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LEVEL II

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AIR TRAFFIC CONTROL/FULL BEACON COLLISION AVOIDANCE SYSTEM CHICAGO SIMULATION

AD A069524

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16. Abstract

The purpose of this project was to investigate Air Traffic Control/Full Beacon Collision Avoidance System (ATC/BCAS) interaction in a high-density terminal area (featuring parallel instrument landing system (ILS) approaches) and to provide data for a comparative study between BCAS and other aircraft collision avoidance systems. The tests were conducted using the Air Traffic Control Simulation Facility (ATCSF) at NAFEC during March and April 1978. Analysis of the results indicated that the presence of BCAS had no adverse impact on the controllers or control procedures because of a very low interaction rate. Controllers were generally indifferent to the use of the BCAS during the simulation. A significant number of controllers desired the displaying of negative commands. Throughout the simulation, BCAS issued a high number of vertical speed limit (VSL) alerts; however, most of these were advisory in nature, having no effect on the aircraft flightpath. Certain changes in the BCAS logic are identified which would significantly reduce the VSL alert rate in the terminal area without derogation of safety. Recommendations are made to investigate further desensitization techniques and further development of a multi-aircraft resolution logic, and to perform additional real-time simulation to assess the effect of profile descent procedures on BCAS alert rates.

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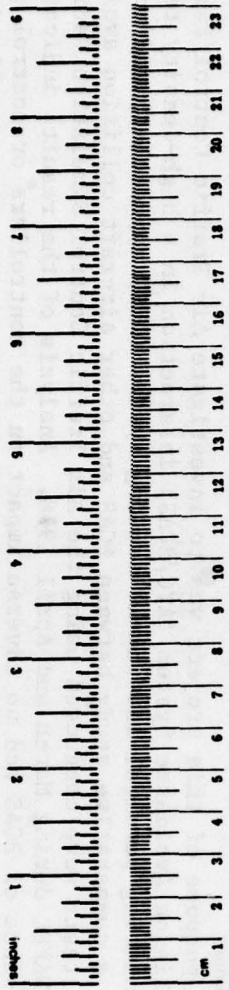
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

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



Approximate Conversions from Metric Measures

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

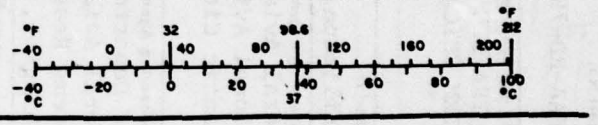


TABLE OF CONTENTS

	Page
INTRODUCTION	1
Purpose	1
Background	1
SYSTEM DESCRIPTION	2
General	2
System Environment	3
Traffic Samples	3
Error and Response Models	5
Design Conditions	5
Controller Questionnaire	7
DR&A Procedures	7
METHODS AND RESULTS	7
Operations Rates	7
Conflict Analysis and Minimum Separation	8
BCAS Alert Rates and Alert Durations	10
Short BCAS Alerts	11
Location of Alerts	18
VSL Filtering Techniques	19
Relative Position Analysis	21
Controller Questionnaire Analysis	21
ACAS/BCAS Alert Rate Comparison	23
CONCLUSIONS	29
RECOMMENDATIONS	30
REFERENCES	31
APPENDICES	
A - Changes to BCAS Logic as Presented in MTR 7532	
B - BCAS Messages and Desensitization Zones	
C - Aircraft Performance Characteristics	
D - Experimental Conditions	
E - BCAS Questionnaire	
F - DR&A Programs	
G - Conflict Analysis and BCAS Actions	
H - Location of Alerts	
I - Analysis of Two-Out-of-Three Rule on VSL Alert Rate	
J - Analysis of Reduction in MTAU2 Values	
K - Analysis of CPA's Following Positive or Negative Commands	

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LIST OF ILLUSTRATIONS

Figure		Page
1	Typical Traffic Flow Pattern	4
2	Experimental Design Conditions and Run Schedule	6
3	Aircraft Conflict Areas	9
4	Histogram of BCAS Alert Durations	14
5	Short-Duration VSL Sequence	15
6	Horizontal View of Typical Noneffective VSL Encounter	16
7	Vertical View of Typical Noneffective VSL Encounter	17
8	Relative Position at Alert Onset	22

LIST OF TABLES

Table		Page
1	Aircraft Operations Rates	8
2	Average Hourly BCAS Alert Rates, VFR Series, 32-Percent BCAS Equipped	12
3	Average Hourly BCAS Alert Rates, VFR Series, 68-Percent BCAS Equipped	12
4	Average Hourly BCAS Alert Rate, IFR Series, 65-Percent BCAS Equipped	13
5	Average Hourly BCAS Alert Rates, VFR High-Density Arrivals, 100-Percent BCAS Equipped	13
6	Location of VSL's in the Terminal Area	19
7	Average Number of VSL's per Hour	20
8	ACAS/BCAS Alert Rate Comparison (VFR Low Mix)	25
9	ACAS/BCAS Alert Rate Comparison (VFR High Mix)	26
10	ACAS/BCAS Alert Rate Comparison (IFR High Mix)	27
11	ACAS/BCAS Alert Rate Comparison (High-Density Arrivals, 100-Percent Equipped)	28

LIST OF ABBREVIATIONS

ACAS	Airborne Collision Avoidance System
ARTS III	Automated Radar Tracking System
ATARS	Automatic Traffic Advisory and Resolution Service
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATCSF	Air Traffic Control Simulation Facility
BCAS	Beacon Collision Avoidance System
CPA	Closest Point of Approach at which two aircraft are expected to pass each other
CSC	Computer Sciences Corporation
DABS	Discrete Address Beacon System
DR&A	Data Reduction and Analysis
GAT-2A	General Aviation Trainer Cockpit Simulator
ID	Aircraft identification
ILS	Instrument Landing System
IPC	Intermittent Positive Control
IPD	Intruder Positional Data (Proximity Warning Indication)
Mode C	Aircraft Encoding Altimeter Capability
TAU	Ratio of Range to Rate of Closure
VSL	Vertical Speed Limit

LIST OF BCAS ALGORITHM TERMS

BCASDT	Algorithm subroutine that performs intruder tracking, threat detection, resolution, limit command, and IPD determination, and display functions.
CMDSAV	Command being displayed to own aircraft due to this intruder
CONINT	Identification of the intruder controlling the display of commands
DMOD	Modified tau distance used for positive and negative commands
DMODP	Modified tau distance used for IPD detection
DPLY	Display indicator
DRPAS	Passive mode logic detection and resolution
FLSHFL	Control variable for flashing IPD
HORMAN	Subroutine used to select turn commands
INDEX	Index corresponding to desensitization level used for entering the 3 x 2 matrix of values for the settable parameters
IPDFLG	Control variable for IPD
JNDEX	Index corresponding to intruder's equipage used for entering the 3 x 2 matrix of values for the settable parameters
KHIT	Own intent status indicator with respect to this intruder
LALT	Altitude separation outside which vertical speed limits are not issued
LIMDET	Subroutine which generates VSL's
MTAU2	Modified tau distance used to determine whether VSL commands should be issued
NTENT	Intent of own aircraft
RDTHR	Immediate range threshold used to choose between tau test and range test
RTHR	Immediate range threshold used in threat detection for immediate range test
TAUH	Horizontal tau

TAUR	Range tau
TAUV	Vertical tau
TCUR	Current time
TDROP	Time without reported data to drop an intruder
TIMEV	Look-ahead time used to compute the projected vertical miss distance to determine whether to request a positive or negative command
TIPDF	Tau threshold for flashing IPD test
TPROV	Time at which NTENT is set to provisional command status
TREPT	Time of the last set of target reports for this intruder
TRIACT	Subroutine for tracking intruder data for active mode
TRIPAS	Subroutine for tracking intruder data for passive mode
TRTHR	Value against which modified tau (TAUR) is being compared
TVPCMD	Look-ahead time used to compute the projected vertical miss distance
TVTHR	Value against which vertical tau is being compared
XDINT YDINT ZDINT	Intruder's tracked velocity coordinates
ZDOWN	Own aircraft vertical tracked velocity
ZDTHR	Altitude rate threshold used by threat detection
ZINT	Intruder's vertical tracked position coordinates
ZLIMIT	Simulated airport altitude below which aircraft are not tracked
ZTHR	Immediate altitude threshold used by detection level

INTRODUCTION

PURPOSE.

This report describes the tests conducted and the results obtained from the Chicago Terminal Area Air Traffic Control (ATC)/Full Beacon Collision Avoidance System (BCAS) Dynamic Simulation. This experiment was conducted to (1) assess the impact of BCAS on the controller and control procedures in high-density parallel runway terminal operations, (2) assess the requirements of BCAS information being displayed to the controllers, (3) investigate the effectiveness of desensitization in the terminal area, and (4) to provide certain measures for comparative studies of BCAS alert rates and durations in the Chicago environment with other collision avoidance systems observed in the same simulation environment. A secondary objective of the experimentation was to validate BCAS performance with respect to the number, duration, and location of alerts and resolution effectiveness.

BACKGROUND.

The ATC/BCAS interaction experiment was the second phase of a BCAS evaluation program. The first phase addressed the pilot/BCAS interface. The results of the first phase were reported in reference 1. The second phase was conducted in two parts. The results of the first part, the Chicago BCAS simulation, are reported here. The second part, the Knoxville BCAS simulation, has been conducted to measure levels of BCAS interaction in a terminal area with moderate operations rates which are not high enough to qualify for the Automated Radar Tracking System (ARTS III). The results of the Knoxville simulation will be subsequently reported.

The Chicago area was selected because of its very high operations rates and because other collision avoidance systems had been evaluated in this environment. The use of Chicago permitted the comparison of measurements obtained from BCAS experimentation with the results for other systems under fairly well controlled experimental conditions.

One type of separation assurance system previously evaluated in the Chicago environment was the Intermittent Positive Control (IPC) system. This evaluation was conducted in 1975. Several changes have been made to IPC, and it is now called the Automatic Traffic Advisory and Resolution Service (ATARS). ATARS is a ground-based system which provides protection from all threats equipped with mode C transponder (altitude reporting transponder). ATARS requires a Discrete Address Beacon System (DABS), while BCAS is aircraft-based and is compatible with the current ATC Radar Beacon System (ATCRBS).

Another separation assurance system tested in the Chicago environment was the Airborne Collision Avoidance System (ACAS) (reference 2). ACAS provided protection only from threats that were ACAS equipped; whereas, BCAS provides protection from all threats, provided the intruder has a mode C transponder.

Results of the other separation assurance system evaluations in the Chicago environment have been reported in reference 2. This report compares ACAS and BCAS alert rates. No comparison is made with ATARS because the latest ATARS experimental results are not yet available.

The BCAS evaluations were conducted at the National Aviation Facilities Experimental Center (NAFEC) using skeletal logic (reference 3) provided by Mitre, Inc., and coded and debugged by Computer Sciences Corporation (CSC). For the ATC experiment, Mitre, Inc. provided logic changes which selected the escape mode. The current logic is adaptive to two different modes of operation: the active mode which uses only range, range rate, altitude, and altitude rate in any airspace; and the passive mode, which additionally uses intruder bearing information when within ground surveillance coverage.

Preceding the simulation data runs, several training runs were conducted for controller familiarization and system shakedown. It was noted that a high BCAS interaction rate occurred between aircraft on the ground and aircraft on short final approach; (just outside 2 nautical miles (nmi) from the radar site). To eliminate these unnecessary alerts, BCAS resolution was blocked for "intruders" which were on the airport surface. Other changes, including a more selective coarse filter, were incorporated into the logic prior to conducting phase II experimentation. All logic changes made at NAFEC are discussed in detail in appendix A.

SYSTEM DESCRIPTION

GENERAL.

The Air Traffic Control Simulation Facility (ATCSF) at NAFEC provides real-time, human interaction, ATC simulation capability. Air traffic controllers using standard ATC procedures and phraseology issue clearances and instructions to simulator pilots. The pilots then convert these instructions into special character keyboard entries which are interpreted by the computer to control the flightpaths of the aircraft in the system. The facility provided a method of measuring the impact of 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. In the absence of radar coverage, the BCAS can actively interrogate intruder transponders to provide input to the algorithm. Collision avoidance messages that were generated by BCAS are reviewed in appendix B.

SYSTEM ENVIRONMENT.

The NAFEC Air Traffic Control Simulation Facility (ATCSF) was configured to represent a single ATCRBS site; namely, the Chicago O'Hare terminal area. There were some modifications to the site consistent with previous evaluations. Satellite airports were not included in the terminal area modeled. The navigational fixes and nominal traffic flow patterns were indicative of those currently in use in Chicago except that profile descent routes were not modeled, and overflights were not simulated. Although the Chicago terminal area extends beyond 80 nmi in some directions, the analysis only used data that were generated within 30 nmi of the radar site.

The ATCSF laboratory simulated six ATC control positions; one local control, one departure control, north and south arrival control positions, and two "ghost" enroute feeder control positions. The typical arrival and departure flow patterns are shown in figure 1. Every attempt was made to duplicate the experimental and system environmental conditions modeled in the previously referenced ACAS and IPC evaluations.

All traffic in the experiment was controlled, with full data blocks displayed for each target. The only modification of the data block was the displaying of a blinking character in the third line of data for aircraft receiving a positive BCAS command. This was the only BCAS information displayed to the controller during the simulation.

The simulator pilots received pilot messages when an aircraft they were piloting received a positive or negative command or a vertical speed limit (VSL) alert. The simulator pilots were instructed to inform the controller of the message being displayed only when controller instructions were contrary to the displayed message.

TRAFFIC SAMPLES.

The traffic samples were identical to the traffic samples used in previous collision avoidance studies conducted in the Chicago environment. Eleven categories of aircraft were modeled in this simulation. The performance characteristics of these aircraft are presented in appendix C. The densities and types of traffic are representative of early 1970 traffic levels at Chicago.

Traffic separation employed by controllers met either the standard Visual Flight Rules (VFR) or Instrument Flight Rules (IFR) terminal area separation criteria. Variation in separation for aircraft weight category and wake turbulence avoidance was not provided, since it had not been provided in either the IPC or ACAS study. Since, all aircraft were mode C equipped, all BCAS aircraft were provided protection from all other aircraft. Each simulation run lasted 1 hour and 15 minutes. The initial 15-minute period provided the traffic buildup period. This was followed by a 1-hour data collection period in which the traffic density remained nearly constant at a normal Chicago O'Hare level.

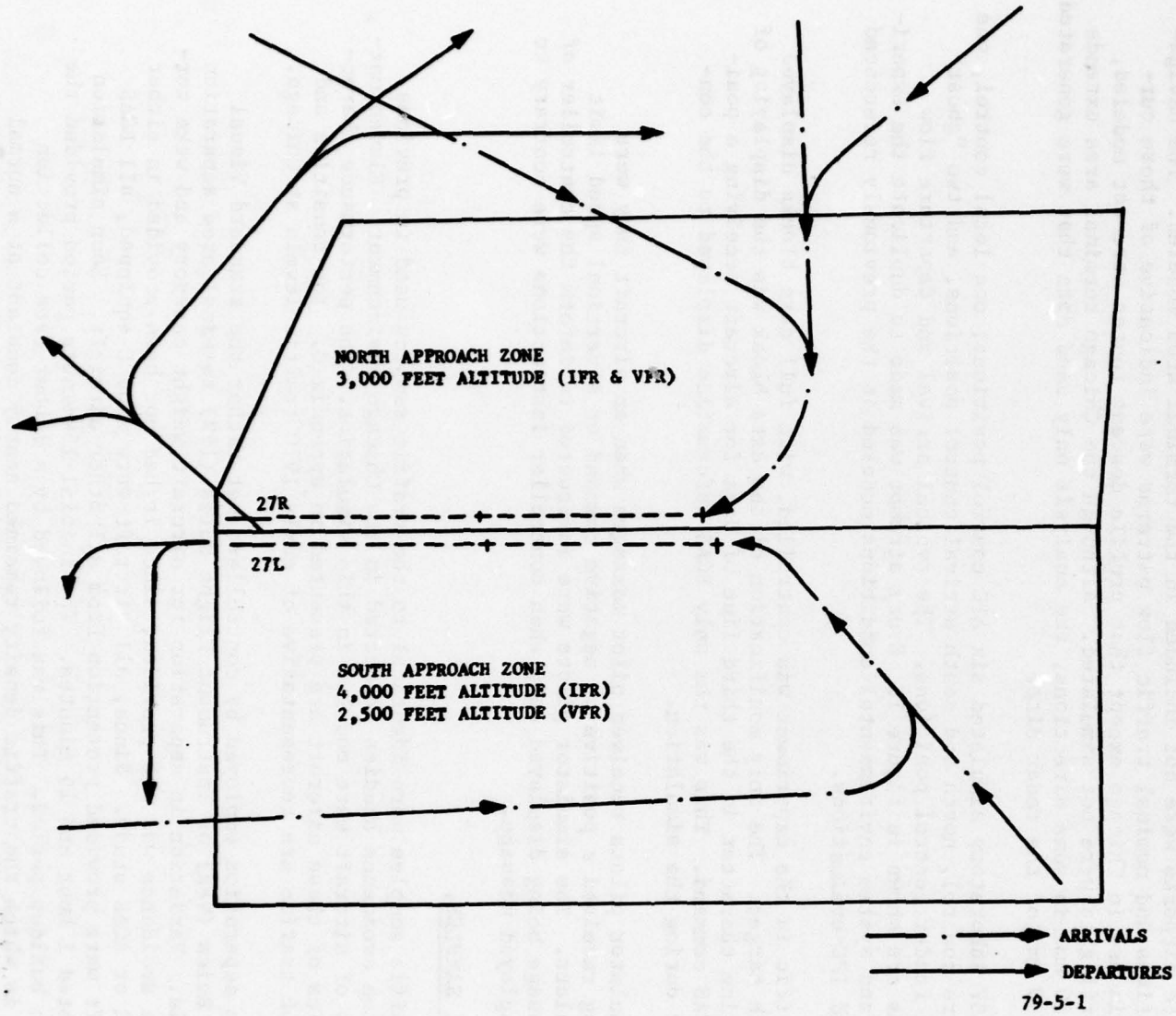


FIGURE 1. TYPICAL TRAFFIC FLOW PATTERN

ERROR AND RESPONSE MODELS.

Transponder mode C accuracy and surveillance accuracy were assumed perfect in all simulation runs. This assumption was made to conform with the simulated radar conditions in previous ATCSF collision avoidance experiments. Since no accurate description or magnitude of the errors in the BCAS-tracked position and velocity of intruders have been published, there was no error distribution to model in simulation; therefore, perfect position and velocity data were provided to the BCAS tracker. However, the reported altitudes of all aircraft were quantized in 100-foot increments, the accuracy limit of mode C transponders.

All BCAS aircraft in responding to a BCAS alert used pilot response and aircraft response delays. The pilot response model used, which was different than the model used in other CAS studies, was the Gamma distribution and resulted from findings in phase 1 experimentation (see reference 5). The aircraft acceleration rate vertically was 6 ft/s^2 (0.18 gravity (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 C.

Review of experimental data and comparison of the two pilot response models indicated this change did not affect the resulting alert rate or alert durations. The new pilot response delay model did provide a more accurate measure of achieved separation following an effective alert.

No comparison of separation following alerts for BCAS and ACAS was made because the data were not available from the ACAS experiment.

DESIGN CONDITIONS.

The experimental design and run schedule duplicated the previously referenced IPC and ACAS experiments, permitting a direct comparison of the results from the two experiments. Four traffic conditions were simulated: low (32-percent BCAS equipped) and high (68-percent BCAS equipped VFR arrivals and departures, high (65-percent BCAS equipped) IFR arrivals and departures, and 100-percent BCAS equipped VFR arrival-only traffic. The experimental design is presented in figure 2. The four experimental conditions are discussed in detail in appendix D.

A fully crossed design could not be used due to time limitation on experimentation. The design factors modeled are the same as those modeled in previous experiments. Each condition was replicated three times resulting in a total of 12 runs. The schedule of the runs (included in figure 2) was designed to reduce any training effect that may have occurred with the controllers. All controllers who took part in the experiment were NAFEC controllers who had participated in previous collision avoidance system simulations.

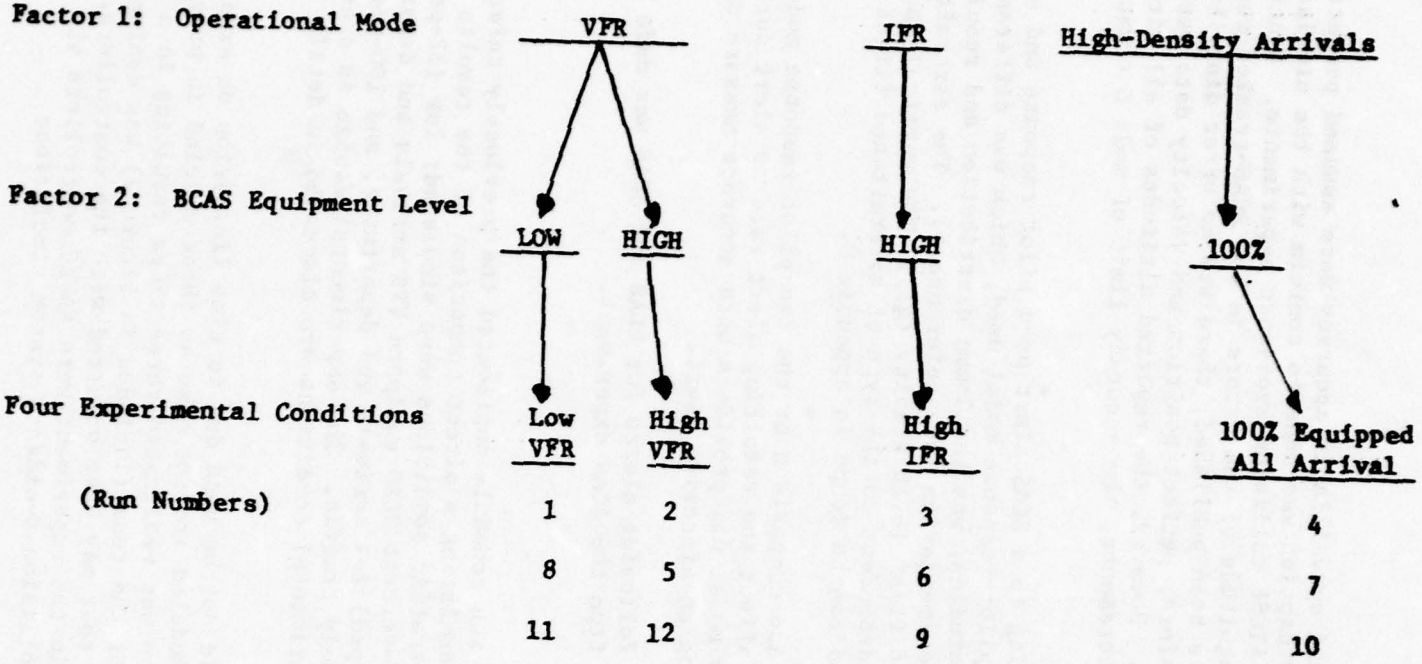


FIGURE 2. EXPERIMENTAL DESIGN CONDITIONS AND RUN SCHEDULE

CONTROLLER QUESTIONNAIRE.

The controllers' opinions and their assessment of the impact of BCAS on controller procedures were collected by means of questionnaires. A questionnaire was completed by each controller following every data collection run. The questionnaire is identical to one used in the IPC (ATARS) experiment and is included as appendix E. The questionnaire data collected were used to analyze the effect of BCAS on controllers and control procedures. The requirements of the BCAS controller display were also addressed through this questionnaire.

DR&A PROCEDURES.

Extensive use was made of computer programs to retrieve and analyze data from the Chicago experiment. The two primary programs used were the ATCSF LINK 3 program (reference 6) and the BCAS Allocate program (reference 7). Additional programs were developed to provide statistical analysis and aircraft encounter plots from the retrieved data. The use of the programs is discussed in appendix F.

METHODS AND RESULTS

This section presents the analytical techniques used and the results of that analysis. Some of the topics presented include operations rates, conflict analysis, alert rates, alert durations, geographic locations of alerts, relative altitude and range of conflicting aircraft, and the effect on VSL alert rates caused by different VSL alert filtering techniques.

OPERATIONS RATES.

The effect of BCAS on operations rates was investigated. Since the Chicago simulation included no overflights, total operations consisted of the sum of the arrivals and departures from O'Hare during an average 1-hour data collection period. The operations rates for each four experimental conditions are presented in table 1. Each entry represents the average for three 1-hour periods. For comparative purposes the operations rates from the ACAS experiment are also included in table 1.

TABLE 1. AIRCRAFT OPERATIONS RATES

Weather and Equipment Level	BCAS Arrivals	BCAS Departures	BCAS Total	ACAS Total
VFR 32% Equipped	81.3	89.0	170.3	147.3
VFR 65% Equipped	79.3	87.0	166.3	146.3
IFR 68% Equipped	81.7	90.3	171.1	145.3
VFR 100% Equipped all arrivals	90.0	-	90.0	105.0

Results show that as the percent of aircraft equipped with BCAS increased from 32 to 68 percent, there was no significant difference in arrival or departure rates (least significant difference T-test with p = .01). A 10-percent increase in the arrival rate occurred for the all-arrival series. The limiting factor in this case was the interarrival spacing required to compensate for the runway occupancy time of each arriving aircraft. With two runways in use, the average interarrival time between successive aircraft on the same runway was 80 seconds. Using an average speed of 140 knots, the average interarrival spacing at the outer marker was 3.1 nmi, which represents a fairly saturated system.

CONFLICT ANALYSIS AND MINIMUM SEPARATION.

The LINK 3 data reduction and analysis (DR&A) program provided a list of pairs of aircraft which had violated the ATC separation criteria in use (IFR, 1,000 feet or 3 nmi: VFR, 500 feet or 1 nmi). Analysis of these conflict data allowed an assessment of the orderliness of traffic flow and conformance to ATC separation standards by the controllers. The second use of conflict information was to assess the ability of BCAS to detect conflicts and provide satisfactory resolution when necessary. The areas where the conflicts occurred were divided into several geographical regions. These areas are depicted in figure 3.

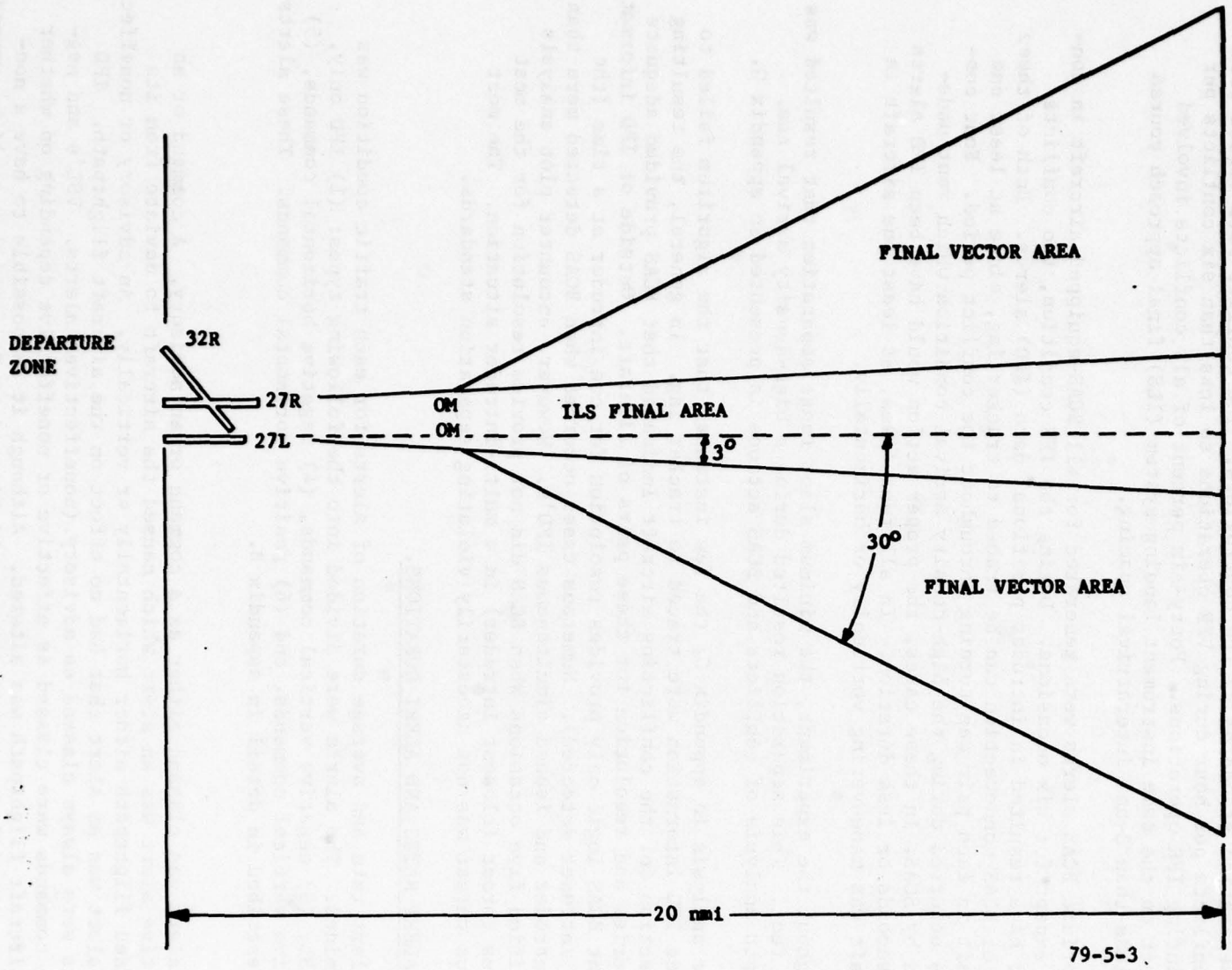


FIGURE 3. AIRCRAFT CONFLICT AREAS

It was found that during all four experimental conditions the ATC conflict rate was quite low, indicating an orderly traffic flow and general compliance with separation standards by the controllers. The conflict rate varied from two conflicts per hour during VFR operations to less than six conflicts per hour during IFR operations. Forty-six percent of all conflicts involved aircraft on the same instrument landing system (ILS) final approach course with less than 3-nmi interarrival spacing.

