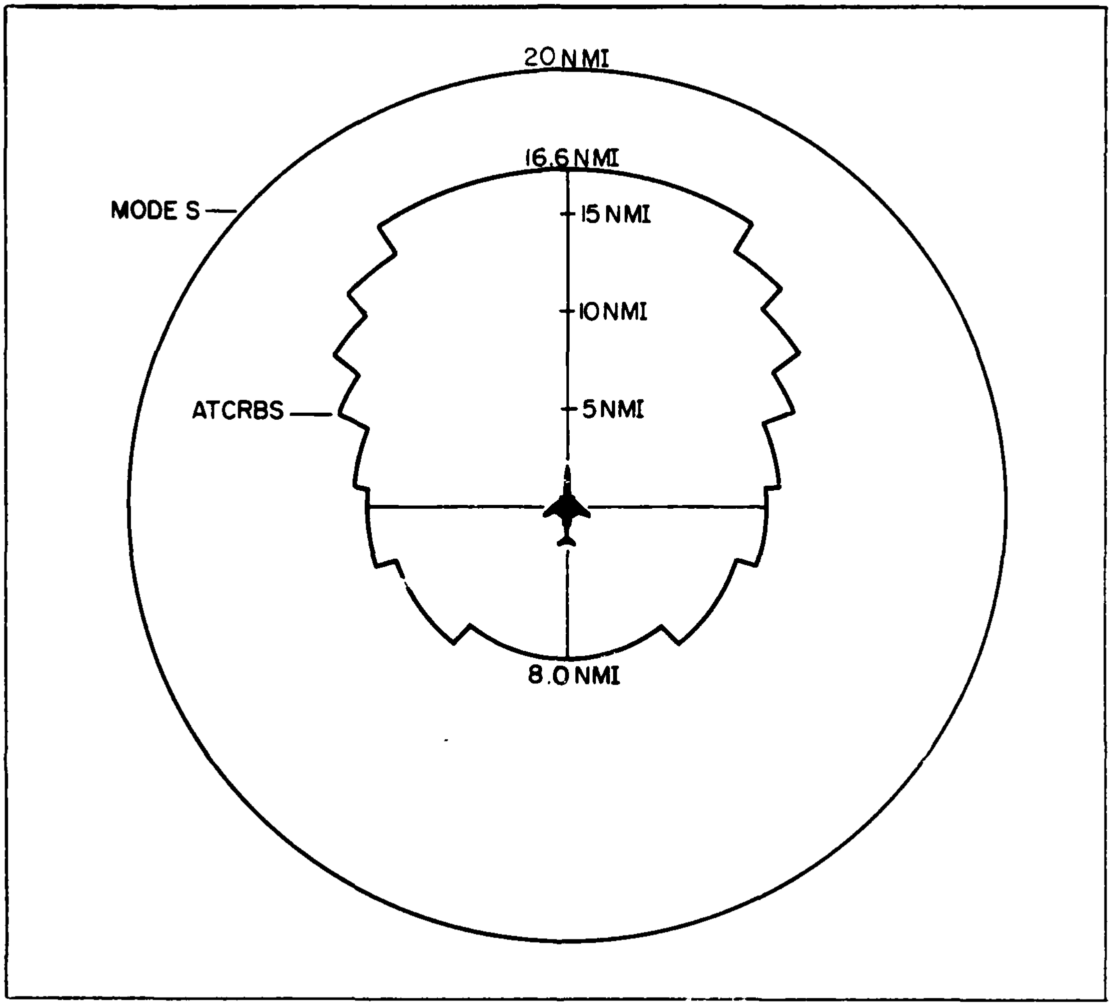


Figure 2-4. TCAS III surveillance region.

ATCRBS tracking. In ATCRBS tracking, only those aircraft from which the TCAS III-equipped aircraft have received correlated replies are actively tracked during this interval. Each of these aircraft is interrogated individually and the track interrogation format used is a function of the number of previous replies received from the victim aircraft. Also, interrogation power is attenuated as shown in TABLE 2-3.

TABLE 2-3

ATTENTUATION AS A FUNCTION OF RANGE
(ATCRBS AND MODE S)

Target Range (nmi)	ATTN (dB)
14.9 - up	0
13.3 - 14.9	1
11.9 - 13.3	2
10.6 - 11.9	3
9.4 - 10.6	4
8.4 - 9.4	5
7.2 - 8.4	6
0. - 7.2	7

For aircraft that the TCAS III-equipped aircraft has received 1 or 2 previous replies, a double 4-level w/s interrogation sequence is transmitted. Those with three previous replies are interrogated with a single 4-level w/s interrogation sequence which is immediately repeated at full power if no reply is received. These aircraft are automatically interrogated once per second.

For those aircraft with four or more previous replies, the track interrogation format used is identical to that used for aircraft with three previous replies but at an interrogation rate determined by their motion relative to the TCAS III-equipped aircraft. Three times are determined for each of these aircraft: time 1 equals the amount of time the target takes to move 1000 feet in slant range relative to the TCAS III-equipped aircraft; time 2 equals the amount of time the target takes to move 4 degrees in bearing relative to the TCAS III-equipped aircraft; and time 3 equals the amount of time the target takes to move 100 feet in altitude relative to ground. The interrogation rate is then set at the minimum of these three times with a maximum rate of once per second and a minimum rate of once per 4 seconds. If the CAS logic has determined the target to be a proximity, traffic, or resolution advisory, however, the interrogation rate is automatically set to once per second.

