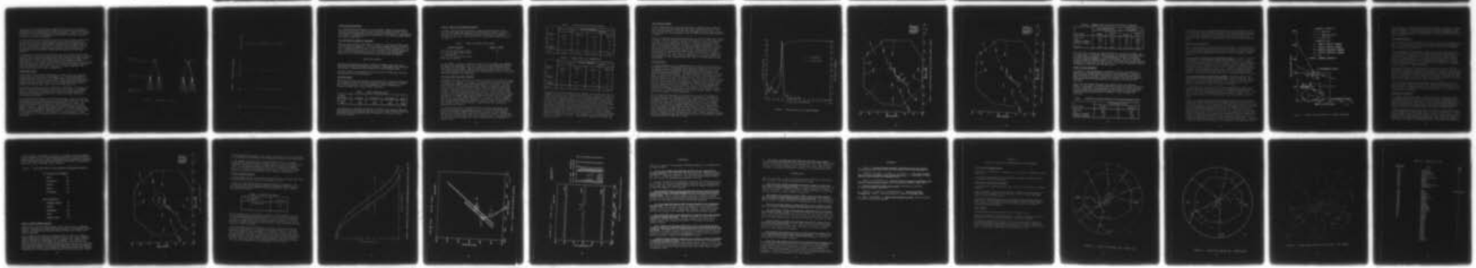
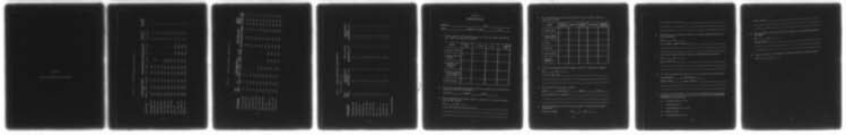
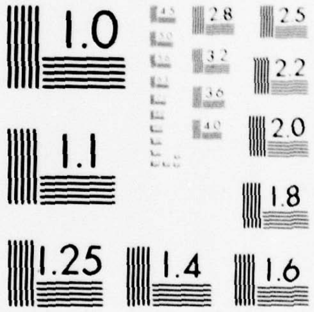
AD-A074 555 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 17/7
AIR TRAFFIC CONTROL/FULL BEACON COLLISION AVOIDANCE SYSTEM--KNO--ETC(U)
AUG 79 B BILLMANN, T MORGAN, R STRACK
UNCLASSIFIED FAA-NA-79-9 FAA-RD-79-25 NL

| OF |
AD
A074555





END
DATE
FILMED
11-79
DDC



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

Report No. FAA-RD-79-25

LEVEL II

AIR TRAFFIC CONTROL / FULL BEACON COLLISION AVOIDANCE SYSTEM – KNOXVILLE SIMULATION

B. Billmann
T. Morgan
R. Strack
J. Windle

FINAL REPORT

AUGUST 1979

Document is available to the U.S. public through
the National Technical Information Service,
Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No.
FAA-RD-79-25

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
⑥ AIR TRAFFIC CONTROL/FULL BEACON COLLISION AVOIDANCE SYSTEM--KNOXVILLE SIMULATION.

5. Report Date
⑪ Aug[redacted]79

6. Performing Organization Code
ANA-260

7. Author(s)
⑩ B. Billmann, T. Morgan, R. Strack, [redacted] J. Windle

8. Performing Organization Report No.
⑭ FAA-NA-79-9

9. Performing Organization Name and Address
Federal Aviation Administration
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

⑫ 48

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
052-241-310

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Aviation Administration
Systems Research and Development Service
Washington, D.C. 20590

13. Type of Report and Period Covered
⑨ Final rept.
Apr[redacted]—May [redacted]78,

14. Sponsoring Agency Code

15. Supplementary Notes
⑱ FAA-RD ⑲ 79-25

16. Abstract

This project was conducted in response to an ARD-200 request to investigate the interaction between a full beacon collision avoidance system (BCAS) and the present air traffic control (ATC) system in a real-time simulation environment. The specific objectives addressed the impact of BCAS on controllers and control procedures, the requirement of BCAS information to be displayed to the controller, and the effectiveness of alarm threshold desensitization in a terminal area. An additional objective was to evaluate the BCAS algorithm performance in terms of number, duration, and location of alerts and resolution effectiveness.

The tests were conducted using the Air Traffic Control Simulation Facility (ATCSF) at the National Aviation Facilities Experimental Center (NAFEC) during April and May 1978. Analysis of results indicated that the presence of BCAS in a moderate-density ATC terminal environment had no adverse effect on controllers or control procedures because of an extremely low positive command rate. A high number of BCAS advisory alerts which were displayed to aircraft but not to controllers had no effect on aircraft flightpaths. Many of these alerts were generated for aircraft navigating on established airways with proper ATC separation. A significant number of participating controllers favored the use of BCAS as a backup to the ATC system.

17. Key Words
Beacon Collision Avoidance System
Air Traffic Control
Simulation

18. Distribution Statement
Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
48

22. Price

240 550

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

79 09 26 023

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

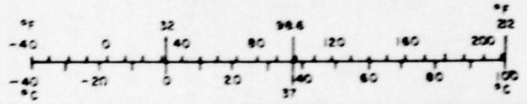


TABLE OF CONTENTS

APPENDICES

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF ABBREVIATIONS

ARTS III	Automated Radar Tracking System
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATCSF	Air Traffic Control Simulation Facility
BCAS	Beacon Collision Avoidance System
CAS	Collision Avoidance System
CPA	Closest Point of Approach in Three Dimensions
CPAH	Horizontal Separation at CPA
CPAV	Vertical Separation at CPA
DMOD	Modified Tau Distance Used for Positive and Negative Commands
DR&A	Data Reduction and Analysis
IPD	Intruder Positional Data
LALT	Altitude Separation Outside Which Vertical Speed Limit Commands Are Not Given
MTAU2	Modified Tau Distance Used to Determine Whether Vertical Speed Limits Should Be Given
SCPA	Slant Range at CPA
SCPAH	Horizontal Distance at CPA
SCPAV	Vertical Distance at CPA
TAU	Range/Range Rate Ratio
TAUR	Range Tau
TAUV	Vertical Tau
VSL	Vertical Speed Limit
XANG	Encounter Crossing Angle

INTRODUCTION

PURPOSE.

This report describes the tests conducted and the results obtained from the Knoxville terminal area air traffic control (ATC)/full Beacon Collision Avoidance System (BCAS) dynamic simulation. The purpose of this simulation was to (1) assess the impact of BCAS on controllers and control procedures in a moderate-density terminal area, (2) assess the requirements of BCAS information to be displayed to the controller, and (3) assess the effectiveness of desensitization in a moderate-density terminal area. An additional objective was to evaluate BCAS performance with respect to the number, duration, and location of alerts and resolution effectiveness.

BACKGROUND.

The ATC/BCAS Interaction Simulation was the second phase of the ATC/BCAS evaluation at the National Aviation Facilities Experimental Center (NAFEC). The results of the first phase were reported in reference 1. The second phase was conducted in two parts. The first part was the simulation of the Chicago environment with the results being reported in reference 2. This part, the Knoxville Simulation, was conducted to measure BCAS interaction with controllers and the ATC system in a moderate-density terminal area. As opposed to Chicago, Knoxville was chosen for simulation because it does not have an ARTS III system, and, therefore, terminal area conflict alert was not available.

The evaluation was conducted at NAFEC using prototype logic for a full BCAS formulated by MITRE, Inc. (reference 3). Computer Sciences Corporation (CSC) implemented and debugged the logic for the simulation. Changes which were made in the logic were reported in reference 2. Following the Chicago simulation, an additional logic change was made so that MTAU2 (the tau (collision avoidance separation criterion) distance modifier for vertical speed limits (VSL's)) was reduced to conform with the values of DMOD, the tau distance modifier for positive and negative commands. This reduction was made in hope of reducing the high VSL alert rate which occurred in the Chicago simulation.

The lack of an adequate characterization of passive (full) BCAS system errors required that the simulation be conducted in an error-free environment. Because of this, the results provide an upper bound for expected BCAS performance.

DISCUSSION

SYSTEM DESCRIPTION.

GENERAL. The Air Traffic Control Simulation Facility (ATCSF) (reference 4) at NAFEC has a real-time, human interaction capability. Air traffic controllers using standard ATC procedures and phraseology issue clearances to simulator pilots who then convert these messages for entry into the computer via special keyboards. The computer interprets these entries and controls the flightpaths of the aircraft in the system. The facility provided a method of measuring BCAS in a systematic way.

Within radar coverage, the BCAS utilizes the air traffic control radar beacon system (ATCRBS) interrogation and transponder signal structure to provide inputs to the BCAS detection and resolution algorithm. As a backup system outside of radar coverage, BCAS can actively interrogate intruder transponders to provide input to the algorithm.

BCAS MESSAGES AND DESENSITIZATION BOUNDARIES. Three types of BCAS messages were provided in the simulation, Intruder Positional Data (IPD), Vertical Speed Limits (VSL), and positive and negative commands. IPD warnings provide an alarm of a potential threat. IPD warnings provide the BCAS-equipped aircraft with relative bearing, relative altitude, and range information on an intruder aircraft. Alert messages do not include IPD warnings.

VSL's are types of alerts which reduce the possibility of collision by limiting the vertical velocity of own aircraft. The six alerts are; "Limit Climb to 2,000 ft/min or less," "Limit Climb to 1,000 ft/min or less," "Limit Climb to 500 ft/min or less," and the three complementary descent alerts.

The negative types that could be provided were; "Do not turn left," "Do not turn right," "Do not descend," and "Do not climb." The positive types of alerts provided were "Turn right," "Turn left," "Climb," and "Descend." Only one VSL or positive or negative alert could be displayed at one time. Multiple IPD warnings could simultaneously be generated, each representing a different threat.

Four levels of desensitization currently exist in the BCAS logic. The choice of level is based on range from radar site and altitude of own aircraft. Two levels of desensitization played a key role in this experimentation. The level 4 desensitization area is the area in which BCAS tracking of intruder aircraft is performed, but all resolution logic is blocked. The level 4 area extends outward for a 2-nmi radius from the radar site. The idea behind level 4 logic is to prevent the issuance of alerts to aircraft on final approach and to aircraft on the ground. The next least protection area extends from 2 nmi to 15 nmi below 10,000 feet altitude. This area is called level 3. The boundary between the level 3 and level 2 areas (medium protection area) is a circle centered on the radar site with a radius of 15 nmi. The highest protection area, level 1, extends upward from 10,000 feet out to 50 nmi from the radar site, at which point it includes all airspace from the surface up. (Figure 1 shows the desensitization boundaries.)

SYSTEM ENVIRONMENT. The ATCSF was configured to represent a single ATCRBS site; namely, the Knoxville terminal area. Satellite airport traffic was not modeled; however, the high volume of overflight traffic below 10,000 feet that occurs in the Knoxville area was modeled. The traffic volume simulated represents the traffic conditions projected for the mid-1980's. The navigational fixes and the traffic flow patterns used were similar to the routes and fixes that exist in Knoxville today.

