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ACTIVE BEACON COLLISION AVOIDANCE SYSTEM (BCAS) LOGIC PERFORMANCE DURING OPERATIONAL FLIGHT TESTS

R.A. TORNESE
A.L. MCFARLAND

The MITRE Corporation
McLean, Virginia 22102



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16. Abstract Between 13 July and 9 September 1980, operational flight tests of an Active BCAS Experimental Unit (BEU) were conducted. The flight tests included 129 approaches to 28 different airports during 60 hours of flight: 14 unplanned encounters which gave rise to BCAS alerts were recorded. In each of the encounters, the aircraft carrying the BEU came into a conflict with another aircraft entirely by chance. The other aircraft was not associated with the BCAS test program in any way. The primary purpose of the flight tests was to determine how many unplanned alerts would occur during normal flight operations and to assess whether each was a desirable or unwanted alert. In addition, alert correctness, timeliness, and utility were considered along with the potential impact of BCAS on the ATC system. The data was also used to determine approximately the region(s) where desensitization of BCAS threat logic should be applied to limit unwanted alerts. In addition to the unplanned alerts obtained during the operational flights, an analysis of five other unplanned alerts is also provided. Four of these alerts occurred while conducting planned encounters in the Los Angeles area from 18-20 July and the other alert occurred during a Loran C calibration flight test on 4 August 1980.			
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SUMMARY AND CONCLUSIONS

In 36 hours of flight experience on the Western Tour, the Active Beacon Collision Avoidance System (BCAS) produced alerts against 13 different airborne aircraft. These encounters were entirely unplanned and the other aircraft involved were not a part of the test program. Of these 13 encounters, eight produced a positive advisory at some point during the encounter. The remainder produced only Vertical Speed Limit (VSL) or negative advisories. In 23.5 hours of experience on the Eastern Tour, BCAS produced one alert against an airborne aircraft. This alert also included a positive advisory.

While the BCAS aircraft was on the Western Tour, eight hours of planned encounters with another FAA aircraft were flown in busy airspace in the Los Angeles area. Four encounters occurred when other aircraft, not part of the planned encounter tests, came into conflict with the BCAS aircraft. Two of these four encounters produced positive alerts. All four of these encounters are analyzed in this document. However, for the purposes of computing an average alert rate, these eight hours and the four alerts are not included in the data base because it is felt that the operations being conducted at the time were not typical of normal airline operations.

Four encounters producing alerts on the Western Tour occurred at or below 500 ft above ground level (AGL) when the BCAS aircraft was on final approach. (Three of these encounters produced positive alerts.) It is felt that in normal operations BCAS alerts would be inhibited at or below 500 ft AGL in the vicinity of airports, so these alerts also are omitted from the data base for determining alert rates.

While the BCAS aircraft was being flown for tests that were a part of another project (a Loran C calibration flight), the BCAS experienced an alert on 4 August 1980. Discussion of the encounter causing this alert is also included in this report.

A summary of all of the unplanned encounters analyzed during this study is presented in the following table.

SUMMARY OF UNPLANNED BCAS ENCOUNTERS

Test Phase	Hours of Flight	Intruder Airborne		Intruder on the Ground
		BCAS Above 500 ft AGL	BCAS at or Below 500 ft AGL	
Western Tour (during approaches)	36.0	9	4	30
Los Angeles (during planned encounters)	8.0	4	0	-
Eastern Tour (during approaches)	23.5	1	0	Not Analyzed
4 August (Loran C flight)	-	1	-	-

The conclusions that follow are based on all available data on the encounters listed in this table. It is recognized that the total amount of operational flight experience with BCAS is still relatively small. However, the results do suggest certain trends and conclusions which are enumerated below.

1. With the adjustments to the data base discussed above and combining experience from the Western Tour and the Eastern Tour, BCAS produced an average of one alert of any type in six flight hours. It produced an average of one positive alert in ten flight hours. All of these positive alerts occurred in encounters in which relatively close separations actually occurred or were imminent. Whether each of these alerts would be considered justified in the circumstances is a matter of individual pilot opinion.
2. During the entire BCAS operational tests, no multiple aircraft alerts that were not a part of the planned encounter tests were experienced. (A multiple aircraft encounter is a situation in which the BCAS is issuing resolution advisories against two or more intruders at the same time.) However, there was one situation in the San Francisco area which was nearly a multiple aircraft situation. The alert for one intruder began within five seconds of the time that an alert ended for another intruder.

This shows that multiple encounters are possible and that the BCAS logic is likely to experience multiple encounters in operational flights.

3. Numerous alerts were generated due to aircraft on the ground when the BCAS aircraft was on short final approach. These alerts occurred at nearly every airport visited. A total of 30 such alerts due to aircraft on the ground occurred during the Western Tour. Such alerts were experienced at altitudes as high as 600 feet AGL and for aircraft at ranges from the BCAS aircraft as great as 1.5 nmi. It is felt that this demonstrates conclusively that BCAS operation must be inhibited on short final approach.
4. Several alerts due to airborne aircraft were also received when the BCAS was on short final. Four of the 19 alerts due to airborne aircraft occurred when the BCAS aircraft was at or below 500 feet AGL. Nearly all of these alerts would have appeared justified, had they occurred away from the airport landing patterns. However, when they occur at such low altitudes and in routine airport operations, the nuisance caused by their frequency and the distraction caused in a critical phase of flight may outweigh their benefits. Thus, the flight test results suggest that the BCAS logic should be inhibited from generating resolution advisories when the BCAS aircraft is below 500 feet AGL in the vicinity of an airport.
5. The BCAS detection logic uses progressively smaller detection threshold parameters as an aircraft approaches a major airport. The threshold settings are determined by a sensitivity level setting. The smaller the sensitivity level the smaller the detection thresholds and the associated protection volumes. In sensitivity level 2, BCAS alerts are inhibited. In levels 3, 4, and 5 BCAS uses increasingly larger detection thresholds. During the operational flight tests, some approaches were made in sensitivity level 4 without switching to sensitivity level 3. The results were studied to determine what they suggest about where the BCAS logic should be switched from sensitivity level 4 to sensitivity level 3. The limited data available suggests that switching from level 4 to level 3 at roughly ten nmi would be correct. The data further suggests that a significant number of unwanted alerts would be experienced if level 4 were used too close to the airport.
6. If the proposed nominal sensitivity level boundary separating the sensitivity level 4 region from the level 3 region had been used for the entire flight tests, one less alert would have been experienced. (This boundary is nominally ten nmi from the airport and causes the sensitivity level to switch from level 4

to level 3 when inbound aircraft are ten nmi from the airport.) This one alert was not a positive alert.

7. In all 18 unplanned encounters (except the 4 August encounter) the BCAS logic picked what was clearly the best sense (either the up sense or the down sense) for the resolution advisory.

Due to a sudden vertical maneuver by the intruder just prior to the BCAS selecting the sense of the advisory, the BCAS logic picked the wrong sense of the advisory for the 4 August encounter. In this encounter, the intruder was climbing from below the BCAS aircraft at a rate of about 3000 fpm. The BCAS logic predicted that the intruder would be safely above at the closest slant range and hence issued a don't climb to the BCAS aircraft. However, this intruder leveled off abruptly while still below the BCAS aircraft, effectively defeating the BCAS resolution. At the actual point of closest approach, the intruder was 800 feet below the BCAS aircraft. Since the time of this flight test a new vertical tracker, which is more sensitive to vertical maneuvers, has been developed and incorporated into the BCAS logic. When the surveillance data from the 4 August encounter is replayed through the new vertical tracker, the BCAS logic chooses the correct sense for the advisory. This encounter shows clearly the merit of the new vertical tracker. However, it must be pointed out that the new vertical tracker cannot eliminate the phenomenon of incorrect sense choice due to a sudden maneuver by an unequipped aircraft. It only reduces the probability of its occurrence. In the 4 August encounter, even with the new vertical tracker, the BCAS would have selected the wrong sense if it had selected advisories one second earlier.

8. This residual vulnerability to selecting the wrong sense of the advisory because of vertical maneuvers suggests that the BCAS alert time parameters should not be made any larger than necessary. The uncertainty of predicted future vertical position becomes too great if the prediction time is too large. This effect is illustrated by the fact that the BCAS logic with the original vertical tracker generated the correct sense advisory for the 4 August encounter when using sensitivity level 4 parameters. (The BCAS logic was using sensitivity level 5 parameters in flight.) The level 4 alert time parameter is 25 seconds while the level 5 parameter is 30 seconds.
9. Several advisory transitions involving VSL advisories were observed in the advisory sequences associated with the unplanned encounters. In these transitions, a VSL transitioned to a negative or vice versa, or a VSL transitioned from one magnitude to another. The sense of the advisory did not change during

these transitions. These transitions were often due to small residual oscillations in the vertical tracker. These oscillations caused the BCAS aircraft to momentarily appear to have a small vertical rate toward the intruder, when in fact, it did not. Since the time of these flight tests, the BCAS logic was modified so that the VSL logic would only be applied if the BCAS aircraft had a significant vertical rate toward the intruder. These flight test results lend confirmation to the need for this modification.

10. A VSL was issued at some point during the advisory sequence in only three of the 19 encounters. In only two of the encounters was the VSL the only advisory issued. In all three encounters the BCAS aircraft was in level flight. Hence, with the new logic modification to require significant rate toward the intruder before testing for VSL's, none of the 19 encounters would have resulted in a VSL advisory, either as the only advisory in an encounter or in a sequence with other positive or negative advisories. With the logic modification, a negative advisory would have been issued in place of the VSL in each of the three encounters. Thus, these flight test results fail to confirm the usefulness of the VSL advisory. In none of these encounters did VSL advisories permit the pilot to maintain a vertical rate in a situation where a negative advisory would have interrupted his rate.
11. A Radar Beacon Transponder (RBX) is being developed as part of the BCAS program for installation on the ground at major airports. One of the functions of the RBX is to receive downlinked notification of BCAS generated alerts from the BCAS unit and to relay the information to the terminal Air Traffic Control (ATC) facility for display to the controller responsible for the BCAS aircraft. The operational flight test results were analyzed to determine the characteristics of the alerts that related to this automatic notification feature. Four attributes of the encounters were studied: a) the time prior to the closest point of approach at which the controller receives notification of the BCAS advisory; b) the duration of the advisory; c) the deviation from assigned altitude associated with the BCAS advisory; and d) the frequency with which deviations occur.
 - a) For these encounters, the time from the beginning of a BCAS advisory sequence to the closest point of approach ranged from 34 seconds to five seconds. The average time was 23 seconds. On the average, four seconds should be allowed for communications from the time the advisory first appears in the cockpit until it can be displayed to the controller. This would leave an average of 19 seconds for the controller to see the advisory prior to the closest point of approach.

- b) The duration of the BCAS advisory sequences ranged from five seconds to 37 seconds with an average of 16 seconds.
 - c) Seven encounters (ignoring the four that occurred at or below 500 ft AGL and the four that occurred during planned encounter work) required action on the part of the pilot. Two involved positive alerts which reinforced existing ATC instructions. Two encounters would have involved vertical deviations of 100 ft from the current vertical flight path to comply with the advisory; one encounter would have involved a vertical deviation of 300 ft; and one encounter would have involved a deviation of 400 to 500 ft. The deviation for the New York encounter could not be determined.
 - d) The BCAS aircraft received an advisory indicating a deviation from the flight path, on the average, once in nine hours of flight.
12. During the Western Tour and the Eastern Tour no alerts were generated by BCAS while the BCAS aircraft was under the control of an en route center. The 4 August encounter occurred while the BCAS aircraft was under the control of Washington Center.
13. A deficiency in the collision avoidance logic was observed in one of the encounters in the Western Tour. This deficiency was also previously observed by FAA Technical Center analysts. It relates to the fact that the sense of an advisory and the type of the advisory are determined independently. The sense of the advisory was correct; however, the advisory type selected was not appropriate for the physical situation. The logic will be corrected to cover this special case. The encounter is described in Section 4.7.2.
14. The BCAS surveillance system supported the collision avoidance logic well. In all encounters except one there was good surveillance on the intruder at the time an alert should have been given. In this one encounter the track was not started by the surveillance system until the detection variables had already crossed the alert thresholds. In another encounter, the track on the intruder dropped prematurely immediately after an alert had been generated. Both of these encounters occurred at Denver when the BCAS aircraft was close to the ground and was very close to the airport. These two encounters are being studied to determine the causes for the incomplete tracks.
15. In an encounter in Los Angeles that involved simultaneous alerts from a planned encounter and an unplanned encounter, the surveillance system was observed to swap tracks after both

intruders had passed closest approach. This track swap had no effect on the resolution of this encounter. The track swap in this situation is under study.

16. In the entire Western Tour and Eastern Tour experience there was no instance when BCAS gave an alert that was not produced by an actual aircraft. That is, there were no alerts caused by phantom targets.

1. INTRODUCTION

This document provides an evaluation of the unplanned encounters that were recorded during the Operational Flight Test Phase of the Active Beacon Collision Avoidance System (BCAS) tests.

The BCAS Experimental Unit (BEU) has been subjected to checkout tests at the MIT Lincoln Laboratory, and has also undergone flight testing at the Federal Aviation Administration (FAA) Technical Center. After performing controlled encounter tests at the FAA Technical Center, in which experience with and confidence in the BCAS was obtained, the BEU was flown in an operational environment by visiting 12 different cities in 14 days. This particular series of operational flight tests was conducted from 13-26 July 1980 and was called the Western Tour.

From 28 August to 8 September 1980, the BCAS was flown on another series of operational flight tests at six cities on the East Coast. These tests were called the Eastern Tour.

During the Eastern and Western Tours, a total of 14 unplanned encounters was recorded. An unplanned encounter is defined as an encounter that resulted in a displayed advisory to the pilot from an airborne aircraft that was not a part of the BCAS Operational Flight Tests.

One additional unplanned encounter was recorded during a Loran C flight test on 4 August 1980. This encounter will also be presented in this report.

The aircraft used to conduct the tests was N-40, an FAA-owned B-727 equipped with BCAS, an Instantaneous Vertical Speed Indicator (IVSI) modified to display BCAS advisories, and a tabular alpha-numeric display of the ranges and relative altitudes of nearby aircraft (the Airborne Information Display, or AID).

The BCAS aircraft stayed at Los Angeles for three days, 18-20 July. While there, a series of planned encounters was flown with another test aircraft from the FAA Technical Center, N-49, a Convair 580. The results of these planned encounters are not analyzed in this report. However, while these planned encounters were being conducted, unplanned encounters occurred with four different aircraft. These four unplanned encounters are included and analyzed.

Numerous alerts were displayed to the pilot that were caused by aircraft on the runway surface. In this report, these alerts are not examined in terms of the correctness of the alert. They are, however, used to determine where BCAS should be desensitized in terminal areas.

The primary purpose of the flight tests was to determine how many unplanned alerts would occur during normal flight operations and to assess whether each was a desirable or unwanted alert. In addition to addressing these subjects, this report considers alert correctness and timeliness along with the potential impact of BCAS on the air traffic control system. The data was also used to determine approximately the regions where desensitization of the BCAS threat logic should be applied to limit unwanted alerts.

2. BCAS LOGIC

The BCAS logic areas of concern to the analysis in this report are Collision Avoidance System (CAS) tracking, threat detection, and resolution. A complete description of the logic that was flown is provided in Reference 1. This version of the logic represented an intermediate stage in the development of the collision avoidance logic, between that documented in Reference 2 and that in Reference 3. Brief (and somewhat simplified) discussions of the three areas of interest are presented in this section.

The logic presented in this section and used to obtain all baseline results in this document is the logic as it existed at the time of the operational flight tests. Several modifications have been incorporated into the logic since the flight tests were conducted. In several cases, the effects that these modifications would have had are also presented and discussed.

2.1 CAS Tracking

The CAS tracking logic tracks own aircraft in altitude and tracks intruder aircraft in range and altitude, using alpha-beta (linear) trackers. Altitude rates and range rates are not measured directly. They are derived only through tracking. The smoothing parameter values used in the CAS altitude tracker are ALPHA = 0.4 and BETA = 0.05. It should be pointed out that the small value of BETA causes heavy smoothing of the altitude reports. This reduces the adverse effects of a one-bit change in the altitude quantizer. However, it also means the tracker responds slowly to valid changes in the altitude rate.

The tracking logic is illustrated by providing the altitude tracking equations. Let ZPREV and ZDPREV be the tracked altitude and altitude rate respectively from the previous tracking cycle. Let ZR represent the current altitude report. ALPHA and BETA are the position and velocity smoothing constants respectively. ZP is the predicted altitude for the current cycle based on the previous tracked values. Let ZNEW and ZDNEW be the new tracked values resulting from updating with the current altitude report. DT is the time between tracking cycles which is one second in the current BCAS logic. The tracking equations are:

$$ZP = ZPREV + ZDPREV * DT$$

$$ZNEW = ZP + ALPHA * (ZR - ZP)$$

$$ZDNEW = ZDPREV + BETA * (ZR - ZP)/DT.$$

2.2 Threat Detection

Once per cycle (every second) every intruder track is evaluated by the threat detection logic. An intruder is declared a threat in range if the current range (R) between the two aircraft is decreasing and the estimated time to separation of the threshold (DMOD) (called TAUR) falls below the threshold (TRTHR). The time derivative of range (RD) is used to make this prediction. Similarly, an intruder is declared a threat in altitude if the aircraft are converging vertically and the estimated time to co-altitude (called vertical tau or TAUUV) is less than the threshold (TVTHR); or the current altitude separation (A) is less than the threshold (ZTHR). An intruder must satisfy both range and altitude criteria to be declared a threat. Additionally, the range and altitude criteria must be satisfied at nearly the same time for an intruder to be declared a threat. In all cases discussed in this report, the thresholds (TRTHR and TVTHR) have the same values.

An intruder may be declared a threat by the detection logic on one cycle. However, it takes two declarations out of three consecutive cycles for a resolution advisory to be displayed to the pilot.

TRTHR, TVTHR, DMOD, and other thresholds in the BCAS logic, can take any one of several values. All of these settable thresholds are controlled by a single index called the BCAS sensitivity level. For these tests there were three sensitivity levels used -- level 3, level 4, and level 5. As the sensitivity level number increases, the threshold values increase, producing larger threat warning volumes. Sensitivity level 3 is intended to be used below 10,000 ft altitude near the airports. Sensitivity level 4 is intended for use below 10,000 feet beyond approximately 10 nmi from an airport. Sensitivity level 5 is used above 10,000 ft. Nominal sensitivity level regions are shown in Figure 2-1. In the nominal design there is a sensitivity level 2 region in the immediate vicinity of the airport in which BCAS alerts are inhibited entirely.

The Radar Beacon Transponder (RBX) is a ground station that is planned for installation at major airports to support BCAS operations. An RBX will have the capability of setting the sensitivity level used in a BCAS equipped aircraft when that aircraft is within range of the RBX. A sensitivity level is assigned to each predefined airspace region within the range of the RBX. A map of the regions, with the corresponding sensitivity levels, is stored in the RBX. When a BCAS equipped aircraft is in one of these regions, the appropriate sensitivity level is uplinked to the BCAS avionics.

29,000 FT MEAN SEA LEVEL

18,000 FT MEAN SEA LEVEL

SENSITIVITY LEVEL 5

10,000 FT MEAN SEA LEVEL

SENSITIVITY LEVEL 3

SENSITIVITY
LEVEL 4

SENSITIVITY
LEVEL 4

10 NMI

900 FT ABOVE
GROUND LEVEL

SENSITIVITY
LEVEL 2

2 NMI

RADAR BEACON TRANSPONDER (REX)
LOCATED AT AN AIRPORT

FIGURE 2-1
NOMINAL BOUNDARIES BETWEEN SENSITIVITY LEVEL REGIONS

For these tests, the sensitivity level was changed by manual control in the aircraft. Table 2-1 shows the nominal values used during these tests for the thresholds that vary as a function of sensitivity level. The sensitivity levels were usually changed at boundaries that approximated those in Figure 2-1. However, in a few instances, level 4 parameters were used closer to the airport to see if the need to desensitize to level 3 could be confirmed. In addition, the BCAS alerts were not inhibited in level 2, since one purpose of these flight tests was to collect data at a number of different airports that would help in determining where the level 2 boundary should be placed.

The RBX is designed to carry out a second function in addition to that of controlling the BCAS sensitivity level from the ground: that is, to receive BCAS-generated advisories that are automatically downlinked by the BCAS airborne equipment and to relay them to the terminal ATC facility for display to the ATC controller responsible for the BCAS aircraft. The operational flight test results have been reviewed to determine their implications concerning the need for and the manner of implementing these two functions of the RBX. The results pertaining to the RBX are presented in Section 5.5.

A flow chart of the simplified threat detection logic described above is presented in Figure 2-2.

2.3 Resolution Logic for Unequipped Threats

On the first cycle that an intruder is declared a threat the sense of the potential resolution advisory to the BCAS aircraft is chosen. That is, the decision is made as to whether the direction of the advisory should be climb or descend. If the threat aircraft is not BCAS equipped (as was the case for these flights) then the sense choice of the advisory to the BCAS aircraft depends on the magnitude of each aircraft's vertical velocity.

If both aircraft have a vertical velocity less than a threshold value considered level flight (nominally 600 fpm), then the sense of the advisory to the BCAS aircraft depends on its current tracked altitude in relation to the threat. If the BCAS aircraft is at an altitude the same as or lower than that of the intruder, then the sense of the advisory is descend. Otherwise, the sense is climb.

However, if either aircraft has a vertical velocity greater than the level flight threshold, then modeling is done of the BCAS aircraft's predicted response to both a climb and a descend

TABLE 2-1

SIGNIFICANT THRESHOLDS THAT VARY AS A FUNCTION OF SENSITIVITY LEVEL

THRESHOLD		SENSITIVITY LEVEL			
		2	3	4	5
ALIM	(ft)	--	340	340	440*
DMOD	(nmi)	--	0.1	0.3	1.0
TRTHR	(s)	--	20	25	30
TVTHR	(s)	--	20	25	30
ZTHR	(ft)	--	750	750	750*

* Within sensitivity level 5, these thresholds have additional variations to account for increasing altimetry errors at higher altitudes.

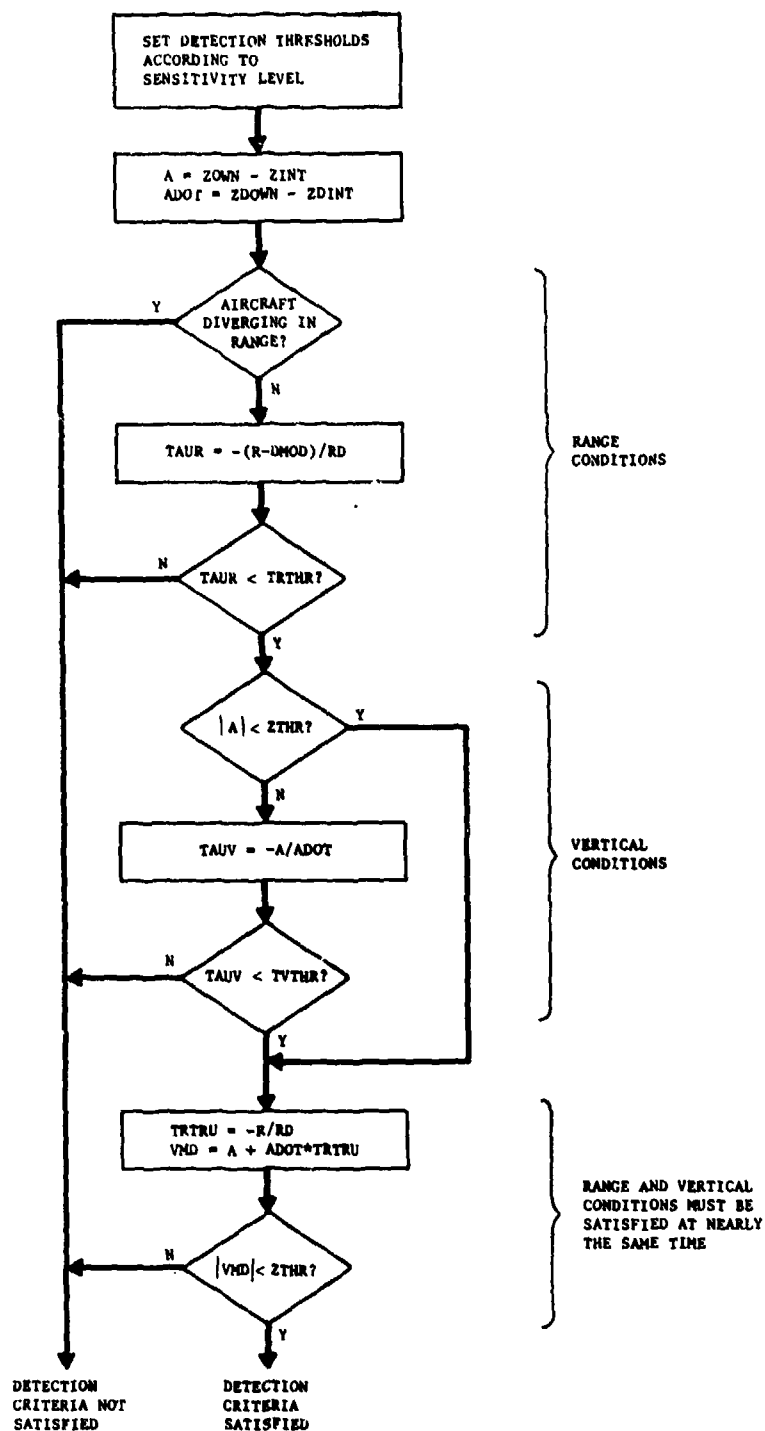


FIGURE 2-2
SIMPLIFIED FLOW CHART OF DETECTION LOGIC

advisory. The period of the modeling is from current time to the estimated time of closest approach (TRTRU, or -R/RD). If TRTRU is too far into the future a maximum look-ahead time is used for the projection. The BCAS aircraft is modeled as accelerating/decelerating at $1/4g$ to the assumed escape rate and then maintaining that rate until time TRTRU. The intruder is modeled as maintaining its current vertical velocity. Then a projected vertical separation at time TRTRU is calculated based on the modeled climb and descend maneuvers of the BCAS aircraft. If the climb maneuver will provide a separation at TRTRU greater than or equal to that of the descend maneuver, then the climb sense is chosen. Otherwise, the descend sense is chosen.

On the second cycle that an intruder is declared a threat the actual resolution advisory is selected. For example, if the sense of the advisory was previously chosen to be climb, then the actual advisory is chosen from the set: climb, don't descend, limit descend to 500, 1000 or 2000 fpm.

When the unequipped threat aircraft has a vertical rate less than a threshold (ILEV) (nominal value of 1,000 fpm) a positive advisory is chosen only if both the current vertical separation (A) and projected vertical separation at closest slant range, which is called vertical miss distance (VMD), are less than the threshold (ALIM). If the threat aircraft has a converging vertical rate greater than or equal to ILEV, then a positive advisory is chosen if VMD is less than ALIM. This latter feature causes a positive advisory to be issued to the BCAS aircraft well before the intruder's altitude comes within ALIM feet, when the intruder has a high vertical rate towards the BCAS aircraft. This is necessary because not enough escape time would be available in this case if the logic were to wait until the intruder had come within ALIM feet.

If the vertical separation is increasing and the separation at closest approach is predicted to be greater than ALIM, even if current vertical separation is less than ALIM, then a positive advisory is not required. This special feature avoids issuing a positive advisory in a vertical divergence situation through use of the VMD variable. VMD plays a role in vertical divergence situations both in the detection logic and in the advisory type selection logic.

If the detection logic indicates that an advisory must be issued, but the conditions for a positive advisory are not satisfied, then either a negative advisory or a Vertical Speed Limit (VSL) advisory will be issued. A VSL will be issued

whenever a VSL will provide adequate separation. If the conditions for issuing a VSL are not satisfied, then a negative advisory is issued.

To choose a VSL advisory, the BCAS aircraft must have a vertical velocity towards the other aircraft and the sense of the advisory must be away from the threat aircraft. Then the maximum vertical velocity which the BCAS aircraft could attain and still be separated in altitude from the threat by ALIM at the time of closest approach is calculated. If this calculated vertical velocity is greater than 500 fpm in magnitude, then a VSL may be given. The calculated VSL is rounded down to the nearest display value of 500, 1000 or 2000 fpm.

A flow chart of the simplified advisory type selection logic is presented in Figure 2-3. This flow chart shows only the logic applying to unequipped threats, since only the logic for unequipped threats was exercised in the operational flight tests. Slightly different logic is used for equipped threats. In Figure 2-3 the two VMD tests could be combined into one to achieve the same logical effect as the flow chart shown. However, the two tests are shown separately to illustrate the two roles played by VMD -- providing extra lead time for unequipped intruders with converging vertical rates, and avoiding positive advisories in a vertical divergence situation.

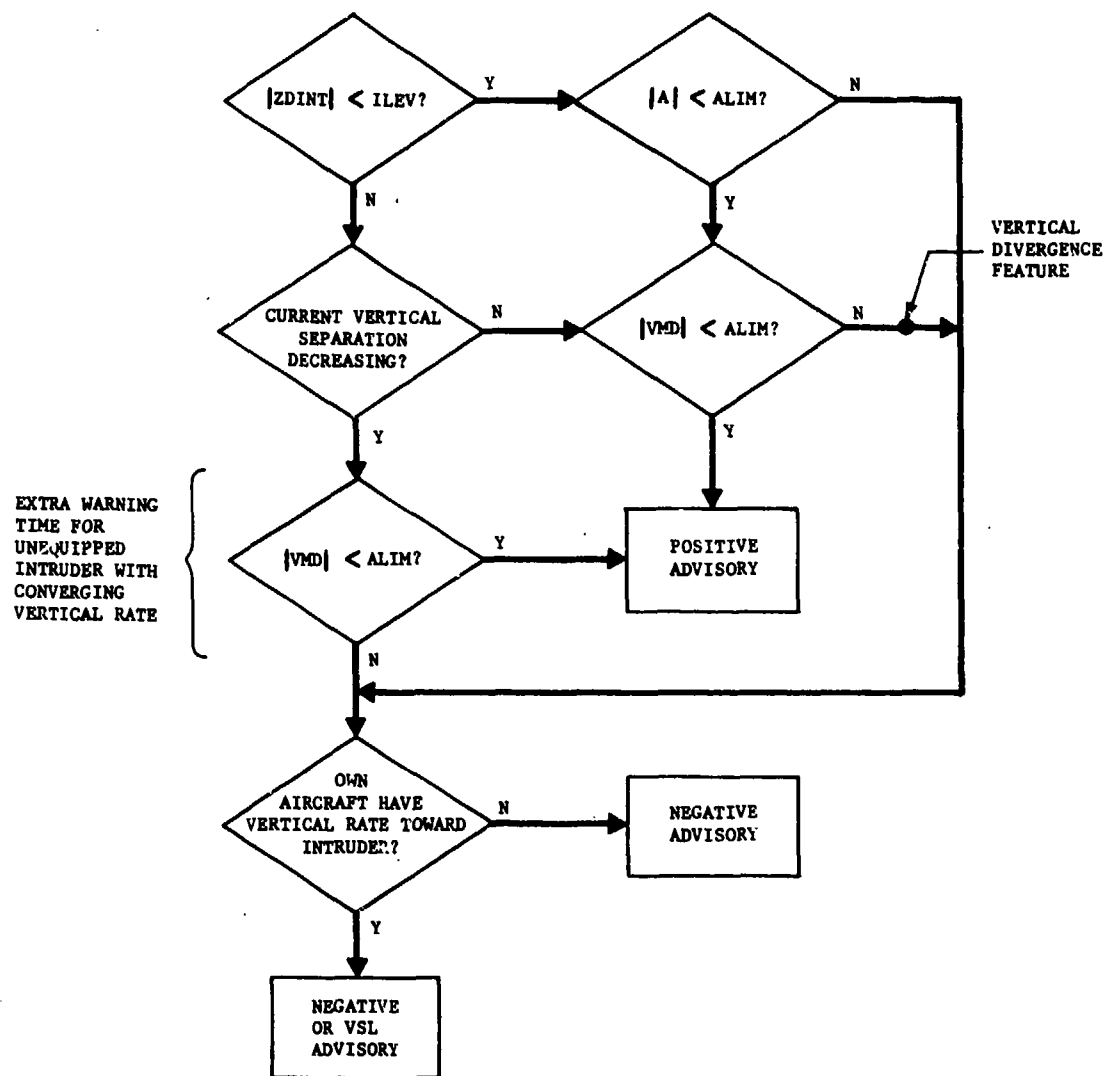


FIGURE 2-3
SIMPLIFIED FLOW CHART FOR DETERMINING ADVISORY TYPE

3. FLIGHT TEST DESCRIPTION

To obtain flight test experience in normal flight operations, the BCAS aircraft was taken to a number of cities on the West Coast and the East Coast of the country. On the Western Tour, the BCAS aircraft visited 12 different cities in 14 days. The 12 cities provided experience at airports having various aircraft densities and operational environments. The tests used standard approach and departure procedures, including the use of parallel runways. The 12 cities visited from 13-26 July 1980 on the Western Tour were Dallas, Houston, Denver, Salt Lake City, Los Angeles, San Diego, Seattle, San Francisco, Oakland, San Jose, Kansas City, and Chicago. From 28 August to 8 September 1980 the BCAS was taken to six cities on the East Coast. The cities that made up the Eastern Tour were Miami, Atlanta, Washington, D. C., Baltimore, Newark, and New York. A total of 28 airports were visited at the 18 cities.

Reference 4 explains the rationale and objectives for the tests. Reference 5 details the tests conducted during the Western and Eastern Tour. Table 3-1 is a summary of the approaches performed at each airport. The number of approaches includes both the initial arrival at an airport and the final departure from it. Other than the initial arrival and final departure, test flights were conducted during peak traffic hours.

An observer was on board the aircraft for each flight to record all BCAS advisories, the time and duration of advisories, the sensitivity level, the BCAS aircraft's transponder beacon code, the test that was being conducted, and any other pilot or personal observations that could help to clarify the source of the advisories. There was also an observer in the Air Traffic Control (ATC) facilities at all times during the flight tests.

At each of the airports visited, a number of standard approach and departure paths were flown by the BCAS aircraft. During these tests data on Air Traffic Control Radar Beacon System (ATCRBS) interrogations and replies, CAS tracks, and BCAS displayed advisories was being recorded on board the aircraft using a Qantex cartridge recorder. At a later time, at the FAA Technical Center, the data was transferred from the cartridges to 9-track tapes for further analysis.

