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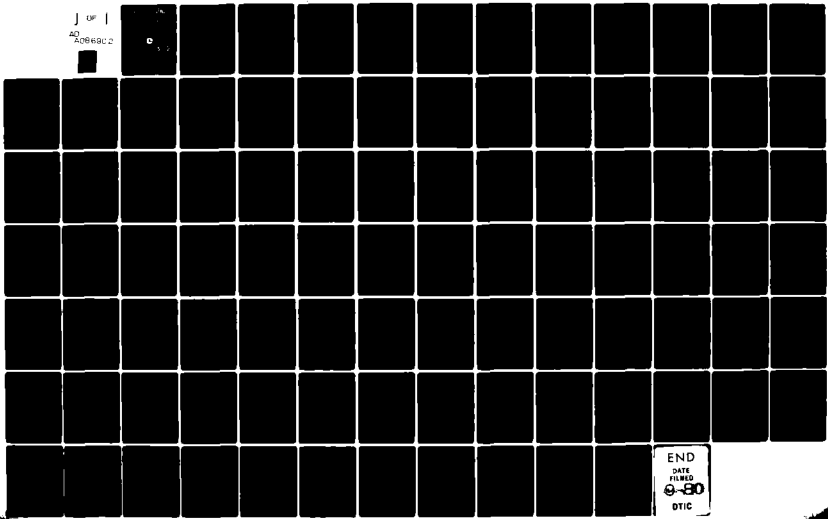

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# AIR TRAFFIC CONTROL/ACTIVE BEACON COLLISION AVOIDANCE SYSTEM KNOXVILLE SIMULATION



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Atlantic City, N. J. 08405





FINAL REPORT

MAY 1980



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16. Abstract

This project was conducted to assess the performance of an active mode Beacon Collision Avoidance System (BCAS) operating in a moderate-density terminal Air Traffic Control (ATC) environment. The specific objectives addressed the impact of active BCAS on controllers and control procedures, the performance of new vertical speed limit (VSL) logic, the effectiveness of an alternate desensitization method, and the impact of "no miss distance" filtering. An additional objective was to characterize and validate the active BCAS algorithm in terms of number, duration, and location of alerts and resolution effectiveness.

The tests were conducted using the ATC Simulation Facility at the National Aviation Facilities Experimental Center during February and March 1979. Analysis of results indicated that an active BCAS system provided an effective aircraft separation assurance system as a backup to the ATC system and had no adverse effect on controllers or control procedures. The VSL logic modifications significantly reduced the BCAS activity for overflight traffic relative to the BCAS alarm rate in the full BCAS tests. An alternative desensitization method to range and altitude, based only on altitude, proved to be reasonably effective. The lack of horizontal miss distance information with active BCAS resulted in an increase in the positive command rate when compared to the full BCAS Knoxville results.


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# METRIC CONVERSION FACTORS

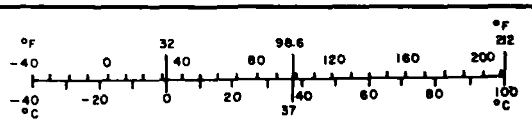
## Approximate Conversions to Metric Measures

| 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 |



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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ARTS III | Automated Radar Terminal System |
| ATC | Air Traffic Control |
| ATCRBS | Air Traffic Control Radar Beacon System |
| ATCSF | Air Traffic Control Simulation Facility |
| BCAS | Beacon Collision Avoidance System |
| CAS | Collision Avoidance System |
| CPA | Closest Point of Approach (in three dimensions) |
| DABS | Discrete Address Beacon System |
| DR&A | Data Reduction and Analysis |
| IFR | Instrument Flight Rules |
| IPD | Intruder Positional Data (Proximity Warning Indication) |
| PPD | Partial Proximity Data |
| RBX | Radar Beacon Transponder |
| SCU | Sensitivity Control Unit |
| VFR | Visual Flight Rules |

## LIST OF BCAS ALGORITHM TERMS

| | |
|---|---|
| DMOD | Modified Tau Distance Used for Positive and Negative Commands |
| LALT | Altitude Separation Outside Which Vertical Speed Limit Commands Are Not Given |
| TAU | Ratio of Range to Rate of Closure ($R/\dot{R}$) |
| TAUR | Range Tau |
| TRTHR | The Threshold Value Against Which the Modified-Tau (TAUR) Is Compared |
| TVTHR | The Threshold Value Against Which the Vertical-Tau (TAUV) Is Compared |
| VMD | Vertical Miss Distance |
| VSL | Vertical Speed Limit |

# INTRODUCTION

## PURPOSE.

This report describes the tests conducted and the results obtained from the Knoxville terminal area air traffic control (ATC)/active mode Beacon Collision Avoidance System (BCAS) dynamic simulation. The purpose of this simulation was to assess the performance of an active mode of BCAS operating in a moderate-density terminal ATC environment. The specific objectives were to assess the impact of active BCAS on controllers and control procedures, the performance of new vertical speed limit (VSL) logic, the effectiveness of an alternate desensitization method, and the impact of "no miss distance" filtering. An additional objective was to characterize and validate the active BCAS algorithm in terms of number, duration, and location of alerts and resolution effectiveness.

## BACKGROUND.

The ATC/active BCAS interaction simulation was the third phase of the overall BCAS simulation effort conducted at the National Aviation Facilities Experimental Center (NAFEC). The results of the first phase which focused on the pilot/BCAS interface were reported in reference 1. The second phase, evaluation of the full BCAS/ATC interface, was conducted in two parts, and the results were reported in references 2 and 3. The second phase evaluated full BCAS in a high-density environment, Chicago, and a moderate-density environment, Knoxville. Phase 3 was conducted to evaluate active BCAS performance and to measure the active BCAS interaction that might exist if the active BCAS were present in a moderate-density ATC terminal environment. The Knoxville terminal area was selected for the study because BCAS might be the only backup to ATC in an area that does not have an Automated Radar Terminal System (ARTS III), and hence, Conflict Alert is not available. The selection of the Knoxville area also provided an environment for making a comparative analysis between the active BCAS and full BCAS systems.

This evaluation was conducted at NAFEC, using prototype (draft) active BCAS logic provided by the MITRE Corporation (reference 4). The logic was not designed at this stage of testing to have a multi-intruder resolution capability. Computer Sciences Corporation (CSC) coded and debugged the logic for the simulation test. The tests were conducted in an error-free environment. With no error mode, the results provide an upper bound for expected active BCAS performance.

DISCUSSION

## SYSTEM DESCRIPTION.

The NAFEC Air Traffic Control Simulation Facility (ATCSF) was utilized in a stand-alone configuration to conduct the test. This facility, described in reference 5, provides a real-time human interaction simulation environment. In simulation, air traffic controllers using standard ATC procedures and phraseology issue clearances to simulator pilots who then convert these messages for entry into the computer via special keyboards. The computer interprets these entries and controls the flightpaths of aircraft in the system.

Active BCAS functions independently of ground surveillance systems. A BCAS-equipped aircraft can actively interrogate and listen for Discrete Address Beacon System (DABS)-equipped and air traffic control radar beacon system (ATCRBS)-equipped aircraft responses providing they have a mode-C altitude reporting capability. The active BCAS algorithm was given the quantized altitude (nearest 100 feet) and range for each threat aircraft. Relative bearing on intruder aircraft was not available for use by the algorithm. All aircraft in the simulation were BCAS-equipped except for the baseline series.

The simulator pilots received BCAS messages anytime an aircraft they were piloting received a BCAS alert. The simulator pilots informed the controller of the displayed BCAS messages when controller instructions were contrary to the displayed message. The aircraft responded to the BCAS alerts automatically. These responses could be overridden by ATC instructions to the simulator pilots.

Three types of active BCAS messages were provided in the simulation: VSL's, negative commands, and positive commands. VSL's are alerts which limit the vertical velocity of the aircraft. The six VSL alerts are "limit climb to 2,000 feet per minute (ft/min) or less," "limit climb to 1,000 ft/min or less," "limit climb to 500 ft/min or less," and the three complementary descent alerts. The negative commands that could be provided were "do not climb" and "do not descend." The positive commands that could be generated were "climb" and "descend." Only one VSL or positive or negative command could be displayed at one time.

The active BCAS logic evaluated does not provide positional data on intruders. Minor algorithm modifications permitted the collection of data on partial proximity data (PPD) alerts. PPD alerts would provide the pilot with range and altitude information on an intruder aircraft. These alerts are called PPD alerts because, in the active mode the relative bearing to the intruder may not be determined; whereas, in full BCAS, relative bearing on an intruder is always provided.

An effective alert was an alert which caused th[illegible] deviate [illegible] intended flightpath. A noneffective alert was an alert that had no effect on the aircraft's flightpath. PPD alerts were always classed as noneffective alerts since they did not affect the aircraft's flight profile. VSL's and negative commands were classed as effective or noneffective depending on whether the aircraft flightpath was altered. A positive command was always classed as effective, since it always affected the aircraft's flight profile.

SYSTEM ENVIRONMENT.

The ATCSF was configured to represent a single ATCRBS site; namely, the Knoxville terminal area. The traffic volume simulated, represented that volume projected for the mid-1980's and included overflight traffic at 10,000 feet mean sea level (m.s.l.) and below. The navigational fixes and the terminal area traffic flow used were the same as the routes and fixes that exist in the Knoxville terminal area today. The traffic samples were created from the actual Knoxville facility aircraft flight strips provided by the chief controller at Knoxville. Based on conversations with the Knoxville Facility Chief, the basic traffic samples used were increased by 30 percent to reflect expected 1985 traffic. The airport simulated was the McGhee-Tyson Airport and featured parallel runways, 4L and 4R. Runway 4L had an instrument landing system and all arrival traffic operating under instrument flight rules (IFR) used this runway. Both runways, 4L and 4R, were used for arrival traffic operating under visual flight rules (VFR). Both runways were used for IFR and VFR departures.

The ATC laboratory simulated four Knoxville controller positions. The positions were local control (tower), east approach, west approach, and final vector control. The approach controllers also handled departure traffic within their sectors. In addition, two "ghost" en route feeder positions were simulated. Figure 1 depicts the laboratory layout. Additional ATC procedures employed in the Knoxville simulation are discussed in appendix A.

All traffic in the experiment was controlled, with full data blocks displayed for each target. Depending on the experimental conditions, IFR or VFR separation standards were applied to all aircraft. The only modification of the data block was the displaying of a blinking character (blinking "↓" for descend, blinking "↑" for climb) 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.

TRAFFIC CONDITIONS.

Two traffic conditions were simulated. The first condition modeled IFR operations, and the second condition modeled an even mix of IFR and VFR operations. Overflights were modeled and represented 15 to 20 percent of the traffic. The average number of active aircraft under terminal control at one time was 15.

Traffic separation procedures used by the c[illegible] or IFR/VFR standards depending on the conditions being simulated. Heavy commercial jets do not use the Knoxville airport; hence, this type of traffic was not simulated, and no variation in separation for weight category and wake turbulence was provided.

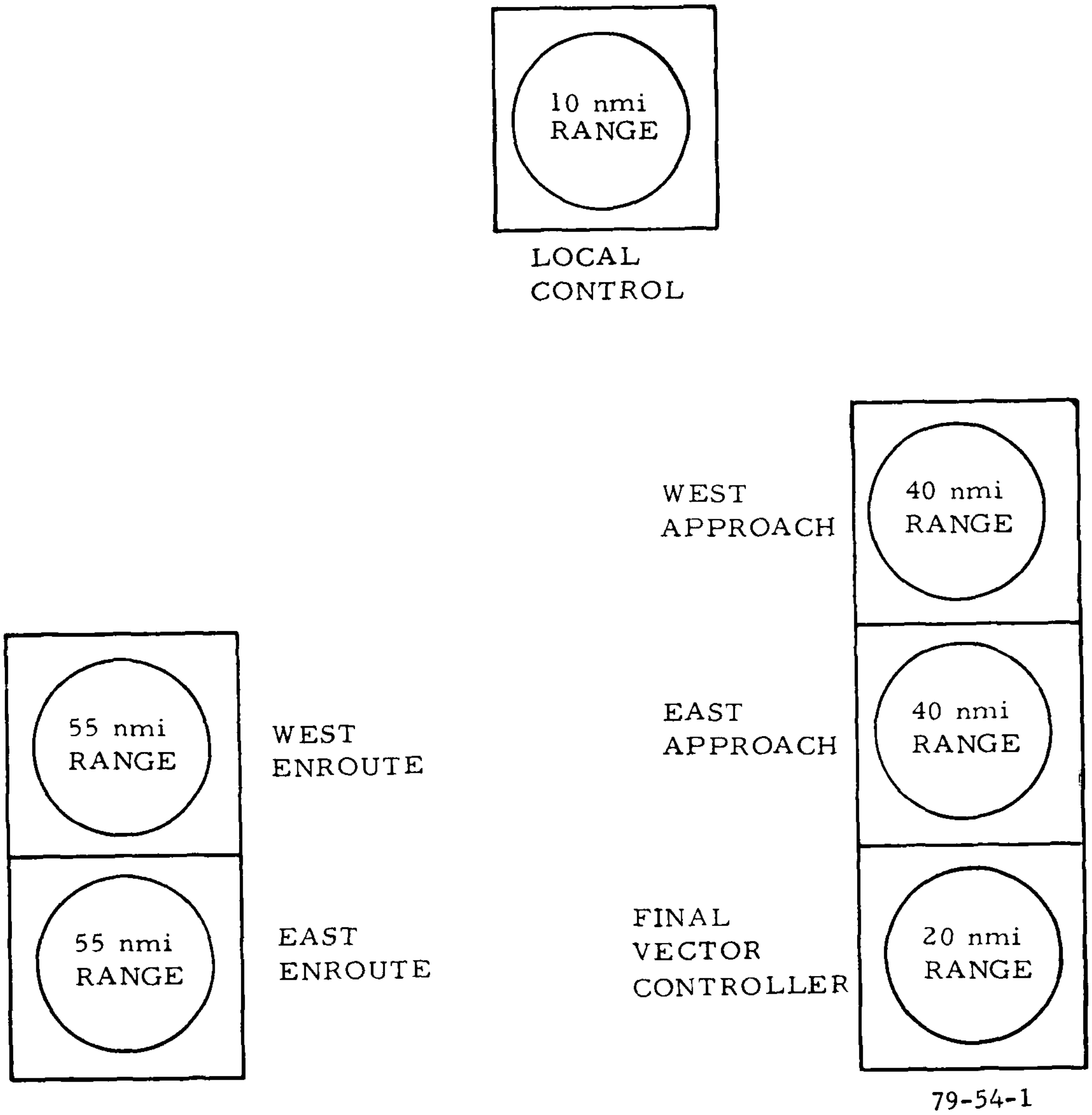



FIGURE 1. ATC LABORATORY LAYOUT

Each simulation run lasted 1 hour and 15 minutes. The initial 15-minute period constituted the traffic buildup period. This was followed by a 1-hour data collection period in which traffic density remained nearly constant.

## ERROR AND RESPONSE MODELS.

Transponder mode C accuracy and surveillance accuracy were assumed perfect in all simulation runs. These assumptions were made to conform with the simulated BCAS conditions in previous ATCSF collision avoidance experiments. Although some measurements of BCAS surveillance error magnitude have been made, an adequate description of the dynamic characteristics of the errors, such as correlation and autocorrelation, was not yet available (reference 6). The dynamic interaction of these errors with BCAS resolution should be identified prior to modeling such errors in simulation. Since no accurate description of the dynamic characteristics of BCAS errors in tracked position and velocity of an intruder has been published, perfect position and velocity data were provided to the BCAS tracker. The reported altitudes of all aircraft were quantized in 100-foot increments, the limit of mode C transponders. All aircraft responded to BCAS alerts using empirically determined pilot and aircraft response delays.

The pilot response delay model was based on the Gamma distribution with a mean of 5.56 seconds. This model was the same one used in the Knoxville full-BCAS study (reference 3). The use of this model resulted from findings in phase 1 experimentation. The aircraft acceleration rate both horizontally and vertically was 6 feet per second squared (0.19 g). The vertical and horizontal speed characteristics were dependent on the type of aircraft and flight condition. The actual values of the aircraft performance characteristics can be found in appendix B.

## DESENSITIZATION METHODS.

Some type of desensitization method in situations of closely spaced maneuvering aircraft is required for BCAS. BCAS must be flexible, insuring adequate protection for en route traffic while keeping the BCAS alert rate in the terminal area at an acceptable level. Based on previous BCAS simulation work, the majority of BCAS activity occurs during the sequencing and spacing of arrival aircraft in the final approach area (references 2 and 3). BCAS must be desensitized (i.e., reduce the threat thresholds which identify the BCAS protection volume) at some point along the arrival path to permit adequate collision avoidance protection without generating an unacceptably high number of BCAS alerts in the terminal area.

The draft of the active BCAS National Standard describes the desensitization as five performance levels of BCAS threat detection and resolution logic. The draft describes a method of automatically determining the performance level based on determining aircraft altitude and range from a radar site using a radar beacon transponder (RBX) or sensitivity control unit (SCU). As the performance levels increase from 1 to 5, the threshold parameters become more sensitive, thereby increasing the protection volume around each BCAS-equipped aircraft. When the BCAS performance level is set to level 1, BCAS does not transmit interrogations. The performance level 2 desensitization area is where BCAS tracking of an intruder aircraft is performed, but all resolution logic is blocked. The level 2 area extends outward for a 2-nautical mile (nmi) radius from the radar site. Performance level 3 airspace extends from 2 nmi to 15 nmi below 10,000 feet m.s.l. Performance level 4 area, an intermediate protection area, extends from 15 nmi to 50 nmi below 10,000 feet m.s.l. The highest protection area, performance level 5 airspace, extends upward from 10,000 feet m.s.l. out to 50 nmi from the radar site, at which point it includes all airspace from the surface up. Figure 2 shows the BCAS performance levels and boundaries for this method of desensitization.

A second method of desensitization used in these tests was based solely on altitude and was used to measure the effect that the lack of radar range information might have on BCAS alert rates. This method of desensitizing the system would be employed where ground reference information (radar, RBX, and SCU) was not available. Figure 3 presents the altitude stratification used in this method. The altitude stratification utilized in this simulation was based on traffic sample information for the Knoxville terminal area. Overflights utilized en route cruise altitudes between 6,000 feet m.s.l. and 10,000 feet m.s.l.; hence, this altitude strata constituted performance level 4 desensitized airspace. Performance level 5, the highest BCAS protection, was assigned to the area above 10,000 feet m.s.l. and level 3, terminal area protection, was assigned to the area below 6,000 feet m.s.l. To prevent BCAS interaction with aircraft on the runway and to provide performance level 2 desensitization, the floor of the BCAS resolution function was set at 500 feet above ground level (AGL). This resulted in a larger volume of airspace for performance level 3 than allowed in the altitude/range desensitization method.

## DATA COLLECTION PLAN.

A data collection plan was developed to provide the most direct approach in addressing the project objectives. Twenty-four simulation runs were made consisting of eight baseline (no BCAS) runs, eight runs using the altitude desensitization method, and eight runs using the altitude/range desensitization method. Within each group of eight, four runs were made with all aircraft operating in IFR conditions, and four runs were made with an even mix of IFR and VFR traffic.

To provide some degree of randomness in the traffic flow, two traffic samples were developed for each of two traffic conditions. For all traffic samples, current peak-hour operations for Knoxville were increased by 30 percent to simulate 1985 traffic projections for Knoxville. The traffic samples were varied by changing the aircraft start times and identifications. The partially crossed, nested design used is reflected by the run schedule shown in table 1.

## CONTROLLER QUESTIONNAIRES.

All controllers who participated in the simulation completed questionnaires at the conclusion of the tests. The questionnaires were used to measure

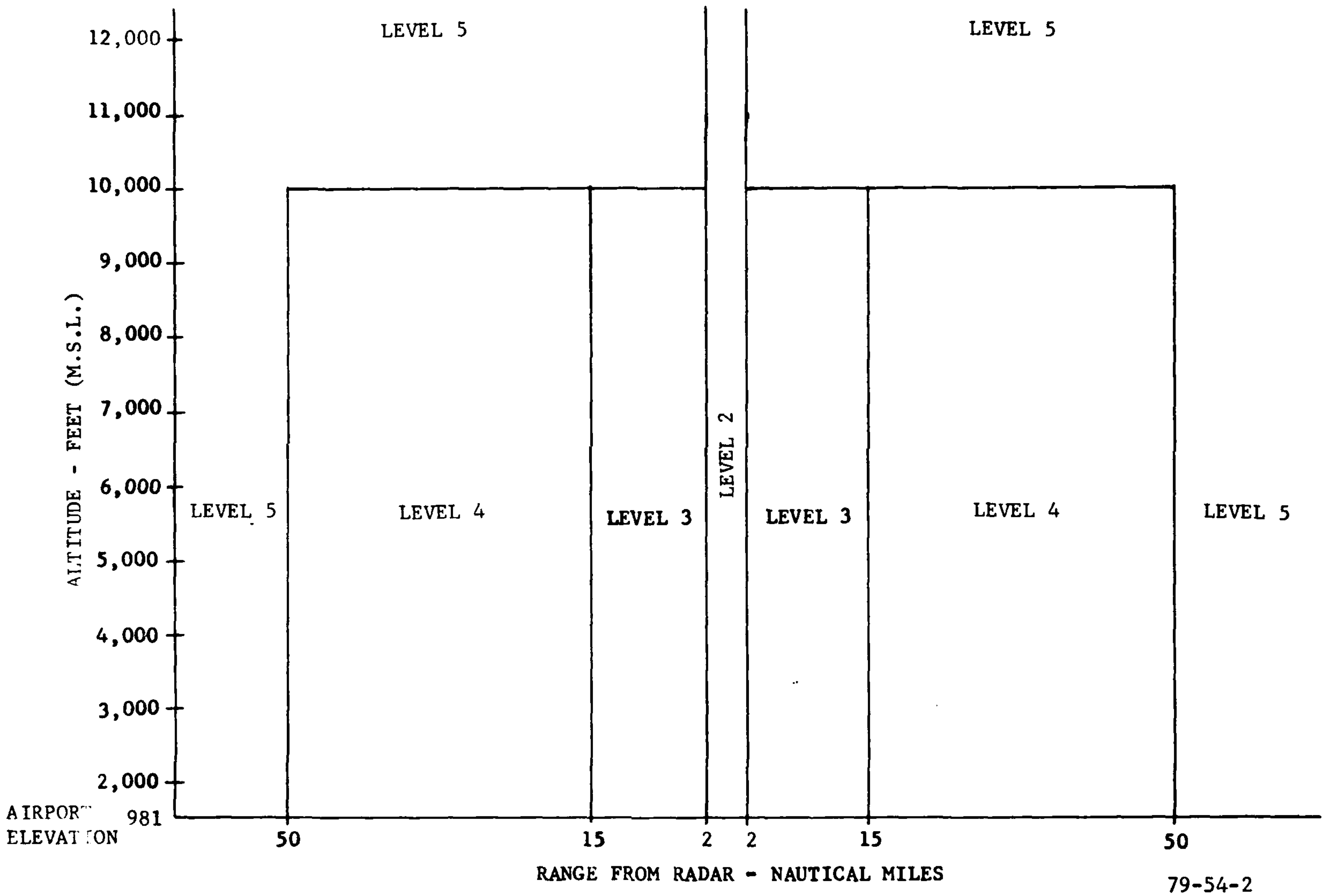



FIGURE 2. ALTITUDE/RANGE DESENSITIZATION ZONES FOR KNOXVILLE

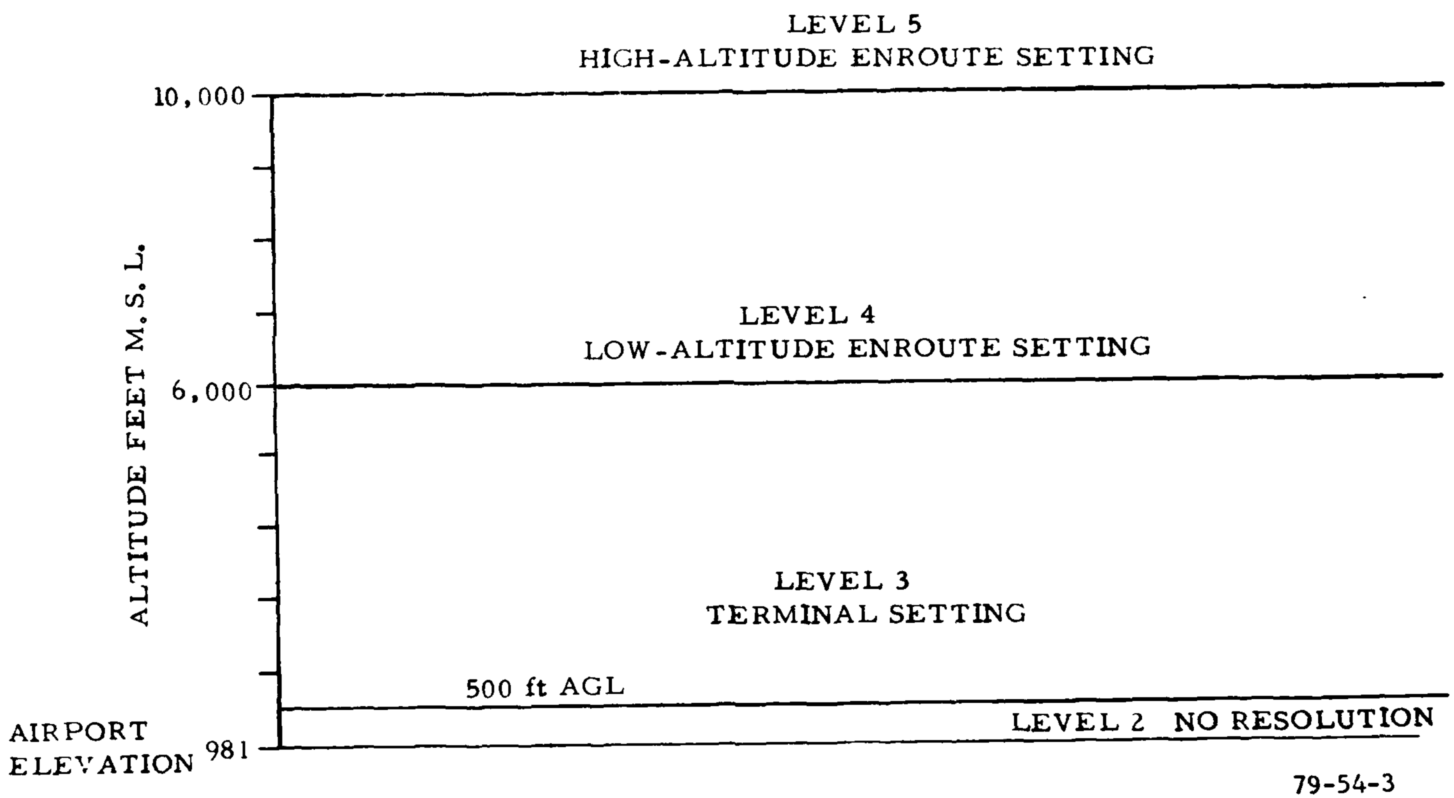



FIGURE 3. ALTITUDE DESENSITIZATION ZONES FOR KNOXVILLE

TABLE 1. SIMULATION RUN SCHEDULE

| Run Number | Team | Traffic Sample | Traffic Condition | Desensitization |
|---|---|---|---|---|
| 1 | 1 | 1 | I | No BCAS |
| 2 | 2 | 2 | I | No BCAS |
| 3 | 3 | 3 | I/V | No BCAS |
| 4 | 4 | 4 | I/V | No BCAS |
| 5 | 1 | 4 | I/V | No BCAS |
| 6 | 2 | 3 | I/V | No BCAS |
| 7 | 3 | 2 | I | No BCAS |
| 8 | 4 | 1 | I | No BCAS |
| 9 | 1 | 1 | I | Altitude/Range |
| 10 | 2 | 3 | I/V | Altitude/Range |
| 11 | 3 | 4 | I/V | Altitude |
| 12 | 4 | 2 | I | Altitude |
| 13 | 3 | 2 | I | Altitude/Range |
| 14 | 2 | 4 | I/V | Altitude/Range |
| 15 | 1 | 3 | I/V | Altitude |
| 16 | 4 | 1 | I | Altitude |
| 17 | 2 | 1 | I | Altitude/Range |
| 18 | 3 | 3 | I/V | Altitude/Range |
| 19 | 1 | 4 | I/V | Altitude |
| 20 | 4 | 2 | I | Altitude |
| 21 | 1 | 2 | I | Altitude/Range |
| 22 | 2 | 4 | I/V | Altitude/Range |
| 23 | 3 | 3 | I/V | Altitude |
| 24 | 4 | 1 | I | Altitude |

controller opinion on BCAS and were identical to those used in the previous Knoxville full BCAS simulation. The complete questionnaire is included as appendix C.

