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TCAS II Logic Performance During Phase One Operational Evaluation

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Final Report

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16. Abstract

This document describes the performance of the collision avoidance logic during the Phase I Operational Evaluation of the Traffic Alert and Collision Avoidance System called Minimum TCAS II. Between November 1981 and March 1982, TCAS units were installed on two Piedmont Airlines B727 aircraft flown on regularly scheduled passenger flights. For this phase of testing, data was recorded while trained observers viewed the TCAS advisories. However, these displays were not shown to the flight crew.

The analysis of logic performance first required identification and removal of alerts caused by hardware or software coding problems that were subsequently fixed, or else caused by problems in the collision avoidance logic which were subsequently removed. Examples are shown for which logic improvements correct earlier problems. Operational questions, observer comments, and an assessment of the true alert rate are then examined using the recorded data.

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CONCLUSIONS

1. The TCAS equipment generated a number of unwanted alerts as a result of detecting intruders on the ground. A new scheme for eliminating these unwanted alerts was developed and will be used in future flight tests.

2. Performance of the Collision Avoidance System (CAS) logic is highly dependent on the quality of the surveillance data. A number of dropped, coasted, pop-up, and multipath tracks were discovered in the database.

3. A few hardware interface problems that were caused by initial installation errors were discovered during the testing phase of the program. The affected interfaces were the radar altimeter, antenna, and data recorder. Additional data recording anomalies were also found during the data analysis phase. All problems were documented and referred to the appropriate agency for correction or noted in the permanent database, as required.

4. An error in coding the Traffic Advisory detection algorithm in the prototype unit caused the generation of six incorrect Traffic Advisories.

5. No other TCAS logic errors were discovered; the logic performed well, and as designed.

6. When the Resolution Advisory encounters were replayed through the latest TCAS logic, some improvements were noted.

7. The overall alert rates for valid airborne tracks were one Traffic Advisory every 5.5 hours and one Resolution Advisory every 40 hours; this was lower than expected. The alert rates for Traffic Advisories will increase if the non-Mode C detection logic is included in future flight tests.

8. Analysis of all tracks present at the time of each recorder trigger indicates that increasing the proximity range ring around the TCAS aircraft from 2 nmi to 4 nmi should not substantially increase the number of Mode C Traffic Advisories displayed during an encounter.

9. Analysis of the inflight and post-flight observer data revealed that 45 percent of all observed TCAS advisories had accompanying ATC advisories at some time during the encounter. In approximately 50 percent of all observed TCAS advisories either the observer or crew was able to visually acquire the intruder aircraft. At least seventy percent of the observed encounters occurred in VMC or marginal VMC conditions.

1. INTRODUCTION

In an effort to reduce the risk of midair collisions, the Traffic Alert and Collision Avoidance System (TCAS) has been under development by the Federal Aviation Administration (FAA). Minimum TCAS II is an airborne system that provides vertical separation assurance against altitude-reporting transponder equipped aircraft; it is the successor to the Beacon Collision Avoidance System (BCAS). As part of the system validation, TCAS units were installed on two Piedmont Airlines B-727 aircraft and were flown on regularly scheduled passenger flights over a five month period from November 1981 to March 1982, for a total of 928 flight hours. For this Piedmont Phase I evaluation, the TCAS displays were located outside the view of the flight crew, and were seen only by trained observers.

The purpose of the Piedmont Phase I Evaluation was to examine the operational aspects of integrating TCAS into the cockpit of a commercial air carrier. Specific areas of interest included the following:

- The potential interaction of TCAS with the current ATC system
- The frequency of alerts and their effect on the flight crew
- The circumstances surrounding individual alerts
- The potential for visual acquisition of intruders using TCAS displays

Two methods of data collection were used for this flight program. First, TCAS logic parameters and intruder position data were automatically recorded on magnetic tape by the TCAS on an event triggered basis, i.e., whenever a Traffic Advisory (TA) or Resolution Advisory (RA) was generated. These flight data tapes were subsequently reduced and analyzed, as described in Sections 3 and 4 of this document. Second, inflight questionnaires and post-flight narratives were completed by the observers for all observed flights. These questionnaires provided subjective information about the individual alerts.

A number of modifications to the logic have been designed and tested since these flights were made. These modifications can be shown to improve protection performance, or to improve the selection and transition sequences of the RAs. In order to verify the TCAS logic during its development, each version of the logic has been programmed at MITRE in a fast-time simulation. As part of the

technical evaluation of the Phase I flights, data from the flight tapes were input to the simulation to produce encounter plots. These plots show the advisories generated by both the logic version flown and the current TCAS logic. Section 5 presents specific examples of the effects of the logic updates.

A number of organizations participated in this operational evaluation. The TCAS equipment was built by Dalmo Victor Operations of Bell Aerospace Textron using surveillance algorithms designed by M.I.T. Lincoln Laboratory and collision avoidance logic designed by The MITRE Corporation. ARINC Research Corporation designed and coordinated the test. Piedmont Airlines installed and flew the equipment in their aircraft. The data was initially correlated by ARINC Research and case studies were made for each Resolution Advisory. The data was then furnished to MITRE for further analysis of the TCAS logic performance. Plots of each RA encounter from the Phase I evaluation, along with correlated observer comments, can be found in the ARINC final report, Reference 1. The present document contains plots only of those encounters of interest to the technical evaluation of the logic -- specifically, encounters with detected anomalies, and encounters that demonstrate the effect of TCAS logic improvements.

2. THE TCAS LOGIC

The tracking, threat detection, and resolution logic which was coded into the Dalmo Victor TCAS unit used for the Piedmont Phase I Evaluation consisted of the October 1980 BCAS logic, listed in Reference 2, plus logic updates included in the MITRE letters listed in References 3 through 8. Further changes have been made to the logic subsequent to the Phase I Evaluation. Both an overview and a complete specification of the current TCAS logic are contained in Reference 9.

The TCAS logic version that was flown during Phase I provided display of Traffic Advisories and Resolution Advisories against aircraft equipped with altitude encoding transponders. Neither Proximity Advisories (all tracked aircraft within a specified radius) nor non-Mode C advisories were provided by this version of the TCAS logic; although both are now specified in Reference 9.

Sensitivity level selection, designed to vary the protection volume around the TCAS aircraft according to altitude, was performed automatically at preselected radar altimeter trip points. Subsequently, the logic was modified to use a continuous radar altimeter input; however the sensitivity level boundaries have not been changed. (The primary use of the continuous radar altitude is in determining whether an intruder is on the ground.)

Other logic changes discussed in this report are the determination of confidence (or "firmness") of an intruder's tracked vertical rate, and changes to minimize transitions in advisory strength during an encounter. Advisories are delayed for tracks with low firmness, in order to minimize selecting an incorrect sense for a maneuvering intruder.

3. SUMMARY OF DATA COLLECTION AND REDUCTION

This section summarizes the data collection and reduction process. A more detailed explanation appears in Reference 10. The Piedmont Phase I flight data recorded on the Dalmo Victor system's nine-track cassette tape was processed through a data reduction package. A scanning program was first used to locate messages on the tapes that indicated an advisory display. A directory of the advisories was produced, containing the associated system times and record numbers, and the track number that TCAS assigned to each intruder aircraft. After locating the beginning and end of each encounter on the tape, another program was used to create a permanent encounter database. The intruder track number and starting record number from the tape directory were used to extract Collision Avoidance System (CAS) logic information and the tracked range, altitude, and vertical rate information on the TCAS and intruder aircraft, second-by-second. Once this encounter database was created, encounters were replayed through the TCAS fast-time simulation to produce plots of the aircraft tracks, the CAS logic variables and advisory sequences. Advisories generated by the new logic (Reference 9) were compared to those generated by the logic flown. The most important benefit of this data reduction package is the capability to quickly evaluate new logic features and modifications using actual flight data.

The second-by-second encounter database was then reduced to create a summary database organized as a single record per encounter. The summary database contains the position and rate of each aircraft at the time a Traffic Advisory or Resolution Advisory was first displayed. In addition, the database contains sensitivity levels, time difference between Traffic Advisory and Resolution Advisory, horizontal and vertical closest approach, number of simultaneous Traffic Advisories, and other useful data (Reference 10).

Another useful input to the database was the observer's comments. Information such as phase of flight, meteorological conditions, visual acquisition and ATC interaction was obtained from inflight observer logs as well as post-flight questionnaires. This data was manually correlated and entered into the permanent database for further analysis.

To complete the data reduction process, statistical data was compiled using the Statistical Analysis System (SAS). The SAS package uses the summary database to output histograms and scatter plots from subsets of the complete data. These SAS summaries were used as a tool to assess TCAS logic performance and identify specific problems.

4. DATA ANALYSIS

The initial task undertaken for the data analysis effort was identification and removal of anomalous alerts in the encounter database. This was accomplished primarily through manual inspection of individual alerts. Once the alert data was filtered, a new summary database was created and statistical evaluations were made. The following sections describe these analyses in detail.

4.1 Filtering Invalid Alerts from the Database

Both software and hardware problems which gave rise to unnecessary or invalid alerts were discovered during the flight tape analysis effort. The following sections describe the TCAS detection logic, surveillance logic and hardware problems that affected TCAS advisories during the Piedmont Phase I flights.

4.1.1 Alerts Against Aircraft on or Near the Ground

A few problems surfaced during the Phase I evaluation that affected alert generation. The most prevalent problem was the display of TAs and RAs against aircraft on or near the ground. Observers frequently commented that these were unnecessary, and could distract the flight crew during a critical phase of flight. The TCAS logic uses input from the radar altimeter to control switching to and from sensitivity level 2, the airspace in which the display of Resolution Advisories is inhibited. The sensitivity level 2 altitude boundary is 500 feet above ground level (AGL). In past studies this desensitization scheme was shown to be effective in minimizing RAs against aircraft near the airport surface while maximizing the protection area for TCAS equipped aircraft. However, the Piedmont data indicates that this desensitization method is not adequate to eliminate ground aircraft at all airports.

The TCAS TA logic which was flown during Phase I did not inhibit display in any airspace. When the TCAS aircraft was between 2500 and 500 feet AGL, in sensitivity level 4, a TA warning time threshold of 35 seconds was provided (a 20 second warning time threshold is used for RAs). Below 500 feet AGL the warning time threshold for TAs was reduced to 20 seconds. Because the logic continued to detect and display TAs based on small projected separations, a significant number of unnecessary TAs were generated against ground aircraft.

A new scheme for eliminating these alerts has subsequently been developed and tested in simulation and test flights. Henceforth, the TCAS logic will use continuous radar altimeter input rather than discrete altimeter trip points to estimate the airport elevation. When the TCAS aircraft is below 850 feet AGL, its radar altimeter altitude is subtracted from its barometric altitude to estimate elevation of the ground above sea level. TAs and RAs are inhibited for any intruder whose tracked Mode-C altitude is within 180 ft of the estimated elevation of the ground. Non Mode-C aircraft will always be assumed to be airborne.

Because a large number of ground alerts were initially detected, a data filtering process was undertaken to rid the database of these invalid alerts. It was determined by inspection that virtually every sensitivity level 2 TA involved an intruder on the ground. All sensitivity level 2 TAs were therefore deleted from the database. Next, a manual inspection was made of any TAs and RAs which were first generated while the TCAS aircraft was in sensitivity level 4. For each of these TAs and RAs, the second-by-second encounter database was inspected to see if a transition either to or from sensitivity level 2 occurred at some time during the encounter. This implied that the ground level was 500 ft below the barometric altitude at which the transition occurred, and indicated that a take-off or landing profile had triggered the start or end of the RA display. The altitude history of the intruder was also studied, and the encounter was then characterized as being an alert triggered by an aircraft on the ground, an alert against an airborne intruder, or an alert resulting from a configuration in which both the TCAS aircraft and the intruder were landing simultaneously on different runways. The summary database was then manually updated with the appropriate code, and only the ground encounters were eliminated.

A total of 144 TAs were displayed against ground intruders while the TCAS equipped aircraft was in sensitivity level 2. More extensive analysis uncovered an additional 18 TAs generated against ground aircraft where TCAS transitioned into sensitivity level 2 just after alert display ended or transitioned out of sensitivity level 2 just prior to alert display. Five RAs were also determined to have been given against ground aircraft. Of these five, one occurred while the TCAS aircraft was landing; the other four encounters occurred during take-off.

The RAs generated against ground aircraft during take-off were found to be compatible with the aircraft's actual flight path, i.e., three of the advisories displayed were DON'T DESCEND advisories and one advisory was a LIMIT DESCENT TO 2000 FPM. The single RA generated against a ground aircraft while TCAS was landing would have

marginally altered the TCAS aircraft's flight path. The advisory was a LIMIT DESCENT TO 500 FPM.

4.1.2 Alerts Caused by Surveillance Anomalies

In addition to those advisories generated against aircraft on the ground, a few surveillance anomalies were discovered in the Piedmont data which affected the TCAS logic. These surveillance anomalies caused the generation of short, coasted intruder aircraft tracks; tracks that were dropped and later reacquired; pop-up tracks; and tracks that were apparently due to multipath. The next four sections describe these problems in more detail.

4.1.2.1 Short Duration Tracks

The first surveillance problem detected was the presence of numerous short-lived tracks. The second-by-second encounter database reveals that these tracks are characterized by a few seconds of correlated surveillance replies, followed by a series of uninterrupted coasts until the track is dropped.

There were 22 short duration intruder tracks that gave rise to only TAs. The duration of the tracks was generally 10 to 15 seconds. A number of the tracks were of shorter duration; however, these were shorter due to lost data at the start of recording. Without examining the actual reply data of each track in question, along with the replies of any surrounding aircraft, it is difficult to assess whether these tracks are real or false. Of the intruder tracks that gave rise to RA displays, two were also short tracks. While it was not practical to examine the reply data for each of the 22 short coasted TA encounters, the tapes containing the two RA encounters were sent to Lincoln Laboratory for interpretation. The data were examined to determine whether the tracks could be associated with real aircraft replies. One of the tracks was judged to be real. The encounter occurred in a somewhat dense environment in which several tracks appeared to experience reply gaps. The second track was judged to have been formed from a brief series of false replies.

The short-lived tracks which give rise to TAs do not appear to present an operational problem, and in fact, the trained observers made no mention of these encounters in their summary reports. However, false tracks which give rise to RAs could be a nuisance,

particularly if corrective action is needed to comply with the posted RA.

An interface change between surveillance and CAS tracking was made subsequent to the Phase I evaluation. Previously, the surveillance tracker and the CAS tracker independently determined when a track would be dropped, based on the number of coasts. Surveillance dropped both Mode-C and Mode-S tracks after coasting for ten seconds. In future tests, the surveillance tracker alone will determine when a track should be dropped and will so notify the CAS tracker. In addition, the surveillance tracker will coast Mode-A/C tracks for only six seconds and Mode-S tracks for ten seconds before dropping the tracks. These changes should reduce the number of short duration and false tracks.