To analyze threat encounters recorded on board the BCAS flights, four data reduction programs were written (see Figure 3-1). The first step in the analysis is to find the encounters on the data tape. A scanning program scans the tape for BCAS display

TABLE 3-1
SUMMARY OF APPROACH TESTS

Location	Number of Approaches	Duration of Tests
Dallas	8	116 min
Houston	7	120
Denver	7	70
Salt Lake City	9	90
Los Angeles	15	289
Seattle	11	146
San Francisco	8	90
Kansas City	7	59
Chicago	10	116
New York	21	525
Atlanta	9	154
Miami	7	87
Washington, D. C.	6	50
Baltimore	4	20
Total	129	1932

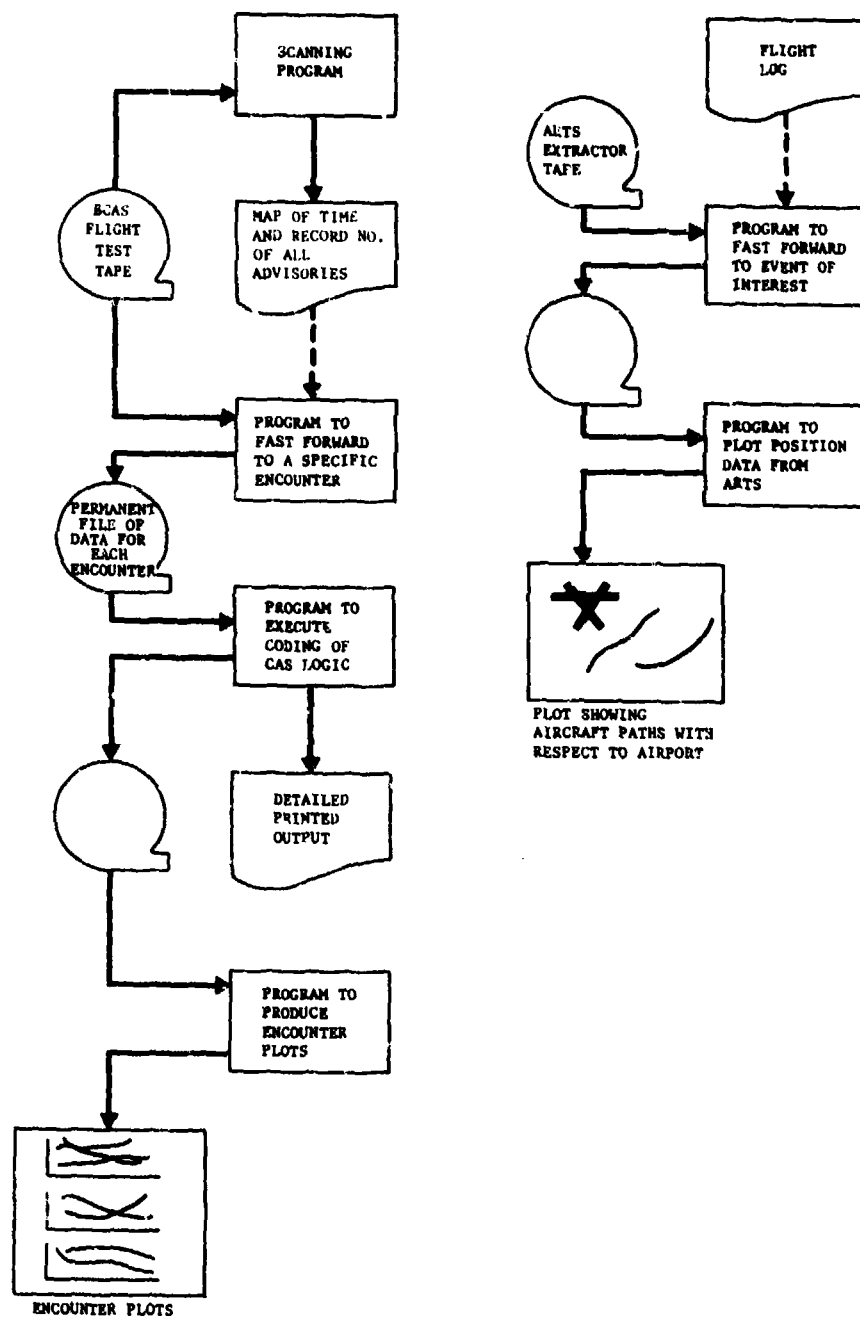


**FIGURE 3-1
FLIGHT TEST DATA ANALYSIS PROCESS**

messages. These messages were created whenever a BCAS advisory was displayed to the pilot on the IVSI. A directory of BCAS advisories, system time, and record number is created. Using this directory and an interactive tape scanning program, the threat tracks that resulted in advisories may be located on the data tape. After locating an encounter and determining the track identification number of the threat, a separate permanent file containing data on each individual encounter is created. These files contain tracked range and altitude information on both the BCAS and the threat aircraft.

To verify the BCAS logic in the BEU at the time of the operational flight tests, a separate version of the BCAS logic was programmed in a fast-time simulation. The file created for each encounter is input to the BCAS simulation. The resulting BCAS advisories should be identical to those generated by the BCAS on board the aircraft. Any discrepancies are investigated and resolved.

The BCAS logic simulation outputs a disk file that may be used to plot various aspects of the encounter on a Calcomp plotter. Plots of aircraft altitude, altitude rate, relative altitude, relative range and calculated tau values versus system time may be generated. Examples of the plots presented in this report are shown in Figures 3-2 and 3-3. The plots in Figure 3-2 are really three separate plots. The X-axis for each plot is the current system time as recorded on the Qantex tape. The range tau (TAUR) and vertical tau (TAUV) values are plotted as the ordinates of the first plot at the bottom of the page. The legend shows which symbol is plotted for each variable. It should be remembered that each variable need not be calculated every second. For example, TAUV is not calculated when the current altitude, A, is less than ZTHR.

If there is a threshold associated with the plotted variable, it is shown as a dashed line and the value is printed in the legend. The thresholds TRTHR and TVTHR are associated with the tau thresholds, TAUR and TAUV, respectively.

The second plot, in the center of Figure 3-2, is a plot of current altitude separation, A, and projected altitude separation, VMD, versus system time. The thresholds for threat detection, ZTHR, and positive/negative advisory selection, ALIM, are both plotted.

The plot at the top of Figure 3-2 shows the current altitude of

the BCAS aircraft, ZOWN, and of the threat aircraft, ZINT, versus system time. The scale for the altitude plot is on the left hand vertical axis. The range between the two aircraft, R, is also plotted. The scale for R, in nmi, is on the right hand vertical axis. The three curves on this top plot provide a representation of the physical geometry of the real world encounter. The other two plots in Figure 3-2 present the time history of the significant CAS logic variables.

Figure 3-3 also presents three plots on one page. The X-axis is system time in seconds. The bottom plot is range with the scale being shown on the left hand vertical axis. The range-rate, RD, is also plotted, with the scale in knots being the right hand axis.

The plot in the center of Figure 3-3 is the altitude rate of the BCAS aircraft, ZDOWN, and the threat aircraft, ZDINT. The units on the Y-axis are fpm. This plot is directly below the plot of the altitude profile of each aircraft. The altitude profiles are repeated on this page so that the plot of altitude rates may be shown directly below the altitude profiles.

Appearing above the top plot is a representation of the advisories generated by the BCAS simulation. To facilitate determining the conditions at the time of the first advisory, a vertical line is drawn through each plot at the time the advisory is given, which is the second declaration of conflict in three consecutive one second cycles.

The arrows indicate the sense of the advisory; an up arrow is climb and a down arrow is descend. An X through the arrow indicates a negative advisory. An up arrow with an X through it is don't climb. A horizontal line through the arrow indicates a VSL and the number of lines indicates the magnitude. One horizontal line through an up arrow is a limit climb to 500 fpm. Two lines indicates a limit of 1000 fpm and three lines indicates a limit of 2000 fpm.

The encounter in Figure 3-2 shows the BCAS aircraft (ZOWN) level at 10,700 ft and a threat aircraft (ZINT) climbing out of 10,000 ft at system time 2175, when a climb advisory was first displayed. At that time, TAUR = 18 seconds and A = 700 ft. The advisory was generated because TAUR was below the TRTHR threshold and the current altitude separation was below ZTHR for two seconds. The range was just over 2 nmi at that time.

The tracked vertical velocity of each aircraft is shown in Figure 3-3. The tracked vertical rate of the threat aircraft (ZDINT) is just over the ILEV threshold (1000 fpm), so the unequipped intruder logic uses VMD to choose the severity of the advisory. Since VMD is less than ALIM, a positive advisory was chosen.

After six seconds, the climb advisory transitioned to don't descend. This was because VMD increased above the ALIM threshold after the BCAS aircraft maneuvered in response to the climb advisory. After receiving the don't descend, the BCAS aircraft began to level-off. The value of VMD began to drop as a result of the BCAS aircraft's level-off. When VMD dropped below ALIM the advisory transitioned from negative to positive. As the aircraft began to diverge in range, the aircraft were no longer declared in conflict.

From the plots shown in Figures 3-2 and 3-3, it is obvious that there are times when data is missing. Data is missing from the BCAS tapes because of problems with the Qantex recorder and overloading of the data recording buffer. The missing data on the plots presented in this report does not necessarily imply that surveillance data on the track was missing at that time. When large gaps of data are missing, this was a problem with the recorder. When data appears in cycles of two to three seconds with a one to two second gap, this was caused by the buffer overflow problem. A fix has been added to the data extraction function of the BEU to alleviate the buffer overflow problem. This fix was present when the BCAS aircraft was flown on the Eastern Tour.

Where possible, Automated Radar Tracking System (ARTS) extractor tapes were obtained from the ATC facilities that include data for the time of the BCAS operational flight tests. For those locations where ARTS III extractor tapes are available, the BCAS and intruder tracks are extracted from the ARTS data to show what the aircraft were doing with respect to the airport.

4. ANALYSIS OF INDIVIDUAL ALERTS

There were 14 unplanned alerts with airborne aircraft recorded during the normal flight tests. Thirteen of these alerts were experienced during the Western Tour, and one during the Eastern Tour. In addition, one alert was recorded during a Loran C flight test on 4 August 1980. There were also four unplanned alerts caused by aircraft not associated with the tests that were recorded during the planned encounter work at Los Angeles from 18-20 July.

These encounters occurred at various stages of flight, from 500 ft above the airport while the BCAS aircraft was on an approach path to 16,000 ft altitude in en route flight.

Table 4-1 identifies the location and date of occurrence of each unplanned encounter. The Mode C altitude, altitude Above Ground Level (AGL), BCAS sensitivity level and the resulting advisory sequence are shown. Both the advisory sequence generated by the BEU in flight and the advisory sequence generated by the BCAS simulation in playback are shown. An encounter identification number is given to each encounter. This number will be used in the report to identify the encounters. Ground level at each airport except San Francisco was determined from the Mode C reports of aircraft on the runway surface. The BEU advisory sequence shown in Table 4-1 considers only the advisories calculated by the resolution logic in the BEU. The BCAS logic has a feature that prevents descend advisories from being issued at less than 500 ft AGL. The logic uses a radar altimeter input to implement this feature. In this situation, a descend advisory is converted to a don't climb advisory. This feature was implemented in the BEU, but was applied outside the computer to the display output coming from the computer. Consequently, the recorded BEU advisories do not reflect the descend inhibit feature.

There were some alerts experienced on the Eastern Tour due to aircraft on the ground at the airports. However, there was only one encounter which produced an alert because of an airborne aircraft. The recorder on the BCAS aircraft was operating at the time of this alert, however, other technical difficulties caused the tape to be unreadable and no analysis of this alert can be made. This alert occurred when the BCAS aircraft was at a Mode C altitude of 900 ft while conducting an approach to LaGuardia airport in New York. Because recorded data was not available, it could not be determined conclusively that the advisories were due to an airborne aircraft. But, due to the location of the BCAS aircraft at the time of the alert, those

TABLE 4-1
UNPLANNED ENCOUNTER SUMMARY

Encounter Number	Location	Date	Mode C Altitude (ft)	Altitude AGL (ft)	Sensitivity Level	BEU Advisory Sequence*	Simulation Advisory Sequence
1	Dallas	7/14	2900	2500	4,3	D, NC, D	D, NC, LC, NC, D
2	Houston	7/14	400	300	3	D, NC	D, NC
3	Houston	7/14	5000	4900	4	C, ND	C, ND
4	Denver	7/15	5600	500	3	D	C
5	Denver	7/15	10700	5600	4	C, ND, C	C, ND, C
6	Denver	7/15	5500	400	3	C	C
7	Denver	7/15	5800	700	3	NC	NC
8	Salt Lake City	7/16	5200	1300	3	ND, C, ND	ND, C, ND
9	Salt Lake City	7/16	5900	2000	3	ND	ND, LD, ND
10	Los Angeles	7/18	7700	7600	4	LD	LD
11	Los Angeles	7/19	7800	7700	4	C, ND	ND
12	Los Angeles	7/19	8200	8100	4	D	D
13	Los Angeles	7/20	8200	8100	4	LD	LD, C
14	Seattle	7/23	3600	3600	4	ND, LD	ND, LD
15	San Francisco	7/24	400	400	4	NC	NC
16	San Francisco	7/24	1700	1700	4	ND, C	C
17	San Francisco	7/24	1500	1500	4	NC	NC
18	Loran C	8/4	16000	-	5	NC	NC
19**	New York	8/29	900	900	3	ND, C	--

* This is the sequence of advisories as calculated by the BEU in the aircraft. These may not be the actual advisories that were displayed because of a hardware problem that was corrected in Los Angeles (See Section 4.2.1).

D - Descend, C - Climb
ND - Don't Descend, NC - Don't Climb
LD - Limit Descend, LC - Limit Climb

** Recorded data not available for the time of this encounter.

present on the aircraft felt it was due to an airborne aircraft. The BCAS issued a don't descend advisory followed by a climb advisory.

4.1 Dallas Encounter

On 14 July 1980, a series of six low approaches to runway 17L at DFW was executed. The BCAS aircraft N-40 (B-727) was used for this series. A number of advisories were seen by the BCAS aircraft that were caused by aircraft on the runway surface. These advisories were seen when the BCAS aircraft was less than 400 ft above the runway and within one nmi of the airport, while BCAS was operating in sensitivity level 3.

4.1.1 Encounter 1

One unplanned encounter occurred with an airborne aircraft in the vicinity of Love Field. Both aircraft were at about 3000 ft altitude, within 10 nmi of the airport. The BCAS aircraft was being vectored to runway 17L while the other aircraft was being vectored to runway 17R. The aircraft were parallel outside the outer marker when the advisories were given. Each pilot had acquired the other aircraft visually before the advisories were given.

This encounter is shown in Figures 4-1 and 4-2. BCAS was operating in sensitivity level 4 when the encounter began, and was changed to sensitivity level 3 during the encounter. The change to level 3 occurred when the landing gear was lowered (which complied with the instructions that the technician controlling the sensitivity level setting had been given for this series of flights). The change in sensitivity level occurred at system time 4978 and is evident on Figure 4-1 by the break in the dotted line representing the TRTHR threshold.

The change in sensitivity level caused the encounter to end sooner than it would have otherwise. However, had the BEU been operating in sensitivity level 3 earlier, the duration of the advisories would have been much shorter. In sensitivity level 3 the advisories would have begun at system time 4981 and lasted for 14 seconds. In sensitivity level 4, the advisories would have begun at system time 4968 and lasted for 34 seconds. The pilot of the BCAS aircraft did not respond to the advisories. Had the BCAS aircraft maneuvered, the duration of advisories and number of advisory transitions would have been less. As the encounter actually occurred, with the switch from sensitivity level 4 to 3, the encounter began at system time 4968 and lasted for 29 seconds.

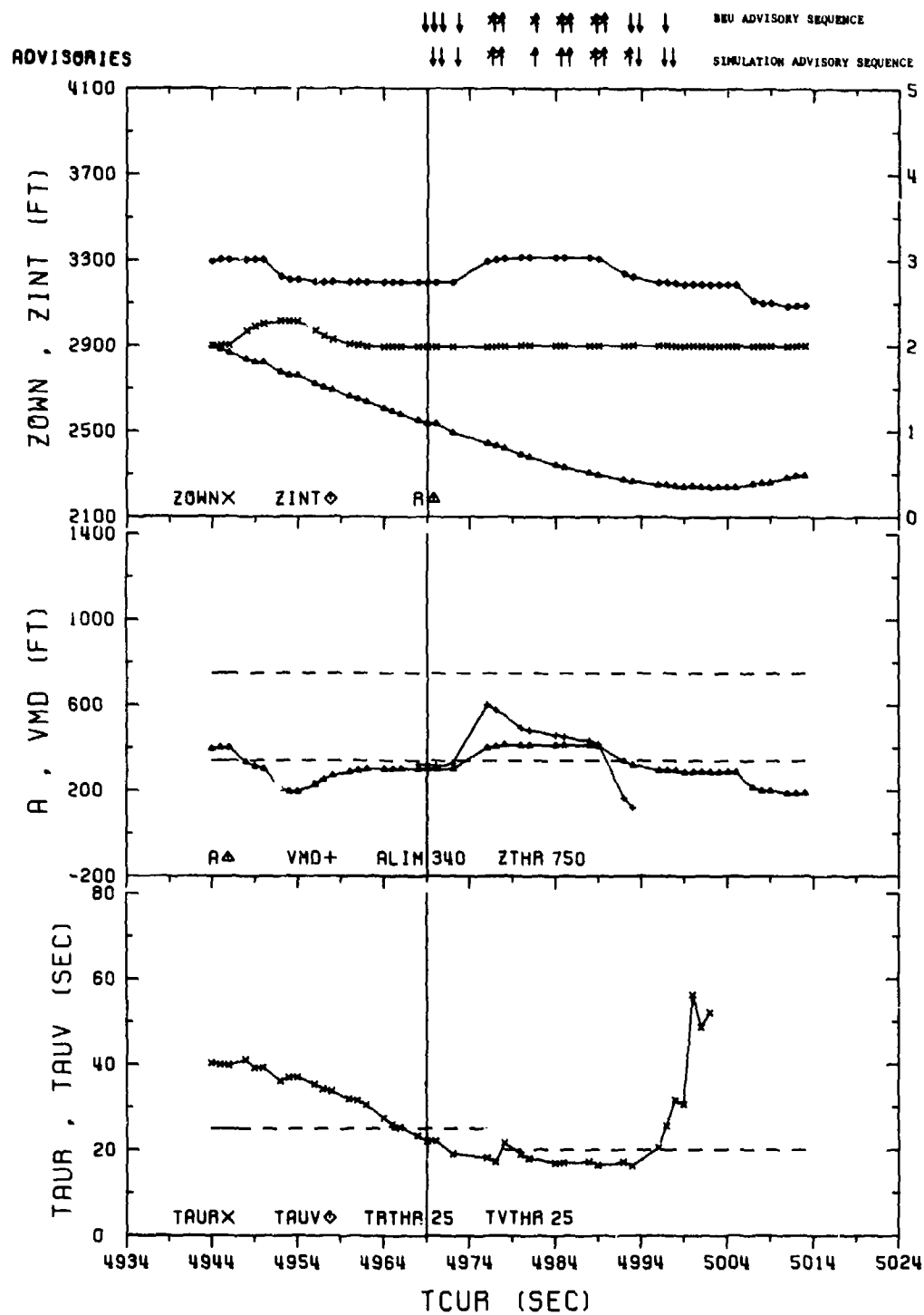


FIGURE 4-1
SEPARATION, TAU PLOTS FOR ENCOUNTER 1 AT DALLAS

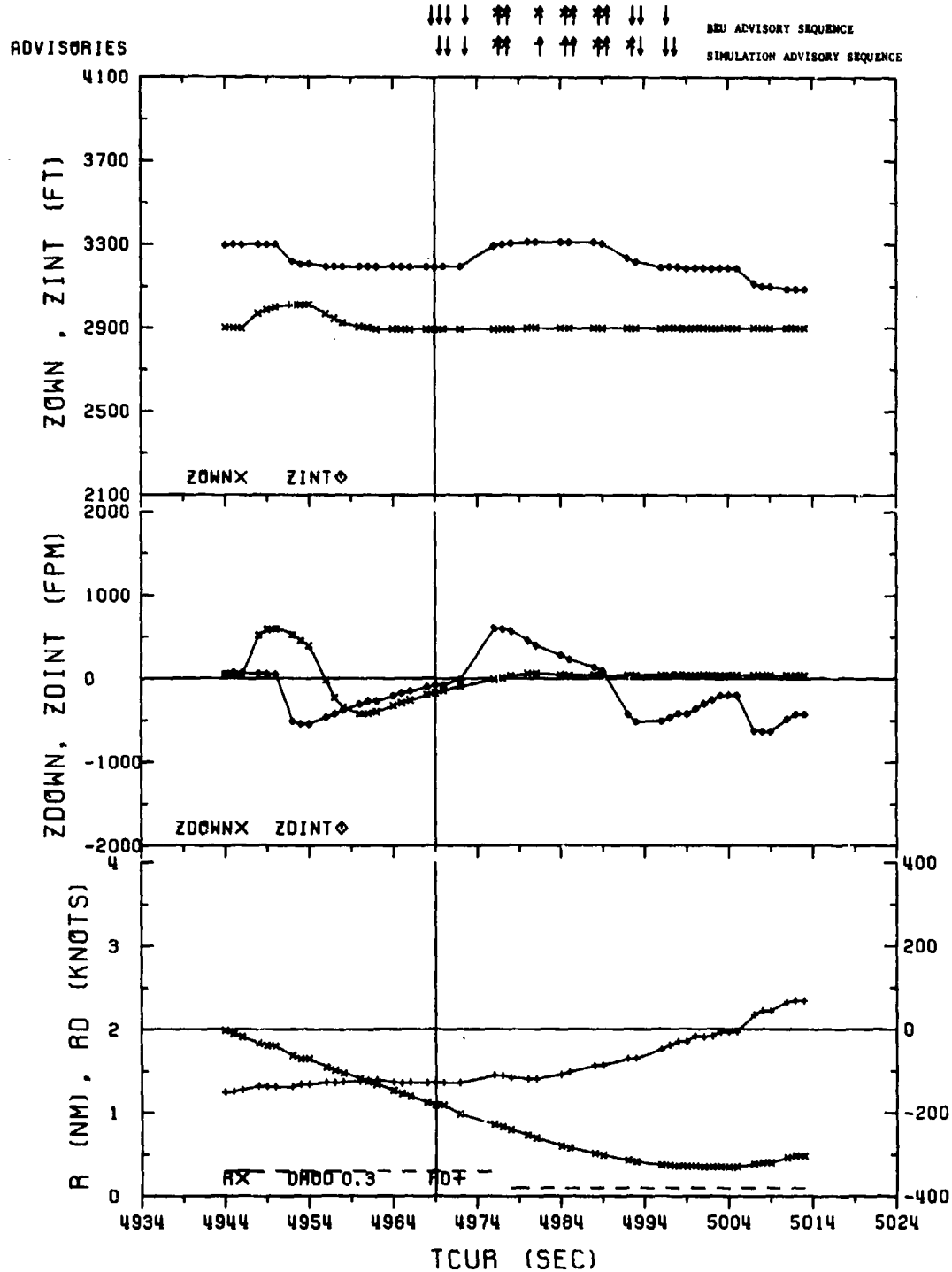


FIGURE 4-2
SEPARATION, RATE PLOTS FOR ENCOUNTER 1 AT DALLAS

Examination of each aircraft's altitude profile in Figure 4-1 shows that the BCAS gave the correct sense advisory. The BCAS aircraft was below the threat, with current and projected vertical separation less than ALIM, which resulted in a descend advisory. A slight altitude excursion by the intruder resulted in the advisory transitioning to negative, then to a VSL and then back to a positive as the intruder came back within ALIM feet of the BCAS aircraft. The encounter ended as the TAUR value increased above the threshold of 20 seconds, just prior to closest approach.

The number of advisory transitions appears to be excessive. However, it should be noted that they were all caused by maneuvers on the part of the intruder, not the BCAS aircraft. Had the BCAS aircraft responded to its advisory, the advisory would have transitioned to a negative after only a 100 ft descent by the BCAS aircraft. Then the advisory would have stayed a negative until dropping at horizontal closest approach.

The gaps in the data seen in the simulation plots are caused by the buffer overflow problem discussed in Section 3. Advisories are shown on the plots only when there is data recorded on the tape. Therefore, gaps are seen in the advisory sequence also. These gaps did not occur in the advisories displayed on board the aircraft during the tests and they do not occur in normal operation of the BCAS logic. The BCAS operation and advisory display were not affected by the tape recorder problems.

4.2 Houston Encounters

On the afternoon of 14 July 1980 a series of five low approaches to Houston Intercontinental was executed. One advisory was seen while the BCAS aircraft was in the vicinity of the airport, caused by an aircraft on the ground. This advisory occurred within one nmi of the airport and at an altitude less than 500 ft above the runway, while the sensitivity level was set to 3.

4.2.1 Encounter 2, Helicopter Encounter

There was one advisory received close to the airport that was felt to be useful by the pilot. On the first low approach event to runway 14, while the BCAS aircraft was on final approach, a helicopter that was cleared to runway 9S flew over and behind the BCAS aircraft. Figure 4-3 shows a plot of this situation from the ARTS extractor tape. The BCAS aircraft is beacon code 4625 and the helicopter is beacon code 0447. On this plot a character is used to plot the position of each aircraft on each

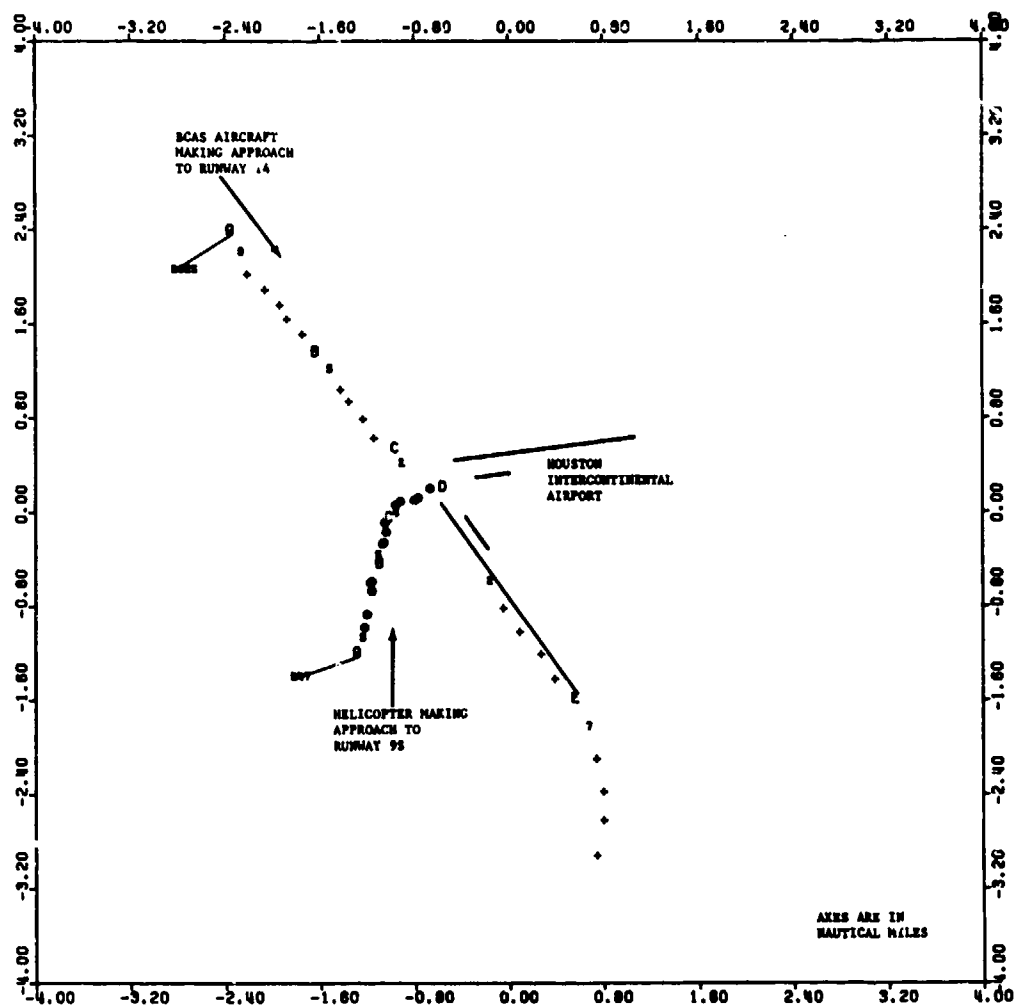


FIGURE 4-3
ARTS PLOT OF ENCOUNTER 2 AT HOUSTON

scan of the ground radar. Every 30 seconds the character used to plot the position is a capital letter. This allows one to determine the positions of the two aircraft at the same time. The plotter uses the capital letters in alphabetical order. This feature makes it possible to determine the direction in which the aircraft were flying the tracks. After each alphabetic character, a decimal character is plotted which indicates the aircraft's Mode C altitude at that point in hundreds of feet. Different symbols are used for the two aircraft to plot the other intervening points. The runways at Houston are also plotted.

Figures 4-4 and 4-5 show this encounter as viewed by BCAS. These figures show the result of the simulation's processing of the flight data. There is a feature in the BCAS logic that prevents a descend advisory from being displayed when the BCAS aircraft is below 500 ft AGL. If a descend would normally be required when below 500 ft AGL, a don't climb advisory will be displayed instead. The BCAS unit determines height above the ground from a radar altimeter on the BCAS aircraft. This feature to inhibit descend advisories when less than 500 ft AGL was not programmed in the simulation, so a descend advisory, instead of a don't climb advisory, appears in Figures 4-4 and 4-5.

The BEU produced a descend advisory which was converted to a don't climb for the display, which was correct. However, it was subsequently determined that there was a hardware problem in the BEU related to this descend inhibit feature. This problem caused the descend inhibit rule to be applied in situations much higher than 500 ft AGL. This problem was discovered during the planned encounters at Los Angeles, when don't climb advisories appeared during encounters in which the pilot was expecting a descend. The problem was corrected at Los Angeles. The BEU advisory sequences in Table 4-1 show what advisories the BEU calculated, but do not necessarily indicate the advisories that were displayed to the pilot.

4.2.2 Encounter 3, Head-On Encounter Away From The Airport

The other unplanned encounter at Houston (Figures 4-6 and 4-7) occurred within 15 nmi of the airport, at 4500 ft AGL. The two aircraft were converging at about a 130° crossing angle. The intruder was seen on the AID in the BCAS aircraft, and both pilots were notified of the traffic by the controller. The BCAS aircraft was advised to climb to 6000 ft prior to the BEU issuing a climb advisory. The BCAS aircraft began a climb in

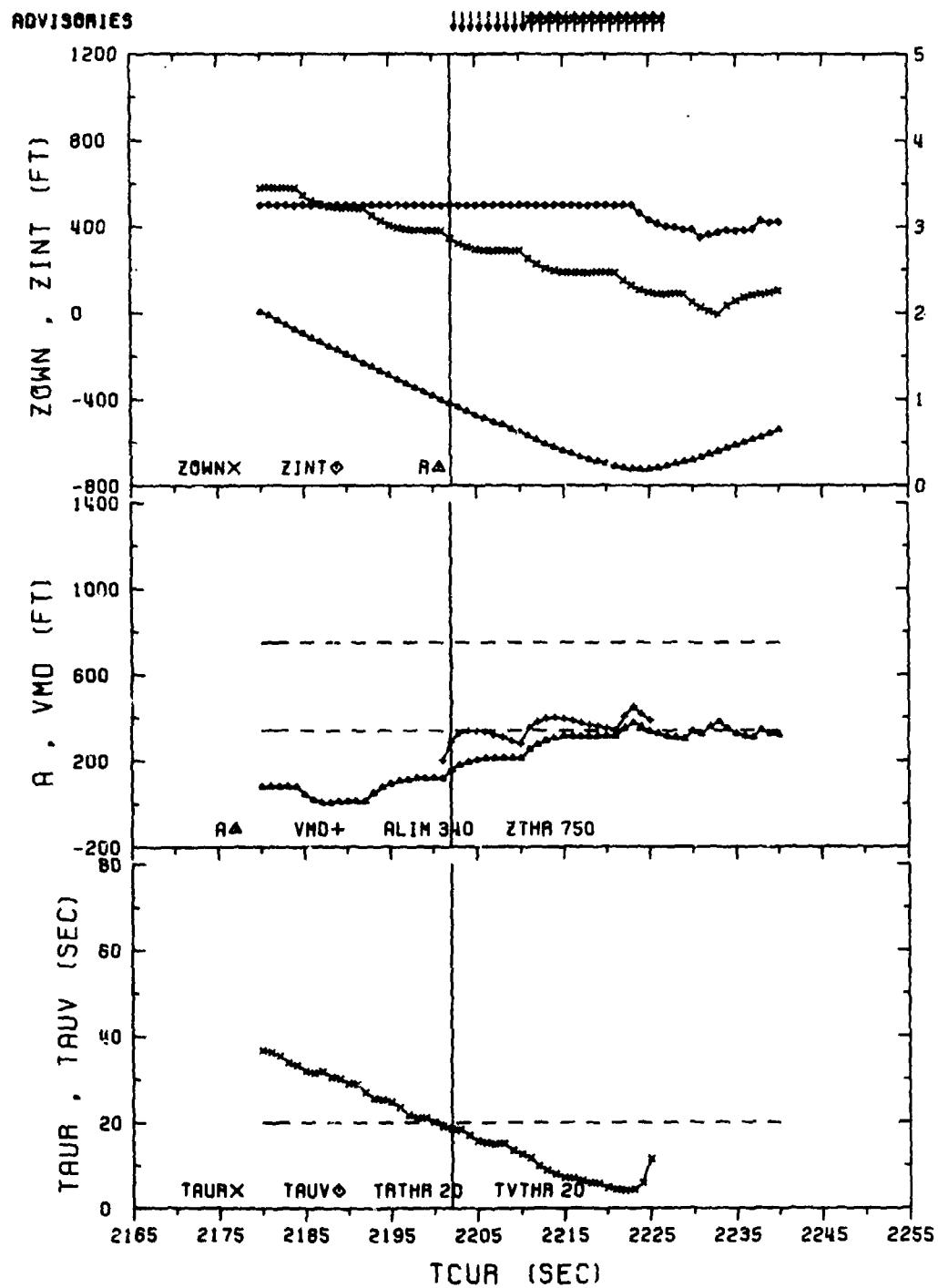


FIGURE 4-4
SEPARATION, TAU PLOTS FOR ENCOUNTER 2 AT HOUSTON

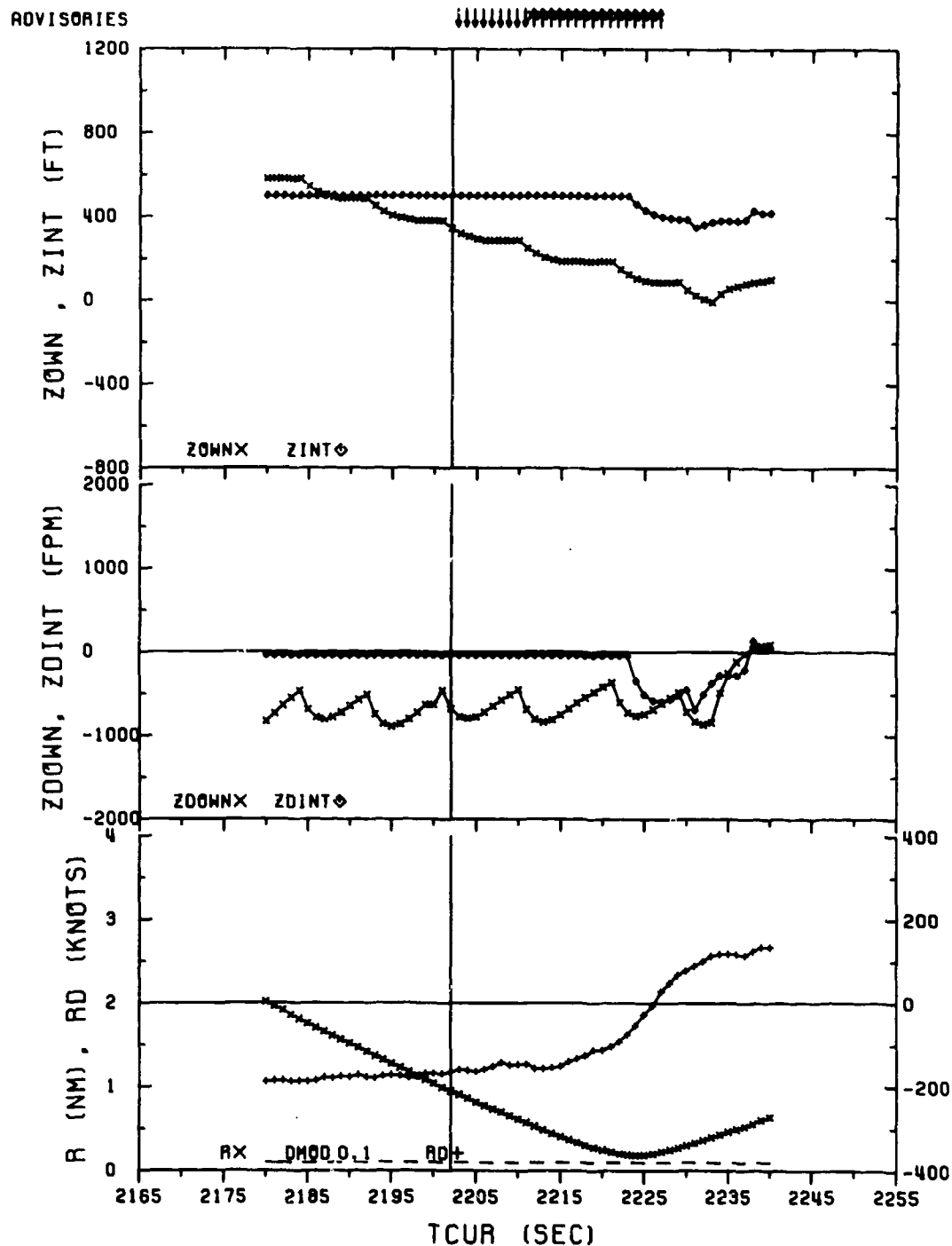


FIGURE 4-5
SEPARATION, RATE PLOTS FOR ENCOUNTER 2 AT HOUSTON

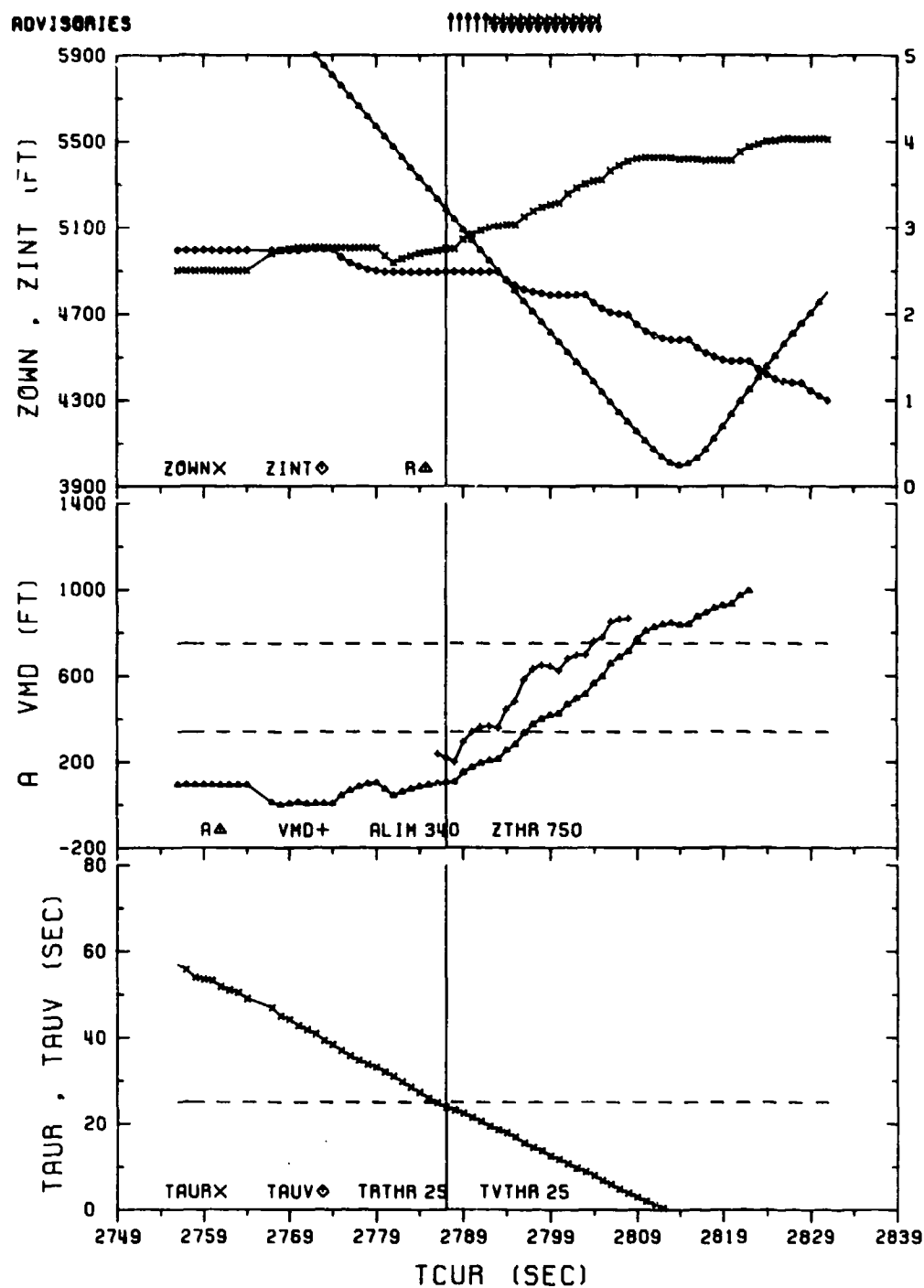
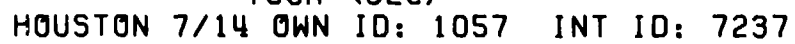


FIGURE 4-8
SEPARATION, TAU PLOTS FOR ENCOUNTER 3 AT HOUSTON

↑↑↑↑↑↑↑↑↑↑↑↑↑↑



4-12

response to the advisory. After the projected vertical separation at closest approach (VMD) crossed the ALIM threshold, the advisory transitioned to don't descend and remained negative until the advisory ended. In this encounter, the BCAS advisory matched the advisory given by the controller.