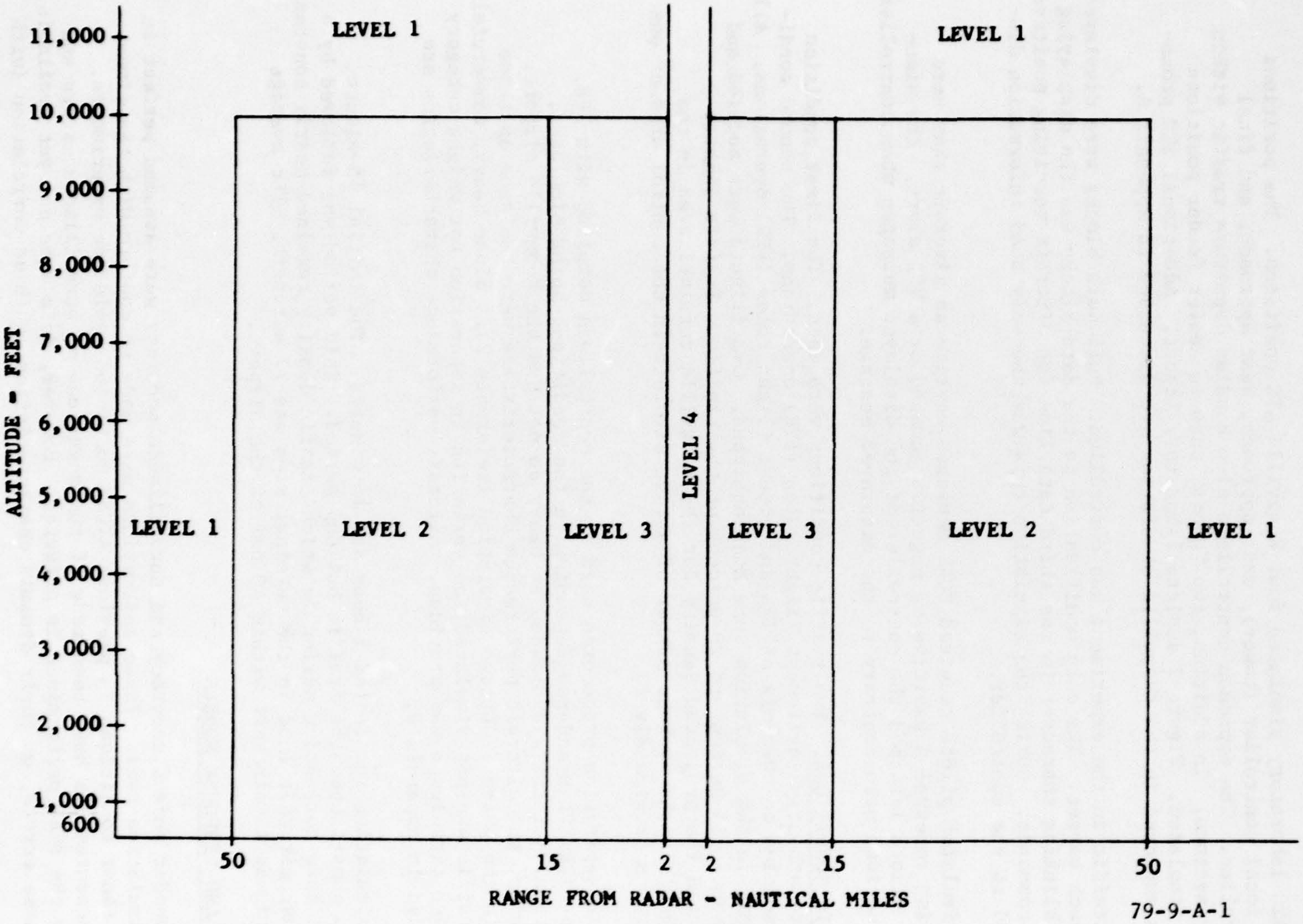


FIGURE 1. BCAS DESENSITIZATION AREAS

The ATC laboratory simulated four Knoxville ATC positions. The positions were local controller (tower), east approach, west approach, and final controller. The approach controllers also handled departure traffic within their sectors. In addition, two "ghost" enroute center feeder positions were simulated. Figure 2 depicts laboratory layout. Additional ATC procedures employed in the Knoxville simulation are discussed in appendix A.

All traffic in the experiment was controlled. Full data blocks were displayed for each target. The only modification to the data blocks was the displaying of a blinking character in the third data line for aircraft receiving positive BCAS commands. During the simulation this was the only BCAS information displayed to the controller.

The simulator pilots received BCAS messages anytime an aircraft they were piloting received a positive or negative command or a VSL alert. The simulator pilots informed the controller of the displayed messages when controller instructions were contrary to the displayed message.

TRAFFIC CONDITIONS.

Two traffic conditions were used. The first condition modeled strictly instrument flight rules (IFR) operations. The second condition modeled an even mix of IFR and visual flight rules (VFR) operations. All aircraft in the simulation were BCAS equipped. Overflights were modeled and represented 15 percent to 20 percent of the traffic. Traffic density reflected the projected density for the Knoxville terminal area in the mid-1980's. The average number of active aircraft in the control area at one time was approximately 15.

Traffic separation procedures used by the controllers complied with IFR, VFR, or IFR/VFR standards depending on the conditions being simulated. Commercial jet traffic classed as heavy do not use the Knoxville airport. Otherwise, the aircraft performance characteristics were the same as those used in the phase I Chicago simulation (reference 2). Since heavy, commercial jet traffic was not simulated, no variation in separation for weight category and wake turbulence was provided. Aircraft performance characteristics are included in appendix B.

Each simulation run lasted 1 hour and 15 minutes. The initial 15-minute period constituted the traffic buildup period. This period was followed by a 1-hour data collection period in which traffic density remained nearly constant. The peak aircraft load in the terminal area was 27 aircraft. The average density was 15 aircraft within 40 nmi of the airport.

ERROR AND RESPONSE MODELS.

Transponder mode C accuracy and surveillance accuracy were assumed perfect in all simulation runs. These assumptions were made to conform with the simulated radar conditions in previous ATCSF collision avoidance experiments. Some measurements have been made of the magnitude of surveillance errors and of how the BCAS performance is affected. However, data were not yet available, for these errors, on their dynamic characteristics, such as correlation (with

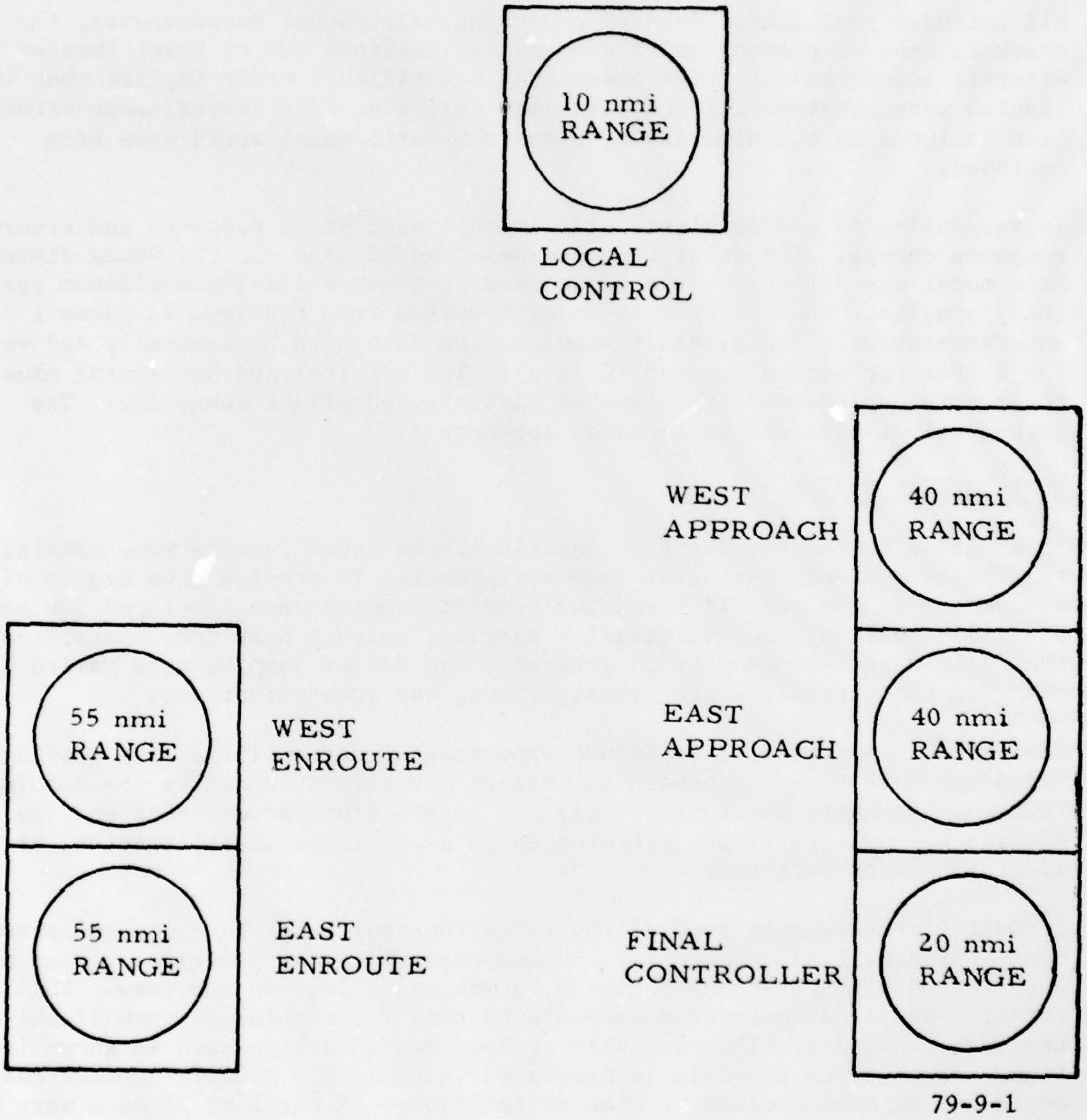


FIGURE 2. AIR TRAFFIC CONTROL SIMULATION FACILITY, KNOXVILLE CONFIGURATION

other factors) and autocorrelation (between an error and its prior value). Availability of the dynamic characteristics would improve the analyses, both mathematically and from simulation of BCAS performance. However, the reported altitudes of all aircraft were quantized in 100-foot increments, the quantization limit of mode C transponders.

The BCAS algorithm contains trackers which smooth own aircraft's position and all intruder positions. Besides smoothing noisy input measurements, the trackers tend to prevent rapid command oscillations due to brief changes in aircraft accelerations. The absence of surveillance error implies that the results were obtained through best case analysis. Had surveillance errors been included in the simulation, algorithm performance would have been degraded.

In responding to a BCAS alert, all aircraft used pilot response and aircraft response delays. The pilot response delay model used was the Gamma distribution. This model was different from those used in other collision avoidance system (CAS) studies. The use of this model resulted from findings in phase 1 experimentation. The aircraft acceleration rate both horizontally and vertically was 6 feet per second squared (0.19 g). The vertical and horizontal maneuver rates were dependent on the type of aircraft and flight condition. The actual values used can be found in appendix B.

EXPERIMENTAL DESIGN.

In addition to the two traffic conditions, two other factors were modeled, traffic sample and controller team assignment. To provide some degree of randomness in the traffic flow, two traffic samples were developed for each traffic condition. For all traffic samples, current peak hour operations for Knoxville were increased by 30 percent. The flight samples were varied by changing the aircraft start times, routes, and identifications.

The factors were modeled to reduce experimental variability. The design provided the most direct approach to measure any effect caused by the modeled factors. However, due to extremely low interaction between BCAS and the ATC system, no significant differences in alert rate, alert location, or alert type were detected.

A controller team consisted of the following positions: tower, east approach, west approach, final controller and two enroute feeder positions. Four teams were formed with personnel rotating between positions on the team. This rotation provided controller exposure to BCAS interaction at each of the terminal positions. The partially crossed nested design used is shown in figure 3. The run schedule is presented in table 1. A fully crossed design could not be used because of time restrictions. A total of 16 runs were made in the Knoxville simulation. The schedule of runs was designed to reduce any training effect. In addition, practice runs were completed prior to data collection.

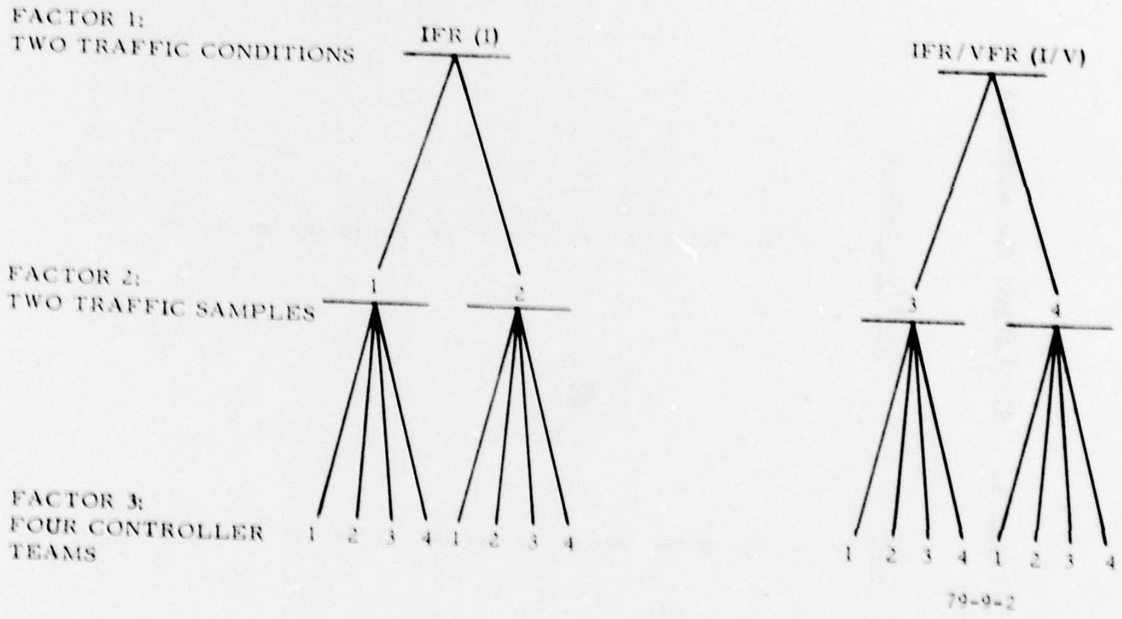


FIGURE 3. EXPERIMENTAL TEST DESIGN

TABLE 1. SIMULATION RUN SCHEDULE

Run #	Team	Traffic Sample	Traffic Condition
1	1	1	I
2	2	1	I
3	3	4	I/V
4	4	4	I/V
5	1	2	I
6	2	2	I
7	3	3	I/V
8	4	3	I/V
9	1	4	I/V
10	2	4	I/V
11	3	2	I
12	4	2	I
13	1	3	I/V
14	2	3	I/V
15	3	1	I
16	4	1	I

CONTROLLER QUESTIONNAIRES.