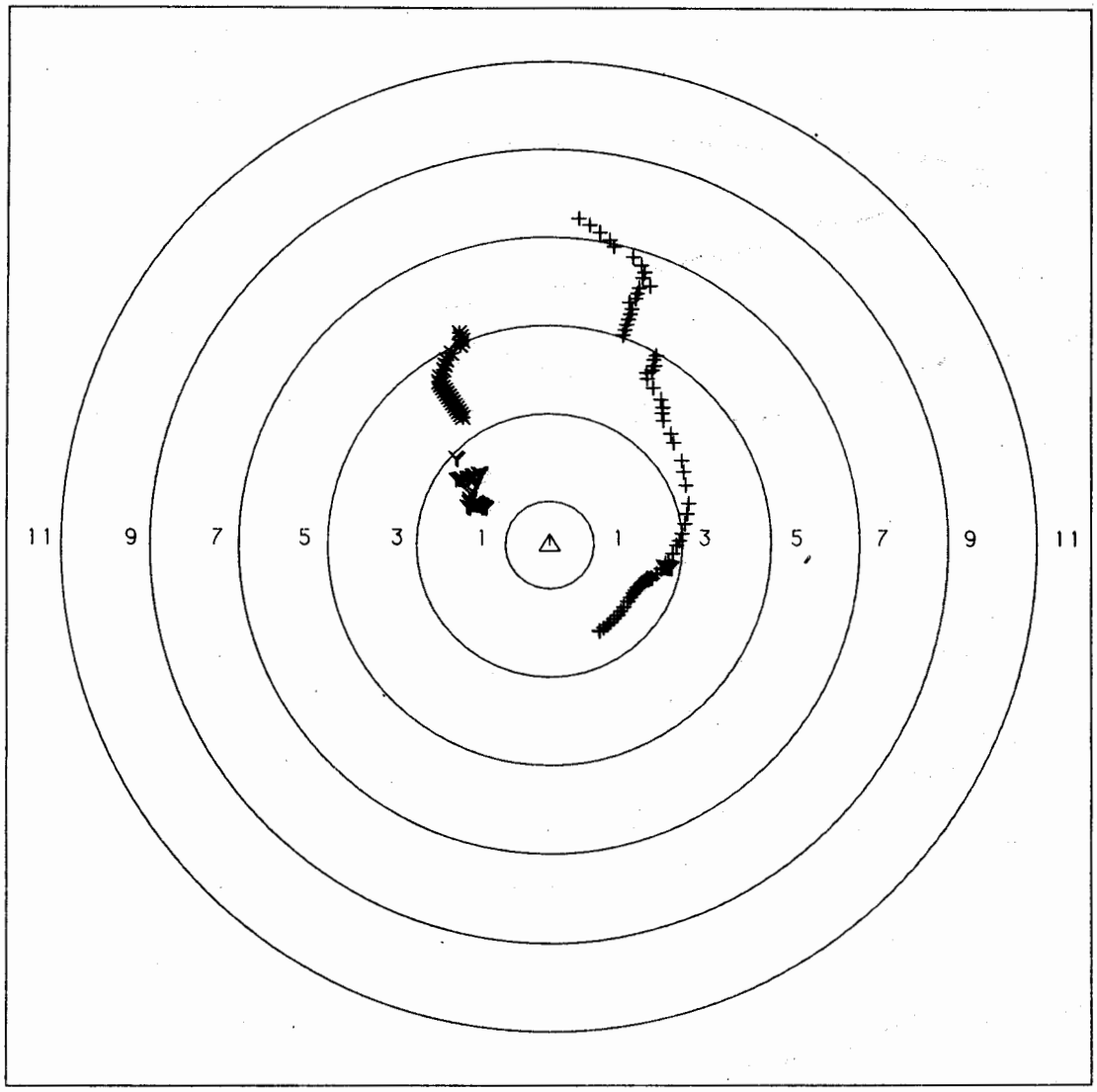
4.1.2.2 Dropped Tracks

A number of tracks were discovered in the database which were dropped, presumably due to a lack of valid reply data, and then often were reacquired a few seconds later and assigned a new surveillance track number. Some of these discontinuous tracks which gave rise to TA and RA display began as short, coasted tracks. Although discontinuous TAs are not considered to be an operational hazard, the potential for ineffective threat resolution does exist when tracks are dropped and reacquired during an RA sequence.

Eight tracks which generated TAs were categorized as having been pairs of dropped and reacquired tracks. Had no track drop occurred, only four TA sequences would have been displayed instead of eight. In addition, 14 more TAs were generated while the TCAS aircraft appeared to be in a holding pattern. As the TCAS aircraft followed the racetrack-shaped pattern, track drop and reacquisition of the same intruders occurred repeatedly. Figure 4-1 shows an example of three TAs overlayed on a single bearing plot. These were recorded during a span of about five minutes. This form of plot indicates these tracks were for a single aircraft.

Four RAs also experienced track drops during the course of the encounter. Figure 4-2 is a plot of one of these encounters, labelled as Case 23. The plots in this report use the same format as in Reference 10. The symbols used are described in Appendix A. As shown on the plot, the intruder's track dropped prior to RA display, while the intruder was just outside of the resolution advisory thresholds. When the track was reacquired five seconds later under a new surveillance number, the intruder had already satisfied the RA criteria and the RA was immediately displayed.

TCAS RANGE VERSUS BEARING PLOT



+ = TRAFFIC ADVISORY ⊙ = RESOLUTION ADVISORY

A003 E 9,10,11 TR 164,145,68

FIGURE 4-1
EXAMPLE OF TRACK DROP FOR TRAFFIC ADVISORIES ISSUED IN HOLDING PATTERN

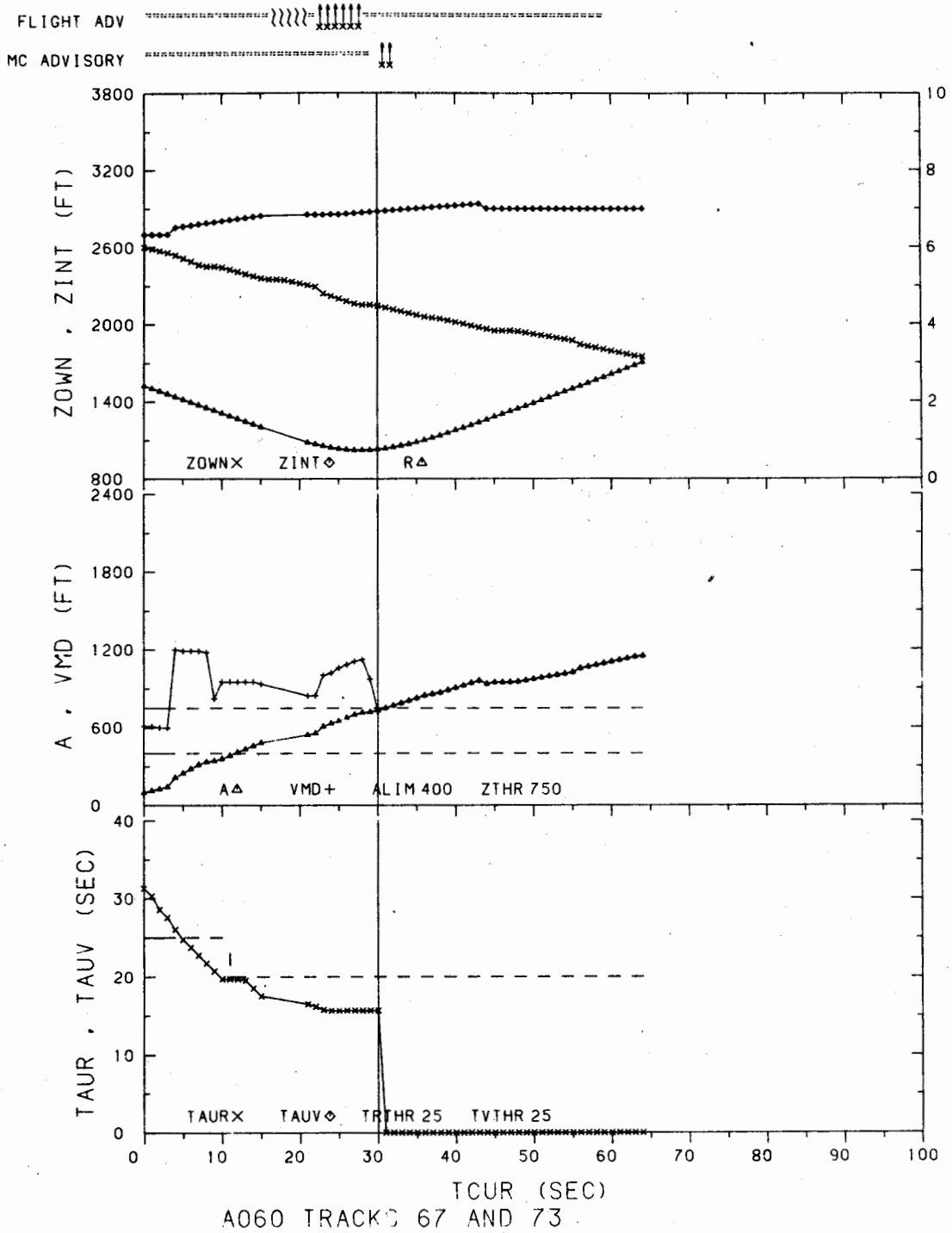


FIGURE 4-2
CASE 23: TRACK DROP IMMEDIATELY PRIOR TO RESOLUTION ADVISORY

During the period of time between track drop and reacquisition, the intruder track had coasted out. Because the resolution advisory boundaries were violated during the track drop period, the alert seems to have been late; computed time to go was only 16 seconds. The nominal warning time in the sensitivity level 4 airspace is 20 seconds.

When this encounter was rerun in simulation, the threat's range and altitude reports within the period of the dropped track were estimated by linear interpolation. Using this method, the vertical miss distance (VMD) falls just outside the alarm threshold, so that the RA is given even later than in the actual flight. Since the threat's actual altitude during this interval is not known, it is not possible to give the time of alarm with certainty, had track drop not occurred.

A second encounter experienced a track drop after a resolution advisory had already been displayed. This encounter is shown in Figure 4-3 and is referred to as Case 5. As shown in the plot, the intruder track had begun to coast out and an RA was generated on the last coasted scan of data before track drop. When the intruder was reacquired six seconds later as a new surveillance track, the threat criteria were no longer satisfied, and the RA did not reappear. As a result, only a single scan of Resolution Advisory was displayed for the duration of the encounter. It is likely that this alert was unnecessary. The advisory was probably generated because coasted position and rate data for the intruder was used by the separation projection algorithms. If the intruder was maneuvering during the coasting period, the coasted projection may have been inaccurate. Hence, continuous surveillance data might have avoided this alert.

The third encounter experienced a track drop during a Resolution Advisory sequence which caused an undesirable RA when the track was reacquired. Figures 4-4 and 4-5 are plots of the two segments of the encounter referred to as Case 18. The encounter occurred during a flight with no observer onboard. The TCAS aircraft was descending through 11,900 feet above Mean Sea Level (MSL) at a rate of 4500 fpm at the time the first RA was displayed. The intruder was tracked to be level at 10,600 feet MSL. A LIMIT DESCENT TO 2000 FPM was selected on the last scan before the intruder track coasted out and was dropped. The duration of the track was very short. One second later, the track was reacquired under a new surveillance number and a DESCEND was displayed. Under normal conditions the TCAS logic is prohibited from changing the directional sense of an RA sequence. Once a CLIMB or DESCEND sense is selected, only the severity of the advisory may change. While the TCAS logic performed appropriately based on the surveillance input, a pilot observing an encounter such as this may experience confusion as a result of the sense reversal.