## RESULTS AND ANALYSIS

This section of the report discusses operations rates, effect of BCAS on the ATC system, conflict analysis, BCAS alert rates, alert durations, alert locations, effect of altitude desensitization, effect of VSL logic modifications, impact of no miss distance on active BCAS performance, traffic density analysis, and active BCAS algorithm deficiencies.

### OPERATIONS RATES.

The operations rates that resulted from the Knoxville active BCAS series and the no BCAS baseline series are shown in table 2. In addition, the operations rates for the previous Knoxville full BCAS series (reference 3) are listed.

The total operations rates reflect the sum of the arrivals, departures, and overflights for an average 1-hour data collection run. The average hourly rates for the full BCAS and active BCAS are based on eight 1-hour runs for each traffic condition. The average hourly rates for the no BCAS series are based on four 1-hour runs for each traffic condition. There is no statistically significant difference in the hourly operations rates for any of the test series.

### EFFECT OF ACTIVE BCAS ON CONTROLLERS AND CONTROL PROCEDURES.

Quantitative and subjective data were gathered to determine the overall impact of BCAS on controllers and control procedures. Table 3 is a listing of the more important quantitative measures collected during the active BCAS series and baseline series (no BCAS). A comparison of ATC performance with BCAS and without BCAS shows that BCAS had no adverse impact on the ATC system. The ATC system performance measures are defined in appendix D.

The subjective results collected from the controller questionnaires indicate that the controller subjects felt that active BCAS is an acceptable separation assurance system when used as a backup to the ATC system. The significant results of the questionnaire analysis are shown in table 4. The "no response" cases for the command agreement question reflects the number of controllers who did not observe any positive BCAS commands throughout the simulation runs.

### CONFLICT ANALYSIS.

Data reduction and analysis (DR&A) software provided a list of aircraft pairs which had violated the ATC separation criteria. [illegible] data allowed an assessment of the orderliness of traffic flow and conformance to ATC separation standards by controllers. For the 16 active BCAS runs, a

TABLE 2. AVERAGE HOURLY AIRCRAFT OPERATIONS RATES

| Test Series | Traffic Condition | Arrivals | Departures | Overflights | Total |
|---|---|---|---|---|---|
| No BCAS | IFR | 26.3 | 36.3 | 16.0 | 78.6 |
| | IFR/VFR | 29.0 | 36.0 | 16.0 | 81.0 |
| Active BCAS | IFR | 27.8 | 34.8 | 15.8 | 78.4 |
| | IFR/VFR | 26.0 | 36.0 | 16.0 | 78.0 |
| Full BCAS | IFR | 26.5 | 36.1 | 14.2 | 76.8 |
| | IFR/VFR | 27.9 | 36.3 | 20.4 | 84.6 |

TABLE 3. ATC SYSTEM PERFORMANCE MEASURES

| | No BCAS | Active BCAS | |
|---|---|---|---|
| TEST MEASURE | (Baseline Series) | (Alt/Rng Desensitization Series) | (Altitude Desensitization Series) |
| Average Total Time-In-System for Arrival Aircraft (minutes) | 22.8 | 23.3 | 22.3 |
| Average Instantaneous Aircraft Count per Control Position | | | |
| East Approach | 6.3 | 6.5 | 6.3 |
| West Approach | 5.3 | 5.3 | 5.2 |
| Final Approach | 2.7 | 3.1 | 2.7 |
| Average Number Control Efforts per Aircraft | 4.2 | 4.2 | 4.0 |
| Average Talk Time per Aircraft (seconds) | 29.0 | 29.4 | 30.0 |

TABLE 4. SUMMARY OF CONTROLLER QUESTIONNAIRES

| Question | Percentage (%) |
|---|---|
| Did you agree with commands? | |
| Never | 0 |
| Occasionally | 0 |
| Usually | 67 |
| Always | 11 |
| No Response | 22 |
| Should BCAS be put into operational use? | |
| Strongly Opposed | 0 |
| Opposed | 0 |
| Indifferent | 33 |
| Favored | 56 |
| Strongly Favored | 11 |

TABLE 5. MINIMUM SEPARATION BETWEEN AIRCRAFT

| Desensitization Method | Traffic Condition | Vertical Separation (feet) | Horizontal Separation (feet) | Minimum Slant Range (feet) |
|---|---|---|---|---|
| Altitude Desensitization | IFR | 418 | 335 | 536 |
| | IFR/VFR | 485 | 359 | 603 |
| Altitude/Range Desensitization | IFR | 511 | 436 | 672 |
| | IFR/VFR | 500 | 471 | 687 |

total of nine violations of ATC separation criteria occurred, resulting in an average of 0.6 violations per hour. The majority of the conflicts occurred within 10 nmi of the airport. Five conflicts were between arrival aircraft in the traffic pattern, and two conflicts were between departure and arrival aircraft approximately 3 nmi off the end of runway 4L. The remaining two conflict pairs were between overflight and arrival aircraft. These two conflicts occurred more than 30 nmi from the airport. The low number of conflicts indicates that proper control procedures were employed throughout the experiment.

ACTIVE BCAS PROTECTION.

A thorough analysis of the protection afforded by active BCAS was made. The analysis included the identification of the minimum slant range that occurred between all encounters. Table 5 presents the minimum slant ranges that occurred for each desensitization method and traffic condition. The minimum slant range is the three-dimensional closest point of approach between any two aircraft. The horizontal and vertical components of these closest points of approach are also included in table 5.

In all cases, the encounters which resulted in the minimum slant ranges had been detected, and a positive BCAS command had been generated. The tabulated minimum slant range values represent the separation that resulted following the positive BCAS commands. Although the minimum values observed are less than previously observed in the Knoxville full BCAS evaluation (due to reduced threshold parameters and escape maneuvering in the vertical plane only), the vertical separation for all four cases exceeded 400 feet.

Throughout the 16 hours of simulation 31 aircraft encounter periods occurred. An encounter period is the time during which at least one of the two aircraft in a BCAS conflict received a positive, negative, or VSL alert. The total number of alerts observed was significantly higher than the number of encounter periods. This resulted because BCAS often generated several alerts during any one encounter period between the same two aircraft.

The 31 BCAS encounter periods were reviewed in detail. Of interest in the analysis were the relative aircraft positions at alert onset. The relative position at alert onset is presented in figure 4. A review of this figure indicates that 80 percent of the alerts began when existing separation exceeded controlled VFR separation standards. A large proportion of the alerts occurred for controlled VFR aircraft which had 500 feet vertical separation.

The three points in figure 4 identified by an asterisk reflect encounters in which alert generation was initially delayed because of performance level 2 logic desensitization (alert generation is blocked).

More important than the relative positions at alert onset is the question of resulting separation following a BCAS alert. The closest points of approach (CPA) that followed BCAS alert action during the 31 encounter periods are presented in figure 5. The reduction in separation when compared to figure 4

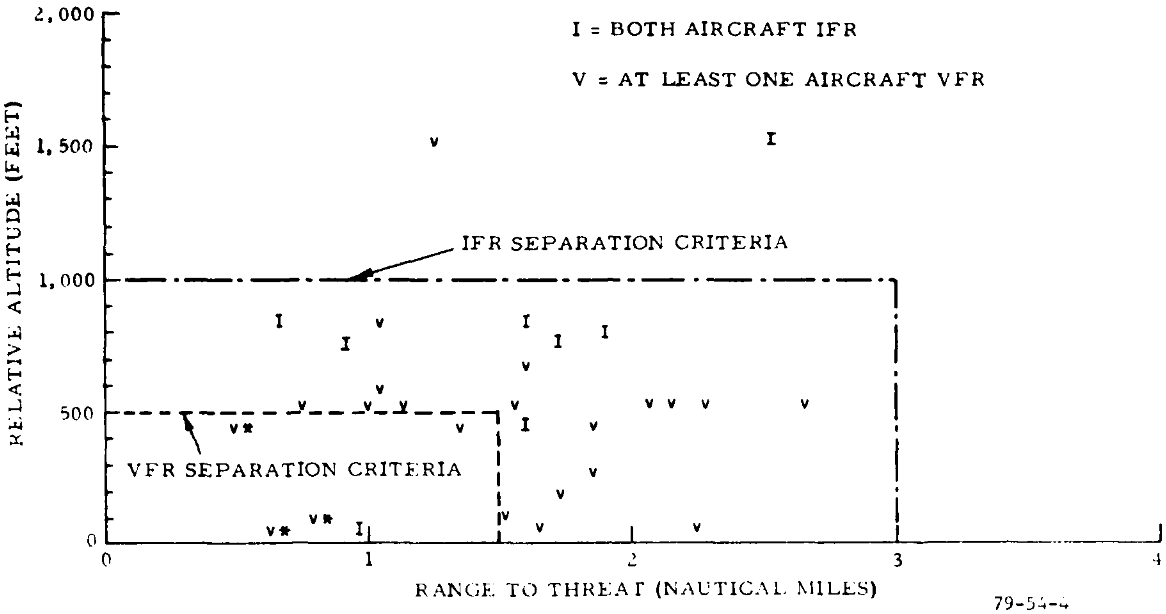



FIGURE 4. RELATIVE AIRCRAFT POSITION AT BCAS ALERT ONSET

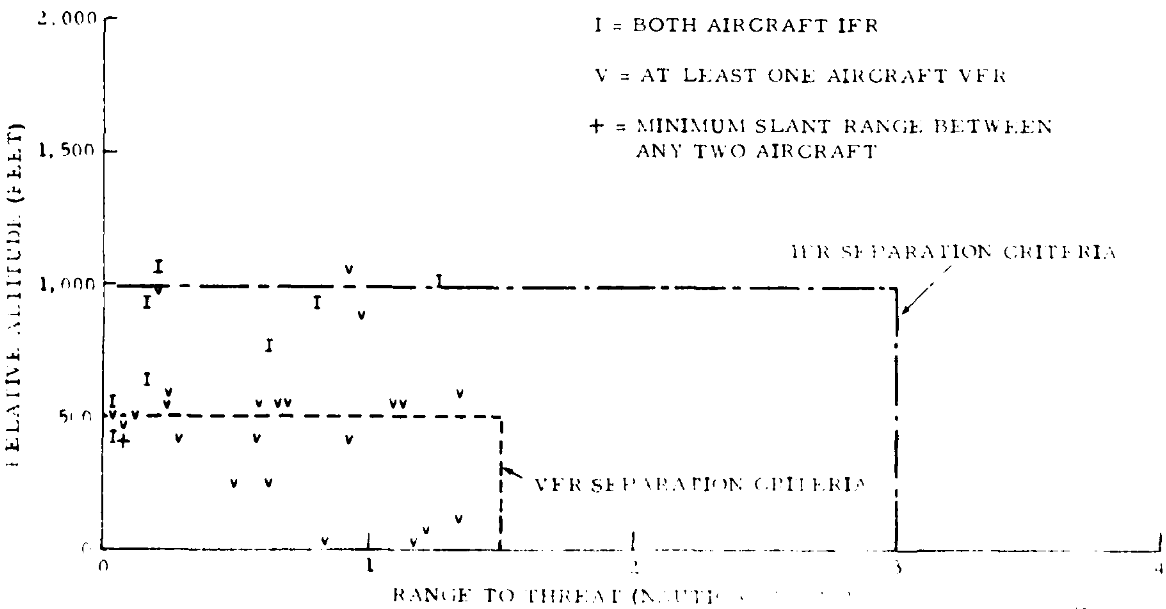



FIGURE 5. CLOSEST POINT OF APPROACH FOLLOWING ACTIVE BCAS ALERTS

represents the closure that occurred between aircraft during BCAS encounter periods. The high number of CPA's which still have a vertical separation of 500 feet represent the result of negative commands which were generated for a pair of level flight aircraft. Although the horizontal components of the CPA's are reduced as expected when compared to the horizontal components of the relative positions at alert onset, the greater dispersion of the vertical components at CPA indicates the effect of positive BCAS vertical commands. The plus (+) identifies the relative position at CPA for the aircraft pair that resulted in minimum slant range throughout the simulation. More than 400 feet vertical separation was attained with a BCAS command in this case. In all cases following BCAS command interaction, either the vertical separation exceeded 400 feet or the horizontal separation exceeded 0.5 nmi.

## ACTIVE BCAS ALERT RATES AND DURATIONS.

Each BCAS alert that occurred in the Knoxville simulation was classed as either an effective or noneffective alert. A noneffective alert is a BCAS alert that has no effect on the aircraft flight profile either horizontally or vertically. VSL's and negative alerts were considered noneffective alerts when the alert caused no effect on the aircraft flight profile. Although it is possible that a positive alert would cause no effect on flight profile (i.e., a climb command being issued to an aircraft that is climbing), this did not happen during the simulation. As a result, all positive commands were classed as effective alerts. Positive, negative, and VSL alerts that caused an effect on the aircraft's flight profile were classed as effective. About 60 percent of all alerts were noneffective and 40 percent were effective.

Table 6 presents the average hourly active BCAS noneffective alert rates, and table 7 presents the average hourly active BCAS effective alert rates. The rates are based on the average of 8 hours of data for each traffic condition.

Throughout the active BCAS simulation, the alert rate averaged less than 3.5 noneffective alerts per hour and less than 2.3 effective alerts per hour. On a per-aircraft basis, 1 aircraft in 23 received a noneffective alert and 1 in 36 received an effective alert. On a per-flight-hour-basis, one non-effective alert was issued every 7.7 aircraft flight hours and 1 effective alert was issued every 11.1 aircraft flight hours. At the request of the Air Transport Association, a detailed analysis of alert rates for air carrier aircraft was made. This analysis is presented in appendix E.

More total alerts occurred for the IFR/VFR runs than for the IFR runs. The hourly command rate for the IFR/VFR runs was twice the hourly command rate for IFR runs. These results are logical, since VFR allow aircraft to operate in a closer proximity and thereby increase the likelihood of a BCAS alert.

Figure 6 provides a comparison of alerts showing percentage of total alerts and percent of each alert type that was effective. The low proportion of VSL

TABLE 6. AVERAGE HOURLY ACTIVE BCAS NONEFFECTIVE ALERT RATES

| Alert Type | IFR | | IFR/VFR | |
|---|---|---|---|---|
| | Number (alerts/hr) | Average Duration (sec) | Number (alerts/hr) | Average Duration (sec) |
| VSL | 1.1 | 8.4 | 1.0 | 8.0 |
| Negative Command | 1.8 | 9.5 | 2.9 | 18.0 |
| TOTAL | 2.9 | 9.0 | 3.9 | 15.4 |

TABLE 7. AVERAGE HOURLY ACTIVE BCAS EFFECTIVE ALERT RATES

| Alert Type | IFR | | IFR/VFR | |
|---|---|---|---|---|
| | Number (alerts/hr) | Average Duration (sec) | Number (alerts/hr) | Average Duration (sec) |
| VSL | 0.1 | 5.0 | 0.6 | 7.8 |
| Negative Command | 0.4 | 12.7 | 0.0 | --- |
| Positive Command | 1.1 | 13.0 | 2.4 | 11.1 |
| TOTAL | 1.6 | 12.4 | 3.0 | 10.4 |

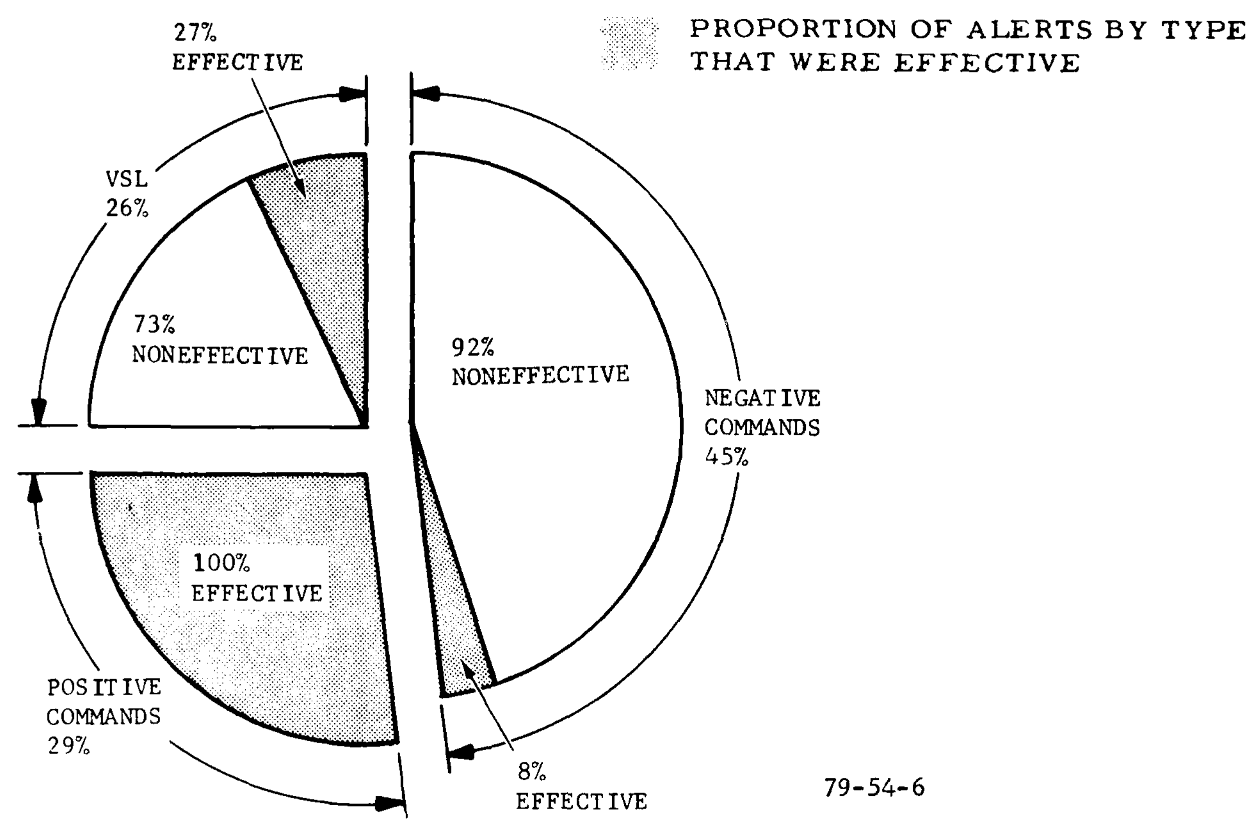



FIGURE 6. COMPARISON OF PERCENTAGE OF ALERT TYPES

alerts (26 percent) and high proportion of negative commands (45 percent) are attributed to the lack of horizontal miss distance filtering in active BCAS and the BCAS logic modifications that followed the Knoxville full BCAS simulation. As a result of the BCAS logic modifications, a conflicting aircraft in level flight will now receive a negative or positive alert instead of a VSL. This partially accounts for the high percentage of negative alerts and their low effectiveness percentage (8 percent). Additionally, a significantly higher proportion of the VSL's are effective when compared to the full BCAS Knoxville results (reference 3). The high proportion of positive commands (29 percent) is attributed to the lack of horizontal miss distance filtering. These factors will be covered in more detail later in this report.

COMPARISON OF ALTITUDE DESENSITIZATION VERSUS ALTITUDE/RANGE DESENSITIZATION.

BCAS has provisions for the use of different logic thresholds (performance levels) in different desensitization zones. The draft of the active BCAS National Standard defines desensitization zones based on aircraft altitude and aircraft range from a terminal radar, RBX, or SCI. An objective of this study was to analyze the effect of an alternate desensitization method which is based solely on aircraft altitude. A comparison was made of the number, duration, and location of alerts for the two methods of desensitizing a terminal area. In general, desensitization based on aircraft altitude proved effective.

Table 8 presents the average hourly active BCAS advisory rates (noneffective alerts) for the two desensitization methods. Table 9 presents the average hourly active BCAS command rates (effective alerts) for the two desensitization methods. These tables are based on four 1-hour runs for each traffic condition under each desensitization method. Table 8 shows somewhat fewer advisories generated in the IFR condition by altitude/range desensitization than with the altitude desensitization; however, the duration for the altitude/range desensitization advisories is almost twice as long. The slightly higher advisory rate generated in the altitude desensitization method is due to an additional 0.7 VSL alerts per hour, nearly twice the VSL advisory rate for altitude/range desensitization. In the IFR/VFR mix condition, the situation is reversed, with the advisory rate being generated by the altitude/range desensitization occurring three times more often than the rate generated with the altitude desensitization method. The pronounced increase in the advisory rate for altitude/range desensitization is due to an increase in negative advisories. VSL advisories were the same for both methods. The higher negative advisory rate for altitude/range desensitization is due to the larger area covered by more sensitive threshold parameters (higher performance levels). Figure 7 compares the level of protection provided by the two desensitization methods.

Table 9 shows little difference in the command rates between the two desensitization methods in the IFR condition (1.3 commands per hour versus 1.5 commands per hour). The average duration is almost the same (13.0 seconds versus 12.4 seconds).

TABLE 8. DESENSITIZATION EFFECT ON NONEFFECTIVE ALERT RATES

| | Alt/Rng Desensitization | | | | Altitude Desensitization | | | |
|---|---|---|---|---|---|---|---|---|
| | IFR | | IFR/VFR | | IFR | | IFR/VFR | |
| Advisory Type | Number (alerts/hr) | Avg Dur (sec) | Number (alerts/hr) | Avg Dur (sec) | Number (alerts/hr) | Avg Dur (sec) | Number (alerts/hr) | Avg Dur (sec) |
| VSL | 0.8 | 10.7 | 1.0 | 10.0 | 1.5 | 7.3 | 1.0 | 6.0 |
| Negative Command | 1.8 | 12.4 | 5.0 | 19.5 | 1.8 | 6.5 | 0.8 | 7.7 |
| TOTAL | 2.6 | 11.9 | 6.0 | 17.9 | 3.3 | 6.8 | 1.8 | 6.8 |

TABLE 9. DESENSITIZATION EFFECT ON EFFECTIVE ALERT RATES

| | Alt/Rng Desensitization | | | | Altitude Desensitization | | | |
|---|---|---|---|---|---|---|---|---|
| | IFR | | IFR/VFR | | IFR | | IFR/VFR | |
| Advisory Type | Number (alerts/hr) | Avg Dur (sec) | Number (alerts/hr) | Avg Dur (sec) | Number (alerts/hr) | Avg Dur (sec) | Number (alerts/hr) | Avg Dur (sec) |
| VSL | 0.0 | --- | 0.8 | 8.7 | 0.3 | 5.0 | 0.5 | 6.5 |
| Negative Command | 0.3 | 6.0 | 0.0 | --- | 0.5 | 16.0 | 0.0 | --- |
| Positive Command | 1.0 | 14.8 | 1.5 | 18.2 | 1.0 | 11.2 | 3.3 | 7.8 |
| TOTAL | 1.3 | 12.8 | 2.3 | 14.9 | 1.8 | 11.5 | 3.8 | 7.6 |

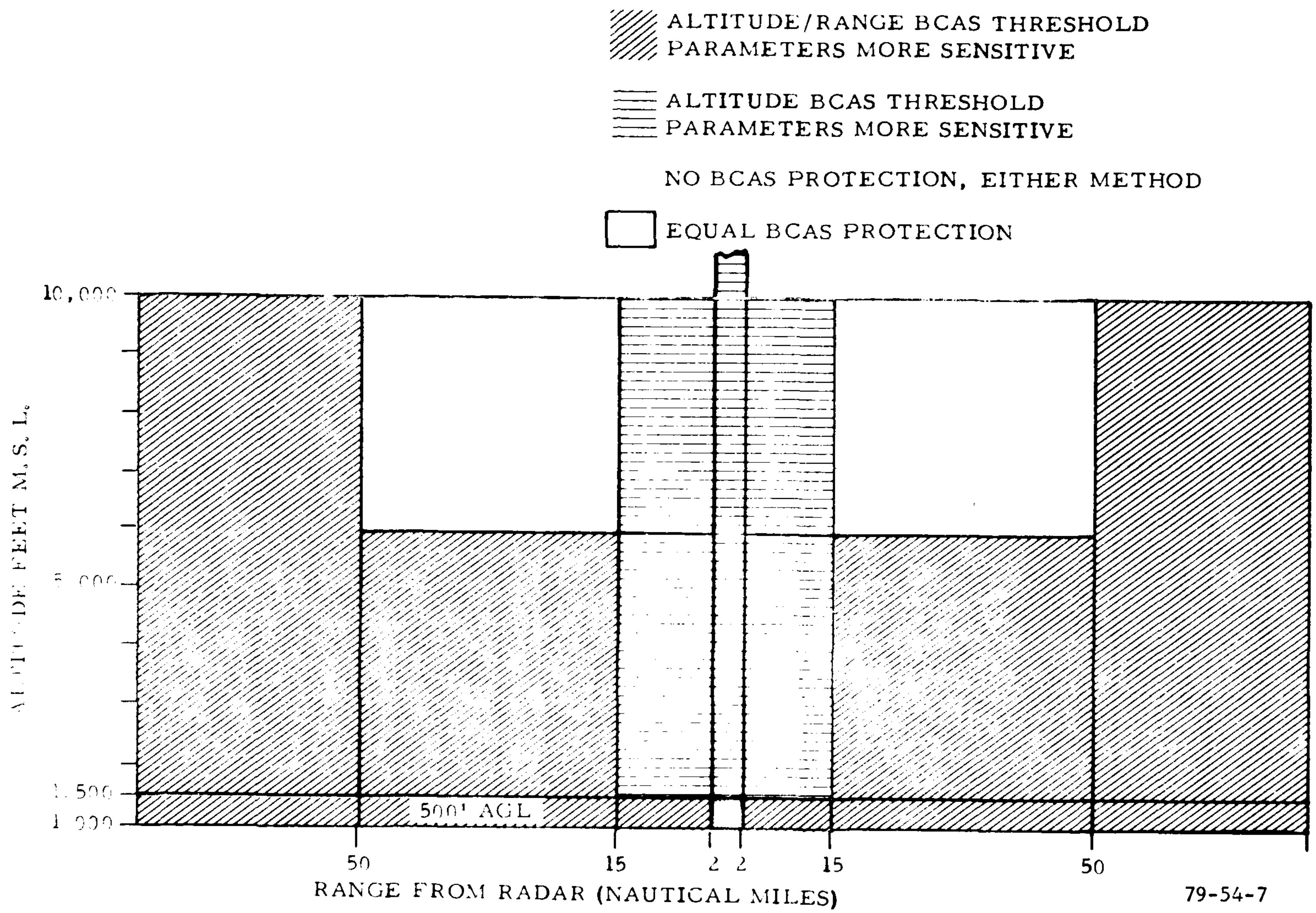



FIGURE 7. DESENSITIZATION ZONE SENSITIVITY COMPARISON

In the IFR/VFR mix series, the command rate in the altitude/range desensitization series was significantly less than the command rate in the altitude desensitization series (2.3 commands per hour versus 3.8 commands per hour); however, the average duration for the altitude/range desensitization was twice that of the altitude desensitization (14.9 seconds versus 7.6 seconds). This difference in command rates in the IFR/VFR mix is due to the higher concentration of positive commands occurring within 5 nmi of the airport in the altitude desensitization series. This is due to the more sensitive BCAS threshold parameters incurred by overflights with altitude desensitization within 15 nmi of the airport and the performance level 2 zone around the airport with altitude/range desensitization (see figure 7).