After all ATCRBS tracking is completed, the ATCRBS search routine is performed in order to acquire targets not already actively tracked. ATCRBS searching is conducted with a well-defined search interrogation schedule which is repeated every 8 seconds (see Figure 2-5). The interrogation schedule is divided into eight 1-second intervals in which 9 to 11 different sectors (beams) may be interrogated per interval. All search interrogations transmitted through the top antenna are composed of a double 4-level w/s sequence with the 4 levels being 18 dB, 14 dB, 10 dB, and 0 dB below the maximum power transmitted for the particular sector (the double interrogation is used for defruiting purposes). Interrogation sequences transmitted through the bottom antenna consist of a double 1-level interrogation. The search interrogation schedule is designed to provide a 0.98 probability of detecting a target before it can pass 10,000 feet into the TCAS III surveillance volume zone.

Mode S Search and Track Routine

To perform Mode S search, the antenna is switched to one of the 12 Mode S squitter listening beams. TCAS III listens at that beam position for approximately 1.2 seconds and is briefly interrupted only to conduct ATCRBS searching and Mode S/ATCRBS tracking (see Figure 2-3). Once a squitter is detected, TCAS III discretely interrogates the aircraft to determine if it is within its surveillance volume. If so, the aircraft is tracked using a protocol similar to that used in ATCRBS tracking.

For aircraft which the TCAS III-equipped aircraft has received 1 or 2 previous replies, a single discrete interrogation is transmitted. Those aircraft with 3 or more previous replies are interrogated with a single discrete interrogation that is immediately repeated at full power if no reply is received. The interrogation rate for all Mode S-equipped aircraft is determined with the identical protocol used in tracking ATCRBS-equipped aircraft. In addition, interrogation power is attenuated as a function of range (see TABLE 2-3). If any aircraft (ATCRBS- or Mode S-equipped) fails to reply to 5 consecutive interrogations, it will automatically be deleted from the TCAS III track file. (For a more detailed description of TCAS III, see Reference 10.)

INTERROGATION INTERVAL (Seconds)										INTERROGATION INTERVAL (Seconds)									
Top Antenna		1	2	3	4	5	6	7	8	Bottom Antenna		1	2	3	4	5	6	7	8
THETA = 0°[a]	0	X				X					1			X				X	
	2				X				X		3		X				X		
	4			X				X			5	X				X			
	6		X				X				7				X				X
	8	X				X					9			X				X	
	10						X				11		X						
	12	X									13					X			
	14							X			15			X					
90°	16		X								17						X		
	18								X		19				X				
	20			X							21							X	
	22	X									23					X			
B	24				X					B	25								X
E	26		X							E	27						X		
A	28					X				A	29	X							
M	30				X					M	31							X	
180°	32						X				33		X						
N	34					X				N	35	X							
U	36								X	U	37				X				
M	38						X			M	39		X						
B	40	X								B	41					X			
E	42							X		E	43			X					
R	44		X							R	45						X		
	46								X		47				X				
270°	48			X							49							X	
	50	X									51					X			
	52				X						53								X
	54		X								55						X		
	56	X				X					57			X				X	
	58				X				X		59		X				X		
	60			X				X			61	X				X			
	62		X				X				63				X				X

Tables repeat after eight interval/seconds. Only even beams on the top antenna and odd beams on the bottom antenna are interrogated during search.

[a]THETA = Interrogation beam angle relative to TCAS aircraft heading.

Figure 2-5. ATCRBS search interrogation schedule.

COMPARISON OF TCAS II AND TCAS III

TCAS II is an airborne system (as is TCAS III) that is designed to use existing ATCRBS and Mode S signal formats to perform the collision avoidance function. (For a more detailed description of TCAS II, see Reference 5.) The antenna design and surveillance protocol used by TCAS II and TCAS III to perform this function are significantly different in several respects.

The main difference between TCAS II and TCAS III antenna design and surveillance protocol is in the technique used to reduce the number of overlapping replies (synchronous garble) received from each interrogation. The current TCAS II antenna design employs a 4-beam (Beam Width = 130°) directional antenna on top of the aircraft and a bottom-mounted omnidirectional antenna for ATCRBS surveillance. A total of 83 w/s interrogations per second is transmitted via these 5 beams (see TABLE 2-4). This technique partitions the ATCRBS environment with respect to transponder sensitivity.

TABLE 2-4

TCAS II WHISPER-SHOUT SEQUENCE

Antenna	Beam	Number of Whisper-Shout Levels
Top	Forward	24
Top	Right	20
Top	Left	20
Top	Rear	15
Bottom	Omni	4

TCAS III employs a 32-beam (beamwidth = 22.5°) directional antenna on top and bottom of the aircraft for ATCRBS surveillance. An average of 52 w/s interrogations per second are transmitted via these 64 beams (see Figure 2-5) while conducting the ATCRBS search routine. The total number of w/s interrogations transmitted per second while conducting ATCRBS surveillance (search and track), however, depends upon the number of ATCRBS-equipped aircraft being tracked. Because the number of interrogation beams is increased and the number of interrogations transmitted per beam is reduced, the ATCRBS environment is essentially partitioned with respect to transponder sensitivity and relative bearing.