This encounter illustrates the vertical divergence features that are incorporated in the BCAS logic. If the aircraft are diverging vertically, the vertical separation at predicted closest approach (VMD) is compared to the threshold ALIM. If it is greater than ALIM, even if current vertical separation (A) is less than ALIM, a positive advisory transitions to a negative advisory. If VMD is greater than ZTHR, even if A is less than ZTHR, a negative advisory transitions to no advisory.

4.3 Denver Encounters

On 15 July 1980 a series of five low approaches to Denver Stapleton airport was executed. Aircraft N-40 (B-727) was used for this series. Three advisories with airborne aircraft were seen near the airport while operating in sensitivity level 3. A fourth encounter was seen while in sensitivity level 4, at about 5000 ft AGL. When using the figures of the Denver encounters, it should be remembered that the runway elevation at Denver is 5100 ft. Numerous alerts were caused by aircraft on the ground when the BCAS aircraft was within 1.2 nmi and 500 ft of the airport.

4.3.1 Encounter 4, Close Parallel Approach

This encounter at Denver occurred while the BCAS aircraft was on short final approach, with the other aircraft landing on the parallel runway (see Figures 4-8 and 4-9). A climb advisory occurred when the BCAS aircraft was at 400 ft AGL.

The separation at closest approach for this encounter was 0.15 nmi, or about 900 ft. This is a very close situation that would seem to warrant an advisory. In this case, though, the aircraft were landing on parallel runways that are separated by only 900 ft. If the same separations had existed in a random encounter away from the airport, the alert would certainly seem justified. However, in the circumstances here (where normal parallel approaches are being conducted and the altitude is only 400 ft AGL) the alert could be more harmful than beneficial by distracting the pilot during a very high workload period.

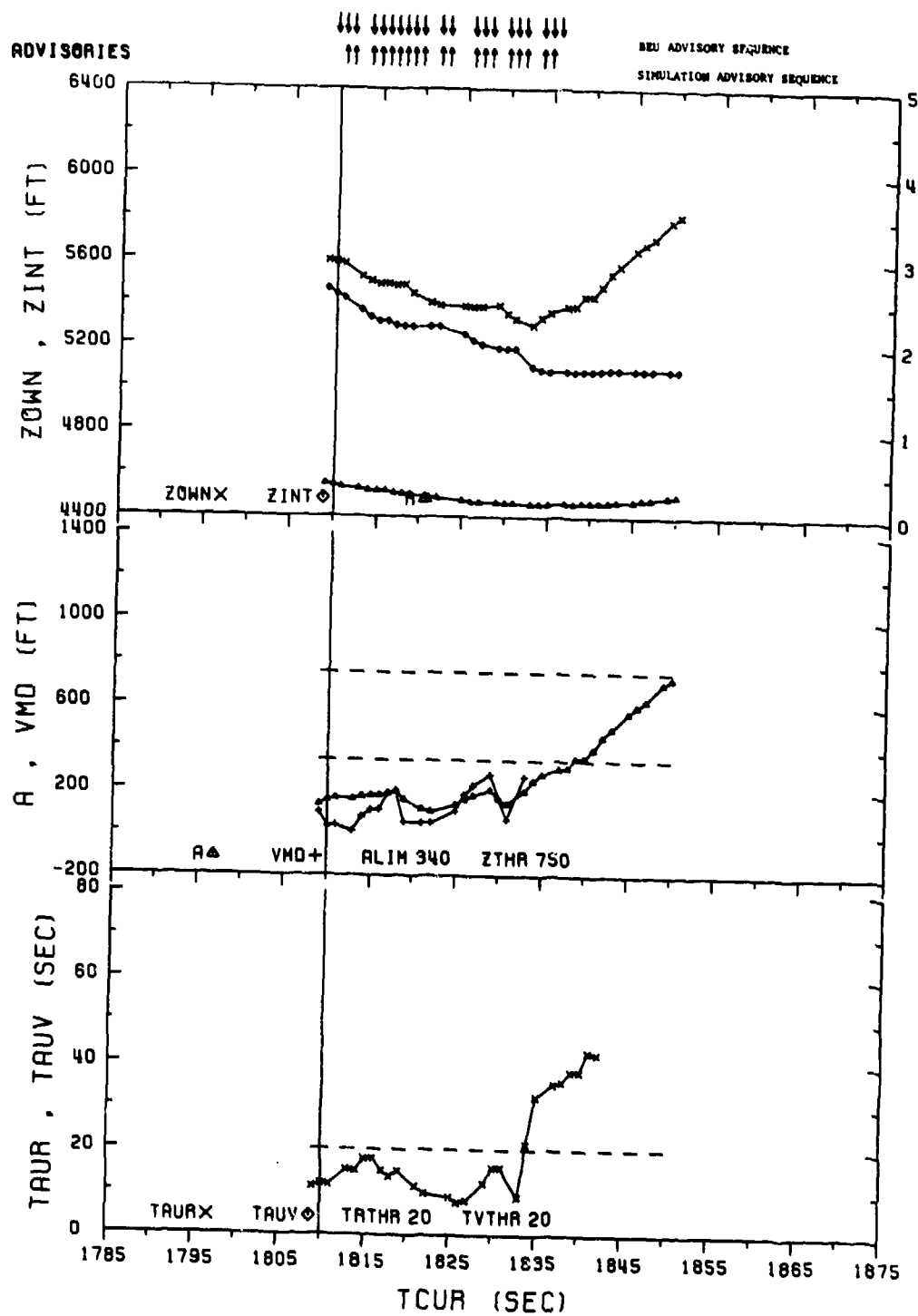


FIGURE 4-8
SEPARATION, TAU PLOTS FOR ENCOUNTER 4 AT DENVER

Figure 4-8 shows that the simulation calculated a climb advisory. However, the BEU calculated a descend advisory. (Recall that a descend advisory is converted to a don't climb advisory when below 500 ft AGL. However, this conversion takes place outside the BEU computer and is not reflected in the recorded data.) Since all data is missing from the tape just prior to the advisory sequence, the cause of this discrepancy cannot be conclusively established. However, because all of the alert variables are well below threshold on the first cycle of data, it is evident that the BEU had chosen a descend based on earlier data. It is presumed that the descend was the correct choice at that time. At the time the simulation generated the advisory, the aircraft were within 100 ft of each other in altitude. It is entirely plausible that shortly before that time they were even closer vertically, so that a descend would have been appropriate.

In Figure 4-8 the CAS logic variables are all well below threshold at the beginning of the plot. The BEU data tape was investigated for a period of time prior to the time of the first data on this plot. It was determined that there was a recording gap for four seconds prior to the first data plotted during which surveillance data was not present for any track. During the period of time prior to the four second gap there was data on other tracks, but the track shown in Figure 4-8 did not appear. It seems clear that this track was only started by the BCAS surveillance system at or near the time of the beginning of the plot. This is the only encounter for which the surveillance system did not have a well established track at the time the alert should have been given. The BCAS aircraft was close to the ground and was very close to the airport at the time of this alert. The cause for the missing track in this encounter is under investigation.

4.3.2 Encounter 5, Intruder With Vertical Rate and Pilot Response to Advisory

The encounter at 5000 ft AGL occurred while the BCAS aircraft was being vectored for final Instrument Landing System (ILS) approach to runway 26R. The other aircraft (B-727), was climbing out from departure (see Figure 4-10). Each pilot had acquired the other aircraft visually. The BCAS was operating in sensitivity level 4 and computed a climb advisory. The BCAS aircraft responded to the positive advisory by climbing. As the aircraft began to diverge vertically, the advisory transitioned

ADVISORIES

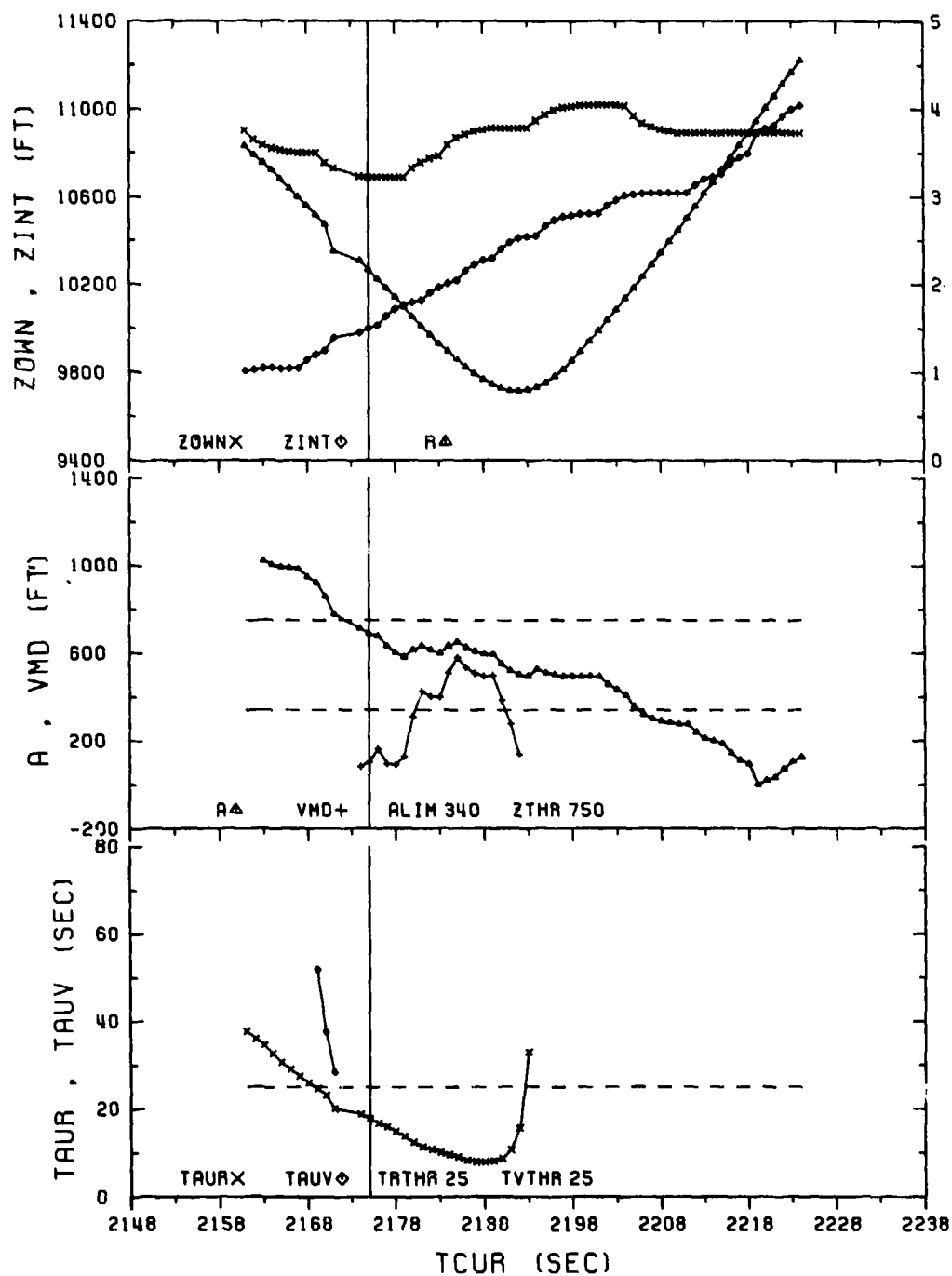


FIGURE 4-10
SEPARATION, TAU PLOTS FOR ENCOUNTER 5 AT DENVER

to negative. The BCAS aircraft responded to the negative advisory, Don't descend, by leveling off. After the level-off, VMD dropped below ALIM and the advisory transitioned back to positive. VMD alone was used to determine the severity of the advisory since the intruder had a rate greater than 1000 fpm (see Figure 4-11). This is an example that shows how the BCAS logic gives an earlier alert against an unequipped intruder with a high converging vertical rate.

While two transitions occurred in this advisory sequence, they both reflected the continuing evolution of the conflict. Because the intruder continued to close vertically on the BCAS aircraft, the second set of positive advisories was considered quite appropriate. The number of transitions seems justified in this case.

4.3.3 Encounter 6, Parallel Approach

The encounter shown in Figures 4-12 and 4-13 also occurred on short final. The BCAS aircraft was approaching runway 26R and the threat aircraft was approaching runway 26L. At the time of the advisory the BCAS aircraft was at 400 ft AGL. The threat aircraft touched down just after the advisory appeared. In this encounter, as in encounter number 4, the advisory appeared during a period of critical pilot workload. The range at closest approach was about 1000 ft because the aircraft were in an approach pattern to parallel runways that are separated by only 900 ft.

4.3.4 Encounter 7, Final Approach

The last encounter at Denver (see Figures 4-14 and 4-15) also occurred on final approach. At the time of the alert, the BCAS aircraft was at 700 ft AGL. The advisory for this encounter, which was a don't climb, was considered undesirable by the pilot. In fact, the pilot felt that he had received the wrong sense advisory for this encounter. The pilot had visually acquired an aircraft in front of and slightly below the BCAS aircraft. Since that aircraft was slightly below the BCAS aircraft, the pilot felt that the advisory should have been either climb or don't descend, but not don't climb.

Examination of the BCAS tape shows that the aircraft acquired visually by the pilot was not the source of the advisory. Another aircraft, not seen by the pilot at range 1.3 nmi and 600 ft above the BCAS aircraft was the source of the advisory. This

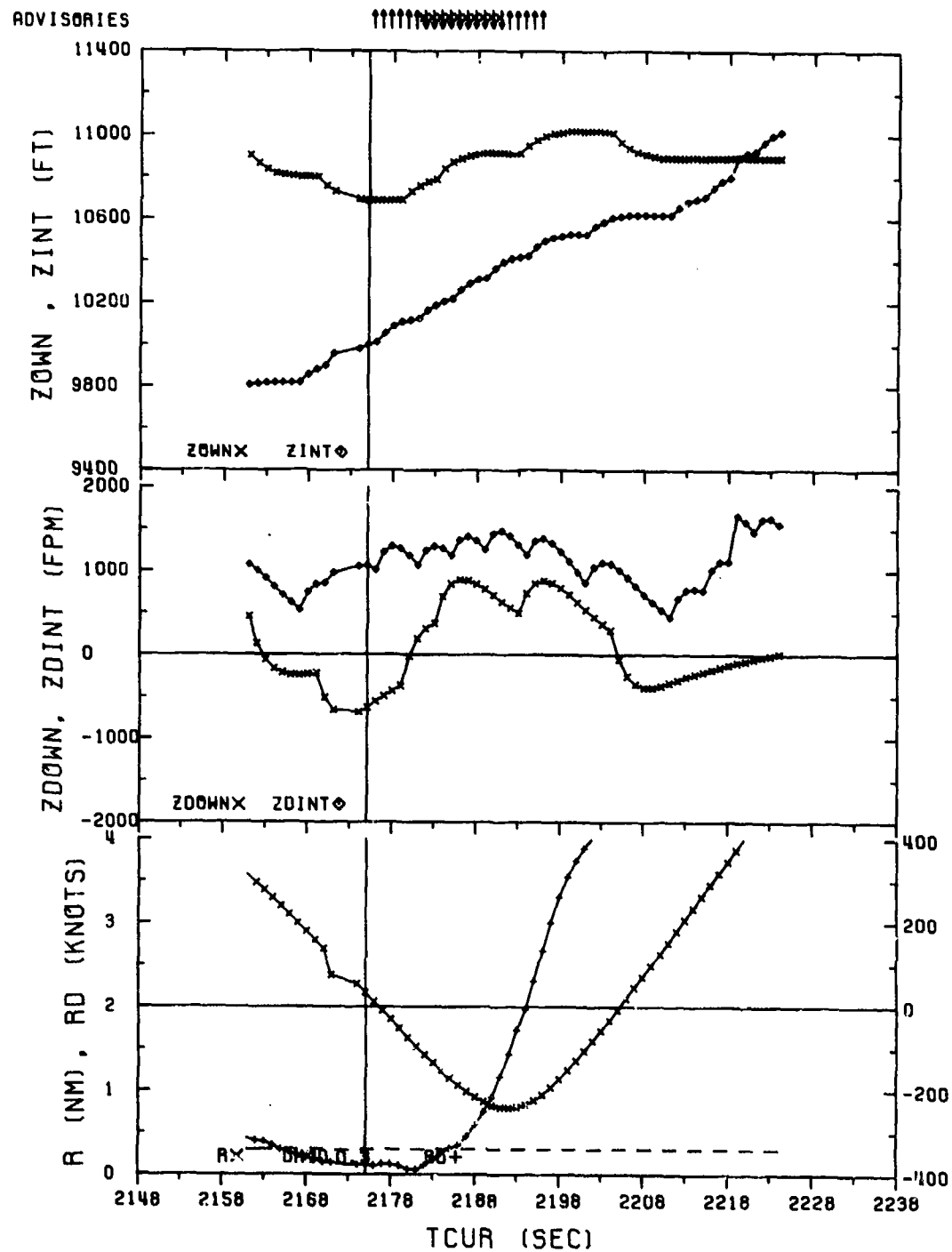


FIGURE 4-11
SEPARATION, RATE PLOTS FOR ENCOUNTER 5 AT DENVER

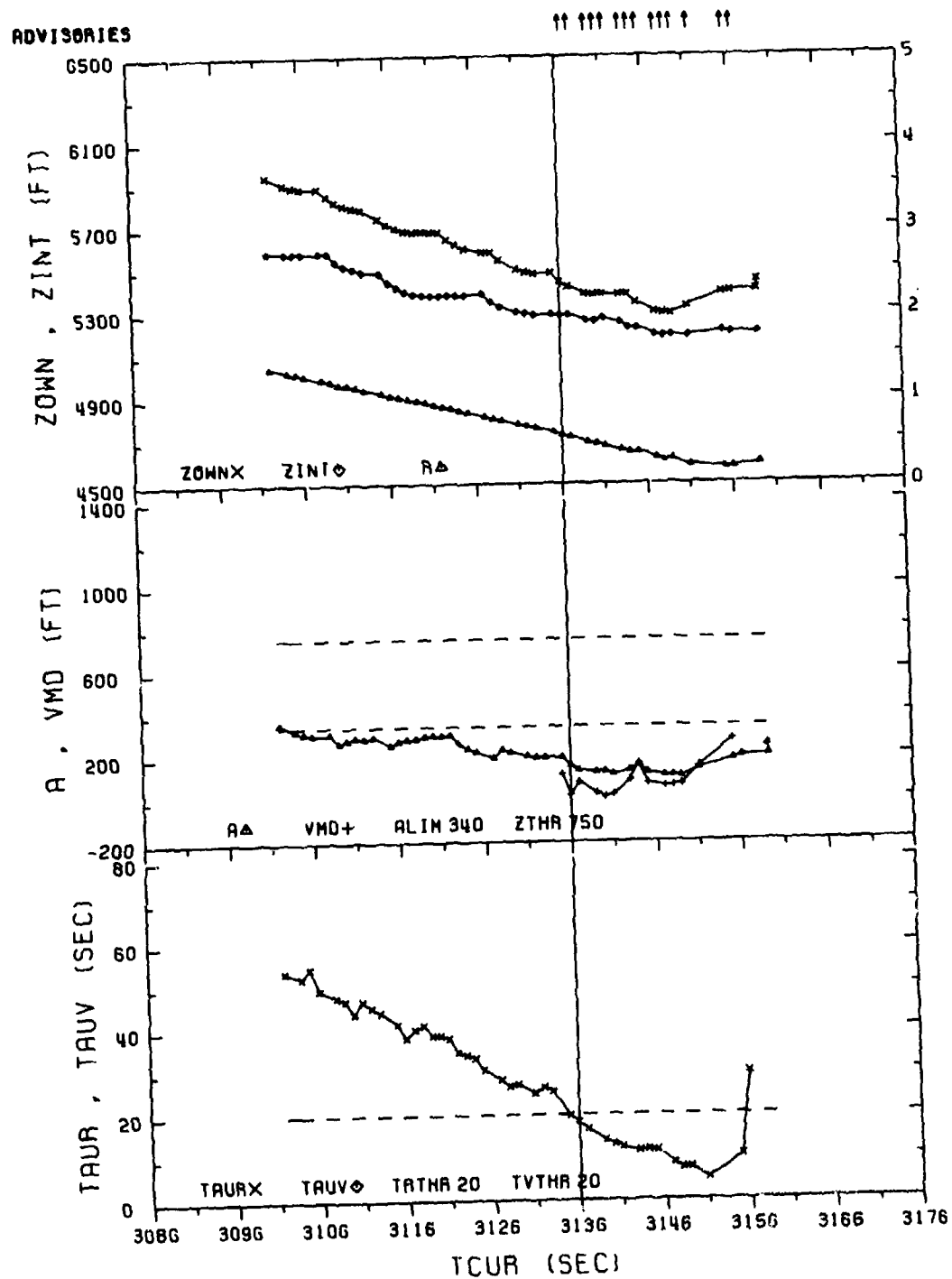


FIGURE 4-12
SEPARATION, TAU PLOTS FOR ENCOUNTER 6 AT DENVER

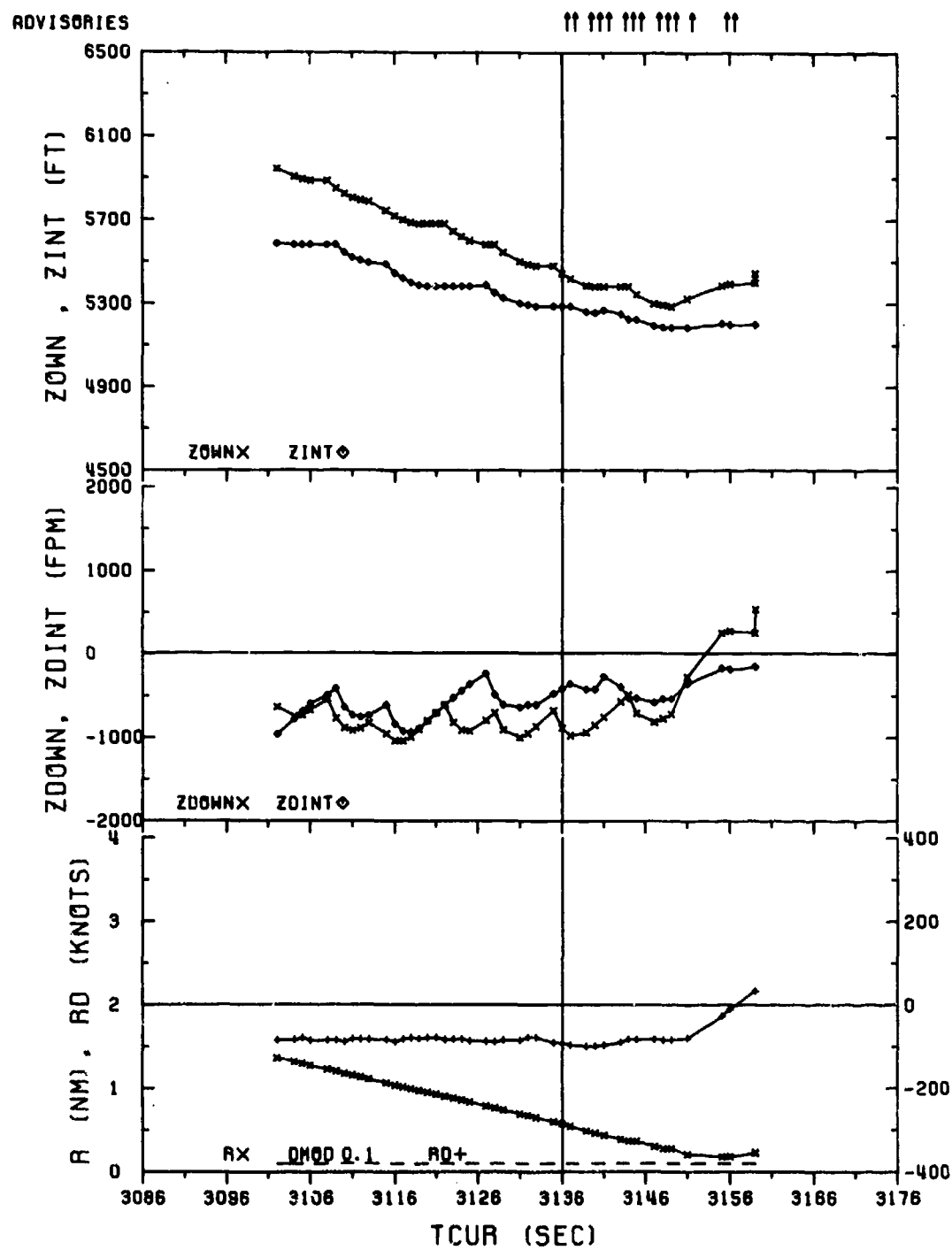


FIGURE 4-13
SEPARATION, RATE PLOTS FOR ENCOUNTER 6 AT DENVER

ADVISORIES

111

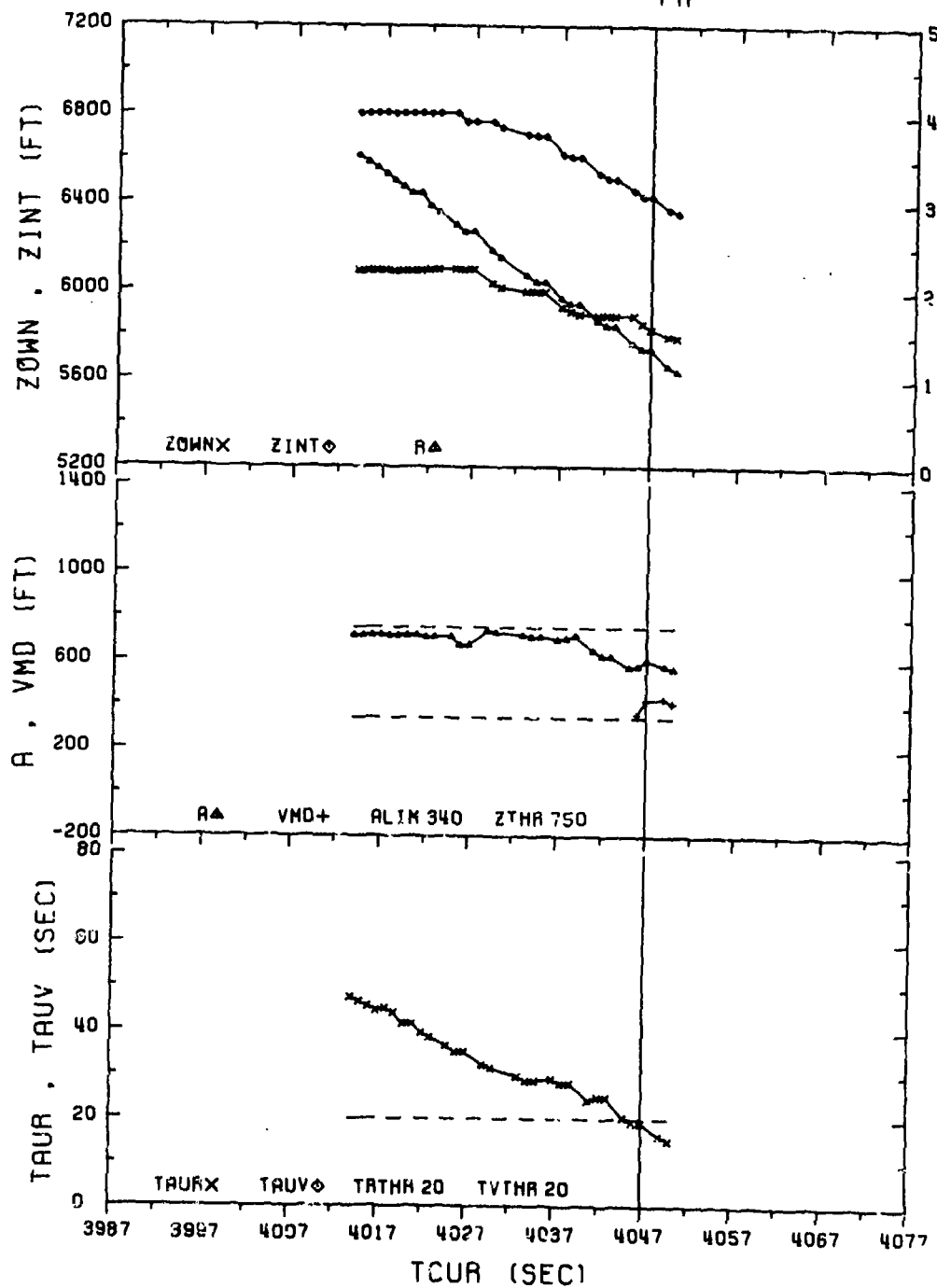


FIGURE 4-14
SEPARATION, TAU PLOTS FOR ENCOUNTER 7 AT DENVER

ADVISORIES

44

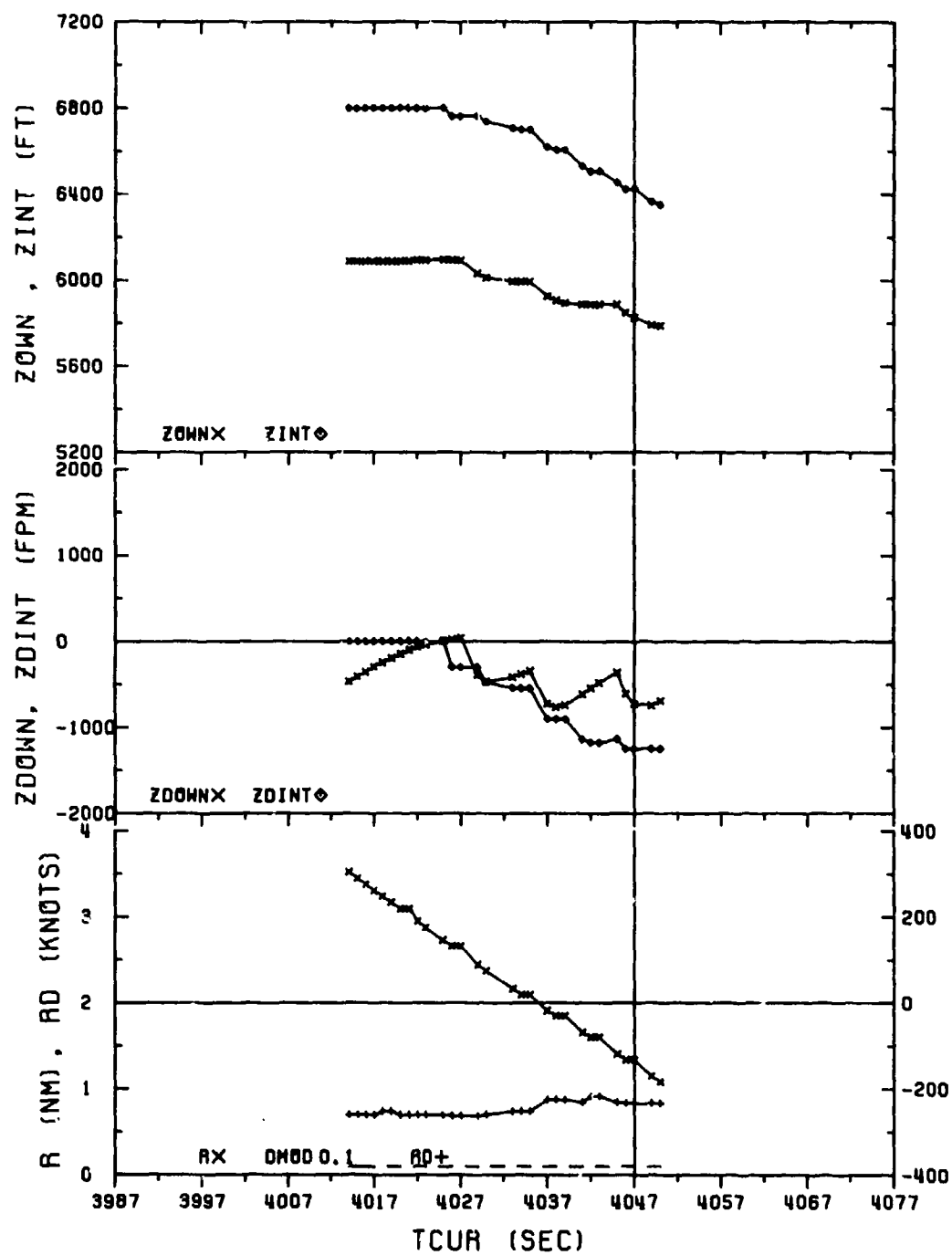


FIGURE 4-15
SEPARATION, RATE PLOTS FOR ENCOUNTER 7 AT DENVER

is the encounter shown in the figures. For this geometry, don't climb was the correct advisory. There is enough history on this track that it appears to be a valid track. The BCAS system was also tracking the aircraft that was visually sighted by the pilot, but did not generate an alert because of it. The data for this aircraft is plotted in Figures 4-16 and 4-17. At the time of the alert (system time 4047) this aircraft was at a range of 0.4 nmi and was 100 ft below the BCAS aircraft. The rate of closure with this aircraft was small, so that the value of TAUR never dropped below TRTHR. In fact, TAUR is large enough that it does not appear on the plot.