A Calcomp program was used to identify and plot the alert locations. The results for the two methods of desensitization are presented in figures 8 and 9. For each encounter pair, the most severe alert type for each aircraft was plotted. Within the alert sequence, the increasing order of severity was VSL alerts, negative alerts, and positive alerts. The established airways, navigational fixes, and control area boundaries are shown as background information. The symbols represent the aircraft location where the alert first occurred. A red symbol indicates the alert was generated for an overflight aircraft. All alerts for nonoverflight aircraft occurred within 10 nmi of the radar site. The majority of these alerts appear to be located within 2 nmi of the ILS centerline, with the remaining alerts occurring on the downwind leg of the traffic pattern.

The location of alerts for overflight traffic varied with the desensitization method as depicted in figures 8 and 9. The majority of alerts occurring within the overflight band of 6,000 feet to 10,000 feet m.s.l. in the altitude desensitization series were within 15 nmi of the airport. The alerts for overflights in the altitude/range desensitization series were located outside the 15 nmi range. Figure 7 shows an area sensitivity comparison of the two desensitization methods. The difference in the location of performance levels accounts for the different alert patterns. Within the overflight altitude band, altitude desensitization is more sensitive than altitude/range desensitization within 15 nmi of the airport (performance level 4 versus performance level 3) and provides a larger protection volume around each BCAS-equipped aircraft. Altitude/range desensitization provides a larger protection volume around each BCAS-equipped aircraft beyond 50 nmi of the airport (performance level 5 versus performance level 4).

An investigation was conducted to determine how the alerts were broken down for specific aircraft operations; i.e., arrival/departure traffic and overflight traffic. Table 10 presents the summary of this investigation for each method of desensitization. Examination of table 10 shows that the total BCAS alerts were about equal for specific operations using either desensitization method; however, the alert durations were twice as long for the altitude/range desensitization method. Few alerts were generated for overflight traffic for either desensitization method.

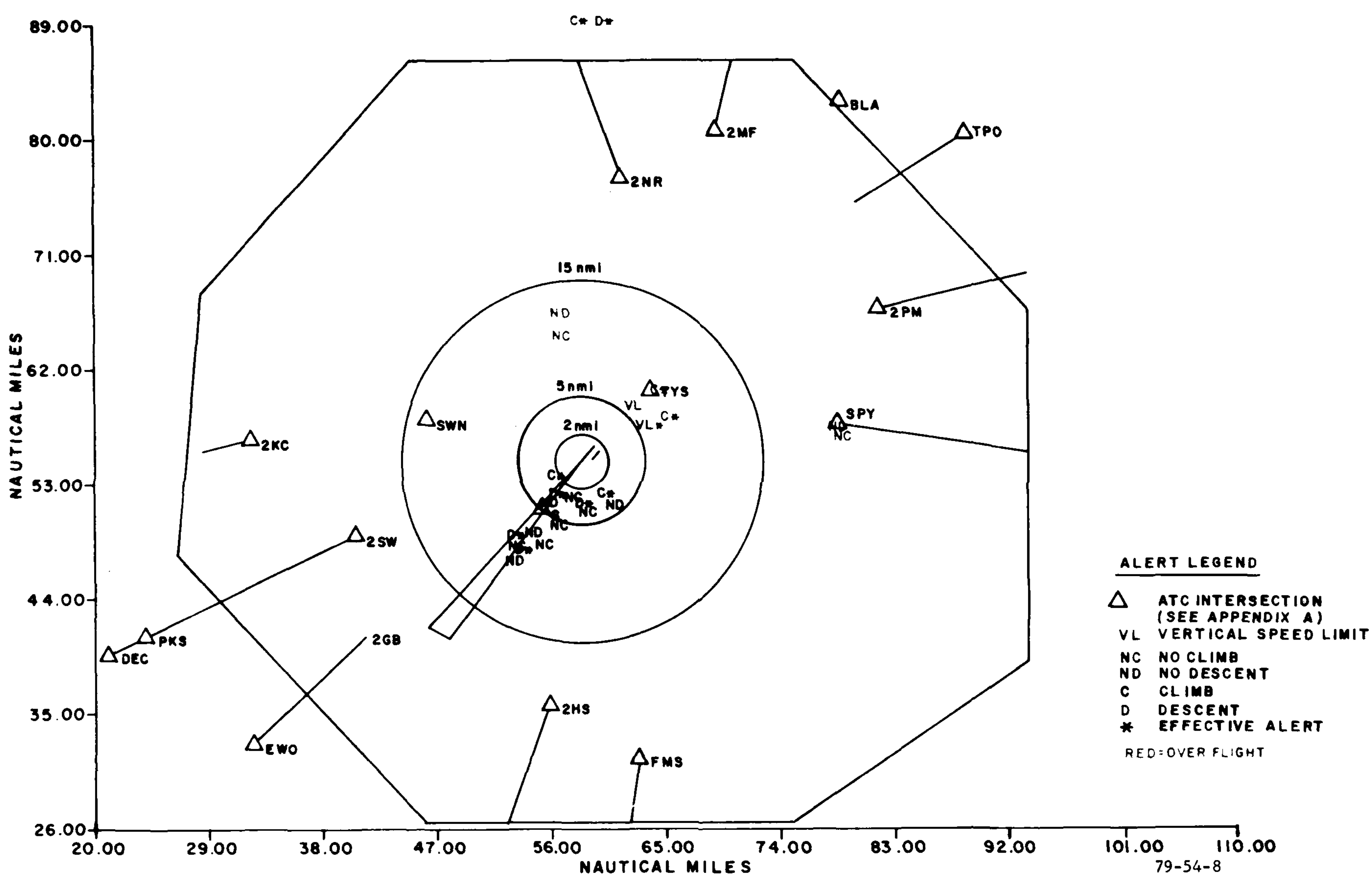



FIGURE 8. ALERT LOCATIONS WITH ALTITUDE/RANGE DESENSITIZATION

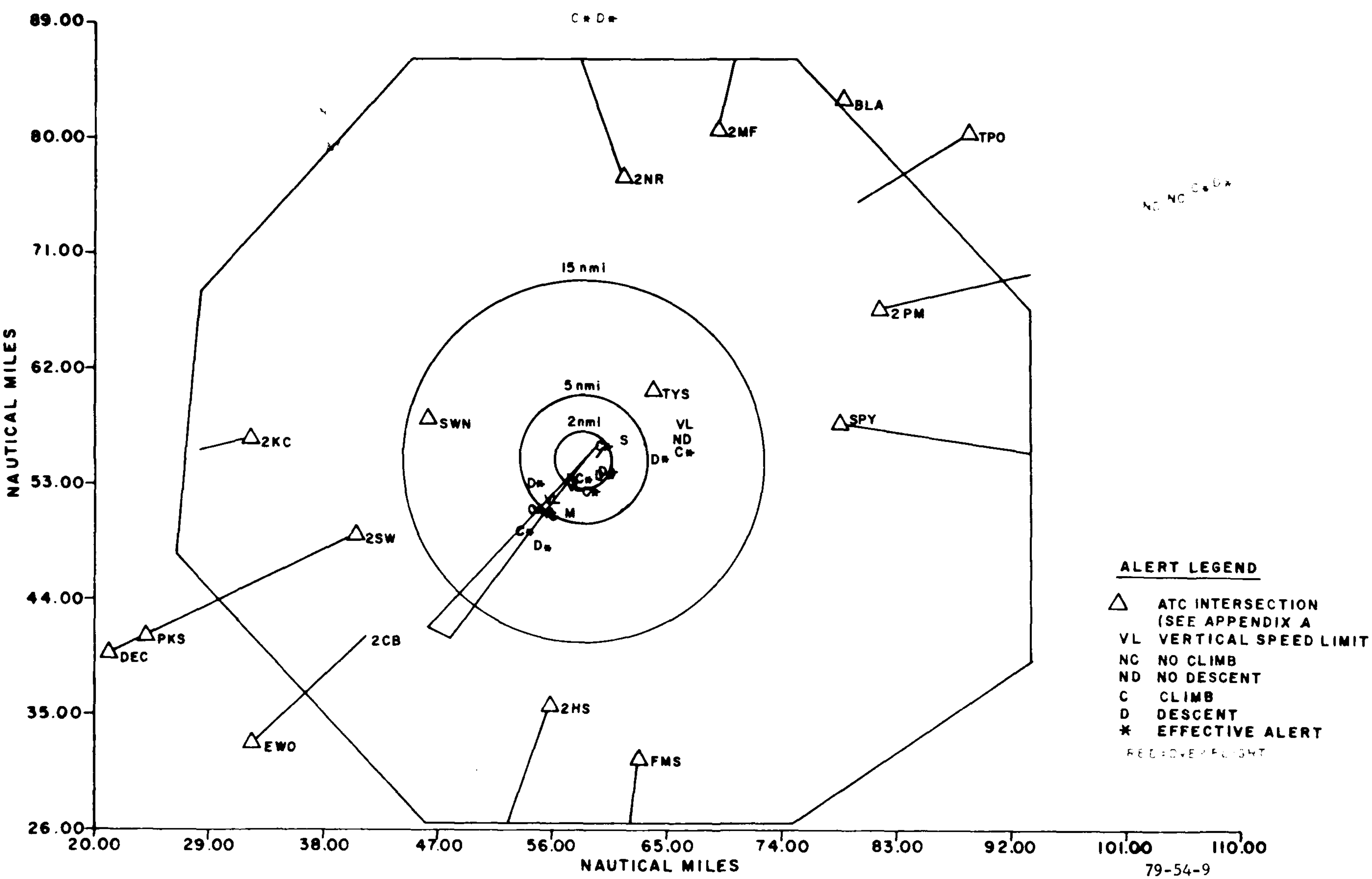



FIGURE 9. ALERT LOCATIONS WITH ALTITUDE DESENSITIZATION

TABLE 10. AVERAGE HOURLY ALERT RATES FOR SPECIFIC OPERATIONS

| Alerts | Active BCAS (Alt/Rng) Desensitization | | | | Active BCAS (Altitude) Desensitization | | | |
|---|---|---|---|---|---|---|---|---|
| | Arr/Dep | | Overflights | | Arr/Dep | | Overflights | |
| | Number (alerts/ hr) | Avg Dur (sec) | Number (alerts/ hr) | Avg Dur (sec) | Number (alerts/ hr) | Avg Dur (sec) | Number (alerts/ hr) | Avg Dur (sec) |
| VSL | 1.1 | 10.1 | 0.1 | 7.0 | 1.6 | 6.6 | 0.0 | --- |
| Negative Commands | 3.1 | 17.5 | 0.5 | 19.7 | 1.3 | 10.8 | 0.3 | 9.5 |
| Positive Commands | 0.9 | 14.2 | 0.4 | 27.5 | 1.9 | 8.5 | 0.4 | 10.0 |
| TOTAL | 5.1 | 15.3 | 1.0 | 21.6 | 4.8 | 8.5 | 0.7 | 9.8 |

## EFFECT OF VSL LOGIC MODIFICATIONS.

The VSL logic in previous simulations resulted in an undesirably high VSL alert rate and a high noneffective VSL alert rate for overflight traffic. The VSL logic modifications, as described in appendix F, eliminated both of these problems. The average number and duration of active BCAS VSL alerts were significantly reduced as shown in table 11.

The Knoxville full BCAS VSL logic resulted in one out of eight aircraft receiving a VSL alert. The active BCAS VSL logic resulted in 1 out of 70 aircraft receiving a VSL alert, with only 1 out of 100 overflights receiving an alert. VSL alerts for overflight aircraft were nearly eliminated in the active BCAS simulation (0.1 VSL/hr, with an average duration of 7 seconds). The overflight alerts which were eliminated were noneffective VSL alerts between aircraft navigating on established airways or direct routes utilizing proper separation techniques.

The overall percentage of noneffective VSL alerts was reduced slightly. The full BCAS VSL logic resulted in 88 percent of the VSL alerts being noneffective. The active BCAS modified VSL logic resulted in 73 percent of the VSL alerts being noneffective. Noneffective VSL alert generation is addressed later in the report under "Algorithm Deficiencies."

TABLE 11. VSL DISTRIBUTION STATISTICS

| BCAS Series | Number (alerts/hr) | Mean Duration (sec) | Percent Effective |
|---|---|---|---|
| Active (Alt./Desensitization) | 1.6 | 6.5 | 24.0 |
| Active (Alt./Range Desensitization) | 1.2 | 9.8 | 31.0 |
| Full (Alt./Range Desensitization) | 10.4 | 36.1 | 12.0 |

## EFFECT OF NO MISS DISTANCE INFORMATION ON ACTIVE BCAS PERFORMANCE.

Table 12 presents the analytical results of applying horizontal miss distance filtering to the active BCAS simulation results. The ATCSF tapes recorded the coordinates of each aircraft and all BCAS variable and parameter values during each second of a simulation encounter. These data allowed the calculation of horizontal miss distance even though it was not available to the active BCAS algorithm. By analyzing each encounter on a second-by-second basis and utilizing the computed projected horizontal miss distance, a new alert command sequence could be generated based on full BCAS logic. The assumption was made that the surveillance data were without error. The horizontal miss distance logic used is shown in appendix F. If projected horizontal miss distance filtering had been used, 53 percent of the positive commands would have been replaced by negative alerts and 14 percent would have been eliminated.

The maximum benefit of horizontal miss distance filtering would be in the final approach area, where aircraft are turning onto parallel final approaches. In previous BCAS experiments analysis identified a problem with unnecessary VSL alerts occurring in the parallel approach area. The alerts occurred because there were no horizontal miss distance filter, even with bearing information for VSL alerts. Logic changes have eliminated the VSL alerts for aircraft in level flight; however, unnecessary BCAS alerts during the turn to final for parallel approaches will continue to be a problem in active BCAS.

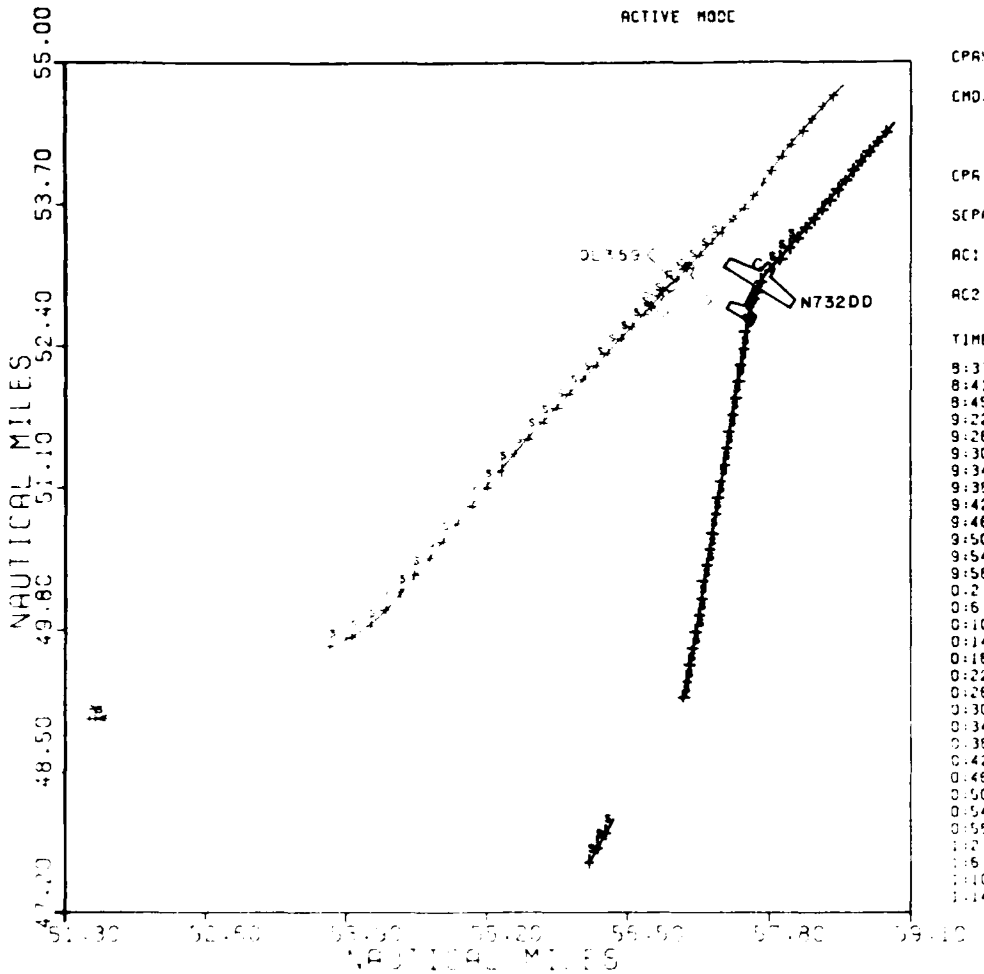
Figures 10 and 11 depict a parallel approach in which N732DD received a "climb" command and DL359 received a "descend" command. Aircraft N732DD executed a missed approach as a result of the positive BCAS command. If accurate bearing information had been available to determine a projected horizontal miss distance, no positive commands would have been generated. Since

TABLE 12. EFFECT OF HORIZONTAL MISS DISTANCE FILTERING

| | No Horizontal Miss Distance Filtering | | Horizontal Miss Distance Filtering Applied | |
|---|---|---|---|---|
| Alert Type | Number (alerts/hr) | Average Duration (sec) | Number (alerts/hr) | Average Duration (sec) |
| VSL | 1.4 | 8.0 | 1.4 | 8.0 |
| Negative Commands | 2.6 | 15.6 | 3.2 | 13.5 |
| Positive Commands | 1.8 | 12.2 | 0.6 | 18.3 |
| TOTAL | 5.8 | 12.7 | | 12.6 |

START TIME = 10 28 37        END TIME = 10 32 2

ACTIVE MODE




ENCOUNTER NUMBER 1
SENSITIVITY 3

CPAH = 3706        CPAV = 20

CMD= C   AT TIME 1:2     MD= 2442

ALT= 20        XANG= 11

CPA AT TIME 1:38     SCPA= 3803

SCPAH= 3722        SCPAV= 778

AC1 ID = N732DD      BCAS EQUIPPED

AC2 ID = DL359      BCAS EQUIPPED

| TIME | AC1 | AC2 | ALT | POS | RANGE | TAUR | TAUV | MD | RZ |
|---|---|---|---|---|---|---|---|---|---|
| 8:37 | | | | | 4.78 | 107 | * | 4.63 | -700 |
| 8:41 | | | | | 4.76 | 113 | * | 4.76 | -700 |
| 8:45 | | | | | 4.76 | 126 | * | 4.76 | -700 |
| 9:22 | | | | | 3.26 | 75 | * | 3.10 | -500 |
| 9:26 | | | | | 3.13 | 70 | * | 1.60 | -500 |
| 9:30 | | | | | 2.96 | 80 | * | 0.65 | -500 |
| 9:34 | | | | | 2.81 | 98 | * | 0.42 | -500 |
| 9:38 | | | | | 2.71 | 94 | * | 0.67 | -500 |
| 9:42 | | | | | 2.62 | 90 | * | 0.53 | -500 |
| 9:46 | | | | | 2.51 | 87 | * | 0.49 | -500 |
| 9:50 | | | | | 2.41 | 83 | * | 0.50 | -500 |
| 9:54 | | | | | 2.30 | 79 | * | 0.51 | -500 |
| 9:58 | | | | | 2.20 | 75 | * | 0.51 | -500 |
| 0:2 | | | | | 2.09 | 71 | * | 0.50 | -500 |
| 0:6 | | | | | 1.99 | 69 | * | 0.49 | -500 |
| 0:10 | | | | | 1.89 | 67 | * | 0.42 | -500 |
| 0:14 | S | S | HI | 9 | 1.79 | 58 | * | 0.27 | -500 |
| 0:18 | S | S | HI | 9 | 1.68 | 56 | * | 0.16 | -500 |
| 0:22 | S | S | HI | 9 | 1.59 | 53 | * | 0.10 | -500 |
| 0:26 | S | S | HI | 9 | 1.48 | 50 | * | 0.05 | -500 |
| 0:30 | S | S | HI | 9 | 1.33 | 47 | * | 0.01 | -500 |
| 0:34 | S | S | HI | 9 | 1.29 | 45 | * | 0.07 | -500 |
| 0:38 | S | S | CO | 9 | 1.20 | 42 | -20 | 0.13 | -398 |
| 0:42 | S | S | CO | 9 | 1.11 | 39 | -12 | 0.19 | -289 |
| 0:46 | S | S | CO | 9 | 1.02 | 36 | -13 | 0.24 | -242 |
| 0:50 | S | S | CO | 9 | 0.94 | 33 | 15 | 0.29 | -181 |
| 0:54 | S | S | CO | 9 | 0.86 | 31 | -4 | 0.34 | -96 |
| 0:58 | F | F | CO | 9 | 0.78 | 31 | -2 | 0.35 | -44 |
| 1:2 | C | C | CO | 8 | 0.73 | 96 | -2 | 0.40 | 20 |
| 1:6 | | | | | 0.72 | 207 | -3 | 0.43 | 48 |
| 1:10 | | | | | 0.71 | 141 | -5 | 0.43 | 190 |
| 1:14 | | | | | 0.70 | 105 | -12 | 0.35 | 340 |

INT DL359    SUBJECT N732DD    TAPES BCAS KNOX    AD23

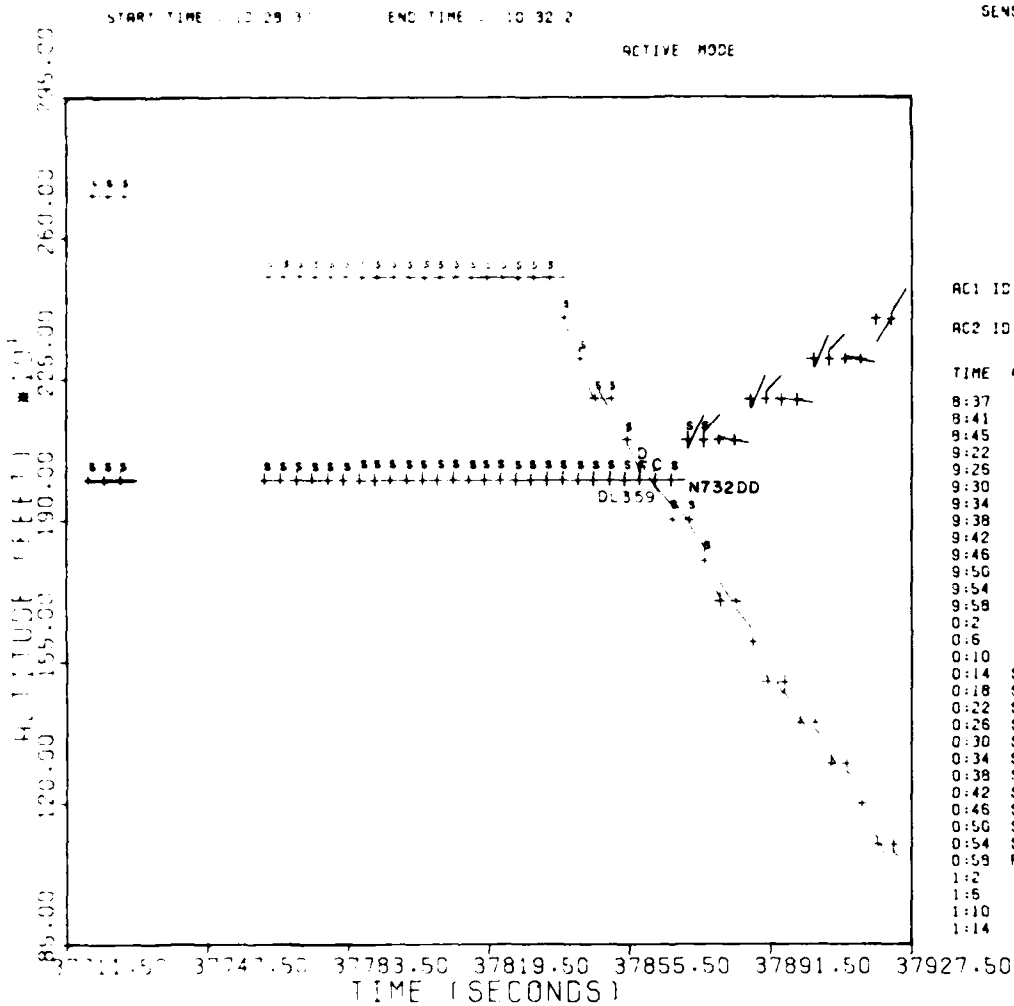
BCAS VERSION 2    REPLAY VERSION 2.2    9 MAR 79

1

79-54-10

FIGURE [illegible]. ENCOUNTER ON PARALLEL APPROACH (HORIZONTAL VIEW)
(SEE APPENDIX H FOR LEGEND)

ENCOUNTER NUMBER 1
SENSITIVITY 3




AC1 ID = N732DD    BCAS EQUIPPED

AC2 ID = DL359    BCAS EQUIPPED

| TIME | AC1 | AC2 | RZ | ADOT | VMD | DOT |
|---|---|---|---|---|---|---|
| 8:37 | | | -700 | -0 | * | * |
| 8:41 | | | -700 | -0 | * | * |
| 8:45 | | | -700 | -0 | * | * |
| 9:22 | | | -500 | -0 | * | * |
| 9:26 | | | -500 | -0 | * | * |
| 9:30 | | | -500 | -0 | * | * |
| 9:34 | | | -500 | -0 | * | * |
| 9:38 | | | -500 | -0 | * | * |
| 9:42 | | | -500 | -0 | * | * |
| 9:46 | | | -500 | -0 | * | * |
| 9:50 | | | -500 | -0 | * | * |
| 9:54 | | | -500 | -0 | * | * |
| 9:58 | | | -500 | -0 | * | * |
| 0:2 | | | -500 | -0 | * | * |
| 0:6 | | | -500 | -0 | * | * |
| 0:10 | | | -500 | -0 | * | * |
| 0:14 | S | S | -500 | -0 | * | * |
| 0:18 | S | S | -500 | -0 | * | * |
| 0:22 | S | S | -500 | -0 | * | * |
| 0:26 | S | S | -500 | -0 | * | * |
| 0:30 | S | S | -500 | -0 | * | * |
| 0:34 | S | S | -500 | -0 | * | * |
| 0:38 | S | S | -388 | -1178 | * | * |
| 0:42 | S | S | -289 | -1464 | * | * |
| 0:46 | S | S | -242 | -1080 | * | * |
| 0:50 | S | S | -181 | -724 | * | * |
| 0:54 | S | S | -96 | -1281 | * | * |
| 0:59 | F | F | -44 | -1122 | -330 | * |
| 1:2 | C | D | 20 | 751 | * | * |
| 1:5 | | | 48 | 826 | * | * |
| 1:10 | | | 190 | 2097 | * | * |
| 1:14 | | | 340 | 1739 | * | * |

INT DL359    SUBJECT N732DD    TAPES BCAS KNOX    AD23

BCAS VERSION-2    COCPLOT VERSION-2.2    8 MAR 79

79-54-11

2

FIGURE 11. ENCOUNTER ON PARALLEL APPROACH (VERTICAL VIEW)
(SEE APPENDIX H FOR LEGEND)

the projected horizontal miss distance would have remained greater than 0.3 nmi (the positive command threshold in performance level 3) and remained less than 1 nmi (the negative command threshold in performance level 3), a negative command would have been generated. Negative commands may have prevented the unnecessary missed approach.