Appropriate BCAS alerts were generated for all BCAS-equipped aircraft in conflict except for six occasions. During the IFR condition, two conflicts should have resulted in intruder positional data (IPD) alerts. Both of these cases of BCAS nondetection can be traced to tracker lag, since at least one aircraft in each pair was turning throughout the conflict period. Four conflicts occurred during the high-density arrival condition which went undetected by BCAS. In these cases, the proper action would have been IPD alerts of 4 seconds or less duration. In all four cases, at least one aircraft in the pair was maneuvering vertically or horizontally.

Throughout the experiment, the minimum slant range separation that resulted was 1,312 feet. This separation resulted during a high-density arrival run. In-depth analysis of conflicts and BCAS actions is presented in appendix G.

In the analysis in appendix G, the few instances that the algorithm failed to provide IPD information were traced to tracker lag. In general, the resulting BCAS action for the conflicting aircraft indicated that BCAS provided adequate advisories and resolution for these pairs of aircraft. Outside of IPD information, current BCAS logic only provides resolution for one intruder at a time (the first intruder detected). Numerous cases occurred when BCAS detected more than one intruder and issued simultaneous IPD's. However, encounter plot analysis identified five occasions when BCAS did not provide resolution for the most serious threat (closest intruder) in a multi-intruder situation. The most serious threat was not necessarily violating separation standards.

BCAS ALERT RATES AND ALERT DURATIONS.

The alert rate and average duration of alerts for each traffic condition was determined. The alerts were divided into the following types: (1) IPD only, (2) VSL, (3) negative vertical commands, (4) negative horizontal commands, (5) positive vertical commands, and (6) positive horizontal commands. These alerts are described in detail in appendix B.

Each alert was classed either as a command or an advisory. A command or an effective alert was an alert which caused the aircraft to deviate from its intended flightpath either horizontally or vertically. An advisory or noneffective alert was an alert that had no effect on the aircraft flightpath. IPD alerts were always classed as advisory (noneffective) alerts. VSL's and negative commands were classed as effective or noneffective depending on whether the aircraft flightpath was altered. Although it is possible to have a noneffective positive command; i.e., a climbing aircraft receiving a climb command, none were observed, and all positive commands were classed as effective.

While multiple IPD's may be displayed, only one of the remaining alert types can be displayed at a time. The number and duration of flashing IPD's was not tabled separately, since flashing IPD's occurred simultaneously with the issuance of the VSL and continued during negative and positive commands. During an encounter period only the most critical type of alert was counted. The most critical alerts were positive commands, followed by negative commands, VSL's, and IPD's.

The BCAS alert rates and durations for each traffic condition are presented in tables 2 through 5. These tables show that more than 86 percent of all alerts were VSL alerts. Of the VSL alerts, only 10 percent were effective and could be classed as commands. The command rate ranged from 11.6 commands per hour for the VFR 32-percent equipped condition to 18.0 commands per hour for the high-density arrival condition.

SHORT BCAS ALERTS.

A histogram of alert durations for all alerts which occurred in the Chicago simulation is depicted in figure 4. From the histogram, it can be seen that 42 percent of all alerts were 4 seconds or less in duration.

The proportion of alert durations remained nearly constant for durations of 5 to 20 seconds. An apparent increase is shown for durations greater than 48 seconds; however, this represents all alerts with a duration in excess of 48 seconds. In reality, the number of occurrences continued to decrease uniformly as the duration increased.

The maximum duration for an alert was 180 seconds. The alerts which exceeded 48 seconds were generally VSL's or IPD's for conflicting aircraft which remained in close horizontal proximity for a long time, while making simultaneous parallel ILS approaches.

More than 80 percent of all the short-duration alerts occurred in the final ILS area of final vector area. Most of the short-duration alerts were VSL's for a pair of aircraft in which one aircraft was established on the ILS final and the other aircraft was maneuvering to intercept the other ILS final. Since north and south arrivals are separated by 1,000 feet vertically, a horizontal separation standard (tau) of 40 seconds or less between the pair will cause a VSL alert. This is because although both aircraft in the conflicting pair are being controlled and separated properly, the maneuvering aircraft's projected position vector conflicts with the projected position vector of the aircraft established on the ILS. The cycle-by-cycle sequence of the typical encounter is presented in figure 5.

In order to better present the problem of the high number of VSL alerts which were noneffective, the plots of the vertical view and horizontal view of a typical encounter situation is shown in figures 6 and figure 7. The aircraft were being vectored for simultaneous approaches to runway 27L and runway 27R.

TABLE 2. AVERAGE HOURLY BCAS ALERT RATES, VFR SERIES, 32-PERCENT BCAS EQUIPPED

Type Alert	Commands		Advisories		Total	
	Number	Avg. Dur. (Sec.)	Number	Avg. Dur. (Sec.)	Number	Avg. Dur. (Sec.)
IPD (only)	-	-	10.7	13.1	10.7	13.1
VSL	11.3	30.2	60.3	26.0	71.6	26.7
Neg. Vert.	0	-	.3	8.0	.3	8.0
Pos. Vert.	.3	5.0	0	-	.3	5.0
Neg. Horz.	0	-	0	-	0	-
Pos. Horz.	0	-	0	-	0	-
Total	11.6	29.5	71.3	24.0	82.9	24.8

TABLE 3. AVERAGE HOURLY BCAS ALERT RATES, VFR SERIES, 68-PERCENT BCAS EQUIPPED

Type Alert	Commands		Advisories		Total	
	Number	Avg. Dur. (Sec.)	Number	Avg. Dur. (Sec.)	Number	Avg. Dur. (Sec.)
IPD (only)	1	-	17.3	9.1	17.3	9.1
VSL	13.7	34.2	115.3	18.2	129.0	19.9
Neg. Vert.	.3	12.0	4.0	4.6	4.3	5.2
Pos Vert.	.7	6.0	0	-	.7	6.0
Neg. Horz.	0	-	0	-	0	-
Pos. Horz.	2.0	6.0	0	-	2.0	6.0
Total	16.7	31.2	136.6	16.7	153.3	18.2

TABLE 4. AVERAGE HOURLY BCAS ALERT RATE, IFR SERIES, 65-PERCENT BCAS EQUIPPED

Type Alert	Commands		Advisories		Total	
	Number	Avg. Dur. (Sec.)	Number	Avg. Dur. (Sec.)	Number	Avg. Dur. (Sec.)
IPD (only)	-	-	19.7	14.8	19.7	14.8
VSL	11.7	34.2	98.0	23.9	109.7	25.0
Neg. Vert.	0	-	0	-	0	-
Pos. Vert.	0	-	0	-	0	-
Neg. Horz.	3.0	6.2	.3	2.0	3.3	5.8
Pos. Horz.	0	-	0	-	0	-
Total	14.7	31.0	118.0	22.3	132.7	23.3

TABLE 5. AVERAGE HOURLY BCAS ALERT RATES, VFR HIGH-DENSITY ARRIVALS, 100-PERCENT BCAS EQUIPPED

Type Alert	Commands		Advisories		Total	
	Number	Avg. Dur. (Sec.)	Number	Avg. Dur. (Sec.)	Number	Avg. Dur. (Sec.)
IPD (only)	-	-	18.3	12.8	18.3	12.8
VSL	18.0	30.4	183.7	183.7	201.7	22.8
Neg. Vert.	0	-	.3	.3	.3	4.0
Pos. Vert.	0	-	0	0	0	-
Neg. Horz.	0	-	0	0	0	-
Pos. Horz.	0	-	0	0	0	-
Total	18.0	30.4	202.3	202.3	220.3	22.0

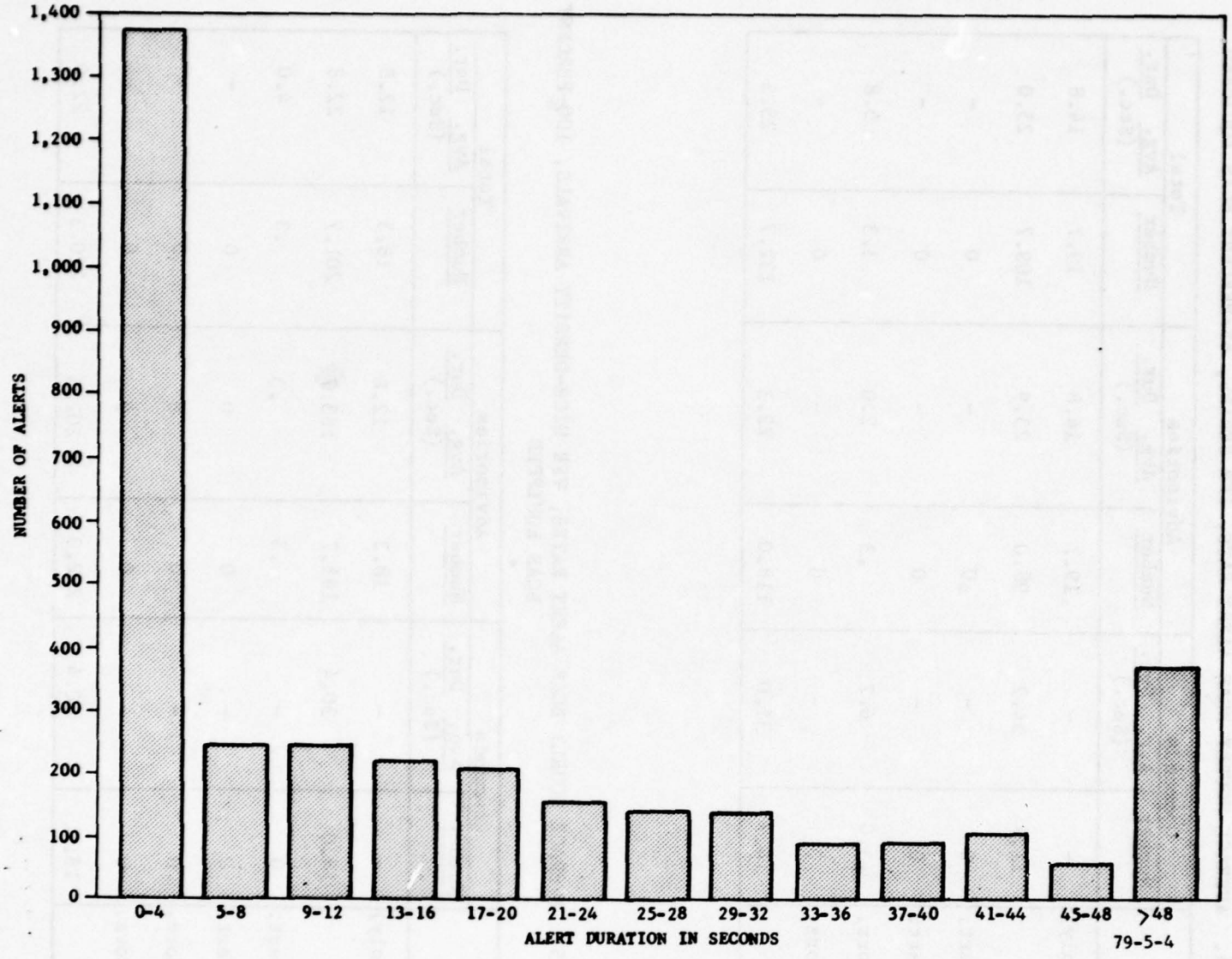


FIGURE 4. HISTOGRAM OF BCAS ALERT DURATIONS

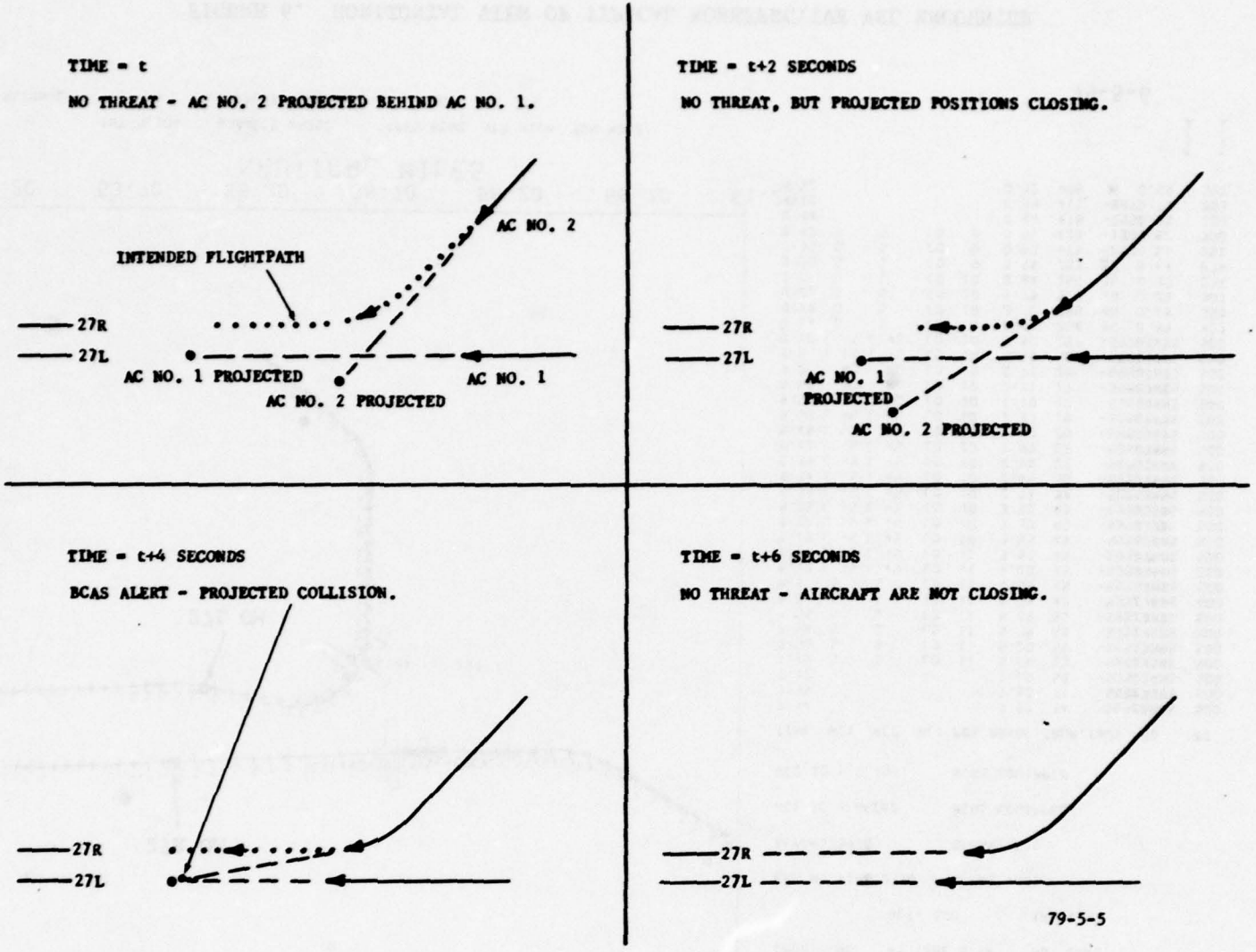
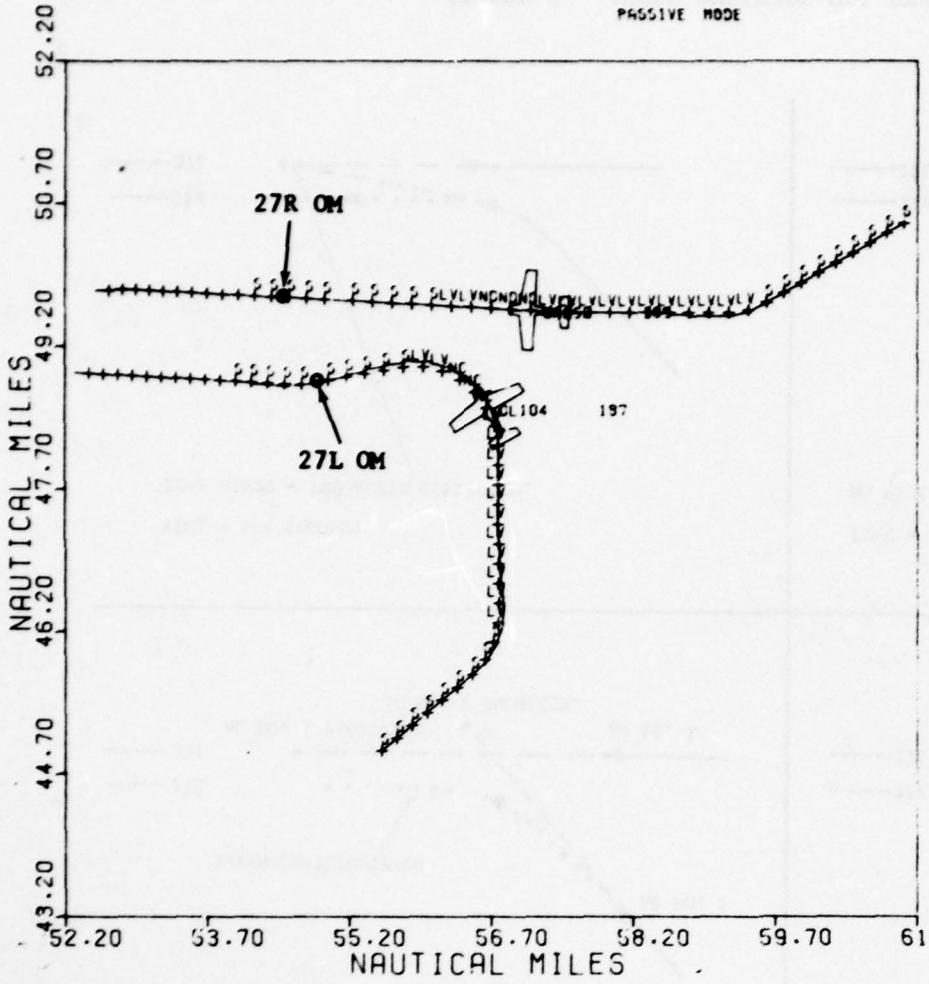


FIGURE 5. SHORT-DURATION VSL SEQUENCE



ENCOUNTER NUMBER 6
SENSITIVITY 3

CPAH = 3970 CPAV = 245

CMD= ND AT TIME 9:54 MD= 2042

ALT= 500 XANG= 57

CPA AT TIME 9:10 SCPA= 4001

SCPAH= 3970 SCPAV= 500

AC1 ID = UA252 BCAS EQUIPPED

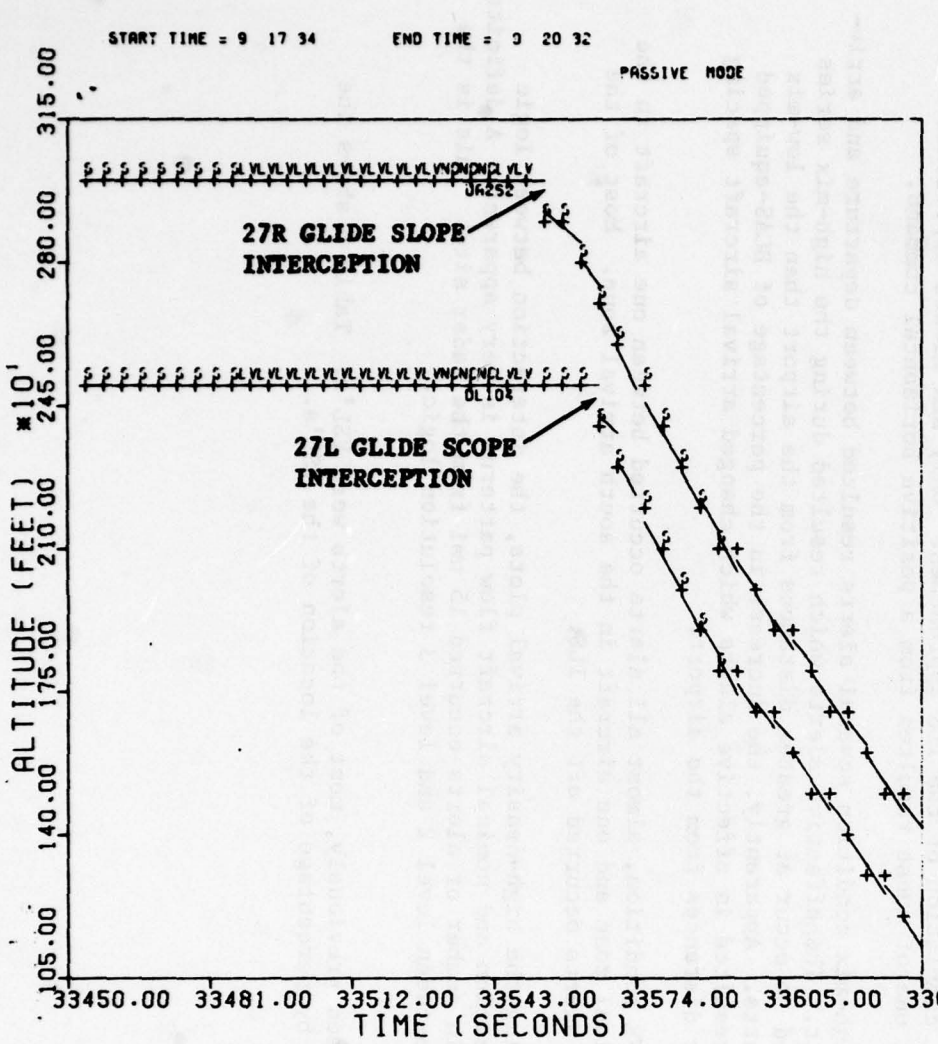
AC2 ID = DL104 BCAS EQUIPPED

TIME	AC1	AC2	ALT	POS	RANGE	TAUR	TAUV	MD	RZ
7:34					7.92	74	-59923895		500
7:39					7.50	71	-59923895		500
7:42					7.09	57	-59923895		500
7:45	S	S	LO	11	6.54	53	-59923895		500
7:50	S	S	LO	11	5.20	59	-59923895		500
7:54	S	S	LO	11	5.79	55	-59923895		500
7:59	S	S	LO	11	5.33	51	-59923895		500
8:2	S	S	LO	11	4.99	47	-59923895		500
8:5	S	S	LO	11	4.59	45	-59983895		500
8:10	L -5	L +5	LO	11	4.20	45	-59983895		500
8:14	L -5	L +5	LO	11	3.97	49	-59983895		500
8:19	L -5	L +5	LO	10	3.59	45	-59983895		500
8:22	L -5	L +5	LO	10	3.30	42	-59983895		500
8:26	L -5	L +5	LO	10	3.02	39	-59983895		500
8:30	L -5	L +5	LO	10	2.74	34	-59983895		500
8:34	L -5	L +5	LO	10	2.45	30	-59983895		500
8:39	L -5	L +5	LO	10	2.16	27	-59983895		500
8:42	L -5	L +5	LO	10	1.97	23	-59983895		500
8:46	L -5	L +5	LO	10	1.59	20	-59983895		500
8:50	L -5	L +5	LO	10	1.33	19	-59983895		500
8:54	ND	NC	LO	10	1.10	17	-59983895		500
8:59	ND	NC	LO	10	0.91	17	-59983895		500
9:2	ND	NC	LO	10	0.77	20	-59983895		500
9:5	L -5	L +5	LO	10	0.59	30	-59983895		500
9:10	L -5	L +5	LO	10	0.55	157	-59983895		500
9:14	S	S	CO	10	0.57	254	39	0.33	427
9:19	S	S	CO	10	0.72	295	40	0.19	393
9:22	S	S	CO	10	0.79	323	19	0.29	307
9:25	S	S	CO	10	0.84	355	25	0.37	274
9:30	S	S	CO	9	0.99	393	59	0.44	274
9:35	S	S	CO	9	0.93	415	-2920	.51	292
9:40	S	S	CO	9	0.95	423	-1900	.52	300
9:44					0.94	419	-2990	.90	303
9:49					0.93	411	-9570	.79	303
9:52					0.92	405	■	0.59	301

11

79-5-6

FIGURE 6. HORIZONTAL VIEW OF TYPICAL NONEFFECTIVE VSL ENCOUNTER



AC1 ID = UA252 BCAS EQUIPPED

AC2 ID = DL104 BCAS EQUIPPED

TIME	AC1	AC2	RZ	ADOT	VMD	DOT
7:34			500	0	*	*
7:39			500	0	*	*
7:42			500	0	*	*
7:45	S	S	500	0	*	*
7:50	S	S	500	0	*	*
7:54	S	S	500	0	*	*
7:59	S	S	500	0	*	*
9:2	S	S	500	0	*	*
9:6	S	S	500	0	*	*
9:10	L -5	L +5	500	0	*	*
9:14	L -5	L +5	500	0	*	*
9:19	L -5	L +5	500	0	*	*
9:22	L -5	L +5	500	0	*	*
9:25	L -5	L +5	500	0	*	*
9:30	L -5	L +5	500	0	*	*
9:34	L -5	L +5	500	0	*	*
9:39	L -5	L +5	500	0	*	*
9:42	L -5	L +5	500	0	*	*
9:45	L -5	L +5	500	0	*	*
9:50	L -5	L +5	500	0	*	*
9:54	ND	NC	500	0	500	*
9:59	ND	NC	500	0	500	*
9:2	ND	NC	500	0	500	*
9:6	L -5	L +5	500	0	*	*
9:10	L -5	L +5	500	0	*	*
9:14	S	S	427	-552	*	*
9:19	S	S	399	-599	*	*
9:22	S	S	307	-949	*	*
9:25	S	S	274	-545	*	*
9:30	S	S	274	-240	*	*
9:35	S	S	292	75	*	*
9:40	S	S	300	100	*	*
9:44			303	53	*	*
9:48			303	21	*	*
9:52			301	-4	*	*

79-5-7

FIGURE 7. VERTICAL VIEW OF TYPICAL NONEFFECTIVE VSL ENCOUNTER

DL104 was making an approach to 27L and was level at 2,500 feet. BN252 was making an approach to 27R and was level at 3,000 feet. The altitude information is obtained from figure 7. The separation between aircraft exceeded the VFR separation criteria throughout the encounter. The 90° intercept angle for DL104 caused an advisory VSL alert which lasted 60 seconds. The slight overshoot on turn to final by DL104 caused a 12-second noneffective negative vertical command. Throughout the encounter the vertical separation was at least 500 feet. The scenario was typical of the type alerts and alert durations that were generated for aircraft being separated using VFR criteria.