This encounter illustrates clearly how the BCAS logic emphasizes closing rate in the threat detection criteria. Threats are determined not solely on the basis of being close in present position, but also by having a high closing rate. In this case, an aircraft at a range of 1.3 nmi was declared a threat while one at 0.4 nmi was not. Given this effect, it is not surprising that the pilot identified a different aircraft than the one generating the BCAS advisory. It is to be expected that this wrong identification could be a common occurrence when BCAS is in operational service.

In this encounter, the track of the intruder stopped shortly after the alert was generated. The recorded data showed that there was data for other tracks immediately after the track was dropped. Furthermore, the last three data points shown on Figure 4-14 were coasted data points by the surveillance system. Thus, this situation seems to involve a track drop at a time when advisories should still continue to be issued. This situation, like the missing track situation in encounter 4 occurs close to the ground and close to the airport at Denver. The reason for the premature track drop is under investigation.

4.4 Salt Lake City Encounters

A series of seven low approaches was performed at Salt Lake City on 6 July 1980. Advisories were generated by aircraft on the runway surface when the BCAS was within one nmi and 500 ft AGL and operating in sensitivity level 3. Two encounters were recorded with airborne aircraft.

4.4.1 Encounter 8, Vertical Divergence Example

The first unplanned encounter at Salt Lake City (Figures 4-18 and 4-19) occurred shortly after a low approach run. The BCAS aircraft was climbing, about 1200 ft above the runway (ground elevation 3900 ft), when a don't descend advisory, was displayed. The intruder aircraft was level at 1200 ft AGL.

ADVISORIES

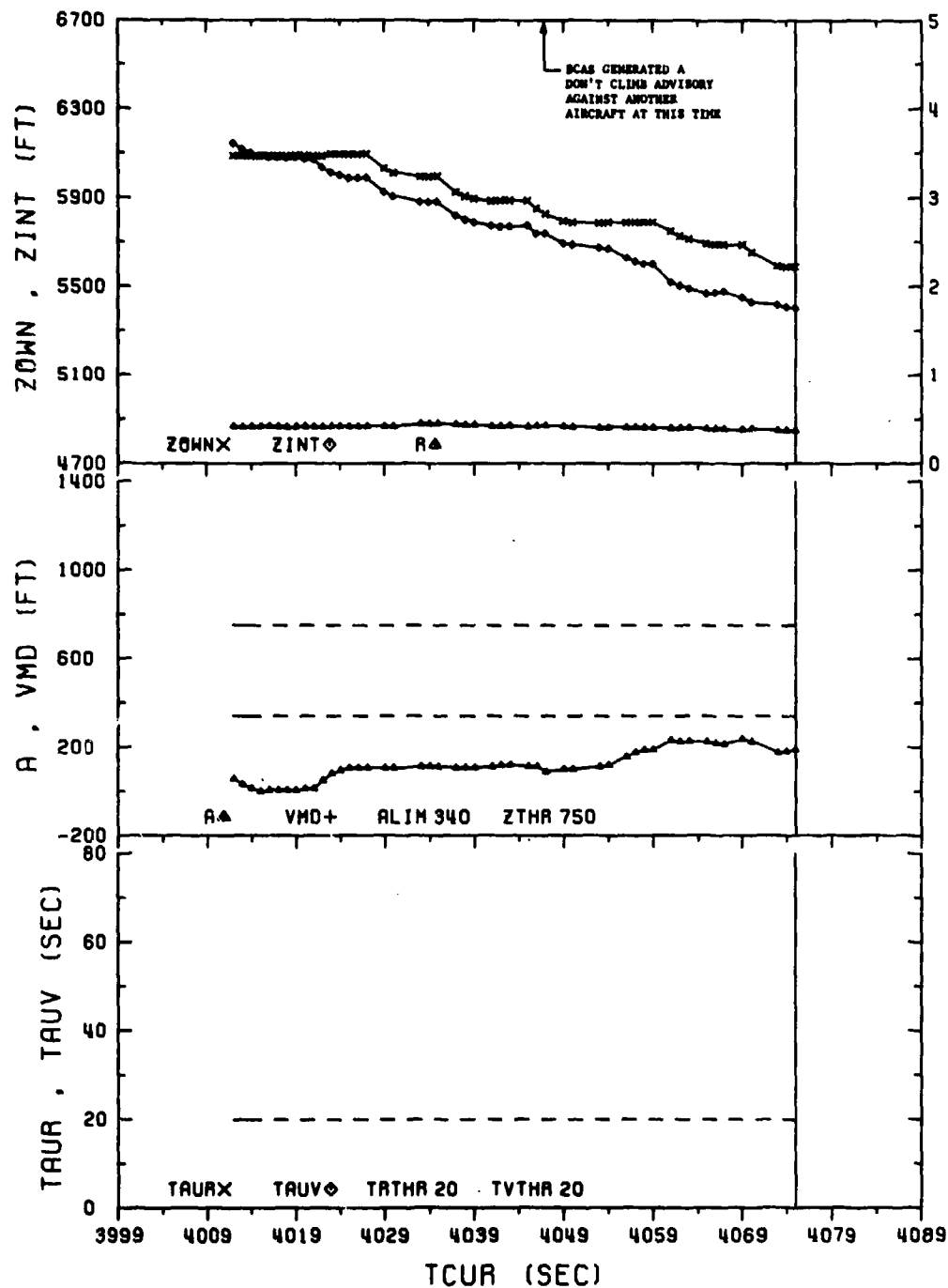


FIGURE 4-16
SEPARATION, TAU PLOTS FOR INTRUDER SEEN BY PILOT AT DENVER

ADVISORIES

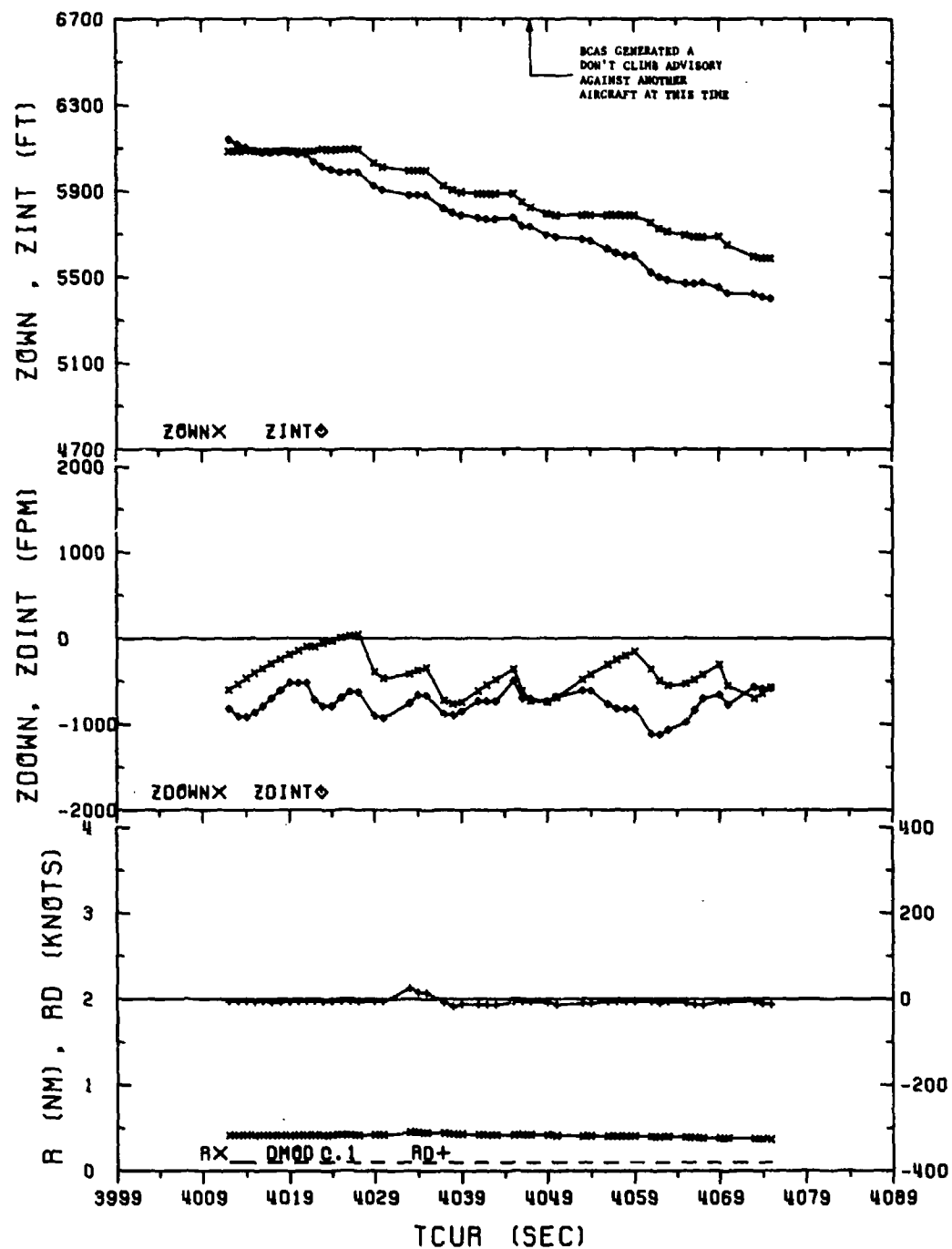


FIGURE 4-17
SEPARATION, RATE PLOTS FOR INTRUDER SEEN BY PILOT AT DENVER

ADVISORIES

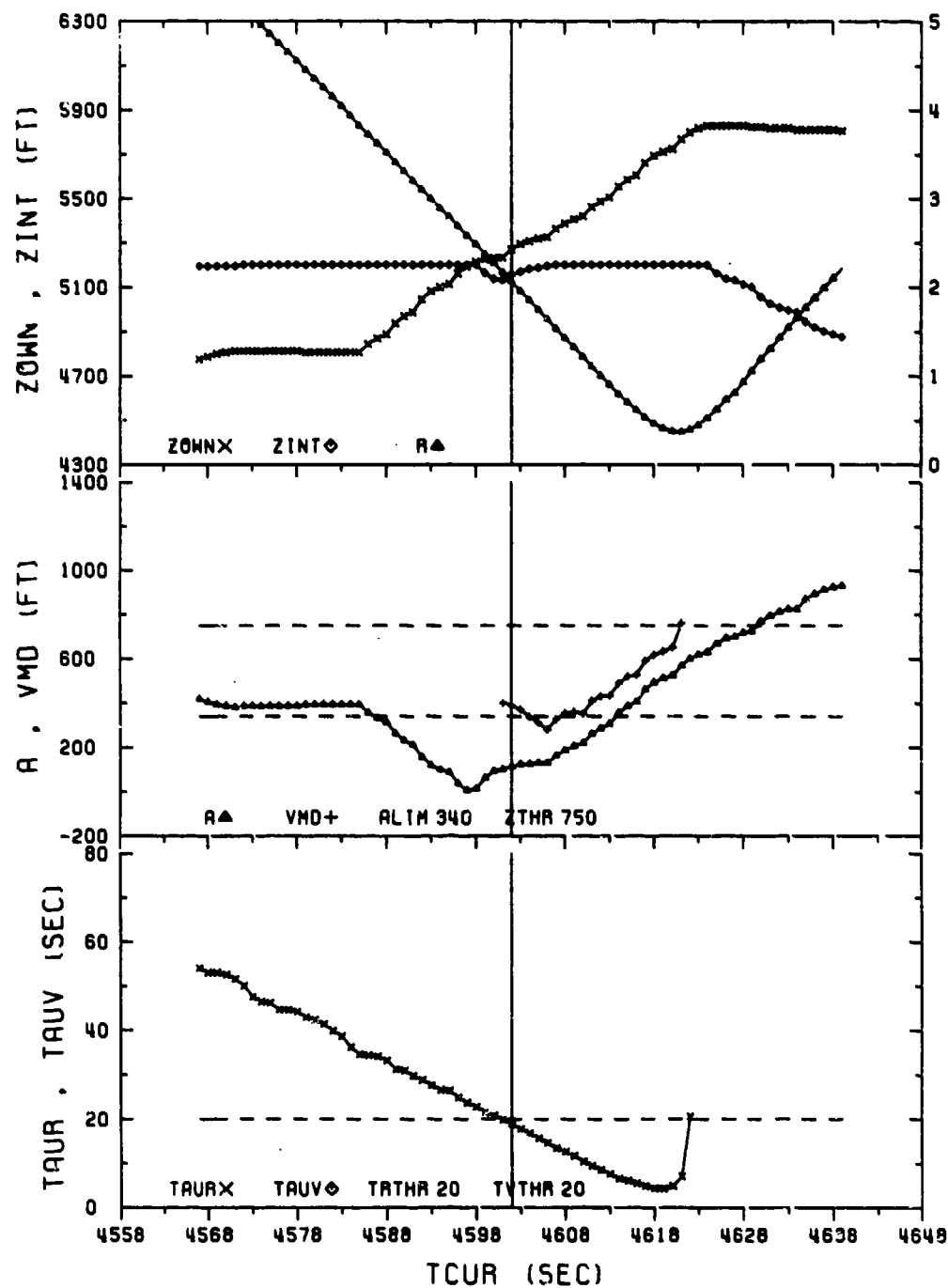


FIGURE 4-18
SEPARATION, TAU PLOTS FOR ENCOUNTER 8 AT SALT LAKE CITY

ADVISORIES

00000111110000000000

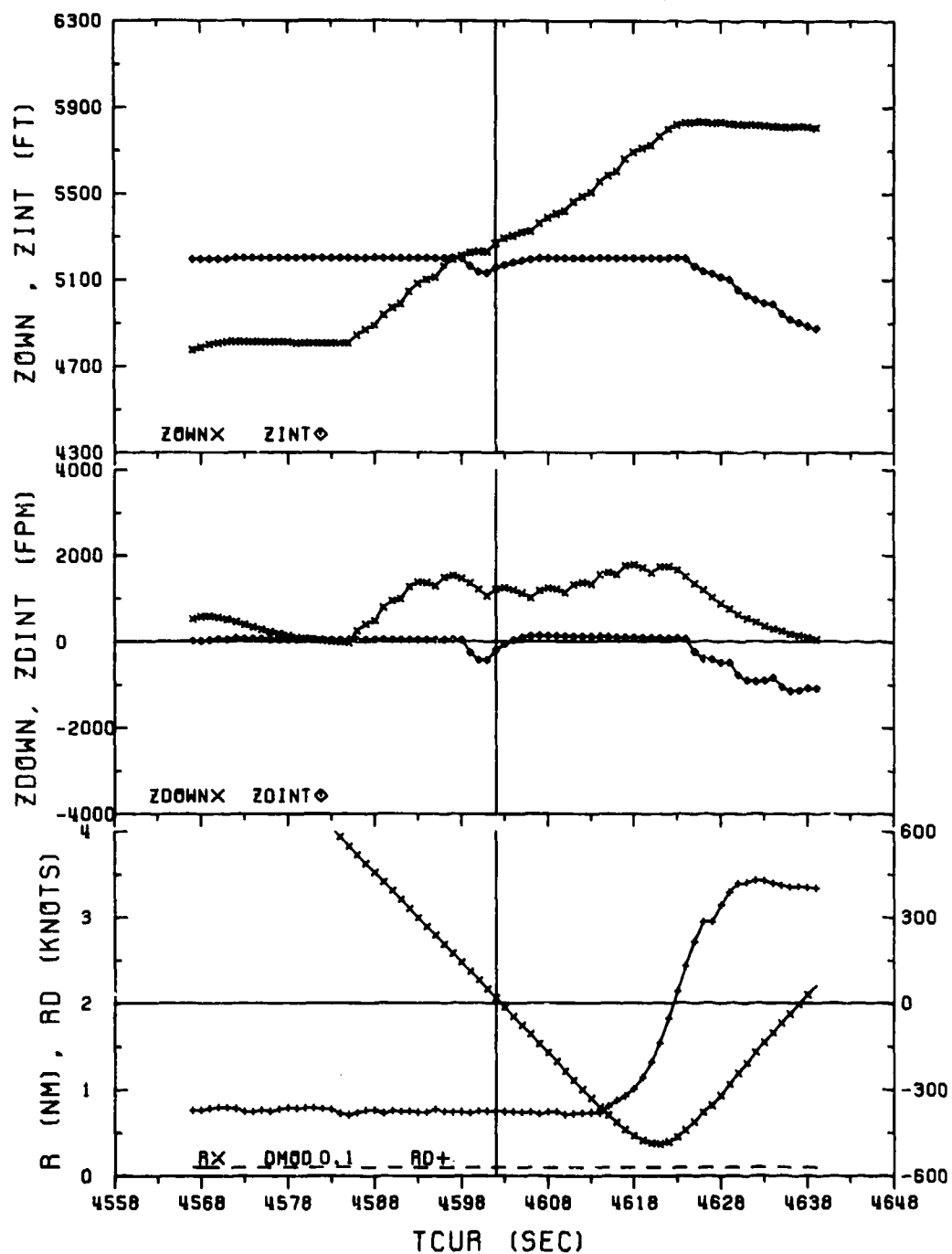


FIGURE 4-19
SEPARATION, RATE PLOTS FOR ENCOUNTER 8 AT SALT LAKE CITY

A Mode C excursion in the intruder's Mode C reports, and the resulting negative vertical tracked velocity, caused the advisory to start as a negative, rather than as a positive. The oscillatory nature of the vertical velocity around zero caused the advisory to transition to positive. As the BCAS aircraft continued its climb, the advisory transitioned back to negative. It is evident from Figure 4-18 that VMD was only momentarily below the ALIM threshold. This was a grazing encounter, where VMD was near the threshold and small oscillations contributed to the advisory transitions. The pilot of the BCAS aircraft felt the advisory was useful in this situation. The sense of the advisory was clearly correct.

This encounter illustrates an attribute of the BCAS logic that could be considered undesirable. The vertical divergence logic can produce a don't descend advisory when the BCAS aircraft is climbing. The don't descend can be issued in a situation in which, if the pilot were to reduce his climb rate to zero (which complies with the intended meaning of the don't descend advisory), he would be too close to the other aircraft. This use of the don't descend advisory might be considered misleading to the pilot. As a result of discussions of this subject, modifications were made to the BCAS logic. The latest logic, documented in Reference 3, would issue an advisory of the form "climb faster than 1000 fpm" in the situation depicted in Figure 4-18. For additional details of the application of this logic see Reference 3.

4.4.2 Encounter 9

Fifteen seconds after the advisory ended for the previous encounter, another advisory was generated because of another aircraft (see Figures 4-20 and 4-21). The intruder was flying level 400 ft below the BCAS aircraft. Since the vertical separation was greater than ALIM, a negative advisory was given. Both aircraft remained essentially level. However, the tracked vertical rate of the BCAS aircraft (ZDOWN), when decaying after the level-off, overshot zero. When it became negative, it permitted the VSL test to be applied and a VSL was issued. When the rate again became positive, the VSL transitioned back to a negative.

The intent in the design of the BCAS logic was that the VSL test only be applied when own aircraft had a significant rate toward the intruder. Tracker residuals should not be permitted to cause transitioning into and out of the VSL logic. The transitions

ADVISORIES

REU ADVISORY SEQUENCE

SIMULATION ADVISORY SEQUENCE

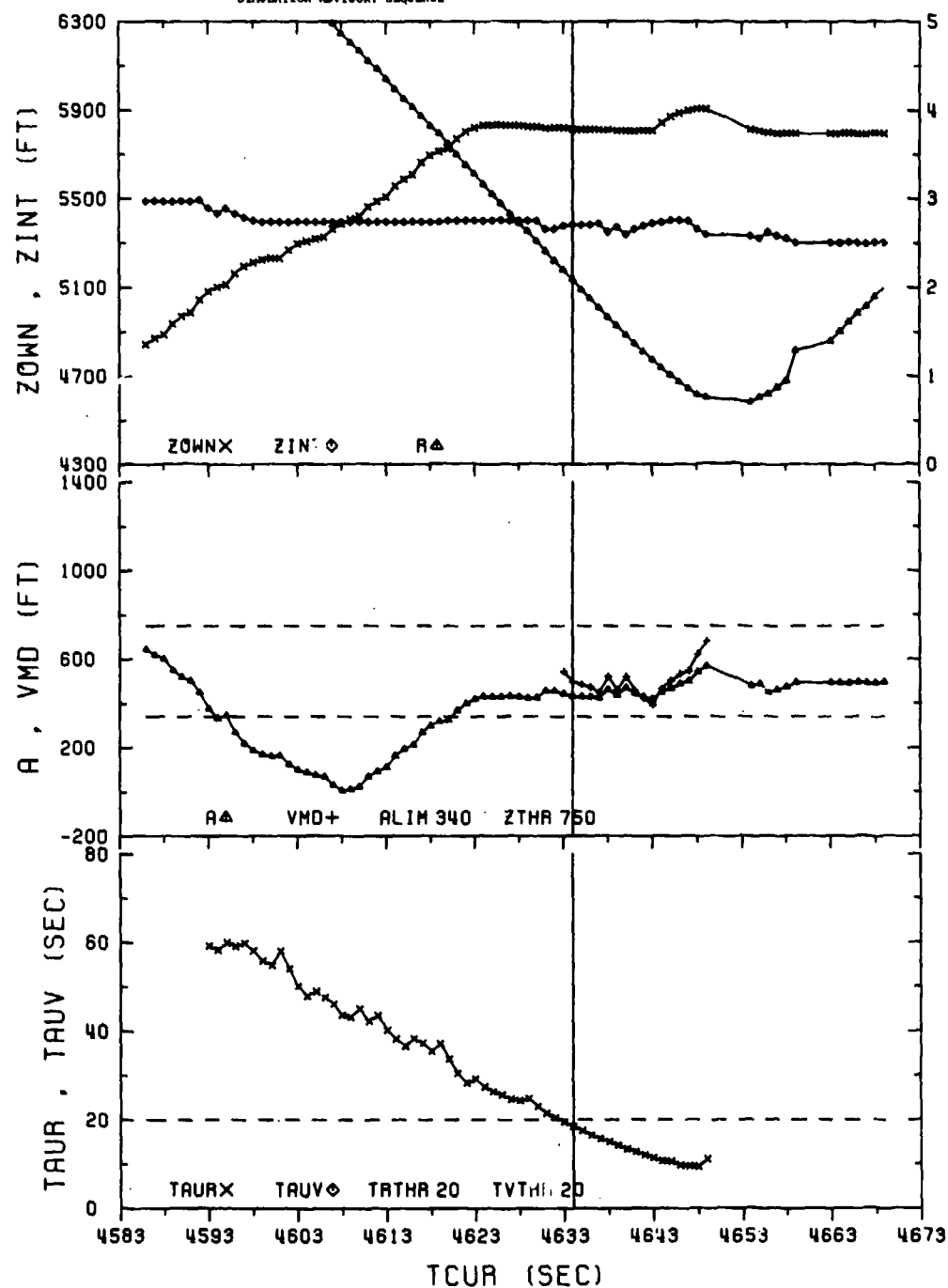


FIGURE 4-20
SEPARATION, TAU PLOTS FOR ENCOUNTER 9 AT SALT LAKE CITY

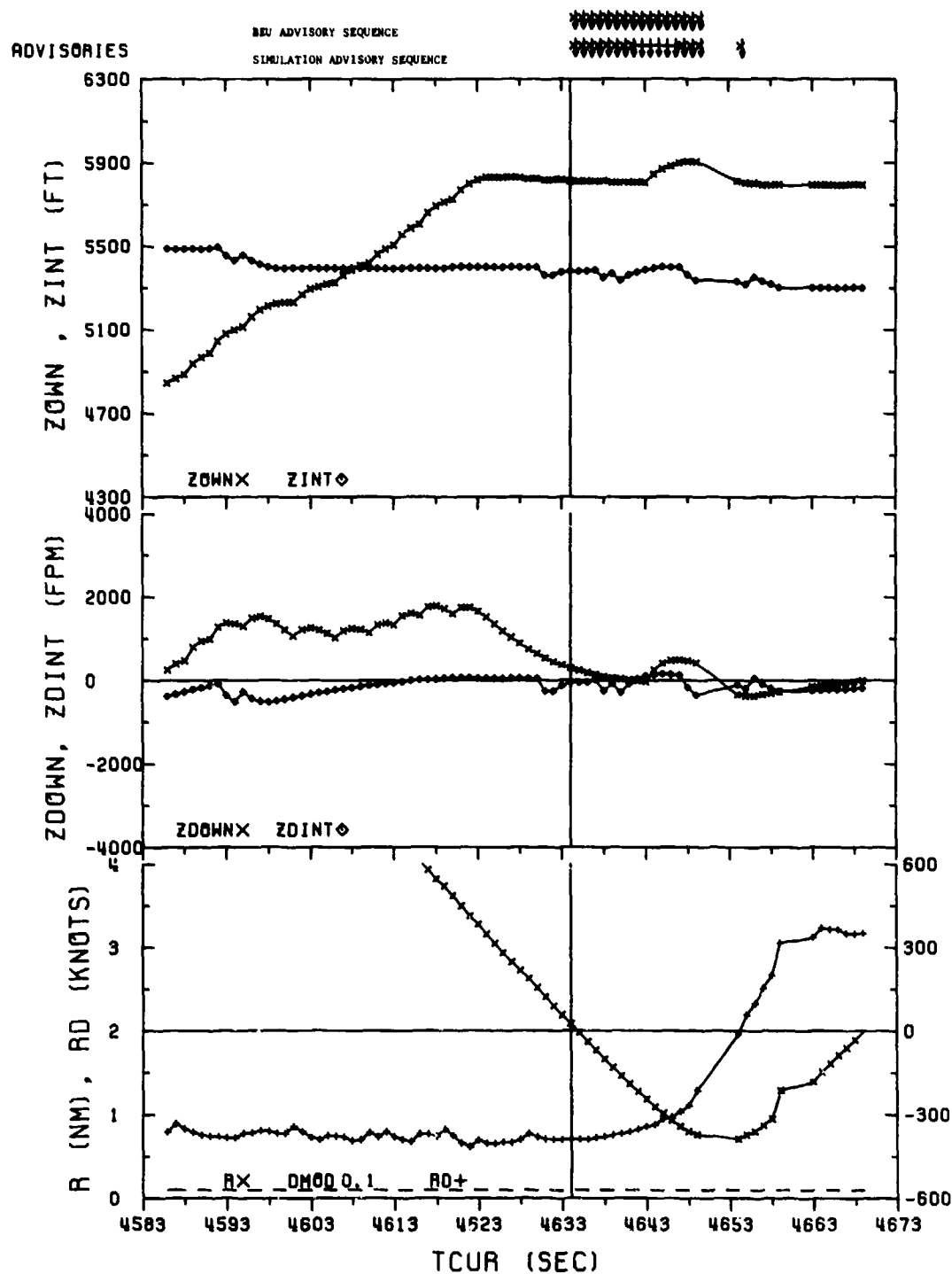


FIGURE 4-21
SEPARATION, RATE PLOTS FOR ENCOUNTER 9 AT SALT LAKE CITY

occurring in this encounter do not reflect significant changes in the physical situation. The BCAS logic has since been modified so that the VSL test is only applied if own aircraft has a significant rate toward the intruder. This modification is included in Reference 3.

4.5 Los Angeles Encounters

Operational tests similar to those conducted at other airports were performed at Los Angeles International on 18 July. In addition, on the afternoon of 18 July and on 19 and 20 July, a series of planned encounters was performed. The other aircraft used for the planned encounters was N-49, a Convair 580 from the FAA Technical Center. During the time that these planned encounters were taking place, advisories were seen that were caused by other aircraft in the vicinity. Only the unplanned encounters are examined in this report. These unplanned encounters did not occur during the operational part of the test at Los Angeles. They occurred while the planned encounters were being conducted over Seal Beach Very High Frequency (VHF) Omni Range (VOR) near a traffic corridor.

4.5.1 Encounter 10, Vertical Divergence Example

During the planned encounters on 18 July, a short advisory sequence was generated by another aircraft (see Figures 4-22 and 4-23). The BCAS aircraft was level at 7700 ft, while the other aircraft was descending from 7300 ft. Their altitude separation at the time of the alarm was greater than ALIM, so a positive advisory was not needed. The altitude tracker indicated a very small negative vertical rate for the BCAS aircraft, therefore a VSL was calculated. This small vertical rate persists for a long time because of the precision of the calculations and roundoff. Normally, the tracker would track the vertical rate to exactly zero after a number of cycles with the same Mode C report. A limit descent to 1000 fpm was generated. The threat was immediately declared not in conflict. However, the five second hold on advisories kept the advisory up for four additional seconds. (In the BCAS logic, once a given advisory is displayed, it must remain displayed for five seconds before another type of advisory can be displayed or the display can be cleared.)

In this encounter, the BCAS aircraft was actually level, so that a negative advisory, don't descend, would have been sufficient and would not have been disruptive. The logic modification discussed in paragraph 4.4.2 would have caused a negative advisory to be issued in this encounter, rather than the VSL.

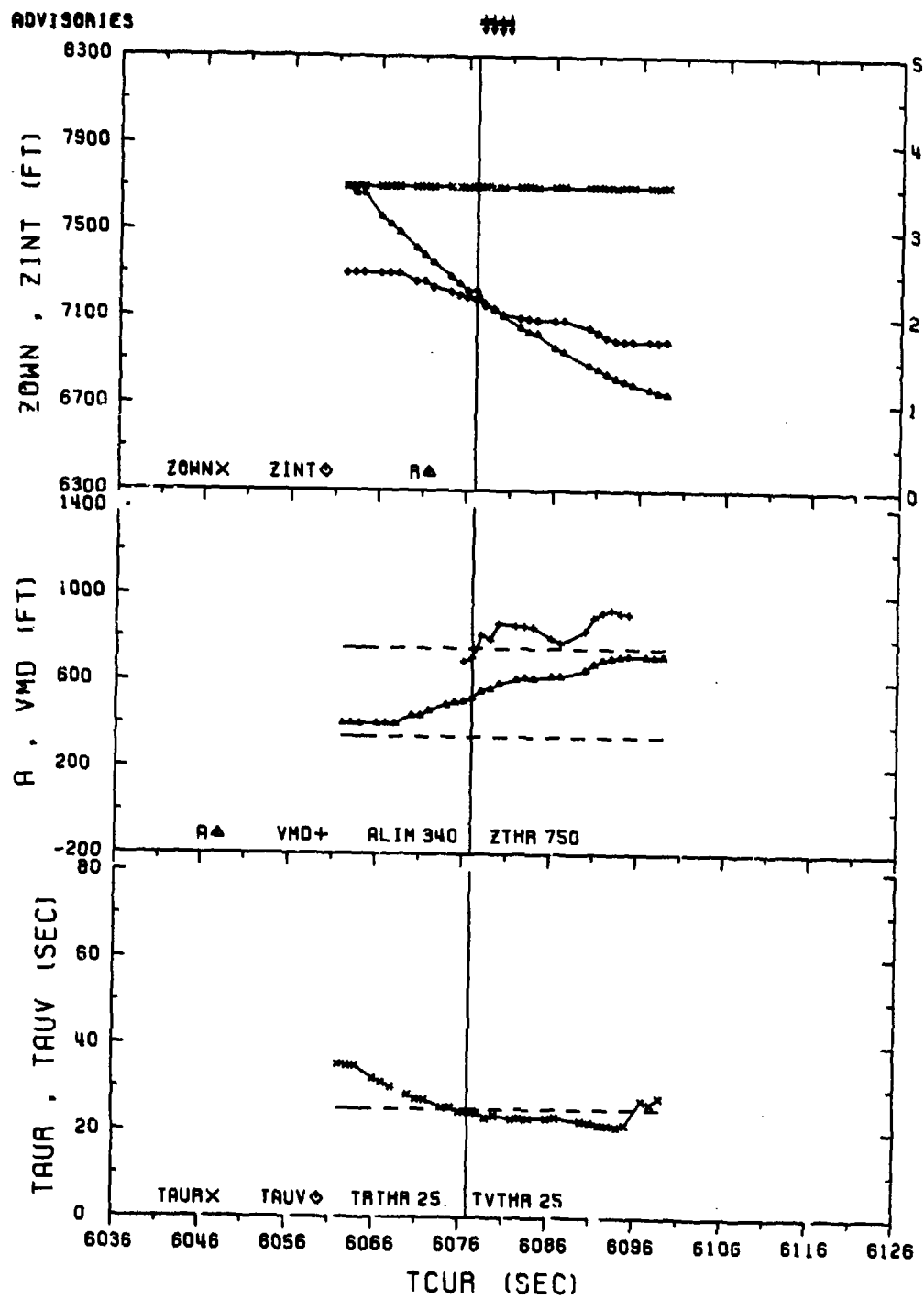


FIGURE 4-22
SEPARATION, TAU PLOTS FOR ENCOUNTER 10 AT LOS ANGELES

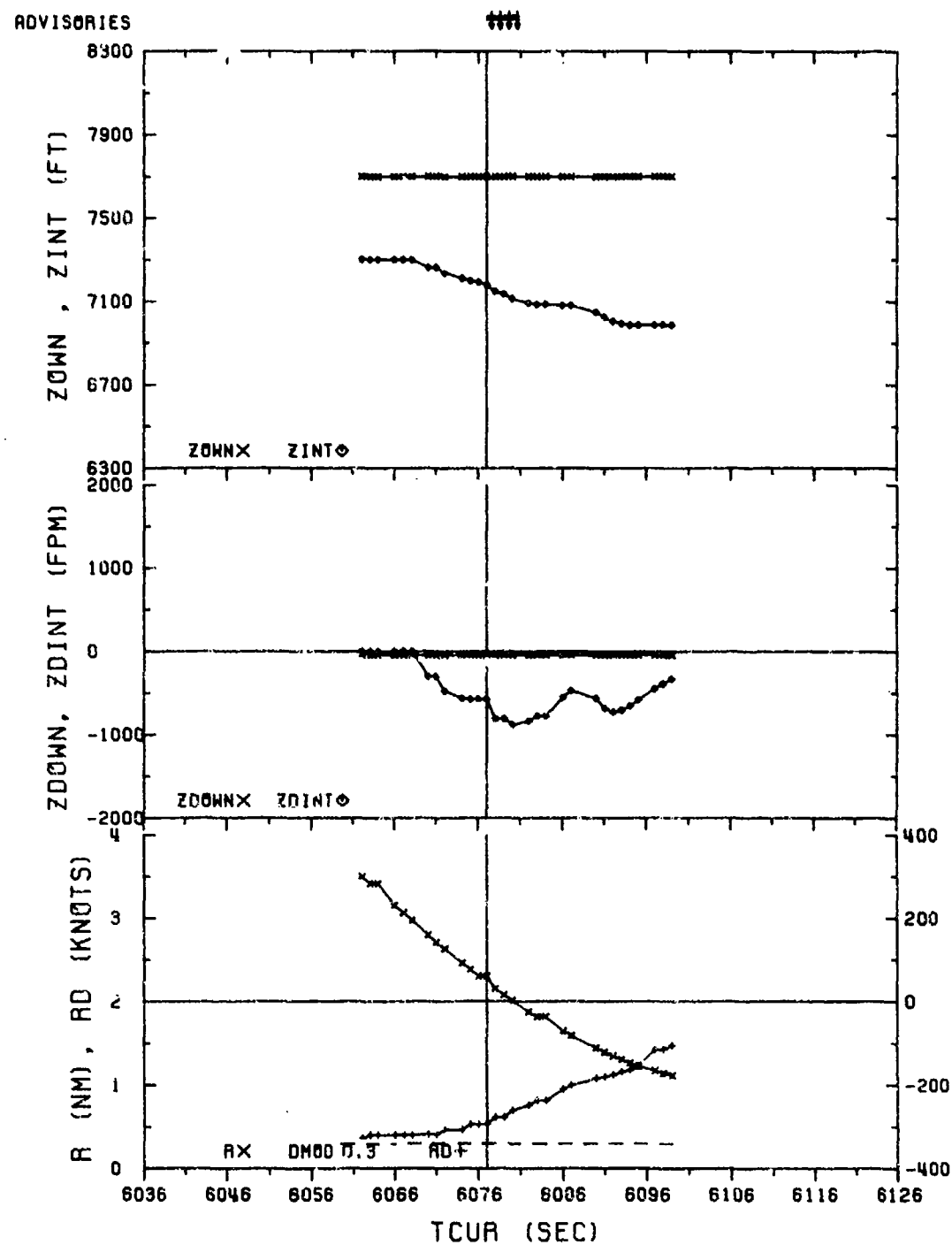


FIGURE 4-23
SEPARATION, RATE PLOTS FOR ENCOUNTER 10 AT LOS ANGELES

4.5.2 Encounter 11, Vertical Divergence Example

On the morning of 19 July, while performing the planned encounter test series, an advisory was generated by an unplanned encounter (see Figures 4-24 and 4-25). The BCAS aircraft was level at 7800 ft and the intruder was level at 7700 ft. The BEU calculated a climb advisory for the BCAS aircraft. Just after the climb advisory was given to the BCAS aircraft, the other aircraft began to descend. The advisory was dropped when the projected vertical separation (VMD) became greater than ZTHR.