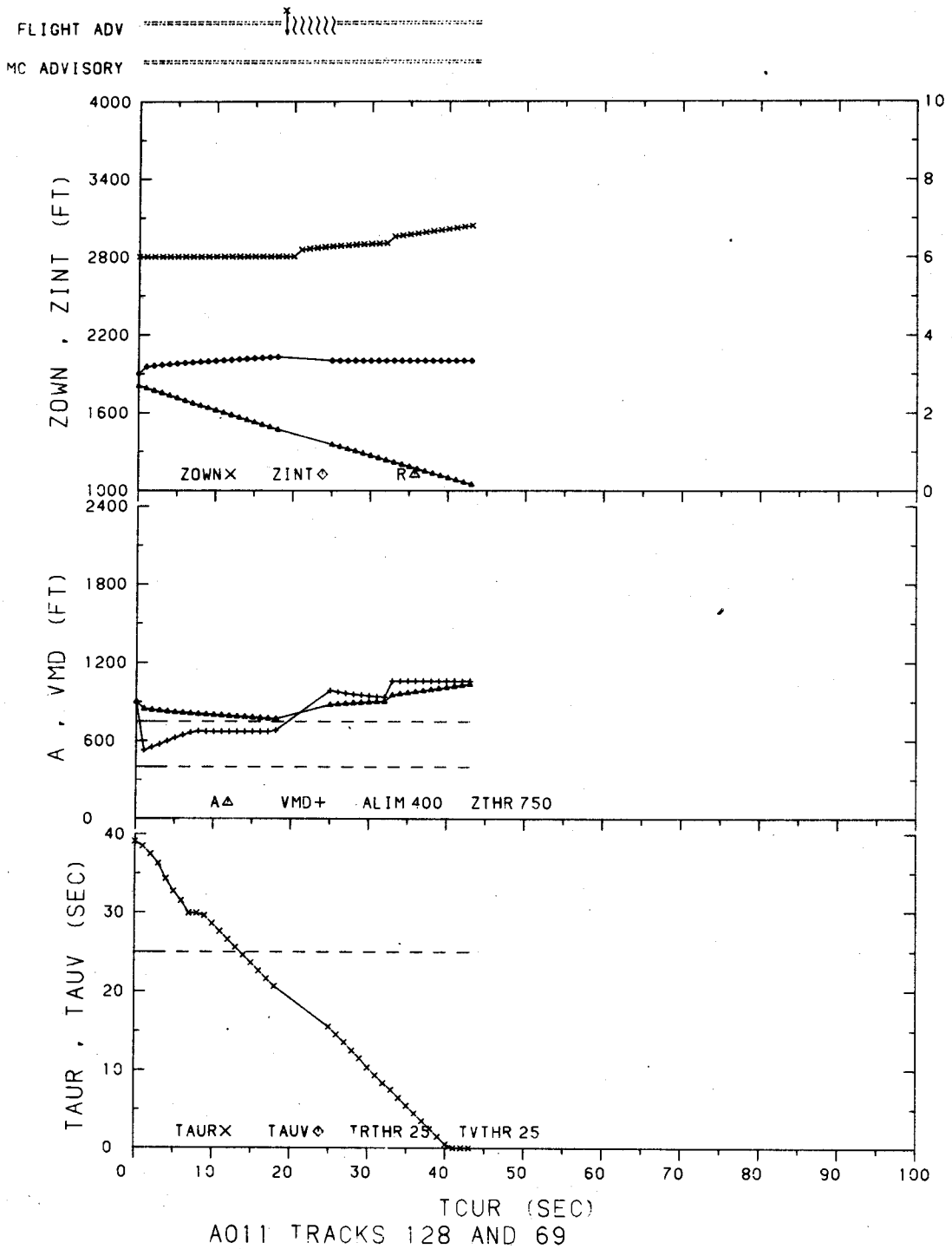


FIGURE 4-3
CASE 5: TRACK DROP IMMEDIATELY AFTER RESOLUTION ADVISORY BEGAN

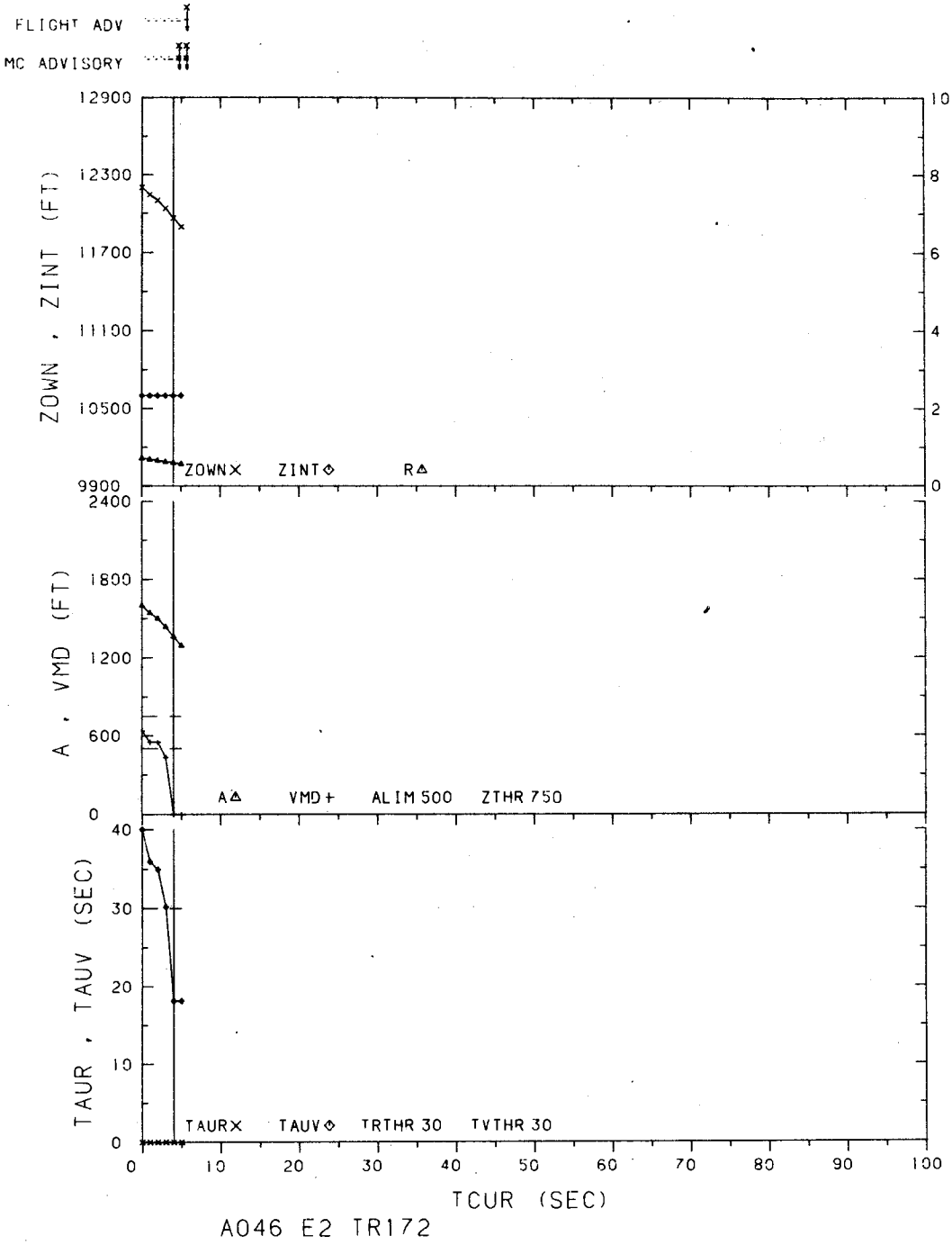


FIGURE 4-4
CASE 18, FIRST SEGMENT: TRACK DROP DURING RESOLUTION ADVISORY

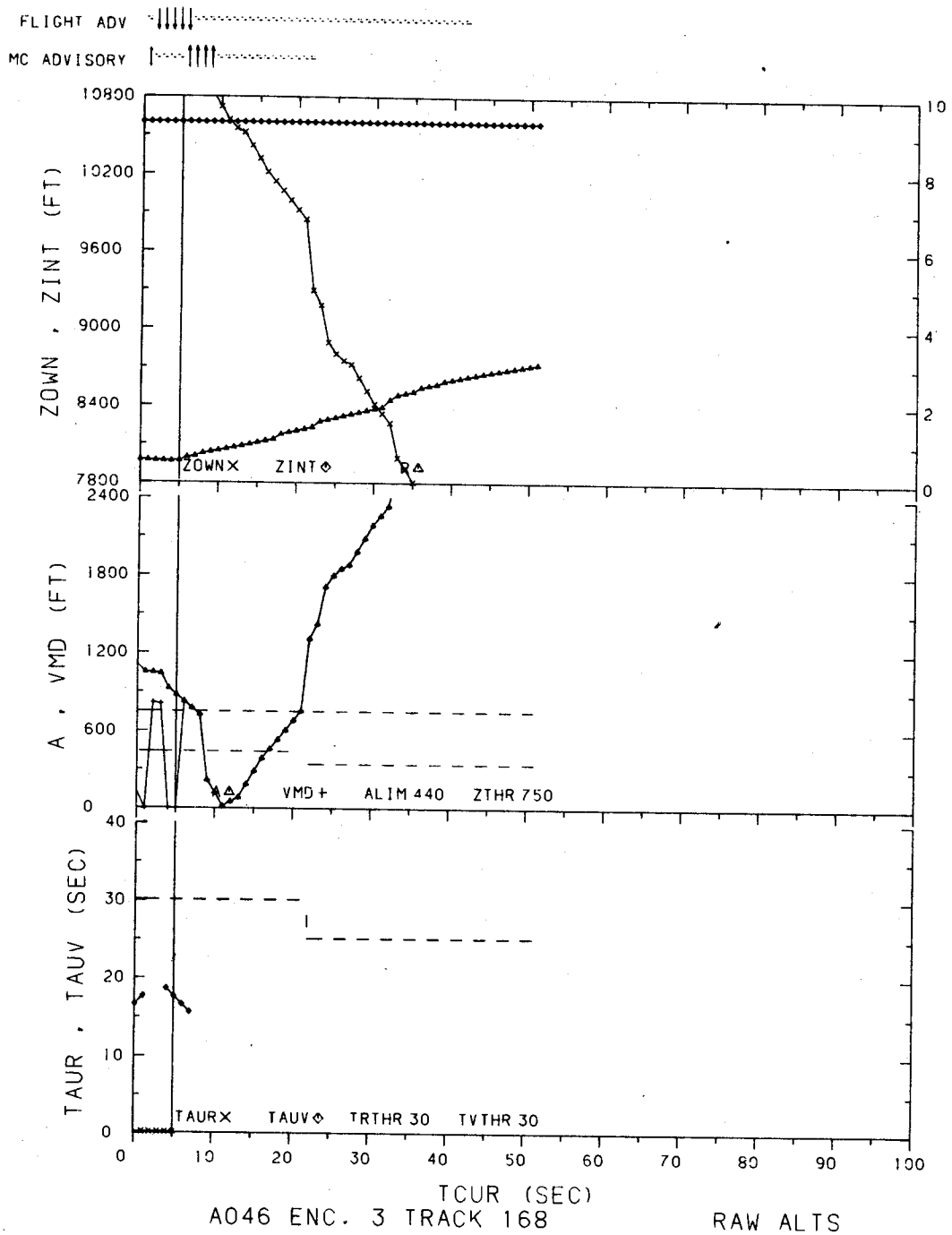


FIGURE 4-5
CASE 18, SECOND SEGMENT: TRACK REACQUIRED, RESOLUTION ADVISORY ISSUED WITH OPPOSITE SENSE

The final RA encounter that involved a track drop does not appear to have a reacquired track associated with it. Like the two previous encounters, the RA was generated and displayed just as the track coasted out. Figure 4-6 shows the altitude and Tau history of this encounter, referred to as Case 20. Only a one second DON'T DESCEND advisory was displayed on the last scan of data passed to the CAS logic. It is likely that the intruder aircraft did not actually continue to converge. Rather, linear projections of the coasted data resulted in a prediction that the intruder would violate separation criteria.

4.1.2.3 Multipath Tracks

A few multipath tracks were also found in the database. These tracks are characterized by the appearance of more than one track at approximately the same bearing and altitude, during an overlapping period of time. The multipath track usually appears at a greater range and has a smaller range rate than the real track. The potential problems with multipath tracks are that they can confuse the pilot or they can trigger the multiple aircraft logic. In the latter case, the severity of the posted RA can be changed. This is an undesirable effect.

One RA did actually experience such an advisory transition due to the presence of a multipath track. The encounter occurred during a flight without an observer. Figures 4-7 and 4-8 are plots of the real and multipath tracks of Case 31. The TCAS aircraft was descending through 11,200 feet MSL at a rate of approximately 5000 fpm at the time the first RA was displayed. The intruder was tracked to be level at 8700 feet MSL at a range of 4.7 nmi. A LIMIT DESCENT TO 2000 fpm was generated at system time 7623 and was displayed for 4 seconds. At system time 7626 the multipath track invoked the TCAS multiple aircraft logic and the advisory strengthened to a CLIMB. The multipath target was tracked to be level at 8604 feet MSL, at a range of 4.1 nmi. The multipath track was dropped 10 seconds later.

4.1.2.4 Pop-Up Tracks

The term "pop-up" refers to a track that is established inside the Resolution Advisory protection volume. The pilot does not receive the usual TA warning in advance. Two RA encounters appear to be pop-up tracks. Both occurred in sensitivity level 5 airspace and were not preceded by a TA. An observer was on board, for only one