LOCATION OF ALERTS.

Review of Calcomp plot data in appendix H provided summary data on BCAS alert locations.

For VFR conditions, 78 percent of the effective alerts occurred within 2 nmi of the outer marker; however, these effective alerts had little impact on the successful completion of the ILS approaches. Only six missed approaches occurred, and one of these resulted from a positive horizontal command.

For VFR high-mix condition several alerts resulted between departure and arrival aircraft. The effective alerts which resulted during the high-mix series runs tended to occur at greater distances from the airport than the low-mix series alerts. Apparently, the increase in the percentage of BCAS-equipped aircraft resulted in effective alerts which changed arrival aircraft spacing at greater distances from the airport.

For the IFR condition, almost all alerts occurred between one aircraft in the north arrival zone and one aircraft in the south arrival zone. Most of the effective alerts occurred off the ILS.

In reviewing the high-density arrival plots, the interaction between logic desensitization and nominal aircraft flow patterns is very apparent. A definite increase in number of alerts occurred 15 nmi from the radar site. This is the boundary between level 2 and level 3 resolution logic.

As discussed previously, most of the alerts were VSL's. Table 6 shows the breakdown by percentage of the location of the VSL's.

TABLE 6. LOCATION OF VSL's IN THE TERMINAL AREA

Traffic Condition	Total Number	Effective Percent	On ILS Percent	In Final Approach Area Percent
VFR--32% BCAS Equipped	215	16	59	28
VFR--68% BCAS Equipped	387	11	60	27
IFR--65% BCAS Equipped	329	11	45	42
VFR 100% BCAS Equipped all arrivals	609	9	48	38

Interestingly, the percentage of VSL's on the ILS or in the final approach area remained constant at 86-87 percent for all four traffic conditions.

VSL FILTERING TECHNIQUES.

Previous discussions have shown that a high number of short-duration, noneffective VSL alerts occurred in the ILS final and final vector areas. Four possible methods were considered to reduce the VSL alert rate; (1) change of the shape of the desensitization zones to reduce the high VSL rate just outside 15-nmi range from the radar site, (2) inclusion of a miss-distance check to eliminate certain VSL's, (3) inclusion of a two-out-of-three rule check, similar to the one for positive commands, prior to displaying a VSL, and (4) decreasing the parametric thresholds for generation of a VSL.

Ideally, the alerts that should be eliminated are the short-duration noneffective alerts. The first method mentioned above cannot selectively eliminate short-duration noneffective alerts. Since changing the shape of the desensitization zones may have an impact on safety, method 1 was not analyzed. Method 2, the effect of a miss-distance check on reducing the VSL alert rate, also was not analyzed, since miss-distance information may not always be available in the BCAS active mode.

TWO-OUT-OF-THREE RULE. Basically, a two-out-of-three rule is a filtering technique which requires that the initial BCAS resolution be reinforced at least once out of the next two BCAS cycles before the alert is displayed. An immediate consequence of this type filter is the elimination of all alerts which originally would have lasted for only one BCAS cycle (2 seconds); i.e., a majority of the short-duration noneffective alerts.

In-depth analysis of the effect of a two-out-of-three rule on the VSL alert rate is made in appendix I. In summary, the application of a two-out-of-three rule would reduce the VSL alert rate by 34 to 43 percent depending on the traffic condition. Three percent of the eliminated VSL's would have caused a change in the aircraft flightpath. Analysis of these cases indicates the maximum reduction in vertical separation due to the use of a two-out-of-three rule would have been 128 feet. The results show the application of a two-out-of-three rule would have a very minimal impact on aircraft separation.

PARAMETRIC THRESHOLD CHANGES FOR VSL ALERTS. The method used to analyse the effect the reduction in MTAU2, the tau distance modifier for VSL's, had on the VSL alert rate is presented in appendix J. Table 7 presents the VSL alert rate reduction that resulted when MTAU2 was decreased to correspond with DMOD, the tau distance modifier for positive or negative commands.

TABLE 7. AVERAGE NUMBER OF VSL'S PER HOUR

Traffic Conditions	Original MTAU2 Level 1 = 1.8 nmi Level 2 = 0.75 nmi	Reduced MTAU2 Level 1 = 1.0 nmi Level 2 = 0.5 nmi	Percent Reduction
VFR 32% Equipped	71.6	37.9	47
VFR 68% Equipped	129.0	60.6	53
IFR 65% Equipped	109.7	42.7	61
All Arrivals	201.7	102.9	49

The impact on command rate or separation caused by the tau distance modifier (MTAU2) change could not be measured from previous experimental data. However, the results of the subsequent Knoxville experiment indicated no apparent increase in the percentage of alerts which were commands, or loss in separation when MTAU2 was reduced.

RELATIVE POSITION ANALYSIS.

Figure 8 shows the relative altitude and range between aircraft at the time at least one of them received a positive or negative command. Underlining of a command symbol indicates that the command resulted for an IFR aircraft. The remaining conflicts were between VFR aircraft. Except for two cases, all IFR conflicting aircraft were quite close to the IFR separation criteria (1,000 feet or 3 nmi) when they received a positive or negative command.

For all 12 runs in the Chicago simulation, 34 positive or negative (P/N) commands occurred. Seventy percent of these commands occurred when the separation was less than 1,000 feet or 3 nmi, but greater than the VFR minimum, 500 feet or 1 nmi. Only three P/N commands (8 percent) were generated when aircraft had already penetrated VFR minimum separation. The remaining P/N commands (22 percent) occurred when the separation between the aircraft exceeded minimum IFR separation requirements. The six P/N commands which occurred when the range between aircraft was in excess of 6 nmi represent encounters with aircraft converging at greater than 340 knots. A review of the alert locations indicated these high closing velocities occurred in the final vector area.

Analysis in appendix K shows the closest points of approach (CPA's) that resulted after P/N commands. The majority of CPA's following P/N commands were greater than VFR separation criteria but less than IFR separation requirements. Only three times did the resulting CPA's slightly penetrate VFR separation criteria.

CONTROLLER QUESTIONNAIRE ANALYSIS.

Two objectives of the experiment were to assess the impact of BCAS on the controllers and control procedures and to identify the requirements for BCAS information to be displayed to the controller. The analysis was based primarily on the subjective opinion of the controllers, which was sampled by use of the questionnaire presented in appendix E. Statistical significance was identified through the use of binomial tests on the hypothesized proportion of responses. The significance level used was p=.05.

Only positive BCAS commands were displayed to the controllers. The controllers were not aware of the high VSL alert rate that was occurring, since most of the alerts were advisories which did not alter aircraft flight profiles or control procedures. However, in reality, if such high alert rates were occurring, feedback from pilots might require controllers to make procedural changes, such as increased spacing or lower angle ILS intercepts.

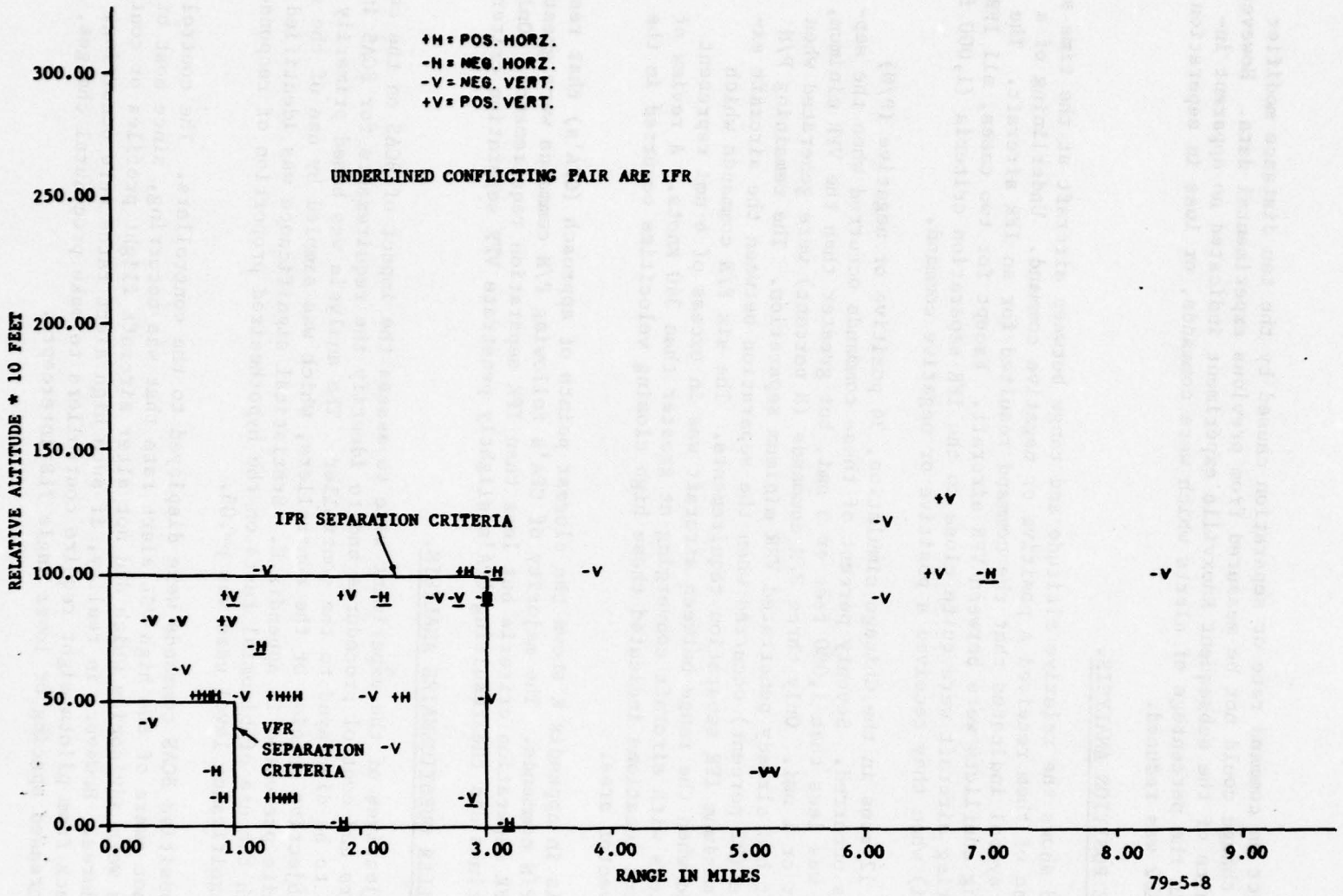


FIGURE 8. RELATIVE POSITION AT ALERT ONSET

The best environment for controller assessment of BCAS is one that permits a high controller/BCAS interaction rate. In this simulation, the aircraft were provided adequate separation, and the algorithm generated few unnecessary positive commands (less than one per hour). In combination, these characteristics elicited a low interaction rate and tended to inhibit the ability of the controllers to adequately observe and assess the impact of BCAS or to identify the BCAS display requirements. During the entire simulation only six missed approaches resulted because of BCAS alerts. One aircraft could not intercept and track the ILS localizer because of a positive horizontal command. Only five times, aircraft made missed approaches because effective VSL alerts caused them to deviate from the ILS glide slope.

All controllers throughout the experiment indicated that their performance would not have improved with an increase in their exposure to BCAS. Three reasons exist for this finding; (1) the BCAS/controller interaction rate was quite low, (2) repeated practice runs had been made before data collection began, and (3) all controllers had participated in previous collision avoidance system simulations.

Although the controllers observed little BCAS interaction, a significant portion of the questionnaire responses indicated that the controllers felt the simulation was realistic enough for them to properly evaluate the impact of BCAS. There was no clear-cut favoring or opposition among the controllers to the use of BCAS. More than 75 percent of the responses indicated the controllers were indifferent to the use of BCAS.

A significant proportion ($p > .25$) of the questionnaire responses indicated the controllers were not in agreement with the BCAS command displayed. In general, the controllers felt the positive commands they observed were unnecessary. To some extent a review of figure 8 supports the controller opinions. On three ocassions, positive vertical commands were issued for VFR aircraft which were more than 5 nmi apart. A total of eight positive commands were issued to VFR aircraft which had separation much greater than the VFR minimum. Almost all responses indicated BCAS had no effect on the following aspects of controller performance: orderliness, traffic-handling capability, safety, workload, stressfulness, and applied separation. In addition, an overwhelming proportion of the responses indicated that the blinking feature was the satisfactory method of command presentation.

ACAS/BCAS ALERT RATE COMPARISON.

Throughout the experiment, the BCAS-equipped aircraft were protected from all other traffic in the sample. This fact was not true in the ACAS experiment, because ACAS provided protection only from intruders which were ACAS equipped. An equitable comparison of alert rates for BCAS with ACAS requires that all BCAS alerts for ATCRBS-mode C only aircraft be eliminated from the alert count.

The alert rates for ACAS were taken from reference 2. The command types for ACAS and BCAS were different, in that ACAS did not have negative vertical commands or negative horizontal commands. These command types were replaced by level-off and limit-turn commands.

Tables 8 through 11 compare the ACAS and BCAS alert rates when outer switch point boundary (O-SPB) (least protection) was used for ACAS. The O-SPB of ACAS is similar in function to BCAS desensitization. The ACAS O-SPB provided a landing/departure mode with reduced resolution thresholds for aircraft on the localizer course at ranges less than 6 nmi from the radar site.

For the first three traffic conditions, the BCAS command rate is almost identical to the ACAS command rate, in spite of a 12-percent increase in operations for these traffic conditions during the BCAS simulation. For the high-density arrival traffic condition, the BCAS command rate was less then half the ACAS command rate. This reduction occurred because of effective limit-turn alerts which resulted with ACAS for aircraft which were maneuvering to intercept the localizer during dense traffic conditions. BCAS generated alerts during the same situation, but the alerts were VSL's. Since aircraft were not generally maneuvering vertically while intercepting the localizer, the VSL's were advisory alerts. This fact is substantiated by the 40-percent increase in the BCAS advisory alert rate over ACAS for this traffic condition.

It is noted that the duration of BCAS commands reflects a 100-percent increase over the ACAS command durations. The increase is due to the longer duration of effective BCAS VSL's. This increase is the result of the BCAS tracker. ACAS did not use vertical tracking, and once relative altitude thresholds were surpassed, the ACAS alert terminated.

The BCAS advisory alert rate ranged from nearly identical to the ACAS rate to more than 50 percent higher, depending on the traffic sample. When 2- and 4-second BCAS advisories are removed from the data base, the resulting BCAS advisory rate ranges from 30 to 40 percent less than the ACAS rate.

TABLE 8. ACAS/BCAS* ALERT RATE COMPARISON
(VFR LOW MIX)

MESSAGE / Commands	ACAS O-SPB		BCAS		BCAS**	
	Number	Avg. Dur. (Sec)	Number	Avg. Dur. (Sec)	Number	Avg. Dur. (Sec)
Positive	0	-	.3	5.0	.3	5.0
Effective Negative	-	-	0	-	0	-
Effective VSL	1.7	11.2	1.0	34.0	1.0	34.0
Level-off or Limit Turn	0.7	21.0	-	-	-	-
TOTAL	2.4	14.0	1.3	27.5	1.3	27.5
Advisories						
IPD Only	-	-	3.3	14.0	2.3	18.3
VSL's	17.3	28.5	13.3	11.8	7.0	20.4
Limit Turn	1.7	4.2	-	-	-	-
Negative Commands	-	-	.3	8.0	.3	8.0
TOTAL	19.0	26.4	16.9	12.2	9.6	19.5

* BCAS alerts for mode C only aircraft deleted.

** BCAS rates when 2- and 4-seconds alerts are removed.

TABLE 9. ACAS/BCAS* ALERT RATE COMPARISON
(VFR HIGH MIX)

MESSAGE	ACAS O-SPB		BCAS		BCAS**	
	Number	Avg. Dur. (Sec)	Number	Avg. Dur. (Sec)	Number	Avg. Dur. (Sec)
Commands						
Positive	0	-	2.0	6.0	.2	6.0
Effective Negative	-	-	0.3	12.0	0.3	12.0
Effective VSL	7.0	13.7	7.3	36.6	7.0	37.6
Level-off or Limit Turn	3.7	13.8	-	-	-	-
TOTAL	10.7	13.8	9.6	29.5	9.3	30.0
Advisories						
IPD Only	-	-	10.7	20.9	3.6	33.7
VSL'S	59.3	30.9	85.3	16.0	45.6	26.6
Limit Turn	5.3	21.8	-	-	-	-
Negative Commands	-	-	2.3	2.0	.0	-
TOTAL	64.7	30.2	98.3	16.2	49.2	27.1

* BCAS alerts for mode C only aircraft deleted.

** BCAS rates when 2- and 4-second alerts are removed.

TABLE 10. ACAS/BCAS* ALERT RATE COMPARISON
(IFR HIGH MIX)

MESSAGE	ACAS O-SPB		BCAS		BCAS**	
	Number	Avg. Dur. (Sec)	Number	Avg. Dur. (Sec)	Number	Avg. Dur. (Sec)
Commands						
Positive	0	-	0	-	0	-
Effective Negative	-	-	1.7	6.0	.7	8.0
Effective VSL	5.0	16.5	5.1	42.8	5.1	42.8
Level-off or Limit Turn	1.3	24.3	-	-	-	-
TOTAL	6.3	18.1	6.8	33.8	5.8	33.6
Advisories						
IPD Only	-	-	10.3	19.5	4.3	40.9
VSL's	64.3	29.2	52.3	23.3	30.3	33.1
Limit Turn	5.3	18.9	-	-	-	-
Negative Commands	-	-	0.3	2.0	.0	-
TOTAL	69.6	28.4	62.9	22.6	34.6	34.1

* BCAS alerts for mode C only aircraft deleted.

** BCAS rates when 2- and 4-second alerts are removed.

TABLE 11. ACAS/BCAS ALERT RATE COMPARISON
(HIGH-DENSITY ARRIVALS, 100-PERCENT EQUIPPED)

MESSAGE	ACAS O-SPB		BCAS		BCAS	
	Number	Avg. Dur. (Sec)	Number	Avg. Dur. (Sec)	Number	Avg. Dur. (Sec)
Commands						
Positive	5.0	9.6	0	-	0	-
Effective Negative	-	-	0	-	0	-
Effective VSL	19.5	21.1	18.0	30.4	17.7	30.7
Level-off or Limit Turn	15.5	11.8	-	-	-	-
TOTAL	40.0	16.1	18.0	30.4	17.7	30.7
Advisories						
IPD Only	-	-	18.3	12.9	3.7	47.9
VSL's	125.0	44.1	183.7	22.2	98.7	36.7
Limit Turn	19.5	42.4	-	-	-	-
Negative Commands	-	-	0.3	4.0	0	37.1
TOTAL	144.5	43.8	202.3	21.3	102.4	37.1

* BCAS rates when 2- and 4-second alerts are removed.

CONCLUSIONS

Based on the analysis and results of this simulation, it is concluded that:

1. The BCAS had little or no direct impact on the ATC system. The operations rate for BCAS increased, in general, over the ACAS operations rates. Throughout the simulation, only six missed approaches occurred because of BCAS. Controllers were not opposed to the use of BCAS as a backup to the ATC system. The only negative item detected in the questionnaire analysis was that usually controllers felt that the positive commands were premature.

2. The high, noneffective VSL alert rate may impact adversely on pilots. Pilot acceptance of and response to BCAS alerts could be affected by the high number of unnecessary noneffective alerts which occur in the final approach area. The high VSL alert rate, which controllers did not see and were unaware of, may indirectly impact on control procedures through feedback from pilots.

3. Standard control procedures and a low positive BCAS command rate resulted in low ATC/BCAS interaction. The low interaction prevented assessment of the controller display requirements.

4. The excessive length of BCAS commands (effective VSL's in particular) is due to large parameter values of MTAU2 and the lack of use of miss-distance information to control command length. Miss-distance information would be quite useful in controlling command length, especially when an aircraft is maneuvering to intercept the localizer during simultaneous parallel ILS approach operations.

5. The BCAS provides adequate pairwise resolution for conflicting aircraft. On five occasions BCAS did not provide resolution for the most critical threat in multi-intruder encounters. Current logic parameters protect against penetration of IFR separation standards. This fact results in a high number of unnecessary alerts during controlled VFR operations.

6. Discrete desensitization methods do not provide adequate filtering of noneffective unnecessary alerts. Discrete desensitization methods caused a high rate of unnecessary alerts in certain geographical areas in close proximity to discrete desensitization boundares. This result was pronounced when simultaneous parallel ILS approaches were in progress.

7. The current BCAS logic can be changed to significantly reduce the high number of short-duration noneffective VSL alerts. Analysis indicated the reduction in MTAU2, the tau distance modifier for VSL's, to coincide with DMOD, the tau distance modifier for positive or negative command, would result in an acceptable alert rate. The same result would occur through the use of a two-out-of-three rule in VSL resolution.

RECOMMENDATIONS

Based on the analytical results and conclusions for this simulation, it is recommended that:

1. Improvements should be made in the BCAS algorithm to reduce the VSL alert rate. Improvements should include the reduction in MTAU2 to conform with the values of DMOD and the use of a two-out-of-three rule in VSL resolution logic to eliminate short-duration alerts. Miss-distance information should be incorporated into the VSL logic to reduce alert durations.

2. Other experimental methods should be developed and used to assess controller display requirements. Proper control procedures and low positive command rates prevented the ATC/BCAS interaction needed to assess controller display requirements.

3. The active BCAS logic should be evaluated in a moderate-density terminal area. Results of this experiment indicate that the passive (full) logic did not negatively impact on the ATC system. The next logical step is the evaluation of the active logic. However, the scope of that evaluation should focus on an area where passive logic cannot be used; i.e., a moderate-density terminal area without an ARTS III system.

4. Future real-time ATC/BCAS simulations should include profile descent traffic. The modeling of profile descent traffic will allow evaluation of BCAS detection and resolution for intruders that have high vertical descent rates.

5. Desensitization methods, such as continuous desensitization, should be investigated. Current discrete desensitization causes high alert rates in certain geographical areas in close proximity to desensitization boundaries. Without site adaptation, the movement of desensitization boundaries to reduce alert rates would also cause a reduction in protection provided.

6. BCAS logic changes should be made so that BCAS provides resolution for the most critical threat, not the first threat detected, in a multi-intruder situation. Resolution of the most critical threat is a logical interim step to the development of a full multi-aircraft logic.

7. Methods of adapting BCAS logic to VFR separation standards should be investigated. During controlled VFR operations, the current logic is not a backup to ATC. It generates alerts prior to the occurrence of VFR spacing violations.

8. Number and duration of alerts as well as the impact of simultaneous IPD's should be analyzed from a pilot's point of view. The pilot interacts with the ATC system, and any impact on him may indirectly affect the ATC system.

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1. Billmann, B., Report of Findings in the BCAS/GAT II Pilot Interaction Experiment, Computer Sciences Corporation, TM-14-009, October 1977.

2. Mullen, W., Rossiter, S., Strack, R., and Windle, J., Simulation Study of Intermittent Positive Control in a Terminal Area Air Traffic Control Environment, U.S. Department of Transportation, FAA-RD-76-193, January 1977.

3. Clark, J., and McFarland, A., Initial Collison Avoidance Algorithm for the Beacon Based Collision Avoidance System, Mitre, Incorporated, MTR 7532, April 1977.

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

5. Billmann, B., Modeling Pilot Response Delays, Computer Sciences Corporation, TM-14-017, January 1978.

6. Comstock, J., Milner, K., and Westmorelamd, C., Standard DSF Link 3 Documentation, Computer Sciences Corporation, TM-04-023, September 1976.

7. Duke, J., and Simon, J., Program Design Specifications for the BCAS/Pilot-Controller ATCSF Simulation, Computer Sciences Corporation, TM-14-025, July 1978.

APPENDIX A

CHANGES TO BCAS LOGIC AS PRESENTED IN MTR 7532

Several coding changes were made to the BCAS algorithm (reference 3) at NAFEC. Except for the coarse track logic, these changes have been coordinated with Mitre, Inc. This appendix discusses each problem and presents flow chart changes that were made to the BCAS algorithm.

Parameter Sets:

The latest parameter values in use at NAFEC conform to MTR 7532 except for the values listed in table A-1.

Coarse Track Logic:

CSC has had to expand the coarse track logic to provide more filtering of undesired tracks in our simulations. The expanded screening uses information only available when operating in a passive mode. Since aircraft densities would be much lower in areas where the active mode would be used, the coarse screening suggested by MTR 7532 would be sufficient for the active mode. Coarse tracks are screened and stored based on a coarse-screening truth table as shown in table A-2. This coarse track logic will not filter out tracks that would result in BCAS alerts, but will reduce the total number of coarse tracks that must be stored.

Inadequate or No Coarse Track Data on the Intruder Prior to Entering a Command Region:

While the algorithm does provide for adequate coarse tracking of an intruder prior to entering the BCAS interaction region, several things could happen to cause the intruder not to be tracked. One cause could be intermittent or inoperative equipment onboard the intruder. Terrain masking could cause a "pop up" type encounter where the aircraft is initially detected when it is well within command range as shown in figure A-1. Another possible cause could be a temporary radar malfunction.

These problems do occur in the real world and the algorithm should be capable of handling them. The same type of problems arise in our simulations. When the intruder becomes active (begins to fly) its entry position might cause it to be immediately in the command generation region of an equipped aircraft. Subroutines which generate the BCAS commands require relative velocity information on the intruder. When these subroutines are entered with the intruder being tracked for just one cycle, the required relative velocity information isn't available. Furthermore, the tracked relative velocities may be quite

TABLE A-1. PARAMETER CHANGES

Parameter	Nominal Value
DMOD	1.0 nmi
	.5
	.3
	1.0
	.5
	.3
MATU2	1.8 nmi
	.75
	.5
	1.8
	.75
	.5
RTHR	.5 nmi
	.4
	.3
	.5
	.4
	.3
TIMEV	25 seconds
	20
	20
	25
	25
	20
TIPDF	35 seconds
	30
	25
	35
	30
	25
TRTHR, TVTHR, TVPCMD	25 seconds
	20
	20
	25
	20
	20

TABLE A-1. PARAMETER CHANGES (Continued)

ZDTHR	-30	ft/sec
	-36	
	-45	
	-36	
	-45	
	-45	
	900	feet
	900	
	900	
	900	
	900	
	900	

TABLE A-2. COARSE-SCREEN TRUTH TABLE

	TAUV<75 RZ<4,000 ft	TAUV<75 RZ>4,000 ft	TAUV>75 RZ< 4,000 ft	TAUV>75 RZ> 4,000 ft
R^2<9 nmi TAUH < 75	T	T	T	F
R^2>9 nmi TAUH 75	T	T*	T*	F
R^2<9 nmi TAUH> 75	T	T	T	F
R^2>9 nmi TAUH> 75	F	F	F	F

TAUV = Time to coaltitude = RZ/RZD

TAUH = Time to CPA $= -\frac{(RX \cdot RDX + RY \cdot RDY)}{(RDX^2 + RDY^2)}$

T = true (track)
F = False (do not track)
* - Track only if the projected range at CPA < 12 nmi.

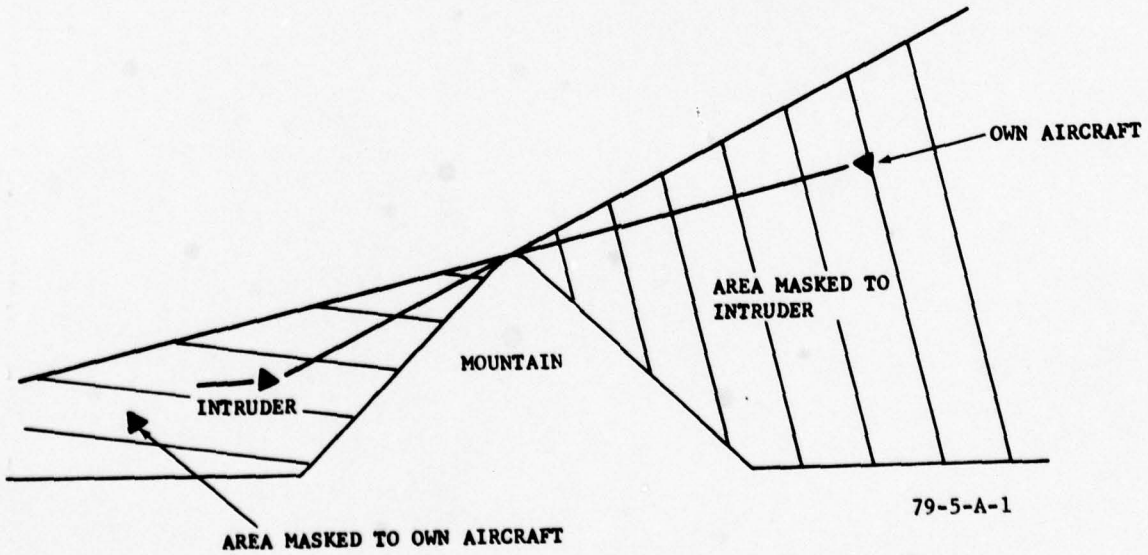


FIGURE A-1. EXAMPLE OF TERRAIN MASKING

inaccurate when based on only a few initial measurements of the intruder position. Additionally, an intruder could be tracked into the command region and then maneuver in such a manner that could cause XDINT, YDINT, and ZDINT values of zero to be passed to the algorithm.