All controllers who participated in the experiment completed questionnaires. The questionnaires were used to measure controller opinion of BCAS. It was identical to the questionnaire used in previous CAS evaluations. Questionnaires were completed following each data collection run. The controller questionnaire is included as appendix C.

DATA REDUCTION AND ANALYSIS PROCEDURES.

Extensive use was made of the Sigma 5/8 computer to retrieve and analyze data from the Knoxville experiment. The two primary programs used were the ATCSF Link 3 program (reference 5) and the BCAS Allocate program (reference 6). The use of the programs was identical to that described in the Chicago experiment. Many additional programs were developed to utilize the Calcomp Plotter to generate plots of aircraft encounters and alert positional information.

RESULTS AND ANALYSIS

Analysis addressed several topics. Besides the primary objectives of the experiment, the BCAS resolutions were analyzed. Measurements were also taken and reviewed to assess the effectiveness of the ATC procedures used.

Graphical results are presented in the form of plots of BCAS alert locations and locations of aircraft encounters.

OPERATIONS RATES.

The operations rates that resulted are tabulated below. The total operations rate reflects the sum of arrivals, departures, and overflights for a 1-hour data collection period. The rates presented in table 2 represent the average for eight runs for each traffic condition.

TABLE 2. HOURLY OPERATIONS RATES

Traffic Condition	Arrivals	Departures	Overflights	Total
IFR/VFR	27.9	36.3	20.6	84.8
IFR	26.5	36.1	14.2	76.8

The reduction in overflights during IFR conditions is the result of IFR overflight projections and does not represent an effect caused by BCAS interaction. Overflight aircraft represented about 20 percent of the traffic in the Knoxville simulation.

CONFLICT ANALYSIS AND MINIMUM SEPARATION.

The LINK 3 data reduction and analysis (DR&A) program provided a list of aircraft pairs which had violated the ATC separation criteria. For the 16 data runs, a total of 26 conflicts occurred, resulting in an average of 1.6 conflicts per hour. The locations of the conflicting aircraft are shown in table 3.

TABLE 3. CONFLICT LOCATIONS FOR ALL RUNS

Conflict Location	Number of Pairs
Both aircraft inside outer marker	14
One aircraft inside marker and one outside marker	2
Both aircraft outside outer marker	3
Both aircraft enroute	7

The low number of conflicts indicates proper control procedures were employed throughout the experiment. Most of the conflicts occurred when both aircraft were inside the outer marker and were caused by the speed variations of the lead aircraft as it landed. Several of the enroute conflicts were caused by the random variations in aircraft altitude tracking which was part of the flight simulation program in the experiment.

BCAS ALERT RATES AND ALERT DURATIONS.

Each BCAS alert that occurred in the Knoxville simulation was classed as either an advisory or a command. An advisory is a BCAS alert that results in no effect on the aircraft flight profile either horizontally or vertically. Intruder positional data (IPD) warnings were always classed as advisories, since there is no effect on an aircraft flight profile. VSL's and negative alerts were considered advisories when the alert caused no effect on the aircraft flight profile. Since these advisories caused no effect on aircraft flight profile, the alerts did not increase separation and were also called noneffective alerts. Although it is possible that a positive alert would cause no effect on flight profile (i.e., a climb command being issued to an aircraft that is climbing), this did not happen during the simulation. As a result, no positive alerts were classed as advisories (see table 4). Positive, negative, and VSL alerts that caused an effect on the aircraft's flight profile were classed as a command (effective alert).

The number and duration of flashing IPD's was not tabled separately, since they occurred almost simultaneously with VSL alerts and continued during negative and positive command display periods. Within the alert sequence, only the most critical type of alert that occurred was counted. The increasing order of criticality was IPD's, VSL's, negative alerts, and positive alerts. The BCAS advisory and command rates and average durations are presented in tables 4 and 5.

TABLE 4. AVERAGE HOURLY BCAS ADVISORY RATES

	Traffic Condition			
	IFR		IFR/VFR	
Advisory Type	Number	Avg. Dur. Sec.	Number	Avg. Dur. Sec.
IPD Only	16.9	21.2	19.4	18.7
VSL	9.0	38.6	9.6	35.5
Negative Command	0	--	-0.5	9.5
Total	25.9	27.2	29.5	24.2

TABLE 5. AVERAGE HOURLY BCAS COMMAND RATES

	Traffic Condition			
	IFR		IFR/VFR	
Command Type	Number	Avg. Dur. Sec.	Number	Avg. Dur. Sec.
VSL	0.8	33.3	1.5	26.5
Negative Command	0	--	0.6	15.1
Positive Command	0.4	28.0	0.4	19.7
Total	1.2	31.5	2.5	21.5

Throughout the Knoxville simulation the command rate averaged less than two commands per hour. As with the BCAS Chicago results, the VSL alerts had the longest average duration. However, the few positive commands (a total of 6 in 16 hours of simulation) that did occur in Knoxville had a longer average duration (21.3 seconds) than those in Chicago (6 seconds). This probably occurred because Knoxville alerts were generated when aircraft were straight and level. In Chicago, the alerts occurred because the aircraft were maneuvering in the parallel instrument landing system (ILS) area, and tracker lag indicated incorrect projected aircraft positions for short periods of time. On a per-aircraft basis, the advisory rate in the phase I Chicago simulation ranged from 1.2 to 2.5 alerts per aircraft. The Knoxville advisory rate was 0.37 alerts per aircraft. The command rate in Chicago ranged from 0.07 to 0.20 alerts per aircraft. The Knoxville command rate was 0.03 commands per aircraft.

SHORT-DURATION ALERTS.

A major problem detected in the previous Chicago simulation was a high number of noneffective short-duration (less than 4 seconds) VSL alerts. The high rate was traced to two factors; the simultaneous parallel ILS interaction and an excessively large parametric value for MTAU2, the tau distance modifier for VSL's.

Prior to conducting the Knoxville simulation, the values of MTAU2 were reduced. The phase I Chicago results indicated that 38 percent of all VSL alerts were 4 seconds or less in duration. To show the effect the reduction of MTAU2 might have on these short-duration VSL's, a frequency distribution of all VSL's is presented in figure 4. Although the duration distribution is still skewed left, the mean duration (36.1 seconds), modal duration (44 seconds), and median duration (40 seconds) are much more concentrated than in the Chicago results. Apparently the MTAU2 change did help reduce the number of short-duration VSL's. Since only 11 percent of all VSL's were 4 seconds or less in duration, the effect that the application of a two-out-of-three rule (requirement for alert reinforcement) would have on VSL alert duration was not analyzed.

ALERT LOCATIONS.

A Calcomp program was used to identify the alert locations that resulted in the Knoxville area. Two examples which depict the results for the runs with the highest and lowest alert rates are presented in figures 5 and 6. The established airways, navigational fixes, and control area boundaries are shown as background information. The symbols represent the aircraft location where the alerts first occurred. The alert symbol in red indicates that the alert was generated for an overflight aircraft. The effective alerts are identified with an asterisk. The results of the 1-hour data collection period, with the highest alert rate (see figure 5), indicates that more than 6 out of 10 alerts for that run were for overflights. Figure 6 shows that all alerts that were generated were for overflights. This occurred even though overflights represented only 20 percent of the traffic. An investigation was conducted to determine how the alerts were broken down for specific aircraft operations; i.e., arrival/departure traffic and overflight traffic. Table 6 presents the summary of this investigation.

Table 6 indicates 40 percent of all alerts that occurred in the Knoxville area were generated for overflight aircraft. Additionally, the alerts for overflight aircraft were significantly longer than the alerts for arrival/departure aircraft. The VSL alert rate increased sharply for overflight aircraft when compared to the arrival/departure rate. The alert location on figures 5 and 6 clearly indicate that numerous alerts occurred between aircraft navigating on established airways or direct routes. Review of aircraft tracks before, during, and after these alert periods indicated that proper separation techniques were being used. Additionally, the overflight traffic in question was not maneuvering vertically. Positive commands occurred for VFR overflights because the BCAS vertical separation threshold for positive commands exceeded VFR separation criteria.