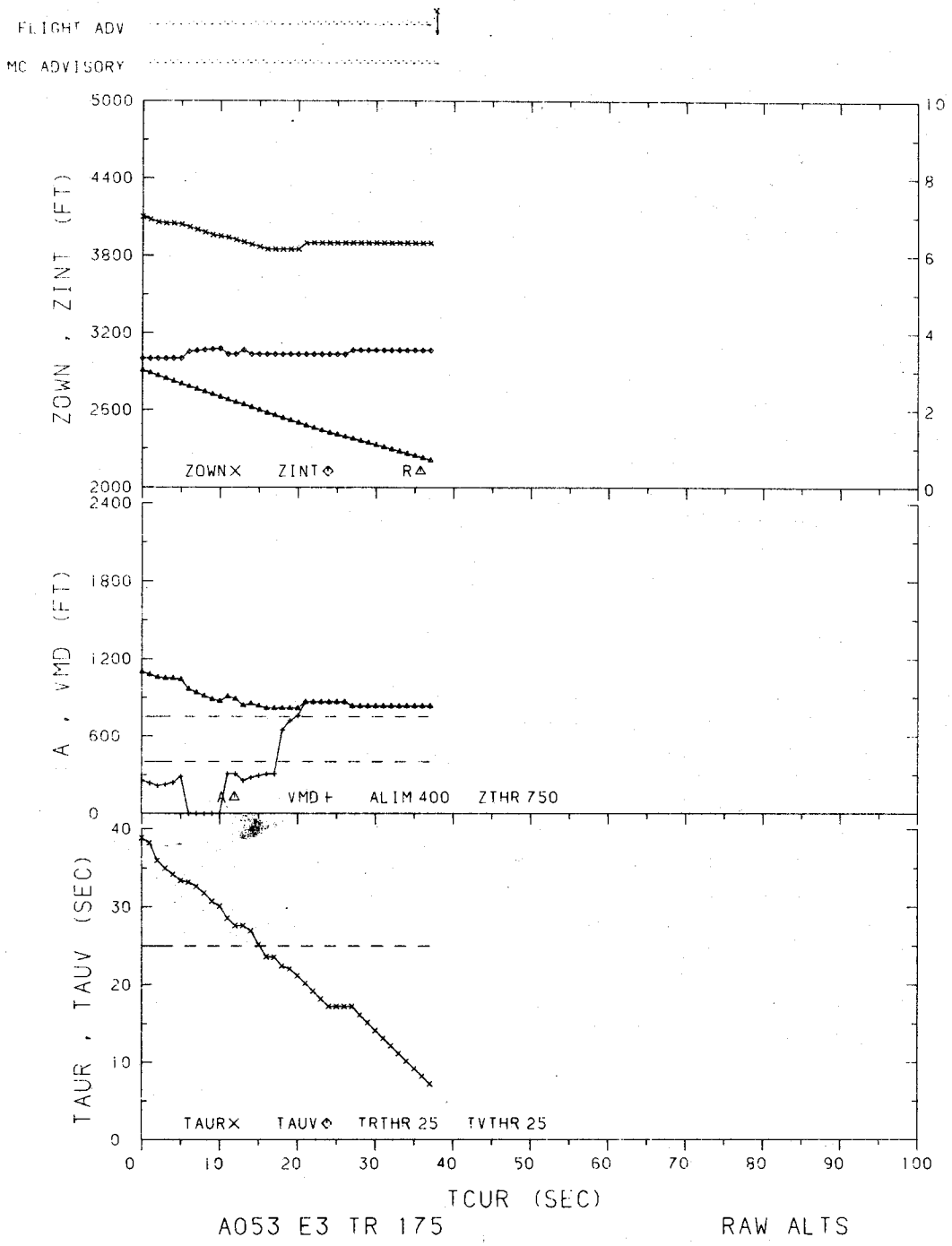


FIGURE 4-6
CASE 20: RESOLUTION ADVISORY ISSUED ON COASTED DATA IMMEDIATELY PRIOR TO TRACK DROP

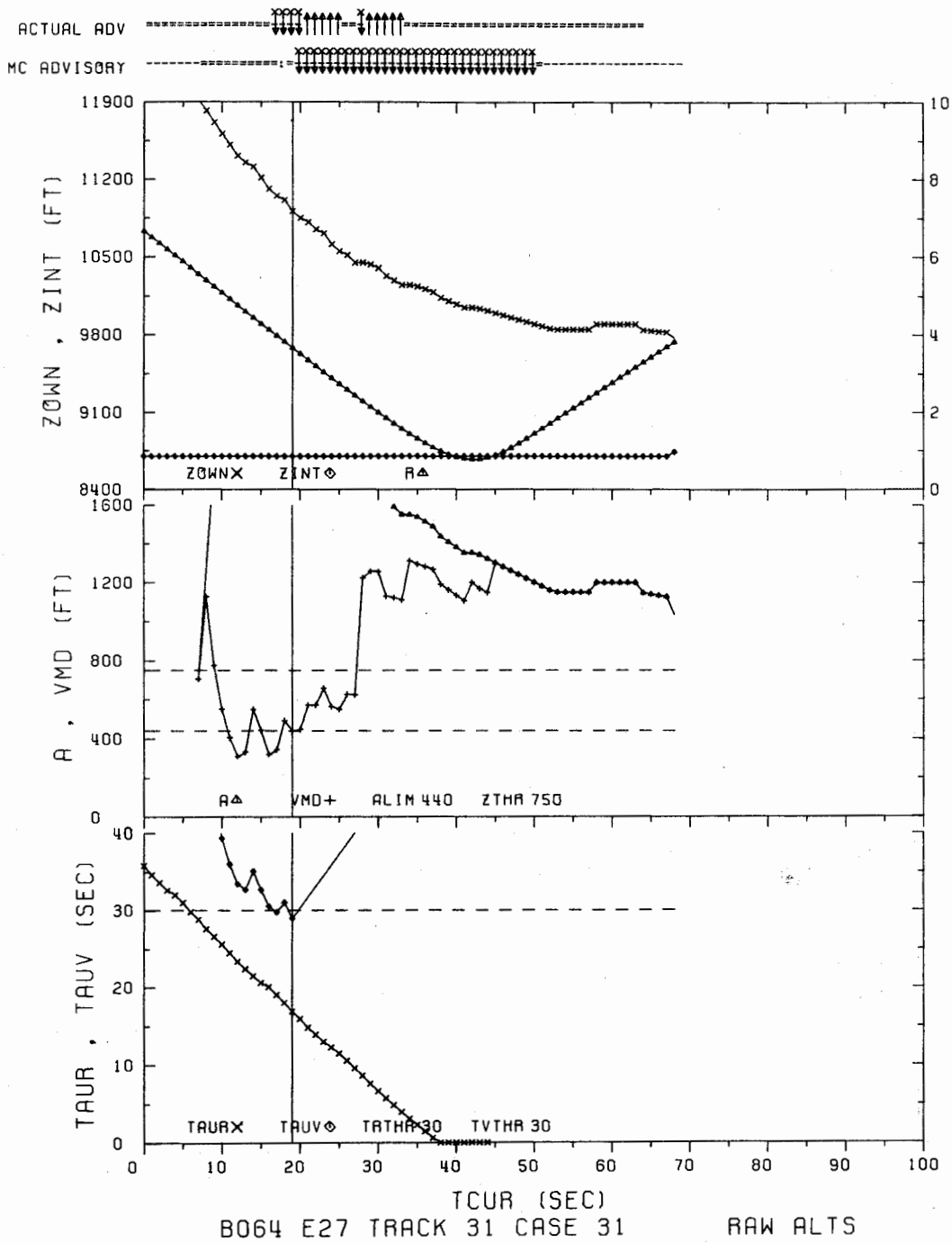


FIGURE 4-7
CASE 31: TRACK OF REAL AIRCRAFT

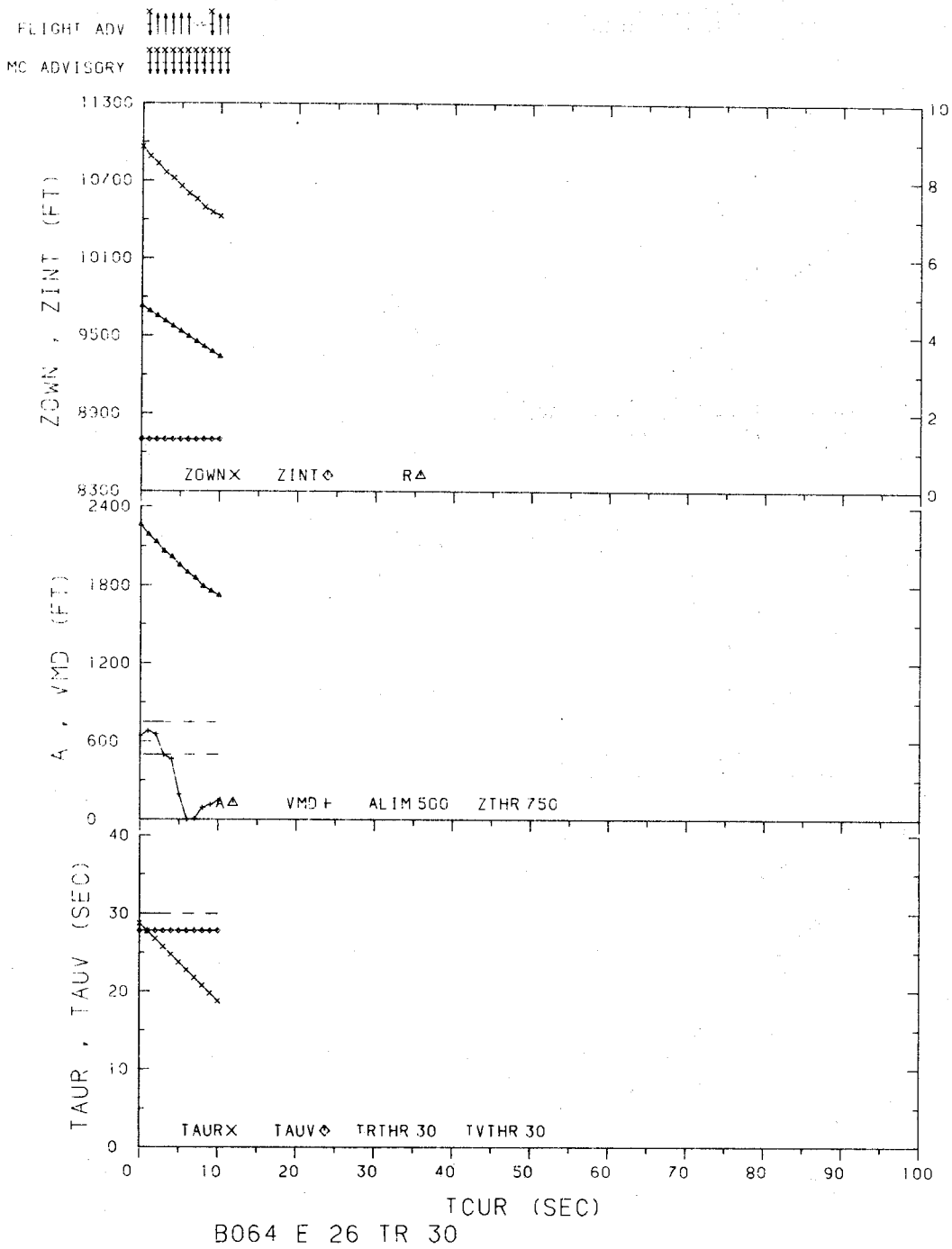


FIGURE 4-8
CASE 31: TRACK OF MULTIPATH-CAUSED PHANTOM AIRCRAFT

of the encounters, and no comment was made concerning the lack of precursor warning prior to the RA. Figure 4-9 is a plot of the observed pop-up encounter, referred to as Case 7. The TCAS aircraft was departing from Norfolk, Virginia when departure control advised of traffic above. The TCAS aircraft was climbing and was instructed to level off at 4,000 feet and to continue its departure climb after visual separation was confirmed. At the time of the first advisory, the aircraft were tracked to be separated by .8 nmi in range and 544 feet in altitude. The TCAS aircraft was in sensitivity level 5 airspace, which provides a nominal warning time of 40 seconds for TA and 25 seconds for RA display. The computed Tau at advisory time for this encounter was only 15 seconds. The first advisory generated was a DON'T CLIMB, followed by a DESCEND.

Figure 4-10 is a plot of the unobserved pop-up encounter, referred to as Case 12. The TCAS aircraft appears to have been on approach, descending at a rate of less than 400 fpm at the beginning of the encounter. At the time of the first advisory, the intruder aircraft was tracked at 2.5 nmi in range, about 550 feet below and level. Although the TCAS aircraft was in sensitivity level 5 airspace, the computed Tau at advisory time was 22 seconds, with no precursor TA. A DON'T DESCEND was generated, followed by two LIMIT DESCENT advisories. Both cases of pop-up tracks were apparently due to late formation of the tracks by the TCAS surveillance function, and not to CAS logic design deficiencies.

4.1.3 Hardware Interface Problems

Three hardware related problems were discovered by ARINC which gave rise to four RAs. The first problem was caused by an altimeter hookup error. This resulted in TCAS obtaining an incorrect reading for own encoded altitude. An observer was onboard during this flight, but the intruder aircraft was not sighted; presumably the intruder was not actually near the TCAS aircraft's true altitude. The second problem, related to system implementation, caused an erroneous computation giving an unreasonably high range rate. This resulted in an incorrect Tau computation, and an advisory was incorrectly generated against an aircraft that coincidentally happened to be on the ground. Both of these problems were corrected as soon as they were identified, during the Phase I test. The third problem was not as easily isolated. The automatic sensitivity level switching mechanism triggered by the radar altimeter exhibited erratic behavior during two separate encounters. At the time that the RAs were generated, the TCAS aircraft should have been in sensitivity level 2, the area in which RAs are inhibited. Instead, although the pilot's radar altimeter showed the correct altitude

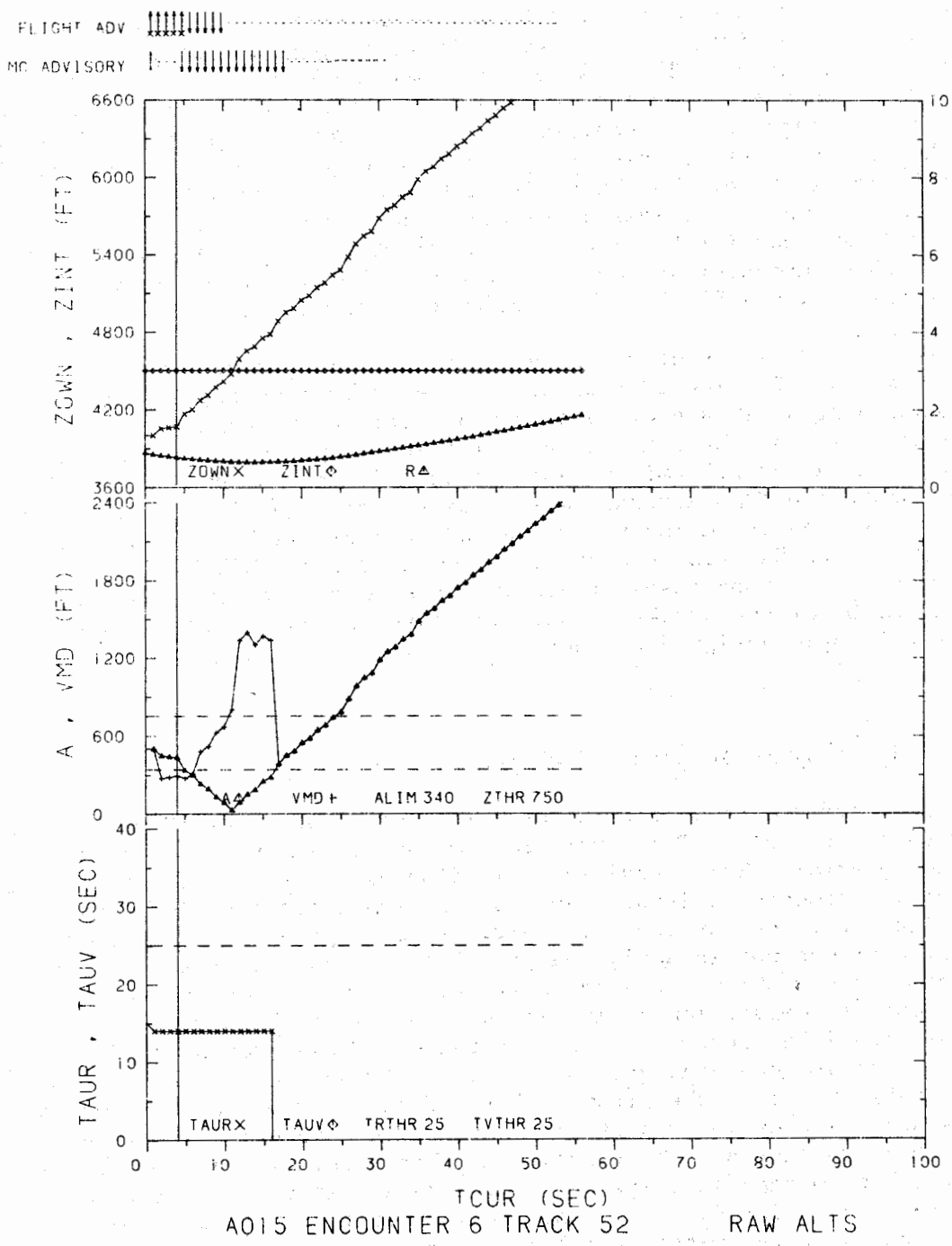


FIGURE 4-9
CASE 7: POP-UP ENCOUNTER INSIDE TCAS PROTECTED VOLUME

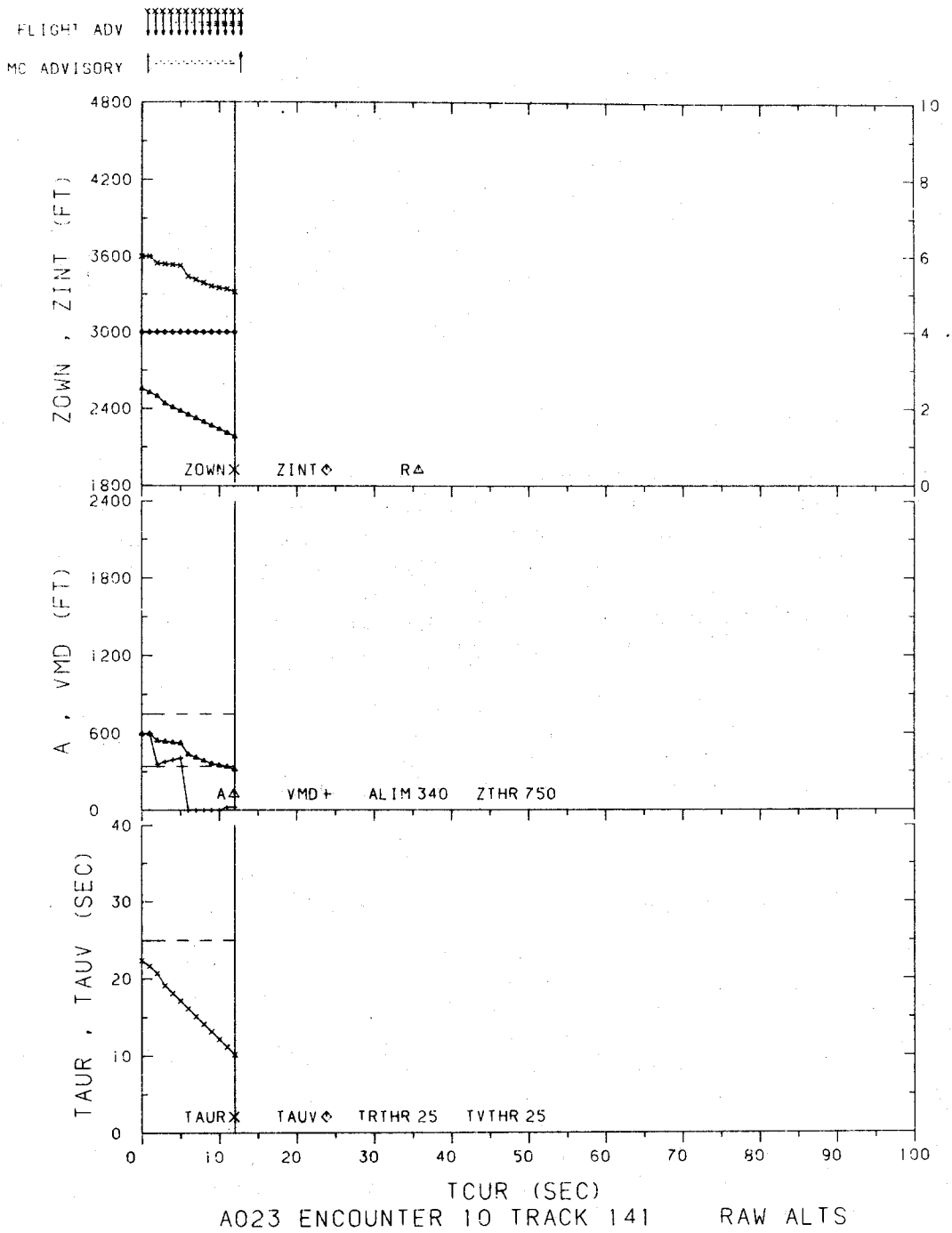


FIGURE 4-10
CASE 12: UNOBSERVED POP-UP ENCOUNTER

above ground, sensitivity levels 4 and 5 were intermittently selected during these encounters. The malfunction was referred to the TCAS equipment manufacturer by ARINC and was corrected.

These alerts, having been generated as a result of hardware interface problems in a newly installed system, were not considered to be representative of TCAS operation in the future. Therefore, unique problem codes were entered into the database records of these encounters, allowing these alerts to be filtered from the analysis.

4.1.4 Data Recording Problems

Seven encounters in the database in which the TA indicator is set were discovered to be the result of data recording errors and were not actually TAs. Due to an apparent malfunction, erroneous data values were recorded in the intruder track file message fields, including an erroneous TA indicator. These encounters were also documented and encoded with a unique problem code, effectively eliminating them from the statistical data.

In addition, four RAs were observed during the flights which were not recorded on the flight tapes due to improper cassette tape loading. These encounters, therefore, do not appear in the database, but have been included in overall alert statistics.

4.1.5 Manufacturer Coding Errors

Eight other encounters were discovered in the database which should not have triggered a TA display at all. These TAs appear to have been generated as a result of a manufacturer's coding error of the TA detection logic in the TCAS unit that was flown for Phase I. The tracked position data as recorded on the flight tapes was used to rerun the encounters through the MITRE fast-time simulation for verification. TAs were not generated by the MITRE logic during these encounters. Each of the eight encounters was documented and a unique code entered in the problem field of the database, thereby filtering them from the statistical data.

4.2 Statistical Evaluation of Alert Data

All of the surveillance, hardware and logic related problems were documented, marked with a problem code, and incorporated into the database for individual encounters. Various statistical analyses of the database were performed, excluding encounters identified with certain problem codes. The specific types of encounters that were eliminated are discussed for each analysis below.

4.2.1 Alert Rates for Valid Airborne Encounters

Table 4-1 shows the breakdown of alert rates for valid airborne TAs and RAs. Those encounters removed from the alert rate data include the following:

- Alerts generated as a result of hardware problems (i.e., altimeter hookup error, high range rate calculation, and erratic sensitivity level switching).
- Alerts generated against intruders on the ground.
- Alerts generated as a result of the manufacturer's coding errors.
- Encounters which experienced data recording problems.

Dropped tracks, short duration tracks, and multipath tracks were included in the alert rates because it is expected that such problems will occassionally occur. Should the incidence of these surveillance anomalies decrease, the overall alert rate will also decrease.

In the 928 hours flown during the Phase I Evaluation, a total of 146 valid airborne TAs and 23 valid airborne RAs were displayed. This corresponds to an overall alert rate of 1 advisory (TA only or TA and RA) every 5.5 hours. The overall alert rate for RAs was 1 every 40 hours.