Currently, if an intruder is detected for the first time when he is within the command region, threat resolution programs (HORMAN for instance) are called with values of zero for XDINT, YDINT, and ZDINT. Since this involves division by zero, we have included checks that cause a return from HORMAN without a command being generated. However, during the next cycle, with nonzero, but still inaccurately tracked values for XDINT, YDINT, and ZDINT, HORMAN will generate a command. We recommend that some tests be included, in DRPAS (the subroutine that calls HORMAN) or HORMAN itself, that delay command generation until at least three cycles of tracking have been done. The tracker TRIPAS (and TRIACT) should keep track of the number of cycles of tracking. Figure 3-1, page 3-9 in MTR-7532 is changed as shown in figure A-2. This change does not prevent use of inaccurate values by HORMAN due to an inadequate coarse track time period. Consideration should be given to making the recommended changes to DRPAS, HORMAN, and TRIPAS (and TRIACT) to insure at least three tracking cycles have been completed prior to calling DRPAS.

Reshaping the Protected Positive Range/Range Rate Area:

In order to reduce the length of positive commands, the protected positive range/range rate area has changed. Figure 3-2 in MTR 7532 should be changed. The new figure should appear as shown in figure A-3. In order to make this change, the flow chart on page 3-2 is changed as shown in figure A-4.

Positive Command Display Problems:

The problem we have encountered is the removal of a negative command from the display when the provisional positive command is first selected. Until the KHIT value is built to four and the positive command coordinated, no command is displayed. A pilot seeing the negative command disappear might tend to feel the conflict has been resolved. A better method of changing commands would be to leave the negative command displayed until the provisional positive command is validated and replaces the negative command.

Several changes have been made to the flow chart to retain a negative command until it is replaced by a validated and coordinated positive command. Figure A-5 shows the changes made to the logic.

Loss of Track of the Intruder while within the Command Region:

The problem of an intruder track being lost while within command range is quite serious, and we cannot expect the algorithm to generate a command sequence to handle this situation. In our simulations, when this happens, the variable CONINT in the own state vector remains set to the ID of the intruder who disappeared while within the command region, thereby preventing display of

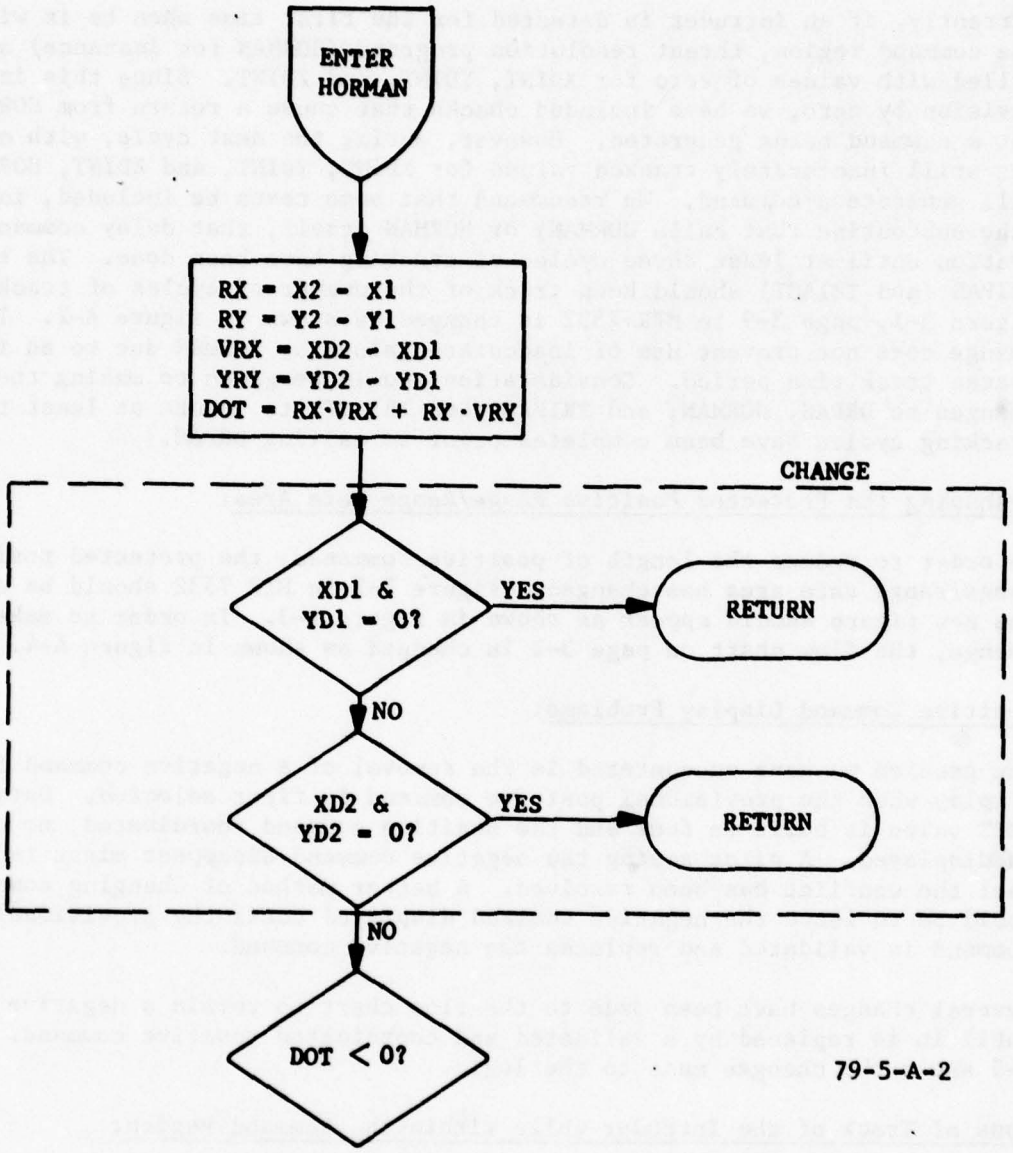


FIGURE A-2. BCAS LOGIC FLOW CHART

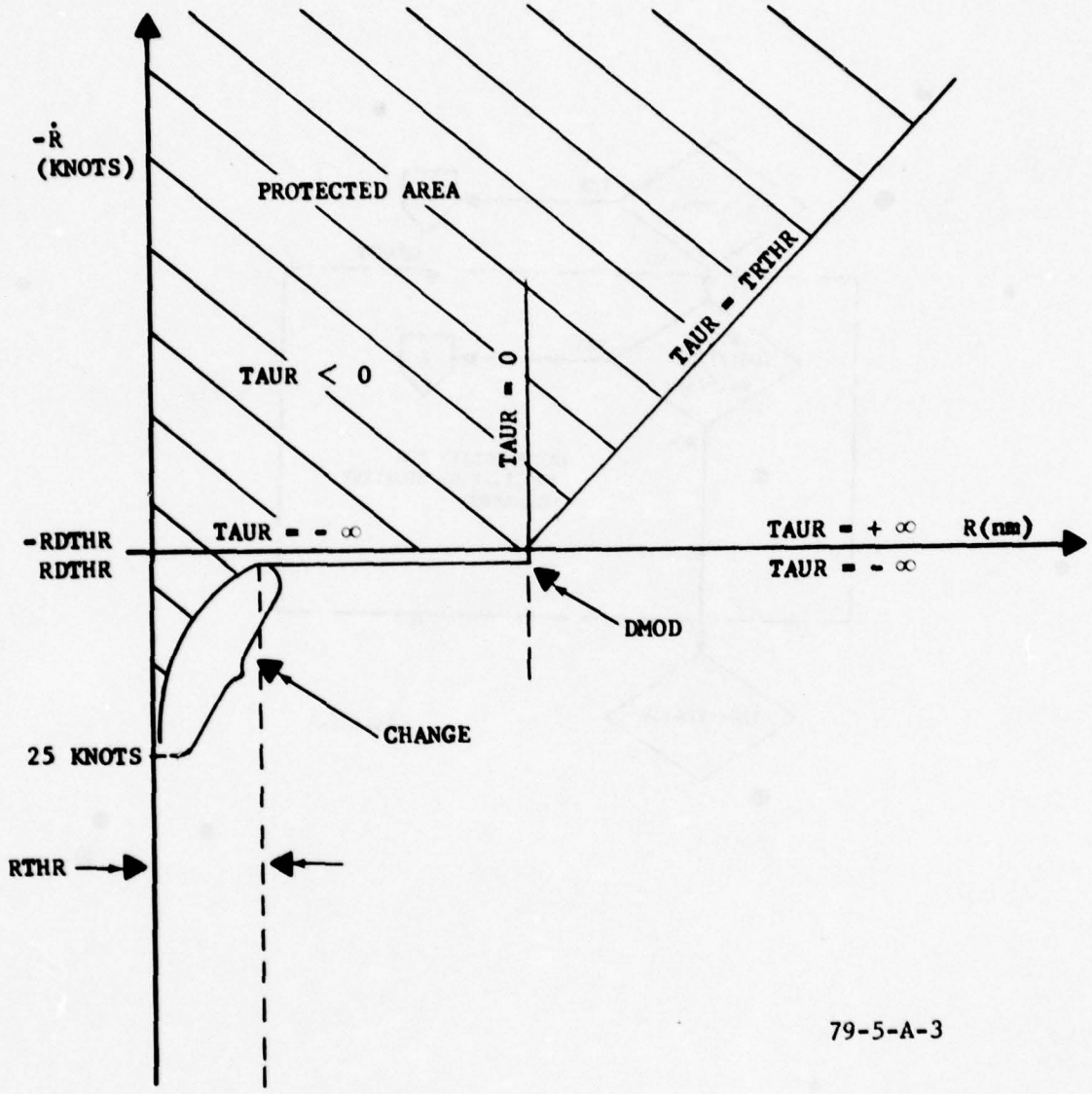


FIGURE A-3. PROTECTION AFFORDED BY THE DETECTION LOGIC IN THE RELATIVE RANGE-RELATIVE RANGE RATE PLANE

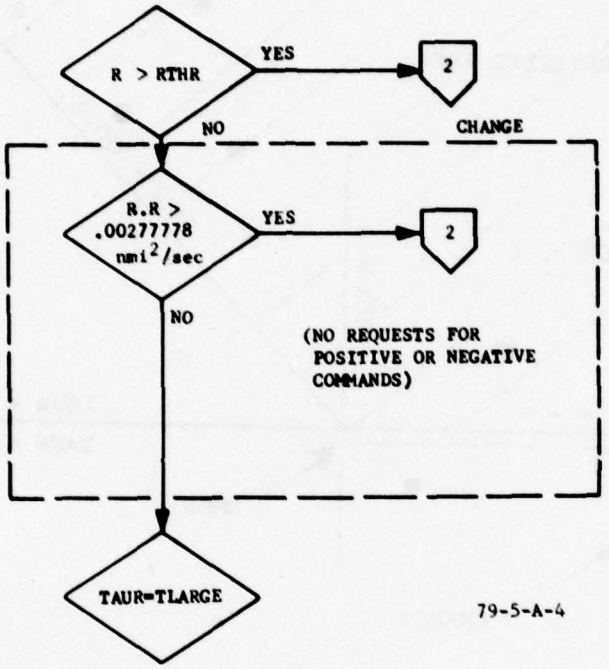
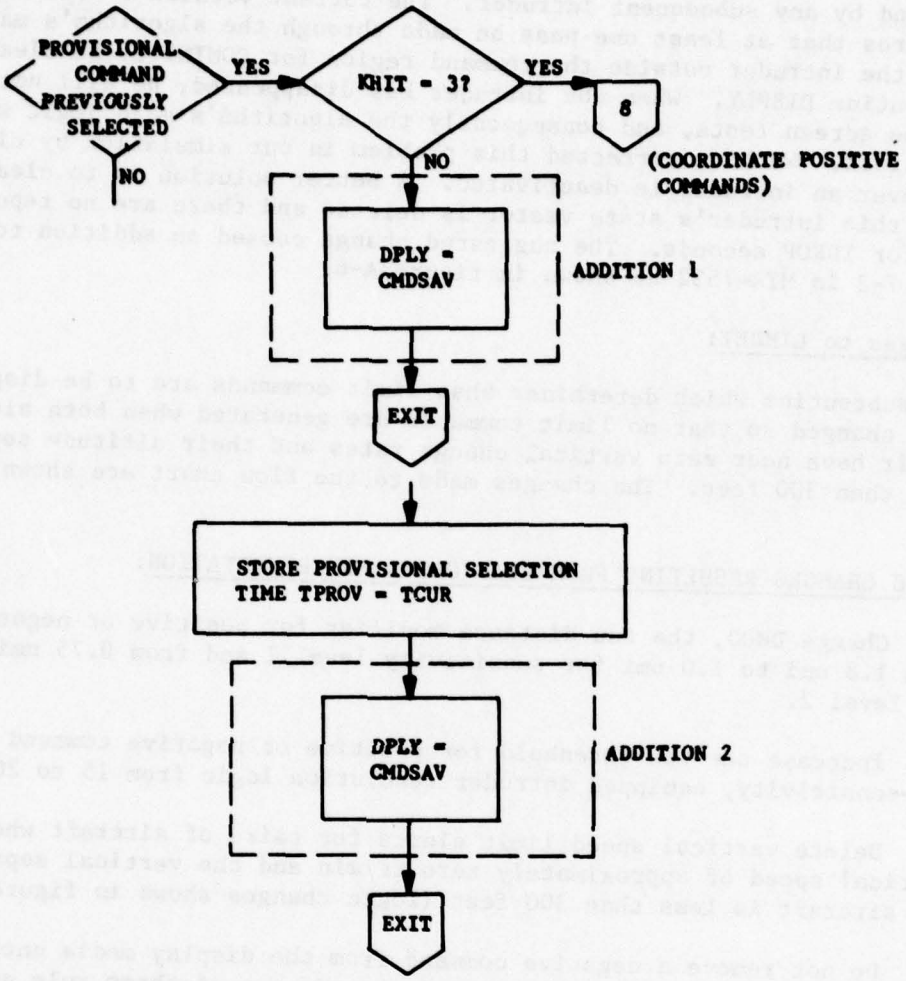


FIGURE A-4. BCAS LOGIC FLOW CHART

TWO ADDITIONS WERE MADE TO THE FLOWCHART ON PAGE 3-5



THE FOLLOWING ADDITION WAS MADE ON PAGE 3-7, MTR 7532

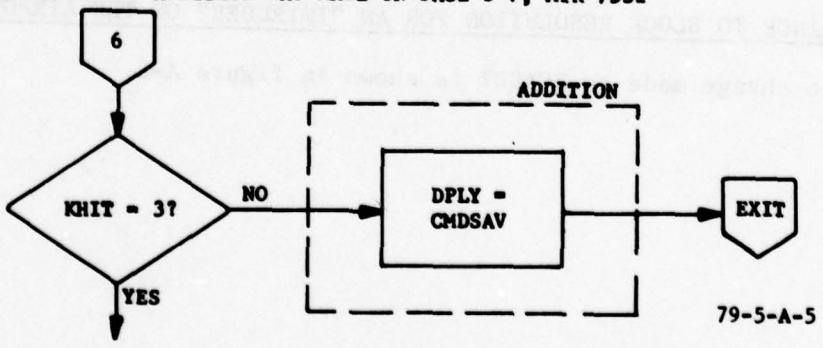


FIGURE A-5. BCAS LOGIC FLOW CHART

command by any subsequent intruder. The current version of the algorithm requires that at least one pass be made through the algorithm's main logic with the intruder outside the command region for CONINT to be cleared by the subroutine DISPLY. When the intruder has disappeared, he will not pass the coarse screen tests, and consequently the algorithm's main logic will not be exercised. We have corrected this problem in our simulation by clearing CONINT whenever an intruder is deactivated. A better solution is to clear CONINT when this intruder's state vector is deleted and there are no reports from him for TDROP seconds. The suggested change caused an addition to figure 7-1, page 7-2 in MTR-7532 as shown in figure A-6.

Changes to LIMDET:

The subroutine which determines what limit commands are to be displayed has been changed so that no limit commands are generated when both aircraft in a pair have near zero vertical change rates and their altitude separation is less than 300 feet. The changes made to the flow chart are shown in figure A-7.

LOGIC CHANGES RESULTING FROM BCAS/GAT2A EXPERIMENTATION:

1. Change DMOD, the tau distance modifier for positive or negative commands, from 1.8 nmi to 1.0 nmi for sensitivity level 1 and from 0.75 nmi to 0.5 nmi for level 2.

2. Increase the tau threshold for positive or negative command generation for low-sensitivity, equipped intruder resolution logic from 15 to 20 seconds.

3. Delete vertical speed limit alerts for pairs of aircraft when each has a vertical speed of approximately zero ft/min and the vertical separation between the aircraft is less than 300 feet (logic changes shown in figure A-7).

4. Do not remove a negative command from the display media until the provisional positive command has passed the two-out-of-three rule and can be displayed (logic changes shown in figure A-6).

LOGIC CHANGE TO BLOCK RESOLUTION FOR AN "INTRUDER" ON THE AIRPORT SURFACE:

The logic change made to BCASDT is shown in figure A-8.

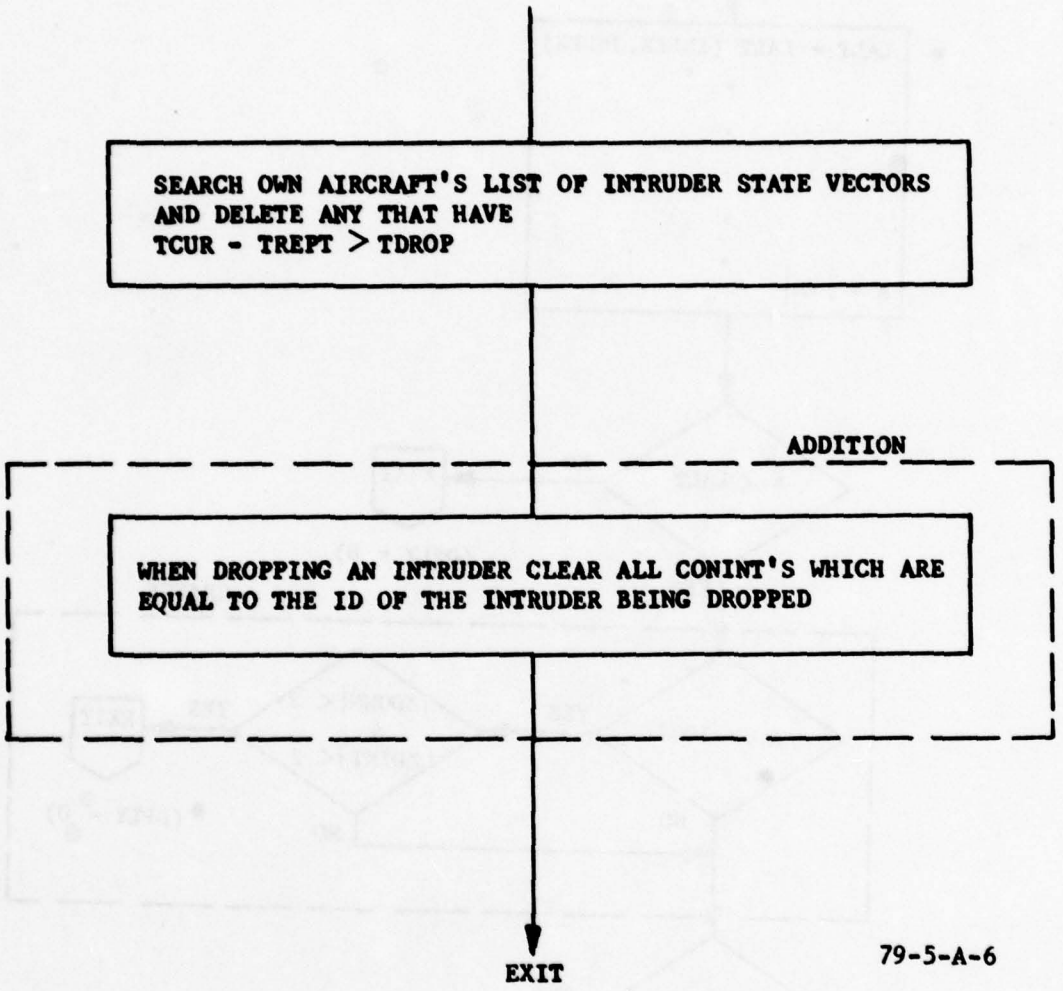


FIGURE A-6. BCAS LOGIC FLOW CHART

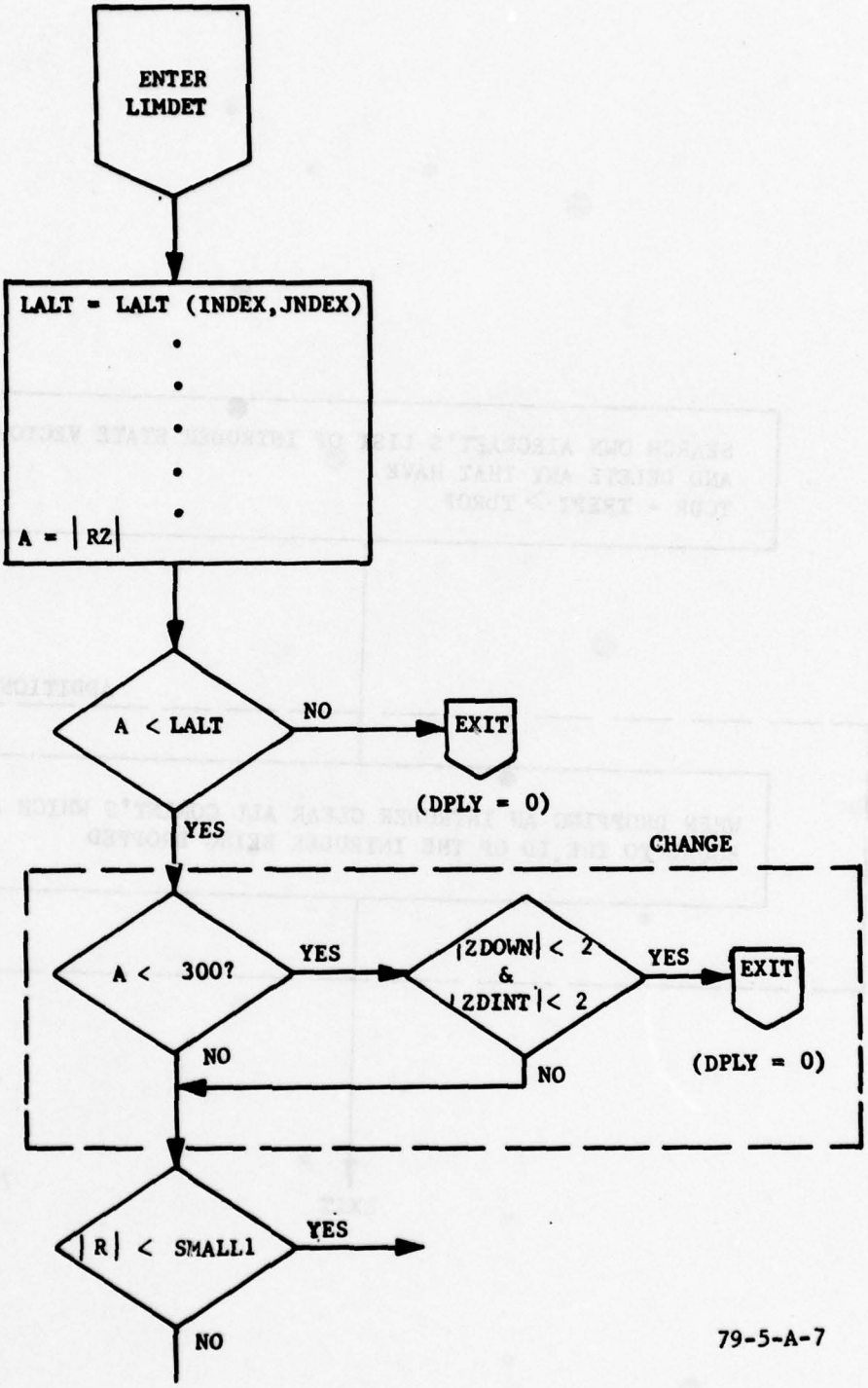


FIGURE A-7. BCAS LOGIC FLOW CHART

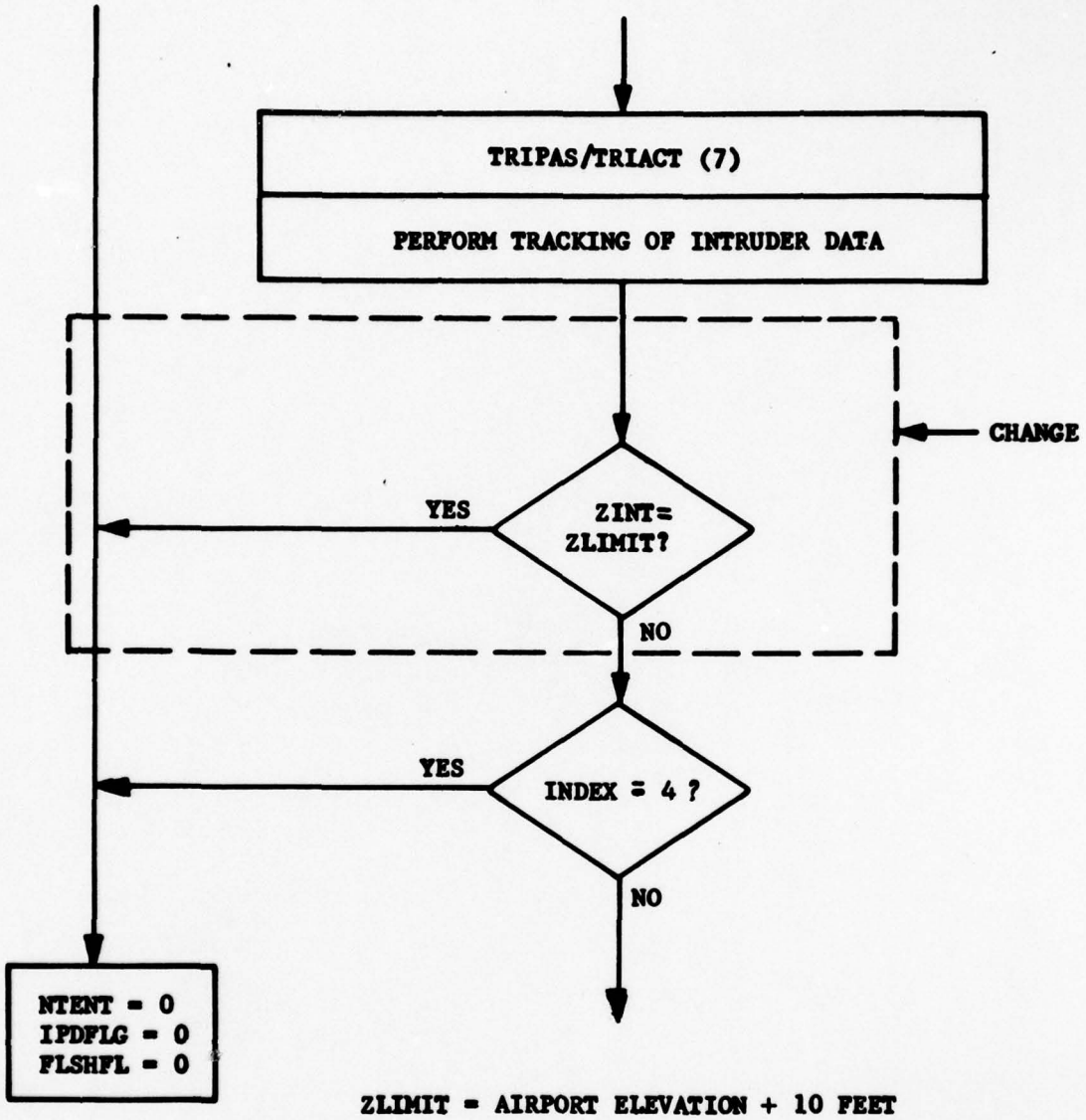


FIGURE A-8. BCAS LOGIC FLOW CHART

APPENDIX B

BCAS MESSAGES AND DESENSITIZATION ZONES

Four types of BCAS messages were provided in the simulation; intruder positional data (IPD), vertical speed limits (VSL's), and positive and negative commands. IPD messages provide an alarm of a potential threat. The threat's relative bearing is depicted within a 30° relative horizontal segment. The current relative altitude of the threat is shown as above, below, or within 500 feet of own aircraft.