The BCAS simulation computed only the don't descend advisory (and not the climb advisory). At the time the advisory was selected, the value of VMD was very close to the ALIM threshold. The slightly different representation of ALIM in fixed point arithmetic in the BEU and floating point arithmetic in the simulation is believed to be the cause of the different advisory selection.

4.5.3 Encounter 12, Multiple Encounter Involving Planned Encounter

During the planned encounter work an unplanned encounter occurred that resulted in a multi-aircraft encounter. The unplanned encounter is shown in Figures 4-26 and 4-27. The BCAS and threat aircraft were both level, and were separated by 300 ft. When TAUR dropped below TRTHR, the aircraft were declared in conflict. Since the current altitude separation was less than ALIM, the advisory selected was positive. Neither of the aircraft maneuvered vertically so the advisory remained until the aircraft began to diverge in range. This aircraft was seen from the BCAS aircraft and was identified as a Mooney aircraft.

The planned encounter that created an advisory while the advisory from the Mooney was being displayed is shown in Figures 4-28 and 4-29. The intruder for this encounter is the second FAA aircraft, the Convair 580. This aircraft was also level at 8500 ft.

The advisory caused by the Mooney aircraft lasted from system time 6637 to 6661 and then came back from 6669 to 6673. The advisory caused by the planned encounter lasted from 6644 to 6671. At system times 6644 and 6669 the multi-aircraft logic in the BEU was exercised to determine the advisory to display. The result of the multi-aircraft logic calculation was to display a descend. A continuous descend advisory was displayed for the entire duration of the encounter. This was clearly the appropriate response for this multiple intruder situation.

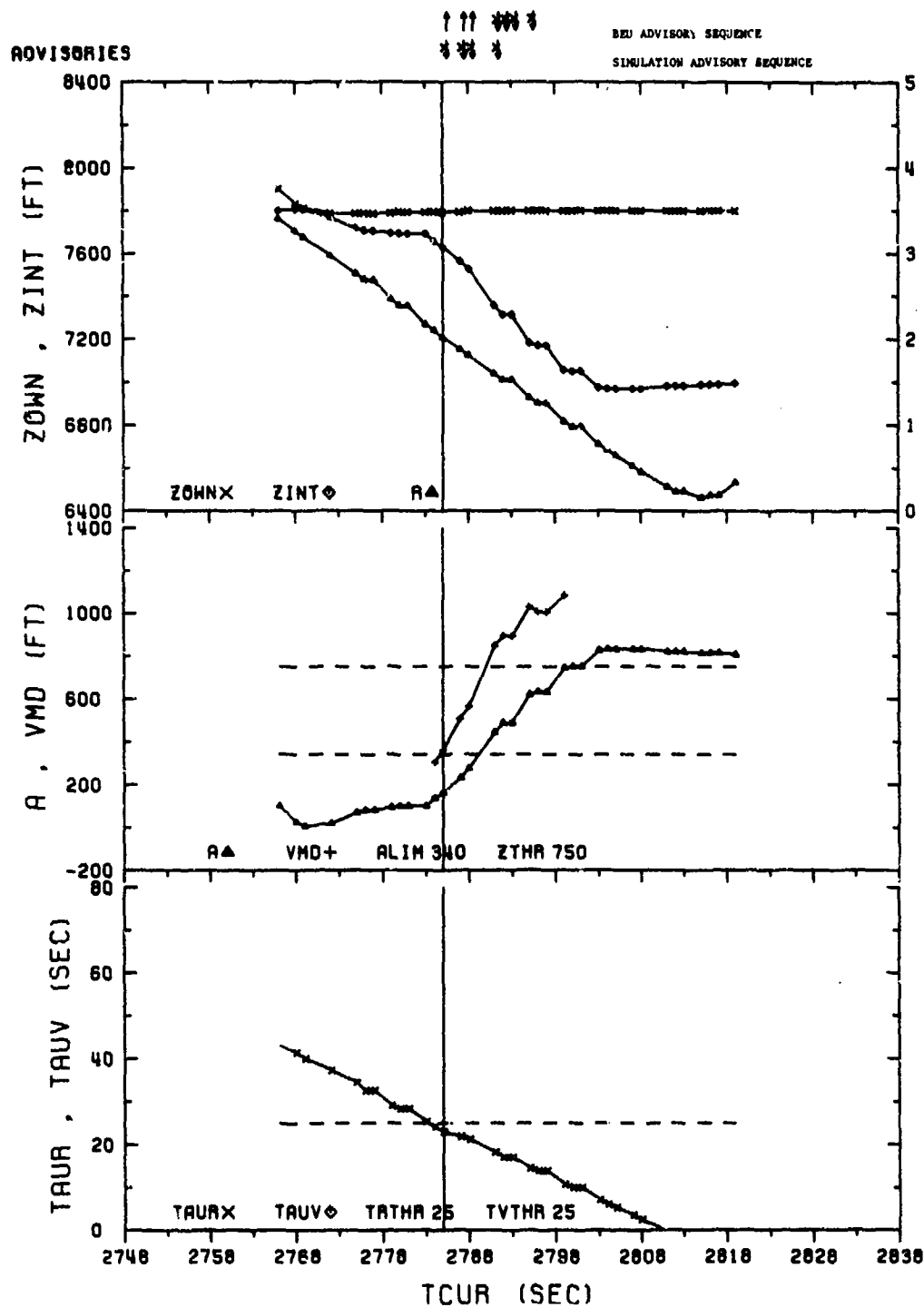


FIGURE 4-24
SEPARATION, TAU PLOTS FOR ENCOUNTER 11 AT LOS ANGELES

ADVISORIES

11 000 3
000 3

REU ADVISORY SEQUENCE

SIMULATION ADVISORY SEQUENCE

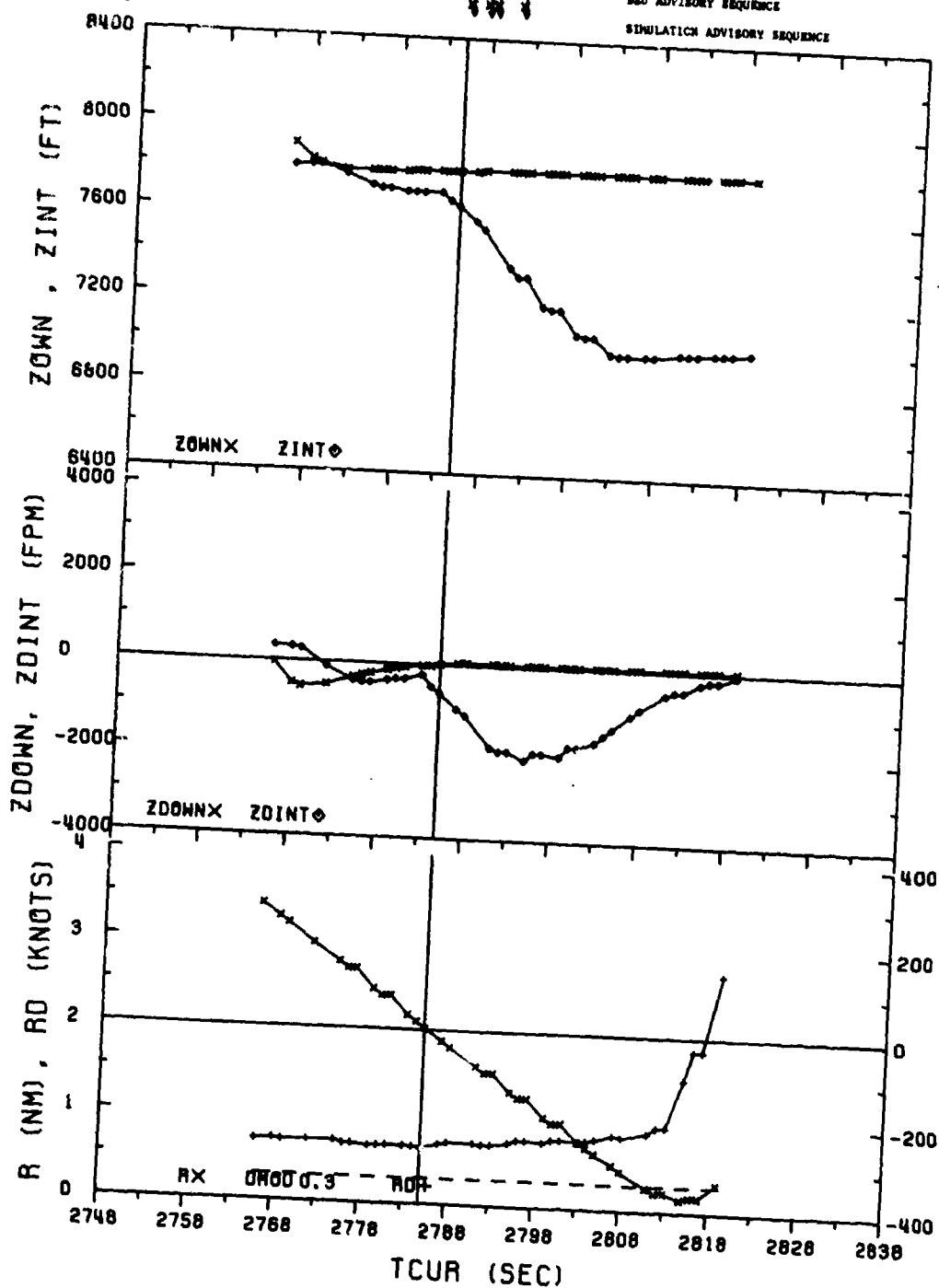


FIGURE 4-25
SEPARATION, RATE PLOTS FOR ENCOUNTER 11 AT LOS ANGELES

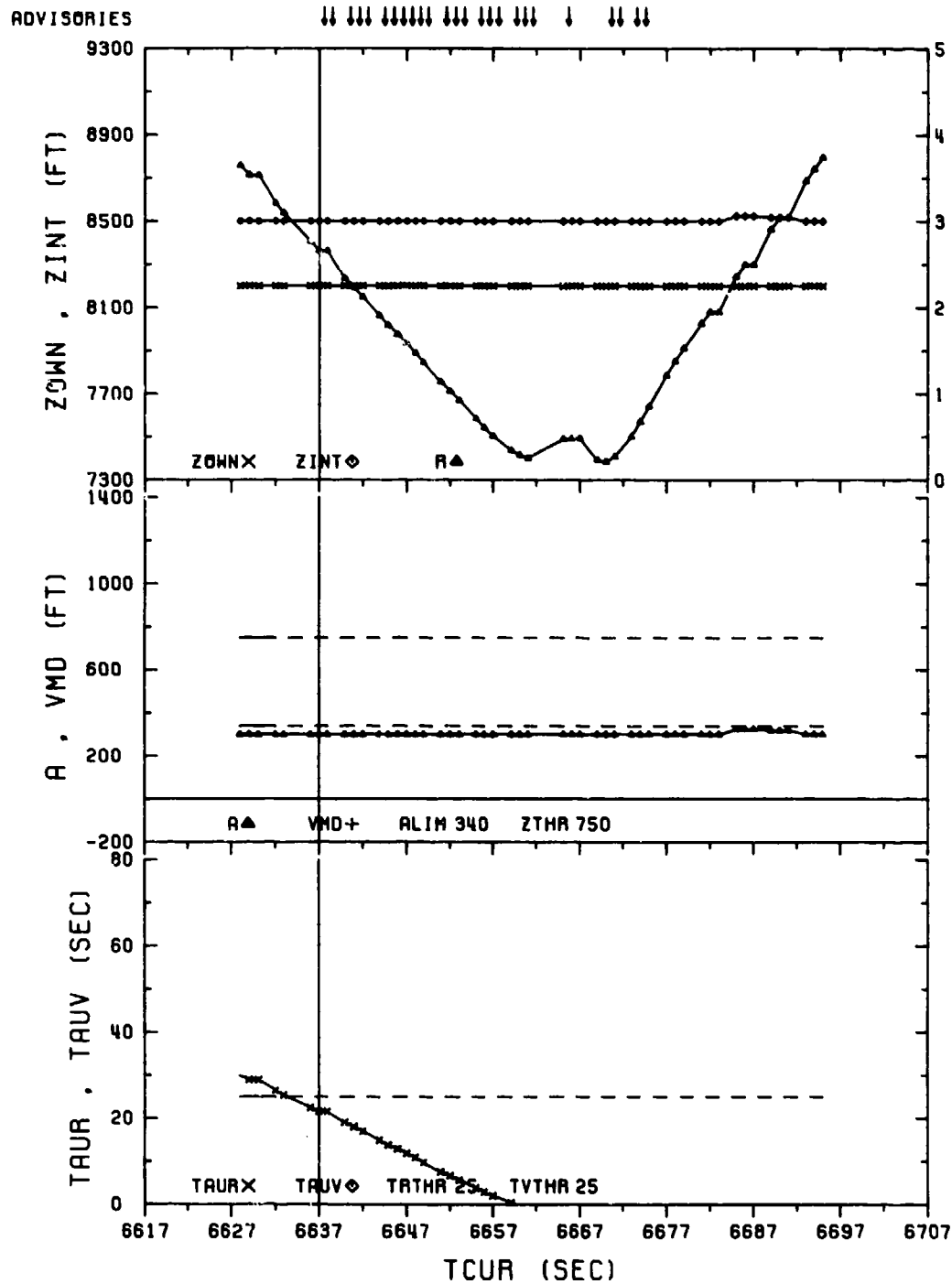


FIGURE 4-26
SEPARATION, TAU PLOTS FOR ENCOUNTER 12 AT LOS ANGELES

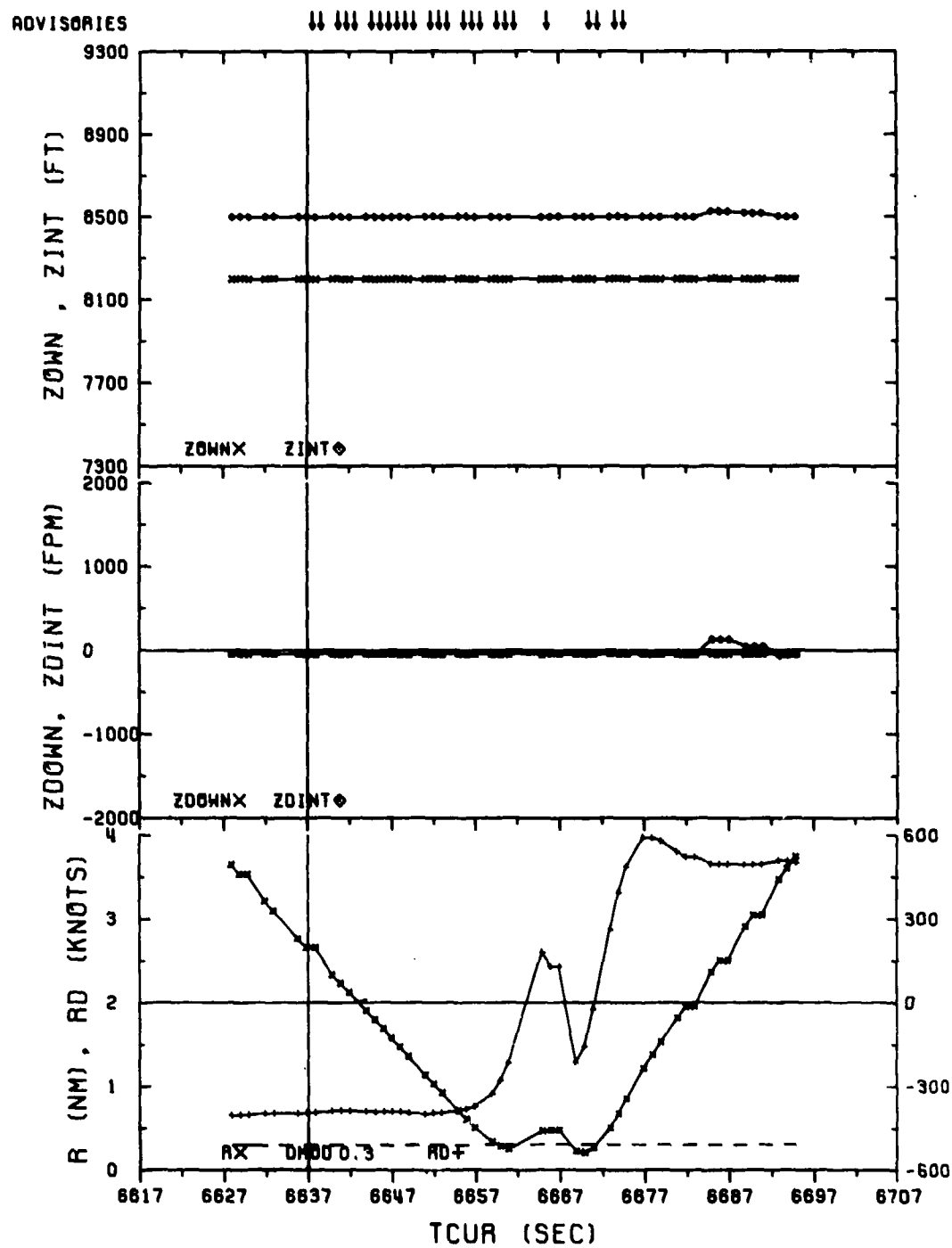


FIGURE 4-27
SEPARATION, RATE PLOTS FOR ENCOUNTER 12 AT LOS ANGELES

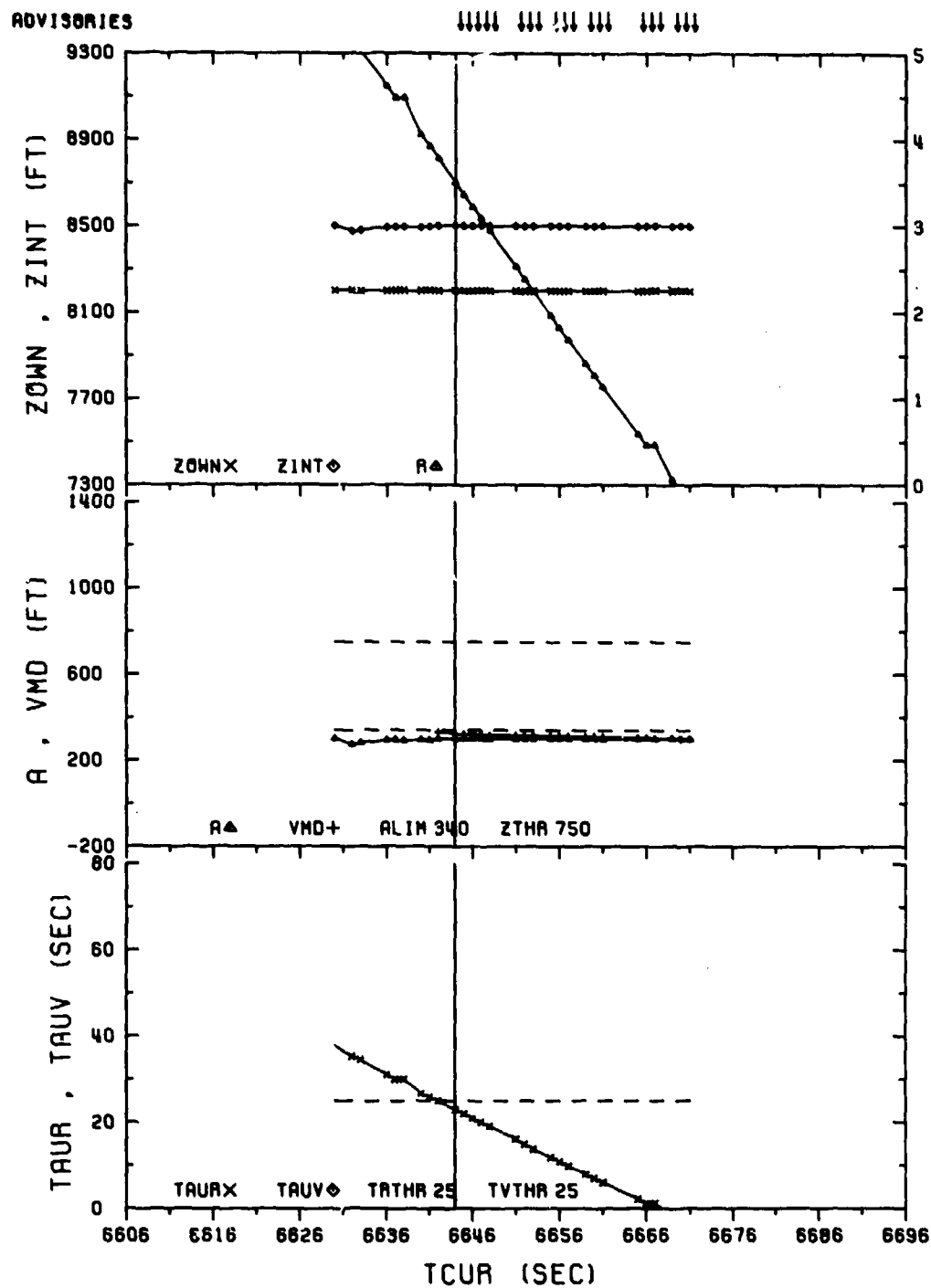


FIGURE 4-28
SEPARATION, TAU PLOTS FOR PLANNED ENCOUNTER AT LOS ANGELES

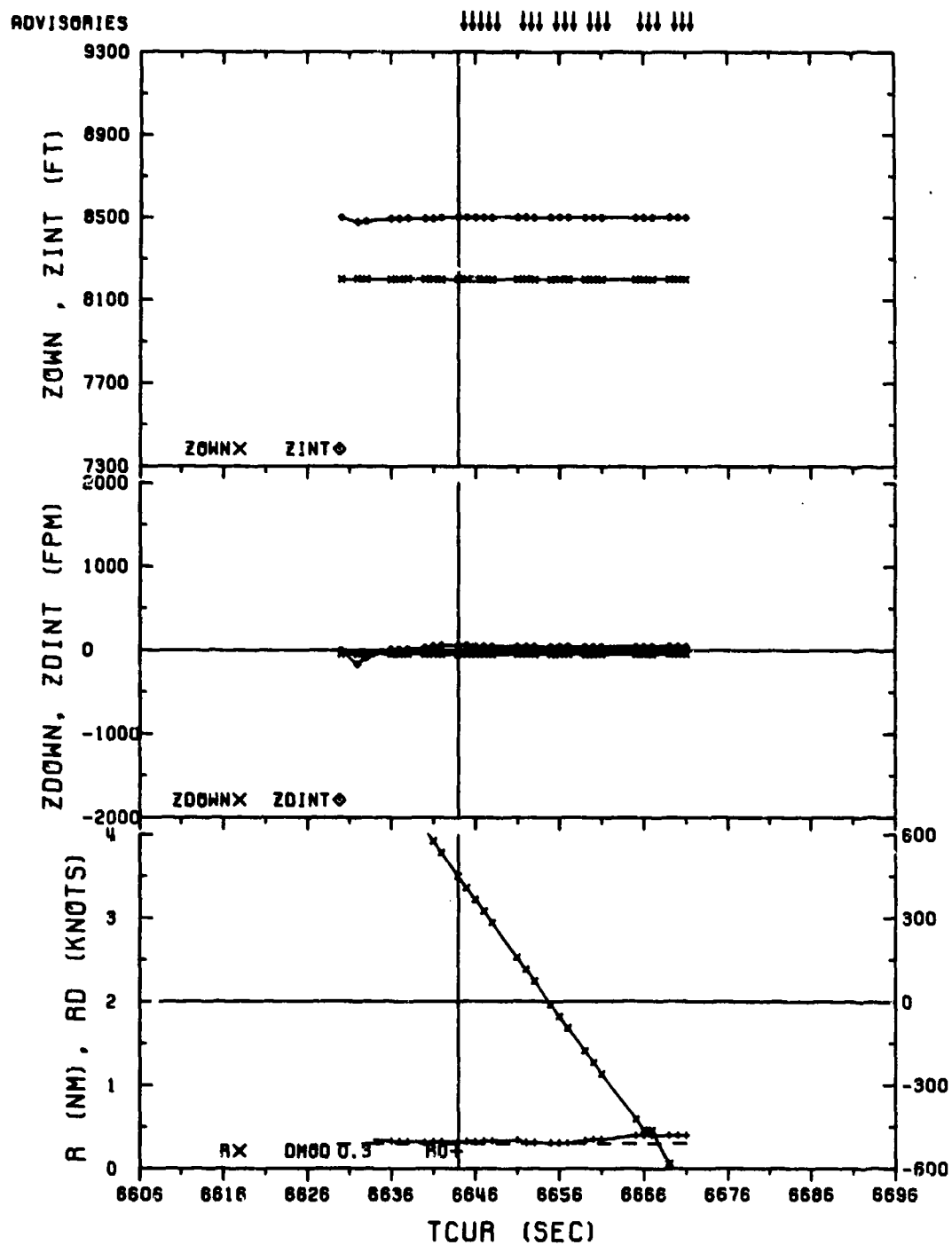


FIGURE 4-29
SEPARATION, RATE PLOTS FOR PLANNED ENCOUNTER AT LOS ANGELES

The simulation did not have the capability to process multiple intruders simultaneously. Therefore, the plots in Figures 4-26 through 4-29 were generated for one intruder at a time. In Figure 4-30, the TAUR and range curves for the two intruders are drawn together on the same plot. While the two intruders had different closing speeds, it is evident that they both reached closest approach at nearly the same time. The surveillance data on both tracks was good.

An ARTS plot of this multi-aircraft encounter is presented in Figure 4-31. The Mooney aircraft was squawking a beacon code of 1200 and was at 8500 ft (an appropriate VFR cruising altitude) tracking to the Seal Beach VOR. The two FAA aircraft were using the Seal Beach VOR as an aid to setting up the planned encounters, and were making East-West passes over the VOR. The capital letters indicate the positions of the aircraft at the same time. The three aircraft arrived at the VOR at very nearly the same time. At this time there is much data missing from the radar plot due to synchronous garble between the three aircrafts' transponders. The superiority of the BCAS surveillance in this situation is quite evident when Figure 4-31 is compared with Figure 4-30.

One final observation about this encounter can be noted here. In Figures 4-27 and 4-29 it appears that the surveillance system swapped tracks when the two tracks crossed in range. The unplanned encounter had a closing speed of about 400 kn prior to closest approach. (See the RD curve on Figure 4-27). After closest approach, it had a speed of about 500 kn. The planned encounter had a closing speed of about 500 kn as can be seen from Figure 4-29. Figure 4-31 shows that both the BCAS aircraft and the Mooney aircraft continue more or less straight after the closest approach, so that the RD curve on the separating side should have nearly the same speed as on the closing side of closest approach. The fact that the speed changed by 100 kn suggests that the surveillance system did swap tracks. In addition, the track for the planned encounter dropped after closest approach (see the R curve in Figure 4-28). Work is going on to study and correct this apparent deficiency in the surveillance system.

4.5.4 Encounter 13, Vertical Closing Encounter

One unplanned encounter was recorded on 20 July, immediately following the first planned encounter. The BCAS aircraft was level at 8200 ft and the intruder was climbing through 7000 ft at 1400 fpm when the advisory, limit descent to 1000 fpm, was displayed. The advisory stayed up for six seconds and was dropped when the aircraft began to diverge horizontally.

ADVISORIES

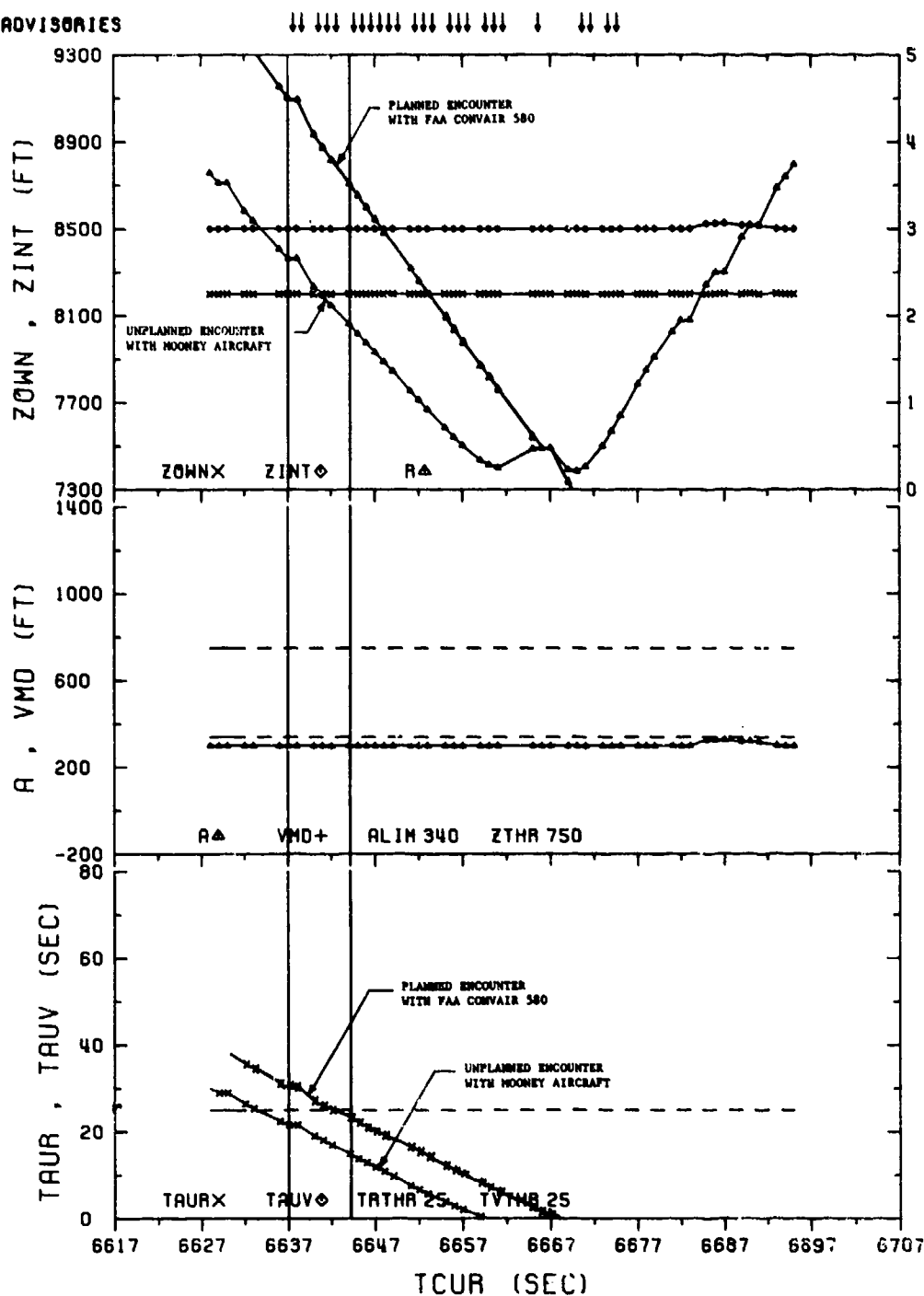


FIGURE 4-30
SEPARATION, TAU PLOTS FOR
MULTIPLE INTRUDER ENCOUNTER AT LOS ANGELES

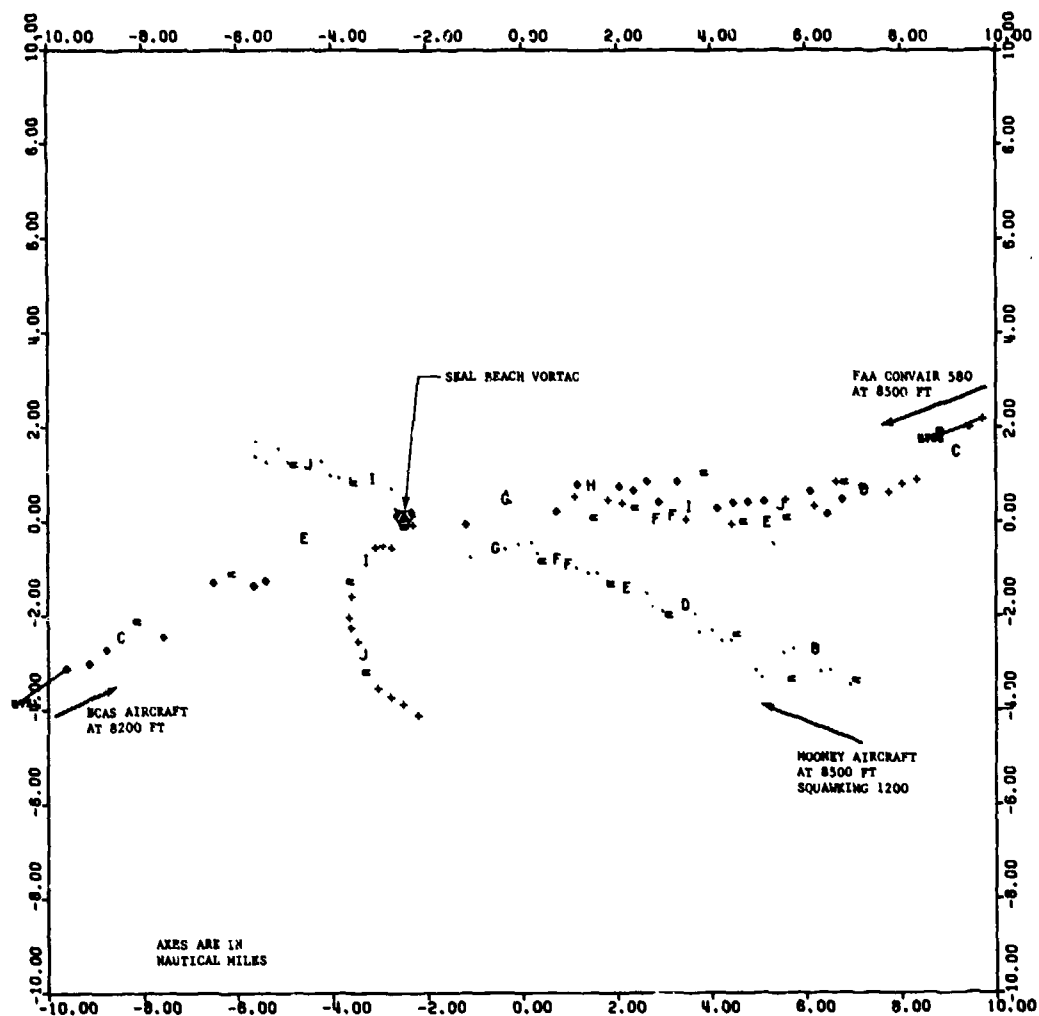


FIGURE 4-31
ARTS PLOT OF MULTIPLE INTRUDER ENCOUNTER AT LOS ANGELES

The BCAS simulation calculated a limit descent to 1000 fpm advisory and then a climb advisory, five seconds later, (see Figures 4-32 and 4-33). On the next cycle the aircraft were declared not in conflict. The climb advisory stayed up for another four seconds because of the five second hold on advisories.