## TRAFFIC DENSITY ANALYSIS.

The Knoxville traffic model used in this experiment was subjected to analysis to identify where and how often the traffic model exceeded the active BCAS density specification of an average of 0.02 aircraft/$nmi^2$. The BCAS density specification is found in reference 6. All aircraft were BCAS-equipped in this investigation.

A program was developed to count aircraft within 10 nmi of specific points which comprise a uniform grid across the Knoxville terminal area. The program identified and plotted the regions in the Knoxville area where the simultaneous aircraft density exceeded the BCAS specification. Appendix G shows several of these plots. Using data provided by this program, the probability of exceeding the BCAS density limit specification at a given range from the radar was determined.

Figure 12 presents the probability of exceeding the BCAS density limit as a function of range from the radar site. By only counting aircraft within 5 nmi of the points in the uniform grid, the effect of limiting transponder interrogation power can be identified. A second curve on figure 12 depicts the effect of limiting transponder interrogation power.

Additional analysis was conducted to identify the effect on density caused by altitude filtering of certain tracks. If the difference between aircraft altitudes exceeded 2,500 feet, the aircraft were not included in the counts for the associated points in the grid. Figure 12 also presents the results of this analysis.

Appendix G describes the regions in detail where the aircraft density in the traffic model exceeded the BCAS density limit. Appendix G and figure 12, when compared to figures 8 and 9, clearly indicate that a majority of alerts occurred in regions where the probability of exceeding the BCAS specification limit was high.

## ALGORITHIM IMPROVEMENTS.

A review of all BCAS encounters has led to the identification of several potential areas for active BCAS algorithm improvements. Specific encounter plots are presented to illustrate these areas which are related to improvements with noneffective VSL alerts, command oscillations, and vertical sense change.

NONEFFECTIVE VSL ALERTS. A capability to [illegible] the [illegible] effective VSL alerts exists. Two aircraft on parallel tracks maneuvering in the same vertical direction but with no vertical closure can both receive

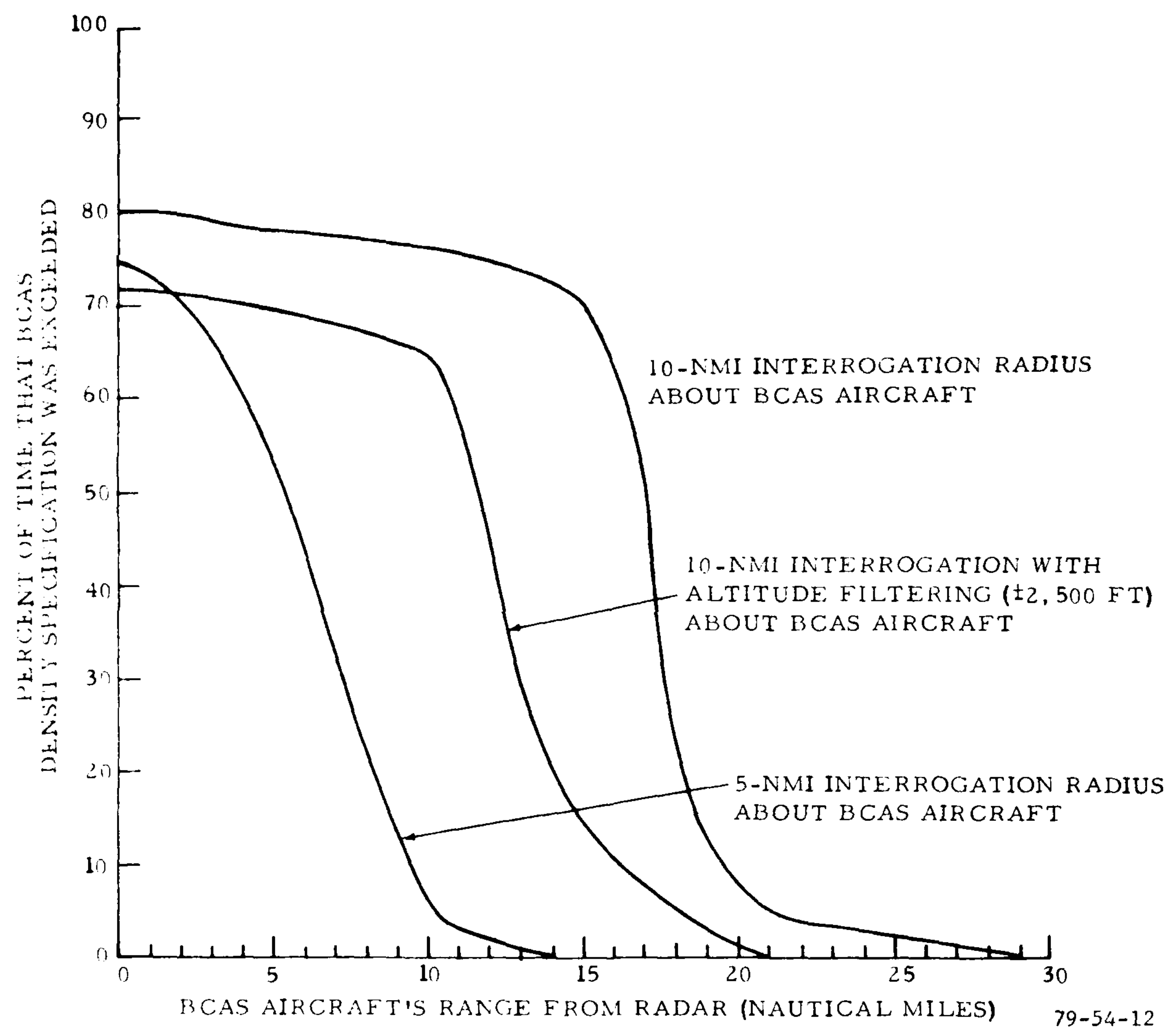



FIGURE 12. PROBABILITY OF EXCEEDING 0.02 AIRCRAFT/$NMI^2$ AT A GIVEN RANGE FROM RADAR

noneffective VSL alerts. This occurs most frequently on parallel departures and approaches. Figures 13 and 14 provide an example of this flaw. N7573Q and PI961 were on parallel headings climbing to altitude. PI961 was climbing at a faster vertical rate than N7573Q, and the pair was separating in altitude. PI961 received a "do not descend" alert and N7573Q received a series of "do not climb" and "limit climb to 1,000 feet per minute or less" alerts. The "limit climb to 1,000 feet/minute or less" alerts were directed to an aircraft which was climbing at 500 feet per minute.

In this case, the VSL alert was undesirable. Proximity information on the intruder aircraft would have been more useful to both pilots. These noneffective alerts could have been eliminated if the active BCAS logic checked for closure and also compared the provisional limit alert with the aircraft vertical rate to ensure that an effective command is issued. If these two checks were made for the VSL alerts that occurred in the active BCAS simulation, the noneffective VSL alert rate would have been significantly reduced. Thirteen of the seventeen noneffective VSL alerts that occurred in the active BCAS simulation would have been eliminated.

COMMAND OSCILLATION. Figures 13 and 14 depict the oscillation of commands that can occur due to BCAS tracker performance. Vertical tracker errors occur because of the 100-foot quantization of mode C altitude data. This process results in erroneous projections of vertical miss distance. The projections cycle in magnitude at low vertical rates causing commands to oscillate. The greatest error in projected position occurs prior to and after a change in reported mode C altitude. (NOTE: This problem has been reduced in later versions of the logic.)

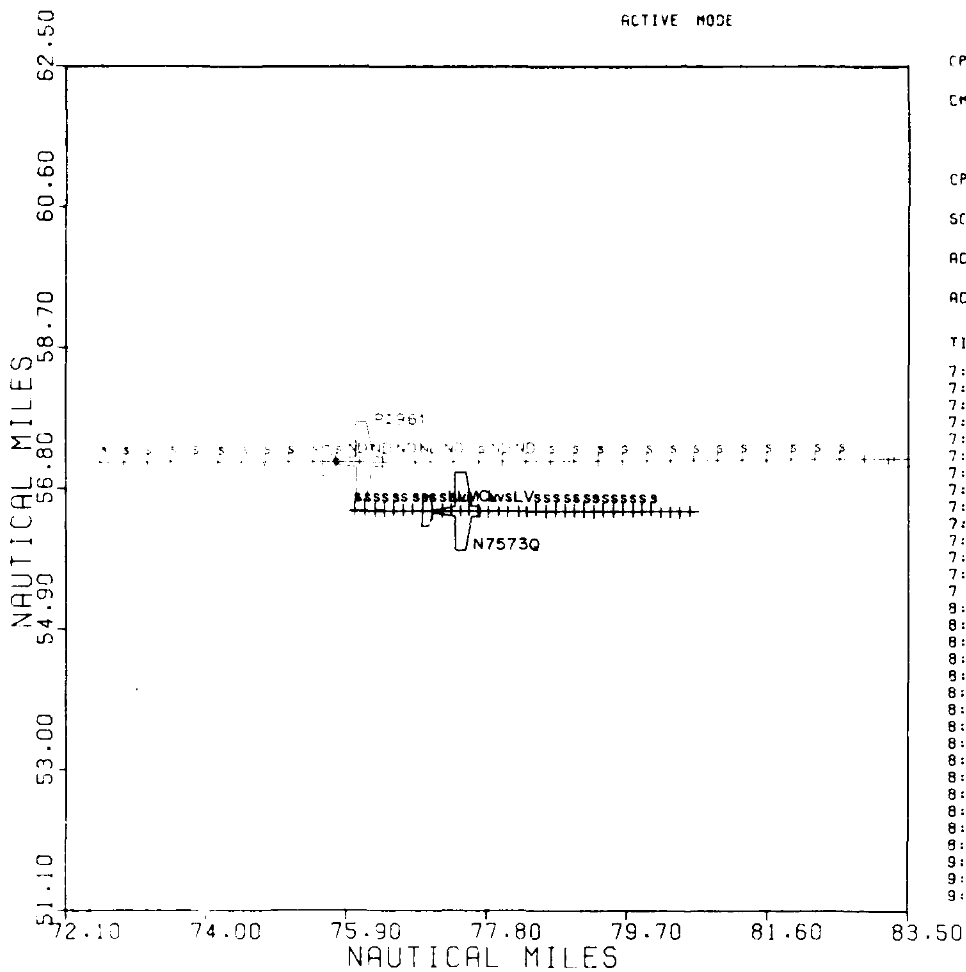
VERTICAL SENSE CHANGE. Figures 15 and 16 depict an example of the tracker noise problem that may occur on rare occasions and cause a change in the sense of direction of BCAS commands. A confusing sequence of alerts can be generated when the relative projected altitude of two aircraft changes. This situation occurred during one encounter in the simulation. SEM826 is projected to be below DL484; therefore, SEM826 receives a "descend" command, and DL484 receives a "limit descent" alert. The next cycle creates a problem. SEM826 is projected to be above DL484, and the resolution logic causes a "climb" command for SEM826 and a "descend" command for DL484. Both pilots would see a reversal of the original BCAS command. (NOTE: Present active BCAS resolution logic now precludes reversals in command sense.)

PARTIAL PROXIMITY DATA ANALYSIS.

Previously, the VSL threat volume was significantly larger than the positive and negative threat volumes. This allowed VSL alerts to serve as precursors to positive and/or negative commands. The new active logic has reduced the VSL threat volume and VSL alerts no longer precede positive or negative commands. With very minor algorithm changes, a precursor could still be provided in the form of Partial Proximity Data (PPD) alerts. Partial Proximity Data consists of intruder range and altitude. Availability of this information to the pilot may inhibit an abrupt turn or vertical [illegible] that could lead to late positive or negative commands. The use of PPD [illegible] would result in less restrictive flight and possibly less ATC interaction. PPD alerts provide

START TIME = 10 57 4        END TIME = 10 59 24

ACTIVE MODE




ENCOUNTER NUMBER 5
SENSITIVITY 2

CPAH = 3690        CPAV = 80

CMD: ND    AT TIME 7:48    MD= 3668

ALT= -485        XANG= 0

CPA AT TIME 8:16    SCPA= 3763

SCPAH= 3590        SCPAV= -738

AC1 ID = N7573Q        BCAS EQUIPPED

AC2 ID = P1961        BCAS EQUIPPED

| TIME | AC1 | AC2 | ALT | POS | RANGE | TAUR | TAUV | MD | RZ |
|---|---|---|---|---|---|---|---|---|---|
| 7:4 | | | | | 3.58 | 66 | -6 | 0.60 | -129 |
| 7:8 | | | | | 3.43 | 62 | -8 | 0.60 | -80 |
| 7:12 | S | S | CO | 6 | 3.21 | 59 | 8 | 0.60 | -191 |
| 7:16 | S | S | CO | 6 | 3.02 | 54 | 12 | 0.60 | -260 |
| 7:20 | S | S | CO | 6 | 2.83 | 50 | -29 | 0.60 | -210 |
| 7:24 | S | S | CO | 6 | 2.65 | 46 | 15 | 0.60 | -290 |
| 7:28 | S | S | CO | 6 | 2.46 | 42 | 17 | 0.60 | -356 |
| 7:32 | S | S | CO | 7 | 2.28 | 39 | -34 | 0.60 | -325 |
| 7:35 | S | S | CO | 7 | 2.09 | 35 | 25 | 0.60 | -387 |
| 7:40 | S | S | CO | 7 | 1.91 | 31 | 22 | 0.60 | -454 |
| 7:44 | S | S | CO | 7 | 1.73 | 27 | -54 | 0.60 | -449 |
| 7:48 | L+10 | ND | CO | 7 | 1.55 | 24 | 43 | 0.60 | -485 |
| 7:52 | L+10 | ND | HI | 7 | 1.38 | 20 | 27 | 0.60 | -551 |
| 7 56 | NC | ND | HI | 7 | 1.21 | 17 | 44 | 0.60 | -622 |
| 8:0 | L+10 | ND | HI | 7 | 1.04 | 14 | 374 | 0.60 | -594 |
| 8:4 | L+10 | NC | HI | 7 | 0.89 | 11 | 39 | 0.60 | -642 |
| 8:8 | S | S | HI | 8 | 0.76 | 9 | 48 | 0.60 | -720 |
| 8:12 | NC | ND | HI | 8 | 0.66 | 8 | -956 | 0.60 | -709 |
| 8:16 | L+10 | NC | HI | 9 | 0.61 | 19 | 57 | 0.60 | -738 |
| 8:20 | | | | | 0.62 | 70 | 55 | 0.60 | -817 |
| 8:24 | S | S | HI | 10 | 0.68 | 109 | * | 0.60 | -833 |
| 8:28 | S | S | HI | 10 | 0.79 | 179 | 98 | 0.60 | -837 |
| 8:32 | S | S | HI | 11 | 0.94 | 266 | 64 | 0.60 | -914 |
| 8:36 | S | S | HI | 11 | 1.10 | 363 | 44 | 0.60 | -1006 |
| 8:40 | S | S | HI | 11 | 1.26 | 464 | -871 | 0.60 | -946 |
| 8:44 | S | S | HI | 11 | 1.44 | 571 | 96 | 0.60 | -1005 |
| 8:48 | S | S | HI | 11 | 1.62 | 681 | 47 | 0.60 | -1104 |
| 8:52 | S | S | HI | 11 | 1.80 | 792 | -311 | 0.60 | -1061 |
| 8:56 | S | S | HI | 11 | 1.99 | 905 | 160 | 0.60 | -1102 |
| 9:0 | | | | | 2.18 | * | 51 | 0.60 | -1202 |
| 9:4 | | | | | 2.37 | * | -546 | 0.60 | -1185 |
| 9:8 | | | | | 2.56 | * | 495 | 0.60 | -1200 |

INT P1961    SUBJECT N7573Q    TAPES BCAS KNOX    A020

BCAS VERSION-2    CSCPLOT VERSION-2.2    8 MAR 79

79-54-13

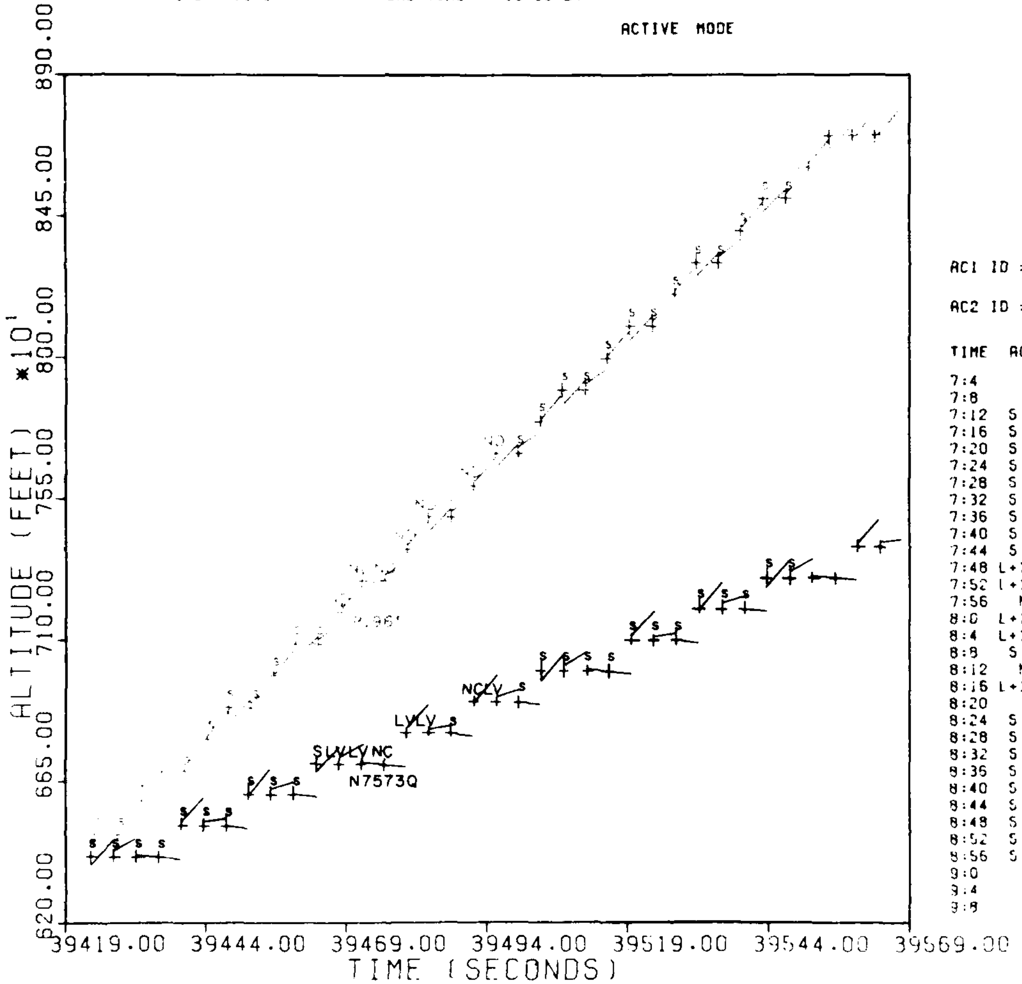
9

FIGURE 15. NONEFFECTIVE CYCLIC VSL ALERT (HORIZONTAL VIEW)
(SEE APPENDIX II FOR LEGEND)

ENCOUNTER NUMBER 5
SENSITIVITY 2

START TIME = 10 57 4 END TIME = 10 59 24

ACTIVE MODE




AC1 ID = N7573Q BCAS EQUIPPED

AC2 ID = P1961 BCAS EQUIPPED

| TIME | AC1 | AC2 | RZ | ADOT | VMD | DOT |
|---|---|---|---|---|---|---|
| 7:4 | | | -129 | -1248 | * | * |
| 7:8 | | | -80 | -606 | * | * |
| 7:12 | S | S | -191 | 1457 | * | * |
| 7:16 | S | S | -260 | 1311 | * | * |
| 7:20 | S | S | -210 | -431 | * | * |
| 7:24 | S | S | -290 | 1142 | * | * |
| 7:28 | S | S | -356 | 1258 | * | * |
| 7:32 | S | S | -325 | -570 | * | * |
| 7:36 | S | S | -387 | 941 | * | * |
| 7:40 | S | S | -454 | 1257 | * | * |
| 7:44 | S | S | -449 | -497 | * | * |
| 7:48 | L+10 | ND | -485 | 673 | 617 | * |
| 7:52 | L+10 | ND | -551 | 1222 | * | * |
| 7:56 | NC | ND | -622 | 840 | * | * |
| 8:0 | L+10 | ND | -594 | 95 | * | * |
| 8:4 | L+10 | ND | -542 | 995 | 838 | * |
| 8:8 | S | S | -720 | 893 | 895 | * |
| 8:12 | NC | ND | -709 | -45 | * | * |
| 8:16 | L+10 | ND | -738 | 780 | * | * |
| 8:20 | | | -817 | 891 | * | * |
| 8:24 | S | S | -833 | 30 | * | * |
| 8:28 | S | S | -837 | 512 | * | * |
| 8:32 | S | S | -914 | 856 | * | * |
| 8:36 | S | S | -1006 | 1357 | * | * |
| 8:40 | S | S | -945 | -65 | * | * |
| 8:44 | S | S | -1005 | 628 | * | * |
| 8:48 | S | S | -1104 | 1420 | * | * |
| 8:52 | S | S | -1061 | -205 | * | * |
| 8:56 | S | S | -1102 | 414 | * | * |
| 9:0 | | | -1202 | 1418 | * | * |
| 9:4 | | | -1185 | -130 | * | * |
| 9:8 | | | 1200 | 145 | * | * |

INT P1961 SUBJECT N7573Q TAPES BCAS KNOX A020

BCAS VERSION-2 CSCPLOT VERSION-2.2 8 MAR 79

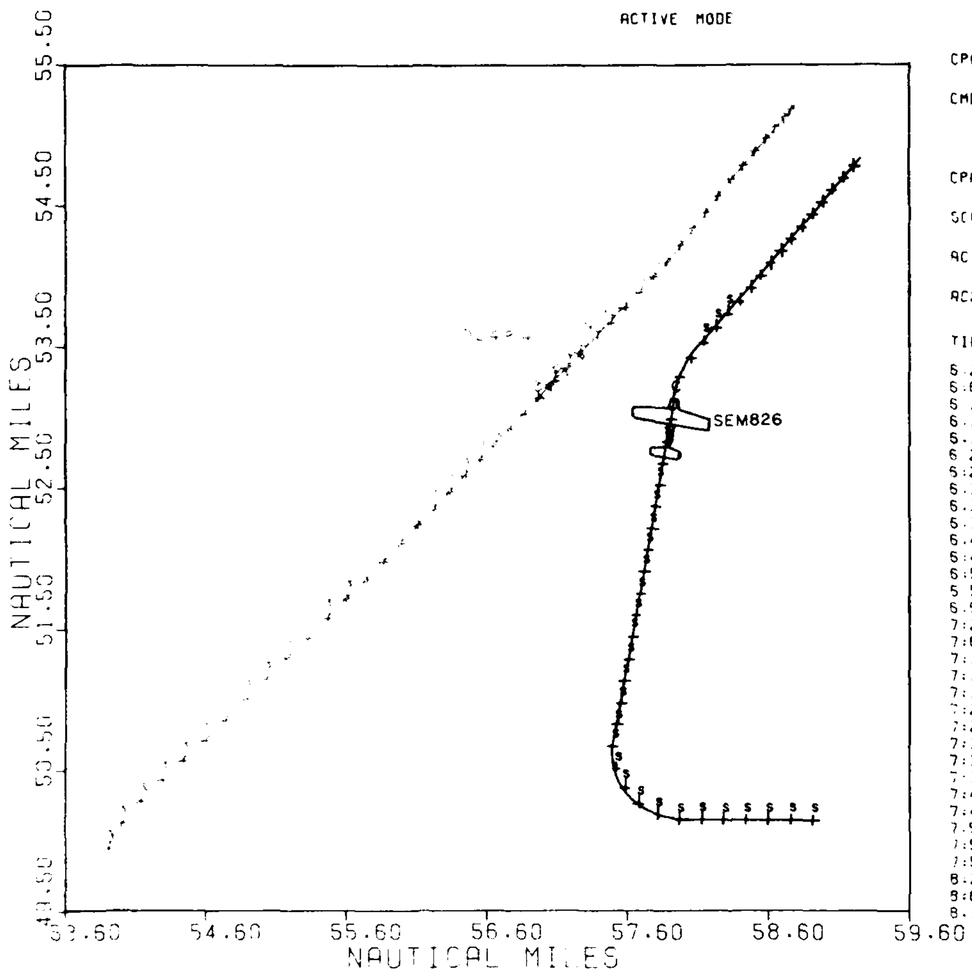
79-54-14

10

FIGURE 14. NONEFFECTIVE CYCLIC VSL ALERT (VERTICAL VIEW)
(SEE APPENDIX H FOR LEGEND)