It is useful to determine how often a pilot can expect an alert to be displayed in the terminal area as contrasted to the en route airspace. An estimate of terminal versus en route alert rates was derived based on the estimated time in the terminal area for each flight and the altitude of the TCAS aircraft at the time each alert was displayed. According to ARINC data, an average of 25 percent of the flight time, or approximately 230 total flight hours, was spent in the terminal area. Almost 700 hours were spent in en route

TABLE 4-1
ALERT RATES FOR VALID ADVISORIES

	OVERALL	TERMINAL	EN ROUTE
Traffic Advisory	1 in 5.5 hrs	1 in 3 hrs	1 in 8 hrs
Resolution Advisory	1 in 40 hrs	1 in 15 hrs	1 in 88 hrs

airspace. Alerts occurring while the TCAS aircraft was above 10,000 feet MSL were categorized as en route alerts while those occurring below 10,000 feet MSL were categorized as terminal area alerts.

The terminal and en route airspace alert rates are as follows: 1 TA every 3 hours in the terminal area; 1 TA every 8 hours in en route airspace; 1 RA every 15 hours in the terminal area; 1 RA every 88 hours in en route airspace.

4.2.2 Number of Simultaneous Traffic Advisories

In addition to the per hour alert rate, it is interesting to note how often more than one TA appeared on the display simultaneously. During the data reduction process a counter was automatically incremented for each simultaneous TA occurrence and was stored in the database along with the surveillance track numbers of the other TAs. The database was then analyzed to determine the frequency of simultaneous TA display. In approximately 12 percent of the airborne encounters, two TAs were displayed at the same time. However, many of these encounters experienced only a brief period of simultaneous display. There were never more than two simultaneous TAs.

Only two of the airborne RAs involved a simultaneous TA display of another threat. One of these TAs was determined to be a false track. Note that this phase of testing was performed prior to the incorporation of the proximity advisory logic in TCAS. The frequency of proximate traffic is analyzed in Section 6.1.

4.2.3 Frequency of Corrective Versus Preventive RAs

The 23 valid airborne RAs were studied to determine how many advisories were corrective, i.e., the pilot would have had to change the vertical rate or direction of the aircraft in order to comply with the advisory, and how many were preventive, i.e., no vertical rate adjustment would have been necessary. The method chosen to compile this data was to consider each sequence of RA transitions against an individual intruder as one RA encounter. If at any time during the encounter a corrective advisory was displayed, then the entire RA encounter was classified corrective. Preventive RAs were those which never transitioned to corrective during an encounter. In some encounters, tracked vertical rate fluctuations near advisory time made it difficult to assess whether an advisory, particularly a Vertical Speed Limit (VSL), was corrective. Also in this category

are those encounters where the TCAS aircraft was in the process of a rate change that was in accordance with the RA. They can be considered corrective or preventive, depending on whether pilot intent is considered.

Table 4-2 shows the number and corresponding percentage of encounters that generated corrective or preventive advisories. The two advisories categorized as undetermined are two of the four advisories which, due to inflight recorder problems, were observed, but not recorded on the flight tapes. Because both advisories were VSL's, knowledge of the vertical speed of the TCAS aircraft is needed in order to determine whether pilot action would have been necessary. Vertical speed data is unknown. It was possible to categorize the two other unrecorded advisories based on the observer reports.

Fourteen advisories (61 percent) can be clearly classified as corrective. Based on known altitude rate data, the vertical profile of the aircraft would have had to be altered in order to comply with the displayed RA. Three advisories (13 percent) were clearly preventive, as they would not have required any deviation in the aircraft's altitude rate or direction in order to comply with the RA. Another four advisories could be classified as either corrective or preventive. They appear to be corrective based on tracked rates at the time of the advisory, but the altitude histories over the duration of the encounter show that vertical rate changes were made in accordance with the posted RA.

To make a very conservative estimate of the percentage of corrective advisories all of the advisories categorized as in the process of a rate change should be included. When these advisories are added to the 14 that were clearly corrective, the total of corrective advisories increases to 18, or 78 percent. On the other hand, if those four advisories are added to the preventive total, the percentage of preventive advisories increases to 30 percent.

4.3 Closest Approach Data

An evaluation was made of the separations between aircraft at the time of the first advisory (both TA and RA) and at the point of closest approach. Only those encounters determined to be against real, airborne intruders were included. The filtering criteria described in Section 4.2.1 was used to select the closest approach data. However, an additional 14 short coasted tracks that experienced some data recording gaps were also eliminated from the separation plots. The reason for filtering out these encounters is

TABLE 4-2
BREAKDOWN OF CORRECTIVE AND PREVENTIVE
ADVISORIES FOR AIRBORNE RAs

	CORRECTIVE	PREVENTIVE	IN PROCESS OF RATE CHANGE	UNDETERMINED
Number of Advisories	14	3	4	2
Percentage	61%	13%	17%	9%

that data gaps occurring near the beginning of the encounter or near closest point of approach (CPA) would provide an inaccurate separation picture.

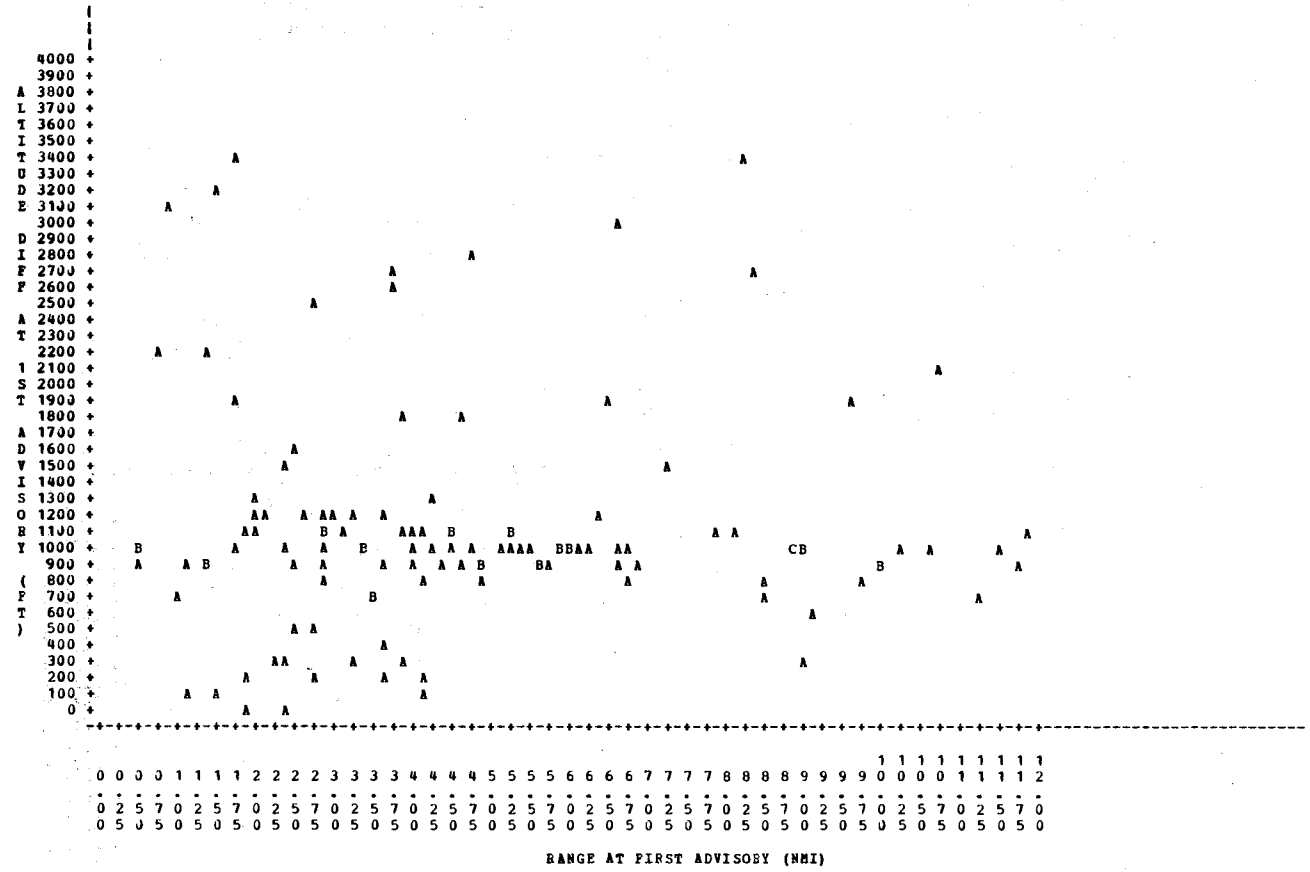
Figure 4-11 is a scatter plot of encounters showing the altitude and range separation at the time a TA was first displayed. In the summary database the separation data for each encounter is stored at the time the first TA is displayed or when appropriate, at the time the first RA is displayed. Therefore, the TA-only and RA advisories have been plotted separately. The plot in Figure 4-11 includes 132 TA-only encounters. The plot shows a number of encounters that have large altitude separations at display time. These encounters are TAUV triggered, i.e., large vertical rates by the TCAS aircraft, the intruder aircraft, or both, were projected to bring the aircraft within the threat volume. The encounters shown to have large horizontal separations at display time are high altitude, high closing speed encounters. The remaining encounters are widely distributed in range, but show a concentration vertically in the 900 to 1100 foot band. As was noted previously, 14 of the TA encounters were determined to be aircraft in holding patterns with the TCAS aircraft, separated by approximately 1000 feet. When the tracks in holding are removed, 52 encounters remain in the band around 1000 feet.

Figure 4-12 is a scatter plot of the altitude and range separations at the time of closest approach for encounters that caused TAs. This plot shows that most of the encounters that were initially detected at long ranges continued on a converging course. One encounter appears to have satisfied the alert thresholds only briefly before diverging, thereby coming no closer than 11.75 nmi. Nineteen encounters came no closer to the TCAS aircraft than 4 to 7 nmi. A number of these encounters may have involved aircraft which were converging at a high rate near the time of alert detection and then maneuvered in such a way as to no longer constitute a threat. Four TAs are plotted which had approximately 100 feet in vertical separation and one nmi or less in range at closest approach. These encounters were individually studied. All four occurred at low altitudes (less than 2500 feet MSL) with both the TCAS aircraft and the intruder aircraft in a landing configuration.

Figure 4-13 is a scatter plot of altitude and range separation at the time each RA was first displayed. The plot includes the 19 recorded encounters that were determined to be real airborne RAs. (Four other airborne RAs were observed, but not recorded.) Eleven of the encounters generated RAs when the relative altitude difference was less than 1000 feet. In five of these encounters, one or both aircraft had very small vertical rates or were level. Of the six involving vertical rates, the TCAS aircraft had the

VERTICAL AND HORIZONTAL SEPARATION AT TIME OF FIRST TA 2
FOR VALID TA S 14:24 TUESDAY, FEBRUARY 1, 1983

PLOT OF ALTDIF*RANGE LEGEND: A = 1 OBS, B = 2 OBS, ETC.



NOTE: 6 OBS HAD MISSING VALUES OR WERE OUT OF RANGE

FIGURE 4-11
SCATTER PLOT OF RANGE AND ALTITUDE AT FIRST TRAFFIC ADVISORY

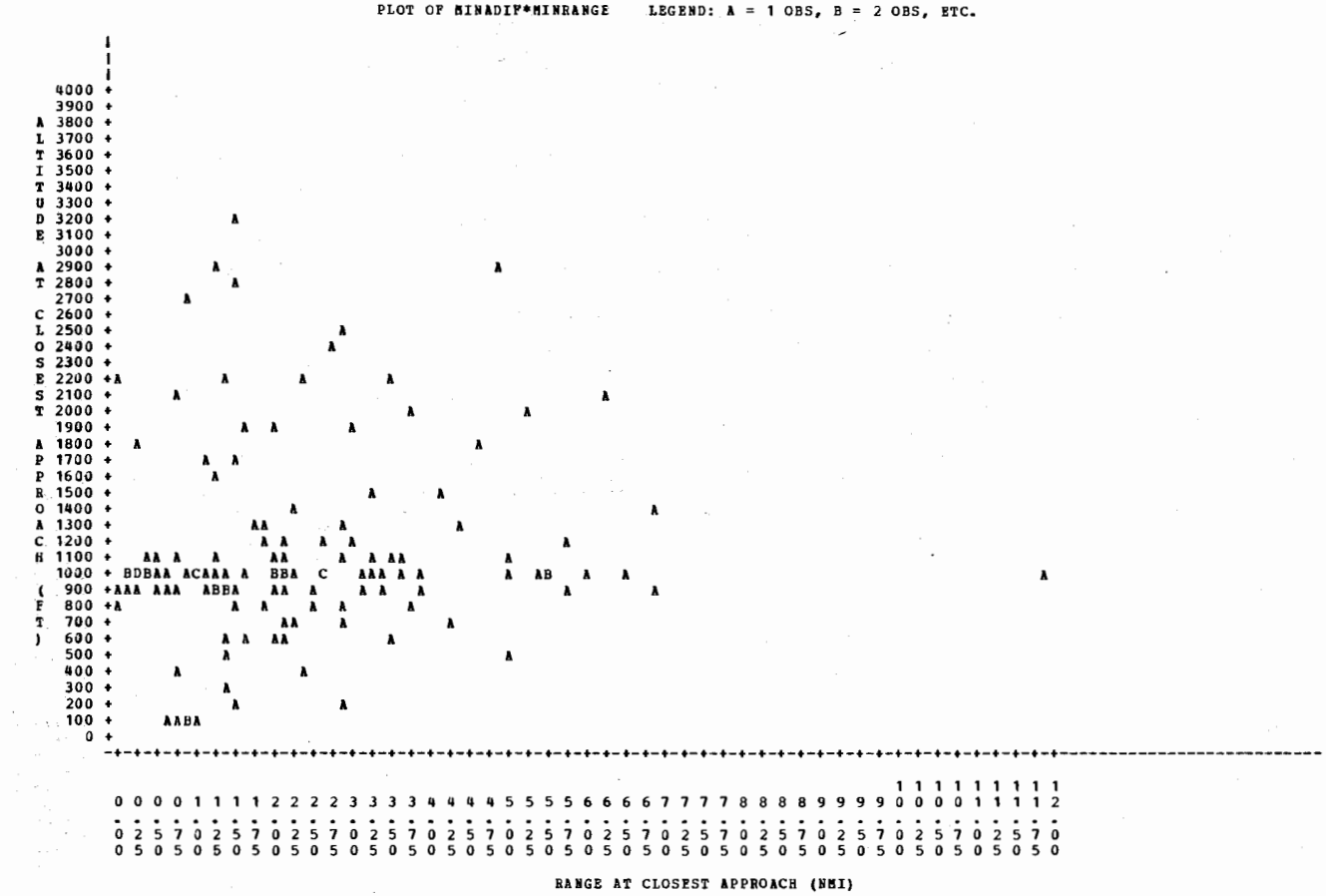


FIGURE 4-12
SCATTER PLOT OF RANGE AND ALTITUDE AT CLOSEST APPROACH FOR ENCOUNTERS THAT PROVIDED TRAFFIC ADVISORIES

VERTICAL AND HORIZONTAL SEPARATION AT TIME OF FIRST RA 4
FOR VALID RA S 14:24 TUESDAY, FEBRUARY 1, 1983

PLOT OF ALTDIF*RANGE LEGEND: A = 1 OBS, B = 2 OBS, ETC.