This is another encounter in which the simulation did not calculate the same advisory as the BEU. In this encounter, as in the previous encounter, the value of VMD was very close to ALIM, so small differences in the thresholds would explain the difference in results. The transition to a positive advisory in the simulation and not in the BEU is therefore not a problem in this case.

This encounter illustrates the use of the vertical tau variable in the BCAS logic. TAUR had fallen below the threshold well before the advisory was issued, but the vertical separation was beyond 1000 ft. TAUUV falling below threshold finally triggered the advisory. At this time, the vertical separation was still greater than 1000 ft. The vertical tau variable provides the required alert time in cases of high vertical closures, when adequate alert time would not be provided by the 750 ft threshold that is applied to present vertical separation.

4.6 Seattle Encounter

On 23 July, a series of seven operational approaches were performed at Seattle, Washington. During these tests, numerous advisories were seen (caused by airborne aircraft) early in the test series. However, the alerts were not valid because the intruders were being tracked with apparent vertical velocities of 7000 to 60,000 fpm and relative range rates of 1400 knots. After the third approach to Seattle, the BCAS aircraft landed for repairs to the BEU. After reloading the system, BCAS seemed to work properly.

During the final four approaches, one valid advisory sequence caused by an airborne aircraft was recorded.

Advisories caused by aircraft on the runway surface were recorded within 1.5 nmi and 500 ft of the runway, while BCAS was operating in sensitivity level 4.

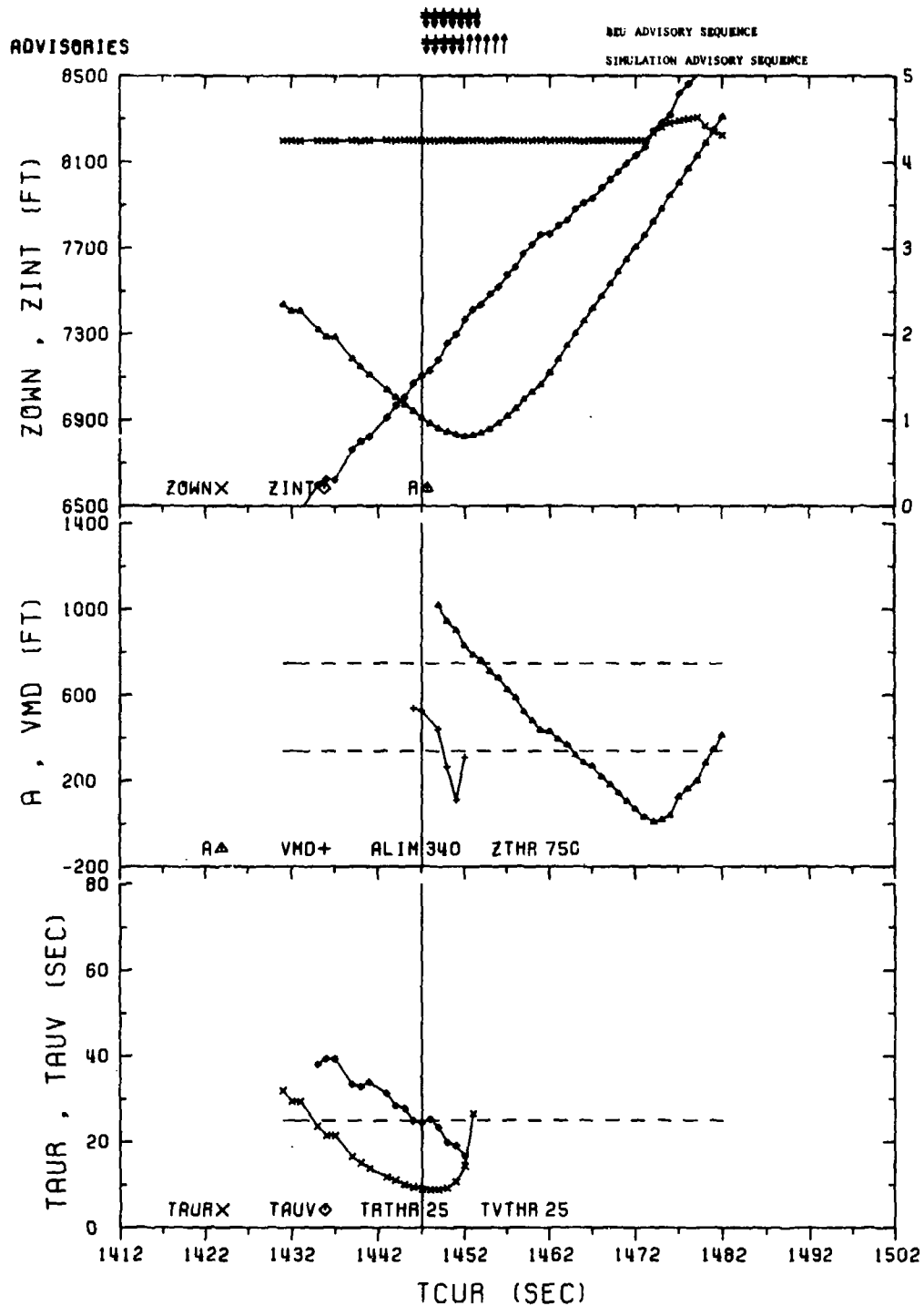


FIGURE 4-32
SEPARATION, TAU PLOTS FOR ENCOUNTER 13 AT LOS ANGELES

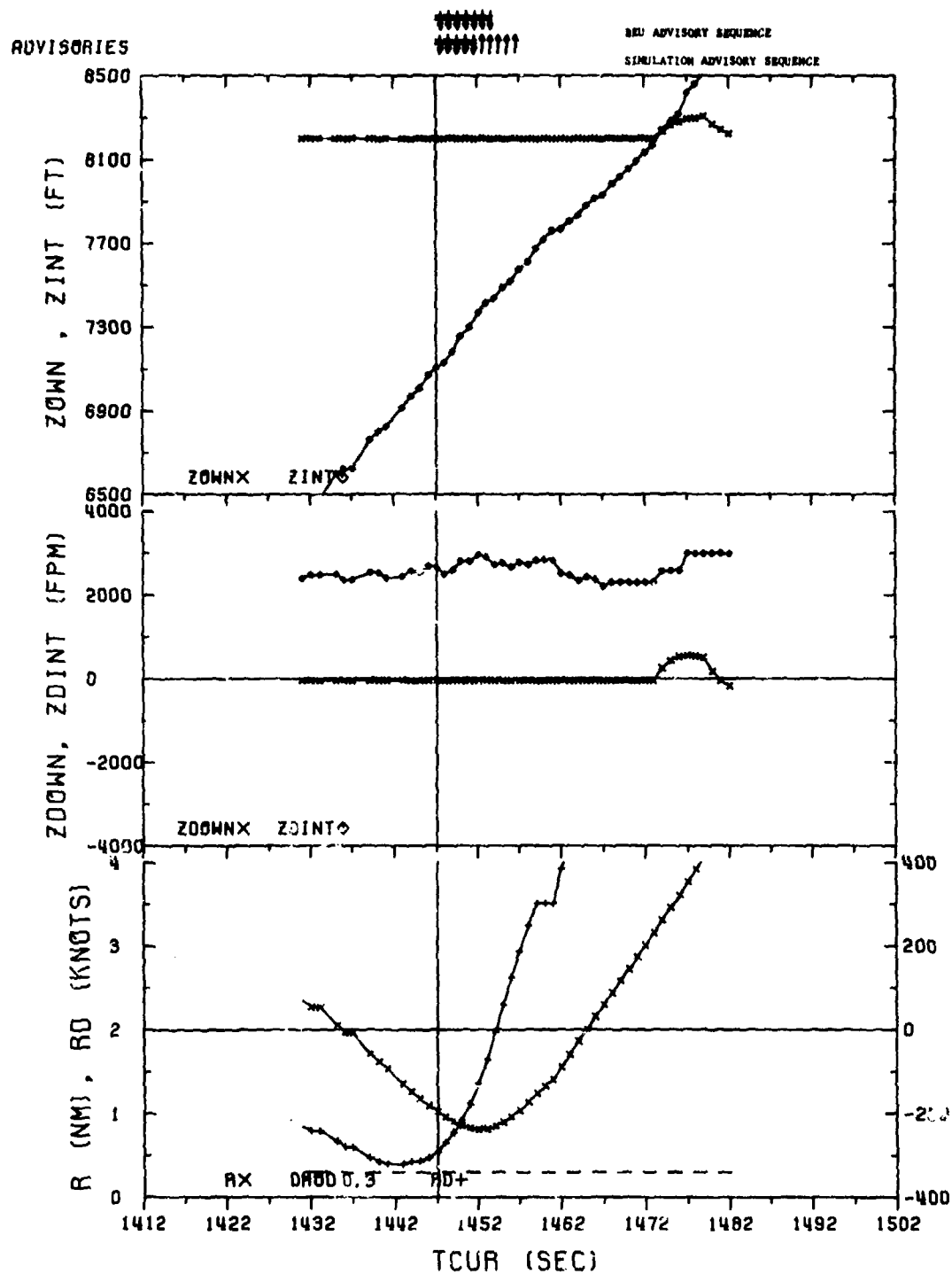


FIGURE 4-33
SEPARATION, RATE PLOTS FOR ENCOUNTER 13 AT LOS ANGELES

4.6.1 Encounter 14

During the sixth approach sequence, while on ILS approach to runway 34R, an advisory sequence was generated by an airborne aircraft (see Figures 4-34 and 4-35). The BCAS aircraft was level at 3600 ft. The other aircraft was at 3000 ft, with its vertical velocity fluctuating between small positive and negative values. When TAUR dropped below the tau threshold, TRTHR, the vertical separation was 600 ft, which resulted in the negative advisory, don't descend.

At the same time that the BCAS advisory was first generated, the other aircraft began to descend. After the five second hold on the don't descend advisory, a VSL, limit descent to 1000 fpm, was computed. Although the BCAS aircraft was actually level, the vertical tracker was still decaying from the previous level-off and was showing a descent rate of less than 200 fpm. The tracked negative vertical descent rate of the BCAS aircraft allowed the advisory to transition to a VSL. The BCAS aircraft began to climb, the other aircraft continued to descend, and the advisory was dropped.

4.7 San Francisco Encounters

On 24 July, a series of low approach flight tests was performed at San Francisco, Oakland, and San Jose airports. Three encounters with airborne aircraft were recorded during the approach sequences to the Oakland airport.

4.7.1 Encounter 15, Short Final Encounter

While performing a low approach to Oakland runway 29, an advisory was seen that was caused by an airborne aircraft. Just prior to touchdown on runway 29, a don't climb advisory was caused by an aircraft in a landing pattern on another runway (see Figures 4-36 and 4-37). The pilot felt that this advisory was very distracting, as it occurred immediately prior to touchdown (when the pilot's attention was needed elsewhere). Although BCAS was operating in level 4 during this approach, the encounter would also have caused an alert with the BCAS operating in sensitivity level 3.

The logic variables are well below threshold at the beginning of this plot. The BEU tape was studied to determine why this was so. It was found that no data for any track was being recorded for 40 seconds prior to the beginning of the plot. This gap in the data is due to a recording problem and is not indicative of a BCAS surveillance problem.

ADVISORIES

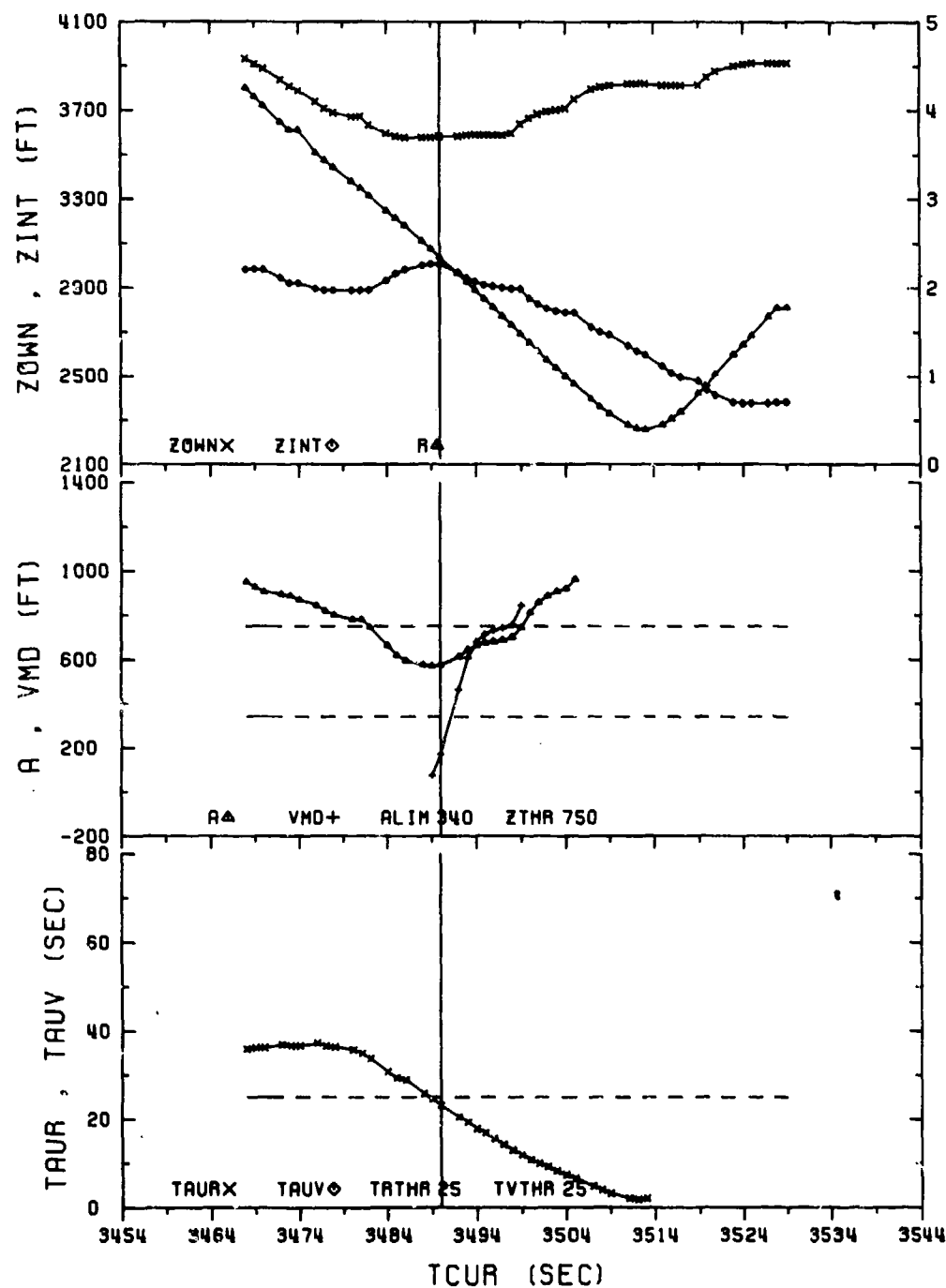


FIGURE 4-34
SEPARATION, TAU PLOTS FOR ENCOUNTER 14 AT SEATTLE

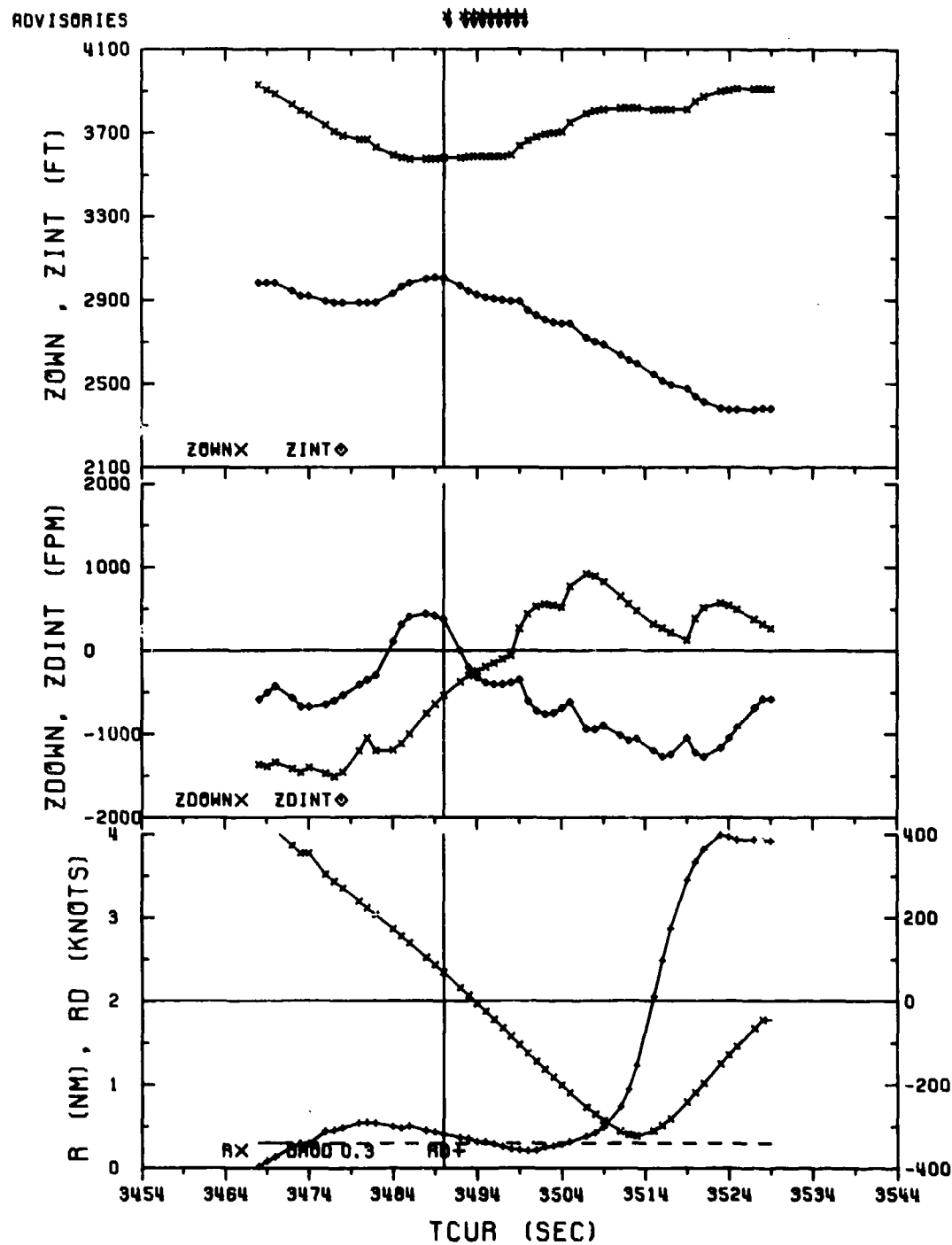


FIGURE 4-35
SEPARATION, RATE PLOTS FOR ENCOUNTER 14 AT SEATTLE

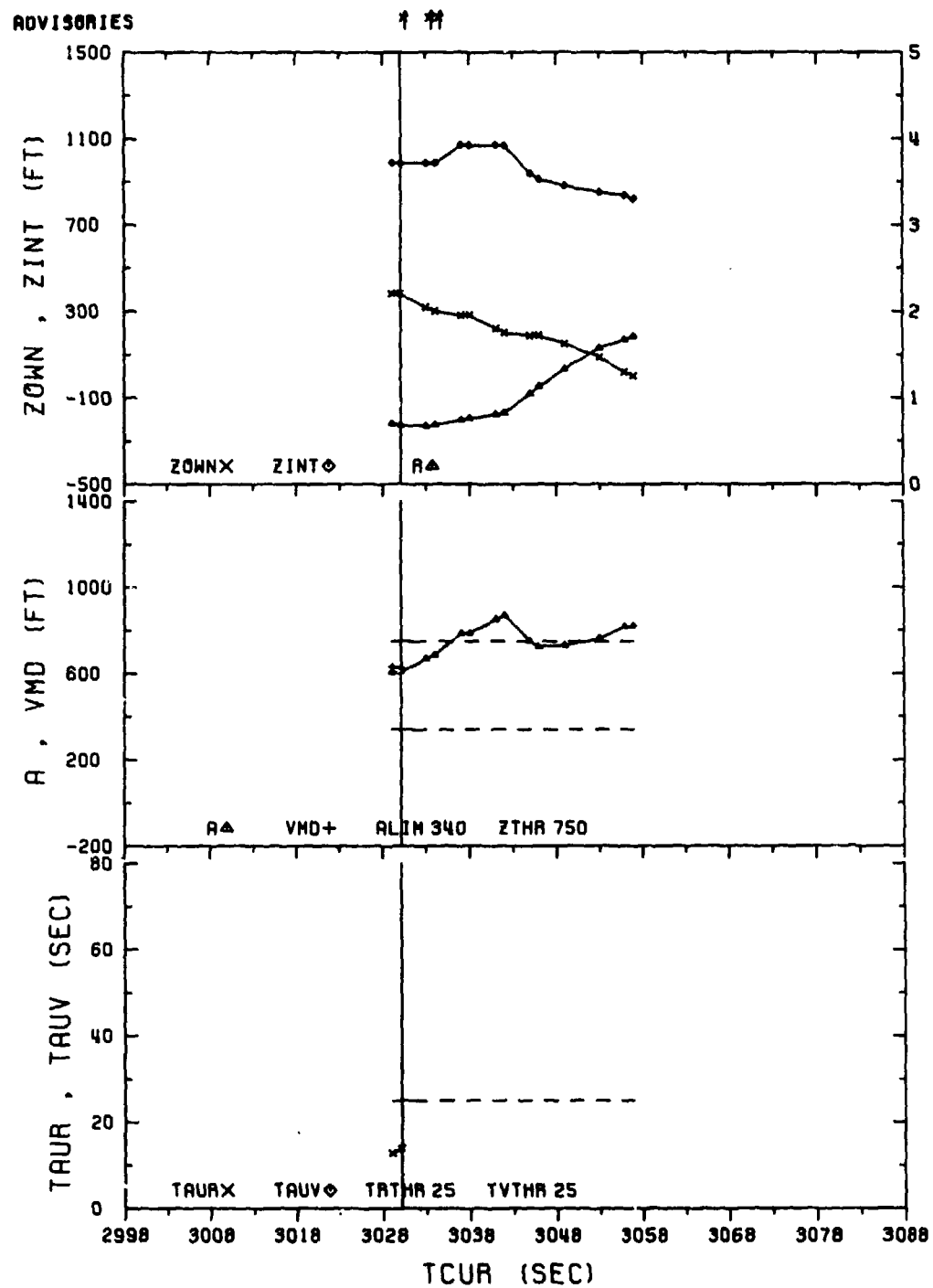


FIGURE 4-38
SEPARATION, TAU PLOTS FOR ENCOUNTER 15 AT SAN FRANCISCO

ADVISORIES

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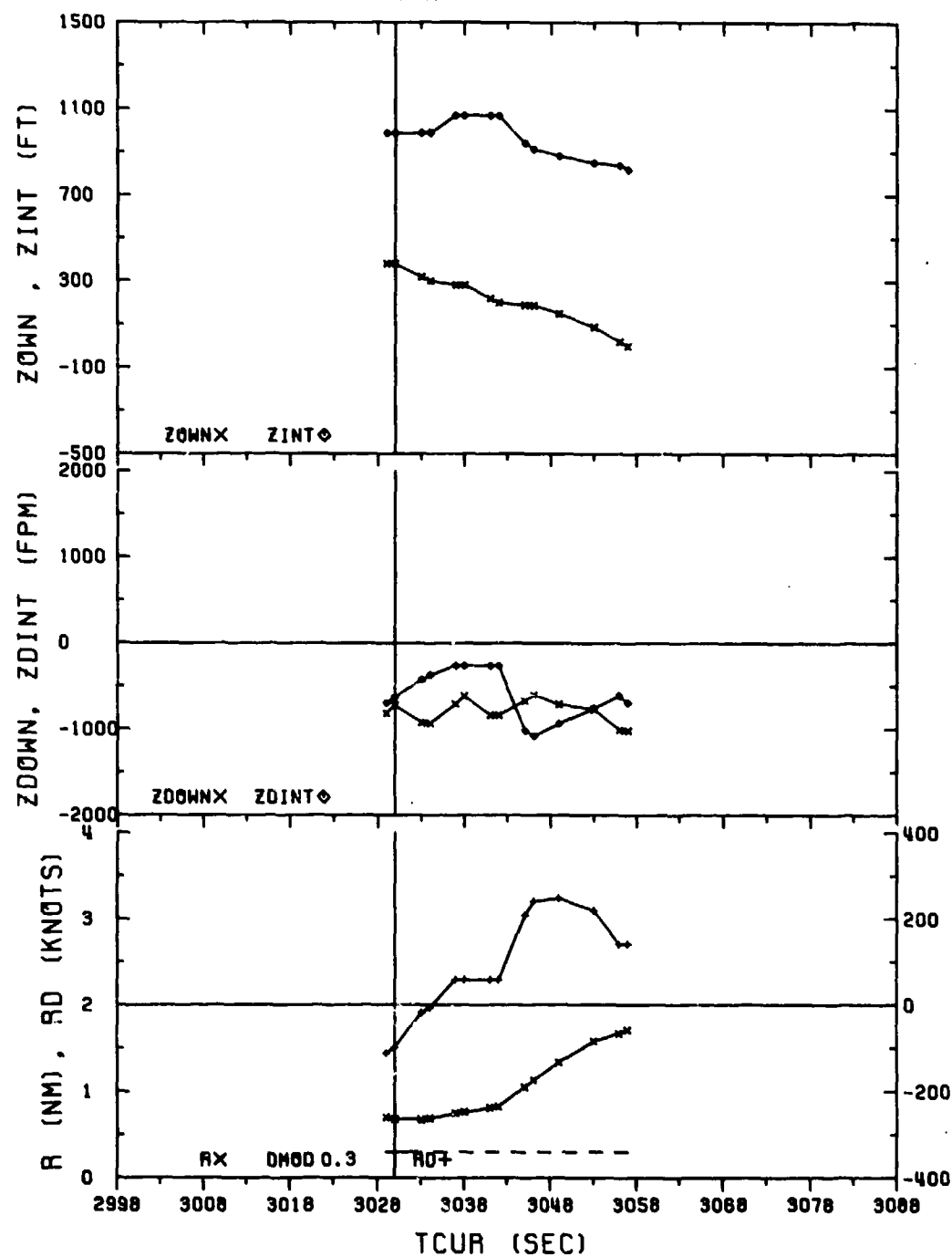


FIGURE 4-37
SEPARATION, RATE PLOTS FOR ENCOUNTER 15 AT SAN FRANCISCO

4.7.2 Encounters 16 and 17, Approach Sensitivity

During the seventh test approach at Oakland, two advisory sequences were generated by two different airborne aircraft. The BEU was operating in sensitivity level 4 for both encounters. While these encounters did not constitute a multi-aircraft encounter, since the encounters did not overlap in time, they occurred close enough in time that they are being discussed together.

Just prior to making the turn to begin the approach to Oakland runway 29, a don't descend advisory was received. The BCAS aircraft was descending through 1800 ft while the other aircraft was climbing through 600 ft. This encounter occurred at approximately seven nmi from the airport. Since the projected vertical separation was greater than ALIM, a don't descend advisory was given by the BEU. Both aircraft then began to decrease their vertical velocity. The value of VMD got smaller, approaching zero. When VMD dropped below ALIM the advisory transitioned to a climb. The advisory was dropped, at system time 7208, when TAUW went above the TVTHR threshold.

The simulation results for this encounter are shown in Figures 4-38 and 4-39. The simulation computed only the climb advisory. However, there are numerous gaps in the data at the time the advisories were being selected, and it seems likely that the simulation would also have computed an initial negative advisory had it been provided with all of the surveillance data.

There is an additional significant observation to be made about this encounter. The BCAS logic requires that the detection logic be satisfied on two of three consecutive cycles before an advisory will be displayed. During the first cycle in which the detection logic is satisfied, the BCAS logic selects the sense of the advisory, but does not display the advisory. On the second cycle that the detection logic is satisfied, the type of advisory (positive, negative, or VSL) to be issued is determined and the advisory is displayed (both type and sense). There is no relationship between the sense selection logic and the type of advisory logic. Consequently, it is possible that the resultant advisory may be inappropriate for the physical situation, as is the case in this encounter.

When the BEU selected the sense, it determined that climb was the correct sense. During the second cycle in which the detection logic was satisfied, the BEU determined the type of

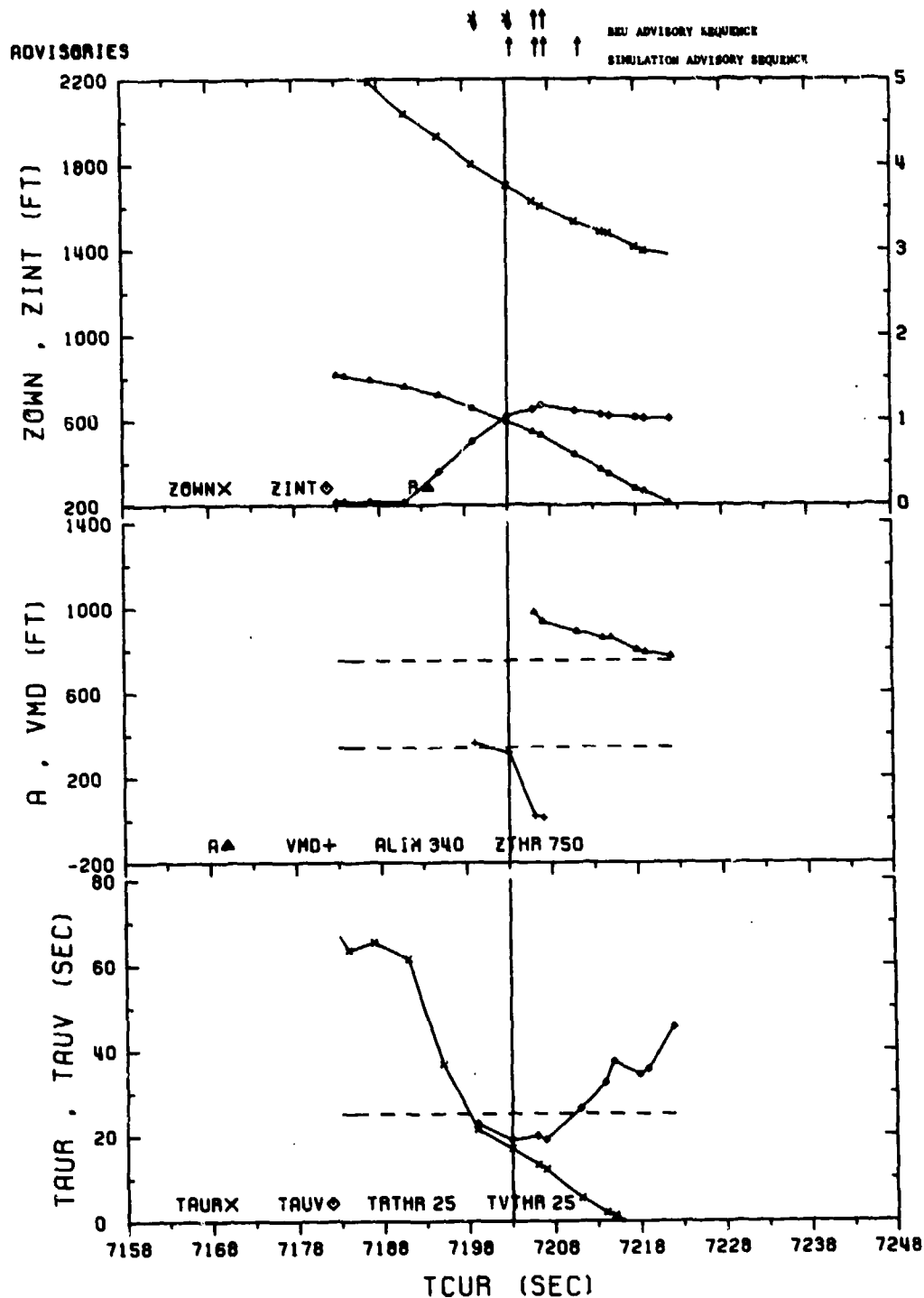


FIGURE 4-38
 SEPARATION, TAU PLOTS FOR ENCOUNTER 1 SAN FRANCISCO

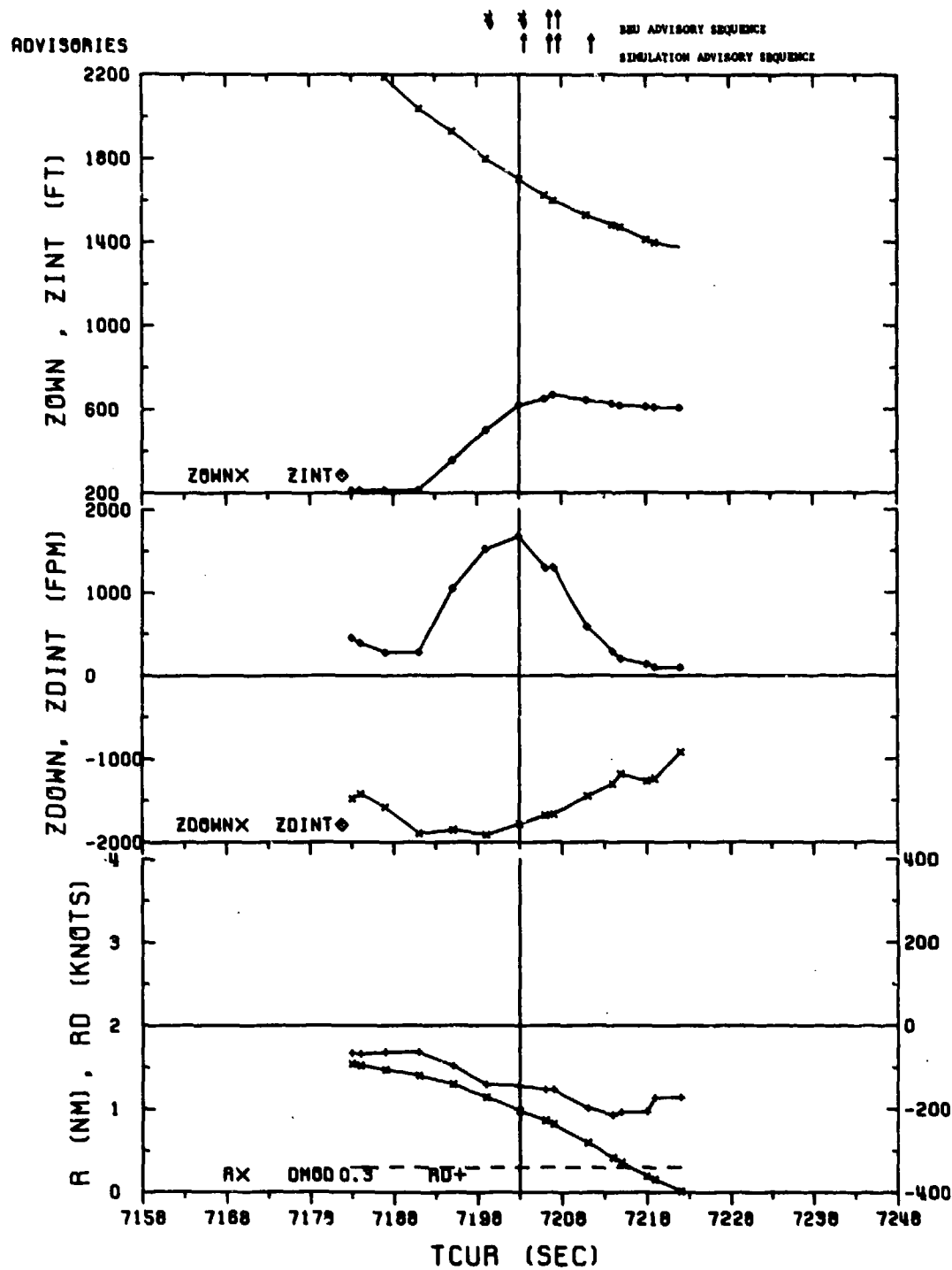


FIGURE 4-39
SEPARATION, RATE PLOTS FOR ENCOUNTER 16 AT SAN FRANCISCO

advisory. Because VMD was greater than ALIM at this time, a negative advisory was selected and a don't descend was displayed. VMD is determined by projecting the altitudes of the BCAS aircraft and the intruder ahead to the estimated time of closest approach. In Figure 4-38, if the vertical trajectories of the two aircraft are visually projected 25 seconds ahead from the point at which the advisories were selected, it is clear that the BCAS aircraft is projected to be below. In fact, it is projected to be slightly more than 340 ft below when the BEU selects the type of advisory, and the vertical divergence feature selects a negative advisory. The vertical divergence logic, in selecting a negative type of advisory, indicates that own will be safely below the intruder at closest approach. Because the climb sense was previously selected, the negative advisory that results is don't descend. But the effect of a don't descend in this situation would be to prevent own aircraft from passing through the intruder's altitude to achieve a safe separation below the intruder. In this encounter, the climb sense turned out to be correct post facto because the intruder leveled off as soon as the advisory was selected.