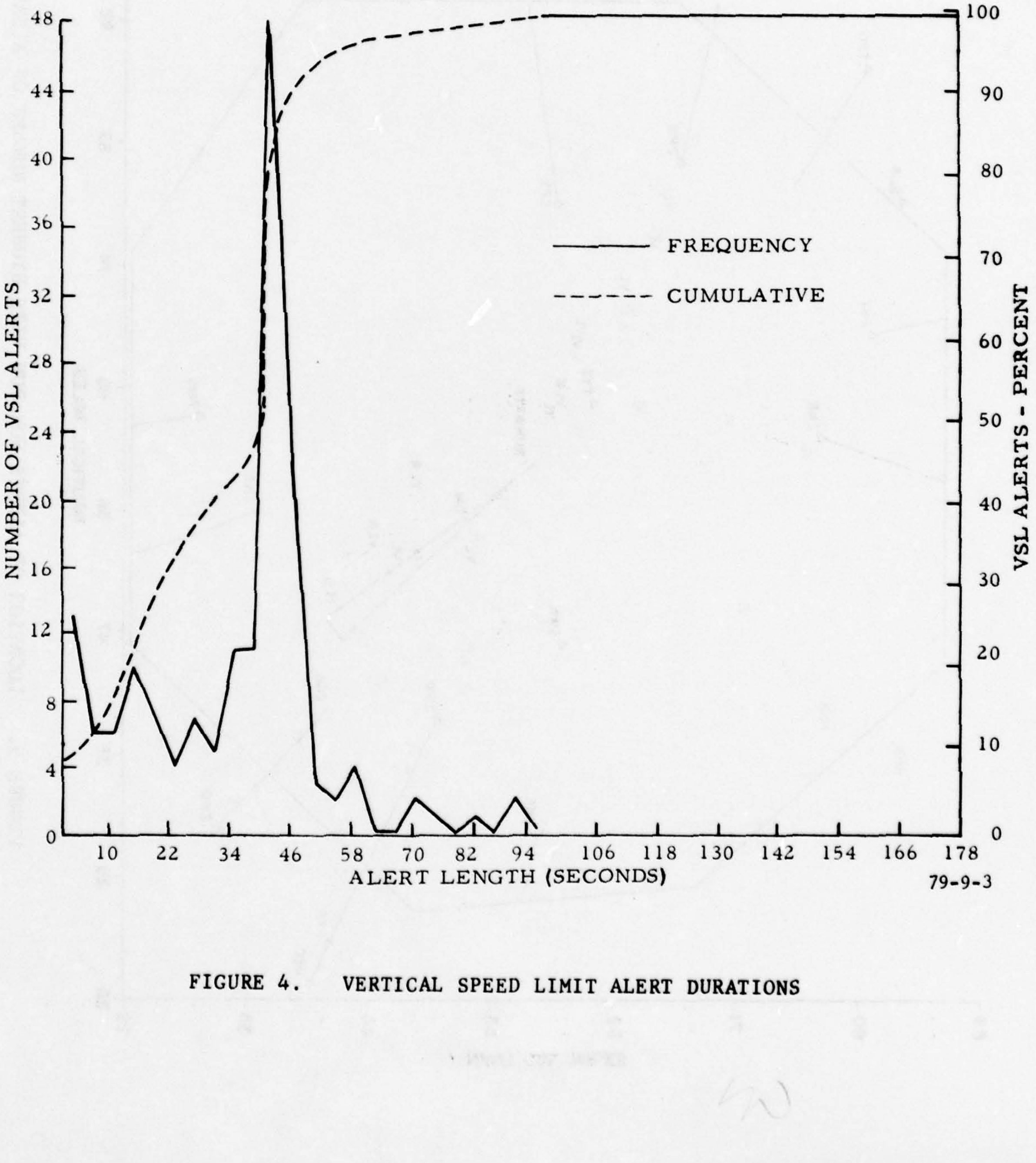


FIGURE 4. VERTICAL SPEED LIMIT ALERT DURATIONS

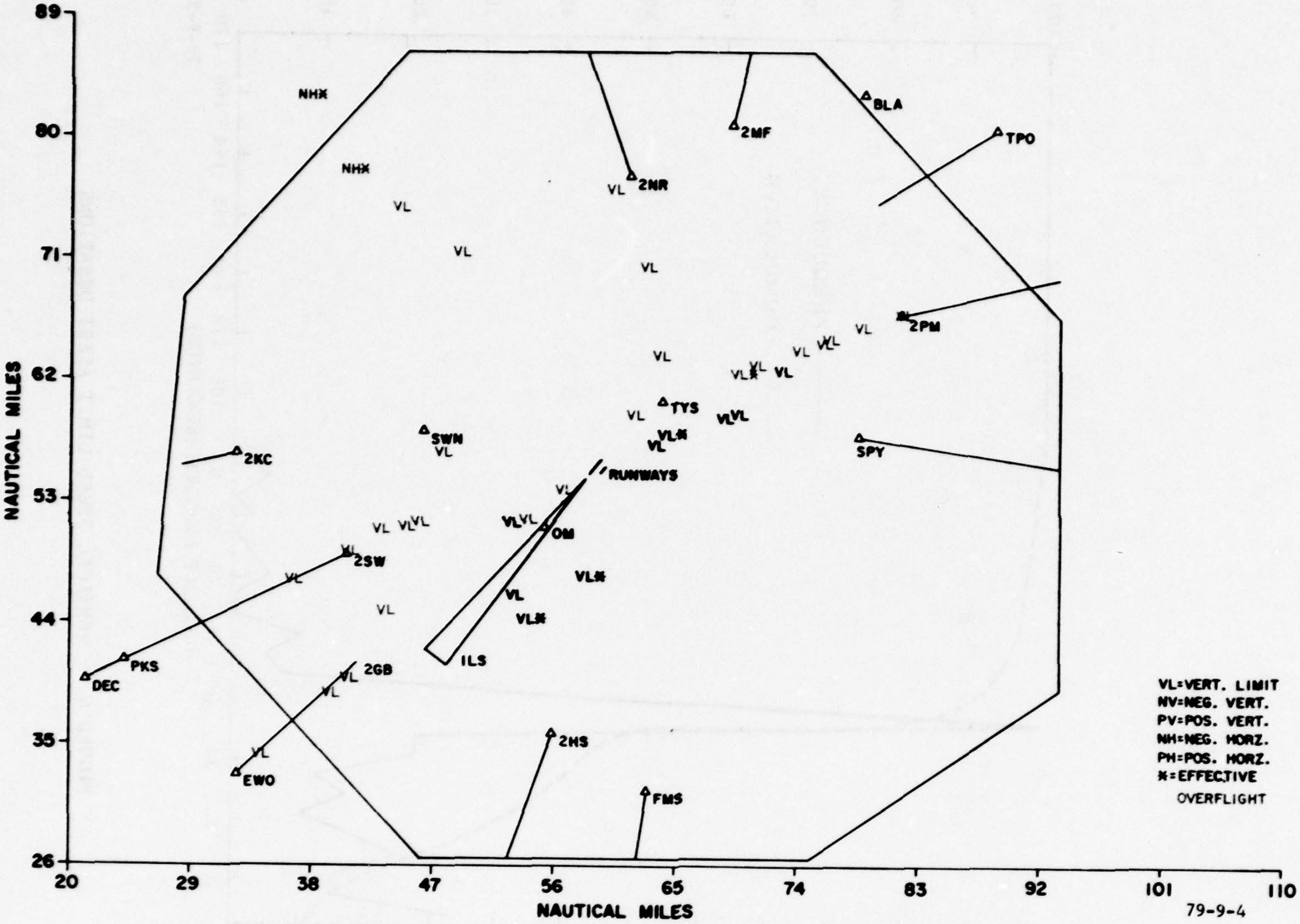


FIGURE 5. LOCATION OF ALERTS FOR RUN WITH HIGHEST NUMBER OF ALERTS

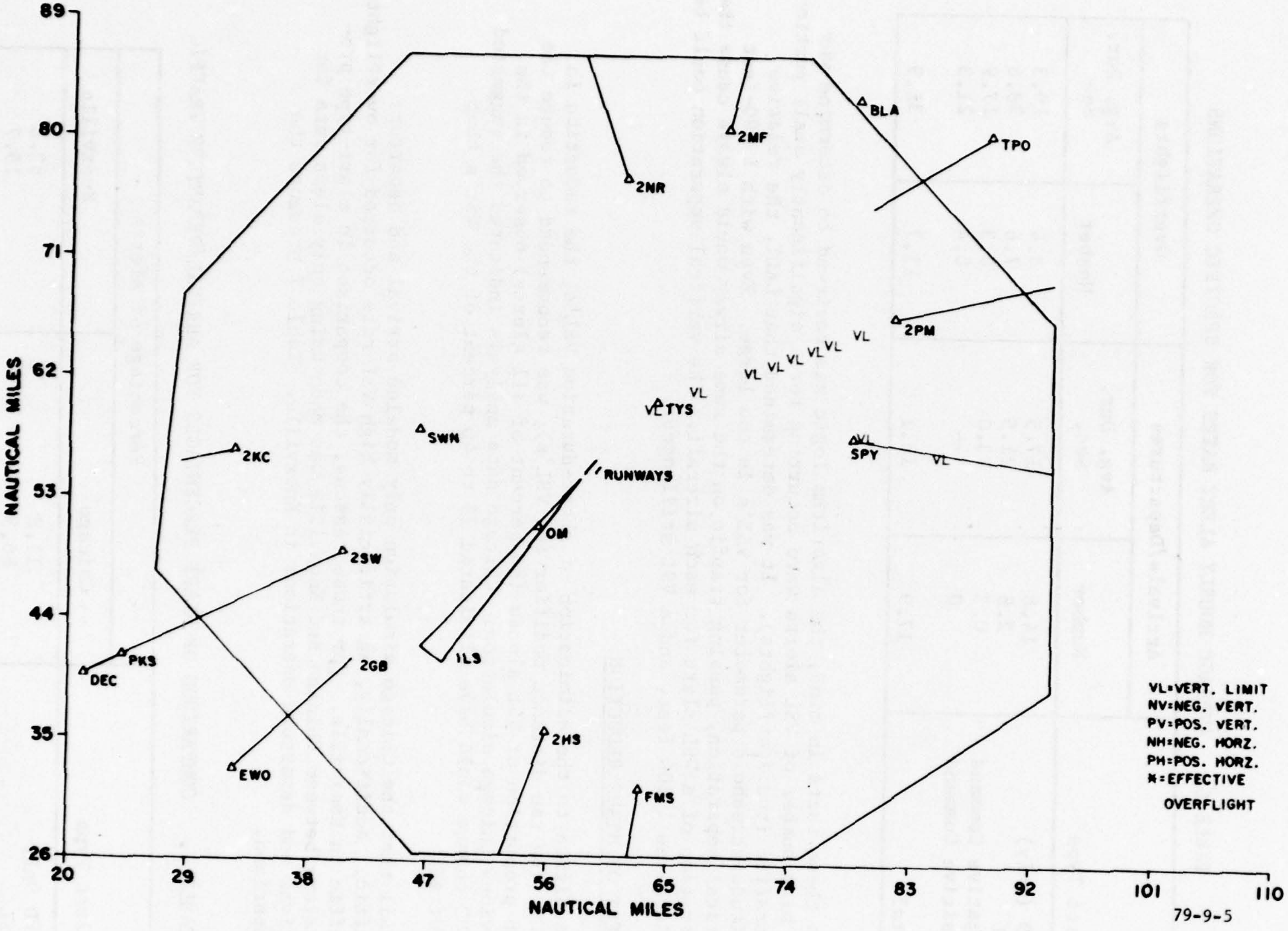


FIGURE 6. LOCATION OF ALERTS FOR RUN WITH LOWEST NUMBER OF ALERTS

TABLE 6. AVERAGE HOURLY ALERT RATES FOR SPECIFIC OPERATIONS

Alert Type	Arrivals/Departures		Overflights	
	Number	Avg. Dur. Sec.	Number	Avg. Dur. Sec.
IPD (only)	14.8	17.5	3.4	19.3
VSL	2.8	21.5	7.6	38.6
Negative Command	0.3	13.0	0.3	17.9
Positive Command	0	--	0.4	21.3
Total	17.9	18.1	11.7	31.9

With these facts in mind, the algorithm logic was reviewed to determine why the high number of VSL alerts were occurring for a significantly small portion of traffic (the overflights). It was determined that LALT, the relative altitude threshold parameter for VSL's is too large. Even with 1,000-feet vertical separation, passing traffic on the same airway would always cause the generation of a VSL alert for each aircraft. The vertical separation could be as large as 1,800 feet, and a VSL still occur.

EFFECT OF MTAU2 REDUCTION.

In addition to the elimination of short-duration VSL's, the reduction in MTAU2 (the tau distance modifier for VSL's), was recommended to reduce the high proportion of VSL alerts (86 percent of all alerts) observed in the previous Chicago simulation. Chicago data analysis indicated the suggested MTAU2 change would have eliminated 35 to 40 percent of the VSL's that occurred.

Recall that the Chicago simulation only modeled arrival and departure traffic. Additionally, an artificially high VSL rate occurred for overflight traffic in Knoxville. For those reasons, the comparison in alert-type proportions between Chicago and Knoxville was made using only alert data for arrival and departure operations in Knoxville. Table 7 presents the comparison.

TABLE 7. COMPARISON OF ALERT PERCENTAGES FOR ARRIVAL/DEPARTURE TRAFFIC

Alert Type	Percentage of Alerts	
	Chicago	Knoxville
IPD Only	11.8	82.8
VSL	86.3	15.7
Negative Commands	1.4	1.5
Positive Commands	0.5	0.0

The comparison of alert percentages indicates that the percentage of alerts for arrival and departure traffic that were VSL's has been reduced from 86.6 to 15.7 percent. The reduction was achieved without an increase in the positive or negative command rate. The reduction exceeded that estimated by analysis of the effect of the smaller MTAU2 values on the Chicago simulation data.

RELATIVE POSITION ANALYSIS.

This section discusses the protection provided by BCAS. Analysis was made of BCAS actions when ATC separation criteria were penetrated. The closest points of approach (CPA's) between aircraft following positive or negative commands were analyzed along with the track of relative position during the command periods.

BCAS ACTION FOR VIOLATIONS OF ATC SEPARATION CRITERIA. In table 3, locations of violations of ATC separation criteria were identified. Each of these conflicts was reviewed to see if BCAS generated a proper alert. An assortment of BCAS alerts ranging from IPD's to positive vertical commands resulted. In only one conflict did BCAS fail to provide an alert. In this case, one aircraft had just completed a turn when the violation of separation criteria occurred. The penetration was minor, since at CPA the minimum horizontal separation was 2.86 nautical miles (nmi) and the vertical separation was 719 feet. The proper alert should have been a very short-duration IPD alert.

CPA'S FOLLOWING POSITIVE AND NEGATIVE COMMANDS. The above analysis indicates BCAS was providing alerts to address ATC conflict situations. No conflicts were critical, and IPD advisories or VSL's were the only BCAS alerts required. On the other hand, high closure rates could cause positive or negative commands when outside ATC separation standards.

Of considerably more importance than the sheer generation of alerts is the protection provided by those alerts. Figure 7 shows the relative position tracks for aircraft pairs during negative and positive command periods. There is not a one-to-one correspondence between the tracks on figure 7 and the alerts shown in tables 4 and 5 because alerts did not necessarily occur in pairs.