Another major difference between TCAS II and TCAS III is in the surveillance protocol of Mode S-equipped aircraft. TCAS II-equipped aircraft must elicit a decodable Mode S reply once per second from all other Mode S equipped-aircraft within approximately 7 nmi, and at a rate which decreases monotonically with range for aircraft beyond 7 nmi. The rate at which TCAS III elicits decodable replies from Mode S-equipped aircraft within its surveillance volume depends upon their motion relative to the TCAS III-equipped aircraft.

Each TCAS II-equipped aircraft also periodically computes interference estimates that are used to ensure that TCAS-II related emissions will not cause excessive interference to ground-based ATC and surveillance systems (see References 5 and 8). Interference-limiting is implemented by adjusting a TCAS II-equipped aircraft's interrogation power and minimum triggering level (MTL) and by eliminating selected ATCRBS interrogation steps from the w/s sequence. The current TCAS III design as embodied in the Bendix experimental model does not employ interference limiting in any form. However, interference limiting may be implemented in future production quality TCAS III units.[13]

---

[13] Draft US National Aviation Standard for the Enhanced Traffic Alert and Collision Avoidance System II, FAA, Washington, DC, 28 August 1984.

SECTION 3
ANALYSIS DESCRIPTION

AIRCRAFT DEPLOYMENT

For this analysis, simulations were conducted using the standard, hypothesized, peak Los Angeles Basin air traffic deployment.[a] The peak deployment consists of 743 transponder-equipped aircraft that are all within 60 nmi of Los Angeles (689 general aviation, 30 air-carrier, and 24 military). The aircraft deployment used consists of a nominal mix of 25% Mode S (44% of these were TCAS III-equipped) and 75% ATCRBS transponder-equipped aircraft. For this deployment, 53 of the general-aviation aircraft are designated high-performance (multiple-engine) aircraft. The 188 Mode S transponder-equipped aircraft include the 30 air-carrier, the 53 high-performance general aviation, and 105 of the remaining general-aviation aircraft. The 30 air-carrier and the 53 high-performance general-aviation aircraft were assumed to be equipped with TCAS III. The remaining 555 aircraft were modeled as equipped with ATCRBS transponders (see TABLE 3-1).

TRANSPONDER CHARACTERISTICS

Each transponder-equipped aircraft is represented by an antenna (omni-directional in azimuth), antenna cable, receiver/processor, and a transmitter. The (quantized) vertical antenna gain patterns, as modeled, are illustrated in Figure 3-1. These patterns were derived from measured data for the Boeing 727 antenna/airframe configuration. For this analysis, it was assumed that ATCRBS transponder-equipped aircraft were fitted with a single, bottom-mounted antenna, while Mode S transponder-equipped aircraft were fitted with both top- and bottom-mounted antennas. ATCRBS and Mode S transponders are assumed to use the same bottom antenna pattern. Polarization losses were not considered.

---

[a]This deployment is identical to that used in the FY84 study (Reference 8) with TCAS II replaced by TCAS III.

TABLE 3-1

AIRCRAFT DEPLOYMENT USED IN THE ANALYSIS

Parameter	Deployment
Total Number of Aircraft	743
Number of Mode S-equipped (TCAS III-equipped)	188 (83)
Number of ATCRBS-equipped	555
Maximum Aircraft Density within 5 nmi of any TCAS III-equipped Aircraft	0.534
Maximum Aircraft Density within 10 nmi of any TCAS III-equipped Aircraft	0.394
Maximum Aircraft Density within 30 nmi of any TCAS III-equipped Aircraft	0.164

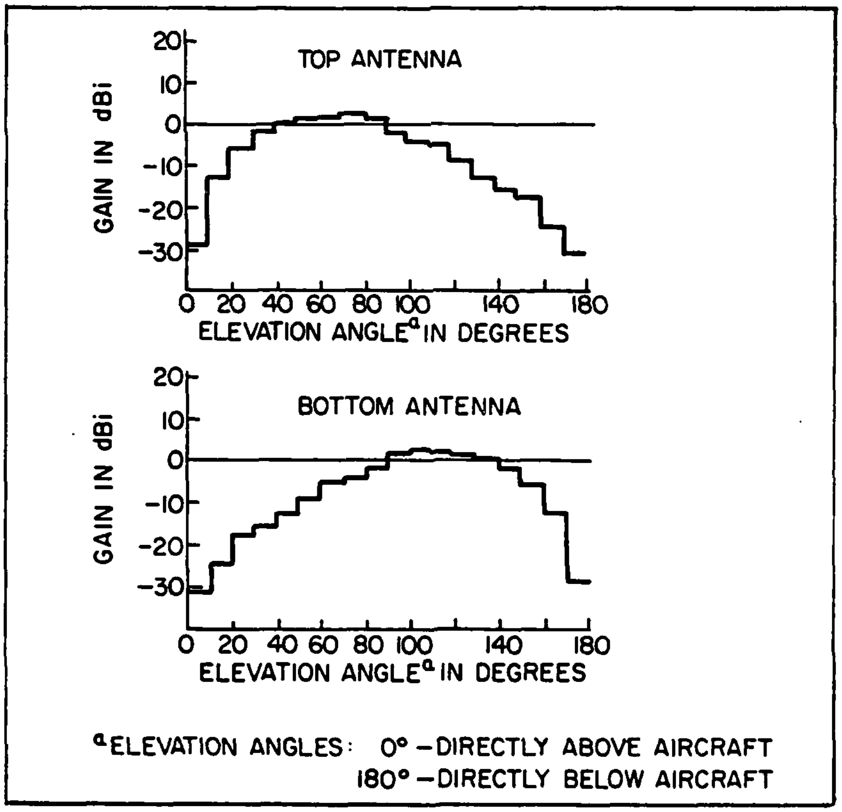


Figure 3-1. Quantized vertical antenna patterns assumed for transponder-equipped aircraft.