It is felt that this deficiency in the logic should be corrected. There appears to be no fault with the sense selection logic here. Instead, it appears that the vertical divergence logic should not be applied in this situation. In correcting this deficiency, consideration will be given to forcing the type of advisory to be positive, whenever the VMD test indicates a negative is appropriate in a vertical crossing situation but the sense selection implies a vertical crossing is undesirable.

The advisory for the second encounter came up at system time 7012 (see Figures 4-40 and 4-41). The BCAS aircraft was descending through 1300 ft while the third aircraft was climbing through 1500 ft. A don't climb advisory was given to the BCAS aircraft. As the aircraft continued to diverge vertically, the advisory was dropped.

There was a gap of only five seconds between the end of the advisory from the first encounter and the beginning of the advisory for the second one. If the advisories had overlapped, the multi-aircraft logic would have been invoked. Because the sense of the advisories against the two threats were opposite, the result of the multi-aircraft logic in this situation would have been the composite advisory, don't climb and don't descend. The BCAS aircraft was in sensitivity level 4, although the aircraft was only seven nmi from Oakland airport. The second encounter would not have created advisories if level 3 had been in effect.

ADVISORIES

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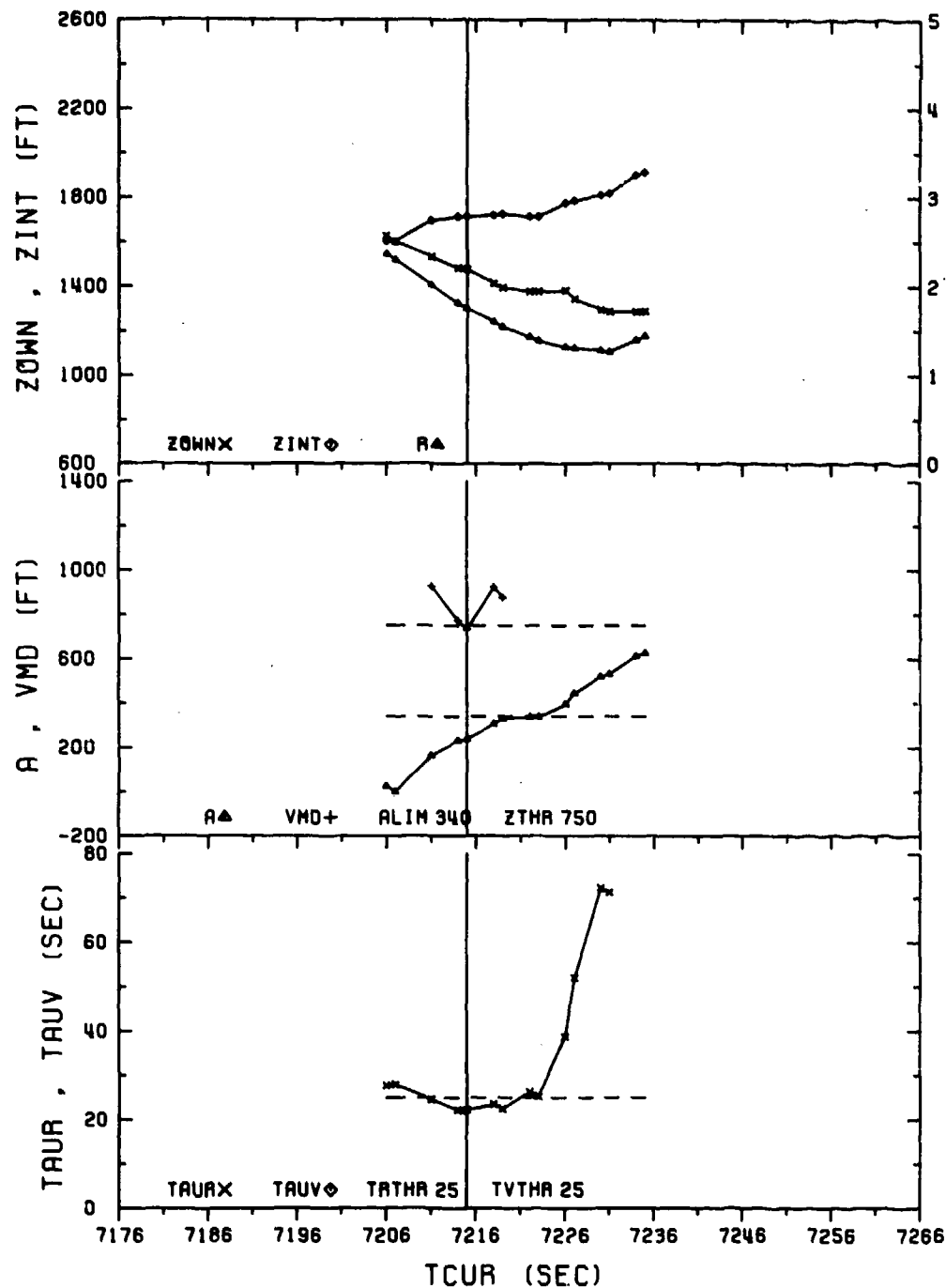


FIGURE 4-40
SEPARATION, TAU PLOTS FOR ENCOUNTER 17 AT SAN FRANCISCO

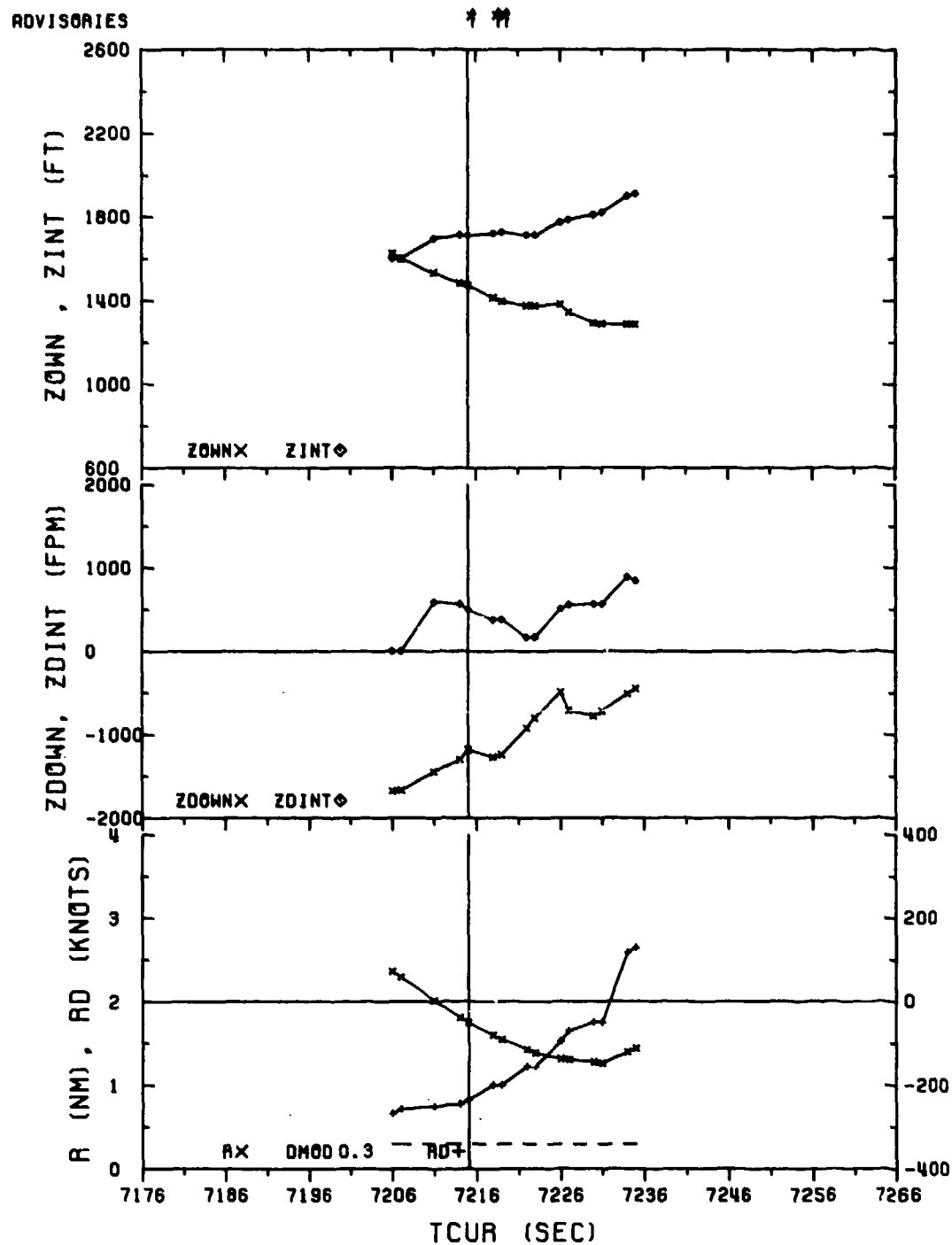


FIGURE 4-41
SEPARATION, RATE PLOTS FOR ENCOUNTER 17 AT SAN FRANCISCO

Even though the multi-aircraft situation did not develop in this instance, the potential for it was there. The multi-aircraft logic has some limitations in its ability to ensure collision protection when two unequipped intruders are involved. For this reason, it should only be invoked when necessary. Operating with larger protection parameters raises the likelihood of multi-aircraft encounters, as illustrated in this situation. Level 4 parameters should not be used too close to busy airports. These two encounters suggest that level 3 should be used in this area at Oakland.

4.8 Encounter 18, Loran C Flight on 4 August

On 4 August 1980 a Loran C flight test was being performed by aircraft N49. The BEU is turned on and operated normally on flights such as this, which are conducted for other projects. Additional useful experience can be realized through these piggyback flights. During this Loran C flight an advisory with an airborne aircraft was received. A don't climb advisory was caused by a DC9 climbing towards the BCAS aircraft, while BCAS was operating in sensitivity level 5.

The BCAS aircraft was level at 16,000 ft. The DC9 was climbing out from 14,000 ft at about 3000 fpm. When the DC9 reached 15,600 ft, it was being tracked as climbing at 2000 fpm. A 30 second projection of the DC9 at this rate would place it 500 ft above the BCAS aircraft. This was the point at which the aircraft were declared in conflict (see Figures 4-42 and 4-43). The sense of the advisory chosen for the BCAS aircraft was descend, since descend would reinforce the predicted altitude crossing and provide more altitude separation than a climb advisory. On the second cycle of declaring the DC9 a threat, the actual advisory was chosen. Both A and VMD were greater than ALIM, so a negative advisory, don't climb, was given and locked into the display for five seconds. The don't climb advisory was given even though the intruder had not yet crossed above the BCAS aircraft's altitude.

The DC9 had begun to level-off just before the advisory was calculated. However, because of tracker lag, the vertical tracker was still showing a climb. During the five second hold on the don't climb advisory, the vertical tracker began to catch up with the DC9's true vertical rate. VMD decreased towards zero. However, at this point, since the intruder's vertical velocity was below 1000 fpm, the unequipped intruder logic was disabled. The current separation, A, was used to choose the

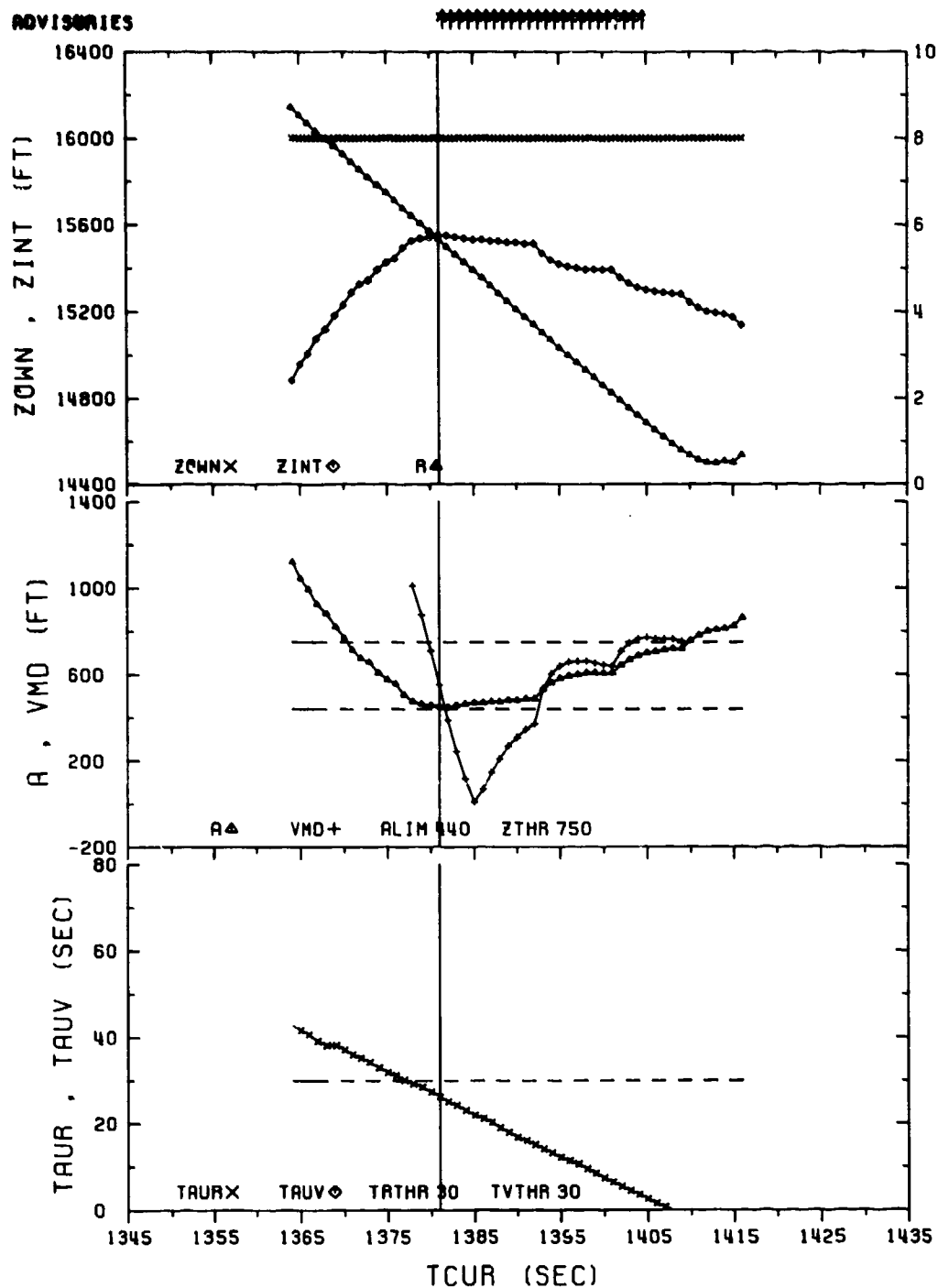


FIGURE 4-42
SEPARATION, TAU PLOTS FOR ENCOUNTER 18 ON 4 AUGUST

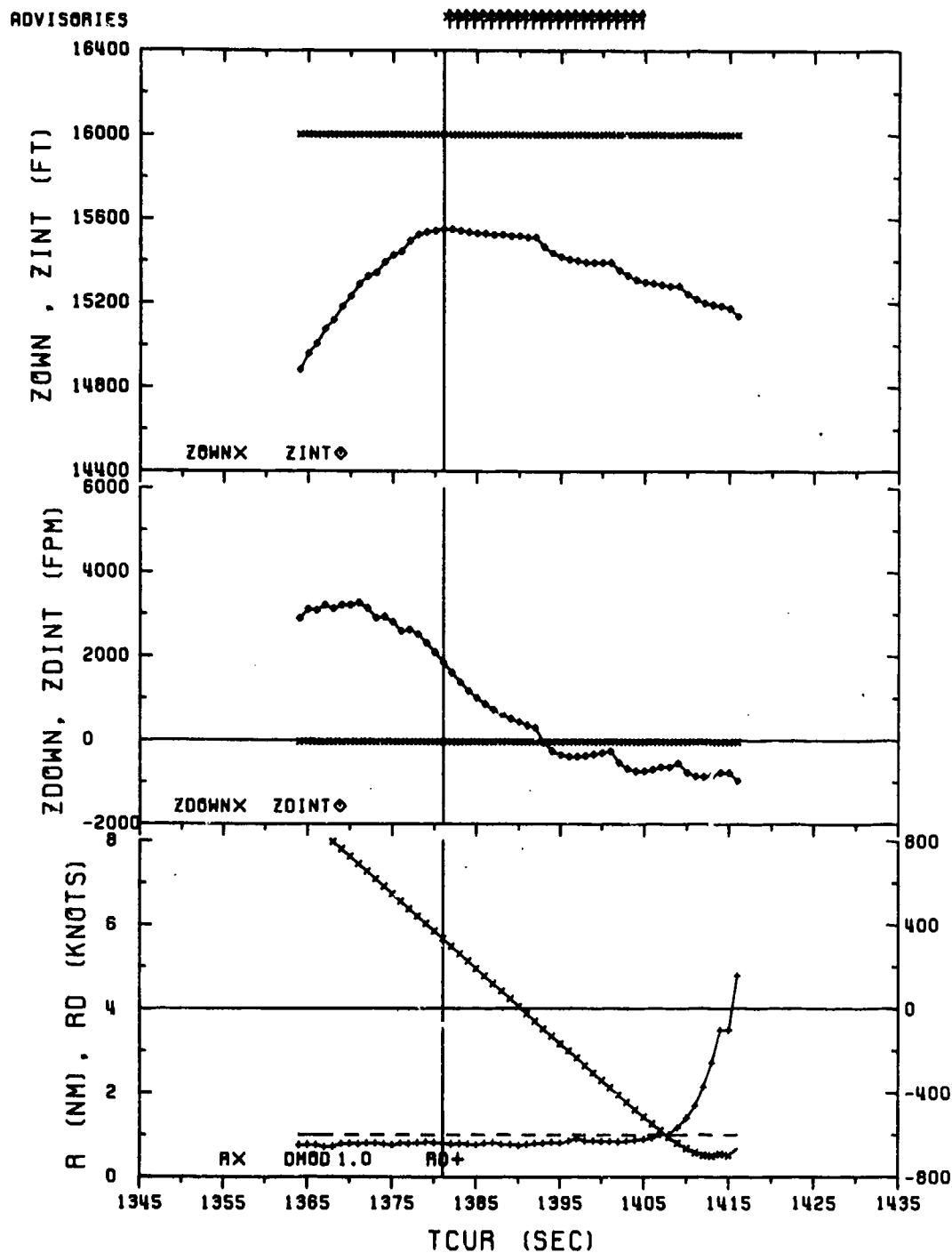


FIGURE 4-43
SEPARATION, RATE PLOTS FOR ENCOUNTER 18 ON 4 AUGUST

advisory. Therefore, the negative advisory, don't climb, remained. The DC9 then descended towards 15,000 ft. The advisory dropped when VMD became greater than ZTHR.

A non-linear altitude tracker has been developed by the MIT Lincoln Laboratory. The details of this tracker are presented in Reference 3. The non-linear tracker is insensitive to isolated one-bit changes in the Mode-C reports. It is more sensitive when two or more consistent Mode-C transitions are observed.

Although this encounter was not planned, it is a very good case for showing the value of a non-linear tracker. This non-linear tracker has been incorporated into the latest BCAS logic documented in Reference 3 since the time of the operational flight tests. In this encounter, the "wrong sense" advisory was chosen because the vertical tracker was showing a large vertical velocity for the DC9, when in fact the DC9 had leveled-off. Figures 4-44 and 4-45 show what would have happened in this case if the non-linear tracker had been used. On the first cycle that the DC9 would have been declared a threat, its vertical rate would have been tracked as -500 fpm. Because of this rate, a vertical track crossing would not have been predicted. Climb would have been the sense of the advisory chosen. Because both A and VMD were greater than ALIM, the actual advisory displayed would have been don't descend.

It should be noted that, if the BCAS logic had been required to select the sense during the interval from system time 1376 to 1378, the "wrong sense" advisory (descend) would have been chosen even with the use of the non-linear tracker. This compares to the seven second interval from 1376 to 1382, during which the wrong sense advisory could have been chosen by the alpha-beta vertical tracker. While the non-linear tracker still lags in tracking the true vertical velocity, it follows the true track more closely than the alpha-beta tracker does for the given vertical velocities seen in this case.

This encounter also illustrates the fact that BCAS resolution capability does not always improve as the protection parameters are increased. This encounter occurred at sensitivity level 5. Here, the alert time parameter is 30 seconds. Figure 4-46 shows the same 4 August encounter when the original alpha-beta linear tracker with $BETA = 0.05$ is used, but the logic is exercised with sensitivity level 4 parameters. Here the alert time parameter is 25 seconds. As is seen, the correct sense advisory (climb) was selected in this case.

ADVISORIES

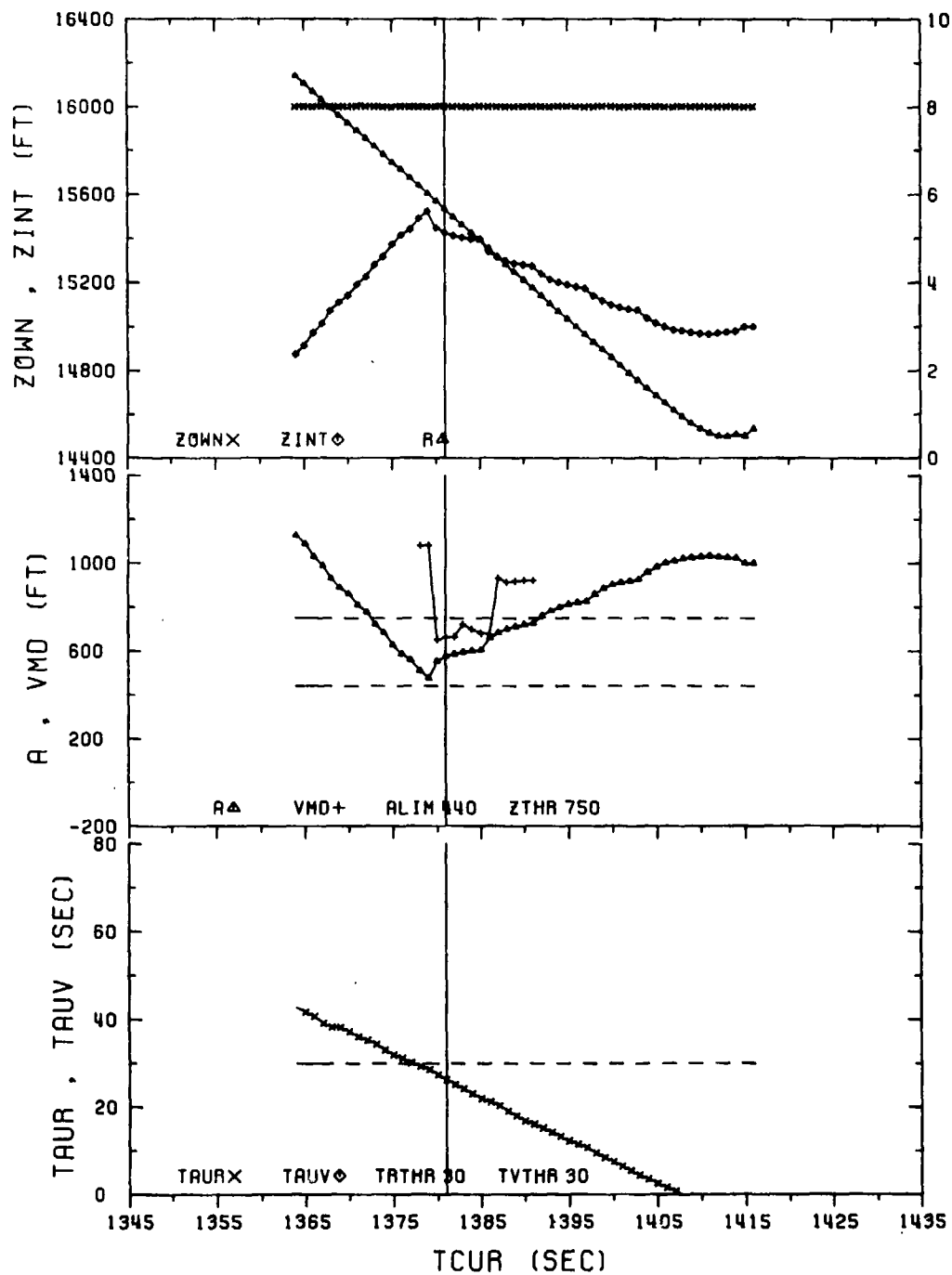


FIGURE 4-44
SEPARATION, TAU PLOTS FOR
4 AUGUST ENCOUNTER USING NON-LINEAR TRACKER

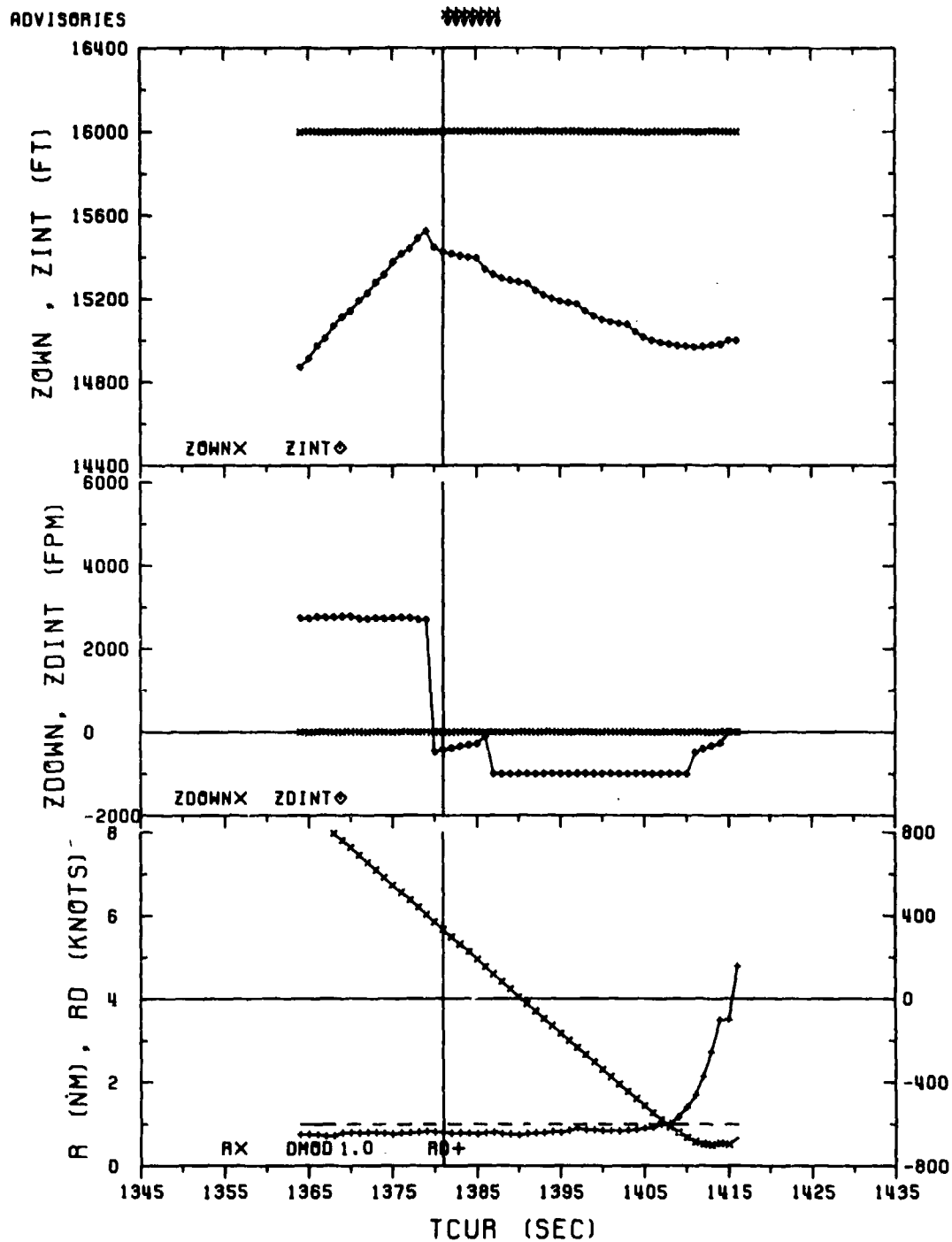


FIGURE 4-45
SEPARATION, RATE PLOTS FOR
4 AUGUST ENCOUNTER USING NON-LINEAR TRACKER

ADVISORIES

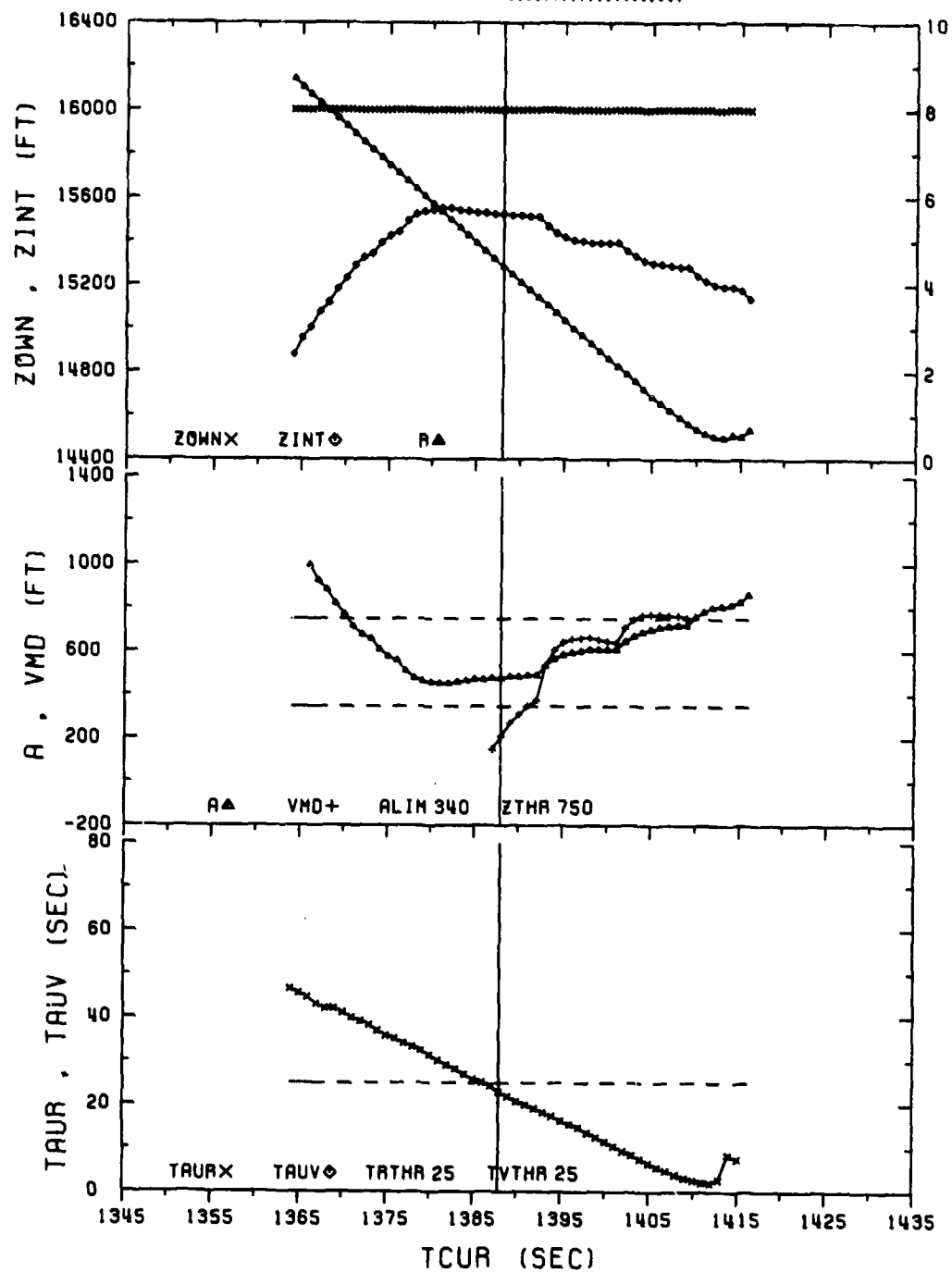


FIGURE 4-46
SEPARATION, TAU PLOTS FOR
4 AUGUST ENCOUNTER USING SENSITIVITY LEVEL 4

The impact that the vertical maneuver by the intruder had on the BCAS logic is seen in Figure 4-42. When the sense of the advisory was being selected, the BCAS logic was predicting that the intruder would be almost 700 feet above the BCAS aircraft at the closest approach. This is indicated by the value of VMD at time 1380, since the BCAS aircraft is level. In reality, the intruder was 800 feet below the BCAS aircraft at closest approach, as indicated by the value of A at about time 1412. This represents a 1500 ft prediction error, which is a graphic illustration of the hazards of predicting too far into the future. In contrast, the prediction with level 4 parameters (Figure 4-46) was in error by 630 ft -- less than half of the level 5 number.

In summary, neither the non-linear tracker, nor smaller alert times, nor both can wholly eliminate the problems caused by sudden maneuvers by an unequipped intruder. However, both can help substantially in reducing the vulnerability to these problems.

5. ADDITIONAL OBSERVATIONS FROM THE OPERATIONAL FLIGHT TEST DATA

Section 4 discussed the details of each unplanned encounter. The relative geometry and resulting BCAS advisories were examined. This section will discuss the observations that can be drawn from this small set of encounters.

