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TCAS III Accuracy in Turn Maneuvers

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16. Abstract

From December 1991 through July 1992, a series of test flights were conducted using a TCAS III Engineering Model (TEM) to determine the ability of the TCAS III to accurately assess an encounter with another aircraft, and monitor the position of the target during a horizontal avoidance maneuver. The flights were conducted using two FAA Technical Center aircraft and the range instrumentation radar as an accuracy reference.

Data from these test flights was processed to determine bearing and bearing rate error, and horizontal miss distance error as compared to the reference radar data. Raw surveillance data was used to overcome shortcomings of the TEM software. For comparison with the reference data, TEM and radar data were converted to similar coordinates using two methods.

Data analysis showed that the TEM bearing and bearing rate accuracy deteriorated during horizontal maneuvering, during which times the target often exceeded the elevation angles and bearing rates planned for the TCAS III standards. Horizontal Miss Distance error calculations indicated that the TEM data quality was insufficient to support both the initial RA determination and subsequent monitoring. The HMD errors increased with range, and would be significantly worse at higher closure rates and TCAS sensitivity levels.

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Summary

From December 1991 through July 1992, a series of test flights were conducted using a TCAS III Engineering Model (TEM) to determine the ability of the TCAS III to accurately assess an encounter with another aircraft, and monitor the position of the target during a horizontal avoidance maneuver.

The flights were conducted using two FAA Technical Center aircraft. Range instrumentation radar (referred to as NIKE radar) data was collected as an accuracy reference. Considerable problems with TEM equipment reliability were encountered. Data from these test flights was processed to determine bearing and bearing rate error, and horizontal miss distance error as compared to the reference data. Raw surveillance data was used to overcome shortcomings of the TEM software. The results were plotted, and the conclusions are based on these plots, which are included in appendices C and D.

For comparison with the reference data, TEM and NIKE data were converted to similar coordinates using two methods. NIKE data was converted to a TCAS-like format of range and bearing, and TCAS data was converted to a NIKE-like format of latitude and longitude.

The TEM bearing and bearing rate accuracy deteriorated during horizontal maneuvering, during which times the target often exceeded the elevation angles and bearing rates planned for the TCAS III standards. Horizontal Miss Distance (HMD) error calculations using TEM data indicated that the data quality was insufficient to support both the initial RA determination and subsequent monitoring. The HMD errors increased with range, and would be significantly worse at higher closure rates and TCAS sensitivity levels.

1 Introduction

This report documents the results of the accuracy in turn maneuvers testing on the Traffic Alert and Collision Avoidance System (TCAS) III Engineering Model (TEM). These flight tests were designed to test the ability of the TCAS III to both accurately assess an encounter with another aircraft, and monitor the position of the target during a turn maneuver similar to those that might be issued by the system.

Ninety encounters were flown between December 1991 and July 1992 to collect data. Range instrumentation radar data was collected as an accuracy reference. The flight data was processed for bearing, bearing rate, and horizontal miss distance accuracy, as compared to the radar reference.

Note: This report, including all plots, was drafted in 1995. Work was discontinued with the cessation of TCAS III work. Final editing and explanatory material were completed in 2009 to format and prepare the report for publication.

2 Background

The Federal Aviation Administration had been tasked with developing a next-generation TCAS which will be capable of generating horizontal escape maneuvers. In the early 1980's, this effort led to the development of the TCAS III concept. TCAS III relied on an accurate angle of arrival (AOA) antenna to provide the horizontal position information necessary for horizontal tracking of target aircraft.

Two TCAS III Engineering Models were built, under contract with the FAA by the Bendix Communications Division in Towson, Maryland, to study the TCAS III concept. The first unit was delivered to the FAA Technical Center in 1983, and the second in 1986. The units were installed in three different Technical Center aircraft: N40, a Boeing 727-100, and N91 (later renumbered N39) and N74, both Convair 580s.

Each TEM was equipped with both a top and bottom AOA antenna system. The TEM software was designed to favor the top antenna, but use the lower antenna if the target was blocked from view by the aircraft, or was at a low elevation angle (below -5° elevation relative to TCAS relative coordinates). By this definition, a TCAS III aircraft turning away from a target was likely to favor the bottom antenna.

During the development of TCAS III Minimum Operational Performance Standards (MOPS), the need to require a bottom directional antenna for TCAS III was questioned. Bottom directional antennas would add considerably to the complexity and the cost of the system. The bottom antenna was more susceptible to multipath replies from the ground. Additionally, other problems were know to exist with the TEM's lower antenna system: Objects (such as gravel) thrown by the front landing gear damaged the antenna. The antenna was affected by obstructions, such as the wings, landing gear, and engine nacelles. The beam steering unit (BSU) aboard N40 blocked access to the luggage compartment, and the BSU and cables were occasionally damaged by sliding luggage. The BSU, when installed in the Convair 580s, was prone to environmental damage, and was very difficult to monitor and service. Three primary questions about the bottom antenna were asked:

- Is the bottom antenna necessary for the success of TCAS III horizontal advisories?
- What is the susceptibility of the bottom antenna to multipath?
- How does the bottom antenna help and/or hurt surveillance and CAS algorithm performance?

2.1 Diversity Antenna Applications Test Plan

In 1991 a test plan, Diversity Antenna Applications, was developed to collect data to answer these questions. The test plan was structured in three sections to determine the following:

1 The susceptibility of the bottom antenna to multipath.
2 The look-down performance of the upper antenna.
3 Top/bottom antenna tracking performance in turns.

NOTE: The test plan was not meant to determine if the TCAS III AOA system was adequate to support horizontal advisories, but to determine the necessity of the bottom antenna.

Section 1 consisted of 48 different two-aircraft profiles designed to characterize the effects of reflected interrogation and reply signals on the bottom antenna bearing accuracy. This data would provide insight into errors introduced into TCAS III through the bottom antenna.

Section 2 consisted of 12 different two-aircraft profiles, as well as several hours of high-density aircraft environment performance, to characterize the look-down performance of the top antenna. These tests would indicate how well the top antenna observed targets at low elevation angles (relative to the aircraft coordinates).

Section 3 consisted of 49 different two-aircraft profiles to determine the bearing accuracy of the TEMs during turns. These tests would indicate the relative accuracies of the top and bottom antennas for determining an appropriate resolution advisory and monitoring the effectiveness of the advisory.

Due to the limited amount of flight time available, and the unreliability of the TEMs, the flight test plan was prioritized to perform the tracking in turns work (section three) first. The tracking in turns flights were also ordered to allow 21 of the scenarios to be eliminated if flight time was not available. The remaining 28 encounters of section 3 were completed. This was the only section of the test plan that was completed, although some test flights from the other sections were performed. This paper includes only the analysis of the tracking in turns flights.

3 Tracking In Turns Test Description

The tracking in turns flights were conducted to determine the usefulness of data derived from the bottom directional antenna in generating and monitoring RAs. The encounters were designed to provide data similar to that which might be expected during the execution of a horizontal RA. The aircraft were placed on varying near-collision tracks, with the TCAS aircraft executing a turn when the TCAS issued a resolution advisory. (The resolution advisory was not necessarily followed. It was merely used as a triggering mechanism for the turns.) These geometries provided varying amounts of fuselage obstruction and a wide variety of elevation angles with which to collect data on both the accuracy effects of antenna obstruction and changes in elevation angle.

Specific horizontal TCAS maneuvers had not been specified. Methods under consideration varied from specifying a bank angle for the length of the RA to advising a specific heading course change. The TCAS III logic installed in the TEMs used the first method, modeling a 10° /second roll to a 25° bank angle, which the pilot was to execute as long as the RA persisted. To provide data that would be useful for either advisory method, the tests were conducted over

a variety of bank angles ranging from 15° to 45°. The turn maneuvers were continued for at least 10 seconds. The full encounter descriptions from the test plan are included in Appendix A.

The tests were conducted using N40 as the TCAS III equipped aircraft. Various Technical Center aircraft were used as the target aircraft. The Technical Center's Vitro RIR-778 range instrumentation radars were used as an accuracy reference. The RIR-778s, commonly referred to as the NIKE radars, use Nike/Hercules radar antennas.

3.1 Test Period

The flight tests were conducted over a period of eight months. This extended time period was due to a combination of several factors: The tests required two aircraft and the use of two NIKE radars as an accuracy reference. The TEMs were becoming more and more unreliable, and efforts to repair and refurbish them took a considerable amount of time. The TCAS III project priority was rather low, and flight time was difficult to schedule. Between aircraft maintenance, aircraft and TEM breakdowns, and the use of the facilities by higher priority projects, it was very difficult to schedule all the required facilities.

3.2 Tests Conducted

Due to the limited amount of flight time available, only the prioritized encounters were performed. The variation in relative altitude for the unperformed encounters was not expected to provide much additional information. Table 1 lists the test flight dates, and encounters performed on those dates.

Table 1 – List of encounters performed and available data from each test flight date.

Flight Date	Encounters Performed
12/18/91	25° track crossings 15, 25*, 35, 45*, 20, 30*, 40, 25, 25*
3/9/92	25° track crossings (target +300) 15*, 25*, 35*, 45*, 20*, 30*, 40* Only one NIKE tape available - not processed
3/10/92	45° track crossings (target +300) 15*, 15*, 15, 25, 35, 45, 20, 30, 40
3/12/92	45° track crossings (target +300) 15*, 25*, 35*, 45*, 20*, 30*, 40, 15, 25, 35, 45, 20, 30*, 30, 40
3/13/92	90° track crossings (target +300) 15, 25, 35, 45, 20, 30, 40, 45, 20, 30, 40*
3/25/92	parallel tracks (target 0) 15*, 25*, 35, 45*, 20*, 30*
6/8/92	45° track crossings (target +300) 15*, 15, 25, 35, 45, 20*, 20, 30*, 40, 40
6/23/92	45° track crossings (target +300) 15, 20, 25*, 30, 35, 40*, 45, 35*, 40, 45
7/23/92	30° convergence runs (target +300) 15*, 20*, 25*, 30*, 35*, 40*, 45*, 15, 20, 25*, 30*, 30, 35*

*full data unavailable

4 Data Analysis

The data analysis of the tracking in turns flights was perhaps the most complicated of the analyses performed on the TEMs. Varying methods of analysis were used to provide a picture of the performance of the TEMs in turns. To eliminate, as much as possible, problems with the TEM software, raw data from the TEMs was increasingly used as the analysis continued.

4.1 Recorded Data

The TEMs recorded data in blocks called "intercepts". These intercepts were set up as groups of logically related data fields, and were output from different modules of the TEM software. Some software modules recorded several different intercepts. The following intercepts were used for the tracking in turns analysis:

Intercept 22: Raw interrogation and reply data.
Intercept 43: Unsmoothed target data.
Intercept 45: Coasted target data.
Intercept 50: Alert and advisory data.
Intercept 64: Raw own data.
Intercept 65: Own data for each coast cycle.

Each software module sent the intercept data to the data recorder when the data block (2048 bytes) was full. As such, the data recorded in each block and intercept was in chronological order on each tape, but the data from different software modules was not.

Additionally, two sets of radar position data (one for each aircraft) were recorded on the ground. This data provided the latitude, longitude, and altitude of each aircraft at a 10 samples/second rate.

All recorded data included time stamps for synchronization. The time of all data sources (TEM and NIKE) was synchronized to the WWV national time standard.

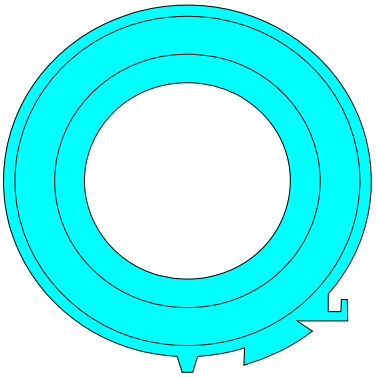
For various reasons, data from all sources was not always available. Those encounters, notated in Table 5, could not be analyzed.

4.2 Merging data

All data was recorded on 9 track computer tapes, and was processed on a Perkin Elmer 3220 (PE) mini computer. The data was downloaded from each tape into standard formats, developed for the PE, for each intercept (or for the NIKE data, which, for convenience, was treated as if it were two more intercepts). This process involved specifying the start and end times of each data run, and creating separate files for each of the data intercepts. To speed further processing, those fields in each intercept file that were used were then merged with each other in chronological order into one or more files. Figure 1 illustrates this process.

Figure 1 - Preparing TEM Data for Analysis

The TEM data were recorded chronologically in various data “intercepts”. These intercepts were individually recorded on the 9-track tape as they were filled.



Example:

..