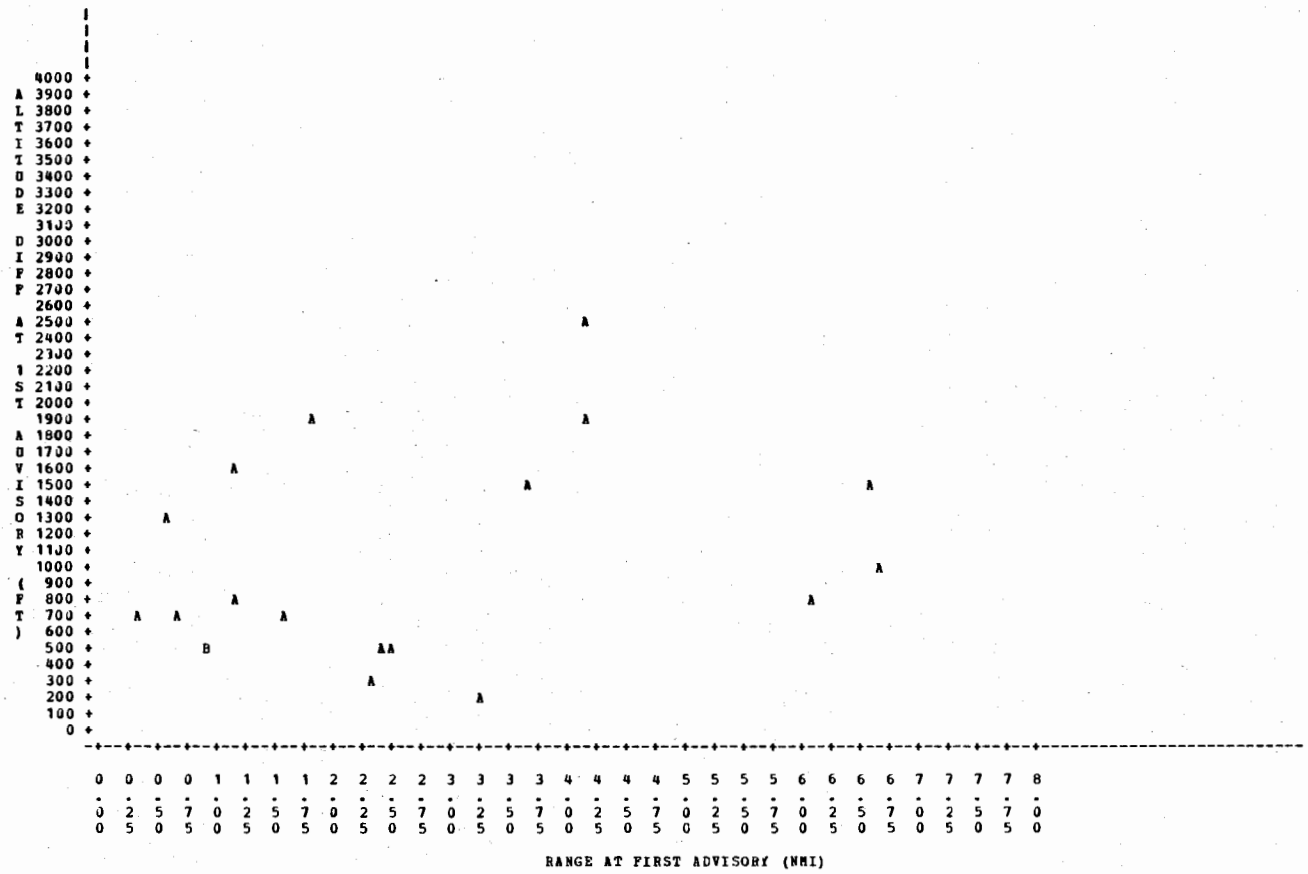


FIGURE 4-13
SCATTER PLOT OF RANGE AND ALTITUDE AT FIRST RESOLUTION ADVISORY

vertical rate in five encounters, while the intruder had the vertical rate in only one.

The eight encounters which generated RAs when the altitude difference was greater than 1000 feet involved high vertical closure rates. In all cases, only one of the aircraft had a substantial rate, the other was either level or had a rate of less than 500 fpm at the time the advisory was generated. The vertical rate of the maneuvering aircraft ranged between 2300 and 5100 fpm. In seven of the eight encounters the TCAS aircraft had the vertical rate. In only one of these encounters did the intruder have a substantial vertical rate. In the majority of encounters, the horizontal separation at the time of the first RA was less than 3 nmi. Figure 4-14 is a scatter plot of the separation at the time of closest approach for each RA. Four of the encounters maintained horizontal separation of about 2 nmi or more while vertical separation was 900 feet or more at CPA. These alerts might be categorized as unnecessary. All four alerts occurred in the high altitude sensitivity level 6 airspace, in which the largest warning times are used in conflict detection.

One of the RA encounters is shown to have separation of less than 0.75 nmi in range while virtually coaltitude. The observer log documents this encounter as one in which both aircraft were instructed by ATC to maintain visual separation. The encounter occurred while in contact with departure control northwest of Norfolk, Virginia. The intruder was a slow moving Navy C-1 aircraft.

Three other RA encounters are shown to have separation of about 0.5 to 0.75 nmi in range and 400 to 500 feet in altitude. Two of these encounters also occurred in the vicinity of Norfolk, Virginia, while observing visual separation rules. In both encounters ATC advised the TCAS equipped aircraft of nearby traffic and provided clearance to resume altitude maneuvers after passing clear of traffic. In each case the observers noted that the advisories would have been timely and correct, had the situation existed for an otherwise undetected intruder.

The third encounter occurred in the vicinity of Tampa, Florida. This encounter is unique because ATC did not advise of any traffic in the vicinity of the TCAS aircraft. Figure 4-15 is a plot of this encounter, referred to as Case 4. The TCAS aircraft was on approach and had been cleared to descend to 4000 feet. A TCAS TA was displayed indicating an intruder at nearly 4 nmi, 300 feet below. Seventeen seconds later, when the range decreased to 2.3 nmi, a CLIMB advisory was generated and transitioned to a DON'T DESCEND after five seconds. The crew of the aircraft was able to visually

VERTICAL AND HORIZONTAL SEPARATION AT CLOSEST APPROACH
FOR VALID RA S

3
14:24 TUESDAY, FEBRUARY 1, 1983

PLOT OF MINADIF*MINRANGE LEGEND: A = 1 OBS, B = 2 OBS, ETC.

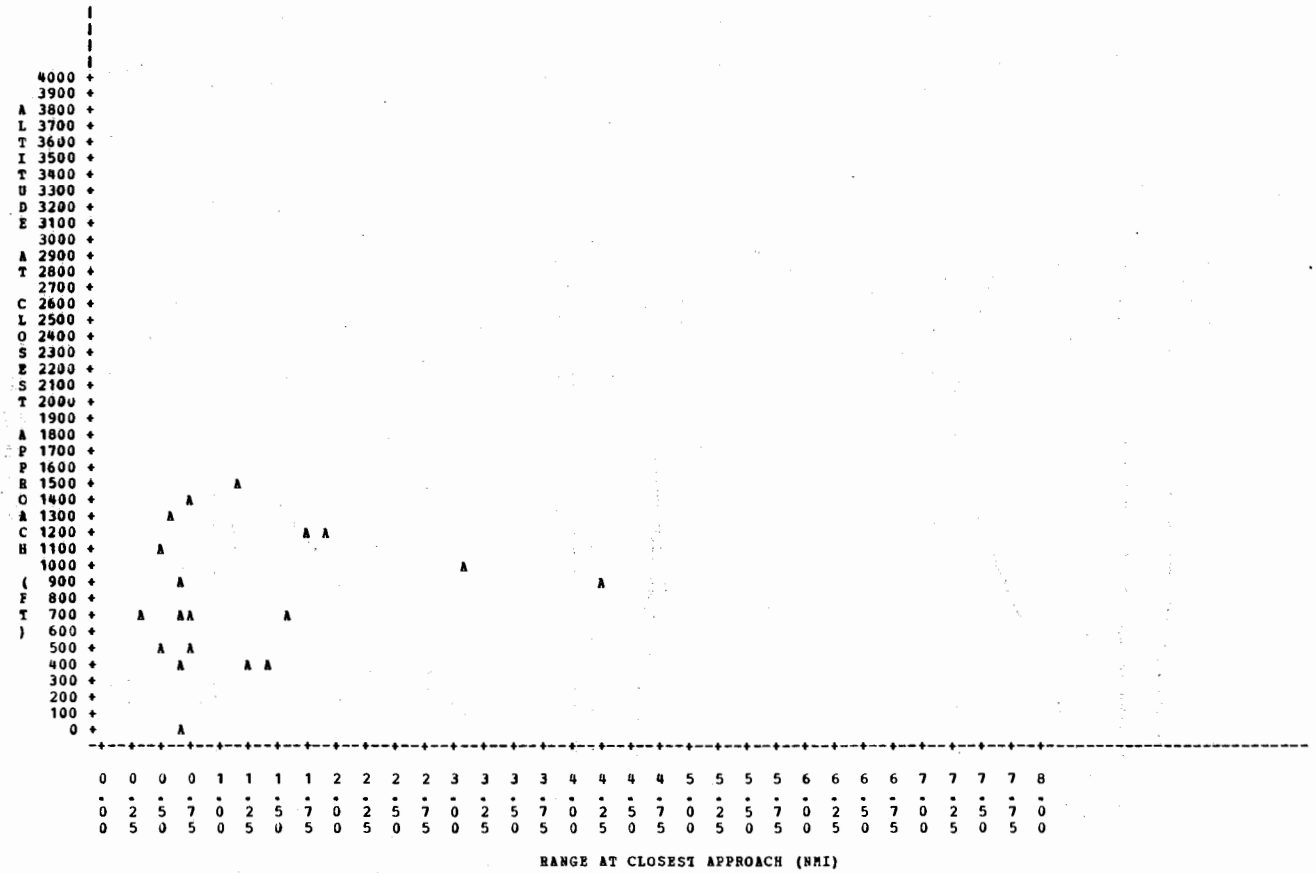


FIGURE 4-14
SCATTER PLOT OF RANGE AND ALTITUDE AT CLOSEST APPROACH FOR ENCOUNTERS THAT PROVIDED RESOLUTION ADVISORIES

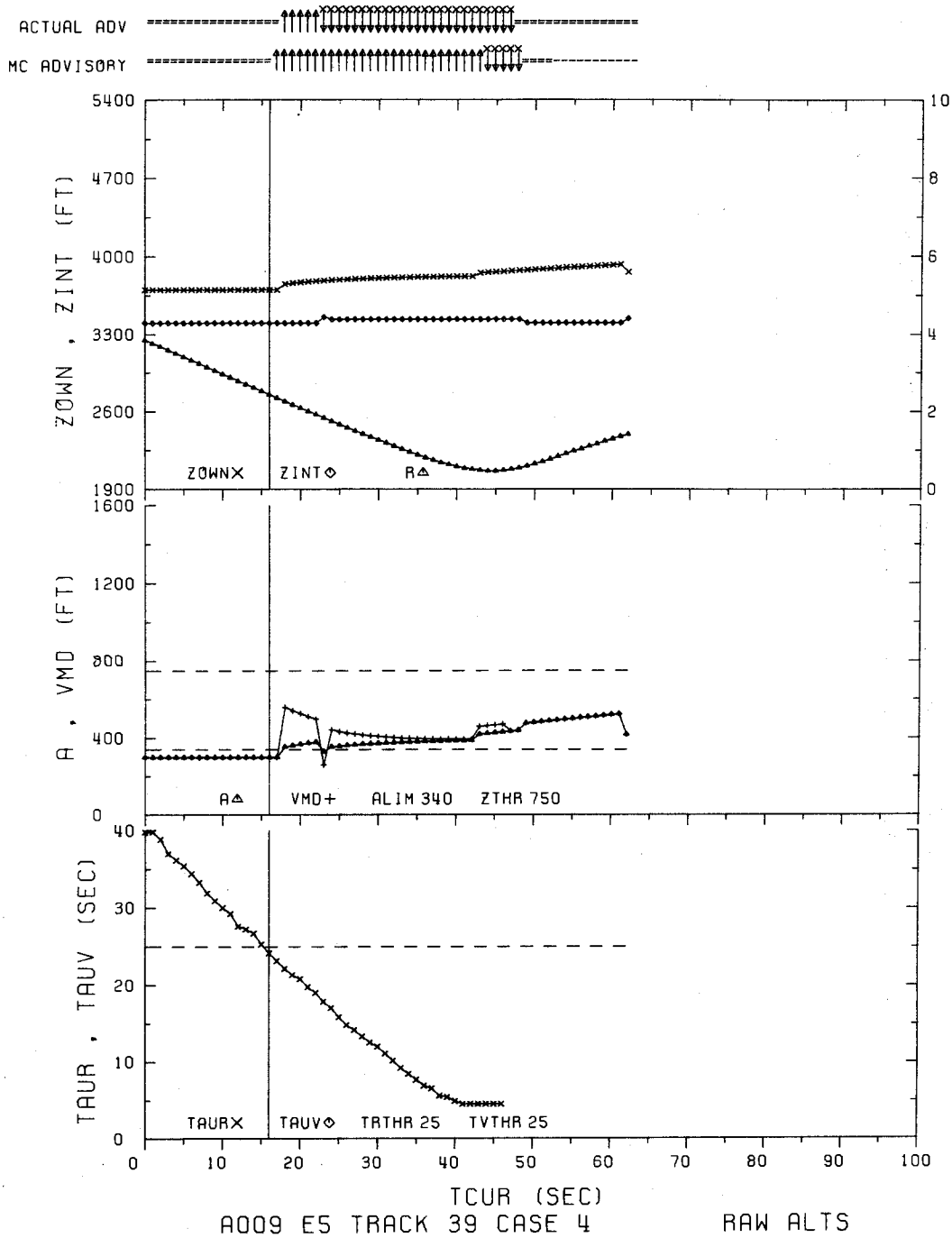


FIGURE 4-15
CASE 4: RESOLUTION ADVISORY WITH SMALL SEPARATION, TAMPA, FLORIDA

acquire the intruder. Closest approach was .46 nmi in range and 462 feet in altitude. The observer felt that the system provided ample warning to resolve the conflict.

5. EFFECTS OF LOGIC MODIFICATIONS ON INDIVIDUAL ENCOUNTERS

One of the benefits of the MITRE data reduction and fast-time simulation software is the capability to determine the sequence of advisories that would have been displayed had the final TCAS logic version been available onboard the test aircraft. This software package can either use the tracked altitude and altitude rate data recorded on the flight tapes or it can retrack recorded raw altitude replies. Refinements to the TCAS logic have been an integral and ongoing part of the program. Modifications have been made to eliminate logic deficiencies and to improve advisory selection and transitioning. Although no wrong advisories were generated during Piedmont Phase I testing, a number of resolution advisories were displayed which were potentially disruptive. The following sections show specific examples of logic improvements that would affect the flight test encounters.

5.1 Inhibiting Advisories Against Intruders on the Ground

The logic that inhibits advisory display against aircraft on the ground was described in Section 4.1.1. Figure 5-1 is a plot of one such encounter replayed in fast-time simulation. The top line, labelled "FLIGHT ADV," shows the advisories that were generated by the airborne equipment. The second line, labelled "MC ADVISORY," shows the advisories generated during the replay with improved logic. The encounter occurred during an observed flight on approach to Denver and is referred to as Case 30. According to the observer, the TCAS equipped aircraft was about to pass over the airport perpendicular to parallel east-west runways when a TA was displayed, followed shortly by a resolution advisory sequence of a LIMIT DESCENT TO 500 FPM. The advisory was clearly unnecessary. In future flight tests radar altimeter input will be used to filter out alerts such as this one. For the fast-time replay, radar altimeter input was simulated using the actual elevation of the airport above sea level which, at Denver, is 5331 feet. The symbol on the second advisory line indicates that no RA was displayed in the replay because the intruder was correctly detected to be on the ground.