5.1 Physical Characterization of the Encounters

Table 5-1 presents additional information about the 18 encounters for which recorded data was available. Values for several of the physical and logic variables at the time of the first advisory are shown in columns 2 through 8. Column 2 shows the range and vertical tau threshold that was in use at the time of the alert. Column 3 shows the value of range tau at the time of the alert. Columns 4 and 5 present the range and relative altitude respectively. Column 6 gives the value for vertical tau, when its value was available at the time of the alert. In many encounters, the vertical separation at the time of alert is less than the ZTHR threshold and vertical tau is not calculated. Columns 7 and 8 give the values for vertical miss distance and closing rate, respectively. Column 9 has a heading of "DENSITY". It presents the total number of active tracks within 10 nmi being maintained by the BEU at the time of the alert. The last two columns present the slant range and relative altitude separation at the time of closest approach.

It is interesting to compare the value of the tau thresholds used in each encounter with the value of range tau, (TAUR), and vertical tau, (TAUV), at the time of first advisory. For an intruder to be declared a threat, the aircraft must be declared in conflict in both range and altitude. The aircraft may violate the alert thresholds in one dimension some time before violating the alert thresholds in the other dimension. The last dimension to fall below its alert threshold is said to "cause" the advisory. If two aircraft violate altitude separation before violating the range tau threshold, then TAUR violating TRTHR is the cause of the alert.

In those encounters where TAUR causes the alert, the value of TAUR is expected to be about two seconds less than TRTHR. TAUV may be greater than or much less than TVTHR. In those encounters where TAUV causes the alert, TAUV should be about two seconds less than TVTHR. TAUR may be much less than TRTHR. For those encounters that have data recorded at the time of first advisory, and the "cause" of the advisory is a tau value crossing a threshold, it can be seen that the tau values are

TABLE 5-1
PHYSICAL CHARACTERIZATION OF THE ENCOUNTERS

Encounter Number	Conditions At First Advisory								Conditions At Closest Point Of Approach	
	TR(V)THR (s)	TAUR (s)	R (nmi)	A (ft)	TAUV (s)	VMD (ft)	RD (kn)	DENSITY ¹	R (nmi)	A (ft)
1	25	23.2*	1.1	300	-	-	-128	7	0.35 ³	288
2	20	18.5*	0.9	156	-	-	-165	6	0.19 ³	346
3	25	23.7*	3.2	106	-	-	-440	1	0.25 ³	837
4**	20	11.8*	0.4	150	-	26	-80	10	0.15 ³	194
5	25	17.8	2.2	687*	-	103	-376	1	0.79 ³	500
6	20	18.3*	0.6	156	-	18	-93	9	0.18 ³	181
7	20	19.1*	1.3	600	-	421	-233	9	1.04	81
8	20	18.9*	2.1	112	-	-	-374	2	0.37 ³	569
9	20	18.4*	2.1	431	-	-	-388	2	0.71	481
10**	25	24.0*	2.2	550	-	-	-277	4	1.10	712
11	25	22.9*	2.0	163	-	-	-270	7	0.16 ³	813
12**	25	21.5*	2.7	300	-	-	-394	4	0.25 ³	300
13	25	8.9	1.0	1094	24.4*	527	-292	7	0.81	831
14	25	23.1*	2.3	575	-	171	-318	6	0.39	1225
15**	25	12.9*	0.7	606	-	-	-112	11	0.67	659
16**	25	21.4*	1.1	1300	22.7	360	-142	8	0.01 ³	7692
17**	25	23.5	1.6	306	-	732*	-234	10	1.27	531
18	30	26.2	5.7	450	-	550*	-641	1	0.49	807

* This variable caused the alert in the sense that it was the last variable to violate threat detection thresholds.

** Exact conditions at first advisory cannot be determined since CAS intruder track file data is missing from the tape at the time of first alarm.

- 1 Density is the number of aircraft being tracked by the BCAS within 10 nmi at the time of first advisory.
- 2 Range tracker overshoot can cause slant range to be less than altitude.
- 3 The BEU produced a positive advisory for these encounters.

never more than 2.1 seconds less than the tau threshold. It should be realized that this two to three second "delay" has been accounted for in setting the value of the tau thresholds.

The RD column shows that five of the encounters had closing speeds greater than 350 knots. This is a significant number of encounters with relatively high closing speeds.

The superscript 3 in the column headed "R" indicates those encounters for which the BEU gave a positive advisory. It is seen that the separations at the actual point of closest approach for these encounters are reasonably small. Four of the encounters in which the BEU gave a positive advisory resulted in vertical separations at closest approach greater than 500 feet. These are encounters 3, 8, 11, and 16. In two of these (encounters 3 and 8), the larger vertical separation resulted from maneuvers on the part of the BCAS aircraft. In the other two, the intruder either initiated a maneuver away from the BCAS aircraft or leveled off from a vertical maneuver at about the time of the alert. Thus, all of the positive alerts occurred in encounters where relatively small separations actually occurred or were imminent. Whether each of these is justified depends upon the perceptions of individual pilots.

Figure 5-1 shows the distribution of encounters with airborne aircraft in terms of the altitude above ground level at the time of the advisory. All of the encounters below 2000 ft AGL occurred while the BCAS aircraft was in the landing phase. The encounters below 500 ft AGL were on short final approach, where the presence of BCAS alerts may actually be a disadvantage because of pilot workload.

Figures 5-2 and 5-3 are plots of the separation at the time of first advisory. They give a pictorial representation of the data in columns 4 and 5 of Table 5-1. Figure 5-2 shows altitude separation versus range at first advisory for the encounters that occurred while BCAS was operating in sensitivity level 3. Figure 5-3 shows the same data for encounters occurring while using sensitivity level 4. As would be expected, the separations at first advisory while operating in sensitivity level 3 were closer than while operating in sensitivity level 4. This is due to the larger tau and DMOD thresholds used in sensitivity level 4.

Figures 5-2 and 5-3 provide some data relevant to the question of whether the pilot may have visual contact with the intruder

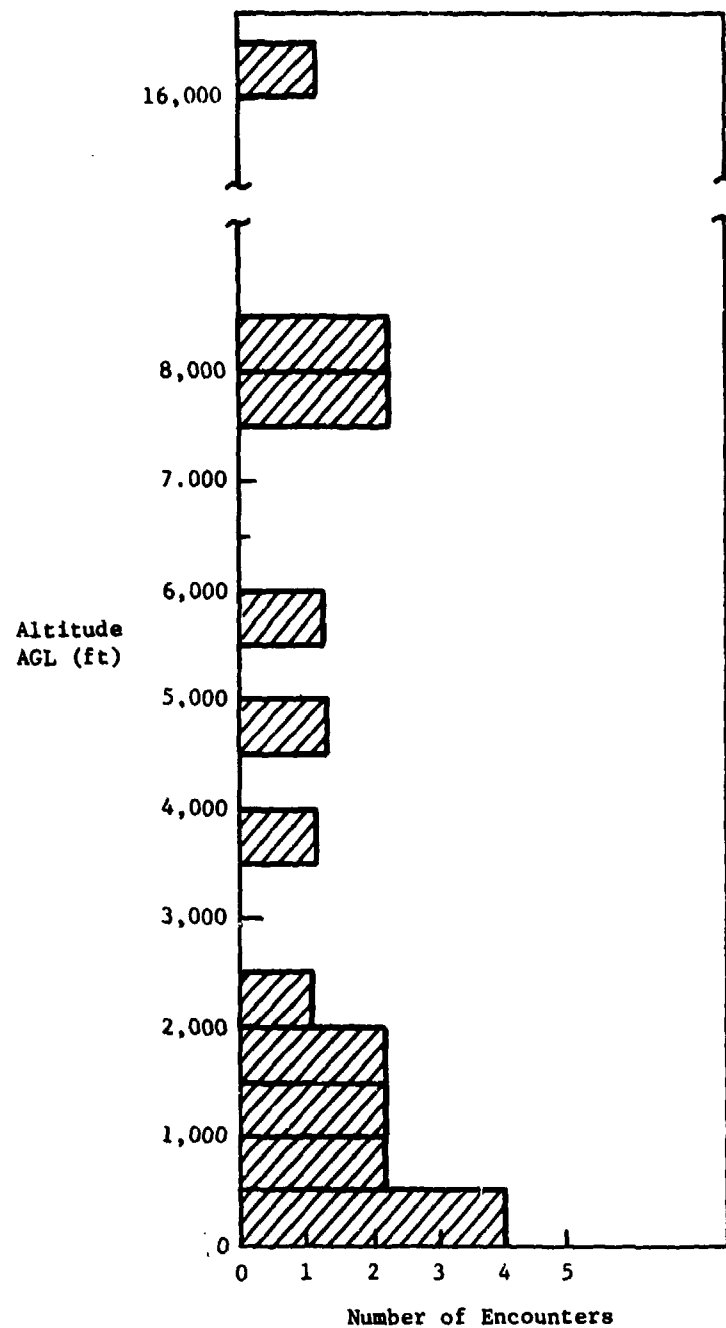


FIGURE 5-1
ALTITUDE DISTRIBUTION OF THE 19 ENCOUNTERS

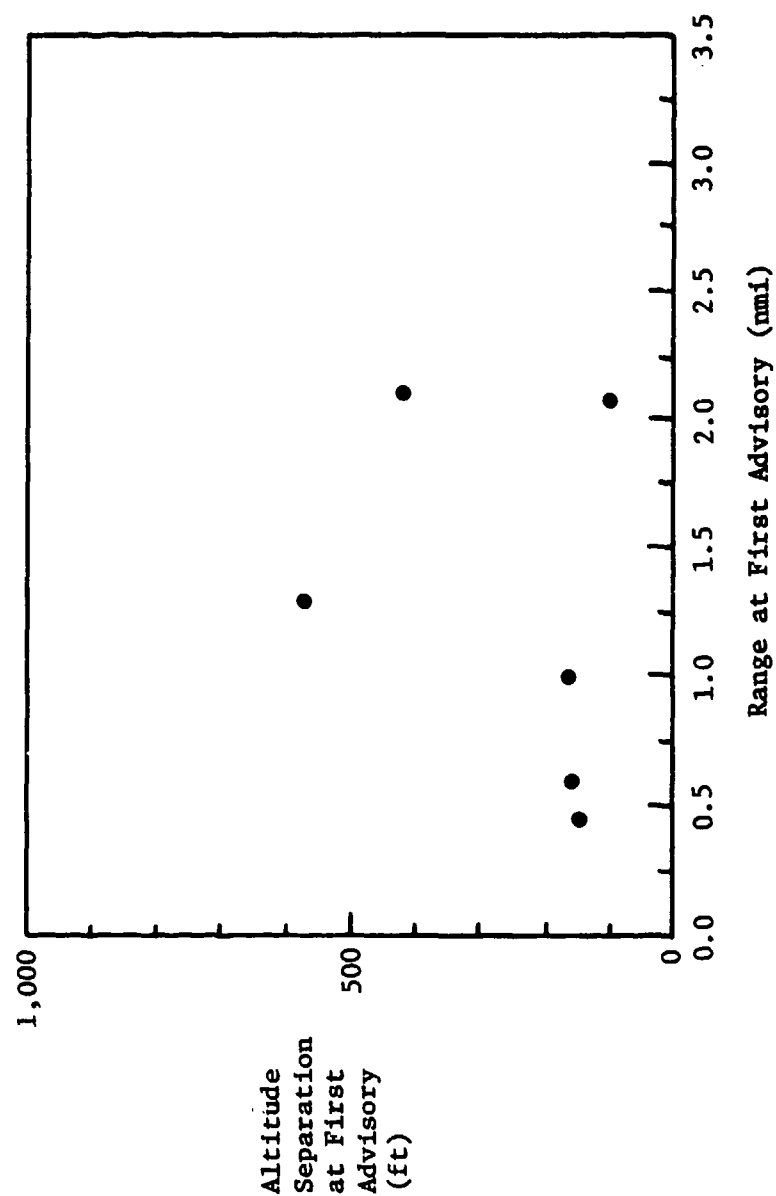


FIGURE 5-2
SEPARATION AT FIRST ADVISORY FOR ENCOUNTERS IN SENSITIVITY LEVEL 3

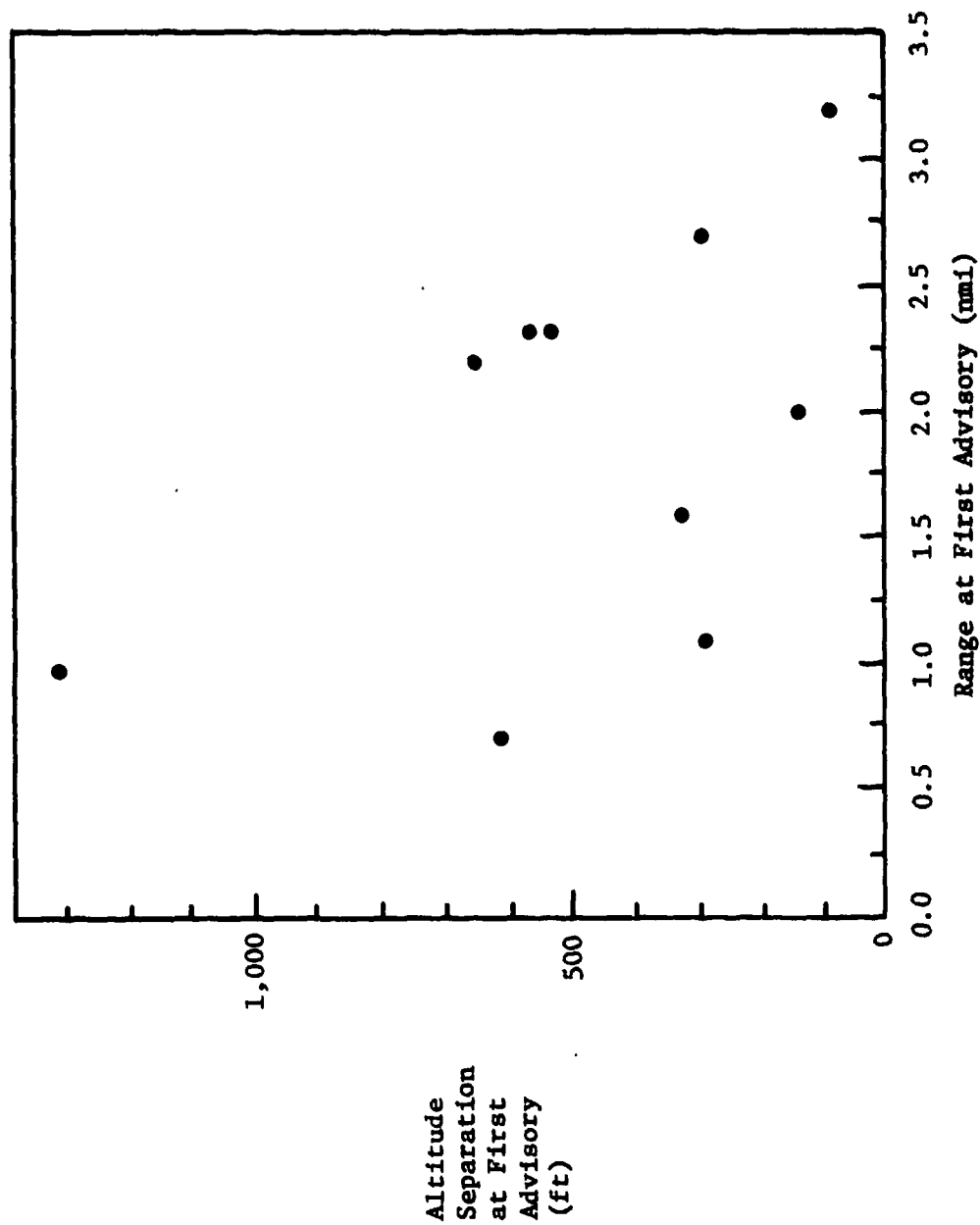


FIGURE 5-3
SEPARATION AT FIRST ADVISORY FOR ENCOUNTERS IN SENSITIVITY LEVEL 4

at the time of the BCAS alert. It is noted that the range at time of alert is greater than 2 nmi for several of the encounters. Depending on the size of the intruder aircraft, the encounter geometry, and the visibility conditions, it is expected that a pilot would not have visual contact at the time of alert for some of these encounters.

5.2 Utility of VSL Advisories

In only three of the 19 encounters was a VSL issued by the BEU at some point during the advisory sequence. These were encounters 10, 13, and 14. In only two of the encounters (encounters 10 and 13, Figures 4-22 and 4-32, respectively) was the VSL the only advisory issued. In both of these encounters the BCAS aircraft was actually in level flight. Due to roundoff in the vertical tracking equations, the tracked vertical rate of the BCAS aircraft does not always go to exactly zero in level flight. A small residual vertical rate from the tracker made it appear to the CAS logic that the BCAS aircraft had a small vertical rate toward the intruder.

The VSL logic was intended to be applied only when the BCAS aircraft had a significant vertical rate toward the intruder. However, the test was implemented simply by testing for a nonzero rate toward the intruder. Since the time of the flight tests, the BCAS logic has been modified so that the VSL logic is only applied if the BCAS aircraft has a vertical rate greater than 600 fpm towards the intruder. With this modification, neither encounter 10 nor encounter 13 would generate a VSL advisory; instead, they would generate don't descend advisories.

In encounter 14 (Figures 4-34 and 4-35), the VSL advisory would also be eliminated by the 600 fpm vertical rate check. It is clear from the altitude profile in Figure 4-35 that, at the time the VSL was computed, the BCAS aircraft did not have a real vertical rate toward the intruder. The prolonged decay of the tracker provided a small residual vertical rate at this time.

The VSL advisory logic was originally incorporated into the BCAS logic to permit a BCAS aircraft with a vertical rate to maintain its rate in scenarios in which it was safe to do so. Without the VSL logic, the BCAS logic would have to issue a don't climb or don't descend advisory. These advisories would disrupt the aircraft's flight path, possibly creating interference with ATC operations.

A VSL as the only advisory for this class of encounter would provide little disruption. However, a VSL occurring in a sequence of advisories involving positive or negative advisories in addition to the VSL would not be useful in avoiding disruption to the aircraft's flight path.

In summary, with the new logic modification requiring significant rate toward the intruder before testing for VSLs, no VSL advisory would have been generated (either as the only advisory or in a series involving positive or negative advisories) from any of the 19 encounters. Thus, these flight test results do not demonstrate the usefulness of the VSL advisory. The results do not imply that VSL advisories would never appear. There are scenarios where VSL advisories would be displayed and would be useful. However, the results suggest that these scenarios occur infrequently.

5.3 Alert Rate Analysis

During these flight tests the BEU flew 44 hours on the Western Tour and 23.5 hours on the Eastern Tour. During this time, 18 encounters produced advisories of some type. Of these, four occurred at or below 500 ft AGL (encounter numbers 2, 4, 6, and 15). It is expected that, in operational practice, BCAS alerts will be inhibited at less than 500 ft AGL, so these four encounters are not included in this alert rate analysis.

Of the remaining 14, four (numbers 10, 11, 12, and 13) occurred at Los Angeles while the BCAS aircraft was conducting planned encounters with another FAA aircraft. While these four alerts were due to random aircraft (not part of the planned encounter tests), these alerts are not included in the alert rate analysis because the BCAS aircraft at the time was conducting operations not typical of airline operations. There were eight flight hours spent conducting these planned encounters. Discarding the four alerts that occurred at or below 500 ft AGL and the four alerts that occurred at Los Angeles, and subtracting the eight hours of planned encounter operations from the total flight hours, yields 10 alerts in 59.5 flight hours. This is a rate of about one alert in six hours.

Of the 10 alert encounters, six involved positive advisories at some point in the advisory sequence. This represents a positive alert rate of one alert in about ten flight hours. In Reference 6, a study of BCAS alert rates in the Houston terminal area produced the result that aircraft flying under ATC control could expect to receive one positive alert in 19 flight hours. These results are considered reasonably consistent, allowing for the fact that the BCAS aircraft in these operational flight tests

spent a higher fraction of the total flight hours making approaches to airports than normal airline operations would require.

Since there was some experimenting with the placement of the sensitivity level boundaries during the operational flight tests, there is interest in determining the alert rates that would have been experienced by the BEU had the nominal sensitivity level boundaries been used. The encounters that occurred when other than the nominal sensitivity level boundaries were being used were rerun using nominal boundaries. The only difference that resulted was in encounter 17. The alert in encounter 17 did not occur when sensitivity level 3 (the nominal sensitivity level for this encounter) was used. Thus, using the nominal sensitivity level boundaries there would have been an average of one alert of any type in seven hours and one positive alert in ten hours.

5.4 Alerts Against Aircraft on the Ground

A number of alerts were recorded during the Western Tour and the Eastern Tour that were caused by aircraft on the ground. These encounters were not analyzed from the point of view of BCAS resolution capability. The alerts against aircraft on the ground from the Western Tour were, however, compiled in an effort to observe where the sensitivity level 2 region might be defined. Table 5-2 is a compilation of these alerts from the Western Tour. The range of the BCAS aircraft from the aircraft on the ground is taken as the approximate distance from the airport. There was one alert against aircraft on the ground when the BCAS aircraft was at 600 ft AGL, and one when it was at 500 ft AGL. All other alerts occurred at or below 300 ft AGL. The maximum distance from an intruder on the ground at which one of these alerts was generated was 1.5 nmi. Alerts against aircraft on the ground were generated at nearly all of the airports visited on the Western Tour and the Eastern Tour.

5.5 Implications of Results for the RBX

The BCAS design includes provision for communication between the BCAS unit and a Radar Beacon Transponder (RBX) on the ground. The RBX is being developed as a part of the BCAS program. The RBX in turn is linked to a terminal ATC facility. The RBX is used for two functions. One function is to control the sensitivity level of the BCAS in an aircraft via uplinks from the RBX. The sensitivity levels are determined from pre-defined airspace regions stored in the ATC facility (and/or the RBX). Each region has a sensitivity level setting associated with it.

TABLE 5-2

ALERTS GENERATED BY AIRCRAFT ON THE GROUND DURING THE WESTERN TOUR

LOCATION	CONDITIONS AT FIRST ADVISORY		SENSITIVITY LEVEL
	RANGE	ALTITUDE AGL	
Dallas	0.9 nmi	100 ft	3
	0.8	300	3
	0.8	200	3
Houston	0.8	300	3
Denver	1.2	100	3
	1.1	100	3
	0.9	200	3
	0.9	100	3
	0.7	200	3
	0.6	300	3
	0.5	100	3
	0.5	100	3
	0.4	100	3
Salt Lake City	0.8	200	3
	0.6	100	3
Los Angeles	1.5	300	4
	1.5	300	4
	1.4	600	4
	1.4	100	4
	1.4	100	4
	1.4	100	4
	1.2	300	4
Seattle	1.2	200	4
	1.2	100	4
	1.1	200	4
	0.6	100	4
Kansas City	1.3	300	4
	1.2	300	4
Chicago	1.4	300	4
	1.2	100	4

The appropriate sensitivity level setting is uplinked to the aircraft when the aircraft is within any of the pre-defined regions. The other function of the RBX is to receive BCAS advisories downlinked from the BCAS unit and to transmit them to the ATC facility for subsequent display to controllers and for recording.

Although an RBX was not used in the operational flight tests, some observations can be made pertaining to the functions of the RBX.

5.5.1 Desensitization

The flight test results indicate that the BCAS should be inhibited at altitudes less than 500 ft AGL when in the vicinity of an airport to avoid unwanted alerts against both aircraft on the ground and aircraft in normal patterns very close to the airport. The sensitivity level 2 region is implemented by the RBX to satisfy this requirement. The proposed nominal sensitivity level 2 boundaries inhibit alerts when the BCAS aircraft is within two nmi of the RBX and is less than 900 ft above the elevation of the airport. The data in Table 5-2 suggests that these boundaries would prevent alerts generated by aircraft on the ground. This conclusion cannot be completely verified, however, because the two nmi range boundary is measured from the RBX, which must be placed at a fixed point on the airport. The ranges in Table 5-2 are measured to the individual aircraft. It is possible that some of the aircraft generating these alerts were holding short of the approach end of the runway to which the BCAS aircraft was making an approach. Presumably, the range to the RBX would be greater than the range to the intruder in this case. There was no convenient way to determine where the BCAS aircraft was with respect to a fixed location at the airport when the alert was given, so the range from a hypothetical RBX location could not be estimated. Nevertheless, the data suggests that the proposed nominal level 2 boundaries would be effective in eliminating alerts generated by aircraft on the ground.

While the RBX can provide the function of inhibiting BCAS advisories near the airport, a means for automatically inhibiting alerts is needed in the time prior to deployment of the RBXs and at airports where an RBX may not be deployed. For these purposes, inhibiting alerts could be accomplished by using a signal from the on-board radar altimeter. If the radar altimeter were used, it would appear from Table 5-2 that alerts should be inhibited when below 600 ft AGL. The same altitude boundary as used by the RBX (900 ft) would not be recommended for use with a radar altimeter because this would result in

alerts being inhibited at ranges greater than 3 nmi from the airport. These flight test results do not indicate whether the RBX would be more effective for inhibiting alerts than the radar altimeter, or vice versa. However, it is to be expected that the RBX would be more effective, because it can use range from the airport as well as altitude above the airport. Moreover, depending upon the local topography, the radar altimeter may or may not provide an accurate indication of height above the airport surface.

The RBX is also used to desensitize BCAS from sensitivity level 4 to sensitivity level 3. There are so few alarms from this flight test that it is impossible to draw firm conclusions about where the desensitization from level 4 to level 3 should occur. To analyze the data that was available, all alerts that occurred while sensitivity level 4 was being used were reviewed.

Encounter number 1 (Figure 4-1) occurred at eight nmi from the airport. It is evident that this encounter would still have generated an alert in level 3, since the actual sensitivity level setting was changed during the advisory sequence and the advisories remained displayed.

Encounter number 15 (Figure 4-36) occurred in level 4 on short final at San Francisco. This alert would still have been given if level 3 had been used. However, because the alert was given at 400 ft AGL, it is felt that level 2 should be used and the alert inhibited entirely.

Encounter number 17 (Figure 4-40) occurred at level 4 at 1400 ft AGL after the BCAS aircraft had become established on the ILS localizer for an approach to the Oakland Airport. The BCAS aircraft was approximately seven nmi from the airport at this time. (The distance to the airport is inferred by noting the range to aircraft whose altitudes indicate that they are on the ground.) This alert was a marginally useful alert because the aircraft never were closer than 1 1/4 nmi. The alert would not have been given had level 3 been in use. This is an encounter for which level 3 would probably have been preferred. With level 4 in use at the time of this alert, encounter number 17 nearly occurred while advisories were still being displayed from encounter number 16. Only five seconds elapsed from the end of advisories for encounter 16 before the beginning of advisories for encounter 17. This indicates that using level 4 too close to the airport may make the BCAS logic more likely to experience multiple intruder encounters.

Encounter number 13 (Figure 4-32) occurred at level 4 while conducting planned encounters in the Los Angeles area. At the

closest range of 0.81 nmi, the aircraft were separated by more than 800 ft in altitude. By the time the aircraft had reached the same altitude, they were separated by 3 nmi in range. This alert is considered a marginal alert. Whether it is regarded as wanted or unwanted is a matter of personal preference. This alert would have been given even if level 3 parameters had been used.

All other level 4 alerts appear to be desirable alerts. In summary, the proposed nominal range from the airport (ten nmi) for desensitizing from level 4 to level 3 appears to be roughly correct. While no large number of unwanted alerts was experienced in these flight tests when operating with level 4 at ranges closer than ten nmi, several encounters suggest that there is potential for generating a significant number of unwanted alerts if level 4 is used too close to the airport.

The above flight test results suggest that it is important to desensitize from level 4 to level 3. This could be done automatically by the RBX. However, this desensitization could also be performed, albeit at less well defined ranges from the airport, by using on-board inputs such as gear or flap extension indications or a radar altimeter input. For example, the radar altimeter might cause the logic to switch from level 4 to level 3 when the BCAS aircraft descends below 2500 ft AGL. The results of the flight tests do not indicate the degree to which RBX control of this desensitization would be more effective than on-board automatic control.

5.5.2 ATC Notification

The second function of the RBX is automatic notification to the controller of BCAS-generated advisories. The purpose of displaying these advisories to the controller is to make the controller aware as soon as possible of BCAS advisories that may affect the path of the aircraft or that may contradict a just released (or about to be released) ATC instruction. The remainder of this section addresses the utility of this feature, as revealed by the operational flight test results.

Table 5-3 is a compilation of the BCAS advisory durations and the time from first advisory to the closest point of approach (CPA). The advisory durations were determined by noting the time of the first advisory and the last advisory in an advisory sequence from the BEU tape recordings. The time from first advisory to CPA was determined by finding the time of the minimum slant range of the intruder in the printout of the BEU data and comparing this time to the time of the first advisory.

TABLE 3-3

DURATION AND TIME BEFORE CLOSEST APPROACH OF BCAS ADVISORIES

Encounter Number**	Duration of Advisory	Warning Time Before Closest Approach
1	29 seconds	34 seconds
3	18	27
5	22	18
7 ¹	--	--
8	20	19
9	15	20
10*	5	22
11	7	30
12	37	33
13	7	5
14	10	23
16*	9	23
17*	8	19
18	24	32
Average	16	23

* The exact time the advisory was generated by the BEU was not recorded. The advisory duration and time before closest approach may actually have been from 1 to 10 seconds greater.

** Encounters occurring at or below 500 ft AGL have been omitted.

¹ Track dropped before advisories were no longer needed.

For the first 18 encounters, excluding those at or below 500 ft AGL, the maximum time of the BCAS alert prior to CPA was 34 seconds and the minimum was five seconds. The average time before CPA was 23 seconds. The five second value occurred in encounter number 13. In this encounter, the range and vertical closest approaches occurred at different times. Vertical tau was the final variable to satisfy the detection criteria and the intruder was only five seconds from the point of closest slant range when the alert was declared. Since the aircraft were separated by 0.81 nmi and 831 feet at closest approach, a serious collision threat did not exist and the short warning time is not considered significant.

In the present design of the RBX, any advisory calculated in the BCAS avionics would be downlinked to the RBX once every four seconds. It is assumed that, on average, the delay between generation of the BCAS advisory and the downlinking of that advisory would be two seconds. Another two seconds of delay time should be allowed between receipt of the advisory by the RBX and display to the controller. Thus, on the average, the controller is notified of the BCAS advisory 19 seconds before closest approach.

It is of interest to know how long advisories last when BCAS generates advisories. The duration of advisory column in Table 5-3 presents this data. The average encounter duration for the first 18 encounters, excluding the four that occurred at or below 500 ft AGL, was 16 seconds. These durations are considered short, and would not seem to contribute significant disruption to air traffic control.

Another measure of the need to display advisories to the controller is the number of times that response to a BCAS advisory would require the pilot to deviate from his ATC altitude assignment. All of the 18 encounters occurring on the Western Tour and the Eastern Tour (excluding the four that occurred at or below 500 ft AGL and the four occurring during planned encounter work) were analyzed to determine how many required deviation from the altitude flight path. All encounters generating positive alerts were considered to require deviations, even though in two cases the advisories reinforced existing ATC instructions. Those encounters generating negative or VSL advisories were considered to require deviation if they required a change in vertical flight path to comply with the advisory. It was determined that, of the 10 encounters considered, encounters 1, 3, 5, 8, 14, 16, and 19 required deviation. Encounter 14 is a marginal encounter in which it is not entirely clear whether the negative advisory required a

deviation from the ATC altitude assignment. These seven encounters (that occurred in 59.5 flight hours) imply that a single aircraft would require deviation from an ATC assigned vertical flight path once in nine hours.

If a controller typically handles six aircraft at a time, of which three are BCAS-equipped, he could expect notification about one BCAS advisory that could potentially cause a flight path deviation in every three hours.

It is of interest to know how large a deviation is, as well as how often it occurs. Of the seven deviations mentioned above, two (encounters 3 and 8) were positive advisories that reinforced instructions given by the controller. In reality, they require no deviation. As mentioned before, it is not clear that encounter 14 actually required a deviation. If so, it was of the order of 100 ft vertical displacement. Encounter one was judged to have required 100 ft displacement from the assigned vertical flight path to eliminate the advisory. The deviation required for the New York encounter (encounter 19) cannot be assessed because of the lack of data. In encounter 5 (Figure 4-10) it appears that the positive advisory may have reversed an existing vertical rate. Because of this uncertainty, it is considered that a 400 or 500 ft deviation would be required for this encounter. In encounter 16 (Figure 4-38) the positive advisory also required reversal of an existing vertical rate and the deviation required is estimated as 300 ft vertical displacement.

One last observation relevant to the RBX has to do with the need to notify en route controllers at an ATC center about BCAS advisories. The question is, "How many BCAS alerts occur while an aircraft is under the control of an en route center?" During the Western Tour and the Eastern Tour, the BCAS was operated continuously while the BCAS aircraft was airborne. The aircraft flew high altitude jet routes between cities at altitudes typical of jet air carrier operations. Thus, the BEU was operated while the BCAS aircraft was under control of the en route centers. None of the alerts generated on the Western Tour and the Eastern Tour occurred while the BCAS aircraft was under control of an en route center. The alert on 4 August, however, did occur while the BCAS aircraft was under the control of Washington Center.

APPENDIX A

GLOSSARY OF ACRONYMS

A	-	Current tracked vertical separation, a variable used in the CAS logic
AGL	-	Above Ground Level
AID	-	Airborne Information Display, a graphic display used to display tabular data (such as range rate and altitude) of aircraft tracked by BCAS
ALIM	-	Altitude threshold for choice of positive or negative advisories
ALPHA	-	Tracking constant for position in the linear CAS tracker
ARTS	-	Automated Radar Tracking System, a computerized radar tracking system used at the FAA's terminal air traffic control facilities
ATC	-	Air Traffic Control
ATCRBS	-	Air Traffic Control Radar Beacon System
BCAS	-	Beacon Collision Avoidance System
BETA	-	Tracking constant for velocity in the linear CAS tracker
BEU	-	BCAS Experimental Unit, the BCAS unit constructed by the MIT Lincoln Laboratory and used for the flight tests which are the subject of this report
CAS	-	Collision Avoidance System
CPA	-	Closest Point of Approach, the point where the intruder reaches the smallest slant range during an encounter
DFW	-	Dallas-Fort Worth Airport
DMOD	-	Immediate separation threshold used in threat detection and modified tau calculation

ILEV - Threshold on vertical rate below which an unequipped intruder is considered level and is treated the same as an equipped threat for selection of advisory type
 ILS - Instrument Landing System
 IVSI - Instantaneous Vertical Speed Indicator, an instrument in the cockpit normally used to display vertical speed, which was modified to display all of the types of BCAS advisories
 R - Current tracked range, a variable used in the CAS logic
 RBX - Radar Beacon Transponder, an electronic device placed on the ground at an airport to control BCAS sensitivity level and to receive downlinked BCAS advisories for relay to an ATC facility
 RD - Relative tracked range rate, a CAS logic variable
 TAUR - Modified range tau ($-(R-DMOD)/RD$), a CAS logic variable giving an estimate of the time to the closest point of approach
 TAUV - Altitude tau, a CAS logic variable giving an estimate of the time until the intruder and own aircraft reach the same altitude
 TRTHR - Modified range tau detection threshold
 TRTRU - True range tau, a CAS logic variable which is the same as TAUR except that it is computed without the DMOD modification
 TVTHR - Altitude tau detection threshold
 VHF - Very High Frequency, a frequency band used in aviation for voice communication and for navigation stations
 VMD - Vertical Miss Distance, the projected vertical separation at the closest point of approach
 VOR - VHF Omni Range, a radio navigation system used in aviation
 VSL - Vertical Speed Limit, a BCAS advisory of the form "Don't Climb Faster than 1000 fpm"

ZDINT - Tracked vertical rate of the intruder
ZDOWN - Tracked vertical rate of the BCAS aircraft
ZINT - Tracked altitude of intruder
ZOWN - Tracked altitude of the BCAS aircraft
ZTHR - Immediate altitude threshold used in threat detection

APPENDIX B

REFERENCES

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