INT20s	block	9:44:20	to	9:46:00
INT20s	block	9:46:01	to	9:47:35
INT40s	block	9:44:20	to	9:47:40
INT20s	block	9:47:36	to	9:49:20
INT20s	block	9:49:21	to	9:52:10
INT40s	block	9:46:10	to	9:53:00
INT20s	block	9:52:10	to	9:53:30
INT60s	block	9:44:20	to	9:54:00

...

Note that the intercept blocks are chronologically recorded on the 9-track tape by the end time of the data within the intercepts.

These intercepts were then processed into individual data files, each in chronological order, on the Perkin Elmer computer:

Example:

INT20s block	INT40s block	INT60s block
INT21.file	INT43.file	INT64.file
INT22.file	INT45.file	INT64.file
...	...	...

Data from each of these files, as required for further processing, were then merged together into one file in chronological order.

Merged file example:

...

9:44:20.1	INT22	bearing	range	...	
9:44:20.1	INT43	bearing	range	track number	...
9:44:20.5	INT64	pitch	roll	heading	...
9:44:20.6	INT22	bearing	range	...	
9:44:20.8	INT22	bearing	range	...	
9:44:20.8	INT43	bearing	range	track number	...
9:44:21.5	INT22	bearing	range	...	
9:44:21.7	INT22	bearing	range	...	
9:44:21.7	INT43	bearing	range	track number	...
9:44:22.5	INT64	pitch	roll	heading	...

...

Each data file name indicated the date and type of file data (i.e. the intercept number or merge information). To further decrease the repetitive task of entering run start and stop times, and

to decrease to opportunity of input errors, each file was tagged with an information block which included the data start and stop times, the date, the type of data, and any other processing information. These steps were important in keeping track of the hundreds of individual files.

The data was examined in several different ways. Bearing and bearing rate error were first examined by comparing the NIKE and TCAS data. The horizontal miss distance, calculated with both NIKE and TCAS data, was then examined.

4.3 Tracking and the TEM

Much of the way the data processing was performed was determined by the availability of data in the TEM intercepts. Most of the original processing was performed using only the recorded data. Unfortunately, many of these fields were found to contain erroneous information, were only calculated at specific times during the encounter, or were affected by poor tracking. Other necessary fields were simply not recorded. As such, the data processing complexity continued to increase.

One of the biggest problems with the TEM was poor target tracking. This was a frequently observed problem in all TEM data, and the problem was investigated prior to this analysis. The investigation revealed that the TEM did a good job of correlating raw replies (recorded in intercept 22) for inclusion in the raw track data (intercept 43). However, the TEM did a poor job of identifying individual tracks in this data. As such, the intercept 43 data, as well as all other track data subsequently processed by the TEM, is highly fragmented. Most tracks are mis-identified as a sequence of different aircraft.

The smoothed track data (intercept 45) had several serious problems. The incorrectly identified track segments caused odd tracks, as each track fragment was initialized, coasted, and dropped. The intercept 45 data also contained no information on the antenna source of the track.

4.4 TEM Recorded Own Aircraft Data

The TEM recorded a variety of own-aircraft state fields. This data was recorded at the nominal rate of 0.5 Hz, which had been used throughout the TEM tests. The TEM was capable of recording the information at a higher rate (approximately 4/second), but this was not done due to the increased load factor on the data recorder.

4.5 Comparing TCAS and NIKE data

NIKE data is recorded as the latitude, longitude, and altitude of each aircraft. The TEM data did not include accurate own-aircraft (own) position. It did include range, bearing, and altitude information on the target, as well as calculated north X and Y relative target position data.

In order to compare the two data sources, they had to be put in a similar format. As such, the NIKE data was used to create a pseudo-TCAS format of range and north-referenced bearing, and relative altitude information. This was accomplished by processing the two NIKE latitude and longitude positions through a routine using Sodano's equations. The relative altitudes were simply obtained by subtracting the measured TCAS aircraft altitude from the measured target altitude. (See figures 2 and 3.)

4.5.1 Latitude and Longitude calculations

One method of comparing the accuracy of TCAS with the NIKE data is to convert TCAS target data into latitude and longitude data. Since the NIKE data is used as a reference, the TCAS position is assumed to be the NIKE own data position. The target latitude and longitude is then calculated from the TCAS range and north referenced bearing relative to the NIKE own data.

The NIKE own position is substituted for the own position measurements on the airplane (which are not accurate) in each update of INT64. (INT64, own data, was updated about every 2 seconds).

For each reply, the target latitude and longitude is calculated from the most current NIKE own data (updated about 10/sec) using the TCAS measured range and north reference bearing. This calculated target latitude and longitude is then added to the INT64 message, if the current own data and reply times match, or to a pseudo INT64 message, with just the target latitude and longitude, if the times do not match. (Again, the INT64 data was recorded only about every 2 seconds. This method provided a target latitude and longitude calculation for every TCAS reply within 1/10 second time accuracy.)

Note that the closest TCAS NIKE data is used in both cases. The NIKE update rate of 10 samples/sec is assumed to provide a data point that is "close enough".

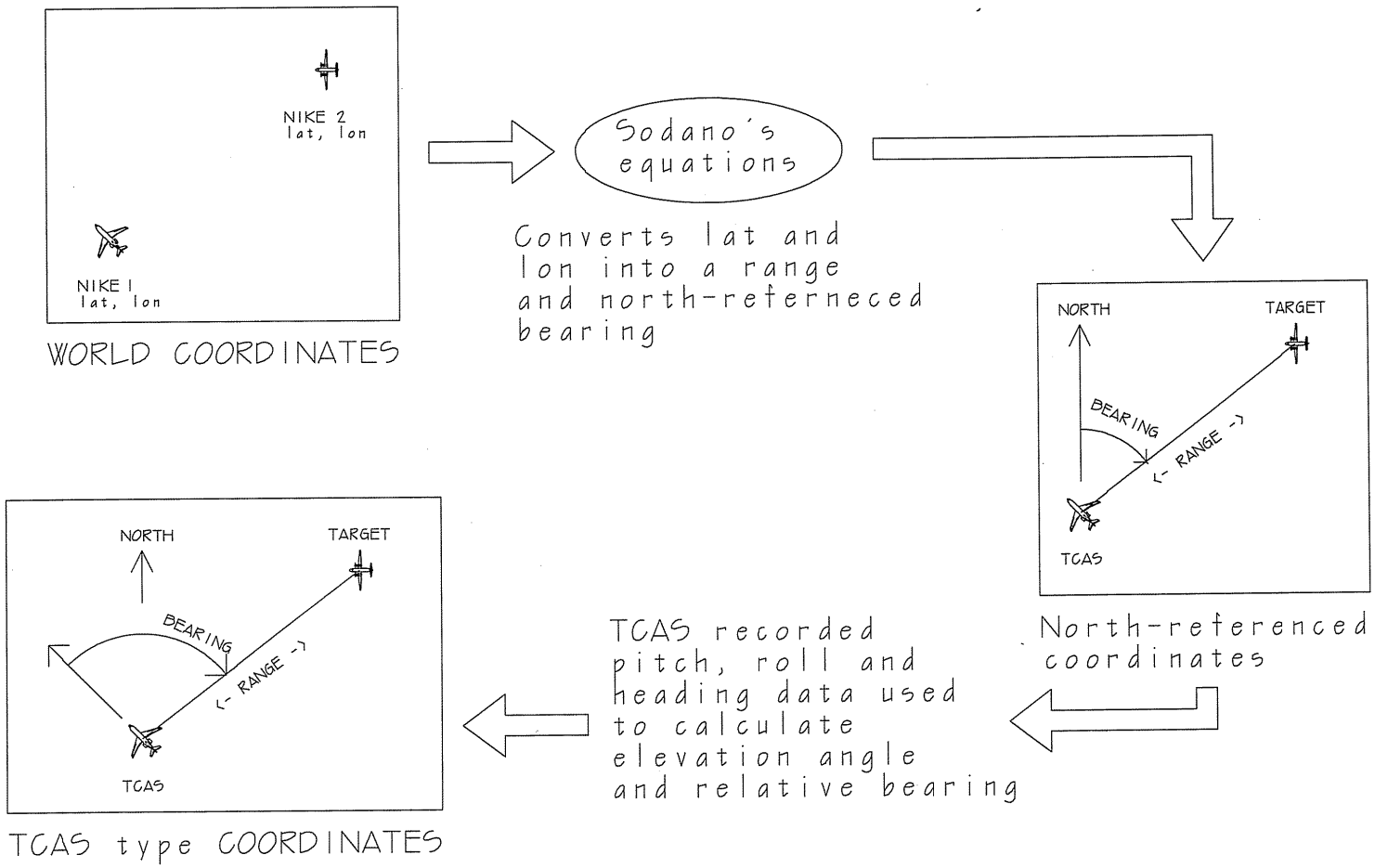


Figure 2 - Converting NIKE data to TCAS-type data

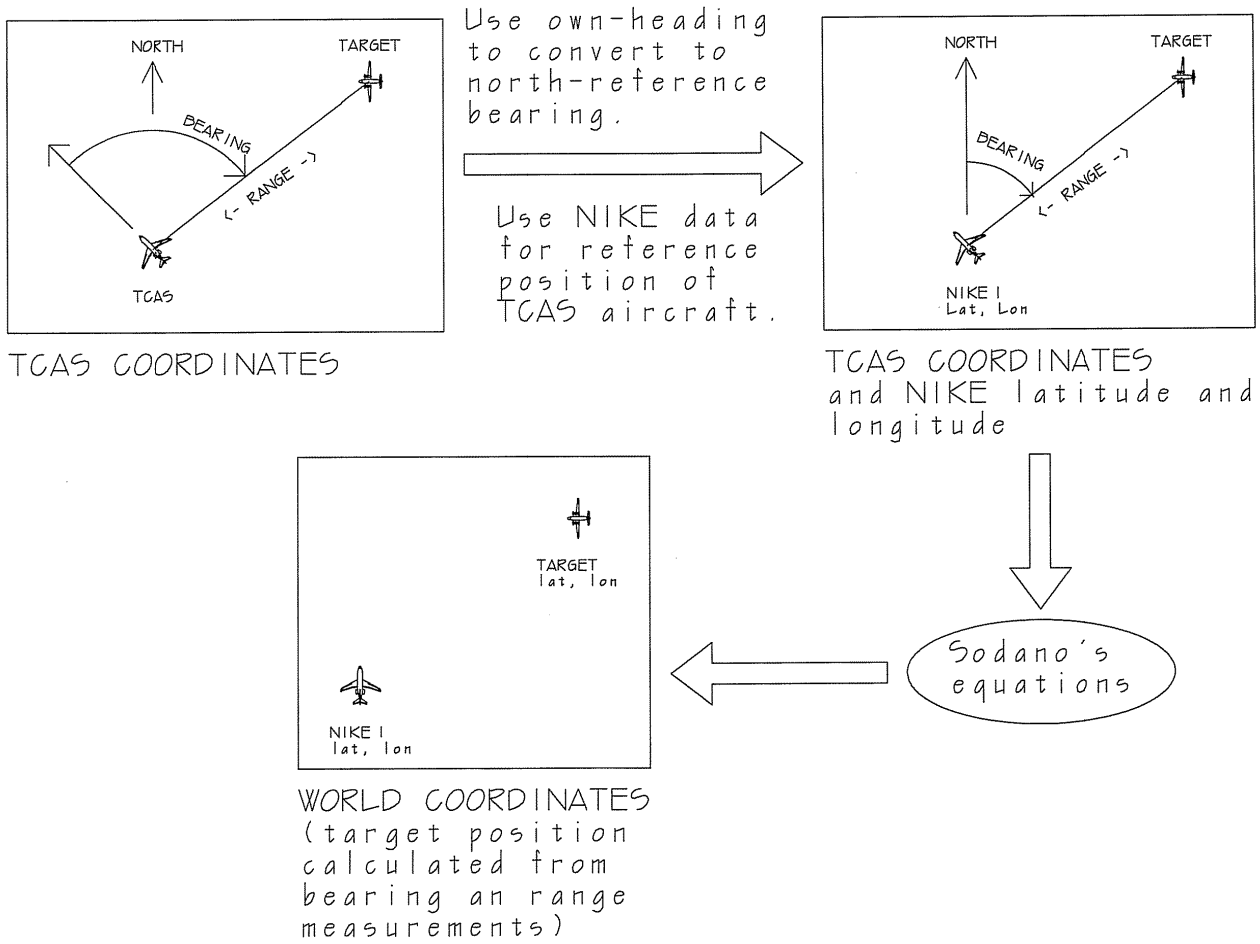


Figure 3 - Converting TCAS data to NIKE-type data

4.5.2 Range, North Reference Bearing, and Relative Altitude calculations

The second method for comparing the accuracy of TCAS with the NIKE data is to convert the NIKE target data into range, north referenced bearing, and relative altitude relative to the NIKE own data. This results in NIKE data converted to look like TCAS data.