The cable loss from the antenna terminals to the receiver/transmitter terminals was assumed to be 3 dB for the entire transponder population.

The receiver sensitivity and transmitter power output of each type of transponder were assigned statistically (see Reference 8), using Monte Carlo techniques, based on measured data[14] for the ATCRBS transponders and equipment specifications for the Mode S and TCAS transponders. The population distributions of ATCRBS receiver sensitivity and transmitter power distribution for the deployment used are illustrated in Figures 3-2 and 3-3, respectively. The average value of receiver sensitivity is -74 dBm; the average value of transmitter power is 27 dBw.

Mode S transponder-equipped aircraft receiver/transmitter characteristics were assigned using the normal probability distribution function (see Reference 11). The receiver sensitivity distribution for Mode S transponder-equipped aircraft that were not TCAS III-equipped was developed using a mean value of -77 dBm with a standard deviation of 1.5 dB. The sensitivity distribution for Mode S transponder-equipped aircraft that were TCAS III-equipped was constructed using a mean value of -77 dBm with a standard deviation of 0.5 dB. Reply power levels for the two populations of Mode S transponders were assigned in a similar way: an average reply power of 27 dBw with a standard deviation of 1.5 dB for Mode S-equipped aircraft that are not TCAS III-equipped and a reply power of 26.2 dBw with a standard deviation of 0.5 dB for Mode S-equipped aircraft that are TCAS III-equipped.

TCAS III SYSTEM MODELING

In determining the TCAS III signal activity for the selected aircraft deployment, an analytical model was developed to simulate the TCAS III surveillance protocol. This model predicted the performance of all transponders during a one-second interval with TCAS III operating. As

---

[14] Colby, G. V., and Crocker, E. A., Final Report Transponder Test Program, FAA-RD-72-30, FAA, Washington, DC, April 1972, AD 740786.

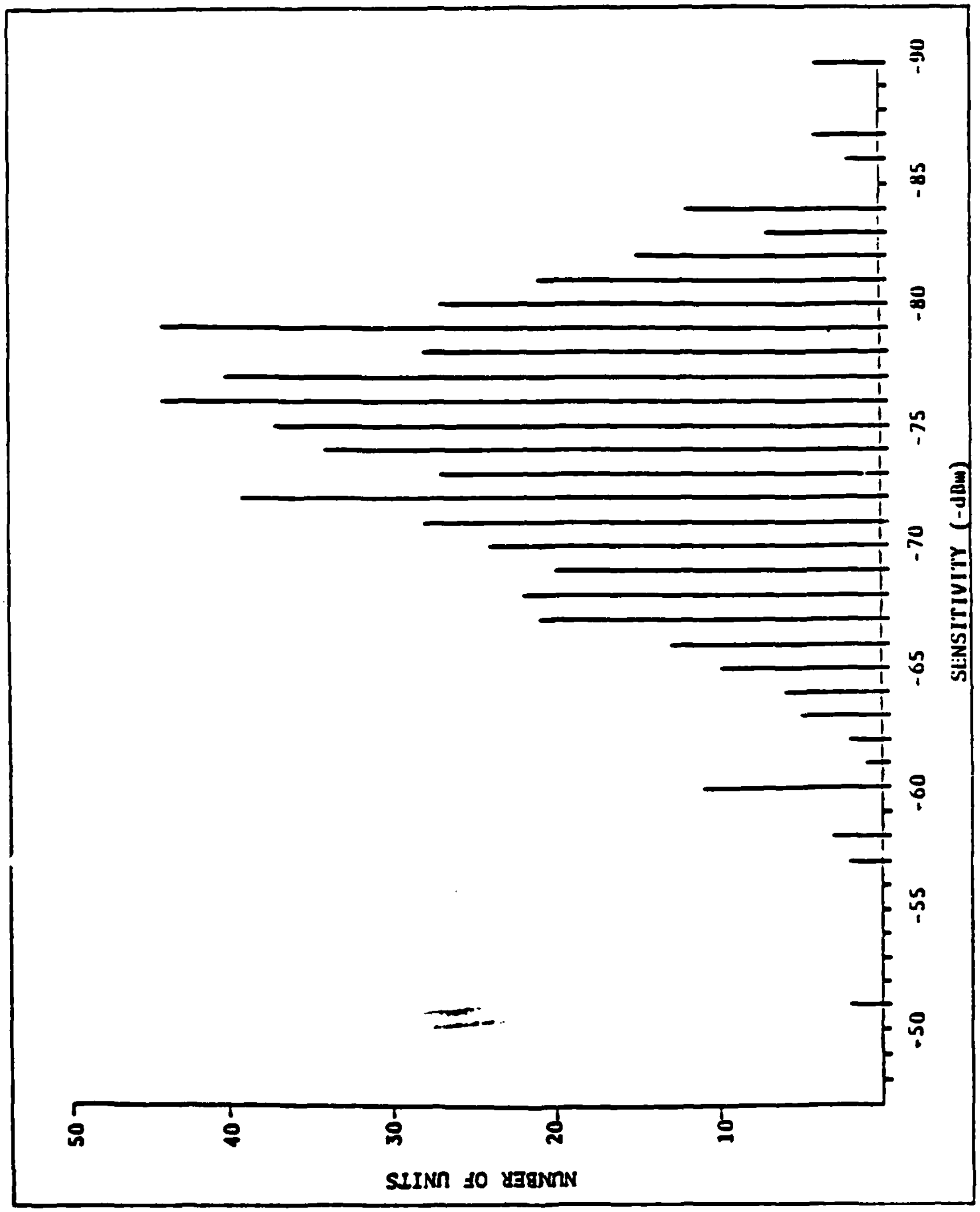


Figure 3-2. Distribution of receiver sensitivities assigned to the ATCRBS transponder population.