In figure 7, the initial relative positions when the alert first occurred is shown. The relative positions when the command terminated or transitioned to a VSL along with the CPA for the pair are also shown. The symbol to the right of each track identifies the command type, and the symbol over each track indicates the separation standards in effect when the command occurred. Only twice did CPA's penetrate VFR separation criteria. On three occasions, commands occurred for IFR traffic. In each case, the penetration of IFR spacing standards was minimal. The remaining seven tracks (58 percent) represent two positive and five negative commands that occurred when aircraft were not violating ATC separation criteria. In these instances, aircraft were in level flight with proper ATC separation, and the alerts are undesireable. Furthermore, if advisory information is wanted for the situations, it is available in the

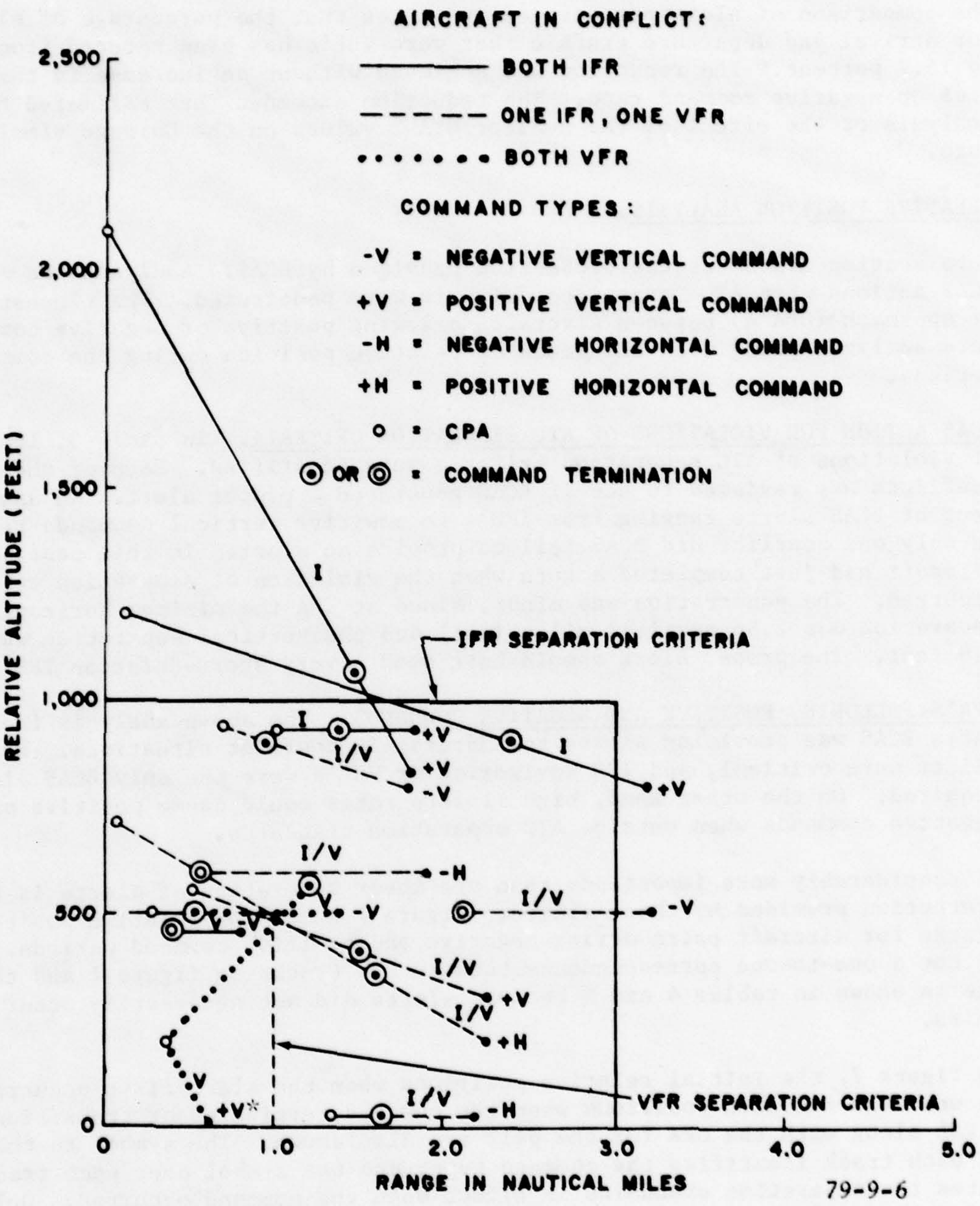


FIGURE 7. RELATIVE POSITION ANALYSIS OF AIRCRAFT ENCOUNTERS

form of IPD's. For such cases, IPD's provide adequate information concerning threat proximity. The one track marked with an asterisk represents a case which was caused by a pop-up threat exiting the level 4 desensitization area (i.e., no BCAS resolution). The command did not terminate until well after the CPA has occurred.

QUESTIONNAIRE ANALYSIS.

The extremely low positive command rate provided very little interaction with the controllers, particularly since only positive commands were displayed to them. In fact, on 13 of the 16 data collection runs, no positive commands were observed by the controllers.

Table 8 summarizes the significant results of the questionnaire analysis. As shown in table 8, the controllers generally were not in agreement with the limited number of commands they saw. They felt that the alerts occurred prematurely and that they (the controllers) had provided adequate spacing. This fact is substantiated by the relative position analysis. It must be noted that only 66 percent of the controllers had an opportunity to observe positive commands. This fact is reflected in the 34 percent of no responses on questionnaires for command agreement.

The impact of BCAS on the ATC system can be measured in part by the BCAS acceptability responses. Seventy-five percent of the controllers who participated in the experiment favored the use of BCAS as a backup to the ATC system. Besides the acceptance of BCAS by controllers, two other facts show that BCAS had no adverse impact on the ATC system or procedures. Throughout the simulation, an extremely low effective alert rate occurred (less than two per hour), and no missed approaches resulted because of BCAS alerts.

The thorough assessment of BCAS controller display requirements was limited by the low level of BCAS/ATC interaction. Controller questionnaires did indicate that the blinking character in the third line of the aircraft's data block (denoting a command) was sufficient information for the controller the few times that it occurred.

DESENSITIZATION ANALYSIS.

The current algorithm uses range from radar and aircraft altitude to select the algorithm sensitivity level. In the Chicago phase I experimentation, this method caused a sharp increase in alert rate when certain desensitization boundaries were crossed. This did not occur in the Knoxville simulation. However, overflight traffic was added to the Knoxville simulation, and this addition identified an algorithm desensitization or adaptation problem.

A high number of BCAS alerts occurred in the vicinity of navigational fixes. Figure 8 graphically presents this fact. On run 11, 39 percent of all alerts occurred within 5 nmi of the Tyson VORTAC. Traffic in the vicinity of navigational fixes is characterized by aircraft in level flight with high relative horizontal velocities and high crossing angles. This results in a rapid reduction in tau values for converging aircraft, permitting alert generation if other parameter thresholds are violated. The range and altitude desensitization scheme did not provide adequate desensitizing for areas around navigational fixes, because the fixes, in general, are not dependent on range from radar. The current logic had not been refined sufficiently to minimize BCAS interaction in the overflight traffic situation.

TABLE 8. SIGNIFICANT RESULTS OF THE CONTROLLER QUESTIONNAIRE ANALYSIS

DID YOU AGREE WITH COMMANDS?	
NEVER	22%
OCCASIONALLY	26%
USUALLY	18%
ALWAYS	0%
NO RESPONSE	34%

BCAS ACCEPTABILITY	
STRONGLY OPPOSED	0%
OPPOSED	0%
INDIFFERENT	25%
FAVOR	75%
STRONGLY FAVOR	0%

RANGE TO THREAT AIRCRAFT ANALYSIS.

IPD alerts are the first BCAS warnings a pilot would receive of impending threats. The ability to visually acquire the threat is a function of several factors. Of these factors, the range when the alert first occurred is of primary importance.

Figure 9 depicts the cumulative probability that the threat was beyond a certain range when the IPD alert initially occurred. The current algorithm uses a 60-second tau (range/range rate) to display IPD's. Range at alert onset is a function of the warning time thresholds. If alert onset was delayed until tau was less than 60 seconds, the range when the alerts occurred would have been reduced. The second curve depicts the cumulative probability that would have resulted if a 45-second tau threshold had been used. Analysis indicated that, of the original 463 IPD alerts, on 162 occasions the tau did

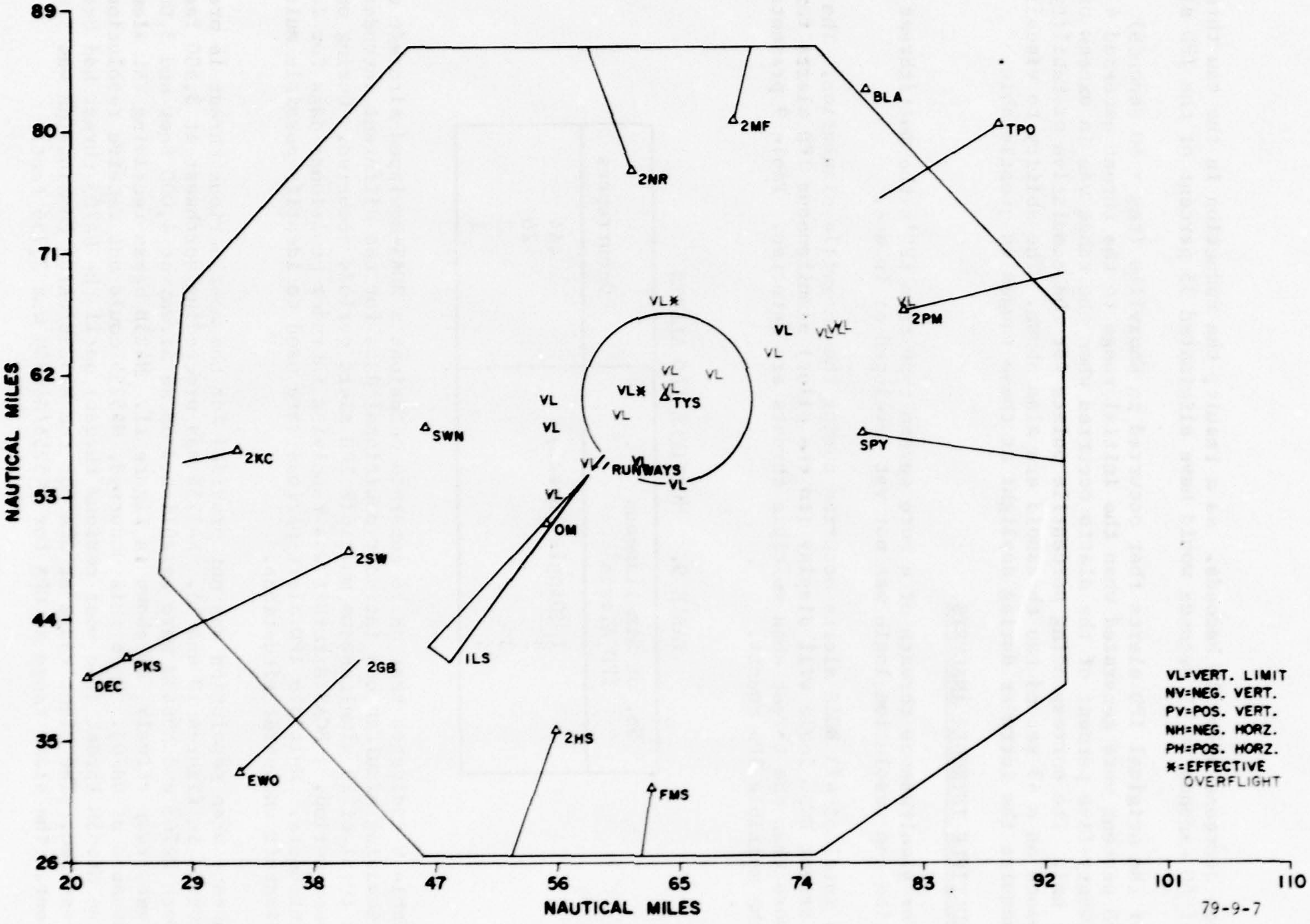


FIGURE 8. ALERT CONCENTRATIONS

not decrease below 45 seconds. As a result, the reduction in the tau threshold of 60 seconds to 45 seconds would have eliminated 35 percent of the IPD alerts.

Of the original IPD alerts that occurred in Knoxville (tau = 60 seconds) 50 percent were generated when the initial range to the threat exceeded 4 nmi. Twenty-five percent of the alerts occurred when the range was in excess of 5 nmi. The corresponding percentile points for the cumulative probability based on a 45 second tau threshold are also shown. The ability to visually acquire the intruder during daylight at these ranges is questionable.

MULTIPLE INTRUDER ANALYSIS.

For simultaneous threats of a more severe type than IPD's the multithreat detection and resolution logic was not yet developed or in use.

A total of 473 BCAS alerts occurred during the Knoxville simulation. The current BCAS logic will display (to the pilot) simultaneous IPD alerts for more than one threat when multiple threats are detected. Table 9 presents the multiple IPD counts.

TABLE 9. MULTIPLE IPD ALERTS

No. of Simultaneous IPD Alerts	Occurrences
1 (Single threat)	444
2	26
3	2
4	1

Table 9 indicates that on 26 separate occasions a BCAS-equipped aircraft was receiving simultaneous intruder positional data for two different intruders. A total of 29 simultaneous multiple IPD alert periods occurred. During one such period, a BCAS aircraft was receiving intruder positional data for four intruders. Multiple IPD alert periods were used to identify possible multiple aircraft encounter situations.

A case when resolution was not provided for the most serious threat is presented in figures 10 and 11. N4525B was proceeding northwest at 3,500 feet. Both UA703 and N6665M were established on an airway at 4,000 feet and 3,000 feet, respectively, as shown in figure 11. N425B began receiving VSL alerts because of UA703. Once this occurred, N4525B could not receive resolution for the N6665M threat (the most serious threat) until the UA703 threat had been resolved. The slant range at CPA for the N4525B/UA703 combination was 5,886 feet. The slant range at CPA for N4525B/N6665M was 3,756 feet.