VSL's are alerts which reduce the possibility of collision by limiting the vertical velocity of the own aircraft. The six alerts are, "limit climb to 2,000 feet/minute or less," "limit climb to 1,000 feet/minute or less," "limit climb to 500 feet/minute or less," and the three complementary descent alerts.

The negative commands that could be provided were, "do not turn left," "do not turn right," "do not descend," and "do not climb." The positive commands provided were, "turn right," "turn left," "climb," and "descend." Only one VSL or positive or negative command can be displayed at one time. Multiple IPD lights could simultaneously be illuminated each representing a different threat.

Four levels of desensitization currently exist in BCAS. 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 rationale for level 4 logic is to prevent the issuance of commands between aircraft approaching to land and aircraft on the airport surface.

The least protection area extends from 2-nmi to 15-nmi below 10,000 feet altitude. This area is called the level 3 area. 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.

Level 2 extends from 15 nmi to 50 nmi below 10,000 feet.

Between 2 nmi and 50 nmi from the radar site the highest protection area (level 1) extends upward from 10,000 feet. Beyond 50 nmi, it includes all airspace from the surface up. (Figure B-1 shows the densensitization zones.)

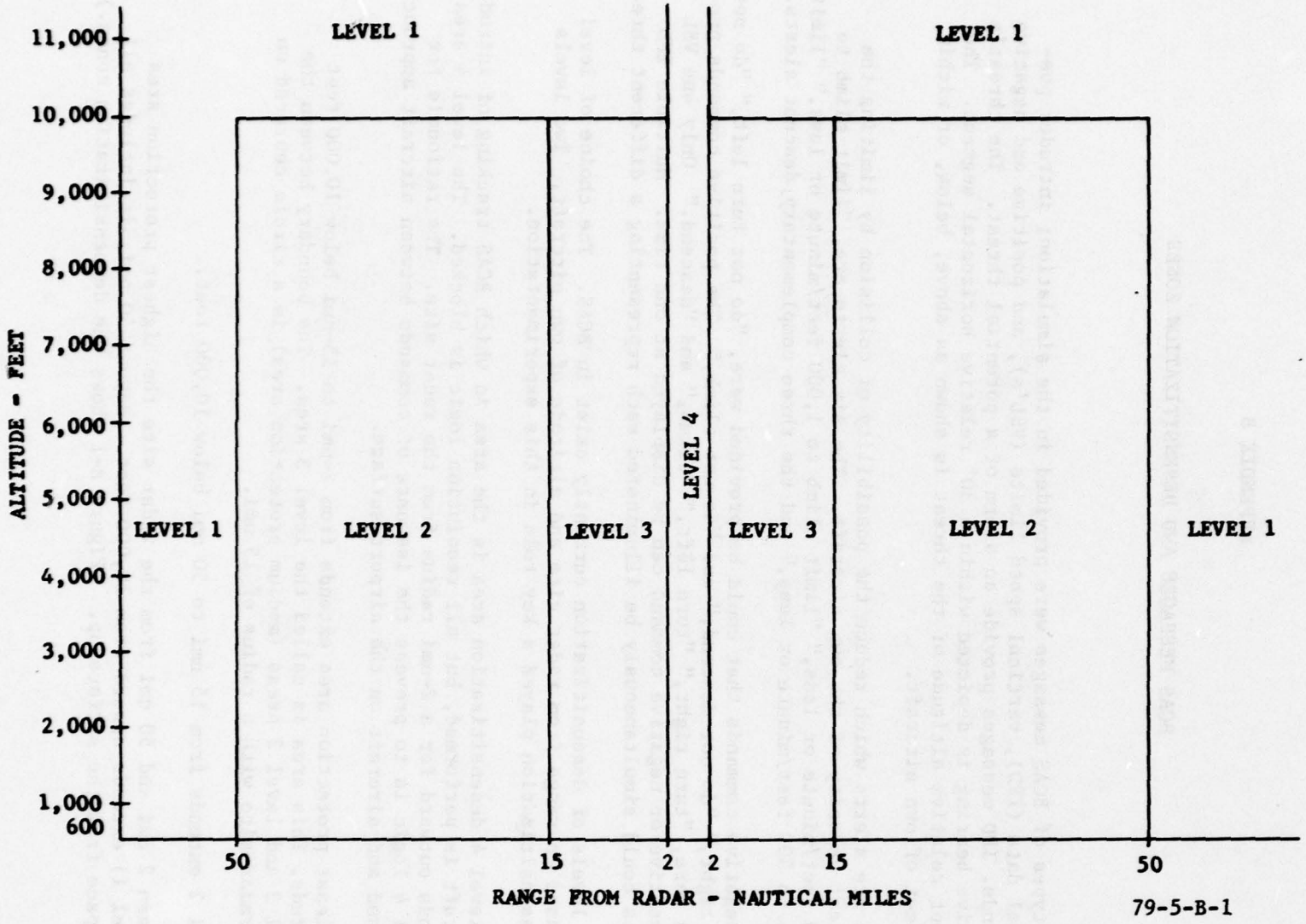


FIGURE B-1. DESENSITIZATION ZONE BOUNDARIES

APPENDIX C

AIRCRAFT PERFORMANCE CHARACTERISTICS

TABLE C-1. CLIMB/DESCENT RATES

AIRCRAFT PERFORMANCE CHARACTERISTICS

Type Aircraft	Descent Rates (ft/min)			Climb Rate (ft/min) (Thousands of ft)					Speed Change (kt/min)		Alt. Change (ft/sec^2)
	Maximum	Enroute	Terminal	0-10	10-20	20-30	30-40	40-50	Accel	Decel	
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	3500	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
Heavy Comm. Jet	4000	3000	1500	2800	3000	3000	3000	2000	65	60	6
High Perf. Jet	4000	3000	1600	3000	3000	3000	3000	2000	60	60	6

TABLE C-2. AIRCRAFT SPEEDS

Type Aircraft	Take-Off Speed	Climb Speeds (kts) To 10,000	10,000 20,000	20,000 30,000	30,000 40,000	40,000 50,000	Route Speeds (kts) Cruise	Transition	Term.	Holding Speed Low Alt.	High Alt.	Final Speed
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
Heavy Comm. Jet	120	275	270	260	260	250	310	250	200	200	250	130
High Perf. Jet	125	260	265	255	255	255	320	250	180	200	250	125

TABLE C-3. RUNWAY OCCUPANCY TIMES

Type Aircraft	Run-Up Time (Sec)	Runway Occupancy Departures (Sec) Avg.	Dur.	σ	Time to Lift-Off (Sec) Avg.	Dur.	σ	Runway Occupancy Arrival (Sec) Avg.	Dur.	σ
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
Heavy Comm. Jet	45	35		3	30		2	55		3
High Perf. Jet	45	38		3	30		2	55		3

APPENDIX D

EXPERIMENTAL CONDITIONS

CONDITION 1--VFR LOW-BCAS MIX

This traffic condition modeled the density and routing of traffic during VFR operations in the Chicago area. Thirty-two percent of all aircraft in the sample were BCAS equipped, and the remaining 68 percent were ATCRBS mode C equipped. As a result, a BCAS aircraft was provided with protection from all other aircraft in the sample. During the VFR series, the controllers applied VFR separation criteria to all aircraft in the sample, permitting aircraft to operate as close as 1 nmi horizontally or 500 feet vertically. Generally, north arrivals landed on 27R, and south arrivals on 27L. Departures were made from 27L and 32R. The vertical separation between north arrivals and south arrivals was generally 500 feet in the ILS final area and final vector area. The total number of aircraft in the sample was 197.

CONDITION 2--VFR HIGH-BCAS MIX

This traffic condition was identical to condition 1 except the percentage of BCAS-equipped aircraft was increased from 32 to 68 percent. The traffic flow patterns and separation criteria were the same as that described in condition 1.

CONDITION 3--IFR HIGH-BCAS MIX

This traffic condition modeled the traffic flow patterns during IFR weather conditions in the Chicago area. Unlike the VFR series, only the high BCAS equipment level was modeled. Sixty-five percent of the aircraft were BCAS equipped and the remaining 35 percent were mode C equipped. Both departure and arrival flights were simulated. Overflight traffic and satellite airport traffic were not included in the sample. There were 196 aircraft in this traffic sample.

The minimum separation criteria between aircraft in this sample was 3 nmi horizontally or 1,000 feet vertically except when an aircraft was on the parallel ILS system where the standard IFR separation criteria for simultaneous approaches was used. North arrival aircraft generally intercepted the 27R localizer at 3,000 feet, and south arrivals intercepted the 27L localizer at 4,000 feet.

CONDITION 4--HIGH-DENSITY ALL ARRIVAL (100-PERCENT BCAS EQUIPPED)

In order to provide a completely saturated approach area, a traffic condition consisting of all arrival traffic was used. All aircraft within the sample were BCAS equipped. VFR separation standards were used during all arrival runs.

Aircraft made approaches to runways 27L and 27R. With no requirements to provide spacing for departures: interarrival spacing was based strictly on the runway occupancy time of an arrival aircraft. There was a total of 156 aircraft in the sample.

APPENDIX E

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 THE controller.

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 perfer to see negative commands displayed in the data block?

YES _____ NO _____

APPENDIX F

DR&A PROGRAMS

1. LINK 3 PROGRAM.

LINK 3 is a standard ATCSF DR&A program. The major use of LINK 3 in this experiment was to identify aircraft pairs which violated the appropriate ATC separation criteria (IFR or VFR). Once the conflicts were identified, the results of the BCAS allocate program were reviewed to see if any BCAS action occurred. The hourly operations rates, both arrivals and departures, were also provided by LINK 3.

Two modifications were made to the standard LINK 3 program; (1) deletion of conflicts when both aircraft were on parallel ILS localizers and (2) when one aircraft in the conflicting pair was on the runway. The standard horizontal IFR separation criteria was 3 nmi. The parallel ILS localizer centerlines were only 0.8 nmi apart, and two aircraft conducting simultaneous parallel approaches would not be considered in conflict even though the horizontal separation was less than 1 nmi.

2. BCAS ALLOCATE PROGRAM.

The data collected by means of the BCAS Allcate pogram formed the major portion of the data base. All alert rates and durations were obtained using this program. Allocate provided the data required for the several statistical and plotting programs which were developed. The major differences between LINK 3 and BCAS Allocate are that LINK 3 uses the true ATCSF flight data (X, Y, Z, $\dot{X}$, $\dot{Y}$, $\dot{Z}$) generated on a 1-second cycle, while BCAS Allocate uses the BCAS-tracked values of (X, Y, Z, $\dot{X}$, $\dot{Y}$, $\dot{Z}$) generated on a 2-second cycle. To conserve space, several figures in this report show 4-second data cycles; however, the logic cycle rate used throughout the experiment was 2 seconds.

3. OTHER PROGRAMS.

Additional programs were required to ovide Calcomp plots of BCAS command and advisory locations and the relative range and altitude between aircraft in a conflicting pair. Programs were developed to analyze the effect that a two-out-of-three rule would have had on the high VSL rate. Another program translated the original lowest tau values for each VSL that occurred into a new tau value based on the use of positive command tau distance modifiers. This program permitted the analysis of the effect that smaller tau distance modifiers had on the VSL alert rate.

APPENDIX G

CONFLICT ANALYSIS AND BCAS ACTIONS

1. VFR CONDITIONS.

All conflicts which occurred on the six VFR runs were reviewed. The conflict rate for the six VFR runs was quite low (two conflicts per-hour). Most of the conflicts occurred in the ILS final area. For all but one conflict, a proper BCAS alert resulted. In the one case where no BCAS alert resulted, one aircraft was landing and one departing from 27L. An alert was not generated because both aircraft were within 2 nmi of the radar site and level 4 logic prevented alert generation.

Tables G-1 and G-2 present the results of the conflict analysis for the VFR runs. The low conflict rate, the relative altitude and range between aircraft in conflict, and location of the conflicts indicated an orderly traffic flow and general compliance with separation standards by the controllers. The minimum slant range distance between any two aircraft in the VFR series was 2,215 feet.

2. IFR CONDITION.

The conflicts and resulting BCAS alert action for the IFR condition is shown in table G-3. A total of 30 conflicts occurred on the three IFR runs. The increase in the number of conflicts over the VFR runs was due to more stringent IFR separation requirements. Included in the 30 conflicts are several cases where there was no true violation of separation criteria. Seven times a conflict was recorded when one aircraft departed and one landed on the same runway within 3 nmi of each other. No BCAS alerts were generated in these cases because BCAS resolution was properly inhibited by level 4 logic. Six additional aircraft pairs were counted in conflict when within 3 nmi of each other even though they were departing from different runways. In five out of these six cases, no BCAS alert resulted because of level 4 logic. The remaining pair received an IPD. If the 13 false conflicts described above are deleted, the resulting conflict rate was less than six per hour for the IFR series. The average relative range (greater than 2.4 nmi) and the average conflict durations (less than 33 seconds) of the remaining 17 conflicts indicate an orderly traffic flow and general compliance to ATC separation criteria by the controllers. The minimum slant range distance between any two aircraft in this traffic condition was 2,362 feet (0.4 nmi).

On two occassions during the IFR series, aircraft were in conflict, and BCAS did not provide any alerts even though at least an IPD was required, both cases of inaction by BCAS can be traced to tracker lag, since at least one aircraft in each pair was turning throughout the conflict period.

TABLE G-1. CHICAGO CONFLICT ANALYSIS VFR* 32-PERCENT BCAS EQUIPPED

Conflict Location	No. of Conflicts	Avg. Relative Range at CPA (nmi)	Avg. Relative Altitude at CPA (feet)	Conflict Duration (seconds)	BCAS Actions and Alert Lengths
Both aircraft on same ILS outside marker	4	0.81	408.5	62	(each conflict involved 1 equipped and 1 unequipped aircraft) 2 IPD's 1 12 sec 500 ft/min VSL 1 12 sec 1,000 ft/min VSL
Neither aircraft in final area	1	0.36	340	29	Equipped aircraft received a 20-second negative vertical command

*Separation Standards = 1 nmi and 500 feet

TABLE G-2. CHICAGO CONFLICT ANALYSIS VFR* 68-PERCENT BCAS EQUIPPED

Conflict Location	No. of Conflicts	Avg. Range at CPA (nmi)	Avg. Relative Altitude at CPA (feet)	Conflict Duration (seconds)	BCAS Actions and Alert Lengths
Both aircraft on same ILS outside marker.	3	0.77	175.3	27.3	1 pr 1,000 ft/min VSL's for 28 sec 1 pr 500 ft/min VSL's for 60 sec 1 pr IPD's
One aircraft on ILS final, one in final vector area.	2	.68	490.0	129.5	1 pr complementary negative vertical commands for 12 1 pr 500 ft/min VSL's for 72 sec
Both aircraft in final vector area.	1	.78	0.0	10.0	1 pr horizontal commands lasting 8 sec
1 aircraft landing 1 aircraft departing	1	.77	257.0	10.0	Nothing+

*Separation Standards = 1 nmi + 500 feet

+BCAS resolution inhibited by level 4 desensitization

TABLE G-3. CHICAGO CONFLICT ANALYSIS IFR* 68-PERCENT BCAS EQUIPPED

Conflict Location	No. of Conflicts	Avg. Range at CPA (nmi)	Avg. Relative Altitude at CPA (feet)	Conflict Duration (seconds)	BCAS Actions and Alert Lengths
One aircraft landing and one aircraft departing same runway.	7	2.42	333.6	14.1	7 pr - Nothing +
Both aircraft departing different runways.	6	2.02	293.0	42.2	5 pr - Nothing + 1 pr - IPD's
One aircraft on ILS final, one aircraft in final vector area.	7	2.02	551.7	32.1	2 pr - Nothing (-) 1 pr - IPD's 4 pr - Various VSL's lasting an average of 18 sec
Neither aircraft in final area	3	2.13	199.3	17.3	1 pr - IPD's 1 pr - Nothing, neither aircraft BCAS equipped 1 pr - 1,000 ft/min VSL's lasting 12 sec
Both aircraft in final vector area.	2	1.98	4.0	14.5	1 pr - Horizontal commands lasting 8 sec 1 pr - Nothing (-)
Both aircraft on same ILS outside marker	4	2.50	81.0	62.0	4 pr - IPD's
Both aircraft on same ILS inside marker	1	2.72	15	6	1 pr - Nothing +

*Separation Standards - 3 nmi + 1,000 feet

+BCAS inhibited by level 4 desensitization
(-) BCAS failed to detect conflict

3. HIGH-DENSITY ARRIVAL CONDITION.

This traffic condition was simulated to provide high-density arrival operations to parallel runways, a "worst case" condition for the BCAS algorithm. No departure operations were included. Although VFR weather conditions were simulated, any violation of IFR separation criteria was also identified as a conflict to provide a better observation of the ability of BCAS to handle the high-density traffic. Forty-seven such conflicts occurred. The average inter-arrival spacing for this traffic condition was 3.1 nmi at the outer marker.

The only type of BCAS alerts that occurred were IPD's and VSL's. This resulted because the traffic flow, although extremely dense, was orderly with only moderate closure rates developing between aircraft. Aircraft were in conflict 10 times, but no BCAS alerts occurred. Six of the 10 times no alert was generated because the closure rate was less than 10 feet/second and the immediate range threshold for IPD alerts (1 nmi or 2 nmi depending on desensitization level) was not violated. In the four cases in which BCAS failed to detect a conflict, the proper actions would have been short-duration (less than 6 seconds) IPD alerts. In all four cases, at least one aircraft in the pair was maneuvering horizontally or vertically. The conflicts that occurred in the high-density arrival condition are shown in table G-4. The minumum slant range separation that occurred for this traffic condition was 1,312 feet ($\simeq$ 0.2 nmi).

TABLE G-4. CHICAGO CONFLICT ANALYSIS HIGH-DENSITY ARRIVALS

Conflict Location	No. of Conflicts	Avg. Range at CPA (nmi)	Avg. Relative Altitude at CPA (feet)	Average Duration (seconds)	BCAS Actions and Alert Lengths
Neither aircraft in final area	17	2.29	72.0	41.9	11 pr - IPD's 4 pr - Nothing (-) 2 pr - 1,000 ft/min VSL's averaging 43 seconds in length
Both aircraft on same ILS outside marker	13	2.51	154.4	49.6	7 pr - IPD's 3 pr - Nothing (range > 1 nmi) 3 pr - Various VSL's lasting an average of 44 seconds
Both aircraft on same ILS inside marker	7	1.86	635.0	22.4	6 pr - Nothing (+) 1 pr - 1,000 ft/min VSL lasting 20 seconds
Both aircraft in final vector area	6	2.49	140.8	18.7	6 pr - IPD's
One aircraft on ILS final, one aircraft in final vector area	4	2.51	524.3	18.0	1 pr - IPD's 3 pr - Nothing (range >2 nmi)

+ BCAS inhibited by level 4 desensitization

(-) BCAS failed to detect conflict

APPENDIX H

LOCATION OF ALERTS

LOCATION OF ALERTS.

A Calcomp program was written to identify the area and flight conditions in which the majority of the BCAS alerts occurred. Plots were made of the geographic location of all BCAS alerts during each 1-hour data collection period. While several different types of alerts may have occurred during one encounter period, only the location of the most critical type of alert was plotted. The alerts which caused a deviation in the aircraft flightpath (classed as commands) were marked with an asterisk. To prevent overprinting of the alert locations, the locations were digitized. If a second alert symbol would overlap a symbol that was already printed, the second symbol was offset 0.07 inches vertically and 0.14 inches horizontally. Each symbol represents the location where the depicted alert first occurred. The radar site was located at the grid reference (X=50 nmi, Y=50 nmi).

VFR SERIES.

The plots of the locations of the alerts which occurred in the VFR series are presented in figure H-1 to figure H-6. The three VFR low-equipage runs indicate that a majority of the alerts occurred with at least one aircraft on the ILS final. For the VFR Low cases, 78 percent of the effective alerts occurred within 2 nmi of the outer marker. These alerts were VSL's that occurred after at least one aircraft in the conflicting pair had intercepted the glide slope and began its descent. The effect of the VSL alert on the ability of the aircraft to complete the ILS was minimal. Only six missed approaches occurred during 6 hourly runs, and one of these resulted from a positive horizontal command.

The three VFR high-equipage plots (figures H-4 to H-6) show a higher BCAS alert rate when compared to the VFR Low runs. Figures H-5 and H-6 reveal that several BCAS alerts were generated between arrival and departure traffic. These alerts are localized geographically and probably caused by the reduced vertical separation for VFR traffic. Only one alert in the VFR Low runs involved a departure aircraft (figure H-3).

Gross comparison between the VFR Low mix runs and VFR High mix runs indicated the command occurred further from the outer marker in the VFR High mix cases. It appears that the high equipage level tends to alter aircraft flightpaths and cause the necessary spacing changes sooner in the aircraft nominal flow patterns then do the low equipage levels.

IFR SERIES.

Figures H-7 to H-9 present the locations of the alerts which occurred in the IFR series runs. Run 9 (figure H-9) had the lowest alert activity of all runs. Almost all alerts occurred between one aircraft in the north arrival zone and one aircraft in the south arrival zone. The IFR effective alerts were not as concentrated in the ILS final area as in the VFR case. Although the command or effective alert rate was about the same, only 35 percent of the effective alerts occurred in the ILS final area. All but one of effective alerts in the ILS final area were VSL's. Only two alerts generated in the IFR runs involved departure traffic. The very low number of alerts which occurred inside the outer marker was due to the increase in separation required in the IFR runs.

HIGH-DENSITY ARRIVAL CONDITION.

The plots of the locations for the three runs in this condition are shown in figures H-10 to figure H-12. All three plots reveal the same pattern. Almost all alerts occurred in the ILS final or final vector areas with a very high concentration occurring just northeast of the outer marker. These alerts were caused by aircraft turning onto the ILS 27R final very close to the outer marker.

A second area of highly concentrated alerts was detected just outside 15 nmi from the radar site (grid X = 65 nmi) in the ILS final and final vector areas. This increase was caused by the increase in logic sensitivity beyond 15 nmi range from the radar site which is the boundary between the least protection (level 3) and the middle protection area (level 2). The VSL alerts were generated in this area because north arrivals and south arrivals are separated vertically by only 500 feet. If two such aircraft are closing and have a horizontal tau of 40 seconds or less, a VSL alert will be generated because the 500 feet vertical separation is less than the VSL alert threshold of 1,000 feet.