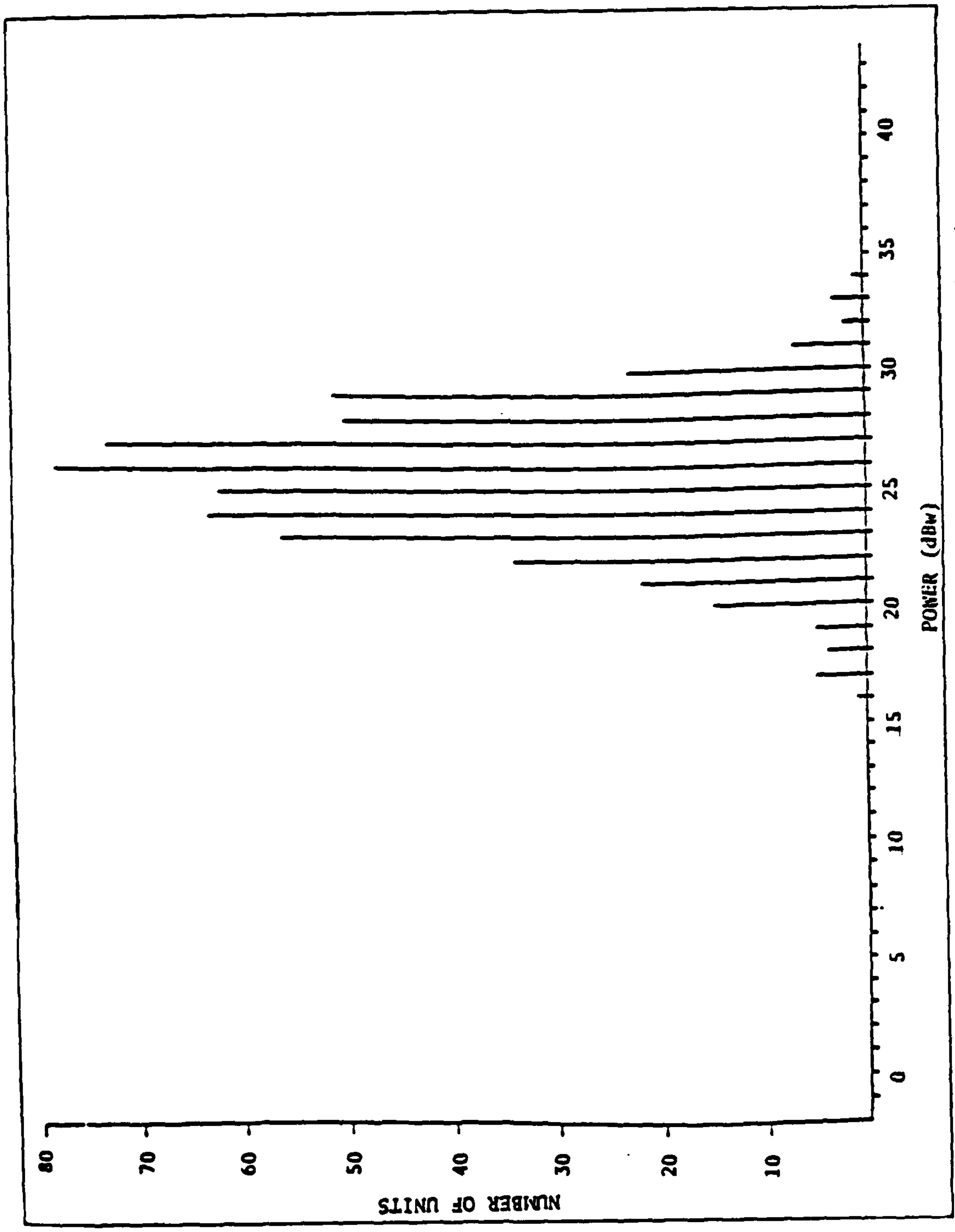


Figure 3-3. Distribution of transmitter power assigned to the ATCRBS transponder population.

described in Section 2, the TCAS III surveillance protocol consists of various interrogation formats transmitted at varying rates. The type of interrogation format used to interrogate a particular target aircraft is dependent upon the TCAS III-equipped aircraft's track history (number of previous replies received) for that aircraft which, in turn, is dependent upon the reply efficiency of the target aircraft and the reply rate (ATCRBS fruit) received at the TCAS III-equipped aircraft.[15,16] The rate at which each target aircraft is individually interrogated is a function of the relative position and velocity of the target aircraft to that of the TCAS III-equipped aircraft. Because TCAS III signal activity is dependent upon the target reply efficiency and ATCRBS fruit rate, an iterative procedure was used in predicting TCAS III signal activity (see Figure 3-4).