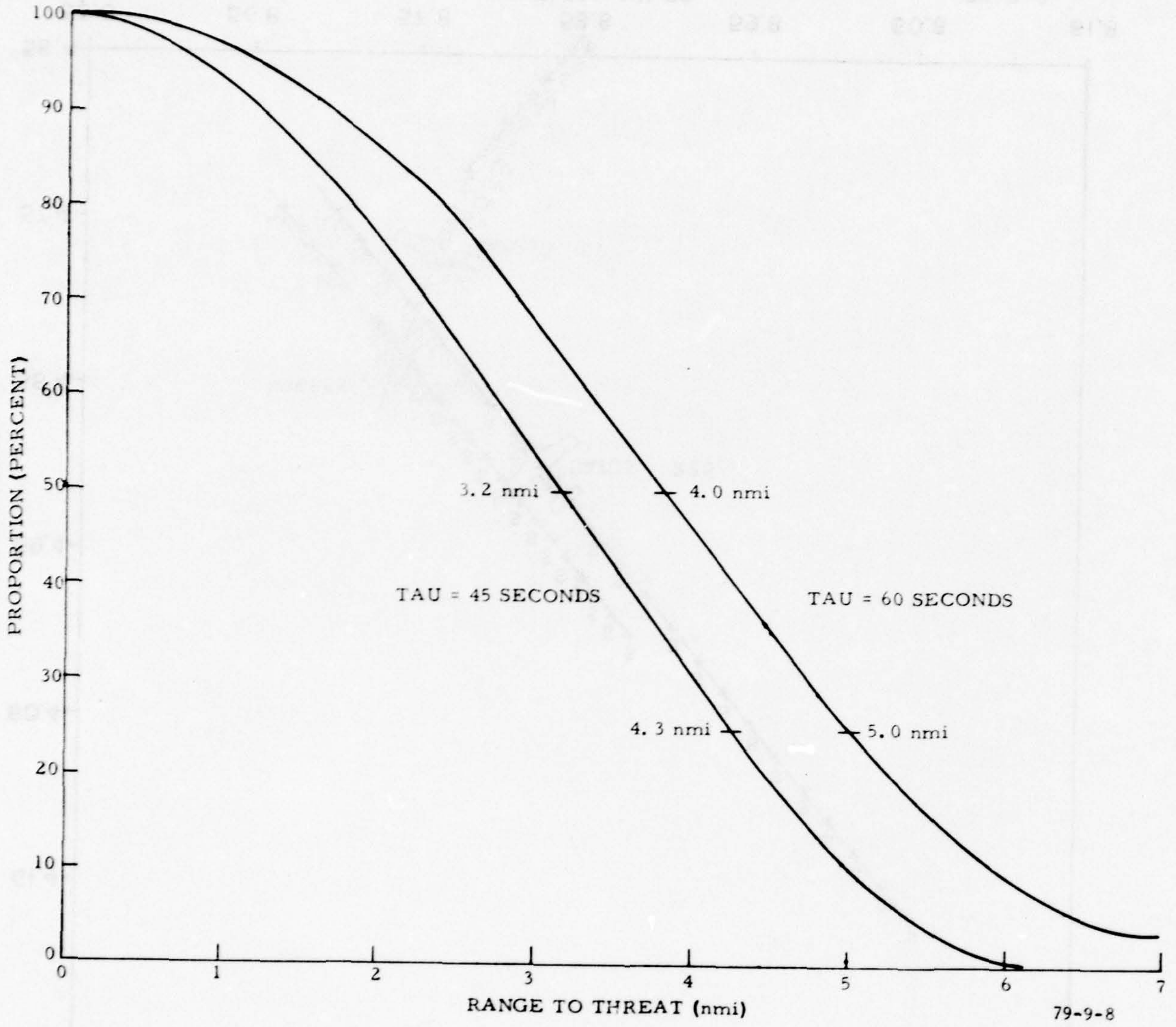


FIGURE 9. PROPORTION OF ALERTS WHICH OCCURRED BEYOND RANGE INDICATED FOR FIXED TAU

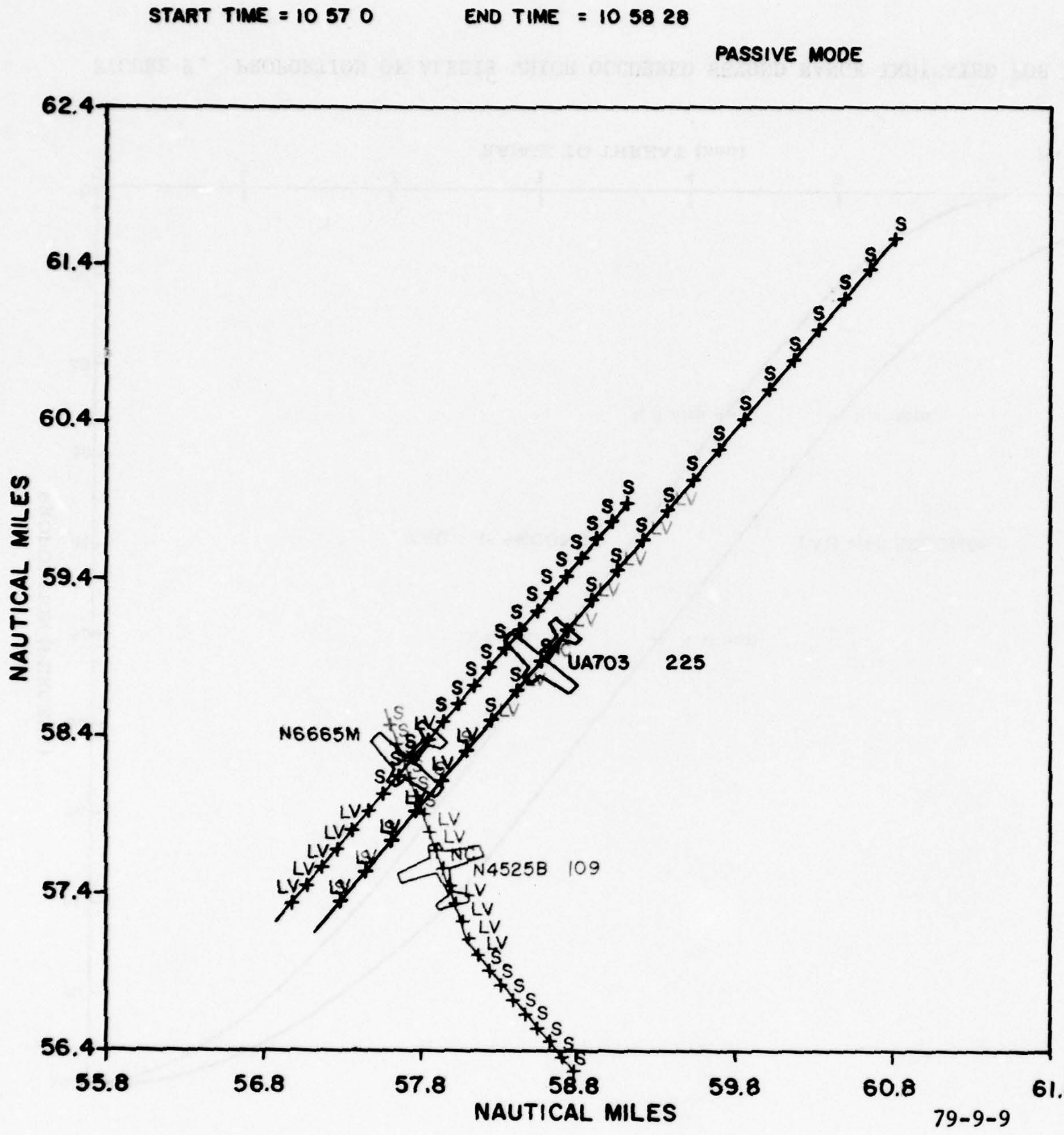
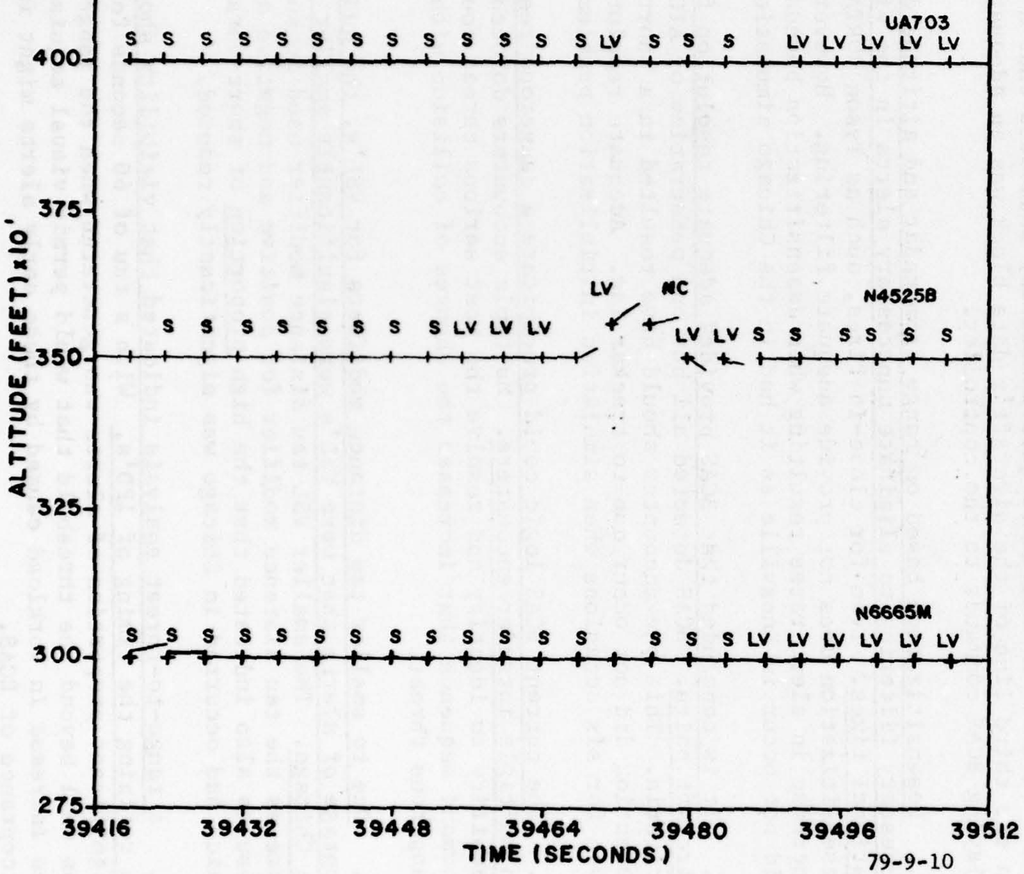


FIGURE 10. HORIZONTAL VIEW OF MULTIPLE ENCOUNTER

ENCOUNTER NUMBER 1
SENSITIVITY 3

START TIME = 10 57 0 END TIME = 10 58 28

PASSIVE MODE



79-9-10

AC1 ID = UA703 BCAS EQUIPPED

AC2 ID = N6665M BCAS EQUIPPED

TIME	AC1	AC2	RZ	ADOT	VMD	DOT
7:0			-989	-164	*	*
7:4			-992	-31	*	*
7:8			-997	31	*	*
7:12			-1000	39	*	*
7:16			-1001	24	*	*
7:20			-1001	8	*	*
7:24			-1000	-2	*	*
7:28			-1000	-4	*	*
7:32	S	S	-1000	-3	*	*
7:36	S	S	-1000	-1	*	*
7:40	S	S	-1000	-0	*	*
7:44	S	S	-1000	0	*	*
7:48			-1000	0	*	*
7:52	S	L-10	-1000	0	*	*
7:56			-1000	0	*	*
8:0			-1000	-0	*	*
8:4			-1000	-0	*	*
8:8	L+10	S	-1000	-0	*	*
8:12	L+10	L-10	-1000	-0	*	*
8:16	L+10	L-10	-1000	-0	*	*
8:20	L+10	L-10	-1000	-0	*	*
8:24	L+10	L-10	-1000	-0	*	*
8:28	L+10	L-10	-1000	-0	*	*

FIGURE 11. VERTICAL VIEW OF MULTIPLE ENCOUNTER

CONCLUSIONS

Based on the results of the Knoxville ATC/BCAS simulation, the following conclusions are made:

1. Due to a low command rate, BCAS had no impact on the controllers or control procedures. The controllers saw very little BCAS command interaction throughout the Knoxville simulation. No missed approaches resulted because of BCAS alerts. Seventy-five percent of the controller questionnaires favored the use of BCAS. No controllers were opposed to its use.

2. Although limited by rare occurrences, evaluation of BCAS/controller interaction (based on controller questionnaires) indicated that a blinking symbol in the third line of the aircraft's data block was an adequate method of displaying BCAS commands to the controller.