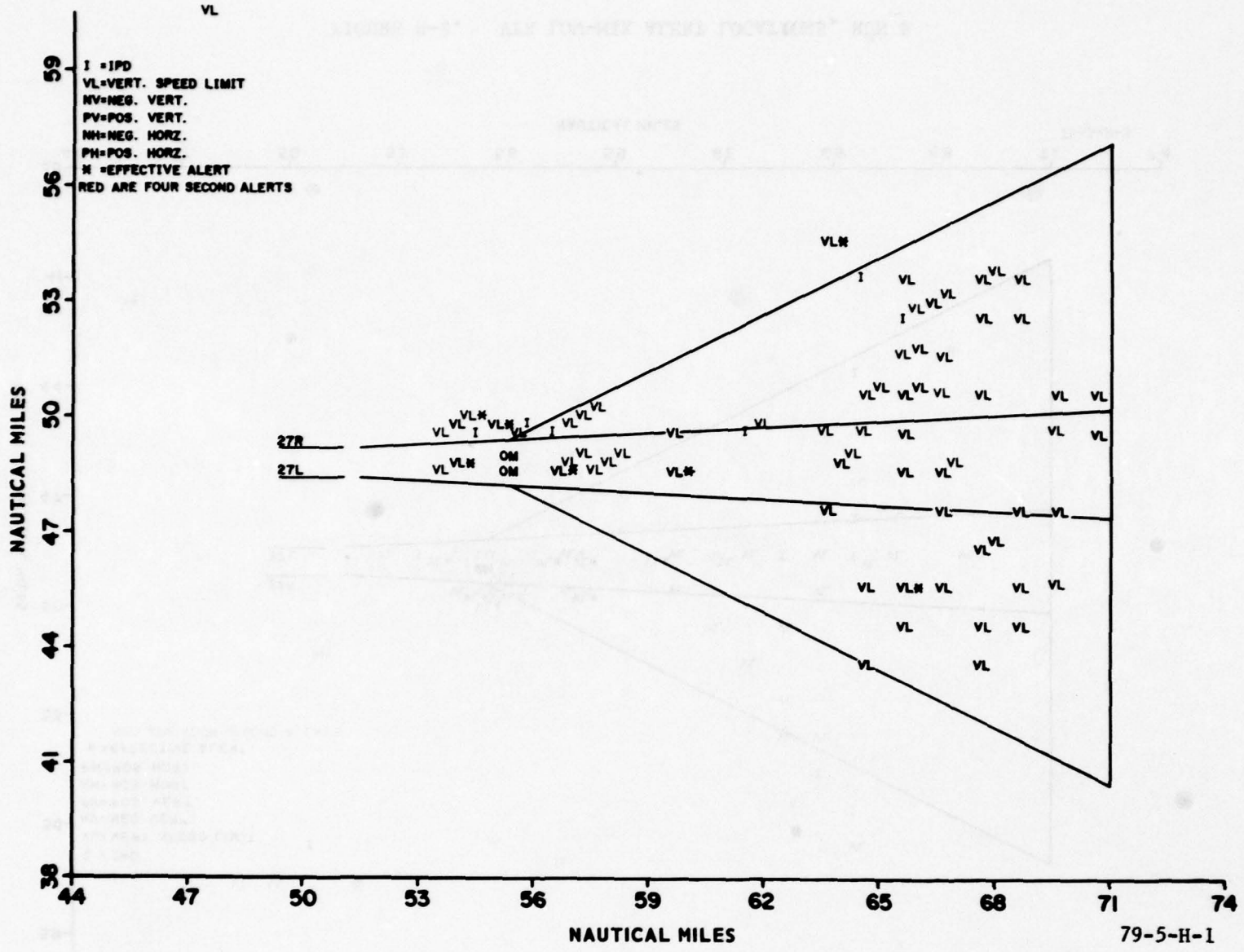


FIGURE H-1. VFR LOW-MIX ALERT LOCATIONS, RUN 1

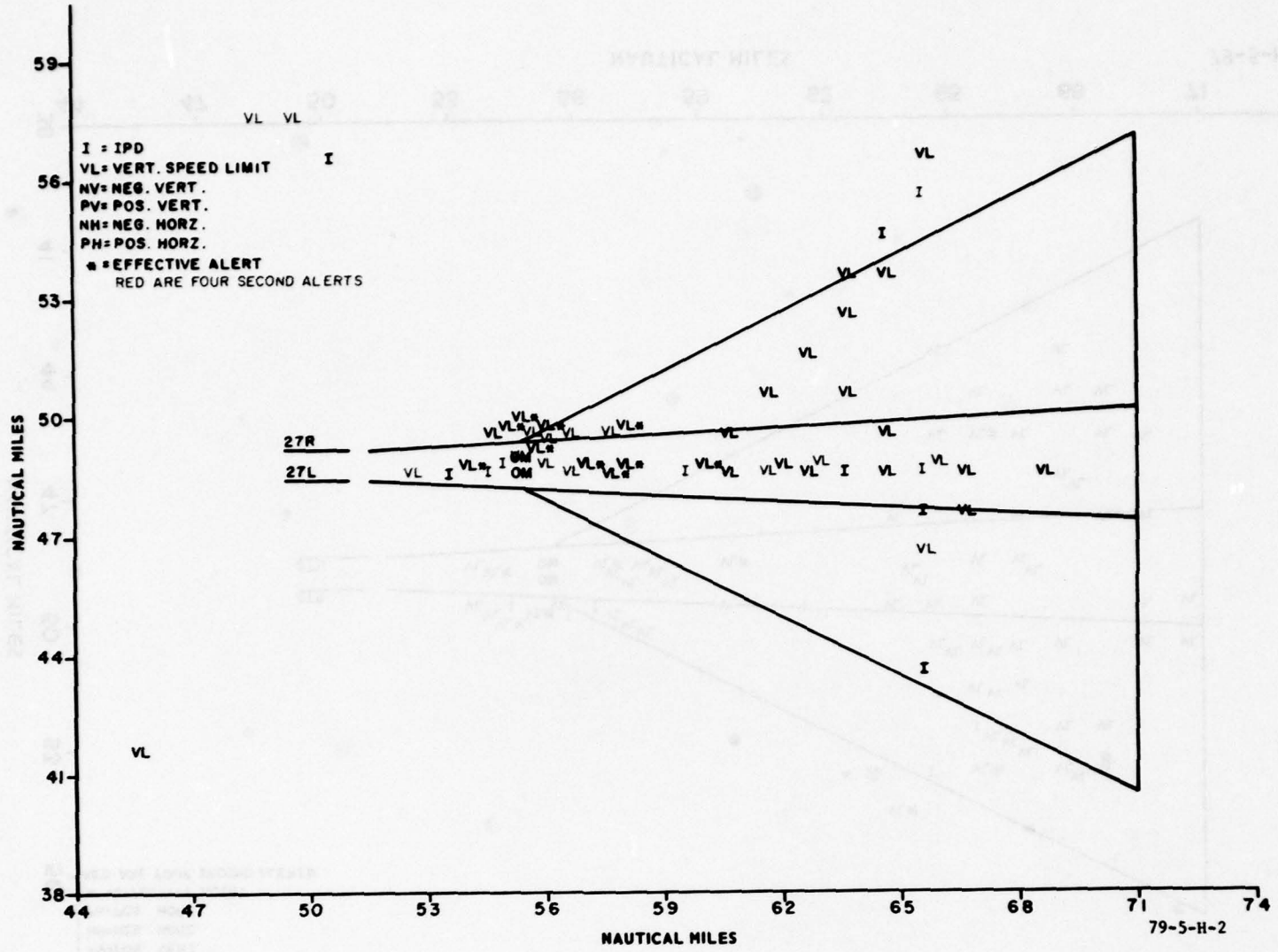


FIGURE H-2. VFR LOW-MIX ALERT LOCATIONS, RUN 8

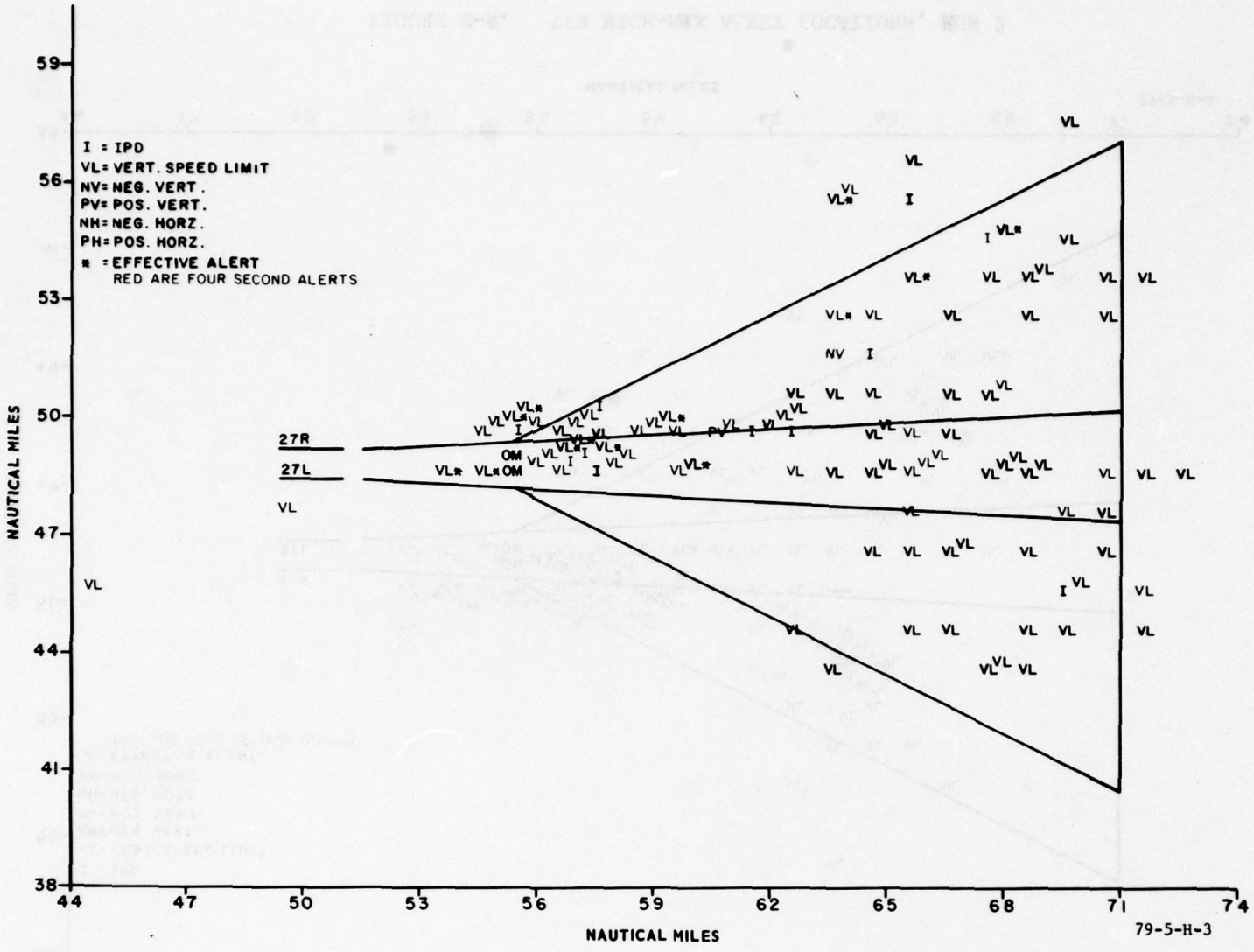


FIGURE H-3. VFR LOW-MIX ALERT LOCATIONS, RUN 11

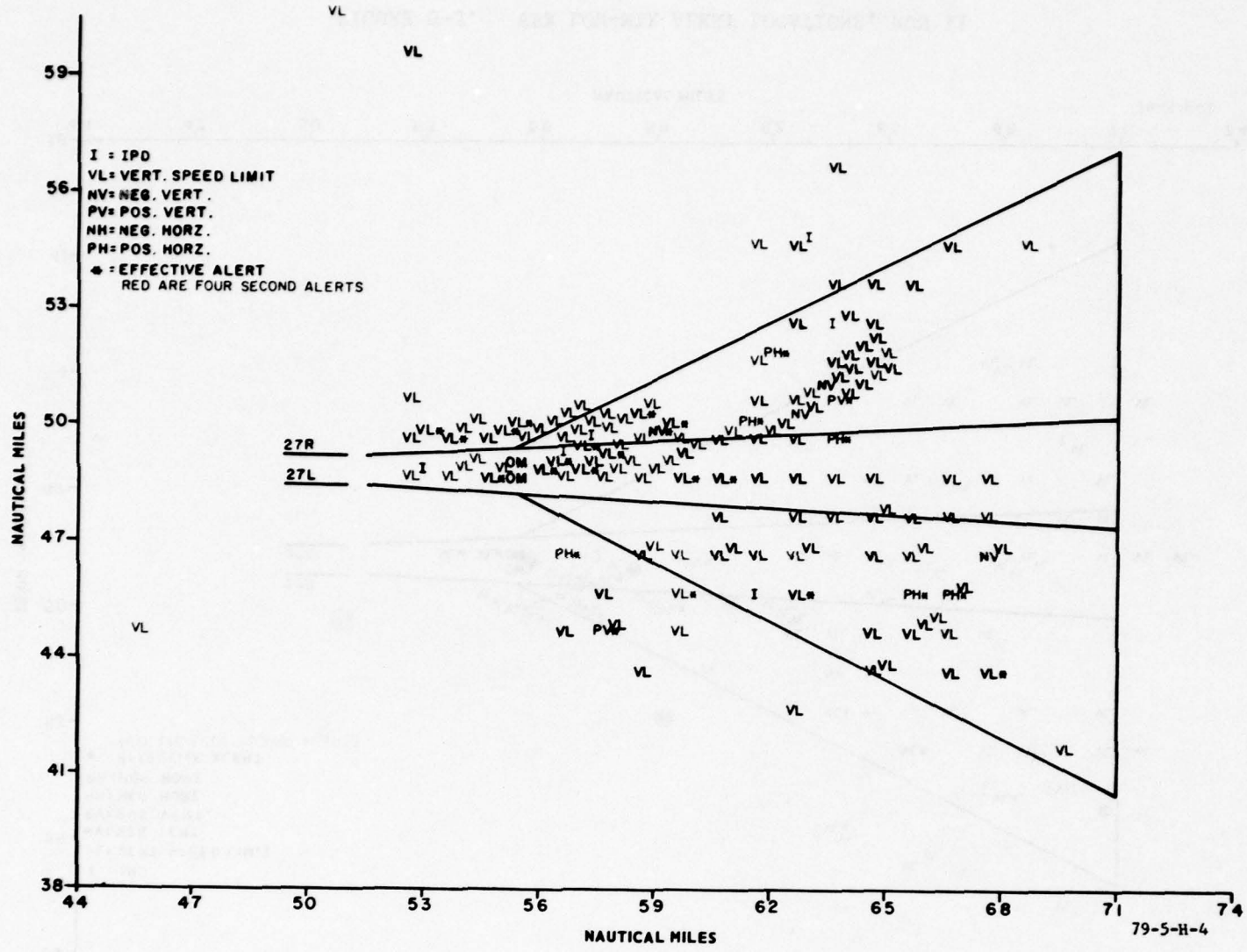


FIGURE H-4. VFR HIGH-MIX ALERT LOCATIONS, RUN 2

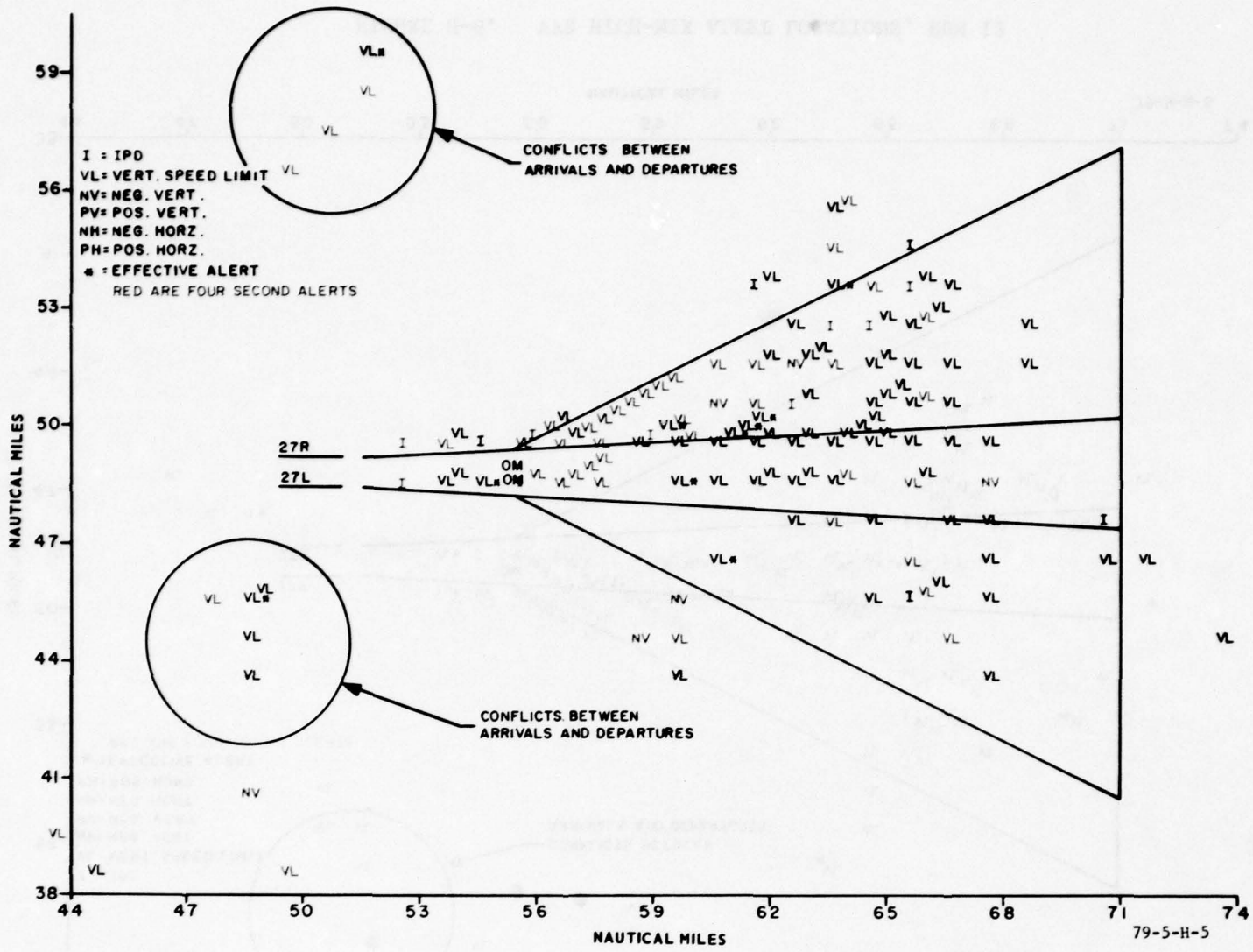


FIGURE H-5. VFR HIGH-MIX ALERT LOCATIONS, RUN 5

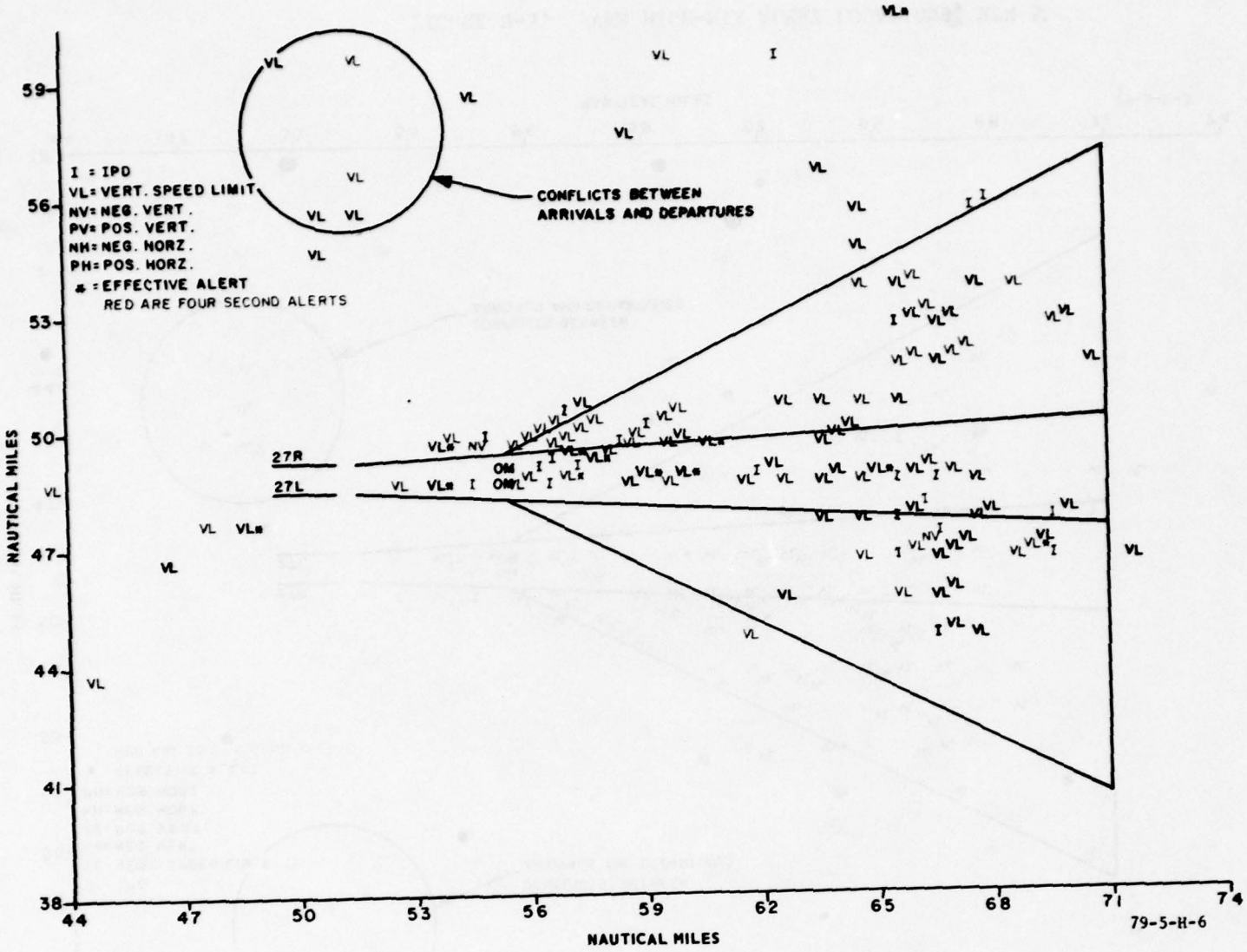


FIGURE H-6. VFR HIGH-MIX ALERT LOCATIONS, RUN 12

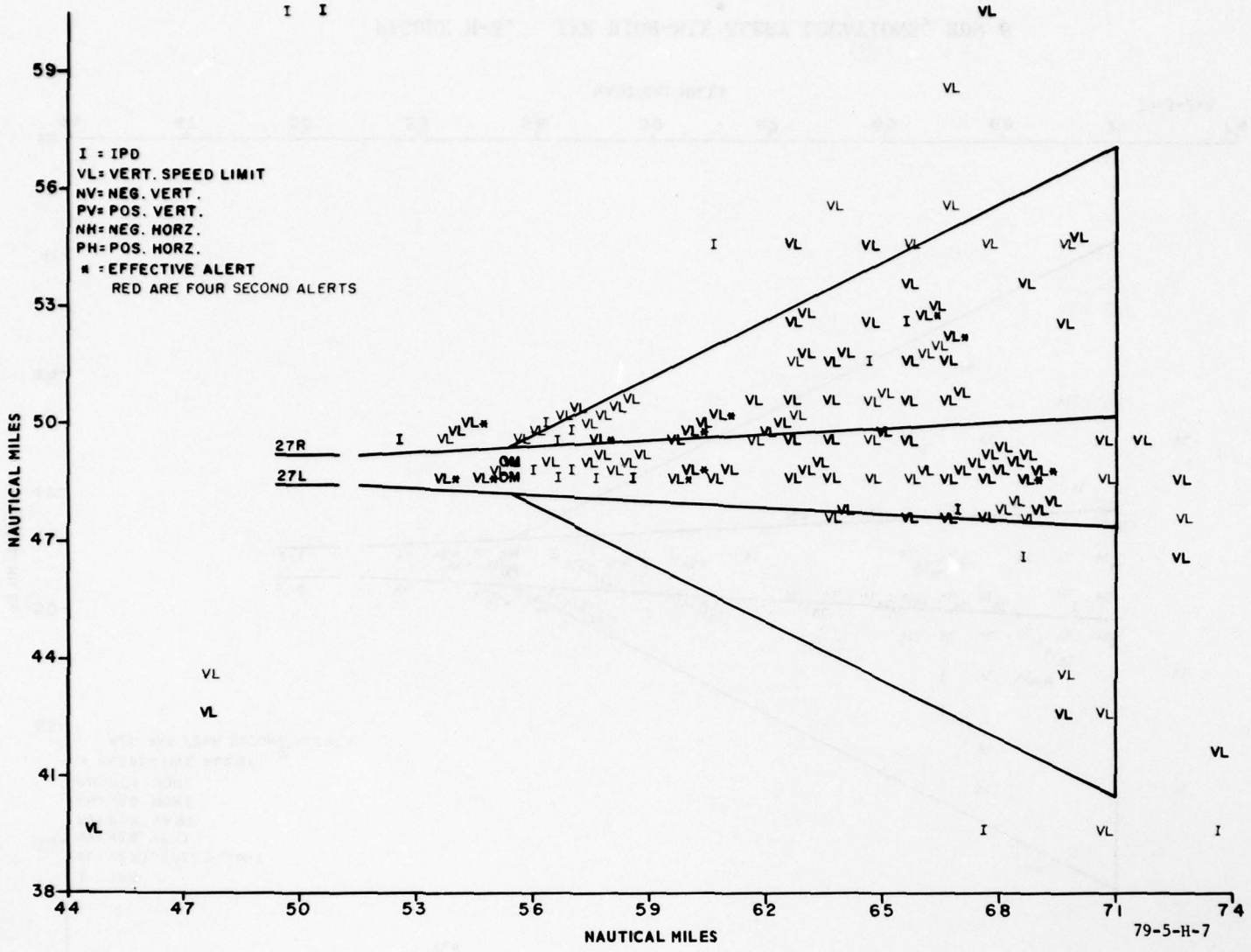


FIGURE H-7. IFR HIGH-MIX ALERT LOCATIONS, RUN 3

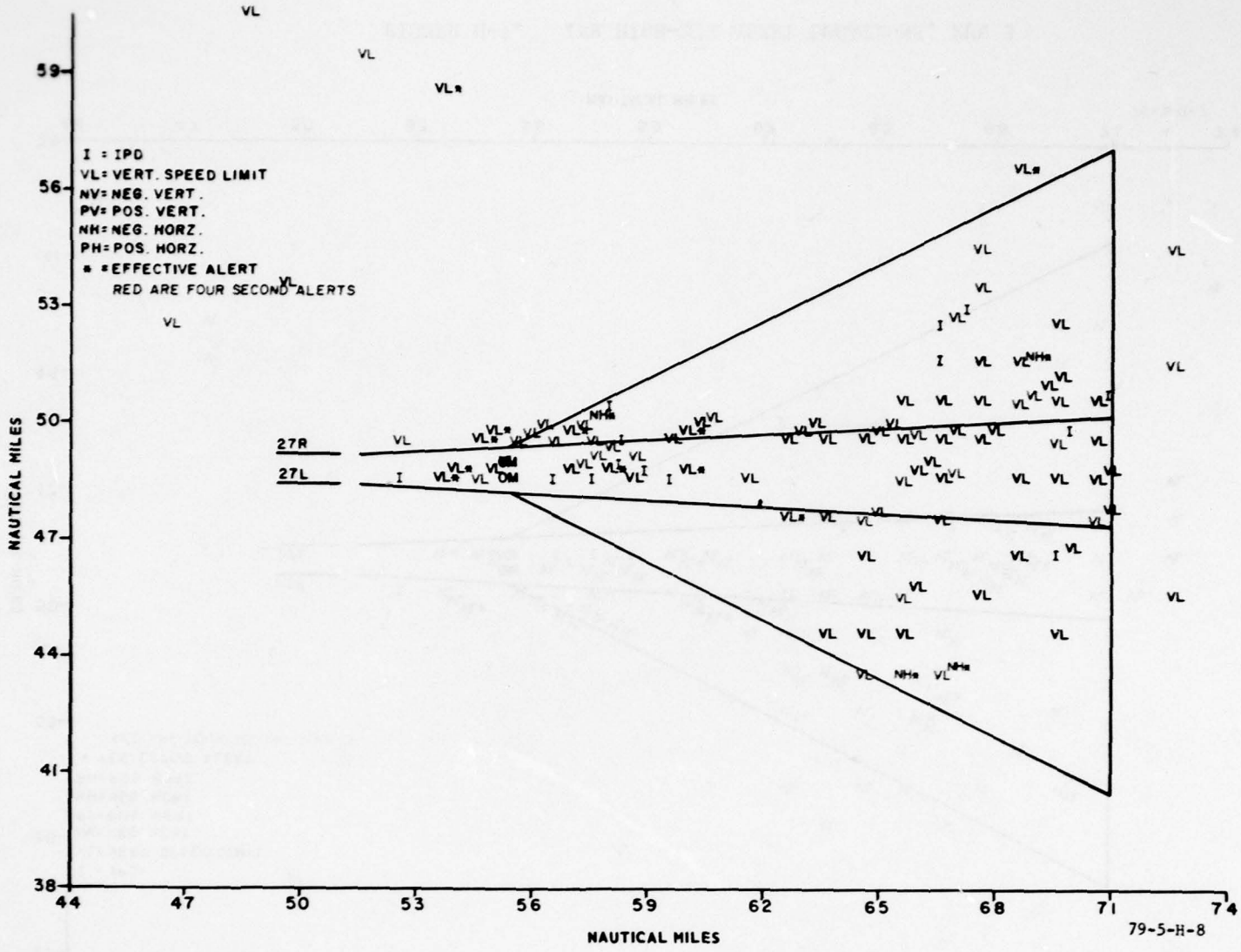


FIGURE H-8. IFR HIGH-MIX ALERT LOCATIONS, RUN 6

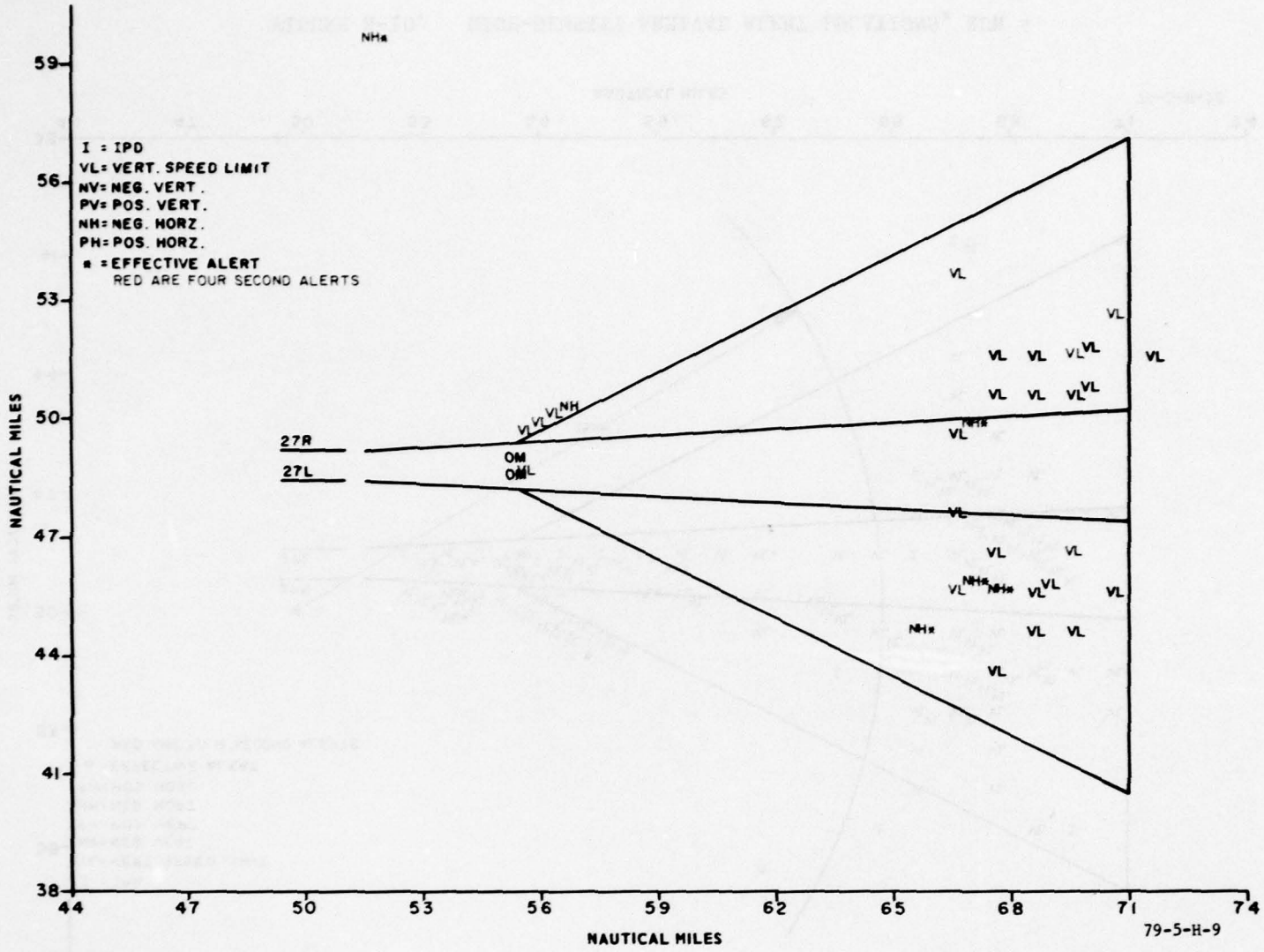


FIGURE H-9. IFR HIGH-MIX ALERT LOCATIONS, RUN 9

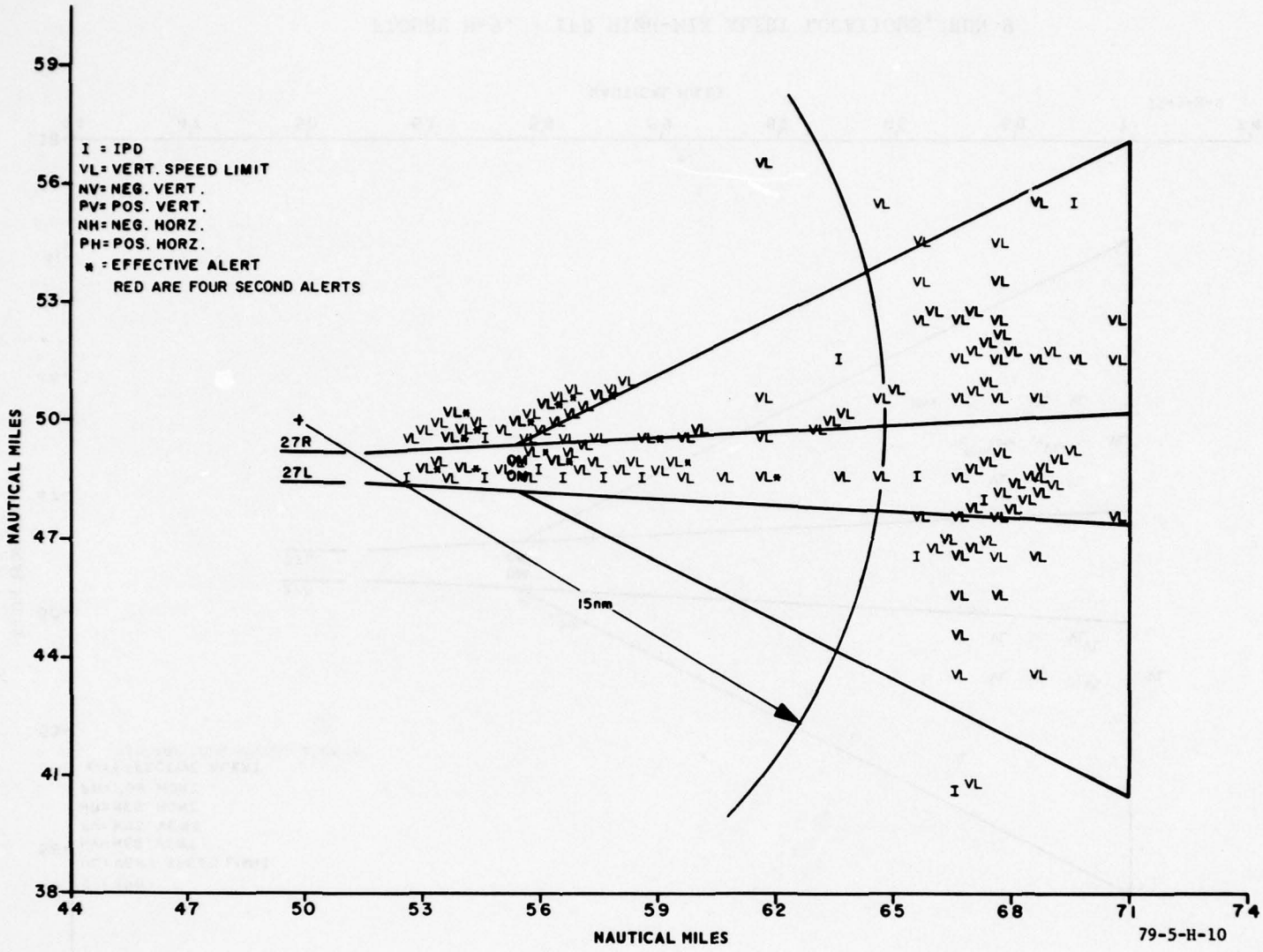


FIGURE H-10. HIGH-DENSITY ARRIVAL ALERT LOCATIONS, RUN 4

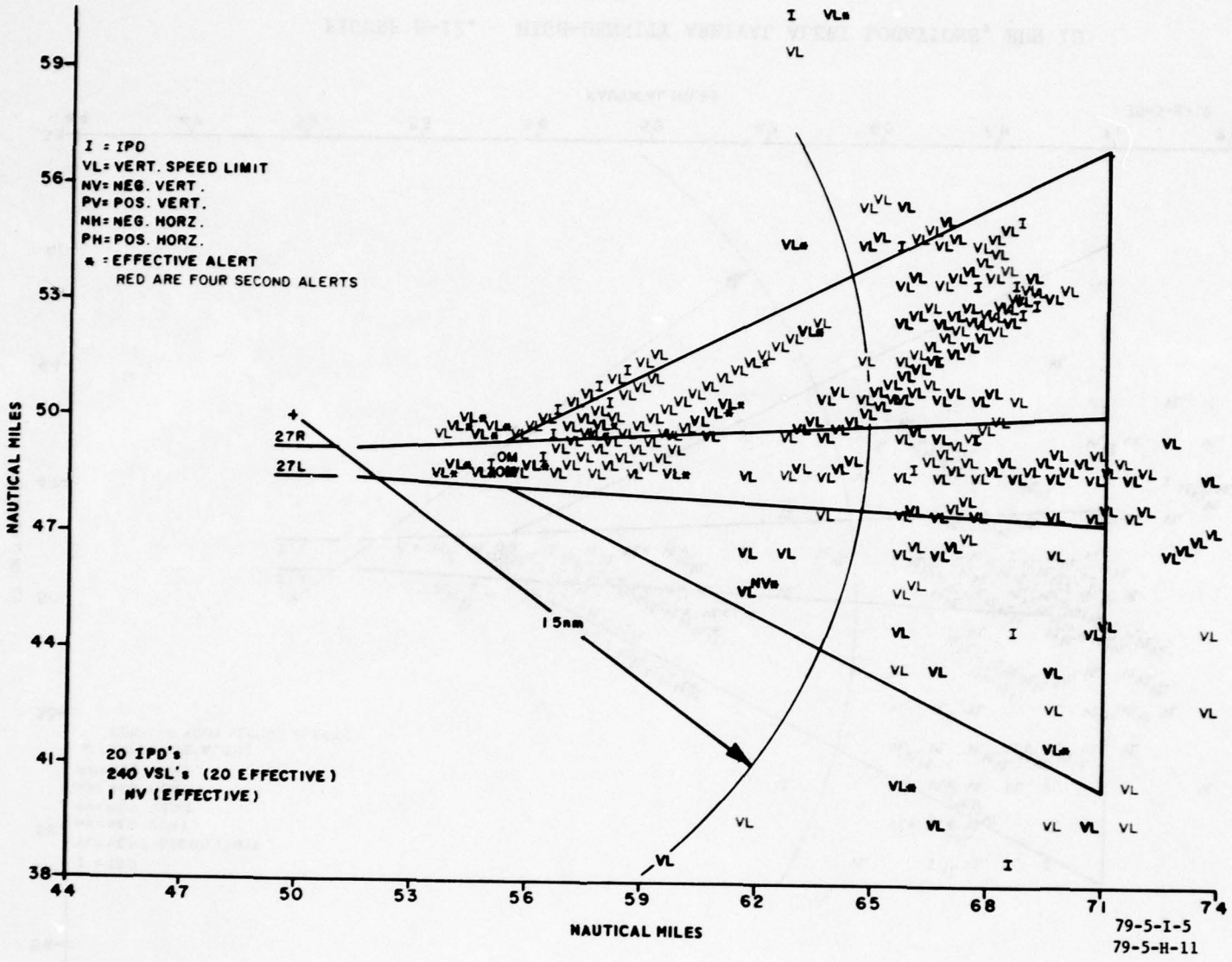


FIGURE H-11. HIGH-DENSITY ARRIVAL ALERT LOCATIONS, RUN 7

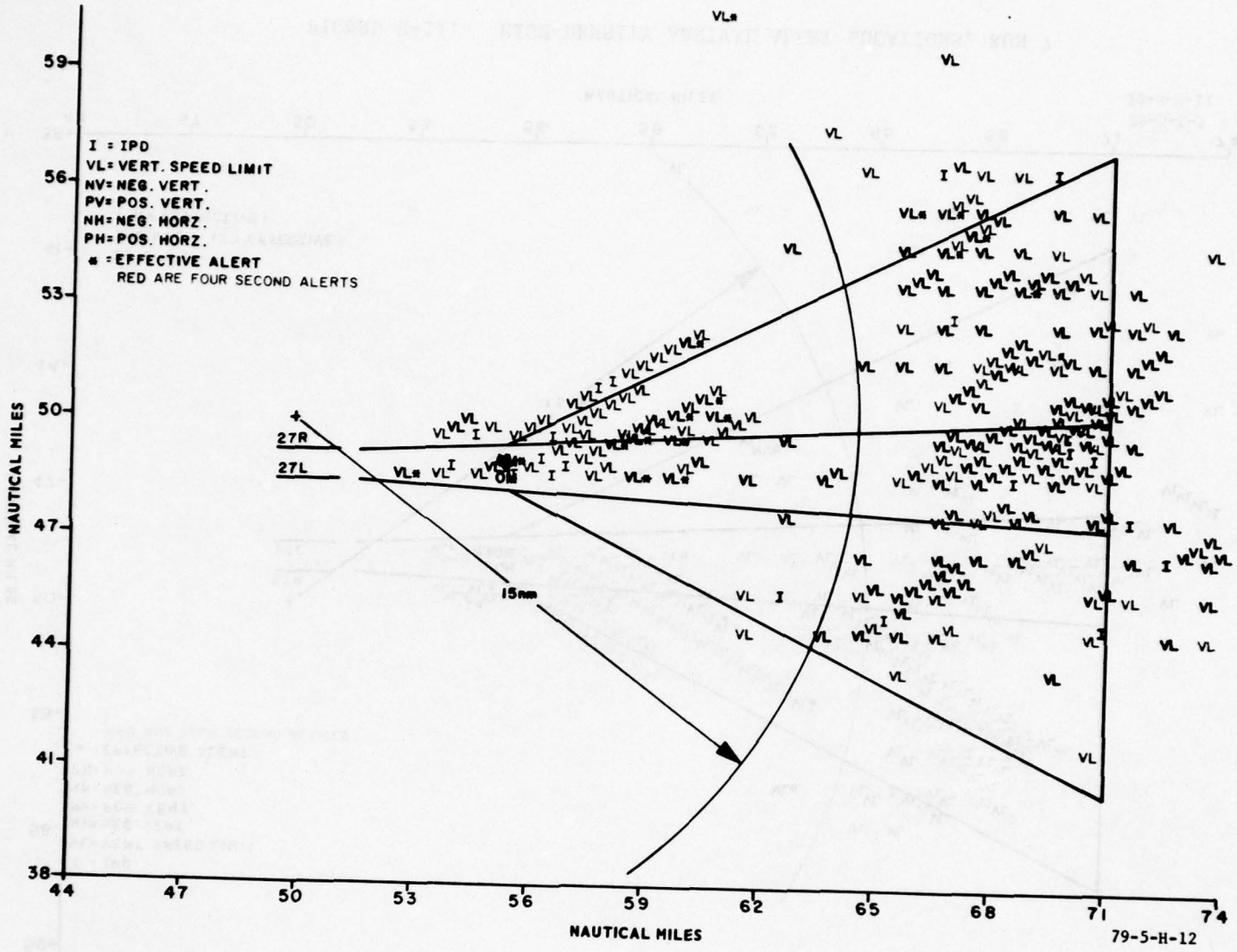


FIGURE H-12. HIGH-DENSITY ARRIVAL ALERT LOCATIONS, RUN 10

APPENDIX I

ANALYSIS OF TWO-OUT-OF-THREE RULE ON VSL ALERT RATE

Initially, analysis was conducted to identify the location where the major proportion of the short-duration VSL's occurred. This permitted the determination of any adverse effect that may be caused by the removal of these alerts. The effect of the two-out-of-three rule on the number of effective and noneffective VSL's was also investigated.

Figures I-1 to I-4 show histograms of the VSL alert durations for the four experimental conditions. Besides the total number of alerts, the number of alerts are graphed for three different areas, the ILS final area, the final vector area, and the remaining area. If neither aircraft in the conflict pair was in the final vector or ILS area, they were considered to be in the remaining area. If one aircraft was on the ILS and the other in the final vector area, they were considered to be in the ILS area.

In summary, the histograms show that an extremely high proportion of the VSL's were 4 seconds or less in duration. This occurred for all four experimental conditions. The highest proportion of these short-duration VSL's occurred with at least one aircraft in the ILS area. Short-duration VSL's have very little effect on increasing separation in the ILS area because of the low relative vertical rates that exist there.