START TIME = 10 16 2        END TIME = 10 18 58

ACTIVE MODE




INT DL484    SUBJECT SEM826    TAPES BCAS KNOX    AD15

BCAS VERSION-2    CSCPLOT VERSION-2.2    5 MAR 73

ENCOUNTER NUMBER 2
SENSITIVITY 3

CPAH = 3247        CPAV = 3

CMD= D    AT TIME 7:46    MD= 591

ALT= -133    XANG= 33

CPA AT TIME 8:14    SCPA= 3253

SCPAH= 3247    SCPAV= 193

AC1 ID = SEM826    BCAS EQUIPPED

AC2 ID = DL484    BCAS EQUIPPED

| TIME | AC1 | AC2 | ALT | POS | RANGE | TAUR | TAUV | MD | RZ |
|---|---|---|---|---|---|---|---|---|---|
| 6:2 | | | | | 4.94 | 76 | 62 | 0.27 | -817 |
| 6:6 | | | | | 4.73 | 65 | -33 | 2.38 | -735 |
| 6:10 | S | S | HI | 12 | 4.40 | 55 | -52 | 2.39 | -717 |
| 6:14 | S | S | HI | 12 | 4.08 | 51 | -22 | 1.97 | -614 |
| 6:18 | S | S | HI | 12 | 3.79 | 49 | -76 | 1.90 | -600 |
| 6:22 | S | S | HI | 12 | 3.50 | 46 | -22 | 1.95 | -521 |
| 6:25 | S | S | CO | 12 | 3.23 | 44 | -53 | 1.96 | -479 |
| 6:30 | S | S | CO | 12 | 2.96 | 42 | 226 | 1.77 | -495 |
| 6:34 | S | S | HI | 12 | 2.71 | 41 | 365 | 1.43 | -502 |
| 6:38 | S | S | HI | 11 | 2.48 | 43 | * | 1.12 | -501 |
| 6:42 | S | S | CO | 11 | 2.29 | 48 | * | 0.85 | -500 |
| 6:46 | S | S | CO | 10 | 2.14 | 62 | * | 0.63 | -500 |
| 6:50 | | | | | 2.04 | 69 | * | 0.50 | -500 |
| 6:54 | | | | | 1.95 | 67 | * | 0.46 | -500 |
| 6:58 | | | | | 1.85 | 65 | * | 0.41 | -500 |
| 7:2 | S | S | CO | 10 | 1.75 | 62 | * | 0.34 | -500 |
| 7:6 | S | S | CO | 10 | 1.65 | 60 | * | 0.27 | -500 |
| 7:10 | S | S | CO | 10 | 1.56 | 57 | -18 | 0.20 | -403 |
| 7:14 | S | S | CO | 10 | 1.47 | 54 | -11 | 0.13 | -309 |
| 7:18 | S | S | CO | 10 | 1.38 | 51 | -37 | 0.06 | -278 |
| 7:22 | S | S | CO | 10 | 1.29 | 47 | -11 | 0.01 | -185 |
| 7:26 | S | S | CO | 10 | 1.20 | 44 | * | 0.08 | -212 |
| 7:30 | S | S | CO | 10 | 1.12 | 40 | -83 | 0.10 | -199 |
| 7:34 | S | S | CO | 10 | 1.03 | 36 | -800 | 0.10 | -198 |
| 7:38 | S | S | CO | 10 | 0.94 | 32 | 697 | 0.10 | -200 |
| 7:42 | S | S | CO | 9 | 0.86 | 28 | 74 | 0.10 | -162 |
| 7:46 | D | L -5 | CO | 9 | 0.77 | 24 | -10 | 0.10 | -133 |
| 7:50 | C | D | CO | 9 | 0.68 | 20 | 22 | 0.10 | -125 |
| 7:54 | | NC | | | 0.60 | 43 | 9 | 0.10 | -173 |
| 7:58 | | NC | | | 0.56 | 273 | 5 | 0.10 | -92 |
| 8:2 | | | | | 0.56 | 132 | -62 | 0.03 | -90 |
| 8:6 | | | | | 0.56 | 107 | -0 | 0.44 | -3 |
| 8:10 | | | | | 0.54 | 166 | -4 | 0.41 | 114 |

79-54-15

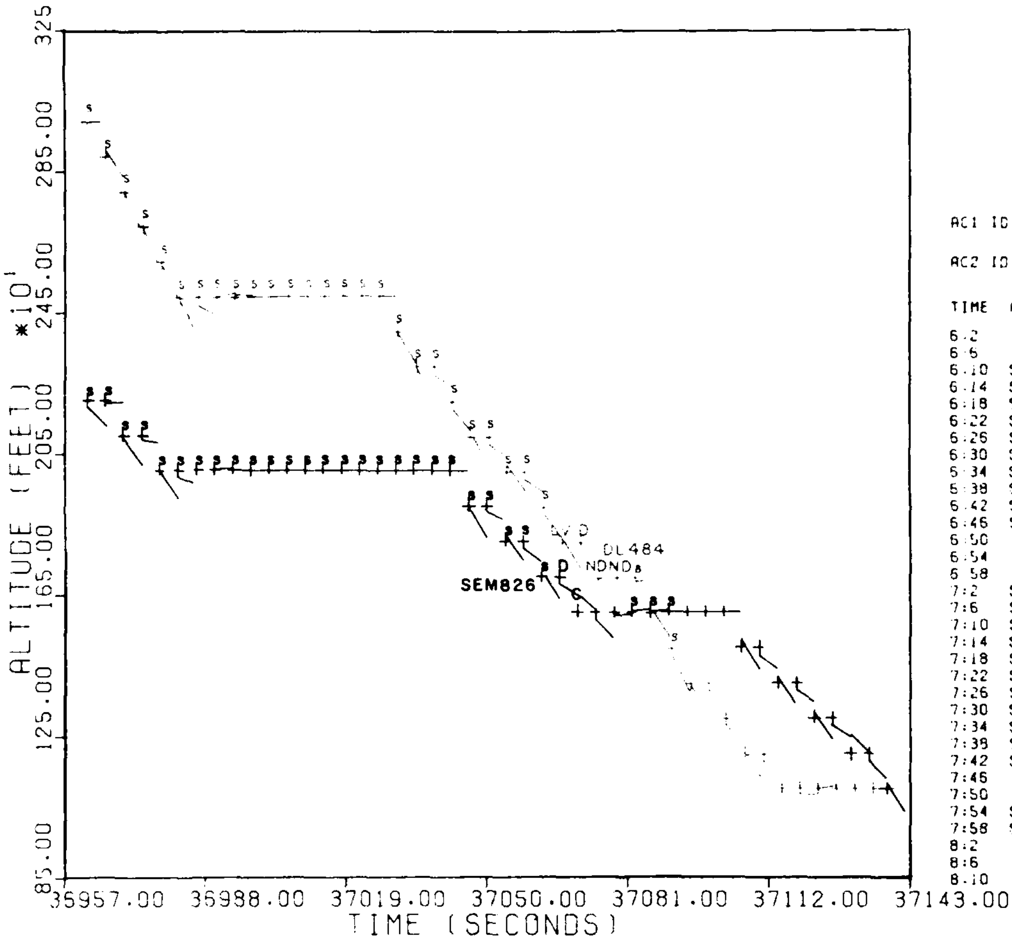
3

FIGURE 15. ENCOUNTER WITH COMMAND REVERSALS (HORIZONTAL VIEW)
(SEE APPENDIX H FOR LEGEND)

ENCOUNTER NUMBER 2
SENSITIVITY 3

START TIME - 10 16 2 END TIME : 10 18 58

ACTIVE MODE




AC1 ID : SEM825 BCAS EQUIPPED

AC2 ID : DL494 BCAS EQUIPPED

| TIME | AC1 | AC2 | RZ | ADOT | VMD | DOT |
|---|---|---|---|---|---|---|
| 6:2 | | | -817 | 789 | * | * |
| 6:6 | | | -735 | -1344 | * | * |
| 6:10 | S | S | -717 | -826 | * | * |
| 6:14 | S | S | -614 | -1679 | * | * |
| 6:18 | S | S | -600 | -474 | * | * |
| 6:22 | S | S | -521 | -1408 | * | * |
| 6:26 | S | S | -479 | -541 | * | * |
| 6:30 | S | S | -495 | 131 | * | * |
| 6:34 | S | S | -502 | 83 | * | * |
| 6:38 | S | S | -501 | -9 | * | * |
| 6:42 | S | S | -500 | -12 | * | * |
| 6:46 | S | S | -500 | 0 | * | * |
| 6:50 | | | -500 | 2 | * | * |
| 6:54 | | | -500 | 0 | * | * |
| 6:58 | | | -500 | -0 | * | * |
| 7:2 | S | S | -500 | -0 | * | * |
| 7:6 | S | S | -500 | 0 | * | * |
| 7:10 | S | S | -403 | -1352 | * | * |
| 7:14 | S | S | -309 | -1627 | * | * |
| 7:18 | S | S | -278 | -448 | * | * |
| 7:22 | S | S | -185 | -1009 | * | * |
| 7:26 | S | S | -212 | 10 | * | * |
| 7:30 | S | S | -199 | -144 | * | * |
| 7:34 | S | S | -198 | -15 | * | * |
| 7:38 | S | S | -200 | 17 | * | * |
| 7:42 | S | S | -162 | 131 | * | * |
| 7:46 | D L | -5 | -133 | -825 | * | * |
| 7:50 | C | D | -125 | 335 | * | * |
| 7:54 | S | NC | -173 | 1186 | * | * |
| 7:58 | S | NC | -92 | 1186 | * | * |
| 8:2 | | | -90 | -87 | * | * |
| 8:6 | | | -3 | -1250 | * | * |
| 8:10 | | | 114 | 1857 | * | * |

INT DL484 SUBJECT SEM826 TAPES BCAS KNOX ADIS

BCAS VERSION-2 CSCPLOT VERSION-2.2 6 MAR 79

79-54-16

4

FIGURE 16. ENCOUNTER WITH COMMAND REVERSALS (VERTICAL VIEW)
(SEE APPENDIX H FOR LEGEND)

more information to the pilot allowing him to assess the situation. VSL alerts direct an action without allowing the pilot full or even partial knowledge of the situation that exists. In fact, limit descent VSL alerts can be caused by intruders which are currently above own aircraft but are projected to be below own aircraft at CPA.

During the Knoxville simulation, modifications to the BCAS logic were made to measure the frequency and duration of PPD alerts. These modifications are shown in appendix F. Table 13 presents the hourly average number and duration of PPD's which resulted. The range threat region for PPD's was defined by a range tau of 60 seconds or range less than 3 nmi. The altitude threat region was defined by a vertical tau of 60 seconds or less than 2,000 feet altitude separation. Both the horizontal and vertical threat conditions must be satisfied before a PPD alert is issued.

The higher occurrence of PPD's for IFR/VFR traffic is expected because of the reduced separation which exists in this case. Only slight variations in rates are observed for the different desensitization schemes. (The total Knoxville area PPD alert rates represent one PPD alert per aircraft flight hour for IFR conditions and 1.4 PPD alerts for every aircraft flight hour in the IFR/VFR condition.) This indicates one out of three aircraft will receive an alert during IFR conditions and one out of 4.2 aircraft will receive an alert during IFR/VFR conditions.

TABLE 13. AVERAGE HOURLY PARTIAL PROXIMITY DATA ALERT RATES

| | IFR | | IFR/VFR | |
|---|---|---|---|---|
| Desensitization Method | Number (alerts/hr) | Average Duration (sec) | Number (alerts/hr) | Average Duration (sec) |
| Altitude | 25.3 | 50.4 | 38.3 | 36.9 |
| Altitude/Range | 26.0 | 34.9 | 32.3 | 42.4 |

The ability to visually acquire the threat is a function of several factors. The range when the alert first occurs is of primary importance. Figure 17 depicts the probability that the threat was beyond a certain range when the PPD alert (based on a 60-second tau) initially occurred. The second curve represents the analytical results that would have occurred in Knoxville if the algorithm used a 45-second tau to generate PPD alerts. The 50th and 75th percentile values for each distribution are also shown. Of the original PPD alerts that occurred in Knoxville (tau = 60 seconds), 50 percent were generated when the initial slant range to the threat exceeded 4.4 nmi. Twenty-five percent of the alerts occurred when the slant range was in excess of 5.4 nmi. According to Andrews (reference 7), the probability of acquiring the intruder at these ranges is extremely low.

An immediate consequence of the reduction of the PPD alert tau to 45 seconds would be a 40-percent reduction in the number of alerts which occurred. On 237 occasions during the Knoxville simulation, the tau values during a PPD alert period never decreased to 45 seconds. The resulting 50th and 75th percentile values for tau = 45 seconds were 3.8 and 4.4 nmi, respectively. A question arises concerning the possiblity of confusing the pilot with PPD for multiple simultaneous threats. Only 25 cases of multiple PPD messages occurred throughout 16 hours of data collection. This rate indicates less than 1 case of multiple PPD alerts per 17 aircraft flight hours.

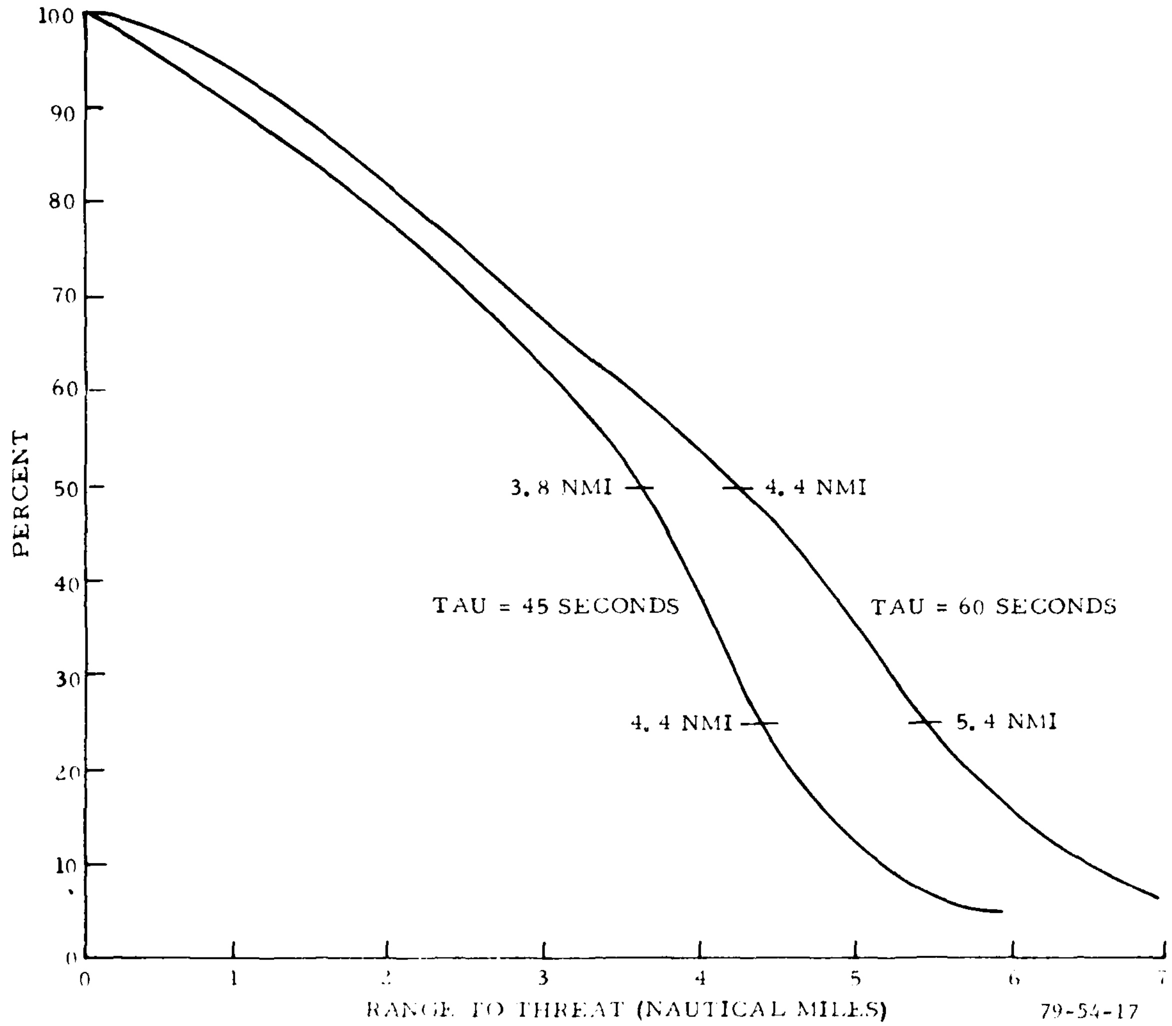



FIGURE 17. PERCENT OF ALERTS WHICH OCCURRED BEYOND RANGE INDICATED FOR FIXED TAU

## CONCLUSIONS

Based on the results of the active Beacon Collision Avoidance System (BCAS) dynamic simulation, the following conclusions are made:

1. The presence of active BCAS in a moderate-density terminal Air Traffic Control (ATC) environment had no adverse impact on the controllers or control procedures. The air traffic controllers who participated in the simulation favored the use of the active BCAS system as a backup to the ATC system. There was no significant difference in the ATC system performance measures between the no BCAS baseline runs and the simulation runs in which all aircraft were BCAS equipped.

2. It is concluded that the active BCAS logic, utilizing either desensitization method, provided adequate resolution of conflicting aircraft pairs. BCAS detected all penetrations of ATC separation criteria.

3. The BCAS logic modifications were effective in reducing the number and duration of noneffective Vertical Speed Limit (VSL) alerts. The high noneffective VSL alert rate for overflight aircraft generated in the previous full BCAS Knoxville simulation was substantially reduced.

4. The increase in positive command rate for active BCAS (compared to full BCAS); is attributed to the lack of horizontal miss distance filtering. If perfect horizontal miss distance information had been available, 53 percent of the positive commands would have reverted to negative commands and 14 percent would have been eliminated. The maximum benefit of horizontal miss distance filtering would be in the final approach area.

5. The increase in the negative command alert rate for active BCAS is due to the lack of horizontal miss distance filtering and the modification of the BCAS logic following the full BCAS simulation. Horizontal miss distance filtering would eliminate some of the negative commands. Due to BCAS logic modifications, many of the encounters that would have resulted in a noneffective VSL now result in a noneffective negative command.

6. A higher BCAS alert rate exists for Visual Flight Rules (VFR) operations when compared to Instrument Flight Rules (IFR) operations. The BCAS logic parameters evaluated were designed to detect penetrations of IFR separation criteria. This results in threshold parameters that generate BCAS alerts for VFR traffic even when VFR separation criteria are maintained.

7. Use of altitude desensitization in the absence of range information may be adequate. Use of altitude was an effective determinant of an aircraft's protection requirements. However, altitude-only desensitization encourages high positive command rates among aircraft over-flying the terminal area.

# RECOMMENDATIONS

Based on the analysis of the data from Knoxville Air Traffic Control (ATC)/ active Beacon Collision Avoidance System (BCAS) dynamic simulation the following recommendations are made:

1. The Vertical Speed Limit (VSL) logic modifications described in Appendix F of this report should be made a permanent part of the BCAS algorithm. These VSL logic modifications reduced the number and duration of undesirable VSL alerts. The VSL logic could be further refined to include additional checks for vertical closure prior to issuing an alert.

2. Since VSL's are no longer used as precursors to positive or negative commands, an examination of the feasibility and benefit of Partial Proximity Data (PPD's) for active BCAS should be made. Active BCAS PPD's give only intruder range and altitude.

3. The BCAS logic should be modified to prevent or limit command oscillation. Although a rare occurrence, the direction of a command generated by the resolution logic can reverse in an encounter and confuse the pilot.

4. A BCAS measurement error model should be incorporated into future BCAS performance analysis. Perfect position and velocity data were provided to the BCAS tracker in the active BCAS simulation, and the results, therefore, represent the upper bound on expected BCAS performance.

5. An examination into the feasibility of making the BCAS logic and resolution parameters sensitive to Visual Flight Rules (VFR) transponder codes should be considered. A reduction of the undesirable alerts generated for VFR aircraft could result.

## REFERENCES

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2. Billmann, B., Morgan, T., Strack, R., and Windle, J., Air Traffic Control/ Beacon Collision Avoidance System Chicago Simulation, U.S. Department of Transportation Report FAA-RD-79-16, April 1979.

3. Billmann, B., Morgan, T., Strack, R., and Windle, J., Air Traffic Control/ Full Beacon Collision Avoidance System Knoxville Simulation, U.S. Department of Transportation Report FAA-RD-79-25, May 1979.

4. Clark, J. and McFarland, A., Initial Collision Avoidance Algorithm for the Beacon Based Collision Avoidance System, MTR-7532, MITRE Corporation, April 1977.

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

6. Cohen, M. and Richardson, C., Beacon Collision Avoidance System - Active Mode, FAA- RD-78-77, October 1978.

7. Operational Characteristic of an Active BCAS, Unpublished Publication, FAA/ARD-250, August 1979.

8. Andrews, J. W., Air to Air Visual Acquisition Performance with Pilot Warning Instruments, FAA-RD-77-30, April 1977.

## APPENDIX A

## KNOXVILLE (McGHEE TYSON) AIRPORT TRAFFIC FLOW PROCEDURES

EAST AND WEST CENTER.

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

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

EAST AND WEST ARRIVAL AND DEPARTURE.

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

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

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

LOCAL CONTROL.

Provide separation between departing and arriving aircraft.

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

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

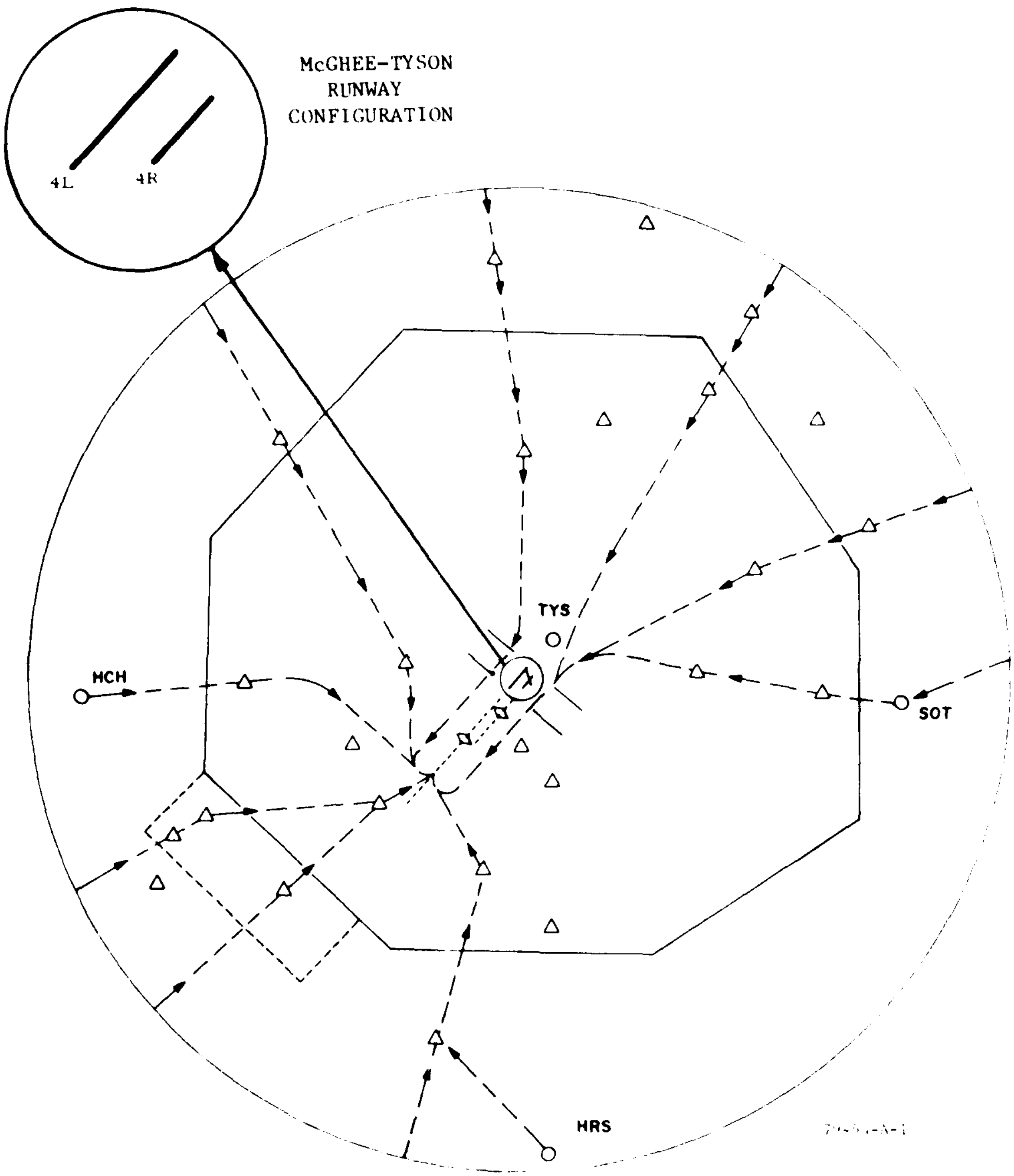



FIGURE A-1. McGHEE TYSON TERMINAL AREA--ARRIVAL FLOW

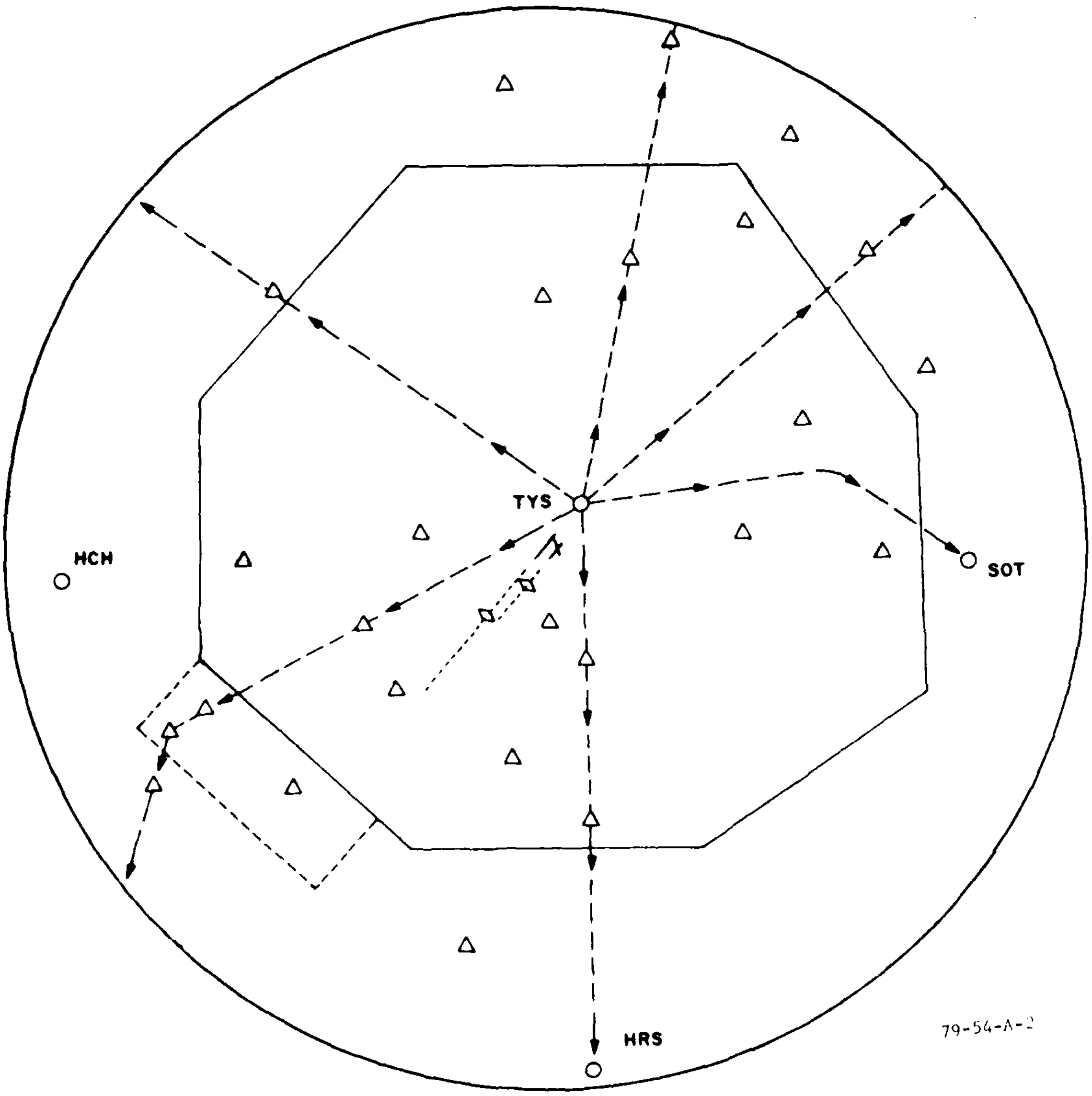



FIGURE A-2. McGHEE TYSON TERMINAL AREA--DEPARTURE FLOW

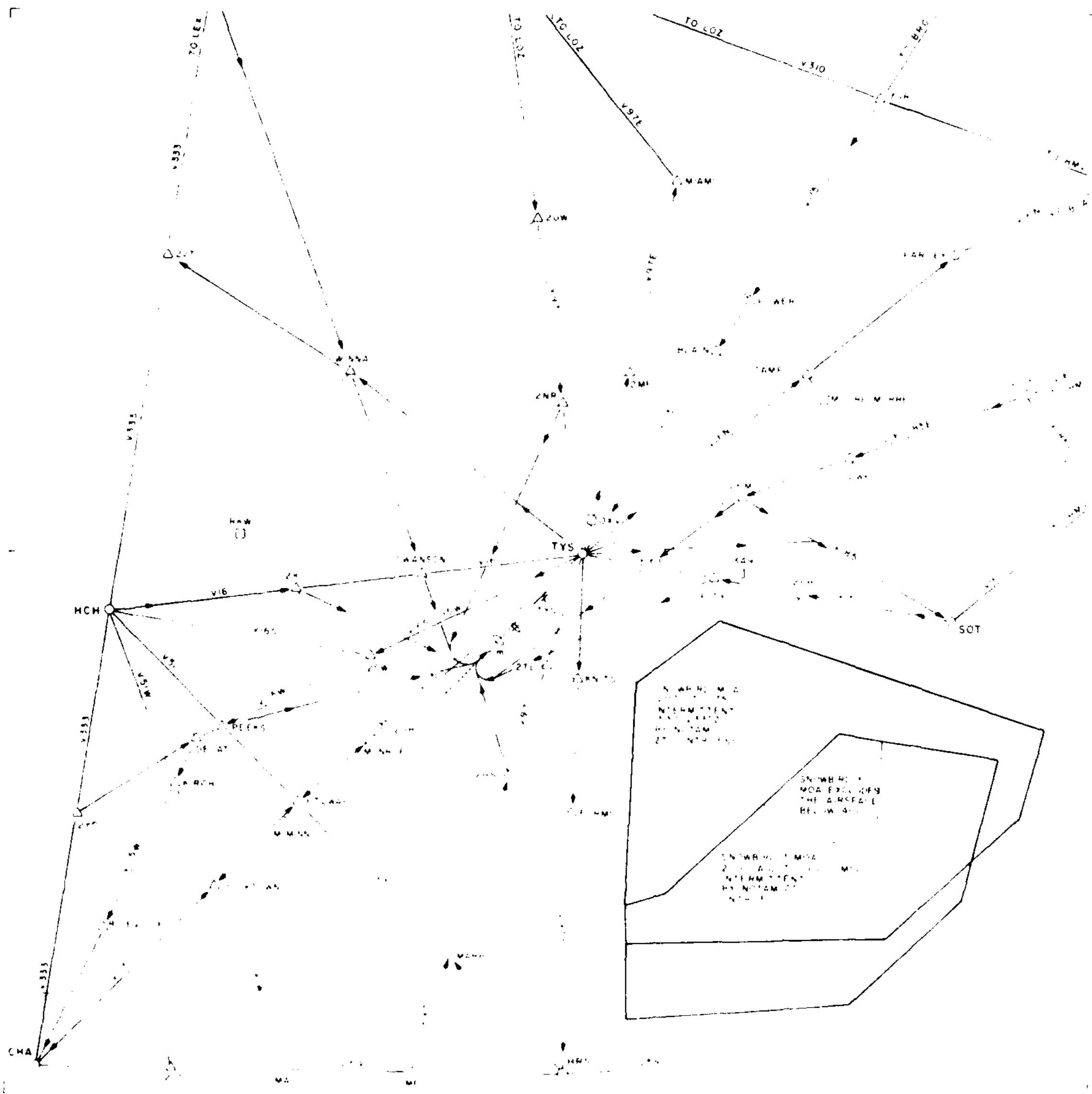



FIGURE A-3. ATLANTA CENTER (KNOXVILLE SECTO... [illegible]