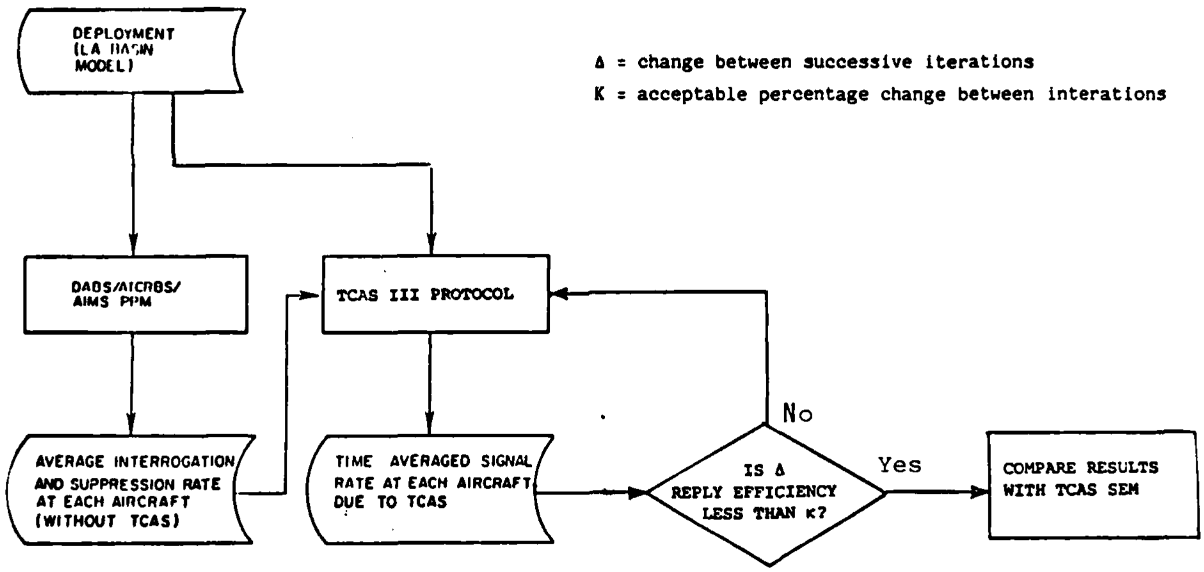


Figure 3-4. TCAS III model flow diagram.

---

[15] McDonald, T. S., BCAS DABS Reply Processing Performance Analysis, Report No. 42W-5062, Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, MA, 8 October 1976.

[16] Matheson, R. J., and Pratt, R. M., Air Traffic Control Radar Beacon System (ATCRBS) Interference Investigation in Los Angeles Area, Report No. 77-125, US Department of Commerce/Office of Telecommunications, June 1977.

To begin the iterative procedure, an initial transponder reply efficiency was estimated by using the results of a 10-scan DABS/ATCRBS/AIMS PPM simulation. The results of this simulation consisted of the time-averaged ATC interrogation and suppression rate received at each transponder within the deployment. These rates were then used in conjunction with the attendant receiver/processor response to estimate the reply efficiency and reply rate of each transponder. The fruit rate due to each aircraft at each TCAS III-equipped aircraft was then estimated by calculating the reply power received at the TCAS III receiver for each transponder replying to ATC interrogations. The total fruit rate was then predicted by summing all transponder replies received above the TCAS III receiver MTL.

Interrogation Format

The next step in predicting TCAS III signal activity was to determine the interrogation format transmitted to each transponder within the TCAS III surveillance volume. Because the interrogation format depends upon the number of previous transponder replies received, a track history[a] was generated for each aircraft within the TCAS III surveillance volume. This was accomplished with a simulated 20-second aircraft deployment movement during which each aircraft within the TCAS III surveillance volume was interrogated once per second. Depending upon the number of replies received during the simulated aircraft movement, the appropriate interrogation format was then assigned to each aircraft. Any aircraft whose replies were all below the TCAS III-equipped aircraft's MTL was not actively tracked.

The interrogation rate for all target aircraft within each TCAS III-equipped aircraft surveillance volume was determined as follows. Target aircraft with less than four decodable replies or within 2 nmi of the TCAS III-equipped aircraft were automatically assigned an interrogation rate of once per second. For target aircraft with four or more decodable replies, the

[a]An aircraft's track history consists of the number of decodable replies to TCAS III interrogations received above MTL during actual inflight operations.

interrogation rate assigned was determined by the amount of time required (due to aircraft's position and velocity) for the target aircraft to move the following distances: 1000 feet in slant range relative to the TCAS III-equipped aircraft, 4 degrees in bearing relative to the TCAS III-equipped aircraft's heading, and 100 feet in altitude relativ to the ground. In this analysis, the times required for the aircraft to move these distances were determined by calculating the average rate of change per second in the target aircraft's slant range, bearing, and altitude. The interval between successive interrogations was chosen as the minimum value of the three aircraft transient times or 4 seconds (whichever was less). The minimum interval between successive interrogations was limited to one second.

Target Tracking

With the interrogation format, interrogation rate, and track record for each target aircraft determined, all target tracking was then performed. The interrogation rate and track record were used to determine, statistically, which target aircraft were interrogated during the one-second interval under consideration. These aircraft were then individually interrogated with the interrogation format previously assigned to them, and the received power for each interrogation at all transponders in the deployment was calculated. If the received power was above the transponder's MTL, the appropriate interrogation or suppression array was incremented, depending upon transmission and target aircraft type (ATCRBS or Mode S). The above process was repeated for every target aircraft within each TCAS III-equipped aircraft's surveillance volume.