While a two-out-of-three rule will definitely reduce the total number of alerts by eliminating all alerts that last only 2 seconds, there was some concern that the change would cause an increase in the number of short-duration alerts. Analysis of the histograms indicates this would not happen. A total of 1,536 VSL's resulted during the Chicago simulation. If a two-out-of-three rule had been used in the Chicago simulation, a maximum of 46 of the resulting VSL alerts (those alerts originally 6 seconds in length) would have been less than 4 seconds in duration. The current algorithm generated 425 VSL's which lasted only 2 seconds.

An investigation was conducted to determine what proportion of the effective VSL alerts would be eliminated by the two-out-of-three rule. Table I-1 presents the average number and duration of effective and noneffective VSL alerts for the different experimental conditions. Table I-2 presents the average number and duration of effective and noneffective alerts that would have resulted if a two-out-of-three rule had been used.

A comparison of tables I-1 and I-2 shows that if a two-out-of-three rule had been used in the Chicago simulation, the number of VSL alerts would have been reduced by 34 to 43 percent depending on the experimental condition. The comparison of the effective alert columns indicates that the use of the

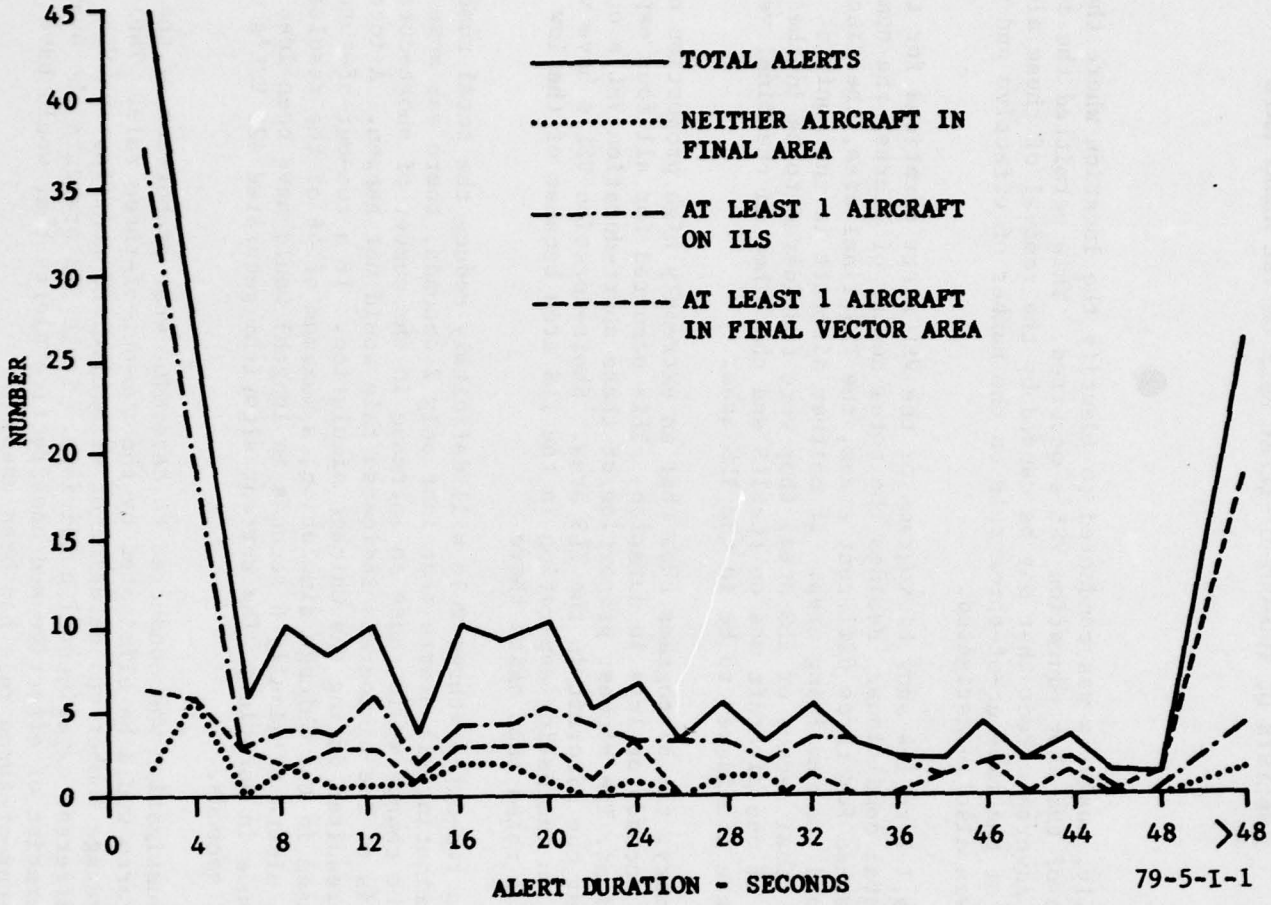


FIGURE I-1. VSL ALERT DURATION--LOW EQUIPAGE LEVEL

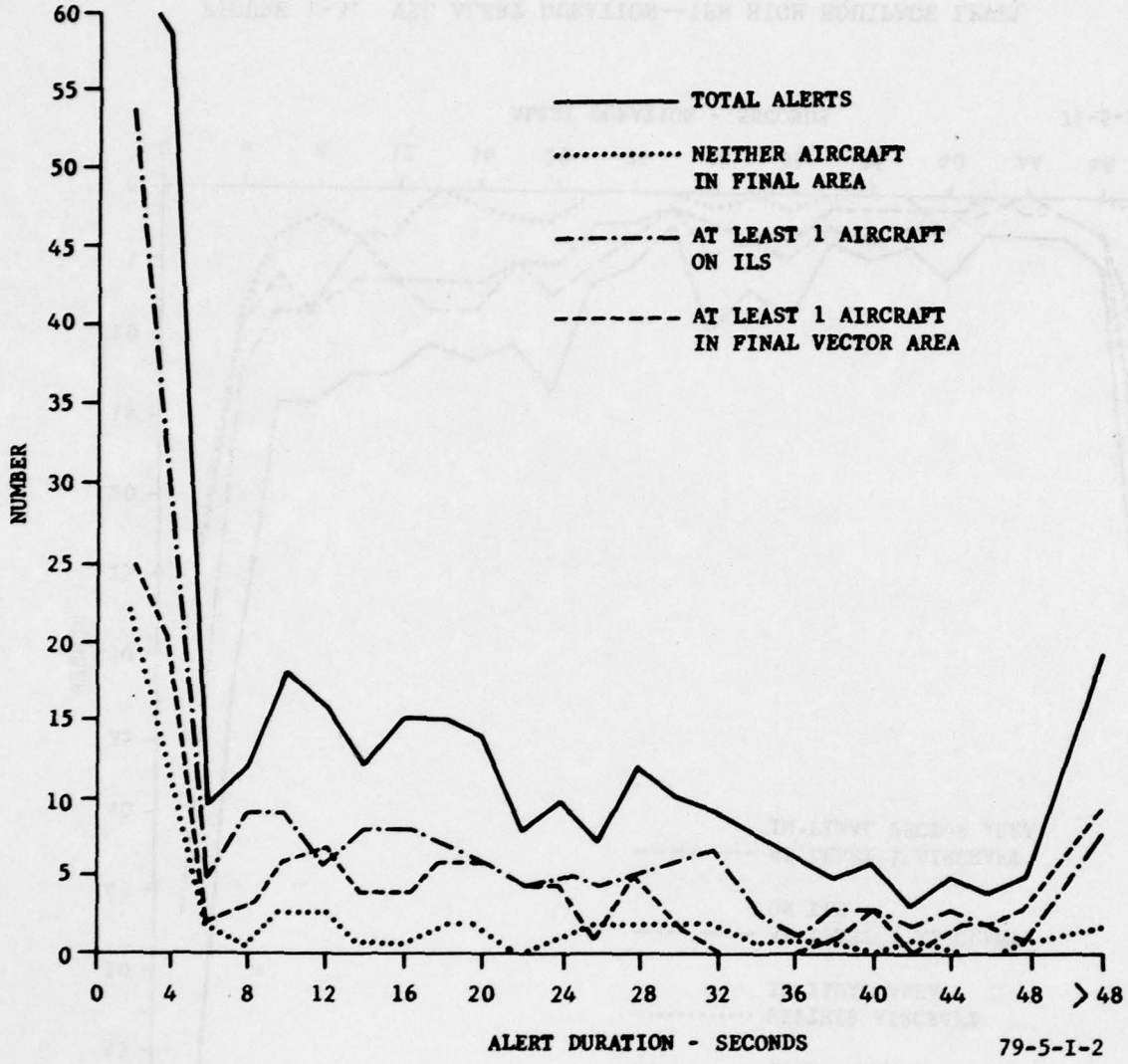


FIGURE I-2. VSL ALERT DURATION--HIGH EQUIPAGE LEVEL

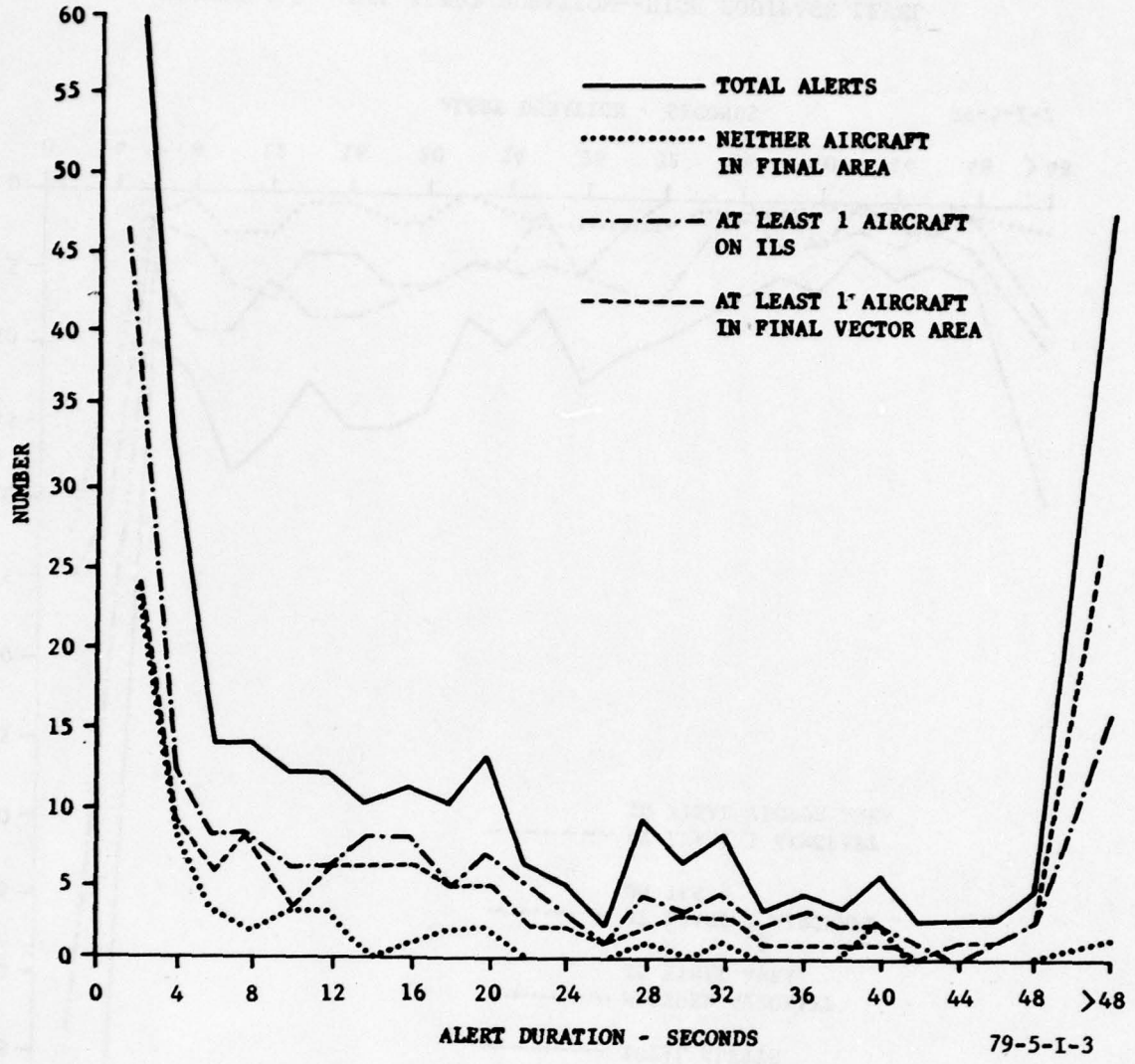


FIGURE I-3. VSL ALERT DURATION--IFR HIGH EQUIPAGE LEVEL

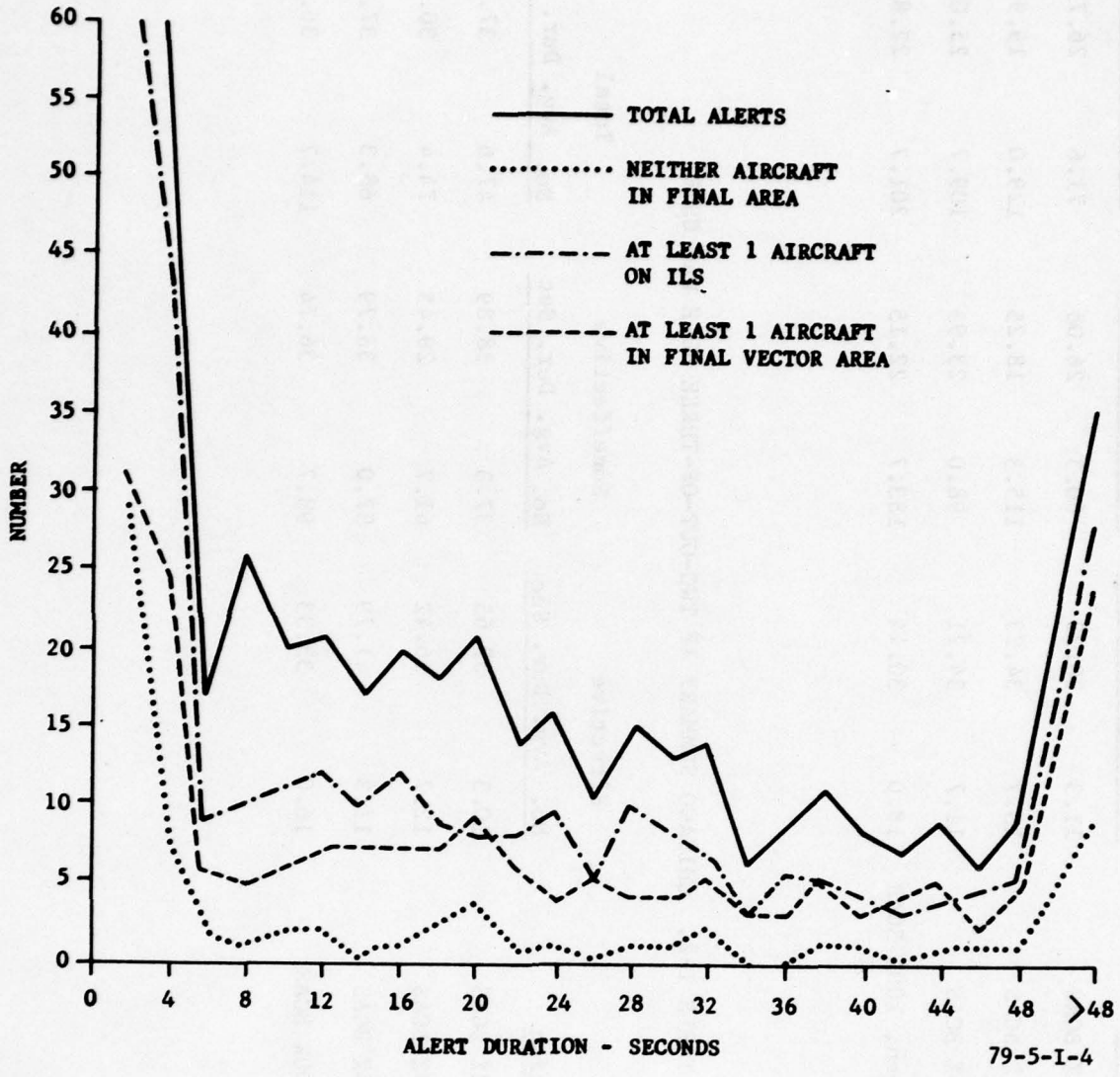


FIGURE I-4. VSL ALERT DURATION--HIGH DENSITY ARRIVALS

TABLE I-1. VSL SUMMARY FOR CHICAGO

	Effective		Noneffective		Total	
Condition	No.	Avg. Dur. Sec	No.	Avg. Dur. Sec	No.	Avg. Dur. Sec
VFR 32% BCAS	11.3	30.23	60.3	26.08	71.6	26.73
VFR 68% BCAS	13.7	34.23	115.3	18.25	129.0	19.95
IFR 65% BCAS	11.7	34.21	98.0	23.93	109.7	25.02
High-Den. 100% BCAS	18.0	30.44	183.7	22.15	201.7	22.89

TABLE I-2. CHICAGO SUMMARY IF TWO-OUT-OF-THREE RULE WAS USED

	Effective		Noneffective		Total	
Condition	No.	Avg. Dur. Sec	No.	Avg. Dur. Sec	No.	Avg. Dur. Sec
VFR 32% BCAS	10.3	32.65	37.3	38.89	47.6	37.54
VFR 68% BCAS	12.7	36.42	61.7	29.45	74.4	30.63
IFR 65% BCAS	11.3	41.79	57.0	36.79	68.3	37.59
HDA 100% BCAS	16.0	33.33	98.7	36.74	114.7	36.25

two-out-of-three rule would have eliminated one effective VSL alert for each of the VFR conditions, two effective alerts for the high-density arrival condition, and an average of less than one alert for the IFR condition. The effective VSL alerts are the only VSL alerts which would have caused an increase in separation between the two aircraft in the conflicting pair. Since the two-out-of-three rule would have filtered only those alerts the durations of which were 4 seconds or shorter, the effective alerts that would have been filtered by the two-out-of-three rule would have provided only a minimal increase in separation.