TABLE A-1. KNOXVILLE FIX LIST

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

# APPENDIX B

# AIRCRAFT PERFORMANCE CHARACTERISTICS

TABLE B-1. AIRCRAFT PERFORMANCE CHARACTERISTICS

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

TABLE B-2. AIRCRAFT PERFORMANCE CHARACTERISTICS

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

TABLE B-3. AIRCRAFT PERFORMANCE CHARACTERISTICS

RUNWAY OCCUPANCY TIMES

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

* Standard Deviation

# BCAS QUESTIONNAIRE

SUBJECT ______________________ DATE ______________

SERIES ____________ CONTROL POSITION(S) __________ RUN # ________

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

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

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

NOT AT ALL ________ SOMEWHAT ________ GREATLY ________

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

YES ________ NO ________

If no, what features were unrealistic? ______________________

______________________________________________

______________________________________________

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

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

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

YES __________ NO __________

If yes, in what way? ______________________________

______________________________

______________________________

6. Did you agree with the BCAS commands:

NEVER __________ OCCASIONALLY __________ USUALLY __________ ALWAYS ________

If not, please cite example(s). ______________________________

______________________________

______________________________

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

Positive commands YES __________ NO __________

If no, what was confusing? ____________________

____________________

____________________

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

YES __________ NO __________

If no, please suggest alternative ____________________

____________________

____________________

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

YES __________ NO __________

Please elaborate ____________________

____________________

____________________

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

FINAL APPROACH __________ VECTOR AREAS __________

HANDOFF POINTS __________ OTHER (SPECIFY) ____________________

____________________

____________________

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

a. I strongly oppose its use

b. I oppose its use.

c. I am indifferent to its use.

d. I favor its use.

e. I strongly favor its use.

Please explain ____________________________________________

____________________________________________

____________________________________________

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

YES __________ NO __________

Please explain ____________________________________________

____________________________________________

____________________________________________

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

YES __________ NO __________

# APPENDIX D

## DEFINITIONS OF ATC PERFORMANCE MEASURES

### 1. AVERAGE TOTAL TIME-IN-SYSTEM FOR ARRIVAL AIRCRAFT (MINS).

Time-in-system, for this measure, is defined as the elapsed time between a flight's actual start time and its termination time. Termination time, in this case, would be either the touchdown time of an aircraft, or the end of the data period. This measure was an accumulation of time-in-system for all arrival aircraft which were active in the system during the 1-hour data period, and stated as an average.

### 2. AVERAGE INSTANTANEOUS AIRCRAFT COUNT PER CONTROL POSITION.

A computer program counted the number of aircraft under each controller's jurisdiction each second during the data period and retained the minimum and maximum count for each 1-minute period. The minimum and maximum counts were accumulated for each 60-second period and averaged for the data hour.

### 3. AVERAGE NUMBER OF CONTROL EFFORTS PER AIRCRAFT PER HOUR.

A control effort is defined as a radar vector, altitude change, or a speed change issued by a controller. This measure is an accumulation of the number of control efforts issued in the east approach, west approach, and final approach sectors throughout the 1-hour data period, divided by the number of aircraft controlled during the 1-hour data period.

### 4. AVERAGE TALK TIME PER AIRCRAFT (SECONDS).

This measure is an accumulation of the message durations for all sectors divided by the total number of aircraft active in the system.

## APPENDIX E

## KNOXVILLE HOURLY ALERTS--AIR CARRIERS

The average alert rate and duration of alerts issued to air carriers is presented in table E-1. Air carrier aircraft comprised 30 percent of all the air traffic in the simulation. The number in parenthesis represents 30 percent of the average alert rate generated for all aircraft during the simulation. No air carriers were overflights.

Due to the high performance of air carrier aircraft, their average time in the system per aircraft was 13.1 minutes compared to 21.1 minutes for all other aircraft. On a per-aircraft basis, 1 in 20 air carriers received an advisory, and 1 in 40 received a command. On a per-aircraft flight hour basis, one noneffective alert was issued every 4.3 aircraft flight hours, and one effective alert was issued every 9.1 flight hours. Air carrier aircraft did not receive more than their expected share of total alerts.

TABLE E-1. KNOXVILLE HOURLY ALERTS (AIR CARRIER AIRCRAFT ONLY*)

| Alerts | Altitude Desensitization | | | | Altitude/Range Desensitization | | | |
|---|---|---|---|---|---|---|---|---|
| | IFR | | IFR/VFR | | IFR | | IFR/VFR | |
| | Number (alerts/hr) | Avg Dur (sec) | Number (alerts/hr) | Avg Dur (sec) | Number (alerts/hr) | Avg Dur (sec) | Number (alerts/hr) | Avg Dur (sec) |
| **Advisories** | | | | | | | | |
| VSL | 0.0 | --- | 0.0 | --- | 0.0 | --- | 0.0 | --- |
| Negative Command | 0.5 | 11.8 | 0.0 | --- | 1.0 | 14.0 | 1.8 | 20.0 |
| TOTAL | 0.5(1.0)** | 11.8 | 0(0.5) | --- | 1.0(0.8) | 14.0 | 1.8(1.8) | 20.0 |
| **Commands** | | | | | | | | |
| VSL | 0.0 | --- | 0.5 | 6.5 | 0.0 | --- | 0.0 | --- |
| Negative Command | 0.0 | --- | 0.0 | --- | 0.0 | --- | 0.0 | --- |
| Positive Command | 0.0 | --- | 0.8 | 9.3 | 0.5 | 14.0 | 0.5 | 12.5 |
| TOTAL | 0.0(0.5) | --- | 1.3(1.1) | 8.2 | 0.5(0.4) | 14.0 | 0.5(1.2) | 12.5 |

* Air carrier aircraft comprised 30 percent of all the traffic.

Average time in system for air carrier aircraft was 13.1 minutes versus 21.1 minutes for all other aircraft.

**Represents expected number of total alerts based on proportion of air carriers in sample.

## APPENDIX F

## BCAS LOGIC MODIFICATIONS

BCAS algorithm modifications were made prior to the Knoxville active BCAS simulation. The modifications included the restructuring of VSL logic, alert initialization changes, and a revised threat volume parameter list. The principal differences between the logic used in the Knoxville full BCAS simulation and the logic used in the Knoxville active BCAS simulation are summarized below:

- Two-out-of-three logic is used for all commands, including VSL's.
- Two consecutive misses are required to turn off commands, including VSL's.
- In order to receive a VSL alert, own aircraft must have vertical rate towards the intruder.
- Parameter values were changed.
  - TRTHR. TRTHR is the threshold value against which the modified-tau (TAUR) is compared. This parameter was changed from 40 seconds to 25 seconds, reducing the threat volume to coincide with positive and negative command threat volumes.
  - DMOD. DMOD is the tau distance modifying parameter. It is applied to the tracked range (R) to prevent late warnings in turning situations. DMOD was reduced from 1.8 nmi to 1.0 nmi for desensitization level 5, 1.0 nmi to 0.5 nmi for desensitization level 4, and from 0.75 nmi to 0.3 nmi for desensitization level 3.
  - LALT. LALT was the altitude separation threshold outside which VSL commands were not given. This threshold was eliminated as the initial check in the determination of the requirement for VSL commands; substituted was a projected miss distance check of VMD<900 feet.
  - TVTHR. TVTHR is the threshold value against which the vertical tau (TAUV) is compared. This parameter was changed from 40 seconds to 25 seconds for VSL's, thereby reducing the threat volume to coincide with positive and negative command threat volumes.

The revised threat parameter definition and values used in this simulation are shown in table F-1.

The integrated VSL and positive and negative command logic is shown in figure F-1.

TABLE F-1. REVISED BCAS COLLISION AVOIDANCE LOGIC PARAMETERS

| Symbol | Utilization | 3 | 4 | 5* |
|---|---|---|---|---|
| ACCEPT | Altitude separation within which own aircraft accepts intruder's selection of vertical command when own selection is incompatible | 400 | 400 | 400 ft |
| ALFAR | Tracking constant for range | 0.4 | 0.4 | 0.4 |
| ALFAZ | Tracking constant for Z position | 0.4 | 0.4 | 0.4 |
| ALIM | Vertical miss distance within which positive rather than negative vertical commands are requested | 400 | 400 | 400 ft |
| ALIM2 | Vertical miss distance in excess of which negative vertical commands are requested rather than horizontal commands or positive vertical commands | (parameter not used) | | |
| BAND1 | Altitude separation within which vertical rate is limited to a maximum of 500 ft./min. | (parameter replaced with vertical rate logic) | | |
| BAND2 | Altitude separation within which vertical rate is limited to a maximum of 1000 ft./min. | (parameter replaced with vertical rate logic) | | |
| BET[illegible] | Tracking constant for range rate | 0.15 | 0.15 | 0.15 |
| BE[illegible] | Tracking constant for Z velocity | 0.15 | 0.15 | 0.15 |
| DM[illegible] | Modified-tau distance used for positive and negative commands | 0.3 | 0.5 | 1.0 nmi |
| DMO[illegible] | Modified-tau distance used for PPD detection | 0.5 | 0.75 | 1.8 nmi |
| LAL[illegible] | Altitude separation outside which vertical rate limit commands are not given | (Replaced with new VSL logic) | | |
| MDC | Square of horizontal miss distance threshold beyond which no positive or negative maneuvers are requested by threat detection logic | (Parameter not used by active BCAS logic) | | |

TABLE F-1. REVISED BCAS COLLISION AVOIDANCE LOGIC PARAMETERS (Continued)

| Symbol | Utilization | 3 | 4 | 5 |
|---|---|---|---|---|
| MDPOS | Square of horizontal miss distance threshold used by threat detector to choose between positive and negative command requests | (Parameter not used by active BCAS logic) | | |
| MTAU2 | Modified-tau distance used to determine whether vertical limit commands should be given | (Parameter replaced with new VSL logic) | | |
| PFUN | Weights used to estimate the predicted vertical miss distance | (1) 4.0<br>(2) 7.2<br>(3) 9.8<br>(4) 11.8<br>(5) 13.5 | 4.0<br>7.2<br>9.8<br>11.8<br>13.5 | 4.0<br>7.2<br>9.8<br>11.8<br>13.5 |
| [illegible] | Range threshold used to desensitize logic to performance level 3 | 15 | 15 | 15 nmi |
| [illegible] | Range-rate threshold use to choose between Tau test and immediate range test | 10 | 10 | 10 ft/sec |
| [illegible] | Range threshold used by program to shut off collision avoidance logic (performance level 2) | 2 | 2 | 2 nmi |
| [illegible] | Immediate range threshold for flashing PPD tests | 0.3 | 0.5 | 1.0 nmi |
| RTH[illegible] | Immediate range threshold for ordinary PPD tests | 1.0 | 2.0 | 3.0 |
| RTH[illegible] | Immediate range threshold used in threat detection for immediate range test | 0.1 | 0.1 | 0.1 nmi |
| RZI[illegible]F | Immediate altitude threshold for flashing PPD tests | 400 | 400 | 700 ft |
| RZ[illegible] | Immediate altitude threshold for ordinary PPD tests | 1000 | 1500 | 2000 ft |
| SMA[illegible] | Small value used to avoid dividing by zero when computing TAUR | (Parameter replaced with new VSL logic) | | |

TABLE F-1. REVISED BCAS COLLISION AVOIDANCE LOGIC PARAMETERS (Continued)

| Symbol | Utilization | 3 | 4 | 5 |
|---|---|---|---|---|
| TAU2L | Threshold against which TAU2 is compared to determine whether limit commands should be given | (Parameter replaced with new VSL logic) | | |
| TDROP | Time without reported data to drop an intruder | 10 | 10 | 10 secs |
| TIMETX | In horizontal resolution, the time to track crossing point threshold | (Parameter not used by active BCAS logic) | | |
| TIMEV | Look-ahead time used to compute the projected vertical miss distance VMD to determine whether to request a positive command or a negative command | 20 | 20 | 25 secs |
| TIPDF | Tau threshold for flashing PPD tests | 30 | 30 | 35 secs |
| TIPDO | Tau threshold for ordinary PPD tests | 60 | 60 | 60 secs |
| TLARGE | Very large positive number | $10^5$ | $10^5$ | $10^5$ secs |
| TMIN | Minimum time alert can be displayed | 5 | 5 | 5 secs |
| TRTHR | Value against which modified-tau (TAUR) is being compared | 25 | 25 | 30 secs |
| TVPCMD | Look-ahead time used to compute the projected vertical miss distance VMD | 20 | 20 | 25 secs |
| TVTHR | Value against which vertical tau (TAUV) is being compared | 25 | 25 | 30 secs |
| TV1 | Look-ahead time used to choose climb or descend command | 8 | 8 | 8 secs |

TABLE F-1. REVISED BCAS COLLISION AVOIDANCE LOGIC PARAMETERS (Continued)

| Symbol | Utilization | 3 | 4 | 5 | |
|---|---|---|---|---|---|
| TXTH | In horizontal resolution algorithm, the track crossing angle at which the resolution strategy changes | (Parameter not used by active BCAS logic) | | | |
| WAITM | Maximum reply wait time | 4 | 4 | 4 | secs |
| ZDESEN | Altitude threshold below which logic is desensitized to performance level 3 or 4, depending on range | 10,000 | 10,000 | 10,000 | ft |
| ZDTHR | Altitude rate threshold used by the threat detection (Note: ZDTHR = -ZTHR/TVTHR) | -36 | -36 | -30 | ft/sec |
| ZIPD | Altitude threshold for co-altitude PPD | 500 | 500 | 500 | ft |
| ZTHR | Immediate altitude threshold used by detection logic | 900 | 900 | 900 | ft |

* BCAS performance level

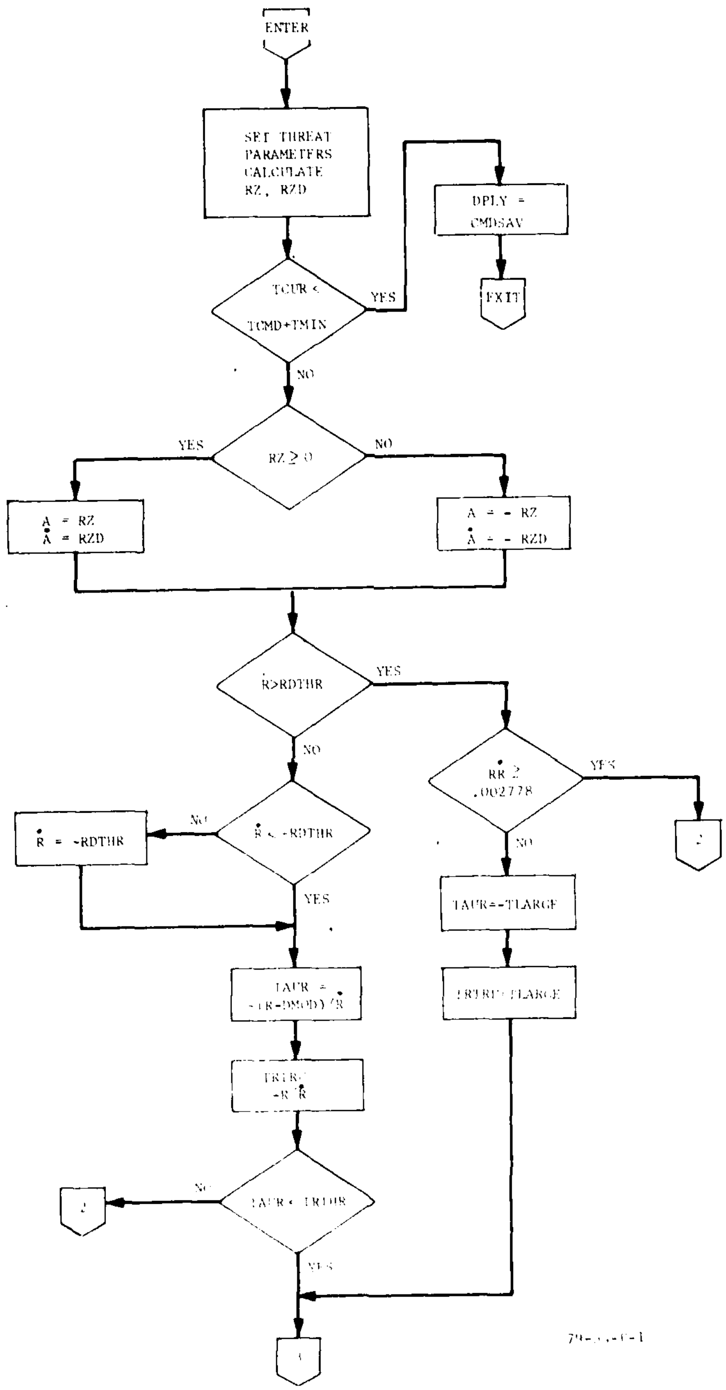
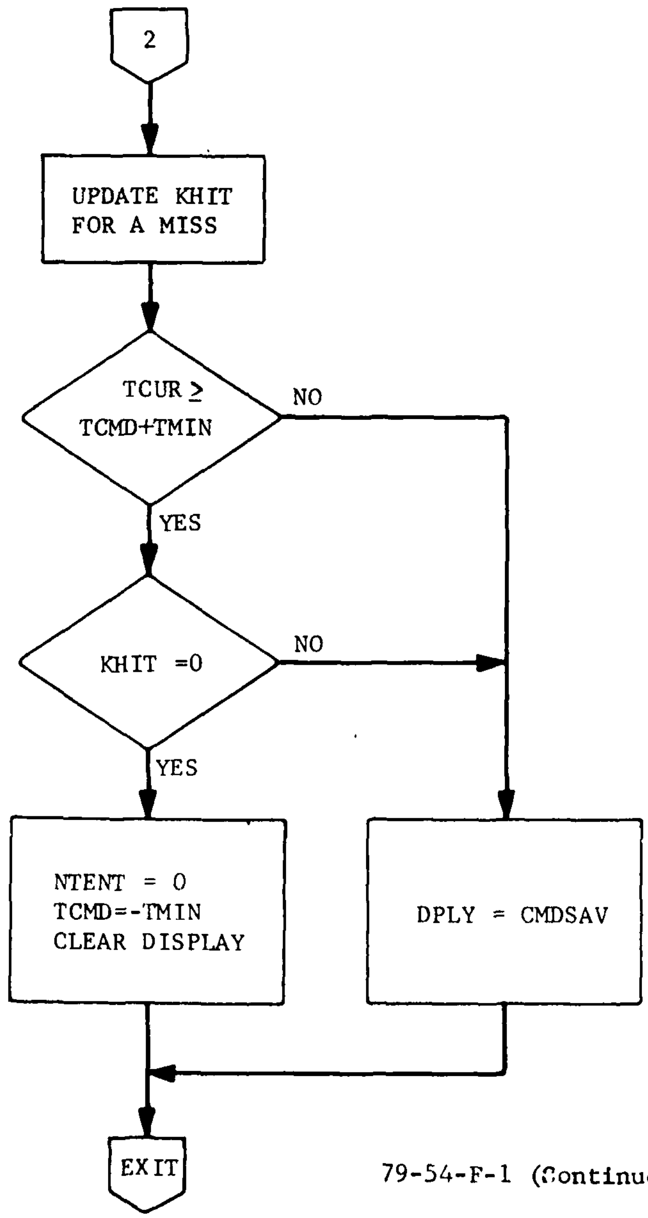



FIGURE F-1. INTEGRATED VSL LOGIC




79-54-F-1 (Continued)

FIGURE F-1. INTEGRATED VSL LOGIC (Continued)

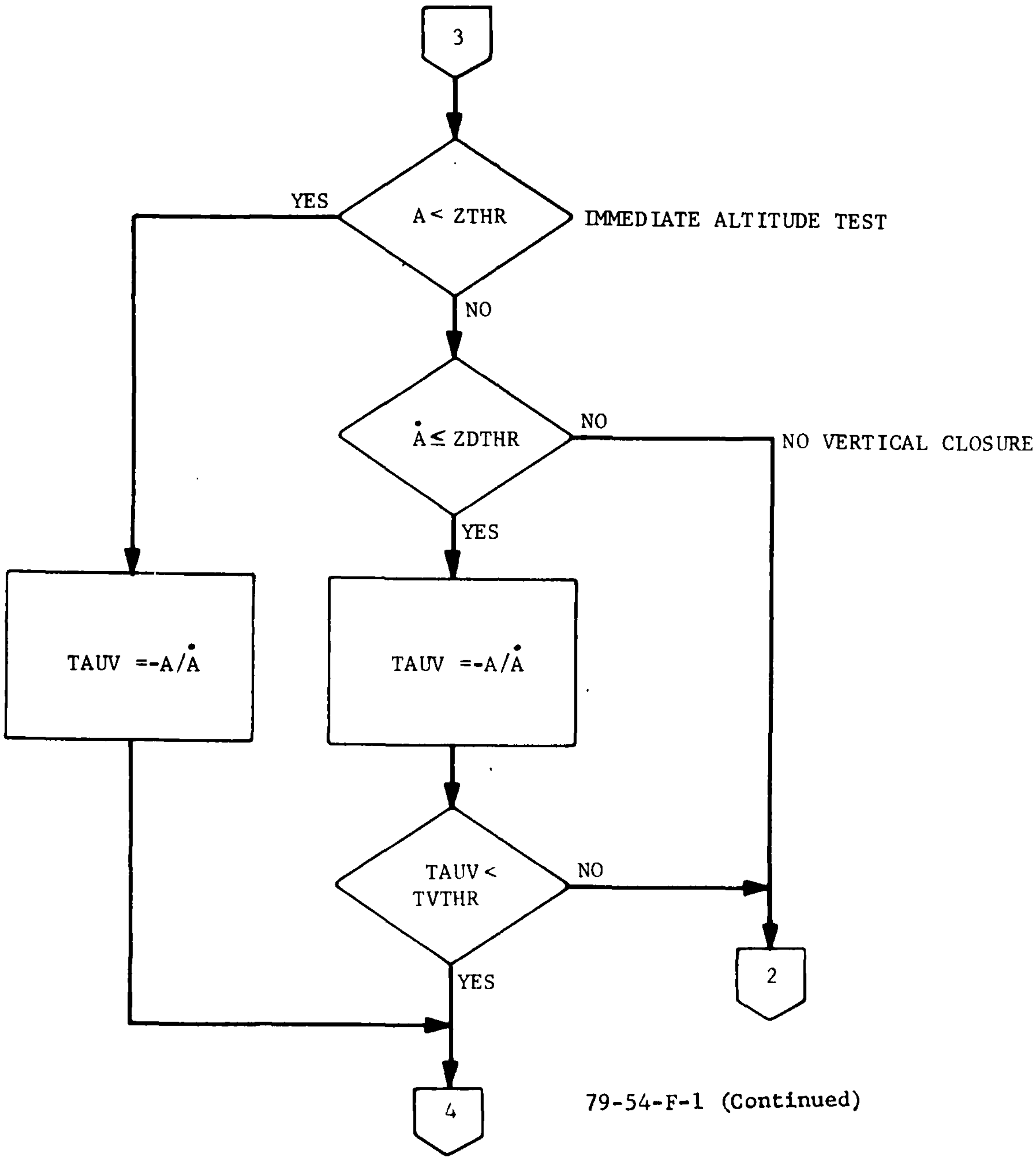



FIGURE F-1. INTEGRATED VSL LOGIC (Continued)