This data was provided by merging the NIKE target position with the other fields previously merged (INT43, 50, and 64, along with the NIKE own data substitution in INT64, and the calculated target latitude and longitude in the actual or pseudo INT64 messages). Both the own and target NIKE data are read, and for each NIKE target report, an output record is included in the merge file. This record includes both the actual NIKE target position data, and the calculated range, north referenced bearing, and relative altitude to the NIKE own data. No TCAS data is used for this calculation. This calculation is based on Sodano's equations, as are all other latitude-longitude to range-bearing conversions performed in the processing.

4.5.3 Horizontal Miss Distance

The TCAS derived horizontal miss distance is calculated as follows (formula supplied by John Warren):

```
VR2= SNXD**2 + SNYD**2
IF (VR2 .LT. 100) THEN
        HMD=SQRT(CNX**2 +CNY**2)
ELSE
        HMD=(CNX*SNYD - CNY*SNXD)/SQRT(VR2)
```

Where:

CNX is Coasted North X
CNX is Coasted North Y
SNXD is Smoothed North X Dot
SNYD is Smoothed North Y Dot

True heading is calculated as such:

```
THEADING=ATAN2(CNX,CNY)
IF(THEADING .LT.0)THEADING = THEADING +360
```

4.5.4 Tracked TCAS Replies

The TEMs did a poor job of recognizing tracks, and assigning track numbers. The tracked data also lacked information helpful to the top/bottom antenna analysis. As such, several analysis tools were developed to overcome these problems.

4.5.4.1 Picking Single Tracks from Data Files

In order to isolate the track of interest in the TCAS data (that is, the target airplane), a graphic interface program was written to isolate single tracks. This program plotted all the raw track data (INTERCEPT 43), and then asked the program operator to point to the start of the desired track. The program searched the data file to match that point, and then used a small "window" to look through the data for the next point in the track. The window allowed a small time, range, and altitude deviation from the previous point. As points were located by the code, they were marked on the graphic display. If there was a large gap in the data, or altitude jumps (as with altitude errors), the program would lose the track. The operator then entered the next unmarked point on the display and resumed the process. The points identified for the particular track were stored in a new file, which was used for further analysis.

It should be noted that the TEM experienced frequent altitude decoding errors. Replies with incorrect altitudes were not included in the single track files. No attempt was made to correct the altitudes.

4.5.4.2 Tracking the Single Track

The single track data was then processed to simulate the original TEM format for smoothed data, INTERCEPT 45. The program used a declining gains alpha-beta tracker. The program was capable of providing two types of output: Smoothed, or smoothed and coasted. Smoothed data (no coasting) was used for most of the analysis work. Unlike the original INT45 format, the pseudo INT45 format provided three different sets of track data; one each for the top, bottom, and diversity antennas.

The minimum gap between replies used for any track was set to 0.5 seconds. This prevented the tracker from attempting to smooth various replies on the same interrogation cycle.

The diversity antenna track favored top antenna data. Data from the top antenna was used unless the target elevation angle fell below -5° (normalized TCAS coordinates). However, the diversity track would use the first available data, regardless of the antenna source, after a 4.1 second reply gap. This reply gap was then reset, so the proper antenna was still favored. (This method sometimes results in sparse data in the diversity track, when data from the preferred antenna is not available.)

The target north referenced X and Y coordinate data was put through the alpha beta tracker. The tracker provided both estimated X and Y position and rate data. Target range, north reference bearing, and bearing rate were then calculated from these fields. Relative bearing was calculated using the recorded own bearing at the time of the reply.

The range rate was also calculated from the tracked data. It should include a contribution due to altitude rate. However, an altitude tracker was not implemented here to derive this data. Since all the flights consisted of level-flight encounters, this omission was considered to be a negligible error source.

4.5.5 Additional NIKE data processing

In the above processing, a smoothed bearing and bearing rate figure are calculated for each TCAS position update, and a range and bearing are calculated for each NIKE target position update. In order to compare the data points as closely as possible, the NIKE data was further processed.

First, the NIKE range, bearing, and altitude data was interpolated to provide data at exactly the same time as the TCAS reply. This interpolation was over a very small period of time (less than one-tenth of a second), and introduced very little error. The calculated NIKE range and north referenced bearing were changed into north referenced X and Y coordinates. This data was then processed through the same alpha beta tracker as was the TCAS data, providing smoothed range, bearing, and also horizontal miss distance.

This program also used TCAS own data and the NIKE data to calculate the NIKE data target elevation angle relative to the aircraft.

5 Test Results

The processed data from the tracking in turns flights was almost entirely prepared as plotted data. An effort was made to prepare tabular information on bearing and bearing rate accuracy, but this data processing method proved to be inconclusive.

5.1 Bearing and Bearing Rate Error

Bearing and bearing rate error plots from the 3/12/92 flight data are included in Appendix C. The following observations can be made about the data plots:

5.1.1 Bearing Bias Error

A bias error of approximately 8° can be observed on all of the bearing error plots. This error was as least partially the result of the placement of the TCAS antenna aboard N40. The antenna required nine holes drilled through the fuselage for cable connections to each antenna element. The antenna was mounted off-center so that the forward and rear element holes would not damage the centerline stringer of the aircraft.

Plot C-13 (Appendix C, page 13) shows both the TCAS and NIKE relative bearings.

5.1.2 Bearing Error

The bearing error plots in Appendix C show that the TEM bearing accuracy is fairly well behaved during level flight, usually varying just a few degrees from the bias error. However, the bearing accuracy deteriorates considerably at some point in almost every turn. These increases in error occur even with slight changes in the elevation angle of the target, but are worse with large target elevation angles. It should be noted that the planned TCAS III specification called for a bearing accuracy of at least 4.0° RMS. This specification applied only to targets with an elevation angle range from -15° to +20°. The TEM bearing accuracy, in contrast, was specified to be 2.0° RMS.

The bottom antenna usually received fewer replies from the target aircraft, and was likely to produce large bearing errors on many runs, even if it was the "preferred" antenna (see Appendix C, 9:33, 9:47, 10:00, and 10:07). However, on some encounters, it maintained the track and bearing accuracy better than the top antenna (see 9:54, and 10:20).

Note: Times, such as 9:33, refer to the encounter start time, and may be used to locate specific groups of plots in the appendices. All plots include a start and stop time for the encounter. See Appendix B for full plot descriptions.

The errors in the top and bottom tracks usually behaved similarly in level flight, but occasionally diverged significantly (see 9:47, 10:07, and 10:20). In level flight, the antennas would often indicate bearing differences of 8° or more. The bearing errors were more likely to diverge during a turn, although the bearing difference peaks between the two antennas were no more than those observed in level flight. The diversity tracking function was more likely to switch antennas during turns, thus forcing the tracker to use diverging information.

Examination of the diversity antenna tracks shows that the use of the bottom antenna data sometimes improved the bearing accuracy during a turn (see 9:33, 10:20), and sometimes deteriorated the bearing accuracy (see 9:47, 10:00).

Overall, the top antenna accuracy appears no worse than the bottom antenna accuracy, even with very low target elevation angles. The top antenna seems no less likely to track the target during these turns.

5.1.3 Bearing Rate Error

Bearing rate error plots of the encounters performed on 3/12/92 are included in appendix C. The bearing rate error is quite low in near level flight, and increases during turns. This, of course, matches the increases in bearing error observed in the bearing error plots. The bearing rate error is particularly bad near CPA on the plots, which is due to the higher (apparent) bearing rate of the target at these times. It should be noted that the planned TCAS III specification called for a bearing rate accuracy of 0.4°/second for target bearing rates up to

±2°/sec. This specification applied only to targets with an elevation angle range from -15° to +20°.

Both the bearing error and bearing rate error specifications were based on the technically feasible design of the TCAS II system. The ranges over which the specification applies should cover most, if not all, collision threats at the time a resolution advisory would be generated. However, it's interesting to note that, during an RA-induced turn maneuver, targets are likely to be positioned in such a way as to exceed the elevation angle range of both the bearing and bearing rate specifications.

Both the bearing error and the bearing rate error appear to be well behaved, according to the TCAS III specifications. The bearing and bearing rate are merely used by TCAS III to determine the threat of a collision, and to monitor the progress of an advisory. As such, the next analysis step was to examine the calculated HMD, which is actually the determining factor for horizontal maneuvers.

5.2 Horizontal Miss Distance Errors

The TCAS-III pseudo code of September 1984 looks for a .5 NM separation minimum at the lowest RA levels (23 second RA). The minimum horizontal separation increases to 1.5 NM at the maximum sensitivity (40 second RA).

Appendices C (3/12/92) and D (all other dates) include all horizontal miss distance plots available from the tracking in turns test flights. A top, bottom, and diversity antenna plot are included for each encounter, when available.

5.2.1 HMD Oscillation

The TCAS measured HMD oscillates significantly around the actual HMD value, usually settling down to a fairly steady value at about the same time as TCAS issued an RA. This oscillation can be seen on almost all of the plots. As an example, view the 9:46 plots from 3/10/92. In this plot, the top antenna TCAS HMD calculation varies from over two miles to the left of the aircraft to over two miles on the right of the aircraft. The value settles down to about a 2000 ft oscillation by the time the RA is issued.

Several things should be noted about the HMD oscillation. First, the HMD errors are caused by the bearing measurement errors, and are a function of the range to the target aircraft. As the range decreases, so does the HMD error. (Compare the HMD plot with the slant range plot for 9:33 on 3/12/92 in Appendix C.) Second, TCAS issues RAs based on the time to CPA. In most of these plots, the HMD oscillation has settled to a fairly stable value at about the same time as the RA is issued; about 30 seconds prior to the closest point of approach. However, the encounters were generally conducted at closing airspeeds of less than 460 knots, well below the TCAS design maximum of 1200 knots. If the closing speed of the encounter was doubled (which is still well within the TCAS design limitations), the range at

which the RA would be issued would also double. This would have the effect of halving the time scale on these plots, into the range with larger HMD errors.

These flights were conducted at fairly low altitudes (usually around 10,000 ft). Increasing the altitude would raise the sensitivity level of the TCAS and result in an earlier RA. (TCAS III RA thresholds normally range from 23 to 40 seconds prior to CPA, depending on the sensitivity level.)

The three figures at the right notionally illustrate the effect of altering the sensitivity level and speed of the encounters.

Figure 4 shows the TCAS RA issued at 30 seconds prior to CPA with approximately 460 knot closure speed, as was used in the encounters.

Figure 5 shows the effect a higher sensitivity level would have on the timing of the RA. The RA is issued 5 seconds earlier (35 seconds prior to CPA).

Figure 6 shows the effect of doubling the closing speed of the encounter. The time prior to CPA at which the RA is issued remains the same (35 seconds), but the range at which the RA is issued doubles. The RA is issued when the HMD value is still highly unstable.