3. Desensitization based on range from radar and altitude does not provide necessary filtering to eliminate unnecessary alerts in the vicinity of navigational fixes. Even for close-in fixes, such as Tyson VORTAC, the current desensitization does not provide adequate filtering. However, the sharp increase in alert rates resulting when desensitization boundaries were crossed did not occur in Knoxville as it had in the Chicago simulation.

4. It is concluded that BCAS provided adequate resolution for conflicting aircraft pairs. BCAS detected all but one penetration of ATC separation criteria. This one encounter should have resulted in a short-duration IPD. Detection did not occur due to tracker lag. Adequate resolution resulted even for six occasions when simulation initialization problems occurred.

5. The current BCAS logic could precipitate a dangerous resolution sequence in multiple intruder encounters. Multiple encounters do occur, and the inability to identify and resolve the most serious threat could lead to a command sequence that increases the chances of collision with the most dangerous threat.

6. Due to smaller tau distance modifiers for VSL's, the quantity and percentage of alerts that were VSL's were significantly smaller in Knoxville than in Chicago. The smaller VSL tau distance modifier used in Knoxville was the same as the tau distance modifier for positive and negative alerts. Knoxville results also indicated that the high proportion of short-duration VSL alerts which had occurred in Chicago was significantly reduced.

7. A range-to-threat analysis indicated that visibility should be considered in refining the timing of IPD's. With a tau of 60 seconds for IPD alerts, a significant proportion of alerts was generated when the range to the intruder was well beyond the threshold that would permit visual acquisition in daylight. The increase in workload caused by these early alerts might impact on pilot acceptance of BCAS.

8. The relative altitude threshold (LALT) for VSL alerts is too large. A high proportion of undesireable alerts resulted for level flight aircraft navigating on established airways with proper separation. Even when separated by 1,000 feet vertically, passing traffic received VSL alerts. Again, in this situation, if proximity information is desired, it is available with IPD's.

RECOMMENDATIONS

Based on the analysis of the data from the Knoxville ATC/BCAS simulation and the conclusions, the following recommendations are made:

1. BCAS controller display requirements should be assessed by other than real-time ATC system simulation methods. If proper control procedures are used, this method of simulation does not provide adequate interaction to evaluate display requirements. Display requirements could be evaluated by controllers reviewing scenarios in which commands are generated.

2. The change in the parametric value of MTAU2, the tau distance modifier for VSL's, should become a permanent part of the algorithm. The reduction in MTAU2 resulted in a significantly smaller proportion of VSL alerts relative to Chicago results. The high proportion of short-duration VSL's was also smaller.

3. Because of the high number of undesirable VSL's for overflight aircraft, LALT, the relative altitude parameter that generates VSL's should be reduced.

4. The alerts which occurred in the Knoxville simulation should be analyzed from the pilot's point of view. Although the command rate was quite low, one-third of all alerts were noneffective VSL alerts. The fact that a majority of these alerts were generated for aircraft operating on established airways with proper ATC separation may impact adversely on the pilot's acceptance of BCAS.

5. Analysis should be conducted to determine how early IPD alerts should be generated in the terminal area. Current logic resulted in an initial range to the threat distance exceeding 5 nmi 25 percent of the time. The range was more than 4 nmi 50 percent of the time. The ability to visually acquire threats at these ranges is questionable.

6. Since multiple encounters did occur in a moderate-density terminal area, a full, multiple-aircraft BCAS logic should be developed. As an interim step logic changes should be made to detect and provide resolution for the most critical threat in a multiple encounter.

7. Active BCAS logic should be evaluated in a moderate-density terminal area. The extremely low interaction level of the full BCAS had no adverse impact on the controllers or control procedures. To date, all system simulations of BCAS have been made in an error-free environment. The development of a realistic BCAS input measurement error model should precede the active logic evaluation. The inclusion of BCAS system errors in the simulation will provide a measure of resolution degradation that can be expected.

REFERENCES

1. Strack, R., Beacon Collision Avoidance System/General Aviation Trainer Pilot Reaction Test, NAFEC Technical Letter Report NA-77-73-LR, December 1977.

2. Billmann, B., Morgan, T., Strack, R., and Windle, J., Air Traffic Control/Beacon Collision Avoidance System Chicago Simulation, U.S. Department of Transportation Report FAA-RD-75-9, September 1978.

3. Clark, J., and McFarland, A., Initial Collision Avoidance Algorithm for the Based Collision Avoidance System, Mitre Incorporation, MTR7532, April 1977.

4. Digital Simulation Facility User's Guide, Simulation and Analysis Division, FAA, NAFEC, June 1975.

5. Comstock, J., Miner, K., and Westmoreland, C., Standard DSF LINK 3 Documentation, Computer Sciences Corporation, TM-04-023, September 1976.

6. Duke, J. and Simon, J., Special DR&A Programs for BCAS, Computer Sciences Corporation, publication pending.

APPENDIX A

KNOXVILLE (McGHEE TYSON) AIRPORT TRAFFIC FLOW PROCEDURES

EAST AND WEST ENROUTE SECTORS.

Inbound traffic will be at or descending to: jet aircraft, 10,000 feet; props, 8,000 feet.

Traffic will be handed off to the appropriate approach controller prior to the approach control area boundary.

EAST AND WEST ARRIVAL AND DEPARTURE.

Arrival--Provide standard separation and control of all aircraft in assigned airspace.

Assign 2,500 feet or above to all aircraft. Sequence arriving aircraft in trail and effect handoff to final controller prior to aircraft reaching a point 3 miles from final sector.

Departure--Turn departing aircraft from assigned runway heading as soon as practicable. Ensure standard separation between arriving and departing aircraft. Hand off to appropriate center sector when clear of arrivals or approaching terminal boundary.

LOCAL CONTROL.

Provide separation between departing and arriving aircraft.

Assign runway heading to departing aircraft. Hand off departing aircraft to appropriate sector (east-west) depending on direction of flight.

The Knoxville terminal area arrival traffic flow is depicted in figure A-1. The Knoxville terminal area departure traffic flow is shown in figure A-2. Figure A-3 shows the Atlanta Center (Knoxville sector) traffic flow patterns. Table A-1 identifies the Knoxville area navigation fix list.