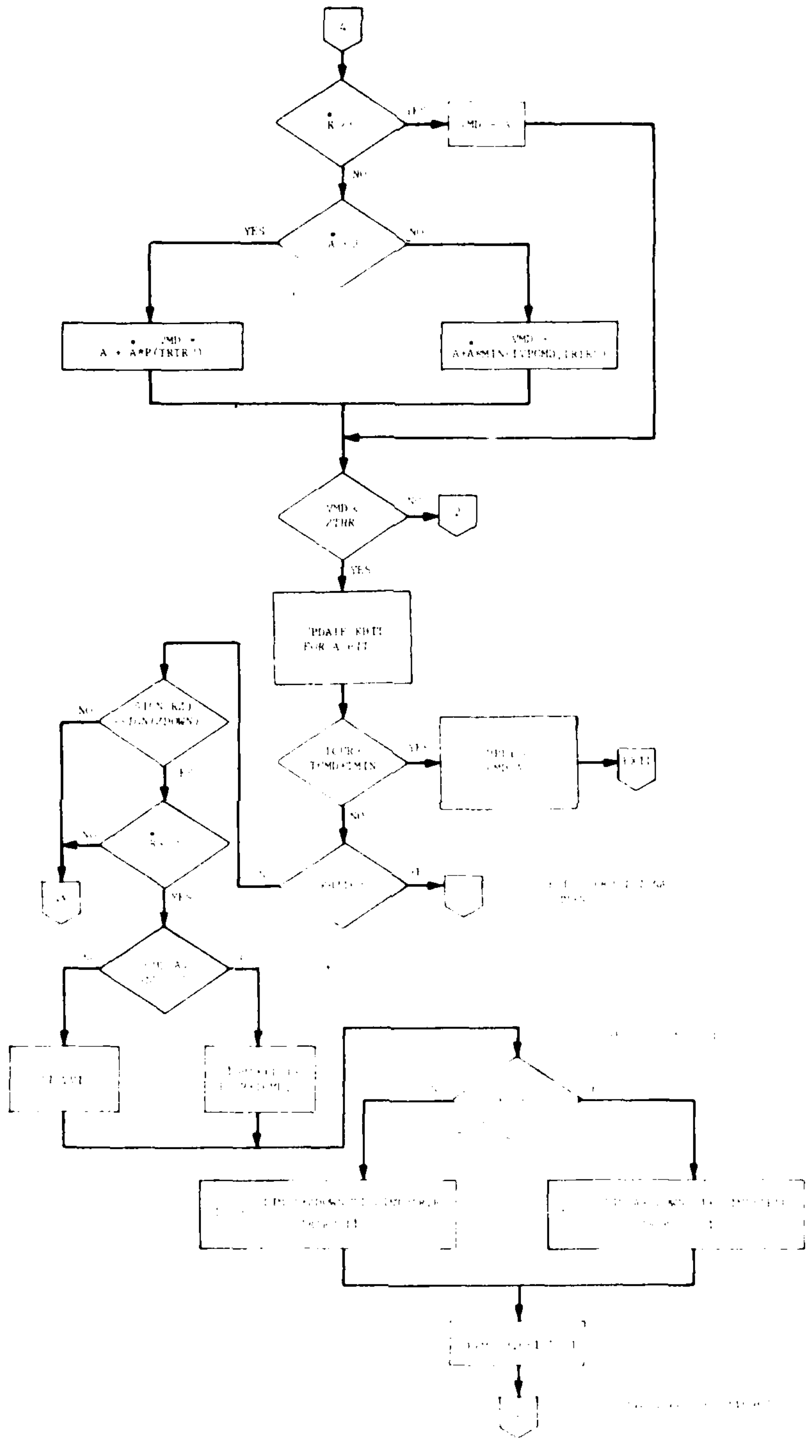


FIGURE F-1. INTEGRATED VSL LOGIC (Continued)

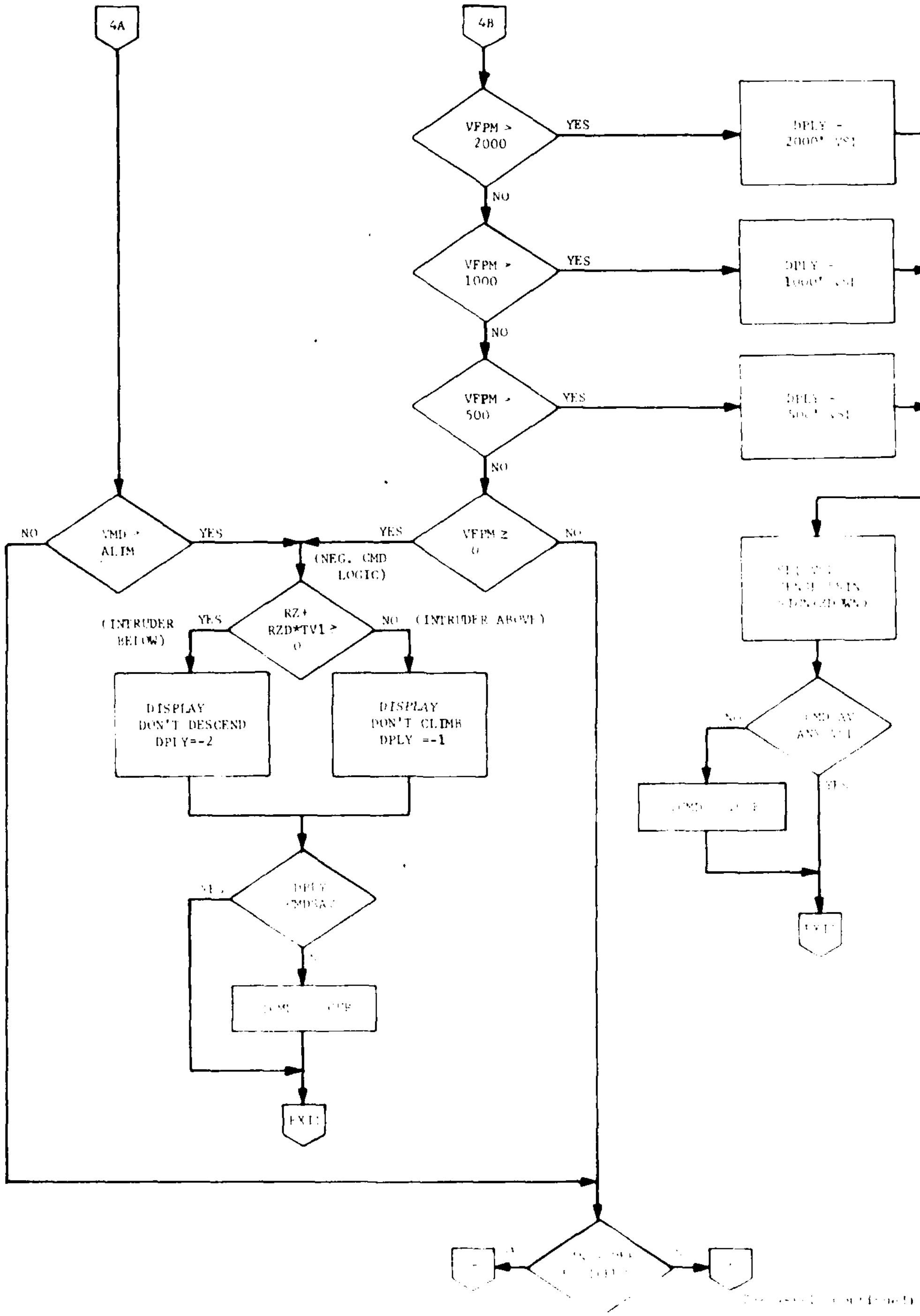



FIGURE F-1. INTEGRATED VSL LOGIC (Continued)

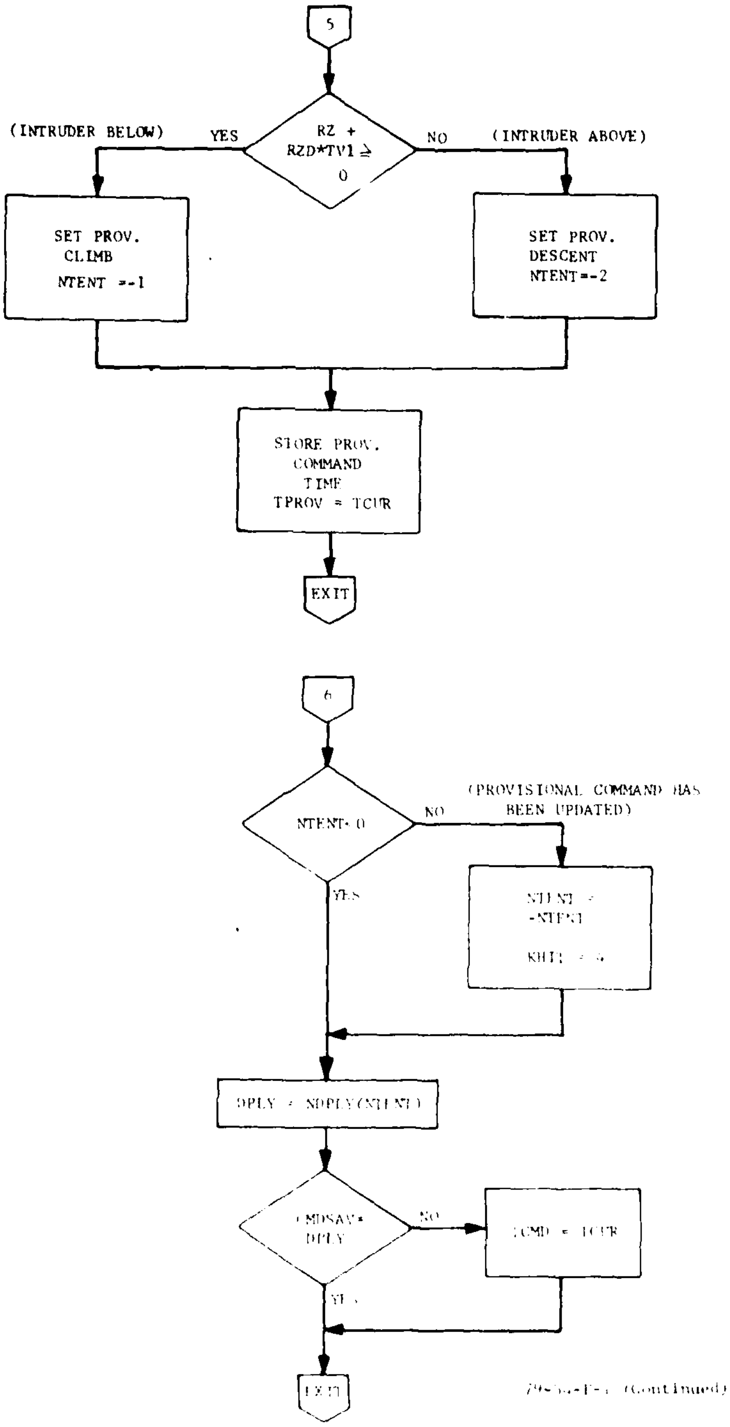
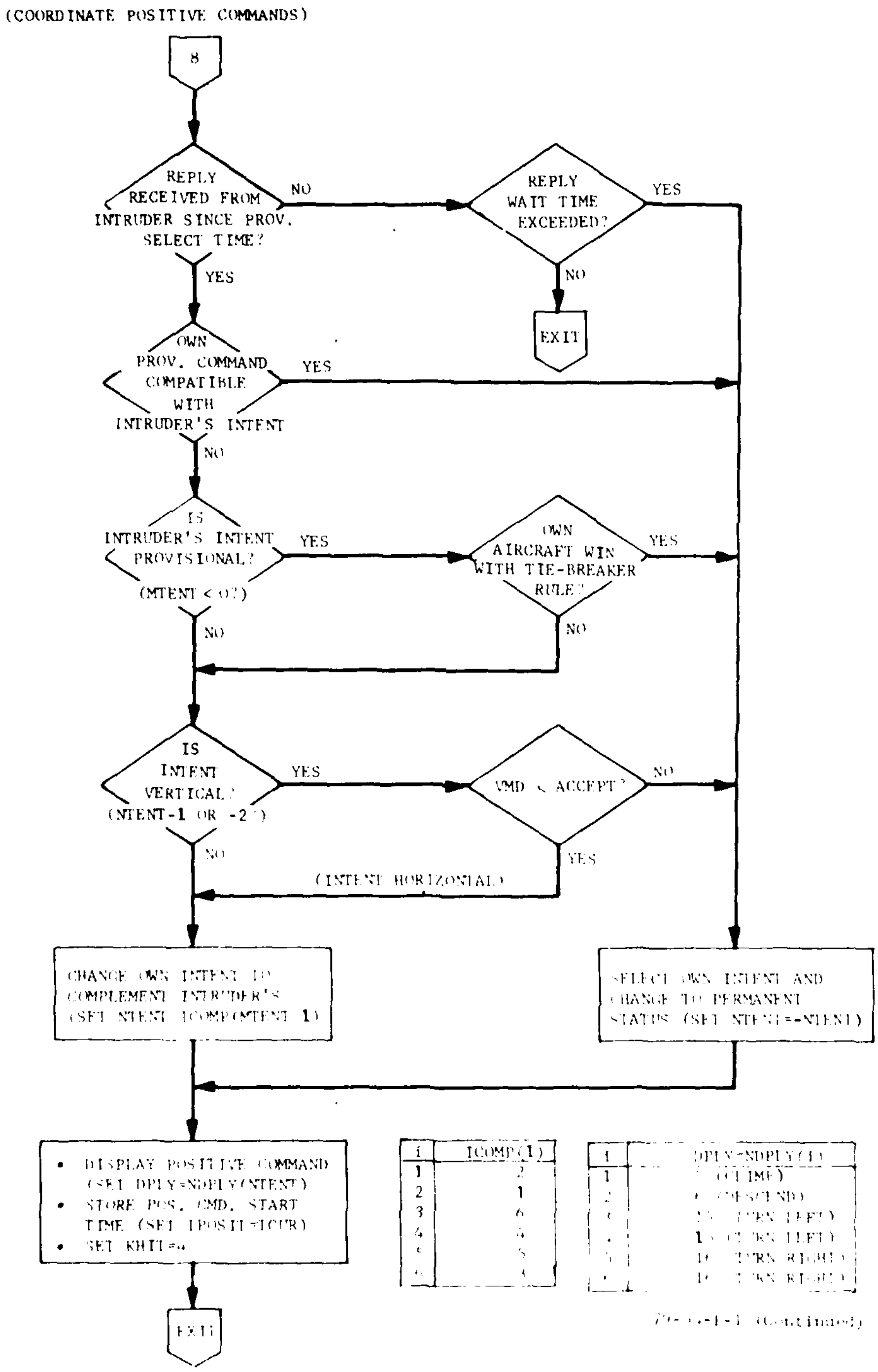



FIGURE F-1. INTEGRATED VSL LOGIC (Continued)




| i | ICOMP(I) |
|---|---|
| 1 | 2 |
| 2 | 1 |
| 3 | 6 |
| 4 | 4 |
| 5 | 5 |
| 6 | 3 |

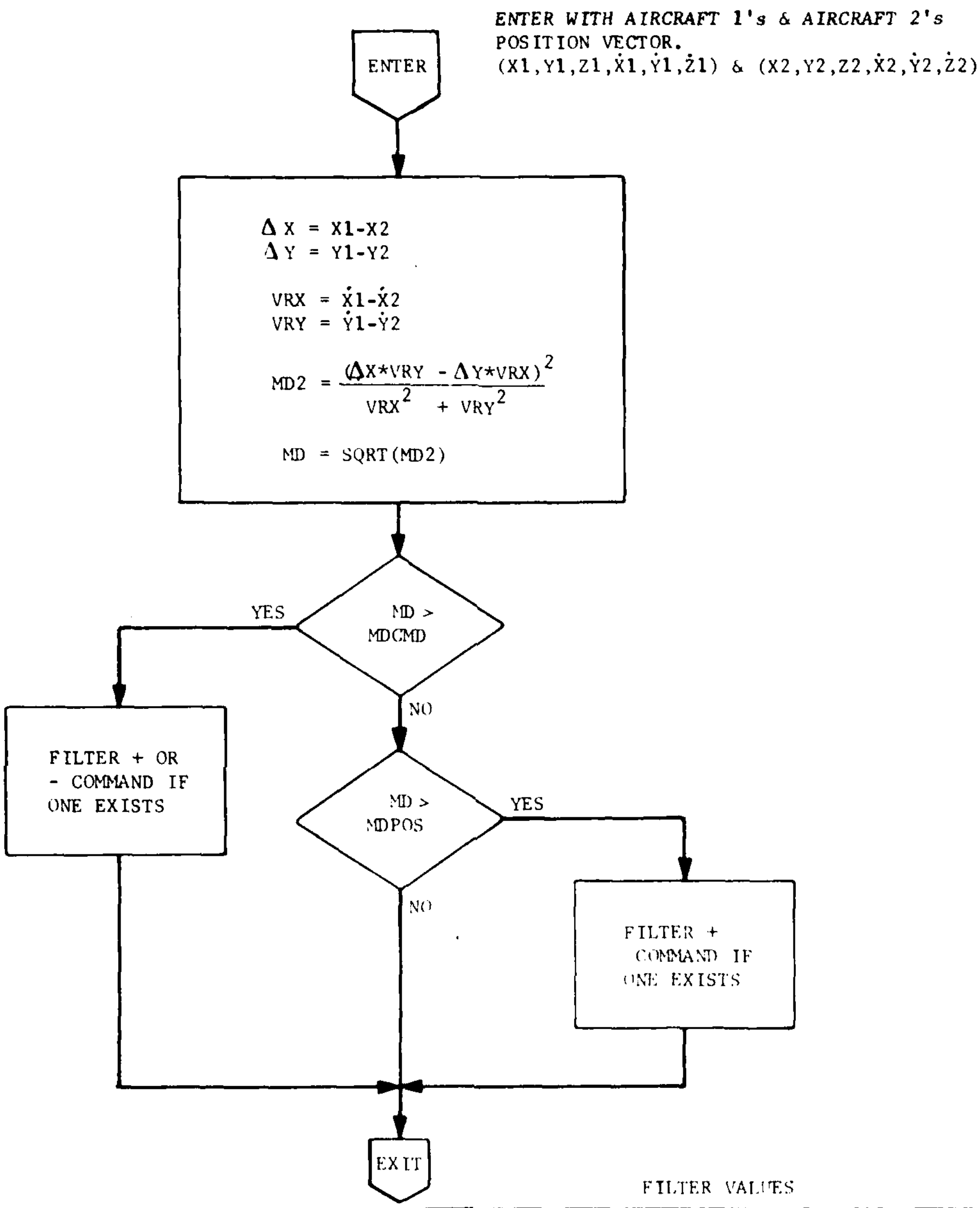
| i | DPLY=NDPLY(I) |
|---|---|
| 1 | [illegible] (CLIMB) |
| 2 | [illegible] (DESCEND) |
| [illegible] | [illegible] (TURN LEFT) |
| [illegible] | 1[illegible] (TURN LEFT) |
| [illegible] | 1[illegible] (TURN RIGHT) |
| [illegible] | 1[illegible] (TURN RIGHT) |

[illegible] (Continued)

FIGURE F-1. INGEGRATED VSL LOGIC (Continued)

## HORIZONTAL MISS DISTANCE FILTER LOGIC.

If bearing information had been available, the positive and negative alert rates could have been reduced. The projected horizontal miss distance (MD) for each data cycle was calculated as shown in figure F-2. When MD exceeded the alert thresholds MDPOS or MDCMD, the alert was filtered for that data cycle. If the alert was filtered each second, the overall positive or negative alert count was reduced by one. The filter thresholds are shown in figure F-2.




FILTER VALUES

| THRESHOLD | PERFORMANCE LEVEL | VALUE |
|---|---|---|
| MDPOS | 3 | 0.4 nmi |
| | 4 | 0.5 nmi |
| | 5 | 1.0 nmi |
| MDCMD | 3 | 1.0 nmi |
| | 4 | 2.0 nmi |
| | 5 | 3.0 nmi |

FIGURE F-2. HORIZONTAL MISS DISTANCE FILTER LOGIC

PPD LOGIC.

The PPD analysis was conducted using a modified version of a previous full BCAS IPD logic. The modifications eliminated alert filtering based on projected horizontal miss distance information. The logic is shown in figure F-3. The values of the threshold parameters were identified in table F-1.

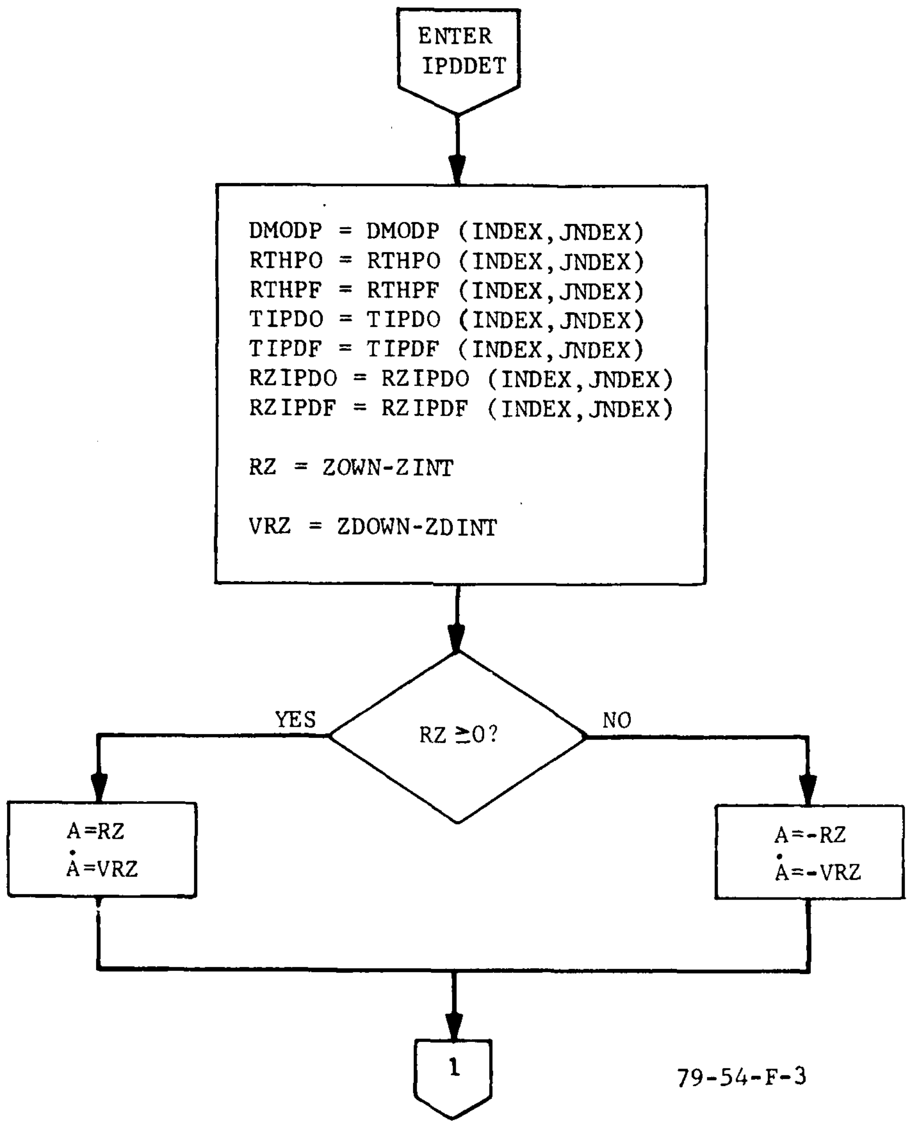



FIGURE F-3. PPD LOGIC

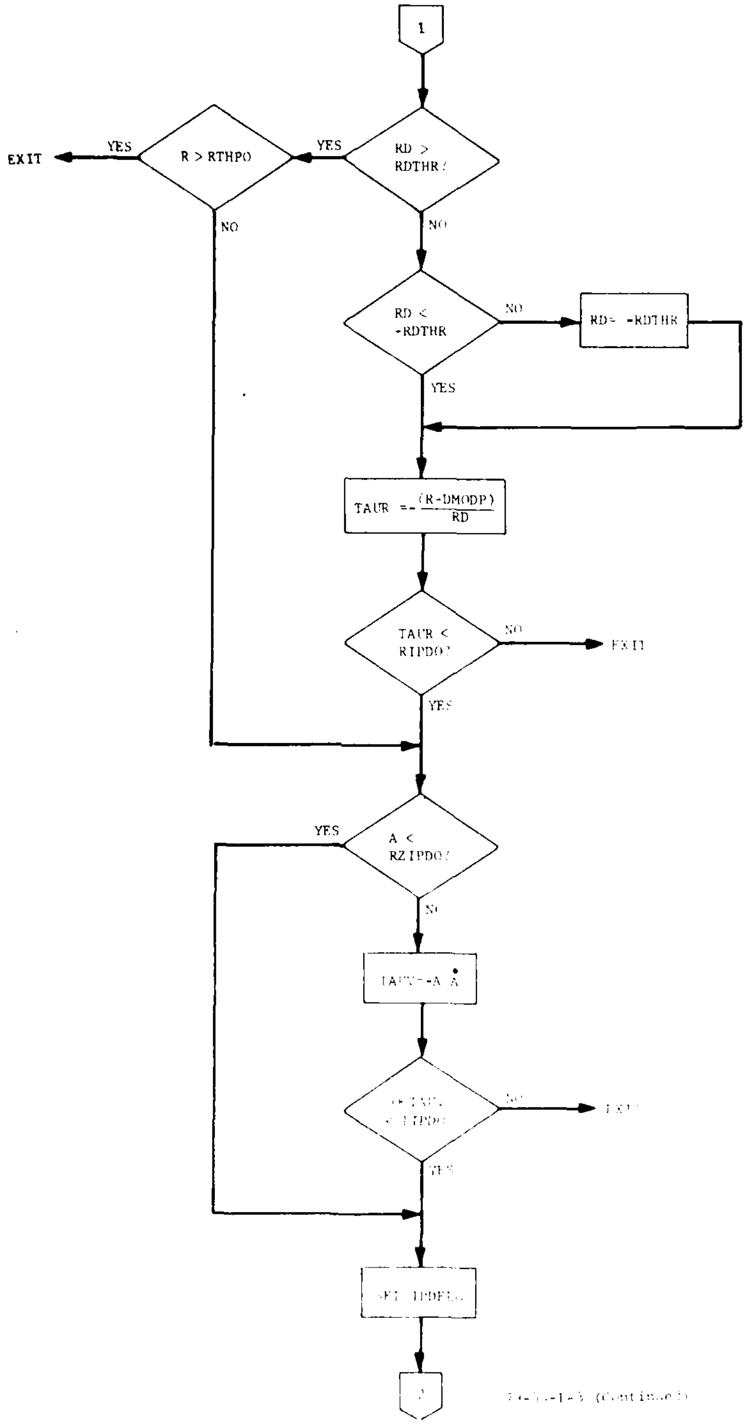



FIGURE F-3. PPD LOGIC (Continued)

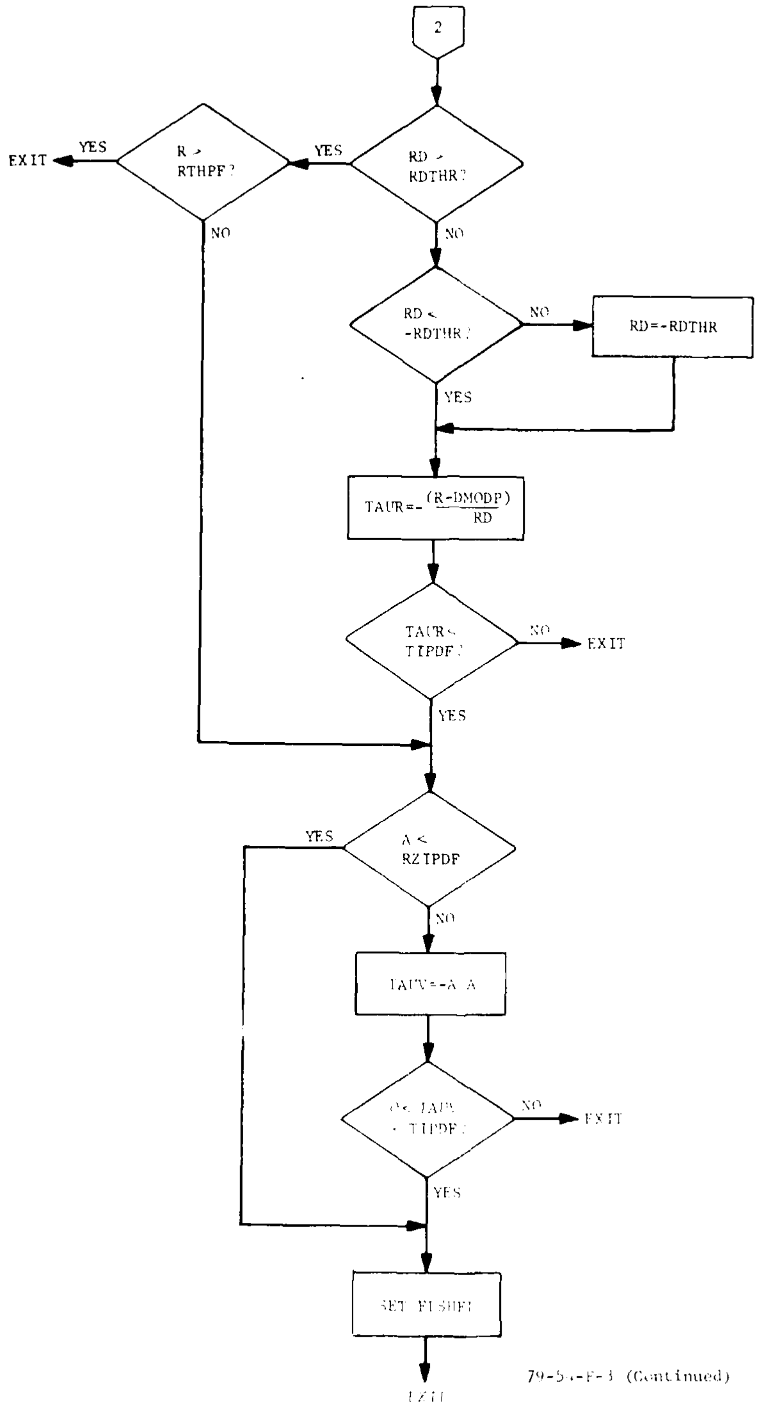



FIGURE F-3. FPD LOGIC (Continued)

# APPENDIX G

## AIRCRAFT DENSITY ANALYSIS

An analysis of the simultaneous aircraft density in the Knoxville air traffic model was made. A grid of 1 $nmi^2$ cells was developed. Aircraft position was recovered for each second, and the appropriate cell count was increased by starting from a count of zero at the beginning of the minute. All aircraft positions for each second were tallied in this manner for the entire experimental run (75 minutes). The number of aircraft within 10 nmi of a fixed point (the center of each cell) was computed for each cell in the grid. Initial analysis did not consider altitude.