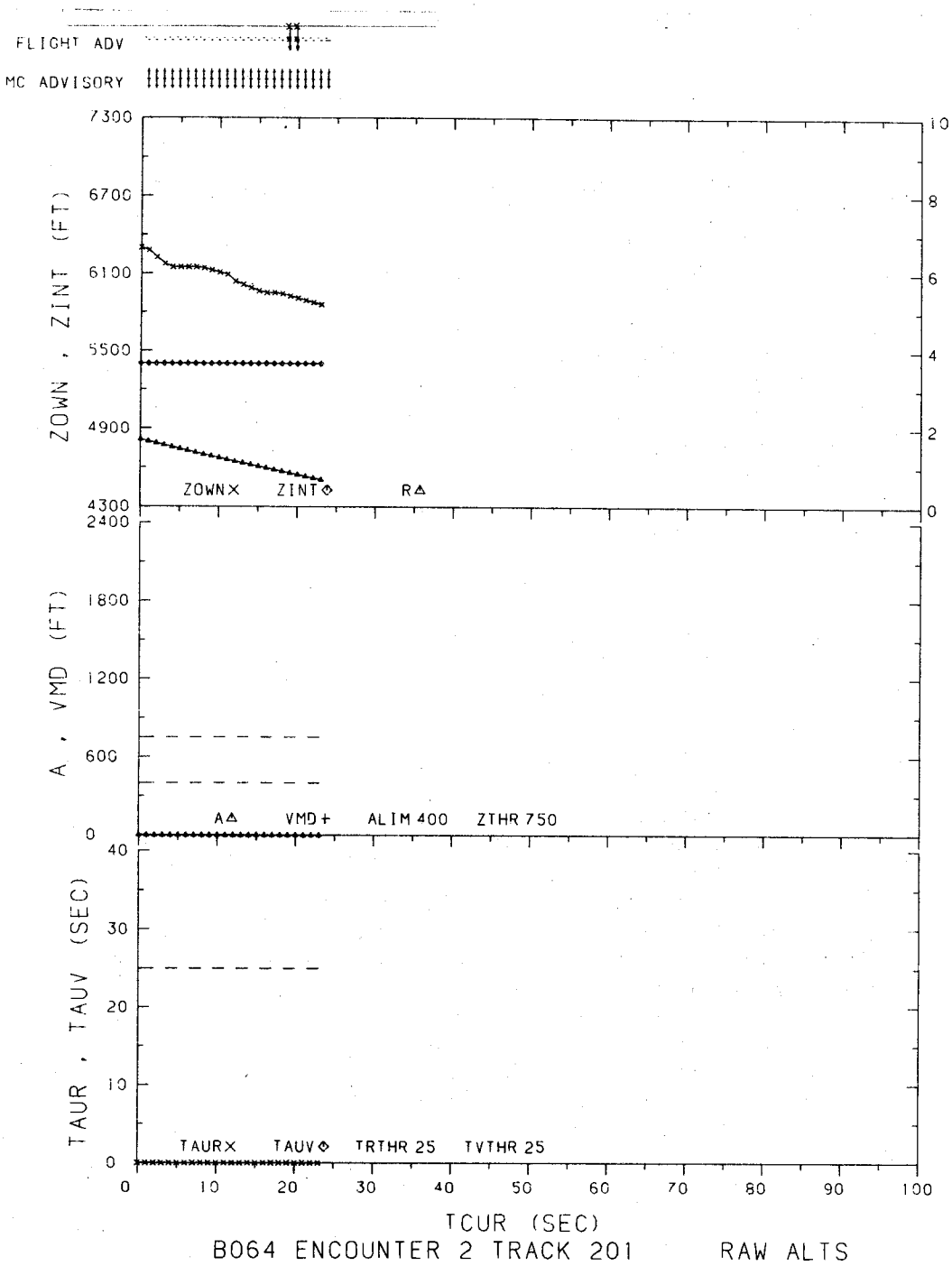


FIGURE 5-1
CASE 30: RESOLUTION ADVISORY AGAINST INTRUDER ON THE GROUND

5.2 Advisory Transitions and Severity

Figure 5-2 shows an observed encounter referred to as Case 11, that took place en route from Norfolk, Virginia to Charlotte, North Carolina. The advisories generated during the flight were a DESCEND followed by a DON'T CLIMB followed by a DESCEND and a final one second transition to DON'T CLIMB. The final one second transition was due to a coding error detected prior to completion of the flight program and was subsequently corrected. Performance of the system was not affected, as the transition occurred after the point of closest approach. During the encounter replay using raw altitude reports, the updated TCAS logic generated only a DESCEND followed by a LIMIT CLIMB TO 1000 FPM and finally a LIMIT CLIMB TO 500 FPM. This sequence of advisories is not as disruptive to the operation of the aircraft.

5.2.1 Advisory Sense

One of the resolution advisory encounters generated an altitude crossing advisory during the actual flight. When replayed in simulation using raw altitude data, the advisory in the direction away from the intruder was selected. Figure 5-3 shows the altitude and Tau history for this unobserved encounter, referred to as Case 21. The TCAS aircraft was descending from an altitude of 7100 feet MSL at approximately 1300 fpm. The intruder was level at 6400 feet. At scan 16, when TAUR fell below the threshold, scan-by-scan printout shows that the margin between a CLIMB and DESCEND was very small, only 55 feet. The logic selected a DESCEND. The aircraft did in fact continue to descend and was provided with adequate separation. However, when the encounter was replayed using raw altitude data the logic selected a CLIMB. The climb or descend margin was so small in this encounter that the slight difference in tracked rates due to the improved vertical tracking algorithm, combined with advisory selection occurring one second earlier (due to elimination of the 2 out of 3 logic) was enough to cause the difference in the direction of this advisory.

5.2.2 Vertical Tracker Firmness

A new feature of the nonlinear vertical tracker evaluates altitude report and coast sequences and assigns a level of confidence or firmness to an aircraft's vertical rate. This feature provides the means to delay threat declaration when the logic is unsure of an intruder's rate. The firmness logic can identify and distinguish

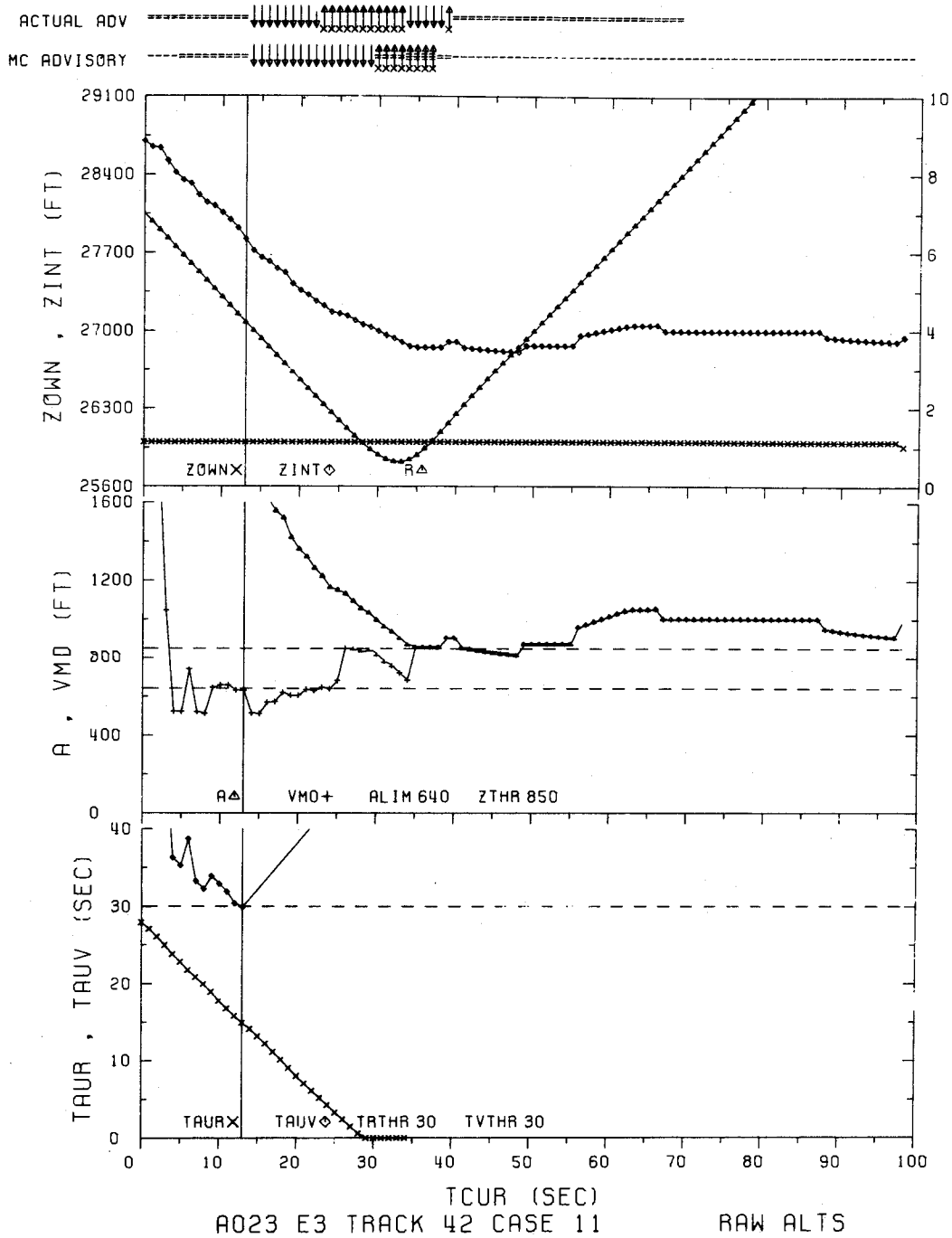


FIGURE 5-2
CASE 11: EXCESSIVE TRANSITIONS OF RESOLUTION ADVISORY SEVERITY

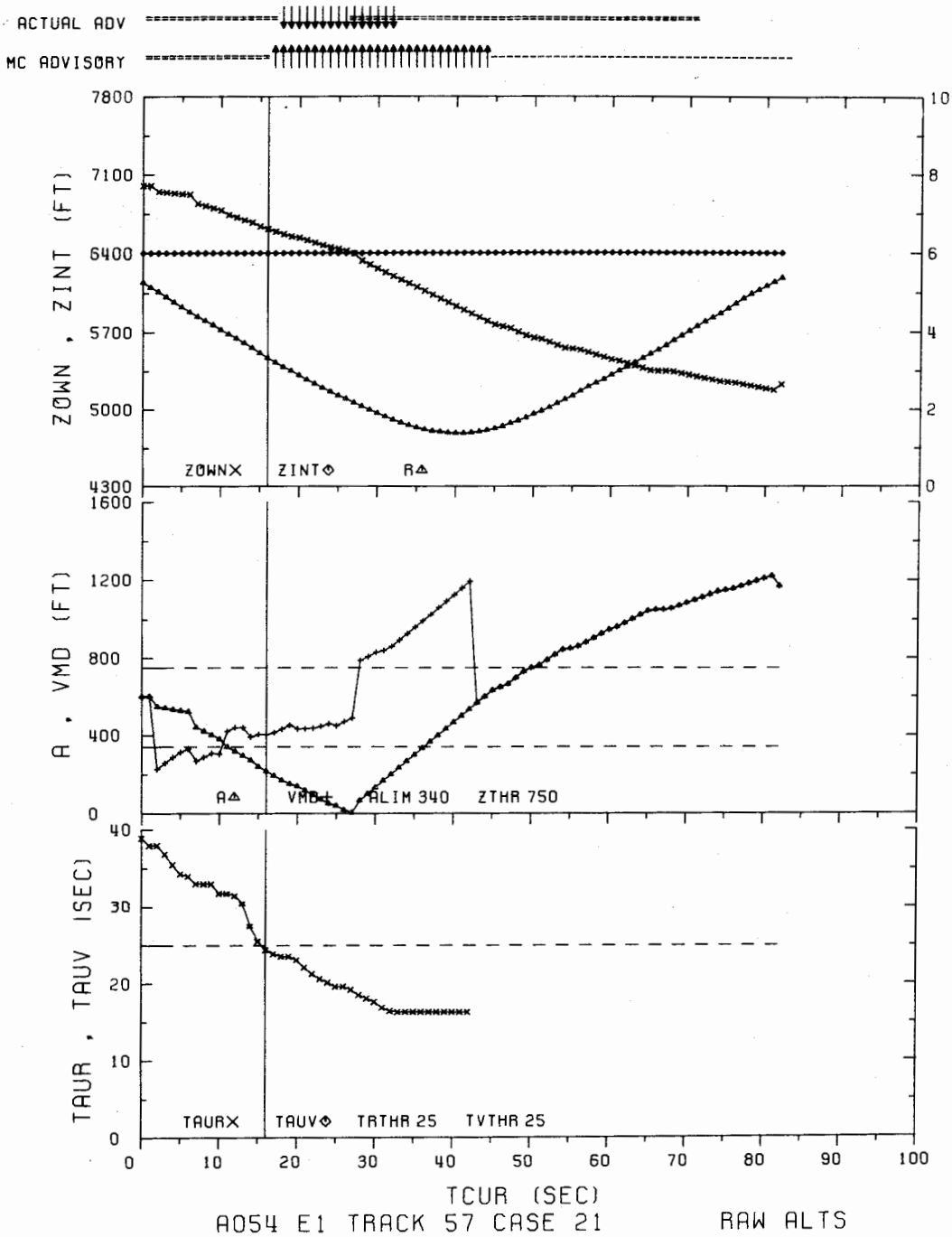


FIGURE 5-3
CASE 21: VERTICAL TRACKING IMPROVEMENTS CAUSE SELECTION OF OPPOSITE SENSE RESOLUTION ADVISORY

among start-up tracks, tracks that are oscillating across bin boundaries, and tracks that show a trend in one direction. A low confidence indication can identify a track that is exhibiting unexpected transitions, for example, a sudden acceleration or leveloff. In those situations it is better to delay a second or more than to risk selecting an incorrect advisory.

Figure 5-4 shows an example of the effect of the firmness logic on a track that was dropped and reacquired, causing an undesirable advisory sequence. (See Section 4.1.2.2 for description of track drops.) The intruder aircraft was level at 10,600 feet MSL. The TCAS aircraft, which was previously separated from the threat by more than the altitude detection thresholds, began a descent toward the intruder when the two aircraft were separated by less than .75 nmi in range. The vertical rate of the TCAS aircraft was fluctuating between -2500 fpm to more than -4000 fpm near the beginning of the encounter. The nonlinear tracker was given only six scans of altitude data prior to the track drop. In the Phase I flight, without the firmness logic, TCAS selected a climb sense and displayed a LIMIT DESCENT to 2000 fpm just as the track coasted out. During a replay of the raw data, a low confidence output from the firmness logic resulted in a delay of sense selection, as indicated on the second advisory line. When the track was reacquired under a new surveillance number, the logic that was flown selected a new advisory sense based on the tracked data available. The descend sense was chosen, as it was predicted to provide the best separation. When replayed through the fast-time simulation using the raw altitude data, a firmness delay of three seconds passed before the logic was allowed to select sense. As a result, a CLIMB was predicted to provide the best separation. When the two segments of the track are viewed as one, the firmness logic caused a single, late CLIMB advisory to be displayed against the intruder, while the logic that was flown displayed two short, opposite direction advisories. A proximity advisory logic has been added to TCAS subsequent to Phase I. The frequency of such advisories is of interest, as well as the useful range. For RAs and TAs, the acceptability of TCAS can be assessed based on observer reaction to the correctness of advisories.

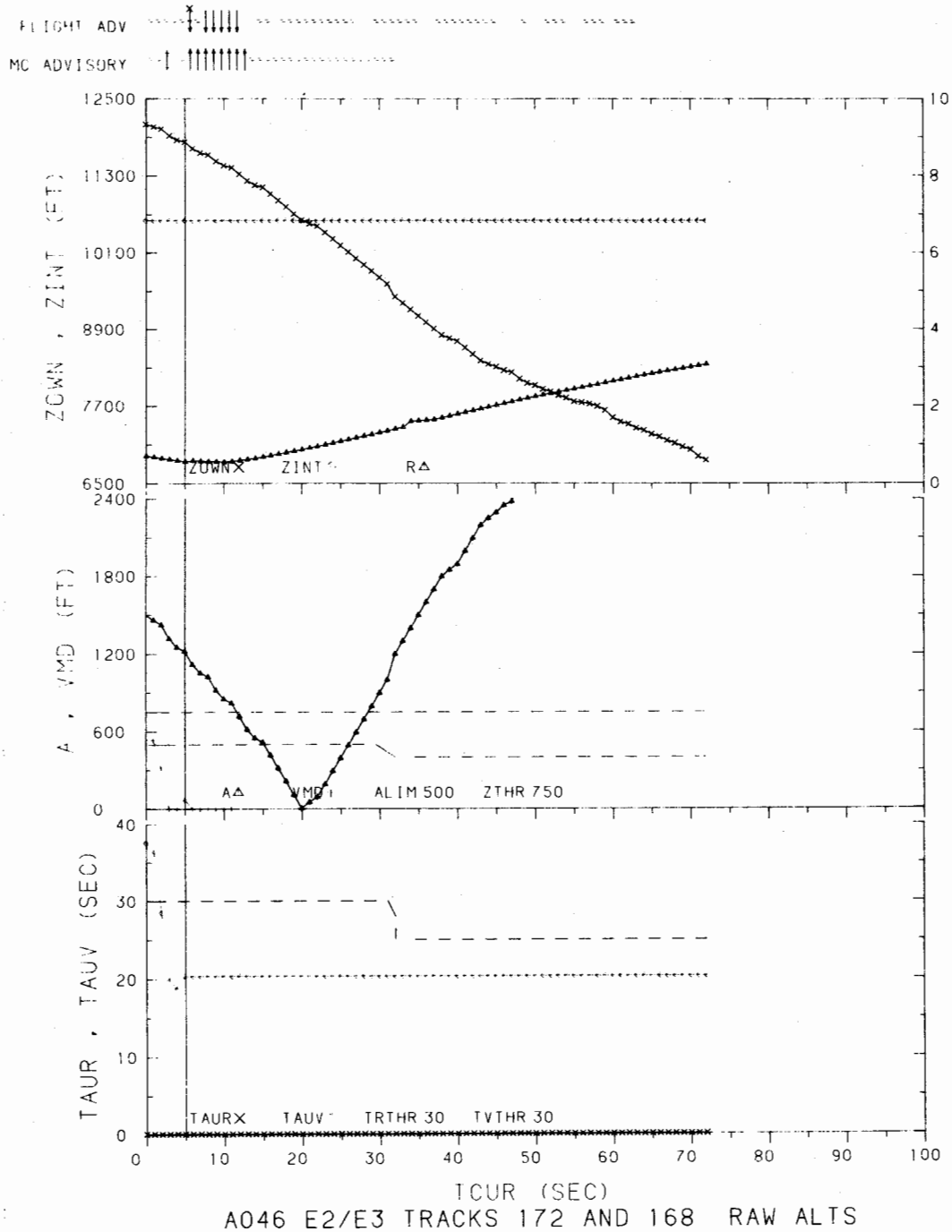


FIGURE 5-4
VERTICAL TRACKING IMPROVEMENTS CAUSE SELECTION OF BEST SENSE RESOLUTION ADVISORY

6. OPERATIONAL TOPICS

The data was also used to support analyses of several operational topics distinct from the recorded advisories.