In determining the channel activity generated by the TCAS III ATCRBS search routine, a similar method was used. The ATCRBS search routine (see Section 2) was performed and the received power for each interrogation at each transponder in the deployment was calculated. Again, if the received signals were above the transponder's MTL, the appropriate array (interrogation or suppression) was incremented according to the type of transponder (ATCRBS or Mode S) receiving the signal.

Transponder Performance

The final step in the iterative process of determining TCAS III signal activity was to determine the cumulative total of interrogations and suppressions from ground-based ATC operations (predicted by the DABS/ATCRBS/AIMS PPM) and TCAS III operations. With these new rates, the reply efficiency of each transponder along with the fruit rate received at each TCAS III-equipped aircraft was recalculated. The entire procedure was then repeated with these new reply efficiencies and fruit rates.

The above iterative process was repeated until the change in average transponder reply efficiency between successive iterations, relative to the overall average transponder reply efficiency, was reduced to 0.02%. At this point, the performance of all transponders was assessed. The effects of TCAS III signal activity on transponder performance was then compared to that predicted for TCAS II. The results of this comparison are presented in Section 4 (see TABLE 4-1) and were used to determine the effects of TCAS III on ground-based ATCRBS performance.

SECTION 4
ANALYSIS RESULTS

UPLINK RESULTS

The performance of all transponders that were within 60 nmi of the Long Beach ATCRBS interrogator and received interrogations and/or suppressions from the Long Beach ATCRBS interrogator is given in terms of interrogation rate, suppression rate, and reply efficiency.[a] The values of these performance parameters (and their standard deviations) are given in TABLE 4-1 along with the corresponding results of the FY84 TCAS II simulation analysis. For the TCAS II simulation analysis, the average transponder reply efficiency was defined as the ratio of the total number of replies to the number of interrogations received (above MTL) at the transponder due to Long Beach ATCRBS interrogations.

For the TCAS III statistical analysis, the average transponder reply efficiency is predicted as one minus the percentage of transponder dead time. Dead time is defined as the time the transponder receiver/processor is occupied with receiving and processing interrogations and suppressions and generating replies to valid interrogations. For TCAS III-equipped aircraft, the transponder dead time also includes the mutual suppressions caused by its own TCAS III interrogations.

As indicated by TABLE 4-1, TCAS II operation increased the average ATCRBS interrogation rate by 13.5%[b] and the ATCRBS sidelobe suppression rate by 20.7% while the ATCRBS interrogation and sidelobe suppression rates resulting from

---

[a]The average ATCRBS interrogation rate, average ATCRBS SLS rate, and average Mode S suppression rate are defined as the average number of each of these types of signals received (above MTL) per second at each aircraft.

[b]Note that these percentage differences are defined as the change in transponder performance when TCAS was introduced into the environment divided by the transponder performance when TCAS was not in the environment.

TABLE 4-1

SUMMARY OF EFFECTS OF TCAS ON ALL TRANSPONDERS RESPONDING TO LONG BEACH ATCRBS INTERROGATIONS (UPLINK)

Total # of Aircraft Within 60 nmi of Long Beach		608	
% Mode S (% TCAS)		28(44)	
% ATCRBS		72	
TCAS Operation	Without	TCAS II[a]	TCAS III [% Diff.[b]]
Average ATCRBS Interrogations Per Second	348	395	366 [-7.3]
(Standard Deviation)	(300)	(324)	(314)
Average ATCRBS Sidelobe Suppressions Per Second	673	812	702 [-13.5]
(Standard Deviation)	(602)	(743)	(643)
Average Mode S Suppressions Per Second Due to TCAS	--	287	165 [-42.5]
(Standard Deviation)	--	(211)	(167)
Average ATCRBS Transponder Reply Efficiency	.957	.940	.947 [+0.7]
(Standard Deviation)	(.034)	(.045)	(.043)
Average Mode S Transponder Reply Efficiency; TCAS-equipped	.957	.939	.942 [+0.3]
(Standard Deviation)	(.023)	(.030)	(.027)
Average Mode S Transponder Reply Efficiency; not TCAS-equipped	.956	.947	.950 [+0.3]
(Standard Deviation)	(.025)	(.029)	(.029)

[a] 46 of the 83 TCAS II-equipped aircraft implemented some degree of interference limiting.

[b] Relative to TCAS II.

TCAS III operation increased by 5.2% and 4.3%, respectively. In addition, the average Mode S suppression rate (due to TCAS operation only) decreased from 287 suppressions per second for TCAS II to 165 suppressions for TCAS III. The reduced interrogation and suppression rates predicted for TCAS III operation resulted in the reply efficiency for each type of transponder to be greater than those predicted for TCAS II operation (also shown in TABLE 4-1). These results yielded a reduction in average transponder reply efficiency of 1.7% with TCAS II operating and of 1.0% with TCAS III operating.

DOWNLINK RESULTS

The downlink analysis consisted of predicting the ATCRBS fruit rate at the Long Beach interrogator. For the TCAS II simulation analysis, the ATCRBS fruit rate was predicted by a 10-scan DABS/ATCRBS/AIMS PPM simulation with the Long Beach Facility being the interrogator-of-interest. This simulation resulted in a predicted ATCRBS fruit rate, with and without TCAS II operating, of 12489 and 11181, respectively (see Reference 8).