Another question is the determination of the loss in separation resulting from the reduction in the length of effective VSL's that were longer than 4 seconds. At most, the VSL presentation would be delayed, or the duration reduced 4 seconds. VSL alerts are terminated in two ways; (1) the conflict is resolved or (2) the VSL is replaced by a positive or negative command. Since VSL's precede positive or negative commands by at least 15 seconds (algorithm parameter), application of the two-out-of-three rule in these cases would still permit VSL's to precede positive or negative commands by at least 11 seconds.

In cases where the conflicts were resolved while the VSL's were displayed, the question remains how often the reduction in length caused by the two-out-of-three rule prevented the resolution prior to generation of a positive or negative command. During all Chicago runs, there were total of 164 effective VSL's which were not followed by a positive or negative command. A review of these encounters showed that the application of the two-out-of-three rule would have caused at most four VSL's to be replaced by negative commands. This analysis shows that a two-out-of-three rule would have very little effect on reducing separation provided by VSL alerts.

The effect of the two-out-of-three rule can be seen graphically by comparing figure I-5 to figure I-6. Run 7 had the highest VSL alert rate in the Chicago simulation.

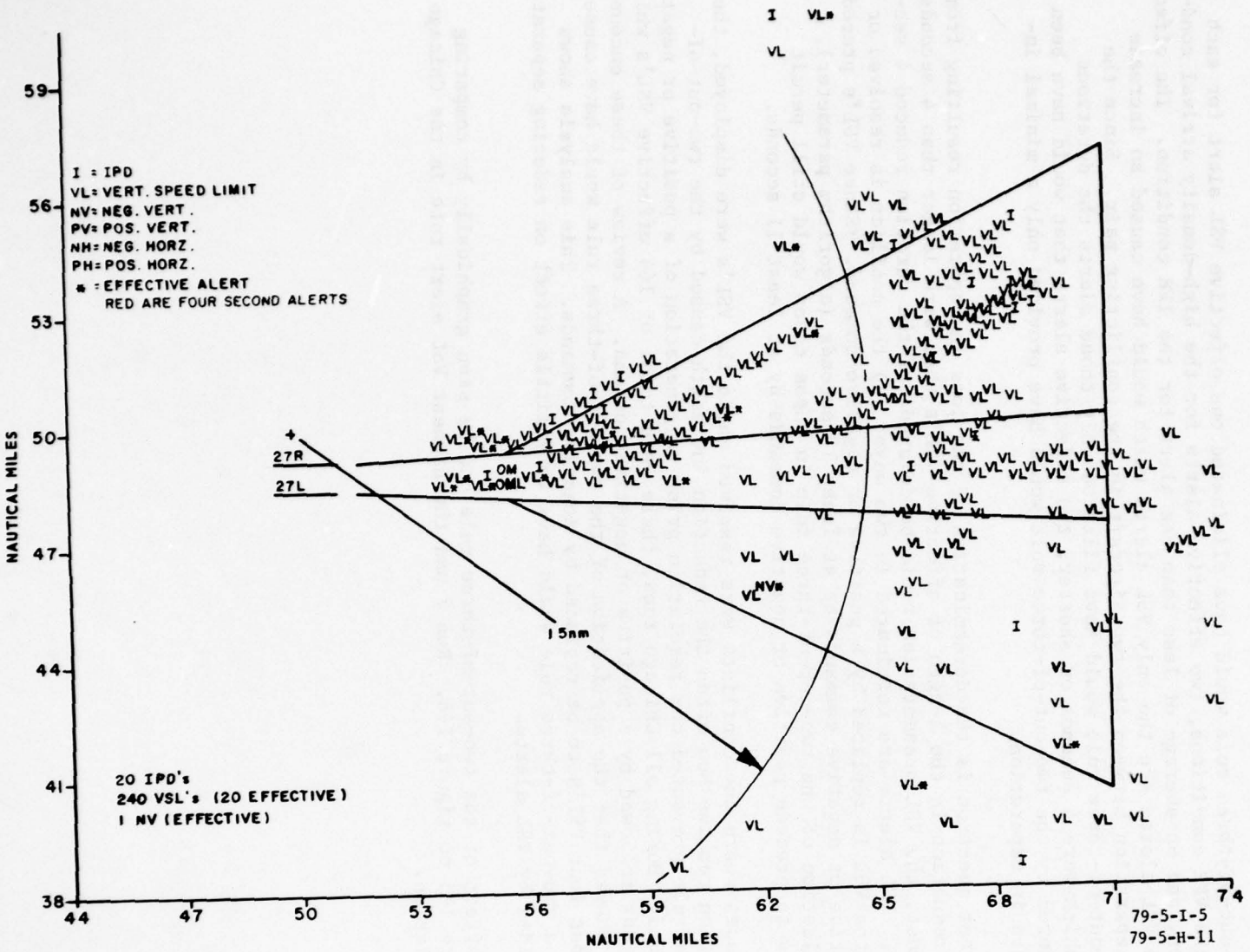


FIGURE I-5. ORIGINAL ALERTS ON RUN 7

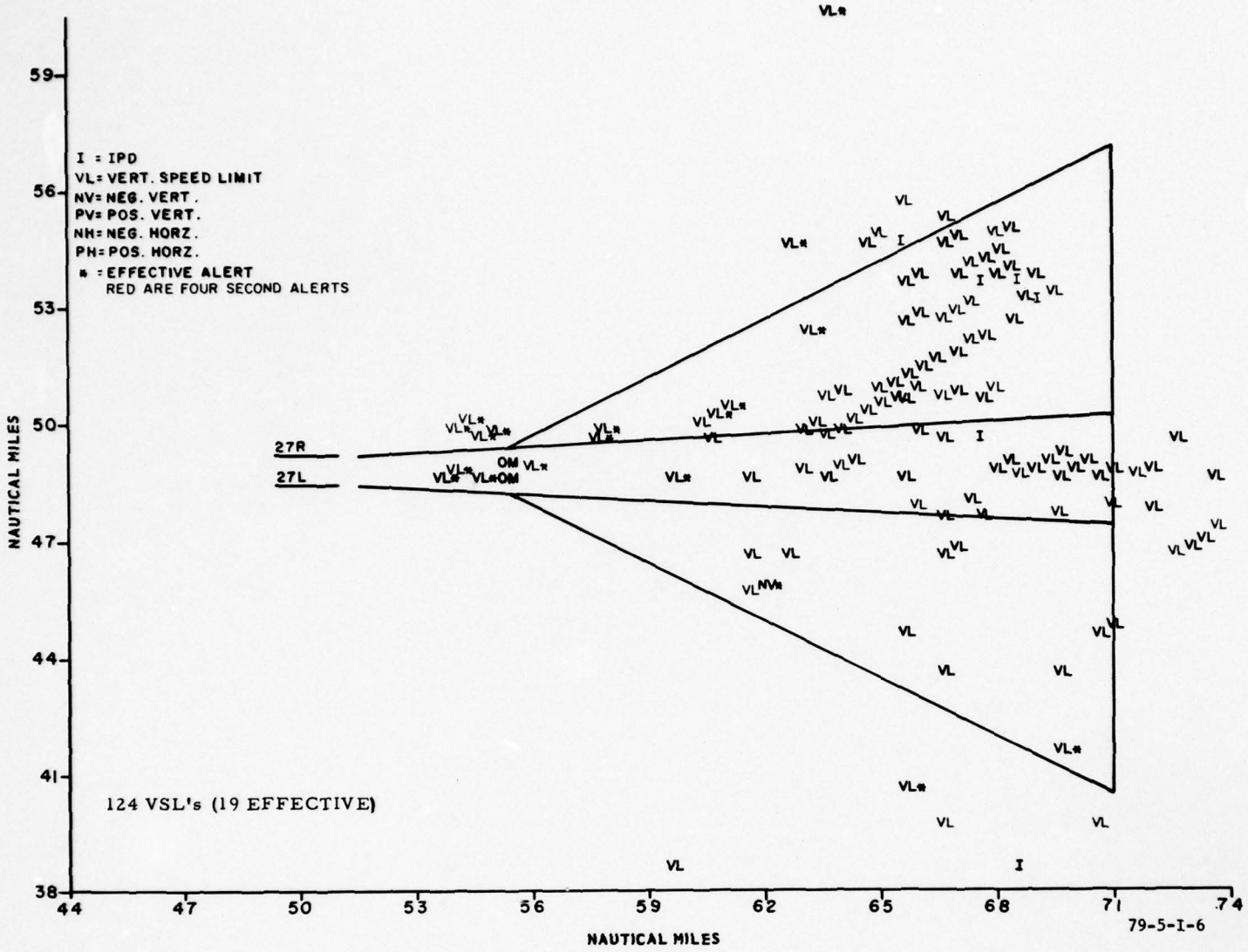


FIGURE I-6. ALERT LOCATIONS IF TWO-OUT-OF-THREE RULE HAD BEEN USED

AD-A069 524 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 17/7
AIR TRAFFIC CONTROL/FULL BEACON COLLISION AVOIDANCE SYSTEM CHIC--ETC(U)
APR 79 B BILLMANN, T MORGAN, R STRACK

UNCLASSIFIED FAA-NA-79-5 FAA-RD-79-16 NL

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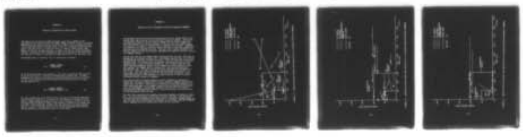

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APPENDIX J

ANALYSIS OF REDUCTION IN MTAU2 VALUES

The results of the GAT Pilot/BCAS Experiment conducted at NAFEC in 1977 indicated the tau distance modifiers, DMOD, DMODP, and MTAU2, should be reduced. MITRE Corporation agreed with the reduction in DMOD, the tau distance modifier for positive and negative commands from 1.8 nmi to 1.0 nmi for desensitization level 1 and from 0.75 to 0.5 nmi for level 2. However, MITRE did not want DMODP, the IPD tau distance modifier, or MTAU2, the VSL tau distance modifier, reduced. Analysis of these experimental data was performed to see what effect the reduction in MTAU2 to correspond to DMOD would have on the VSL alert rate.

The minimum time to collision, Tau, is calculated as follows:

$$\text{Tau} = \frac{\text{Range} - \text{MTAU2}}{\text{Range Rate}} \qquad (1)$$

If all other conditions are satisfied, a VSL alert is generated when tau ≤ 40. As can be seen in (1), a reduction in MTAU2 would increase tau. If MTAU2' represents the value of the reduced tau distance modifier for VSL's then tau', the tau value associated with the reduced tau distance modifier, is found through equation (2).

$$\text{tau}' = \left(\frac{\text{Range} - \text{MTAU2}'}{\text{Range} - \text{MTAU2}}\right) \cdot \text{tau} \qquad (2)$$

For each original VSL alert duration that occurred in the Chicago experiment, there existed a sequence of tau values for each BCAS cycle intthe VSL alert period. Substituting the smallest value in the sequence in place of tau and the range when the smallest value in the sequence occurred in (2) yields the new tau'. A VSL would have occurred with the reduced tau distance modifier only if tau' ≤ 40. Each VSL period in the Chicago experiment was analyzed, and the results are presented in table 7 of this report.

APPENDIX K

ANALYSIS OF CPA'S FOLLOWING POSITIVE OR NEGATIVE COMMANDS

An important question is the resulting separation at the closest point of approach (CPA) that occurred after a positive or negative command. The effect on separation caused by the 14 positive commands can be seen in figure K-1. Each line connects the relative position of the pair when the command first occurred with the point of closest point of approach for that pair. Remember the aircraft in a conflict pair were either both VFR or both IFR: traffic samples did not allow IFR/VFR conflicts. The open circle (usually between the initial command location and the CPA) represents the relative location at which the command stopped.

In only one case did the command remain displayed after the CPA. This case is marked with an asterisk in figure K-1. The command occurred when the aircraft had approached to within 700 feet vertically. Both aircraft were in the south approach zone. The closest point of approach occurred at 800 feet vertical separation and 0.3 nmi horizontal separation. The crossing angle was low, which prevented immediate removal of the command once the horizontal tracks had crossed. The command was not removed until the vertical separation exceeded 900 feet. By this time the horizontal separation had increased to over 1 nmi. Only two positive commands occurred between IFR aircraft. In both cases, they were quite close to the IFR separation boundaries. Only slight penetrations of VFR separation criteria occurred on three occasions following positive horizontal commands.

The resulting CPA's following negative vertical commands are depicted in figure K-2. On three occasions, the vertical negative commands remained displayed after the CPA's. There were no occasions in which VFR separation criteria were penetrated if the command occurred when the separation was greater than the VFR minimum. Two negative commands occurred after the aircraft had penetrated VFR separation criteria. In both conflicts, the vertical separation was greater than 350 feet.

The CPA's that resulted after negative horizontal commands are shown in figure K-3. In 8-out-of-10 cases, the aircraft involved were IFR. IFR separation criteria have been penetrated four times prior to a negative command being issued, but only one of these conflicts resulted in a CPA less than VFR standards. Twice, commands were not removed until after the CPA occurred.

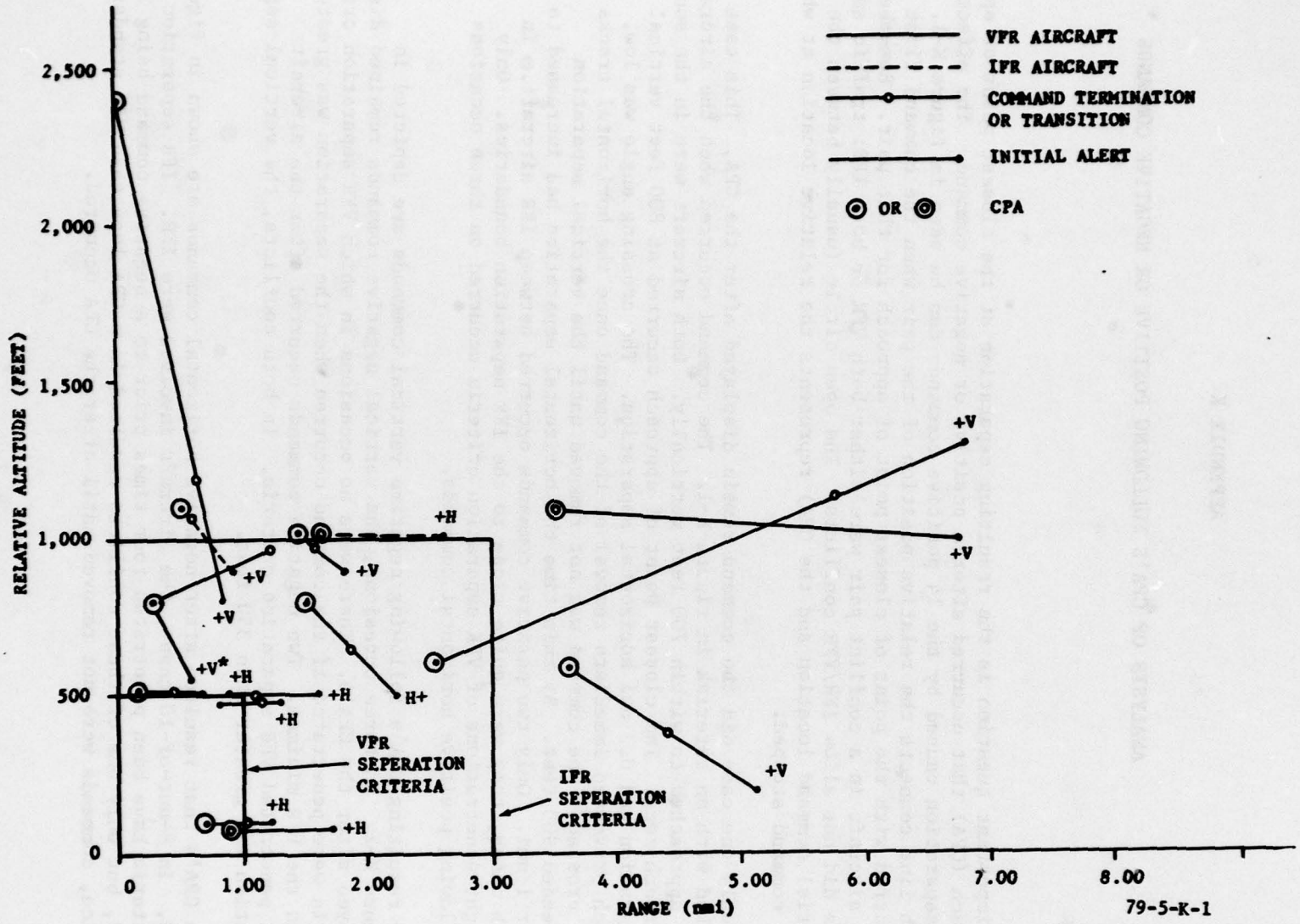

FIGURE K-1. RELATIVE POSITION TRACKS AND RESULTING CPA'S FOLLOWING POSITIVE COMMANDS

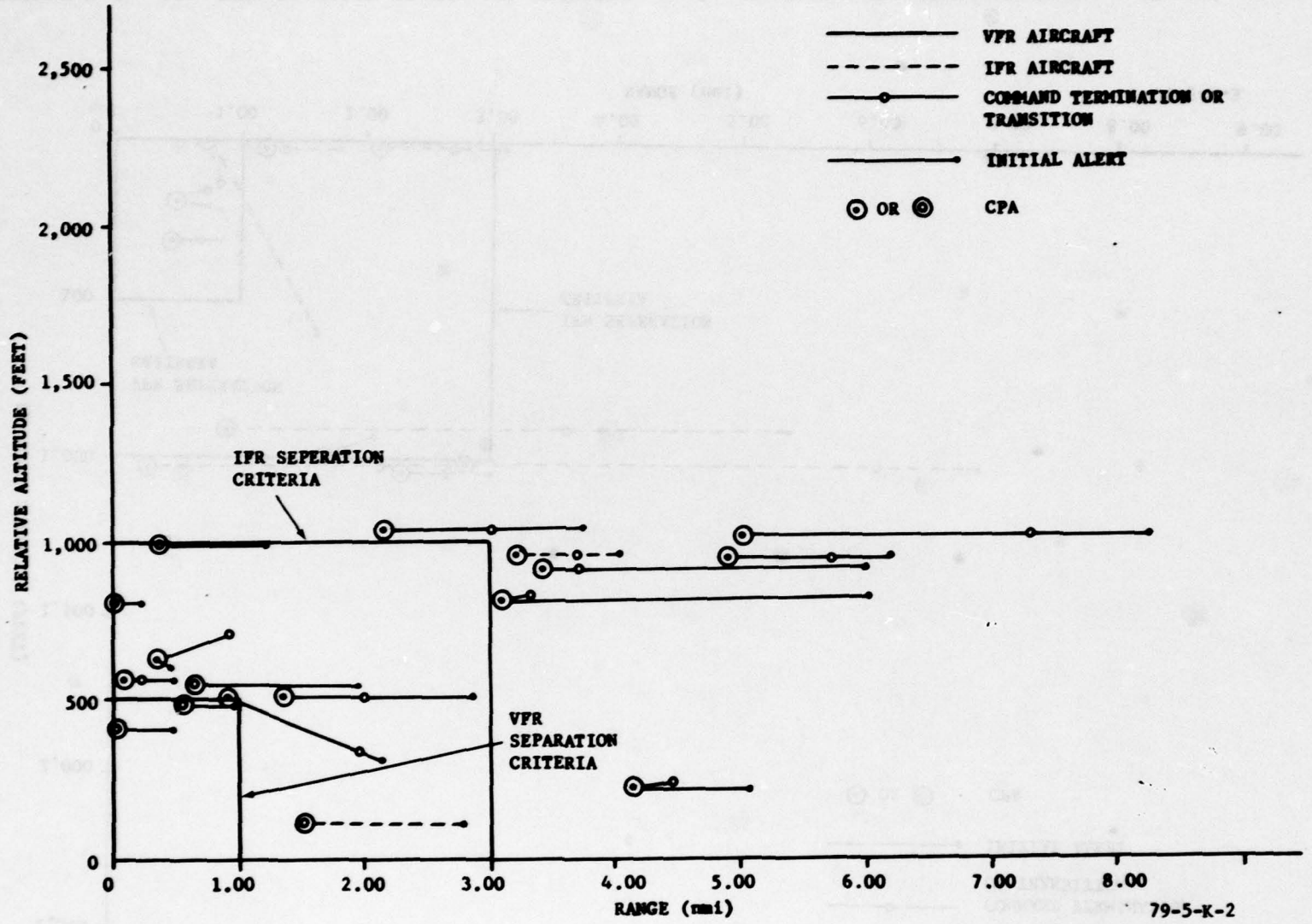

FIGURE K-2. RELATIVE POSITION TRACKS AND RESULTING CPA'S FOLLOWING NEGATIVE VERTICAL COMMANDS

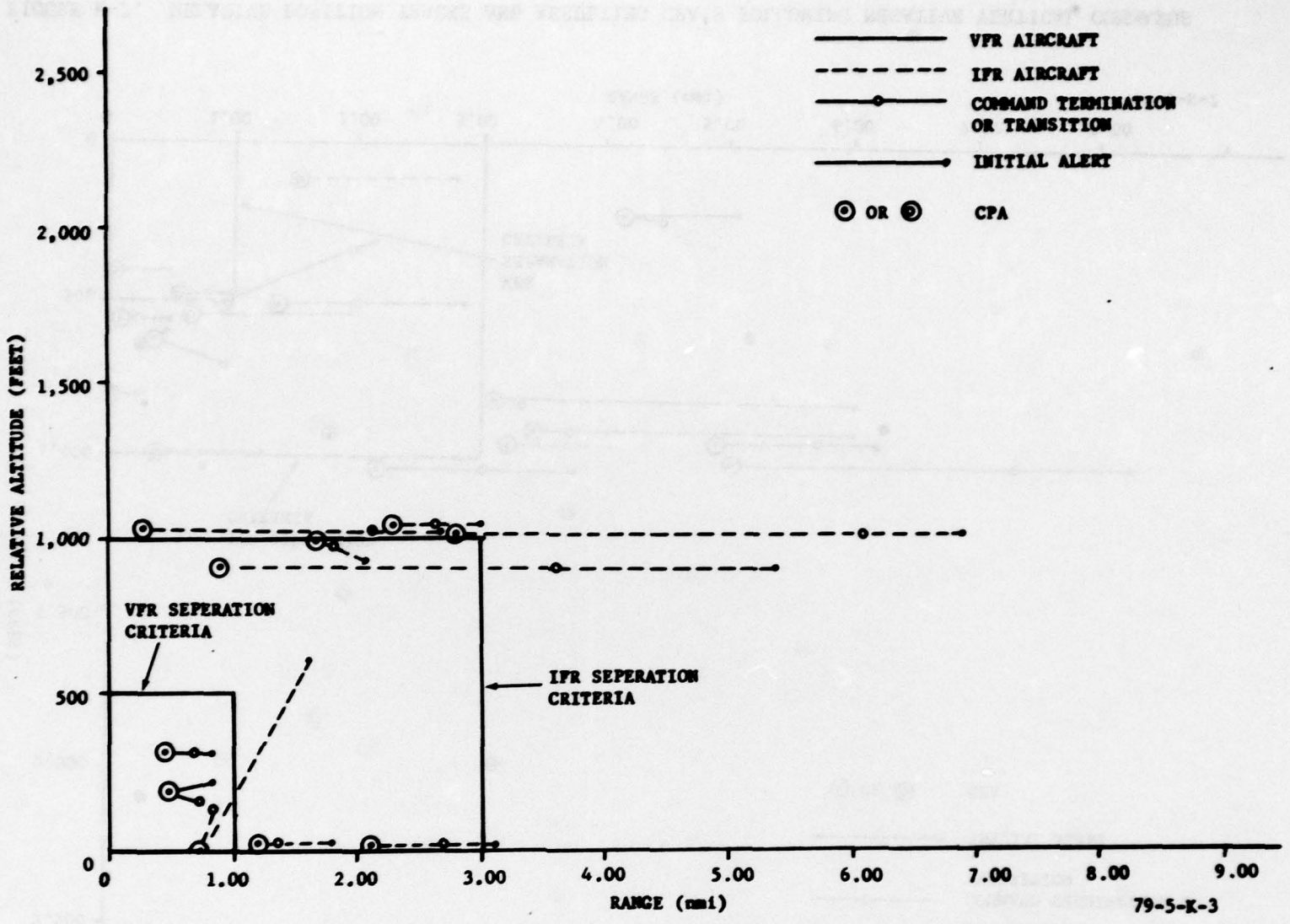

FIGURE K-3. RELATIVE POSITION TRACKS AND RESULTING CPA'S FOLLOWING NEGATIVE HORIZONTAL COMMANDS