The average aircraft density within 10 nmi of each cell was developed for every minute. The BCAS specification density is 0.02 aircraft per $nmi^2$. If the sum of counts in all cells within 10 nmi of the point under consideration exceeded 377 (60 sec/min x $(10\ nmi)^2 \times \pi \times 0.02$ aircraft/$nmi^2$=376.99 aircraft), the average density for the cell in question exceeded 0.02 aircraft per $nmi^2$ for that particular minute. Repeating this process for the 75 minutes of experimental data, the percentage of times the limit was exceeded was obtained for each cell. Figure G-1 presents the results for 10-nmi range and no consideration of altitude. The density legend is in the upper right portion of the figure. Shading identifies the percentage of time the density within 10 nmi exceeded 0.02 aircraft. The pattern depicted indicates the increased density within 15 nmi of Knoxville and the heavier traffic on the routes which converge at Tyson VORTAC.

The above analysis was based on aircraft count within 10 nmi of a cell. Analysis was repeated to identify where the density within 5 nmi of cell exceeded the BCAS specification limit. The regions where this limit was exceeded were considerably reduced. The results of this analysis is shown in figure G-2. The reduction indicates the potential benefits of interrogation power reduction techniques such as whisper-shout.

Figure G-3 represents areas where the BCAS specification limit was exceeded if altitude stratification is considered. The Knoxville traffic model was designed to model the Knoxville terminal area traffic. As a result, overflight traffic above 10,000 feet m.s.l. was not modeled. The regions in figure G-3 represent the plane areas where the density limit was exceeded after altitude filtering had been applied. The results indicate additional reductions in the sizes of the regions where the density limit is exceeded when compared to figure G-1.

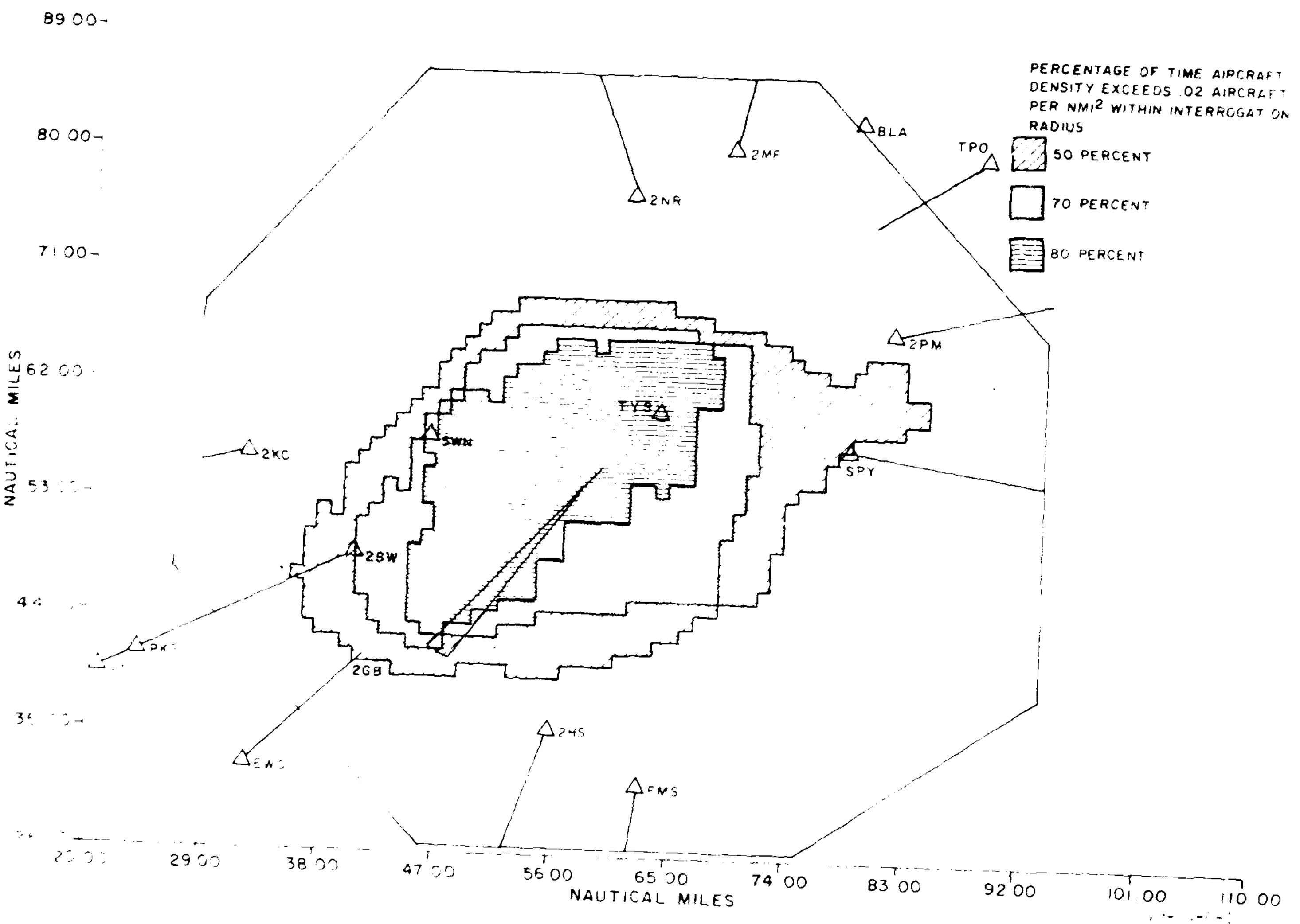



FIGURE G-1. ... 3 NC BCAS WITH 10 NMI INTERROGATION RADIUS

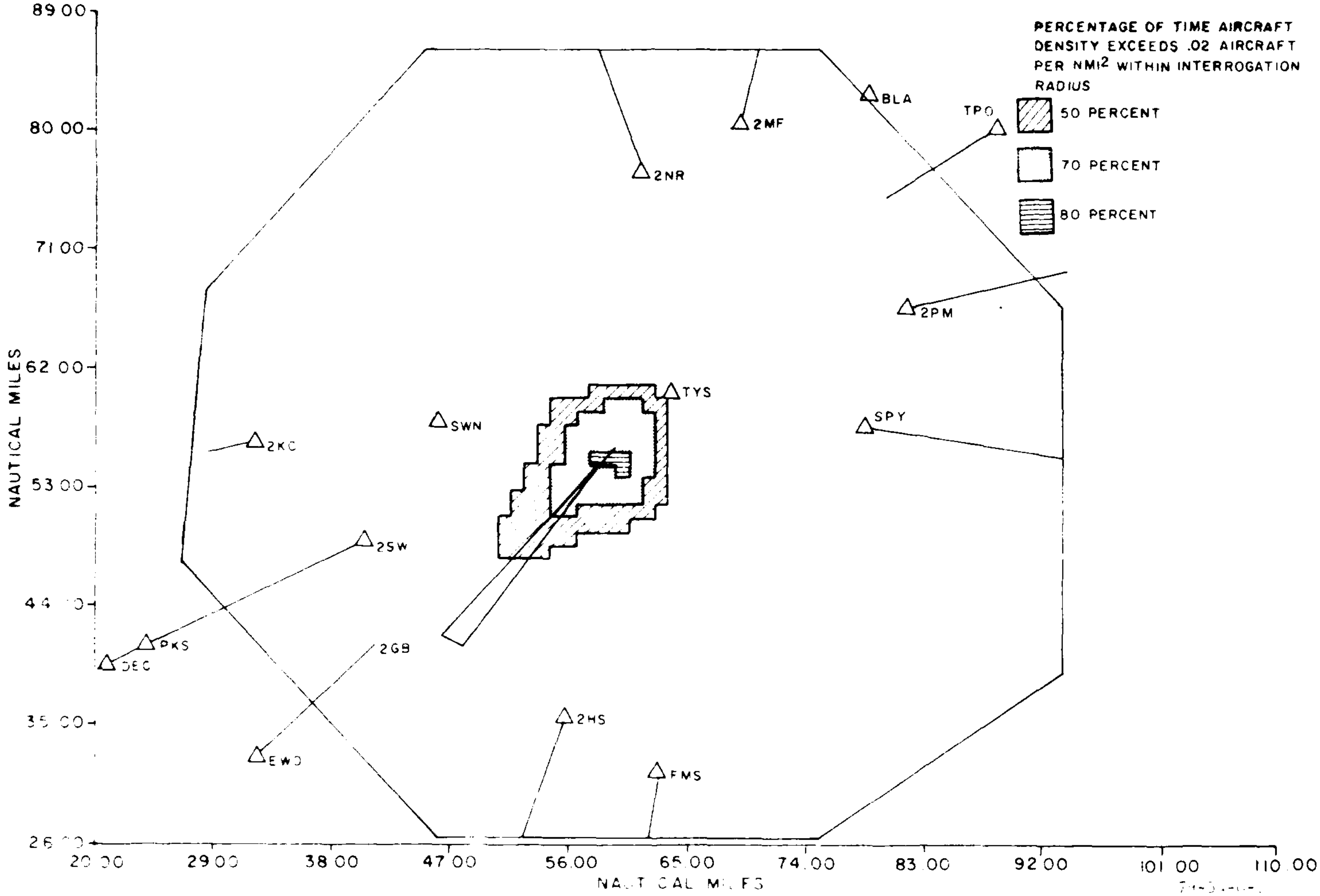
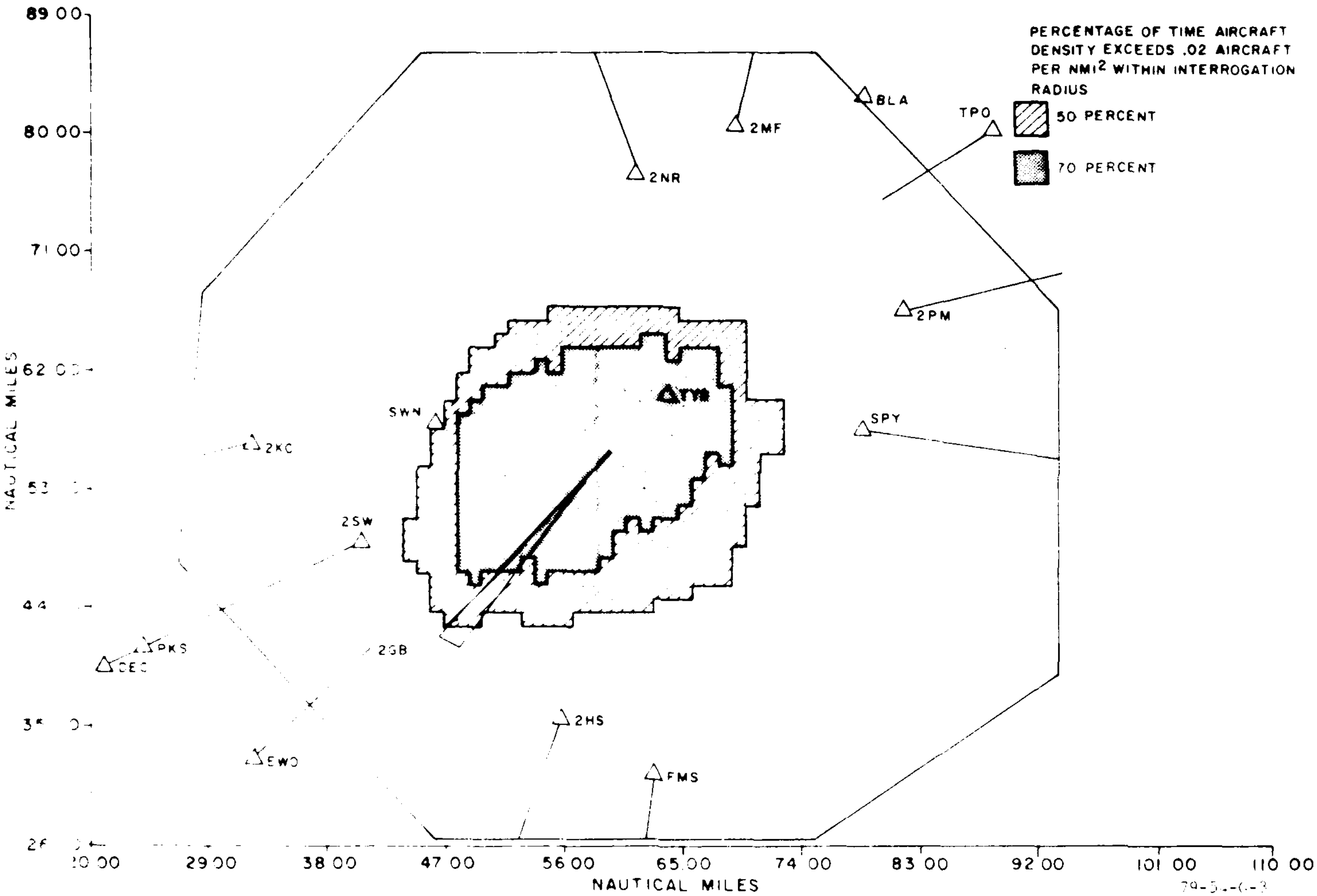



FIGURE G-2. RUN 3 NO BCAS WITH 5 NMI INTERROGATION RADIUS




[illegible] AIRCRAFT DENSITY WITH [illegible]-NMI INTERROGATION RADIUS AND ALTITUDE FILTERING

# APPENDIX H

## DESCRIPTION OF ENCOUNTER PLOTS

A legend for the horizontal view of BCAS encounters is presented in figure H-1 and table H-1. Similarly, a legend for the vertical view is presented in figure H-2 and table H-2.

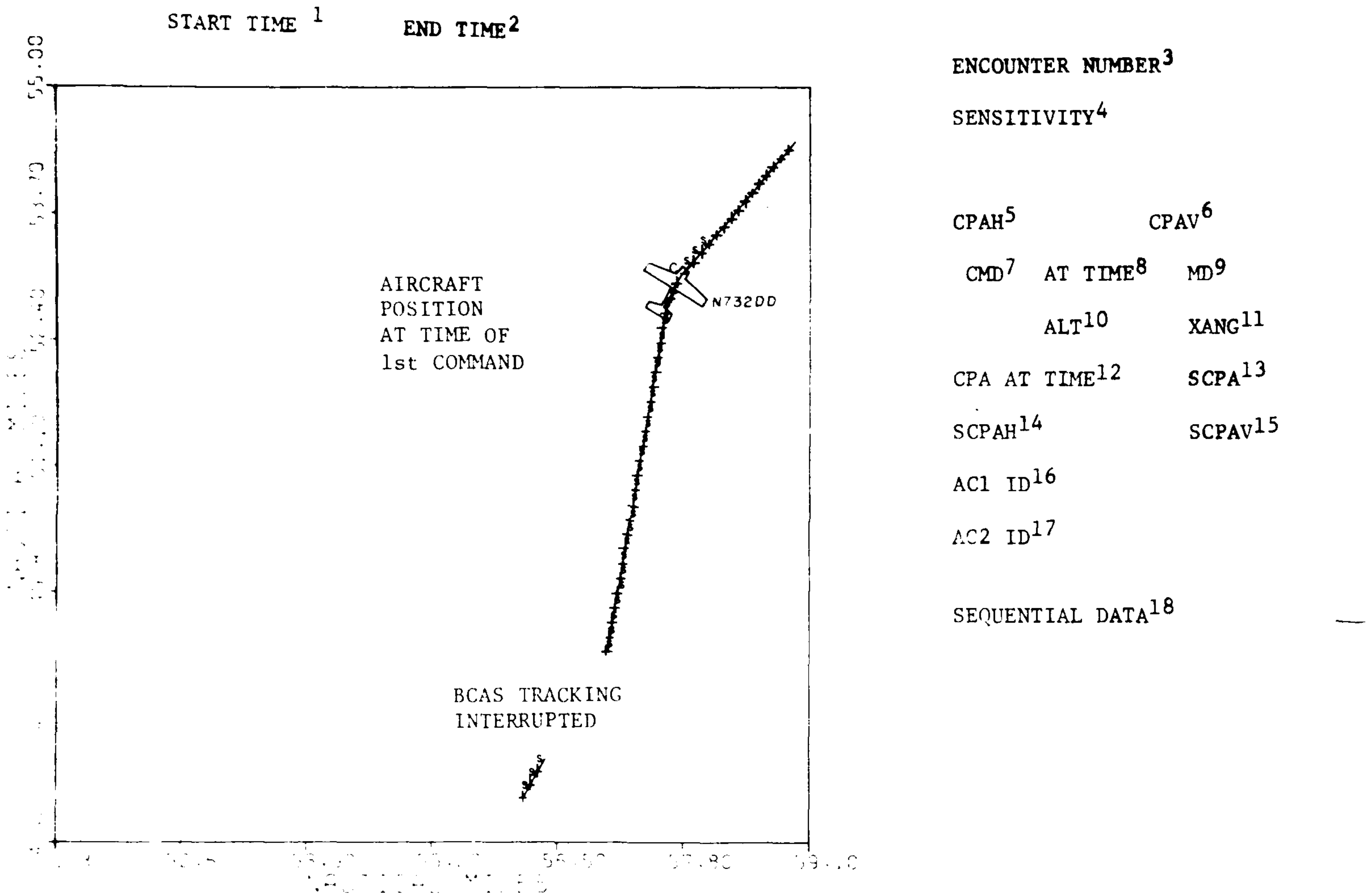



FIGURE H-1. TYPICAL ENCOUNTER HORIZONTAL VIEW

TABLE H-1. INTERPRETATION OF HORIZONTAL VIEW DATA (FIGURE H-1)

1. START TIME = The time in hours, minutes, and seconds when BCAS tracking began for the pair.

2. END TIME = The time in hours, minutes, and seconds when BCAS tracking terminated for the pair.

3. ENCOUNTER NUMBER = Number assigned to the BCAS encounter pair.

4. SENSITIVITY = BCAS performance level at start of encounter.

5. CPAH = The closest horizontal approach in feet for the pair during the encounter period.

6. CPAV = The closest vertical approach in feet for the pair during the encounter period.

7. CMD = 1st BCAS alert for this pair:

| | |
|---|---|
| C = Climb | L+5 = Limit climb to 500 ft/min |
| D = Descend | L+10 = Limit climb to 1000 ft/min |
| NC = No climb | L+20 = Limit climb to 2000 ft/min |
| ND = No descent | L- = Are the complementary limit descent alerts |

8. AT TIME = Time in minutes and seconds for the initial alert in this encounter period.

9. MD = Calculated horizontal miss distance at CPA assuming no horizontal maneuver for either aircraft in the pair.

10. ALT = Relative altitude at time of 1st alert.

11. XANG = Projected crossing angle at time of 1st alert.

12. CPA AT TIME = Time in minutes and seconds of three-dimensional closest point of approach for this pair.

13. SCPA = Slant range in feet at CPA.

14. SCPAH = Horizontal component of SPCA in feet.

15. SCPAV = Vertical component of SCPA in feet.

16. AC1 ID = Identity and BCAS equipment status of aircraft No. 1.

17. AC2 ID = Identity and BCAS equipm[illegible] .

18. The following elements constituted the horizontal view sequential data:

a. TIME = Time in minutes and seconds of the sequential data.

b. AC1 = The alert/advisory being generated for aircraft No. 1. The legend for this entry is

| | |
|---|---|
| S = Steady PPD | LV+5 = Limit climb to 500 ft/min |
| F = Flashing PPD | LV+10 = Limit climb to 1000 ft/min |
| NC = No climb | LV+20 = Limit climb to 2000 ft/min |
| ND = No descent | LV-5 = Limit descent to 500 ft/min |
| C = Climb | LV-10 = Limit descent to 1000 ft/min |
| D = Descent | LV-20 = Limit descent to 2000 ft/min |

c. AC2 = The advisory/alert being generated for aircraft No. 2.

d. ALT = Relative vertical position for the generated PPD (HI = intruder above, CO = intruder within 500 feet vertical, LO = intruder below.)

e. POS = PPD clock position of intruder.

f. RANGE = Range between aircraft.

g. TAUR = Range Tau.

h. TAUV = Vertical Tau (* = not calculated on this cycle).

i. MD = Projected miss distance.

j. RZ = BCAS calculated relative altitude.

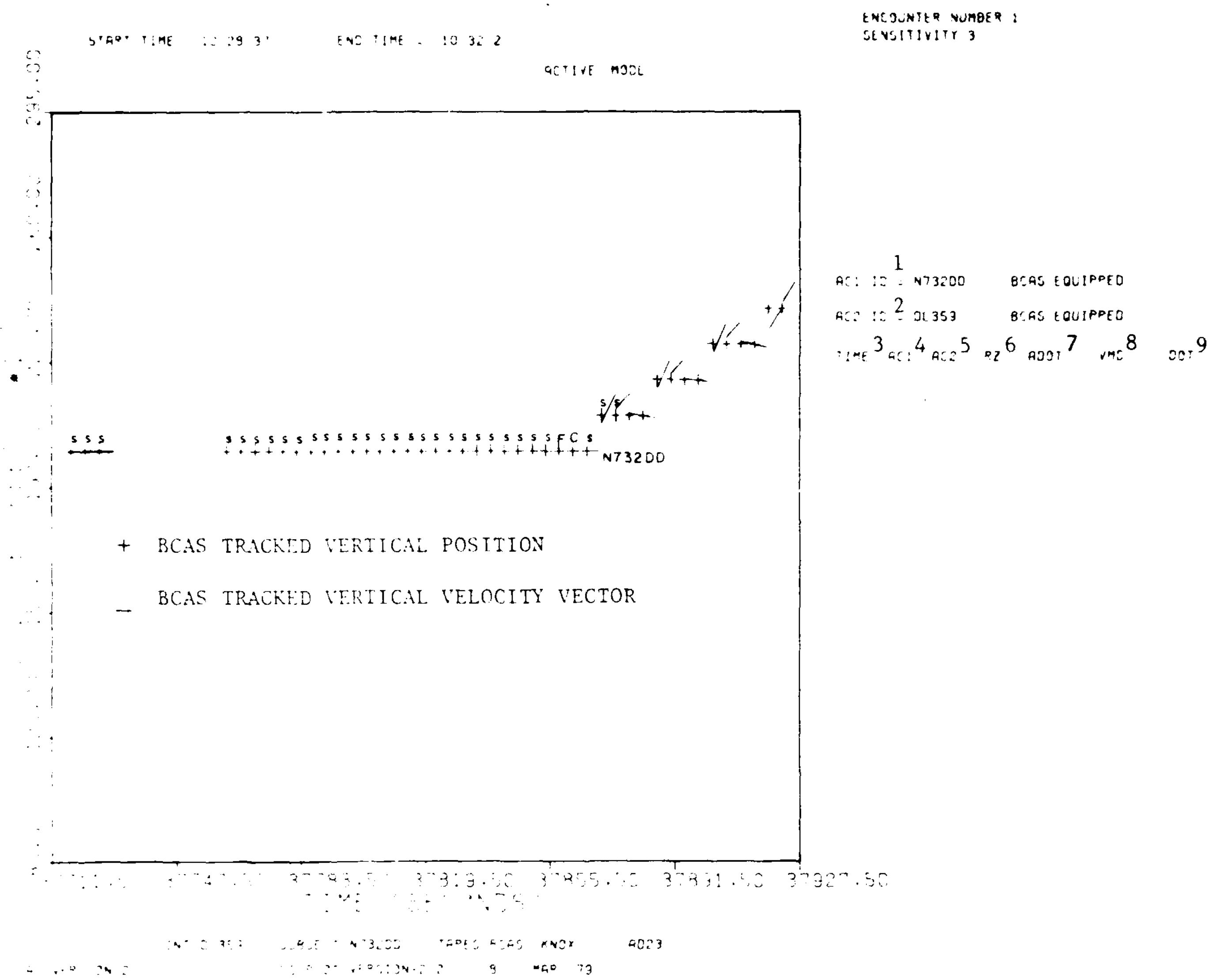



FIGURE H-2. TYPICAL ENCOUNTER VERTICAL VIEW

TABLE H-2. INTERPRETATION OF VERTICAL VIEW DATA (FIGURE H-2)

1. AC1 ID = Identity and BCAS equipment status of aircraft No. 1.
2. AC2 ID = Identity and BCAS equipment status of aircraft No. 2.
3. TIME = Time in minutes and seconds of sequential data.
4. AC1 = Alerts/advisories being generated for aircraft No. 1.
5. AC2 = Alerts/advisories being generated for aircraft No. 2.
6. RZ = BCAS tracked relative altitude.
7. ADOT = BCAS tracked vertical closure rate in feet per minute.
8. VMD = BCAS calculated projected vertical miss distance in feet.
9. DOT = Variable not used by active BCAS.

ND

DATE

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