Figure 4
460 knot closure speed - 30 second RA threshold

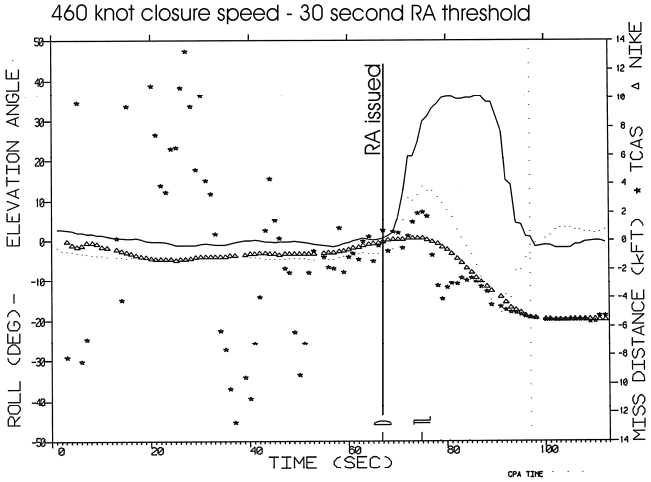


Figure 5
460 knot closure speed - 35 second RA threshold

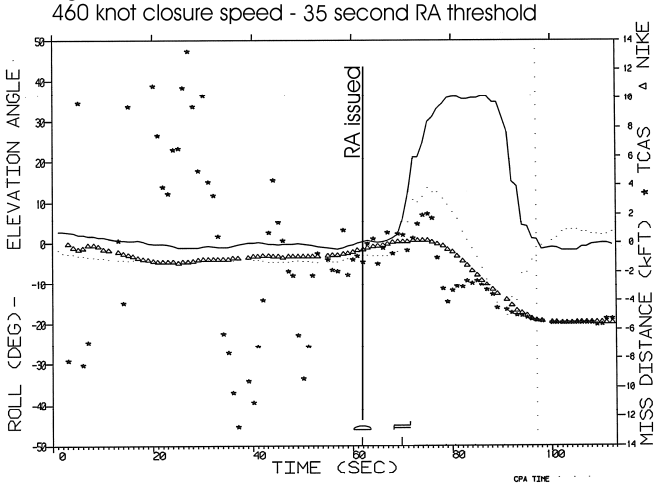
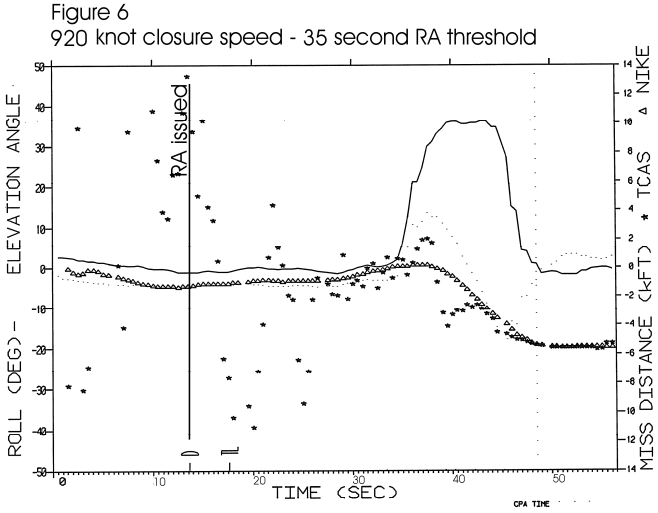


Figure 6
920 knot closure speed - 35 second RA threshold



5.2.2 HMD Errors During Turns

One of the primary goals of this flight test was to collect data showing the performance of the TCAS III surveillance during turn maneuvers as would be expected when following a horizontal RA. The HMD plots for the encounters show a range of accuracy performance in the turns. Generally, however, the HMD calculation is considerably off from the “true” value, and the rate of change of the HMD value is particularly different than the “true” value. Many of the plots show that the measured HMD changes dramatically, while the “true” value remains nearly constant. If TCAS were to use these measured HMDs to monitor the effectiveness of the RA, the RA would likely be dropped or altered well prior to any actual effect from the aircraft maneuver.

5.2.3 Surveillance Problems

Surveillance problems with the TCAS III can be seen in almost all of the plots. There are data gaps in almost all of the plots. The data gaps affect the tracker such that the gaps are usually followed by, and often preceded by, larger measured HMD errors.

6 Conclusions

The purpose of the tracking in turns tests was to determine the ability of TCAS III to both accurately assess an encounter with another aircraft, and monitor the position of the target during a turn maneuver similar to those that might be issued by the system. Analysis of the flight data shows that the TEM accuracy was inadequate to support these TCAS III functions, even though the TEM bearing and bearing rate accuracy used for these tests was better than the proposed TCAS III standard..

In examining the performance of the TEM under turn conditions, effort was made to minimize the effects on the results due to inadequacies in the TEMs. The TEMs, built in 1983, were equipped with early TCAS surveillance software and hardware. While TCAS surveillance systems had improved dramatically since that time, the TCAS III TEM antenna system accuracy was still superior to those in TCAS II production.

The TEM performance in a variety of bank angles and turn durations was examined. Both the top and bottom antenna systems were examined. In all cases, the TEM was found to provide unreliably accurate data on which to base horizontal advisory selection, and to monitor the progress of such an RA. Increasing the sensitivity level or closing speeds of the encounters would further deteriorate the data accuracy.

Bearing performance of the system when using both a top and bottom antenna was not substantially better than when using only a top antenna.

The reliability of the TEM antenna systems also brought to light the problem of effectively monitoring the performance of accurate antenna systems. Failures in the antenna system could greatly decrease the required accuracy, and would be difficult to detect.

The limits of the TCAS III accuracy specifications (elevation angles ranging from -15° to +20°) were frequently exceeded during aircraft maneuvers, as would be expected by following horizontal advisories. If TCAS is required to monitor separation during an advisory, its performance specifications should cover the surveillance geometries expected when following the advisory.

Appendix A Test Plan for TOP/BOTTOM DIRECTIONAL ANTENNA PERFORMANCE IN THE TURN

TOP/BOTTOM DIRECTIONAL ANTENNA PERFORMANCE IN THE TURN

Background: The inclusion of a bottom directional antenna in the specifications for a TCAS-III has generated much debate. Those in favor of the bottom directional antenna feel that the shielding of the top antenna by the aircraft fuselage during aircraft maneuvers, especially those suggested by the TCAS-III, will necessitate the installation of a bottom directional antenna to provide bearing monitoring during these maneuvers. Those opposed to the bottom directional antenna feel that the bearing accuracy in a turn will be too poor to use from either antenna, that fuselage obstructions and multipath will cause many problems, and that the additional purchase and installation costs will not be met with increased performance.

The FAA Technical Center performed a series of tests to compare the accuracy of the top and bottom antenna tracks during turns. The performance of the TEM was poor at the time these tests were conducted, however, and the data was not conclusive.

Objective: To study the performance of the top and bottom directional TCAS antennas during turns. Data from this study may then be used to determine the accuracy of bearing measurements during horizontal maneuvers, and the extent to which this data may be used for monitoring the performance of horizontal advisories.

Method: A series of two-aircraft encounters will be flown. All of these encounters will include turn maneuvers by the TCAS-III equipped aircraft such that the bottom antenna will be angled towards the target aircraft. The encounter angle and the turn angle will vary to collect data with several elevation angles, and varying amounts of fuselage obstruction.

The TEM parameters will be set to allow full range tracking on both the top and bottom antennas and prevent track switching between the two antennas. (Normally, the bottom search range is limited to 4 NM, and the tracks will switch between antennas at approximately -5 degrees elevation angle relative to the TCAS aircraft position.) The TEM software had previously been modified to allow the TCAS to form both top and bottom antenna tracks on the same target.

The TEM has the capability of recording various data groups called intercepts. The data recorder will be set to record the following intercepts:

Intercept 22: Raw interrogation and reply data.
Intercept 43: Unsmoothed target data.
Intercept 45: Coasted target data.
Intercept 50: Alert and advisory data.
Intercept 64: Raw own data.

Intercept 65: Own data for each coast cycle.

If possible, both the TCAS equipped and target aircraft will be tracked by the NIKE (or some other) radar system for comparison of the TCAS data with the radar data.

Encounter Description: The encounters are all described in more detail on the following pages. The following information applies to all encounters.

Airspeed (True): 230 knots (both airplanes)

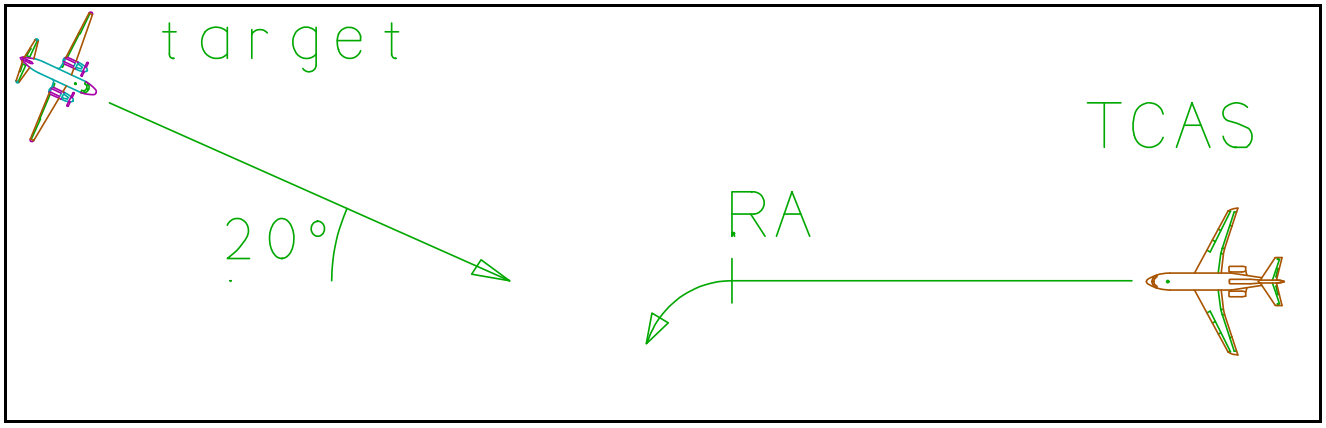
Altitudes: as convenient

Estimated range of target when the resolution advisory is issued:
3.2 NM (TCAS altitudes below 10,000 ft)
3.8 NM (TCAS altitudes above 10,000 ft)

Radius of the TCAS turn: 2.89 NM (15° bank angle)
2.12 NM (20° bank angle)
1.67 NM (25° bank angle)
1.34 NM (30° bank angle)
1.10 NM (35° bank angle)
0.92 NM (40° bank angle)
0.77 NM (45° bank angle)

Analysis: The TCAS track data will be separated into top and bottom tracks, plotted and compared with the radar data, if available, to determine the bias, bearing and bearing rate accuracy of both antennas, as well areas of surveillance problems. This data can be further manipulated to compare the projected miss distances from both antennas.

PROFILES 3-1 through 3-14



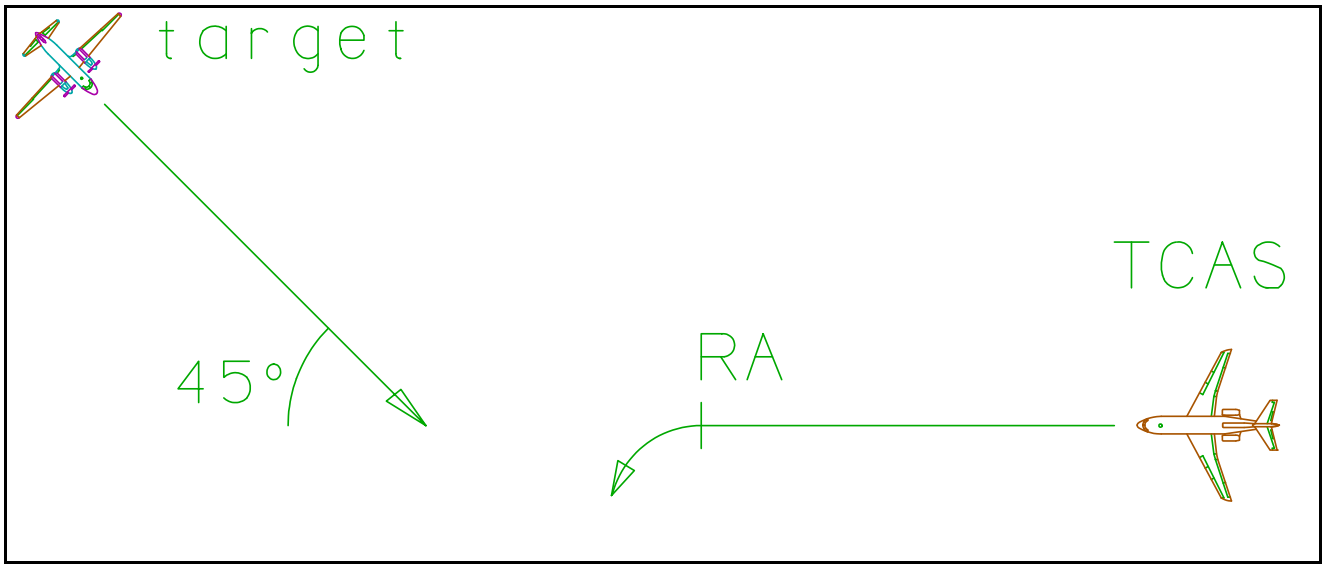
These profiles are 20° track crossings, with the relative altitude of the target described below. When the TCAS-III issues a resolution advisory, no matter what advisory is issued, the pilot will initiate a 10°/second roll rate to the bank angle prescribed for that profile. The direction of turn may be chosen by the pilot. The pilot should continue the turn for at least 10 seconds, and then level-off. The run will end 4 NM after completion of the turn.

NOTE: Set parameters P-26 to 20 (bottom search range 20 NM)
P-48 to 179 (tracks switch antennas at 179° elevation angle)

Profile #	Relative Altitude of Target	Bank Angle of Turn
3-1	-300 feet	15°
3-2	-300 feet	25°
3-3	-300 feet	35°
3-4	-300 feet	45°
3-5*	-300 feet	20°
3-6*	-300 feet	30°
3-7*	-300 feet	40°
3-8*	+300 feet	15°
3-9*	+300 feet	25°
3-10*	+300 feet	35°
3-11*	+300 feet	45°
3-12*	+300 feet	20°
3-13*	+300 feet	30°
3-14*	+300 feet	40°

*These runs may be deleted if insufficient flight time is available.