6.1 Proximity Advisory Rates

The TCAS logic version that was flown during the Piedmont Phase I evaluation provided only one level of Traffic Advisory information. The TCAS logic as it appears in Reference 9 now provides two levels of Traffic Advisories, the Threat Advisory and Proximity Advisory. A Threat Advisory is displayed when an intruder is detected to be converging and satisfies the appropriate range and altitude thresholds. The basic algorithm for this type of TA has not changed since Phase I. However, a second type of TA, the Proximity Advisory, is now displayed whenever a Resolution Advisory or Threat Advisory has already triggered the display. Proximity Advisories are based solely on current separation without regard to projected position or convergence. When an intruder is Mode C equipped, both range and altitude separation are considered. When an intruder is non-Mode C, only range separation is considered.

The utility of Proximity Advisories lies primarily in providing a more complete picture of the surrounding airspace to a pilot in the event that an avoidance maneuver is required. The range threshold used for Proximity Advisories should provide an adequate display of nearby aircraft without adding an unnecessary clutter of aircraft that are not of interest to the TCAS pilot. The range threshold values that have been proposed are 2 nmi and 4 nmi.

In order to provide a statistical base for this operational issue, the Piedmont Phase I data was analyzed to determine the impact of increasing the proximity range ring from 2 nmi (the value in Reference 9) to 4 nmi. One important limitation of this analysis is that non-Mode C tracks were not available on the flight tapes. Therefore, the results below refer only to proximate Mode-C aircraft. The scan-by-scan encounter database could not be used for this analysis because it contains only tracks that generated TAs or RAs. Instead, a second database was used that contains all tracks that the TCAS aircraft detected during the Piedmont flights.

The TCAS flight tapes are event driven, i.e., the data recorder is triggered by a TA or RA and continues to record data until the advisory is removed. For each recorder trigger on the tape, the all-tracks analysis software package samples several scans of data

for each aircraft in track. Range and altitude information is retained from the sampled scans.

The data reduction software used for this effort contained a simple filter designed to remove invalid data such as intruders on the ground and data containing invalid altitudes. Because the filtering criteria were different for the two databases, the number of advisories contained in each is not identical.

The TCAS event recorder was triggered 191 times, during which a total of 219 TAs were generated. For this analysis, the recorder triggers of interest are those which had proximate traffic in track as well as a TA or RA. Seventy-one of the recorder triggers, approximately 40 percent, included proximate traffic within 4 nmi in range and 1200 feet in altitude. Table 6-1 is a breakdown of the number of proximate aircraft within 2 and 4 nmi range rings around the TCAS aircraft.

Of the 71 recorder triggers, only 10 had aircraft both within 0-2 nmi and 2-4 nmi of the TCAS aircraft. There were 34 aircraft present during these 10 recorded encounters; 21 of which were within 2 nmi and 13 that were within 2-4 nmi. Therefore, the total number of proximate aircraft in track within 2 nmi of the TCAS aircraft was 55. The total number of proximate aircraft in track between 2 and 4 nmi of the TCAS aircraft was 53. In effect, increasing the range ring around the TCAS aircraft from 2 to 4 nmi nearly doubles the number of proximity advisories. This can be better appreciated by examining the number of proximate aircraft by display event.

Table 6-2 and Table 6-3 show the breakdown of recorder triggers by the number of proximate aircraft within the two selected range rings. Several significant facts are illustrated by these charts. Table 6-2 shows that, if confined to a 2 nmi range ring, 34 recorded events (48 percent) would have had no proximate aircraft displayed. Secondly, of those events that did have proximate traffic within 2 nmi, 33 (46 percent) had only one or two proximate aircraft displayed. Only four recorded events show more than 2 proximate aircraft (6 percent). Table 6-3 shows that when the range ring is expanded to 4 nmi, 27 events (38 percent) would have been unchanged, i.e., no proximate aircraft would have been added beyond 2 nmi. And finally, when the range ring is expanded to 4 nmi, 52 percent of the recorded events had only one additional proximate aircraft added to the display due to that expansion. Of the 7 events (10 percent) that added more than one proximate aircraft in the 2 to 4 nmi range ring, 6 had no accompanying proximate aircraft in the 0 to 2 nmi range ring.

TABLE 6-1
BREAKDOWN OF ALL RECORDER TRIGGERS WITH
OTHER PROXIMATE TRAFFIC PRESENT

	NUMBER OF RECORDER TRIGGERS	NUMBER OF AIRCRAFT
Proximate Traffic Within 0-2 nmi only	27	34
Proximate Traffic Within 2-4 nmi only	34	40
Proximate Traffic Within Both 0-2 and 2-4 nmi	10	34
TOTALS	71	108

TABLE 6-2
BREAKDOWN OF AIRCRAFT BETWEEN 0-2 NMI
(For advisories with proximate traffic
between 0-4 nmi)

	NUMBER OF RECORDER TRIGGERS	PCT OF ENCOUNTERS
No Proximate Aircraft 0-2 nmi	34	48
One Proximate Aircraft 0-2 nmi	23	32
Two Proximate Aircraft 0-2 nmi	10	14
Three Proximate Aircraft 0-2 nmi	4	6
Four Proximate Aircraft 0-2 nmi	0	0
TOTALS	71	100

TABLE 6-3
BREAKDOWN OF AIRCRAFT BETWEEN 2-4 NMI

	NUMBER OF RECORDER TRIGGERS	PCT OF ENCOUNTERS
No Proximate Aircraft 2-4 nmi	27	38
One Proximate Aircraft 2-4 nmi	37	52
Two Proximate Aircraft 2-4 nmi	6	9
Three Proximate Aircraft 2-4 nmi	0	0
Four Proximate Aircraft 2-4 nmi	1	1
TOTALS	71	100

A023 NO DATA

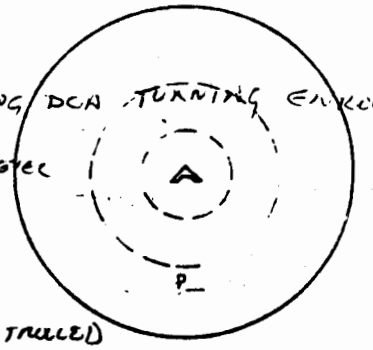
OBSERVER CHECKLIST/RECORD

OBSERVER NAME: BROCK/ARINC DATE: 1-22-82

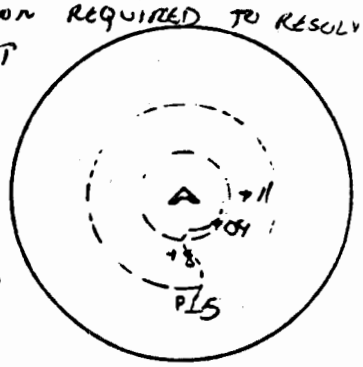
Phase of Flight	Departure ✓	Systems	Flaps
	Climb		Gear
	Cruise		Speed Brakes
	Descent		Power
	Approach		
	Holding		
		Airspace Density	Heavy
			Average ✓
			Light
How Flying	Manual ✓		
	Auto Pilot	Flight Path	Climbing
	Approach		Descending
	Altitude		Level ✓
			Straight ✓ just
Flight Conditions	IMC		Left Turn ✓
	VMC ✓		Right Turn
	Marginal		
	Contact App	Workload	Busy
			Average ✓
			Light

TAPE RECORDER ITEMS

Time/Location 928 EST DEPARTING DCA TURNING ENROUTE
Own Aircraft Intentions LEVEL AWAITING
ATC Advisory NONE ON TGT MAINTAIN LEVEL
Own-Intruder Relationship
(Azimuth, Range, Elevation, Climb/Descent) 30° 2+ +11
Sighting NONE
Timeliness OK
Correctness ?
Usefulness ATC HAD SITUATION CONTROLLED
Disruption
Resolution PERHAPS MORE SEVERE THAN REQUIRED TO RESOLVE
Undetected Intruder
Value of PWI WOULD ALLOW JUDGEMENT OF SITUATION
Comments



DID NOT SEE P5/P6
UNTIL APPROX 11K ALT 30.68
HIGHER THAN STD DAY.



A-6

FIGURE 6-1
EXAMPLE OF COMPLETED OBSERVER LOG

The observation can be drawn from this database that extending the proximity range ring around the TCAS aircraft from 2 nmi to 4 nmi would have added no proximate aircraft in 38 percent of the incidents; only one additional proximate aircraft in 52 percent of the incidents; and would have created two proximities (when there were none before) in 9 percent of the incidents. However, this observation is based solely on Mode-C intruder tracks. The effect of non-Mode C aircraft cannot be assessed using the Phase I database.

6.2 Observer Comments on Operational Topics

The inflight observer data and the post flight observer narratives provided valuable information regarding the circumstances surrounding each recorded encounter. Figure 6-1 shows an example of a completed observer log. The specific elements of interest were the meteorological conditions (IMC or VMC) at the time of each advisory, whether a traffic advisory was called out by ATC at some time during the encounter, and whether the observer and/or crew visually acquired the intruder aircraft. It is important to note that the TCAS displays were not within the field of view of the crew members. However, observers did note instances when the crew verbally indicated sighting the aircraft which was generating the TCAS advisory.

Observer data was available for 90 encounters (77 TAs and 13 RAs). Nearly one-third of these (28) were judged to be against intruders on the ground. The remaining 62 encounters are presumed to be against airborne aircraft, even if the intruder was not sighted. Table 6-4 contains the breakdown of visual acquisition data as it is related to ATC interaction and meteorological conditions.

In seventy-one percent of the observed encounters the observers indicated VMC or marginal VMC conditions. IMC was indicated in 10 percent of the encounters. In the other 19 percent, the observers did not record the conditions. Overall, 45 percent (28) of all observed encounters had an associated ATC advisory. In 50 percent of the observed encounters the intruder was visually acquired by the observer, the crew, or both. In 58 percent of the encounters in which the intruder was sighted, a corresponding ATC traffic advisory against the intruder was given before, during or after the TCAS advisory.

In 34 percent of the encounters, the intruder was never visually acquired. Nearly half of these encounters (48 percent) had no corresponding ATC advisory.

TABLE 6-4
SUMMARY OF VISUAL ACQUISITION OF INTRUDERS

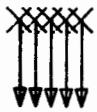
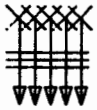
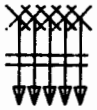
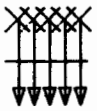
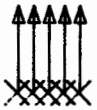
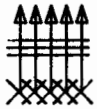
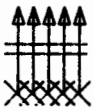
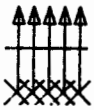
		VISUAL ACQUISITION	NO VISUAL ACQUISITION	ACQUISITION UNKNOWN
ATC Advisory Given	VMC	15	1	3
	IMC	1	-	1
	MARGINAL VMC	1	4	-
	UNKNOWN	1	-	1
No ATC Advisory Given	VMC	6	3	-
	IMC	-	2	-
	Marginal VMC	-	1	-
	Unknown	1	4	-
ATC Advisory Unknown	VMC	3	2	3
	IMC	-	2	-
	Marginal VMC	-	2	-
	Unknown	3	-	2

In addition to the observer comments associated with each TCAS advisory, 17 questionnaires included narratives describing situations in which no TCAS advisory was displayed, but in the opinion of the observer or crew members, would have been useful. These situations probably involved proximate aircraft just beyond the traffic advisory thresholds, or involved aircraft that were possibly not transponder equipped. Four of these narratives described confusion in the cockpit due to multiple aircraft in the vicinity of ATC-called traffic. The observers made note of discrepancies whenever the wrong aircraft was sighted by the crew.

In four more of the narratives, the crew had an aircraft sighted and commented that a TA would have reinforced the visual scene. Two of the narratives described situations in which the crew could not locate traffic in spite of ATC advisories and asked the observer whether a TA was being displayed. In seven more narratives, the observer alone commented that a TA would have been useful either in sighting proximate aircraft or in reinforcing visual or ATC information.

APPENDIX A

ADVISORY SYMBOLS FOR TCAS LOGIC PLOTS

SYMBOL	ADVISORY REPRESENTED
	DON'T DESCEND
	LIMIT DESCENT TO 500 fpm
	LIMIT DESCENT TO 1000 fpm
	LIMIT DESCENT TO 2000 fpm
	CLIMB
	DON'T CLIMB
	LIMIT CLIMB TO 500 fpm
	LIMIT CLIMB TO 1000 fpm
	LIMIT CLIMB TO 2000 fpm
	DESCEND

	TRAFFIC ADVISORY
	PROXIMATE TRAFFIC
	TRACK FIRMNESS DELAY
	RECORDING GAP
	TCAS ADVISORY INVALID
	INTRUDER ON GROUND

GLOSSARY

A	Absolute Value of Relative Altitude
ADOT	Absolute Value of Relative Altitude Rate
ALIM	Positive Advisory Altitude Threshold
DMOD	Incremental Range Protection Volume
R	Tracked Range
RD	Tracked Range Rate
Resolution Advisory	A display indication given to the pilot recommending a maneuver to increase vertical separation relative to an intruding aircraft. Positive, negative, and vertical speed limit (VSL) advisories constitute the Resolution Advisories.
Sensitivity Level	A set of parameter values used by the TCAS equipment to control its threat volume.
TAUR	Modified Range Tau (R-DMOD/RD)
TAUV	Altitude Tau (-A/ADOT)
Traffic Advisory	Information given to the pilot pertaining to the position of another aircraft in the immediate vicinity. The information contains no suggested maneuver.
TRTHR	Range Tau Threshold
TRTRU	True Tau
TVTHR	Altitude Tau Threshold
VMD	Vertical Miss Distance at Closest Approach
ZDINT	Intruder Vertical Rate
ZDOWN	Own Vertical Rate
ZINT	Intruder Tracked Altitude
ZOWN	Own Tracked Altitude
ZTHR	Detection Altitude Threshold

APPENDIX B

REFERENCES

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2. J. Grupe et. al., "Active BCAS Detailed Collision Avoidance Algorithms," MTR-80W286, The MITRE Corporation, McLean, Virginia, October 1980.

3. W. Niedringhaus, MITRE Letter Number W46-800, 1 December 1980.

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10. L. B. Zarrelli, "Performance of the Collision Avoidance Logic During Preliminary Flight Tests of the Traffic Alert and Collision Avoidance System (TCAS II)," The MITRE Corporation, DOT/FAA/PM-83/27, March 1983.