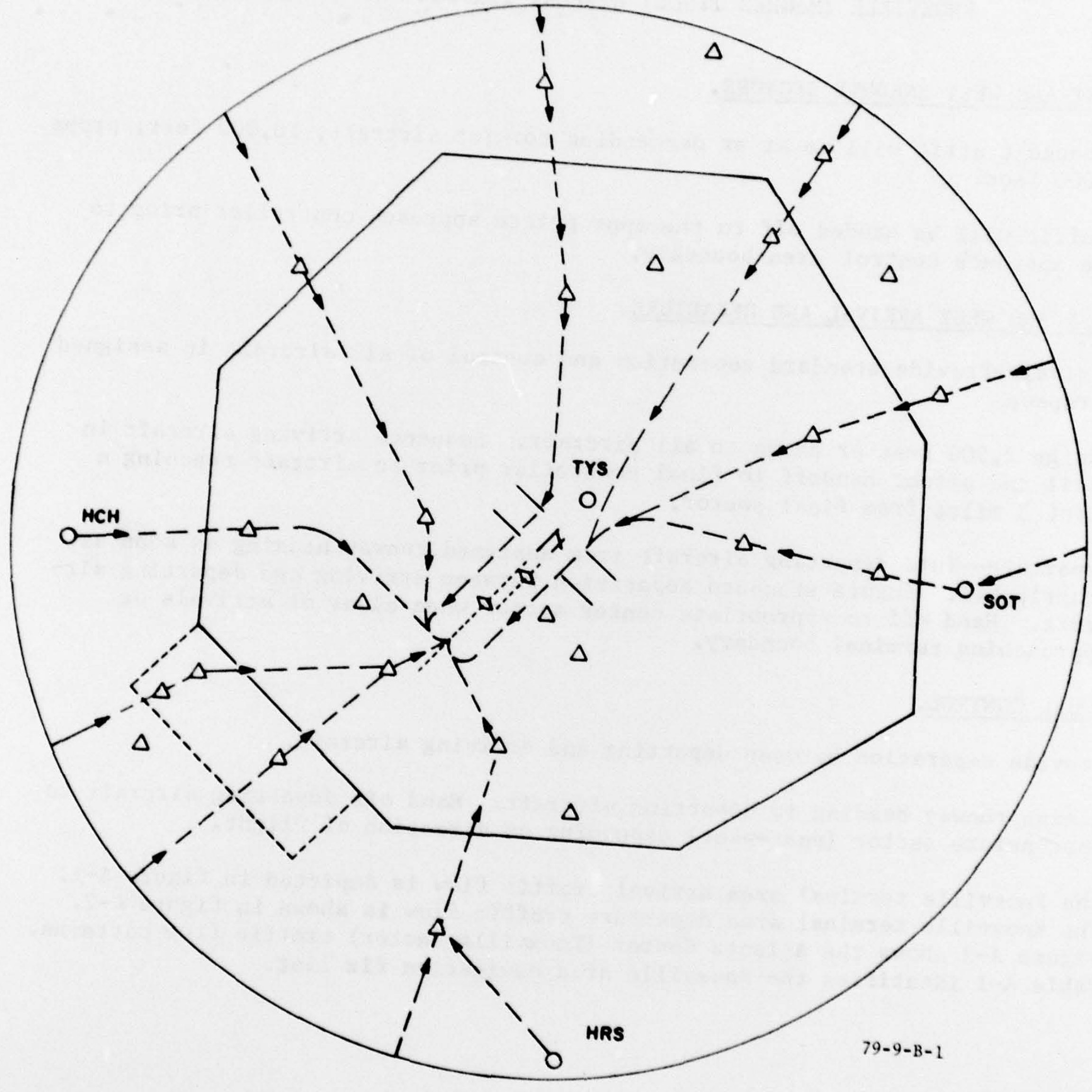


FIGURE A-1. - McGHEE TYSON TERMINAL AREA - ARRIVAL FLOW

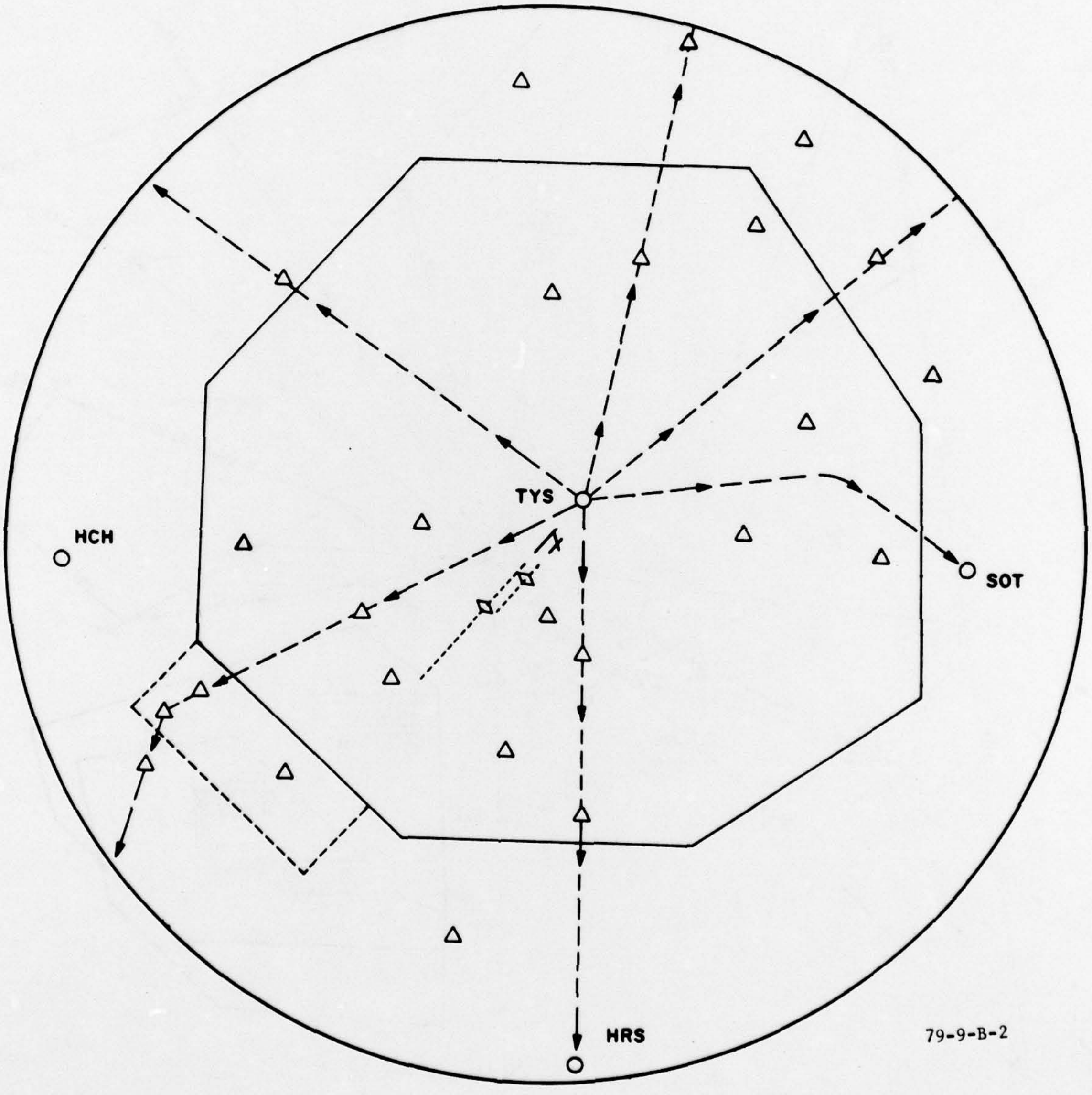


FIGURE A-2. - McGHEE TYSON TERMINAL AREA - DEPARTURE FLOW

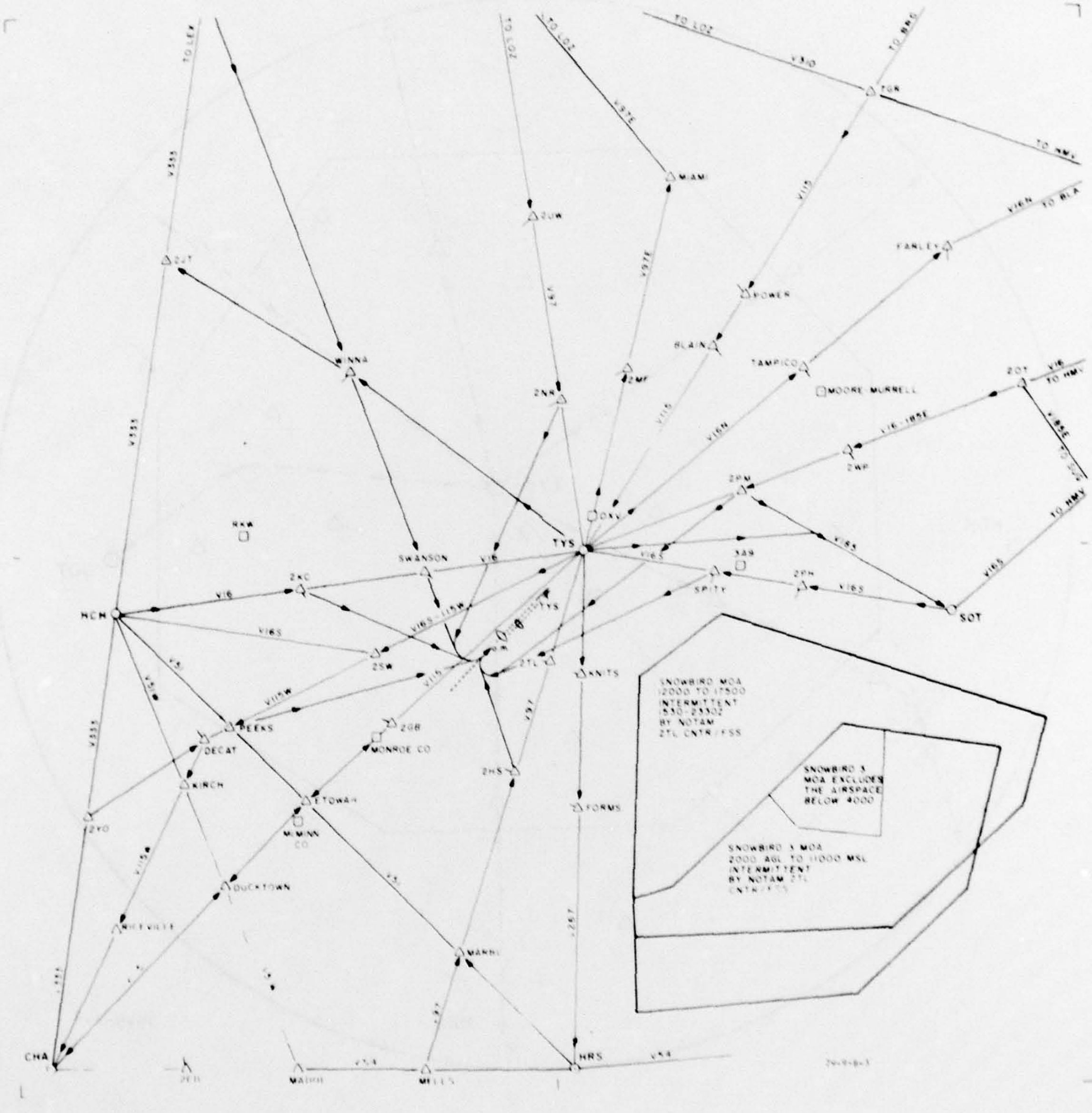


FIGURE A-3. ATLANTA CENTER (KNOXVILLE SECTOR) TRAFFIC FLOW PATTERNS

TABLE A-1. KNOXVILLE FIX LIST

IDENTIFIER	FIX	TYPE
BLA	Blackford	VOR
CHA	Chattanooga	"
HCH	Hinch Mountain	"
HRS	Harris	"
HMV	Holston Mountain	"
LOZ	London	"
RMG	Rome	"
SOT	Snowbird	"
SUG	Sugarloaf Mountain	"
BRG	Whitesburg	"
2KC	Buck	Intersection
2FO	Forms	"
2GB	Greenback	"
2HS	Howard	"
2MF	Maynardville	"
2NR	Norris	"
2OT	Ottway	"
2PH	Pittman	"
2PM	Piedmont	"
2SW	Sweetwater	"
2UW	Westbourne	"
2WP	White Pine	"
EW	Etowah	"
FA	Farley	"
SZ	Swanson	"
TO	Tampico	"
	Blain	"
	Decat	"
	Dubbs	"
	Kirch	"
	Knits	"
	Marbl	"
	Miami	"
	Peeks	"
	Power	"
	Spity	"
	Winna	"
	Ducktown	:

APPENDIX B

AIRCRAFT PERFORMANCE CHARACTERISTICS

TABLE B-1. AIRCRAFT PERFORMANCE CHARACTERISTICS

	DESCENT RATES (FT/MIN)			CLIMB RATE (FT/MIN) (THOUSANDS OF FT)					SPEED CHANGE KT/MIN		ALT CHANGE (FT/SEC^2)
Type Aircraft	Maximum	En-Route	Terminal	0-10	10-20	20-30	30-40	40-50	Accel	Decel	
Prop-Single Eng.	2000	1000	700	400	300	-	-	-	90	90	6
Prop Light Twin	2000	1500	700	600	500	500	-	-	90	90	6
Prop Med. Twin	2000	2000	700	900	800	-	-	-	90	90	6
Prop Heavy Twin	2500	1500	700	900	800	-	-	-	90	90	6
Light Turbo-Prop	4000	2000	1500	2000	2000	2000	-	-	80	60	6
Med. Turbo-Prop	4000	2500	1500	2200	3000	3000	-	-	50	60	6
Heavy Turbo-Prop	4000	3000	1800	2700	3000	3000	-	-	70	60	6
Exec. Jet	4000	3000	1700	2000	2500	3500	3500	2000	60	60	6
Med. Comm. Jet	4000	3000	1500	3000	3000	3000	3000	2000	70	60	6
Stand. Comm. Jet	4000	3000	1500	3000	3000	3000	3000	2000	70	60	6
High Perf. Jet.	4000	3000	1600	3000	3000	3000	3000	2000	60	60	6

TABLE B-2. AIRCRAFT PERFORMANCE CHARACTERISTICS

TYPE AIRCRAFT	TAKE OFF SPEED	CLIMB SPEEDS (KTS)					ROUTE SPEEDS (KTS)			HOLDING SPEED		FINAL SPEED
		TO 10,000'	10,000' 20,000'	20,000' 30,000'	30,000' 40,000'	40,000' 50,000'	CRUISE	TRANSITION	TERMINAL	LOW ALT	HIGH ALT	
Prop Single Eng.	62	85	80	-	-	-	205	155	95	95	142	100
Prop Light Twin	74	100	94	-	-	-	245	165	85	115	170	120
Prop Med. Twin	79	110	105	-	-	-	255	200	95	120	200	130
Prop Heavy Twin	74	105	100	-	-	-	245	200	87	190	210	120
Light Turbo Prop	105	160	170	170	-	-	250	200	170	160	190	120
Med. Turbo Prop	115	200	200	230	-	-	260	250	195	200	220	120
Heavy Turbo Prop	125	240	260	250	-	-	270	250	200	200	230	135
Exec. Jet	125	250	255	245	235	235	280	250	200	210	250	125
Med. Comm. Jet	125	260	265	255	245	245	290	250	200	200	230	130
Stand. Comm. Jet	120	280	275	265	255	245	300	250	180	200	250	130
High Perf. Jet	125	260	265	255	255	255	320	250	180	200	250	125

TABLE 3. AIRCRAFT PERFORMANCE CHARACTERISTICS

RUNWAY OCCUPANCY TIMES

TYPE AIRCRAFT	RUN UP TIME (SECS)	RUNWAY OCCUPANCY DEPARTURES		TIME TO LIFT-OFF		RUNWAY OCCUPANCY ARRIVAL	
		Avg.Dur.Sec.	δ *	Avg.Dur.Sec.	δ *	Avg.Dur.Sec.	δ *
Prop-Single Eng.	30	20	5	15	3	45	5
Prop-Light Twin	35	20	5	15	3	45	5
Prop-Med Twin	35	24	5	18	4	50	5
Prop-Heavy Twin	40	20	5	15	5	20	5
Light Turbo Prop	40	50	4	25	5	45	4
Med. Turbo Prop	40	35	3	25	4	50	3
Heavy Turbo Prop	45	35	3	30	2	55	3
Exec. Jet	40	30	2	32	2	53	2
Med. Comm. Jet	45	30	3	33	3	55	3
Stand Comm. Jet	45	35	3	30	2	55	3
High Perf. Jet	45	38	3	30	2	55	3

* Standard Deviation

APPENDIX C

BCAS QUESTIONNAIRE

SUBJECT ____________________ DATE ____________

SERIES ____________ CONTROL POSITION(S) ________ RUN # ________

1. To what extent did the following aspects of the test create problems for you? Check the appropriate columns.

ASPECT	NOT AT ALL	A LITTLE	A LOT	A GREAT DEAL
a. Traffic density				
b. Mix of BCAS and ATCRBS				
c. Reduced visual separation criteria				
d. Clutter created by the BCAS display features				
e. BCAS concept				

2. Do you feel that your performance would have improved if you had had more experience with the BCAS concept?

NOT AT ALL ________ SOMEWHAT ________ GREATLY ________

3. Was the simulated environment realistic enough for you to properly evaluate the BCAS concept?

YES ________ NO ________

If no, what features were unrealistic? ____________________

____

____

4. How did BCAS affect the following aspects of your control? Check the appropriate columns.

ASPECT	GREATLY DECREASED	DECREASED	DID NOT CHANGE	INCREASED	GREATLY DECREASED
a. Orderliness					
b. Traffic Handling Capacity					
c. Safety					
d. Workload					
e. Stressfulness					
f. Applied Separation					

5. If all aircraft had been BCAS equipped, would your rating have changed?

YES __________ NO __________

If yes, in what way? ______________________________

____

____

6. Did you agree with the BCAS commands:

NEVER __________ OCCASIONALLY __________ USUALLY __________ ALWAYS ______

If not, please cite example(s). ______________________________

____

____

7. Was the presentation of the following command in the data block easily interpreted?

Positive commands YES __________ NO __________

If no, what was confusing? ______________________________

____

____

8. Do you consider the blinking command an acceptable attention device for controller alert?

YES __________ NO __________

If no, please suggest alternative ______________________________

____

____

9. Did you ever have difficulty reading a command because of clutter?

YES __________ NO __________

Please elaborate ______________________________

____

____

10. If clutter presented any difficulty, in which areas was it detrimental?

FINAL APPROACH __________ VECTOR AREAS __________

HANDOFF POINTS __________ OTHER (SPECIFY) ______________________________

____

____

11. In light of your experience to this point, with BCAS, please circle the statement that most closely matches your opinion on whether BCAS should be put into operational use.

a. I strongly oppose its use

b. I oppose its use.

c. I am indifferent to its use.

d. I favor its use.

e. I strongly favor its use.

Please explain ______________________________

____

____

12. Has your answer to the above question changed as you gain more experience with BCAS?

YES __________ NO __________

Please explain ______________________________

____

____

13. Would you prefer to see negative commands displayed in the data block?

YES __________ NO __________