PROFILES 3-15 through 3-28



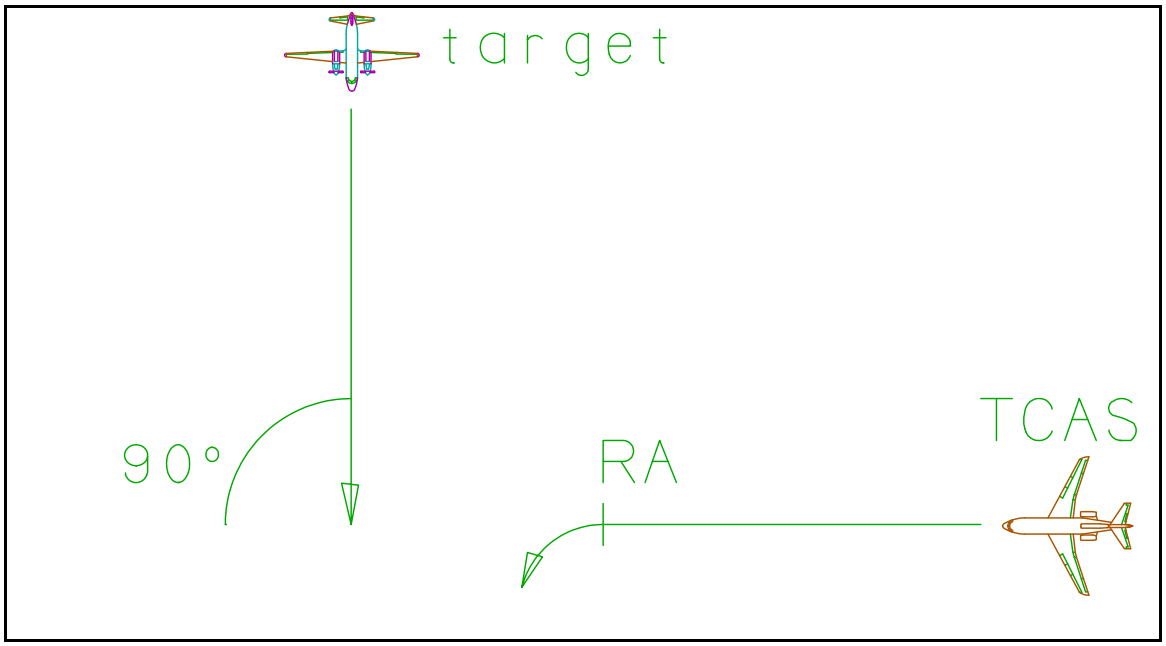
These profiles are 45° track crossings, with the relative altitude of the target described below. When the TCAS-III issues a resolution advisory, no matter what advisory is issued, the pilot will initiate a 10°/second roll rate to the bank angle prescribed for that profile. The direction of turn may be chosen by the pilot. The pilot should continue the turn for at least 10 seconds, and then level-off. The run will end 4 NM after completion of the turn.

NOTE: Set parameters P-26 to 20 (bottom search range 20 NM)
P-48 to 179 (tracks switch antennas at 179° elevation angle)

Profile #	Relative Altitude of Target	Bank Angle of Turn
3-15	-300 feet	15°
3-16	-300 feet	25°
3-17	-300 feet	35°
3-18	-300 feet	45°
3-19*	-300 feet	20°
3-20*	-300 feet	30°
3-21*	-300 feet	40°
3-22*	+300 feet	15°
3-23*	+300 feet	25°
3-24*	+300 feet	35°
3-25*	+300 feet	45°
3-26*	+300 feet	20°
3-27*	+300 feet	30°
3-28*	+300 feet	40°

*These runs may be deleted if insufficient flight time is available.

PROFILES 3-29 through 3-42



These profiles are 90° track crossings, with the relative altitude of the target described below. When the TCAS-III issues a resolution advisory, no matter what advisory is issued, the pilot will initiate a 10°/second roll rate to the bank angle prescribed for that profile. The direction of turn may be chosen by the pilot. The pilot should continue the turn for at least 10 seconds, and then level-off. The run will end 4 NM after completion of the turn.

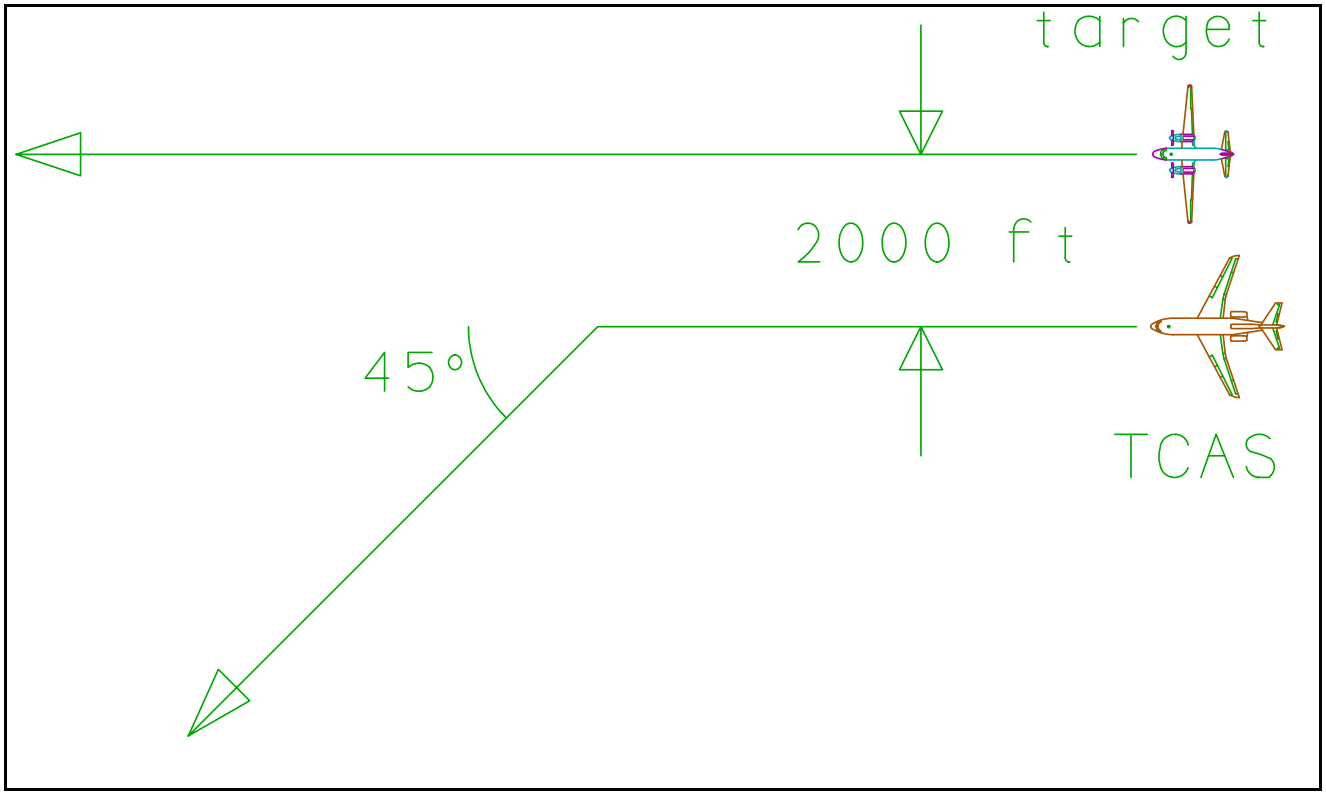
NOTE: Set parameters P-26 to 20 (bottom search range 20 NM)
P-48 to 179 (tracks switch antennas at 179° elevation angle)

Profile #	Relative Altitude of Target	Bank Angle of Turn
3-29	-300 feet	15°
3-30	-300 feet	25°
3-31	-300 feet	35°
3-32	-300 feet	45°
3-33*	-300 feet	20°
3-34*	-300 feet	30°
3-35*	-300 feet	40°
3-36*	+300 feet	15°
3-37*	+300 feet	25°
3-38*	+300 feet	35°
3-39*	+300 feet	45°
3-40*	+300 feet	20°
3-41*	+300 feet	30°
3-42*	+300 feet	40°

*These runs may be deleted if insufficient flight time is available.

TOP/BOTTOM DIRECTIONAL ANTENNA PERFORMANCE IN THE TURN

PROFILES 3-43 through 3-49



These profiles are co-altitude parallel tracks with a turn by the TCAS aircraft. The planes will travel on parallel courses separated by about 2000 feet. After flying side by side for approximately four NM, the TCAS will turn away from the target aircraft with a 10°/second roll rate to the bank angle prescribed for that profile. The run will end 4 NM after completion of the turn.

NOTE: Set parameters P-26 to 20 (bottom search range 20 NM)
P-48 to 179 (tracks switch antennas at 179° elevation angle)

Profile #	Relative Altitude of Target	Bank Angle of Turn
3-43	0 feet	15°
3-44	0 feet	25°
3-45	0 feet	35°
3-46	0 feet	45°
3-47*	0 feet	20°
3-48*	0 feet	30°
3-49*	0 feet	40°

*These runs may be deleted if insufficient flight time is available.

Appendix B - Plot Descriptions

B.1 Basic Plot Layout

While there are several types of plots included in Appendices C and D, they use a similar format, as indicated in Figure B-1.

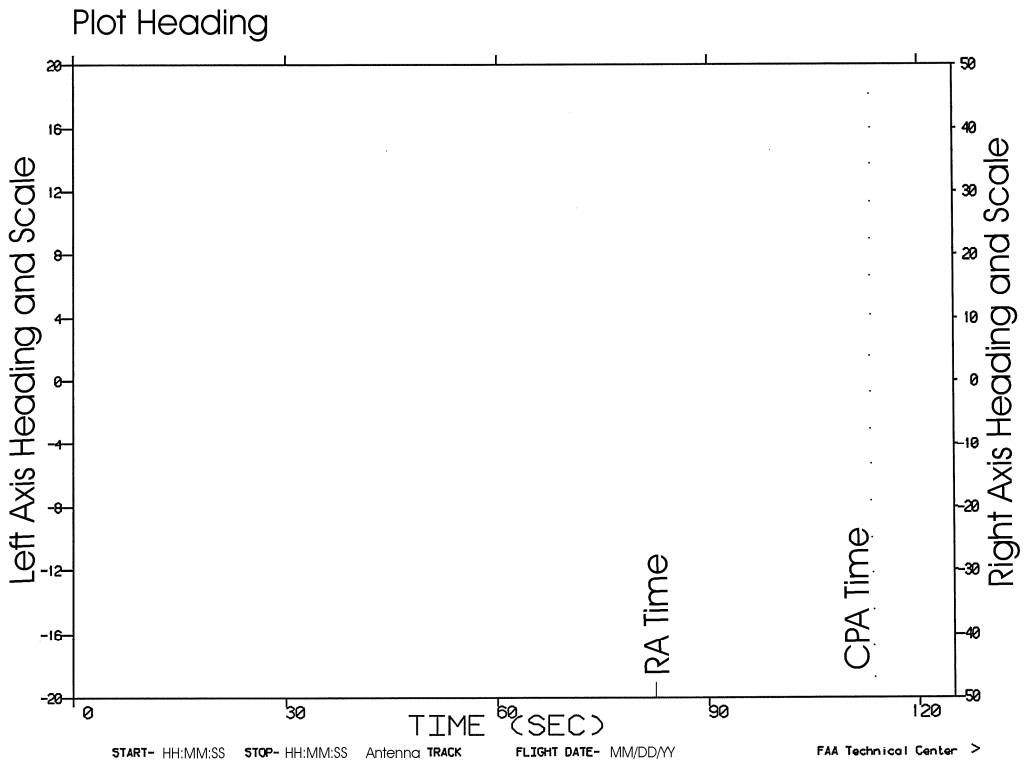


Figure B-1 - Example Plot layout

Plot Heading contains the type of encounter and the planned roll angle of the turn. The turn was generally started when the RA was issued. A complete description of the encounters is included in appendix A.

Left Axis Heading and Scale indicate the data type and associated scale for that data. Correspondingly, the **Right Axis Heading and Scale** indicate another data type and the associated scale for that data. It's important to note that the two data scales are usually not the same, even if the units used for the two scales are the same.

Time (Sec) is the time scale for the encounter, in seconds. The starting time of the scale, "0", corresponds to the actual **Start** time printed below the scale. The right end of the scale corresponds to the **Stop** time.

The encounter **Flight Date** and **Antenna** source used for the plots are indicated below the scale, as well.

RA Time (on some plots) indicates the time and type of any TCAS III resolution advisories.

CPA Time (on some plots) indicates the time of closest point of approach.