For the TCAS III statistical analysis, the ATCRBS fruit rate was predicted by using the linear relationship that exists between transponder reply rate and ATCRBS fruit rate. The ATCRBS fruit rate due to TCAS III operating was then predicted by interpolating between the transponder reply rate,[a] with and without TCAS III operating, and the ATCRBS fruit rate, without TCAS III operating. This interpolation yielded an ATCRBS fruit rate of 11638 with TCAS III operating.

These results yielded an increase in the ATCRBS fruit rate of 11.7% due to TCAS II operating and an increase of 4.1% due to TCAS III operating.

[a]Transponder reply rate is defined as the average ATCRBS interrogation rate times average transponder reply efficiency.

SECTION 5
CONCLUSIONS

An analysis was conducted to predict the effects of TCAS III operations on ATCRBS performance in the Los Angeles Basin. For this analysis, it was predicted that TCAS III operations will have the following effects on airborne transponder and Long Beach ATCRBS interrogator performance, relative to that predicted for TCAS II operations:

1. Decrease the average ATCRBS interrogation rate by 7.3%
2. Decrease the average ATCRBS side lobe suppression rate by 13.5%
3. Increase the average ATCRBS transponder reply efficiency by 0.7%
4. Increase the average Mode S transponder reply efficiency (TCAS III-equipped aircraft) by 0.3%
5. Increase the average Mode S transponder reply efficiency (non-TCAS III-equipped aircraft) by 0.3%
6. Decrease the Long Beach interrogator ATCRBS fruit rate by 6.8%.

These results indicate that, even without using interference limiting, TCAS III operations will reduce airborne transponder performance less than that predicted for TCAS II operations. In addition, since interrogation rates, suppression rates, fruit rates, and transponder reply efficiencies are indicative of ground-based ATC performance, it is predicted that TCAS III operations will reduce the target detection and mode validation efficiency of ground-based ATCRBS less than that predicted for TCAS II operations. (For the Long Beach ATCRBS interrogator, TCAS II operations will reduce the Mode A and Mode C validation efficiencies by 0.3% and 0.7%, respectively, but will not reduce target detection efficiency. See Reference 8.)

LIST OF REFERENCES

1. Theberge, Norman, The Impact of a Proposed Active BCAS on ATCRBS Performance in the Washington, DC, 1981 Environment, FAA-RD-77-140, Washington, DC, September 1977, ADA 048589.

2. Gettier, C., et al., Analysis of Elements of Three Airborne Beacon Based Collision Avoidance Systems, FAA-RD-79-123, FAA, Washington, DC, May 1979, ADA 082026.

3. Hildenberger, Mark, User's Manual for the Los Angeles Basin Standard Traffic Model Card Deck/Character Tape Version, FAA-RD-73-89, FAA, Washington, DC, May 1973, ADA 768846.

4. Patrick, G., and Keech, T., Impact of an Omnidirectional Traffic Alert and Collision Avoidance System on the Air Traffic Control Radar Beacon System and the Discrete Address Beacon System, FAA/RD-81/106, FAA, Washington, DC, November 1981, ADA 116170.

5. Radio Technical Commission for Aeronautics, Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, RTCA/DO-185, Washington, DC, September 1983.

6. Gilchrist, C., et al., Traffic Alert and Collision Avoidance System Signal Environment Model (TCAS SEM) Programmer's Reference Manual, DOT/FAA/PM-85/22, FAA, Washington, DC, July 1985.

7. Crawford, C. R., and Ehler, C. W., The DABS/ATCRBS/AIMS Performance Prediction Model, FAA-RD-79-88, FAA, Washington, DC, November 1979, ADA 089440.

8. Patrick, G., et al., The Impact of a Traffic Alert and Collision Avoidance System on the Air Traffic Control Radar Beacon System and Mode S System in the Los Angeles Basin, DOT/FAA/PM-84/30, FAA, Washington, DC, May 1985.

9. Enhanced TCAS II System Summary, BCD-TR-098, Bendix Communications Division, Baltimore, MD, April 1984, p. 4.

10. Enhanced TCAS II Computer Program Documentation, Bendix Communication Division, Volume 1, Parts I through III, (no date), pp. 3.1-3.65.

11. "US National Aviation Standard for the Discrete Address Beacon System (DABS)," Department of Transportation, FAA, Washington, DC, December 1980.

12. "U.S. National Standard for IFF Mark X (SIF)/Air Traffic Control Radar Beacon System Characteristics," Agency Order 1010.51, FAA, Washington, DC, March 1971.

LIST OF REFERENCES (Continued)

13. Draft US National Aviation Standard for the Enhanced Traffic Alert and Collision Avoidance System II, FAA, Washington, DC, 28 August 1984.

14. Colby, G. V., and Crocker, E. A., Final Report Transponder Test Program, FAA-RD-72-30, FAA, Washington, DC, April 1972, AD 740786.

15. McDonald, T. S., BCAS DABS Reply Processing Performance Analysis, Report No. 42W-5062, Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, MA, 8 October 1976.

16. Matheson, R. J., and Pratt, R. M., Air Traffic Control Radar Beacon System (ATCRBS) Interference Investigation in Los Angeles Area, Report No. 77-125, US Department of Commerce/Office of Telecommunications, June 1977.

END
DTIC
9-86