B.2 Bearing Error and Bearing Rate Error plots

Bearing Error and Bearing Rate Error plots (see Figure B-2) include either Bearing Error or Bearing Rate Error on the left axis of the plot, along with the scale (+/- 20 degrees for bearing error, +/- 5 degrees/sec for bearing rate error), and the Roll Angle of the aircraft on the right side of the plot, along with the Roll Angle scale (+/- 50 degrees). Note that the two scales are different. Bearing Error and Bearing Rate Error data points are indicated by the + symbol on the plots. The roll angle is indicated by a continuous line between data points

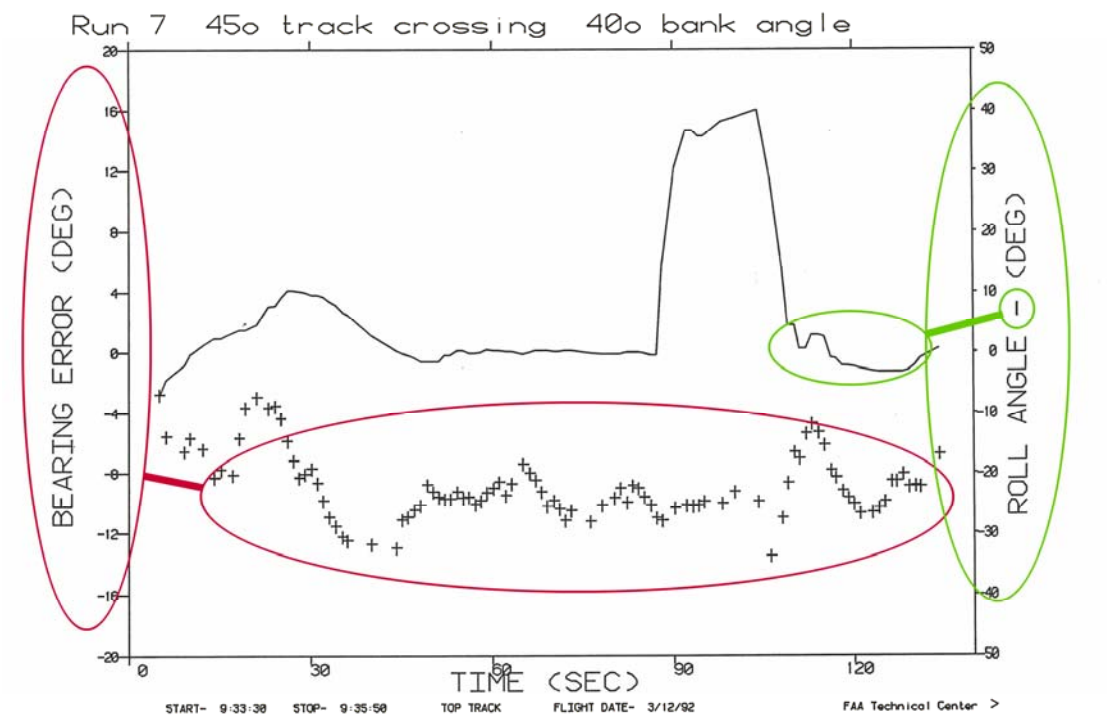


Figure B-2 - Example Bearing Error Plot

B.3 Miss Distance plots

Miss Distance plots (see Figure B-3) include Roll and Elevation Angle on the left axis of the plots, along with the scale (+/- 50 degrees), and Miss Distance on the right axis of the scale (+/- 4 nautical miles in this example). Roll is plotted with a continuous line. Elevation Angle is plotted with small dots. Miss Distance calculated from the NIKE radar data is plotted with triangles, and Miss Distance calculated from the TCAS data is plotted with stars. A vertical line of small dots indicated the closest point of approach (CPA).

Note: The miss distance scaling is nautical miles (NM) on some plots, and thousands of feet (kFT) on others. Some data points may be off scale.

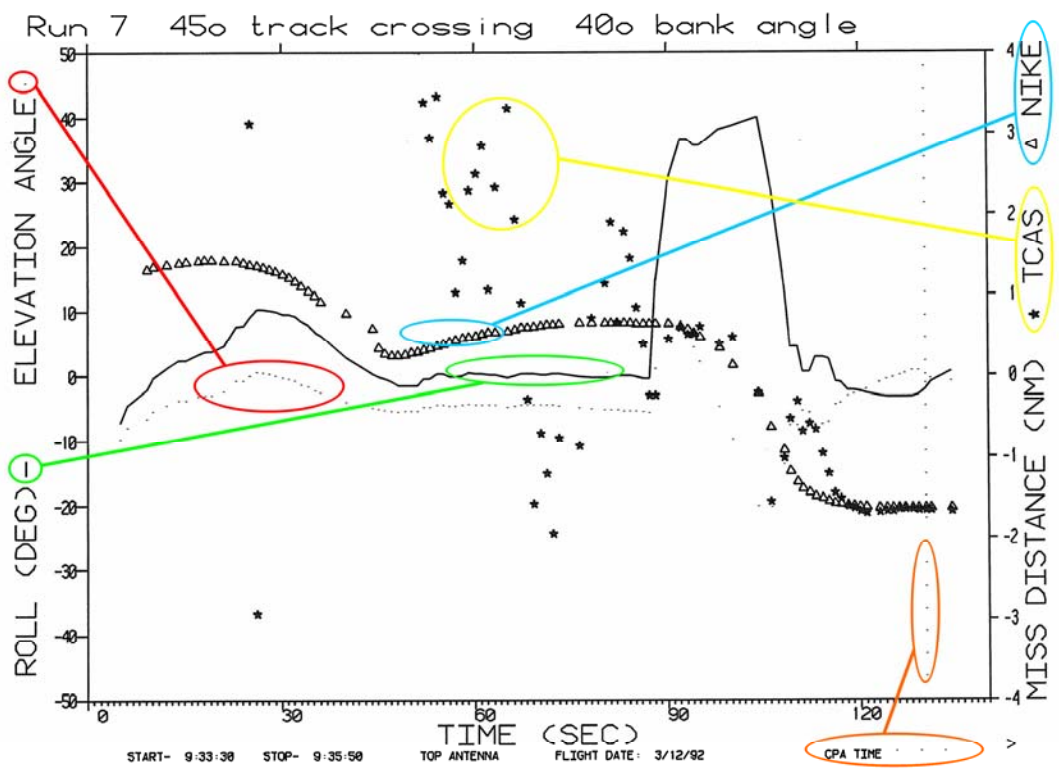


Figure B-3 - Example Horizontal Miss Distance Plot

B.4 Resolution Advisories

Resolution Advisories (RAs): The TCAS III resolution advisories are included on some plots (see Figure B-4). The advisories and time they were issued are indicated along the bottom time scale. This data was not included on all plots, as it was added to the plotting software after many of the plots were printed. As such, the absence of RA information on a plot does not necessarily indicate that no RA was issued by the TCAS. The RA sense was ignored by the flight crew, but the RA was used to trigger the pre-planned turn maneuver.

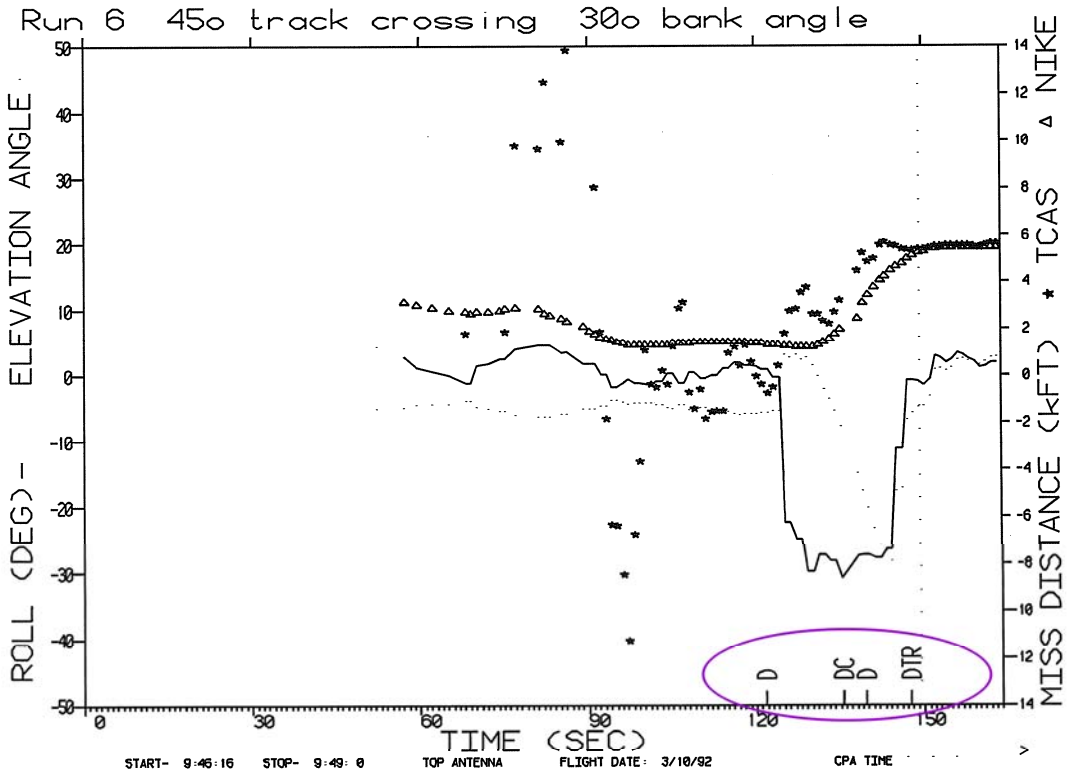


Figure B-4 - Example TCAS Resolution Advisory Data

TCAS III advisories are indicated as:

D	= Descend	TR	= Turn Right
DD	= Don't Descend	DTR	= Don't Turn Right
C	= Climb	TL	= Turn Left
DC	= Don't Climb	DTL	= Don't Turn Left

Compound advisories are possible, such as:
D TL = Descend and Turn Left

Plot C-12 is a **Slant Range plot**, showing the TCAS-measured range (in feet) to the other aircraft. The CPA time is determined from the slant range.

Plot C-13 is a **Relative Bearing plot**, comparing the relative bearing to the other aircraft using NIKE and TCAS data.

Appendix C - Data from 3/12/92, including Bearing Error, Bearing Rate Error, and Horizontal Miss Distance Plots

Flight Date: March 12, 1992

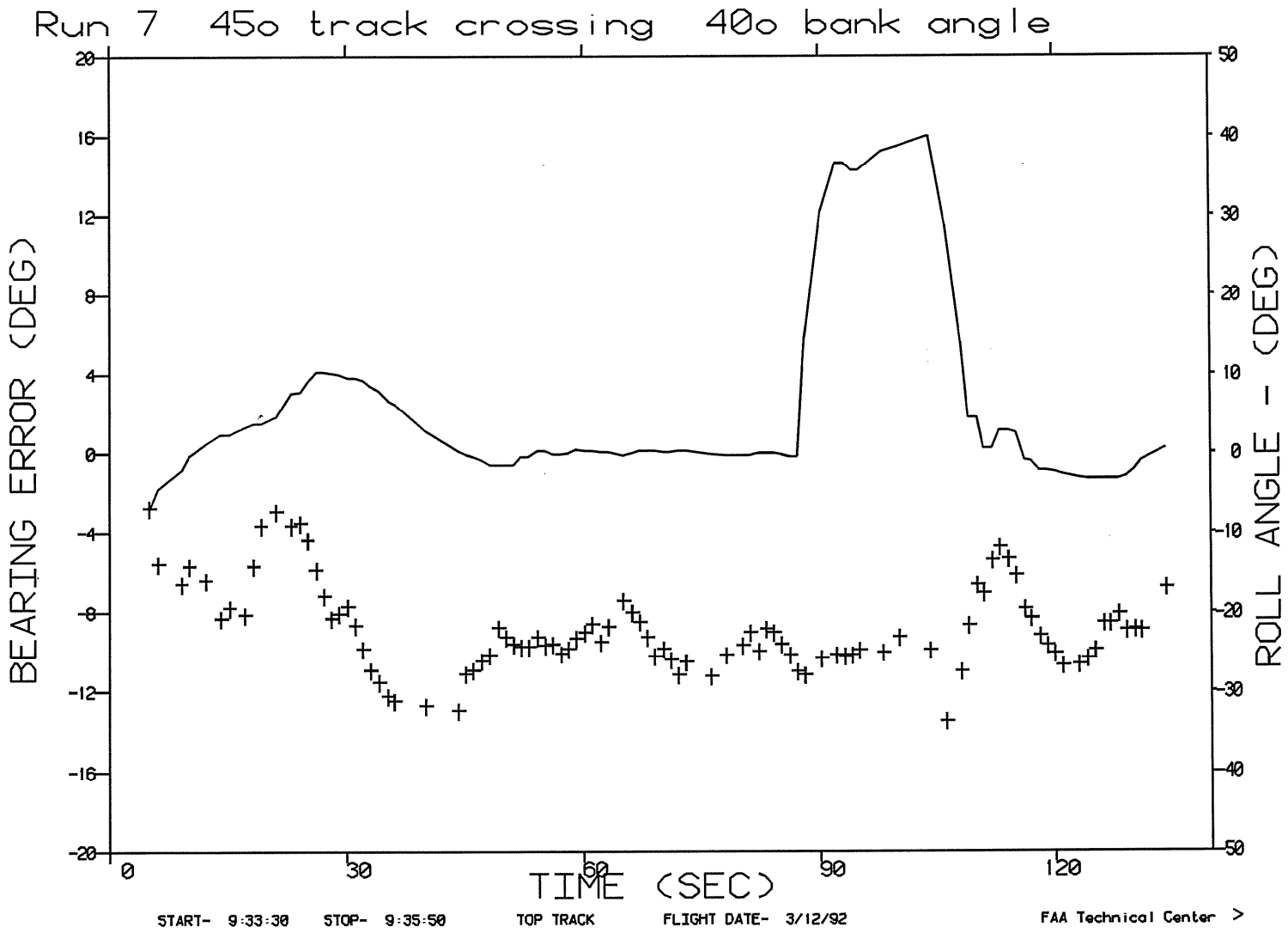
Plots of Run 7 include:

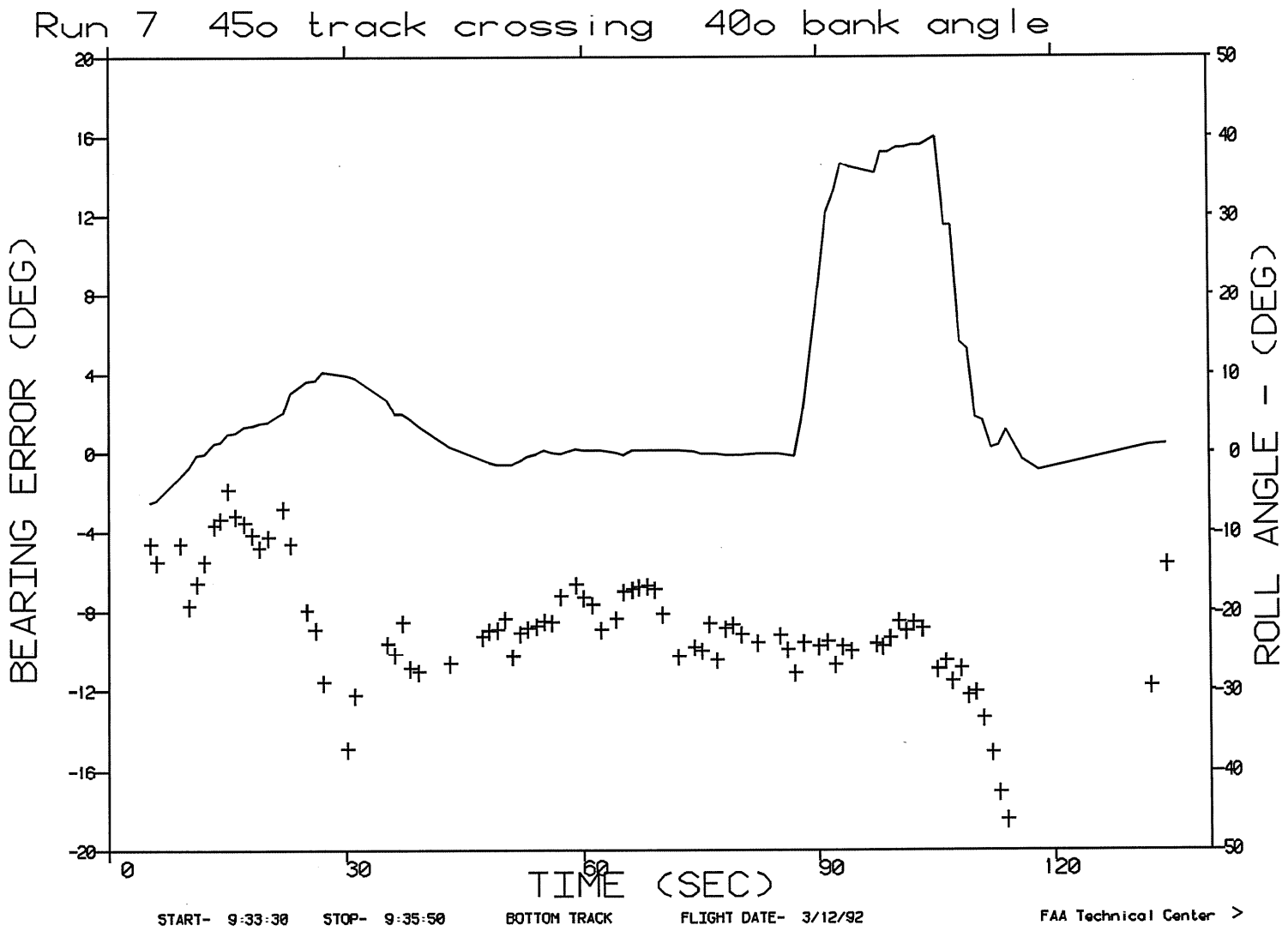
Bearing Error	Top,	Bottom,	Diversity antenna
Bearing Rate Error	Top,	Bottom,	Diversity antenna
Miss Distance	Top,	Bottom,	Diversity antenna
Slant Range			
Relative Bearing (TCAS and NIKE radar)			

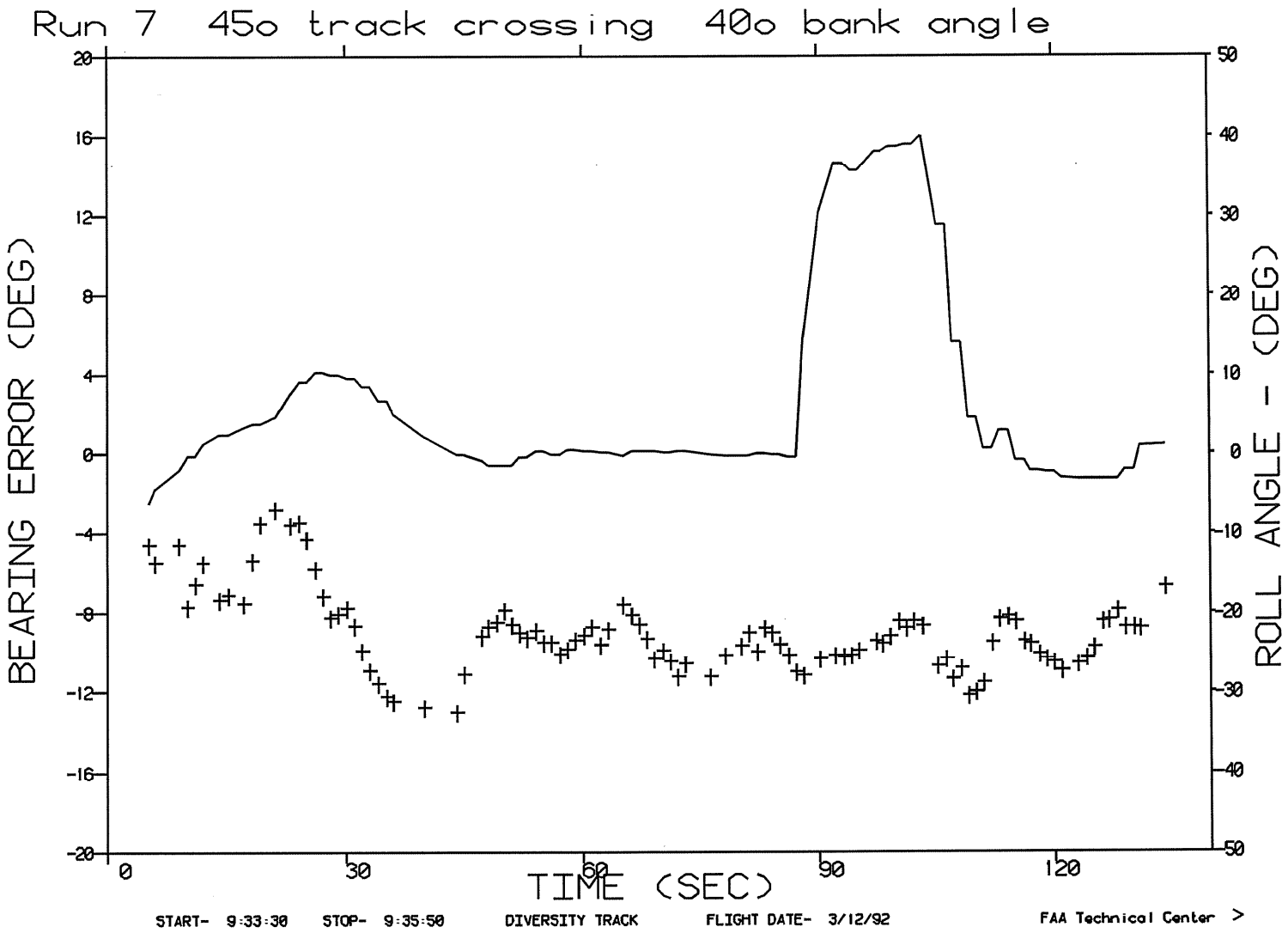
Plots of Runs 1a, 2a, 3a, 4a, 5a, 6b and 7a include:

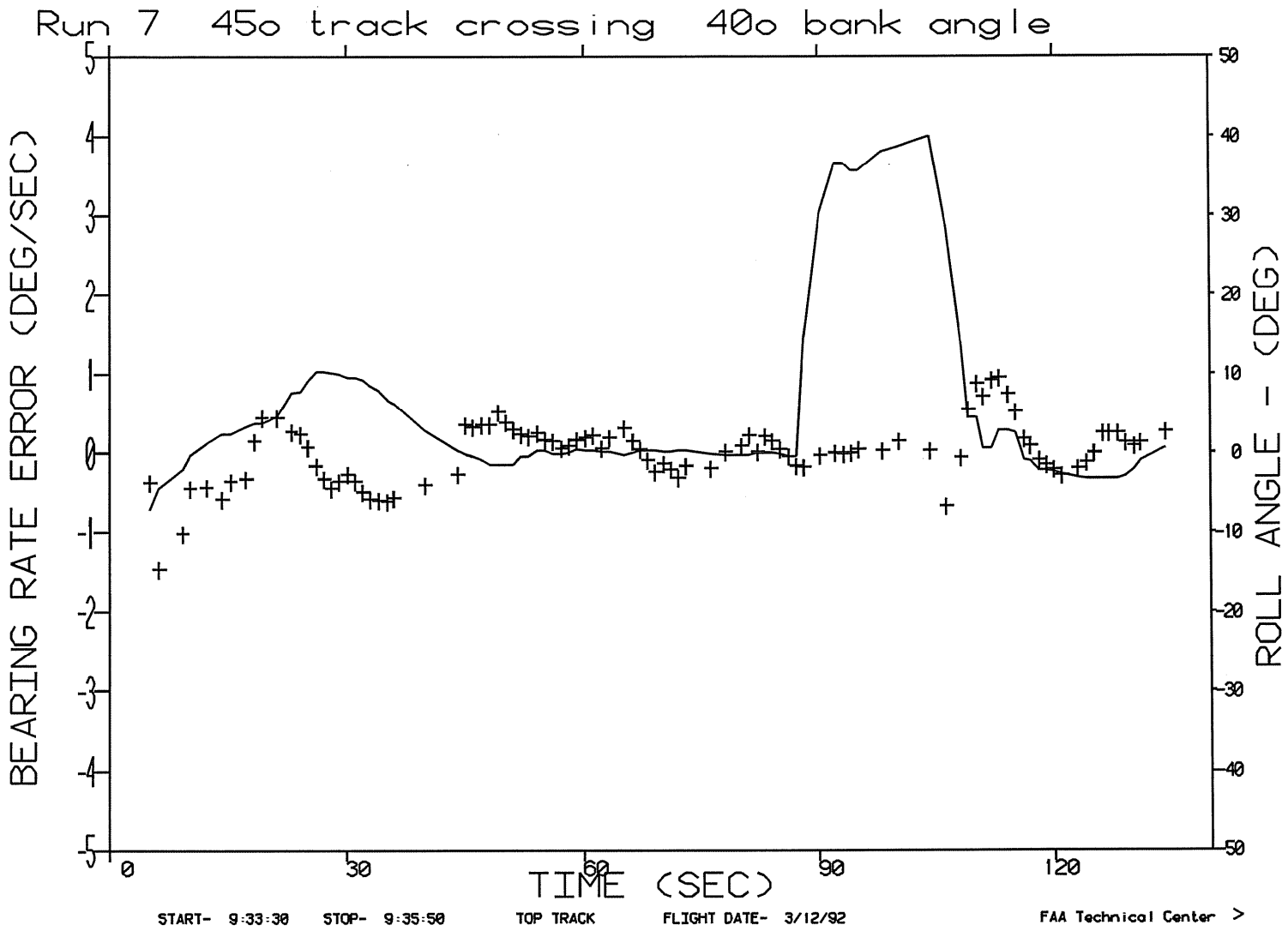
Bearing Error	Top,	Bottom,	Diversity antenna
Bearing Rate Error	Top,	Bottom,	Diversity antenna
Miss Distance	Top,	Bottom,	Diversity antenna

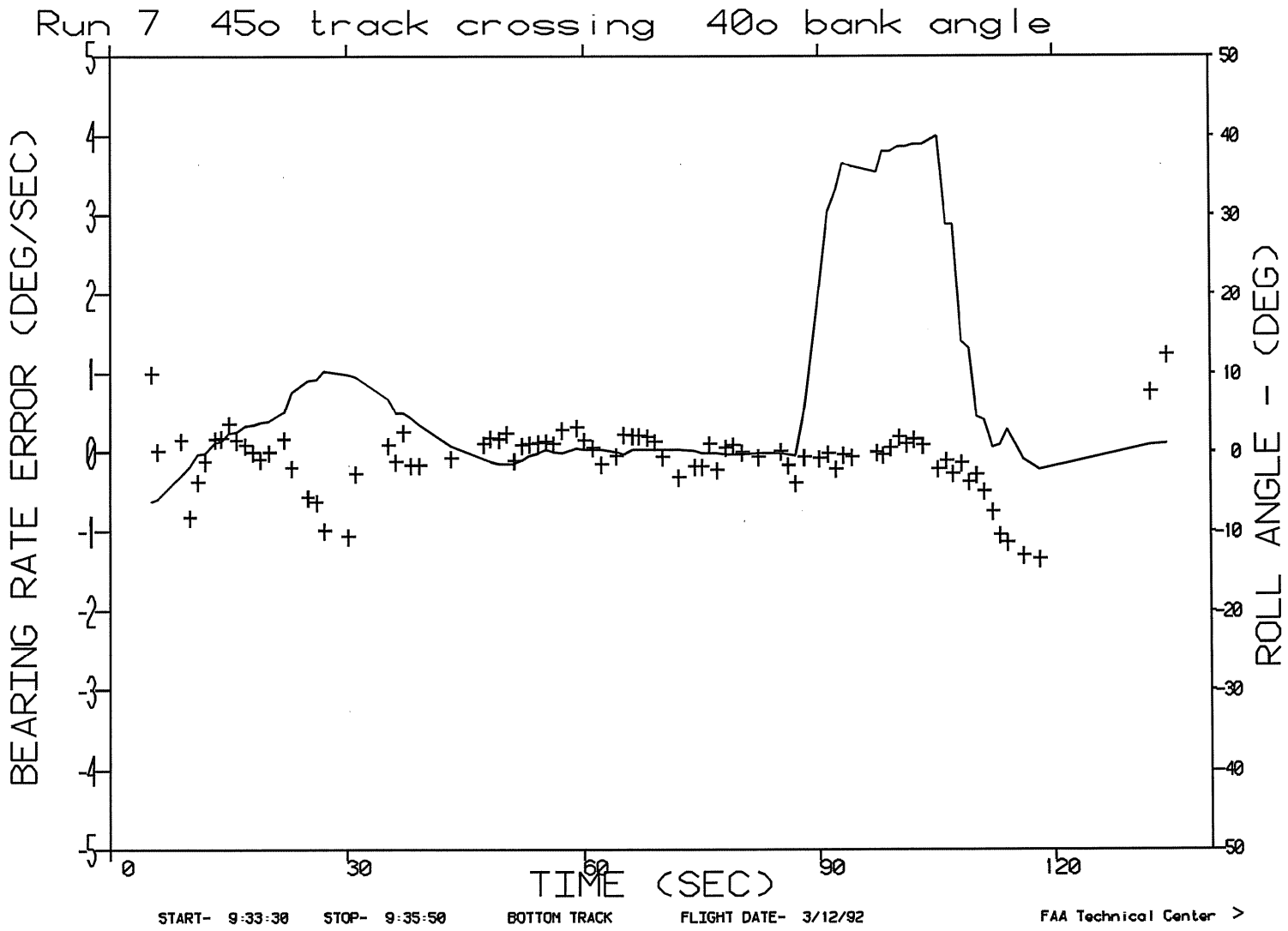
See Appendix B for plot descriptions.

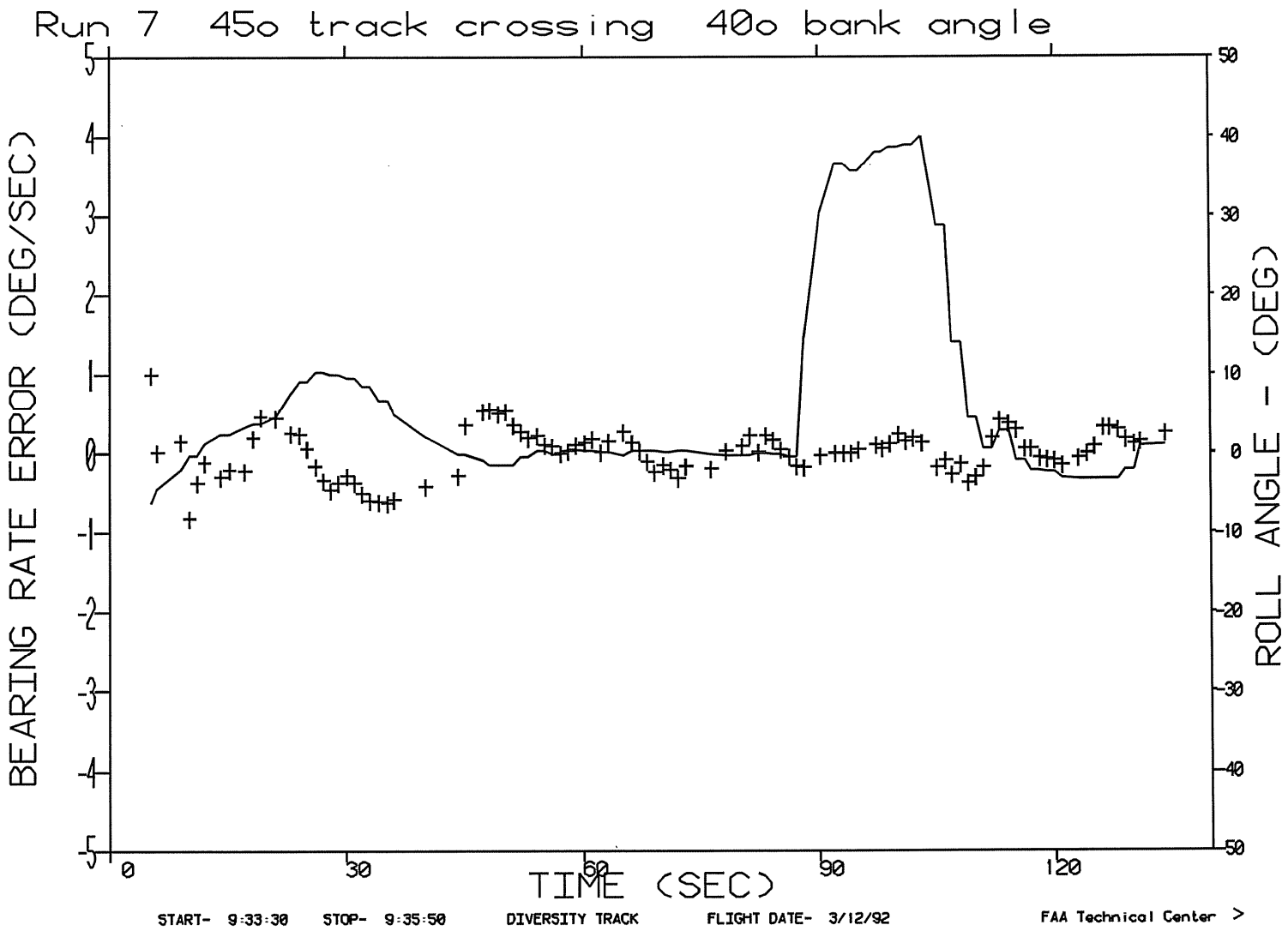

Run 7 45o track crossing 40o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:33:30 STOP- 9:35:50 TOP TRACK FLIGHT DATE- 3/12/92
FAA Technical Center >

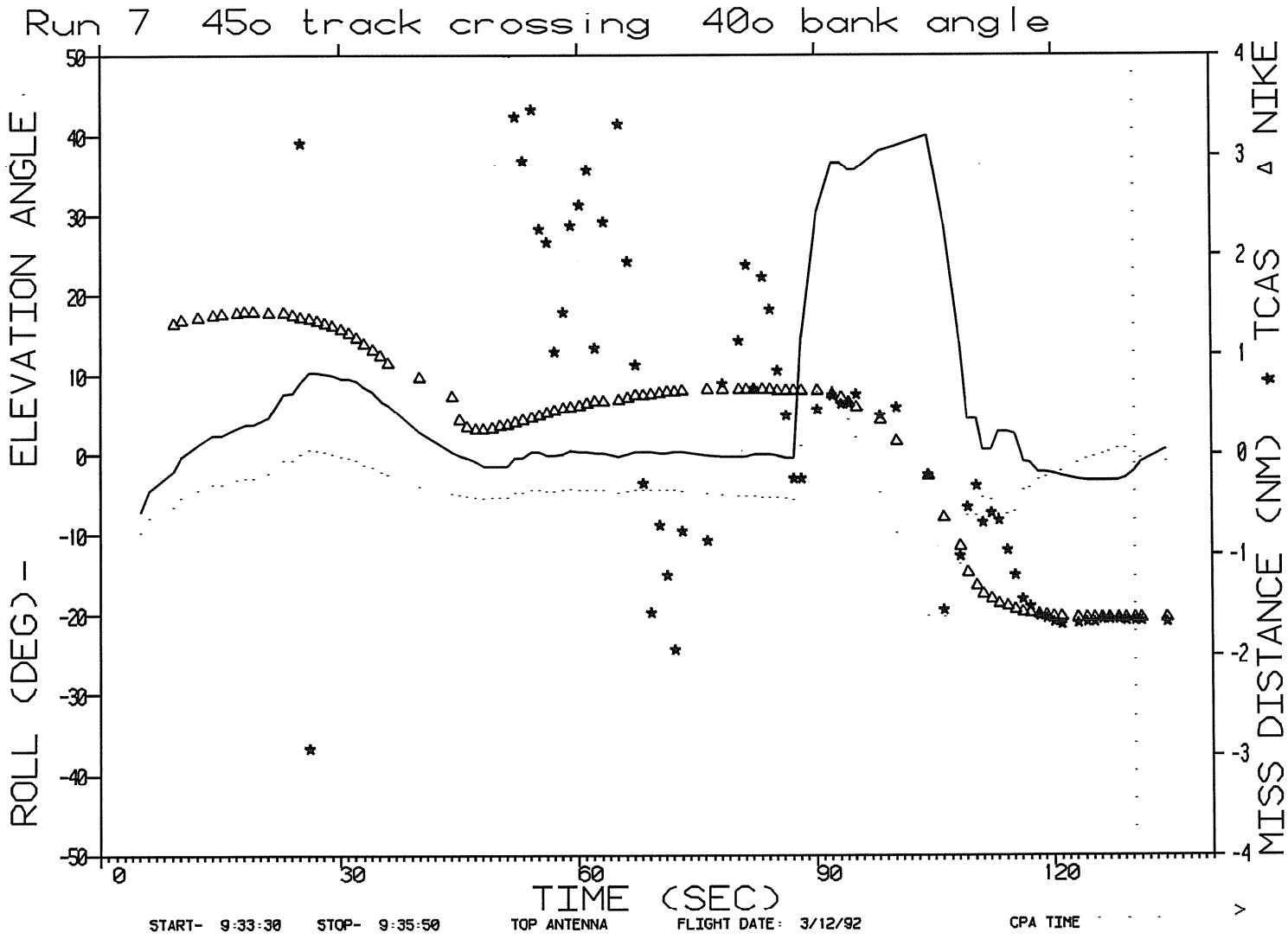

Run 7 45o track crossing 40o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:33:30 STOP- 9:35:50 BOTTOM TRACK FLIGHT DATE- 3/12/92
FAA Technical Center >

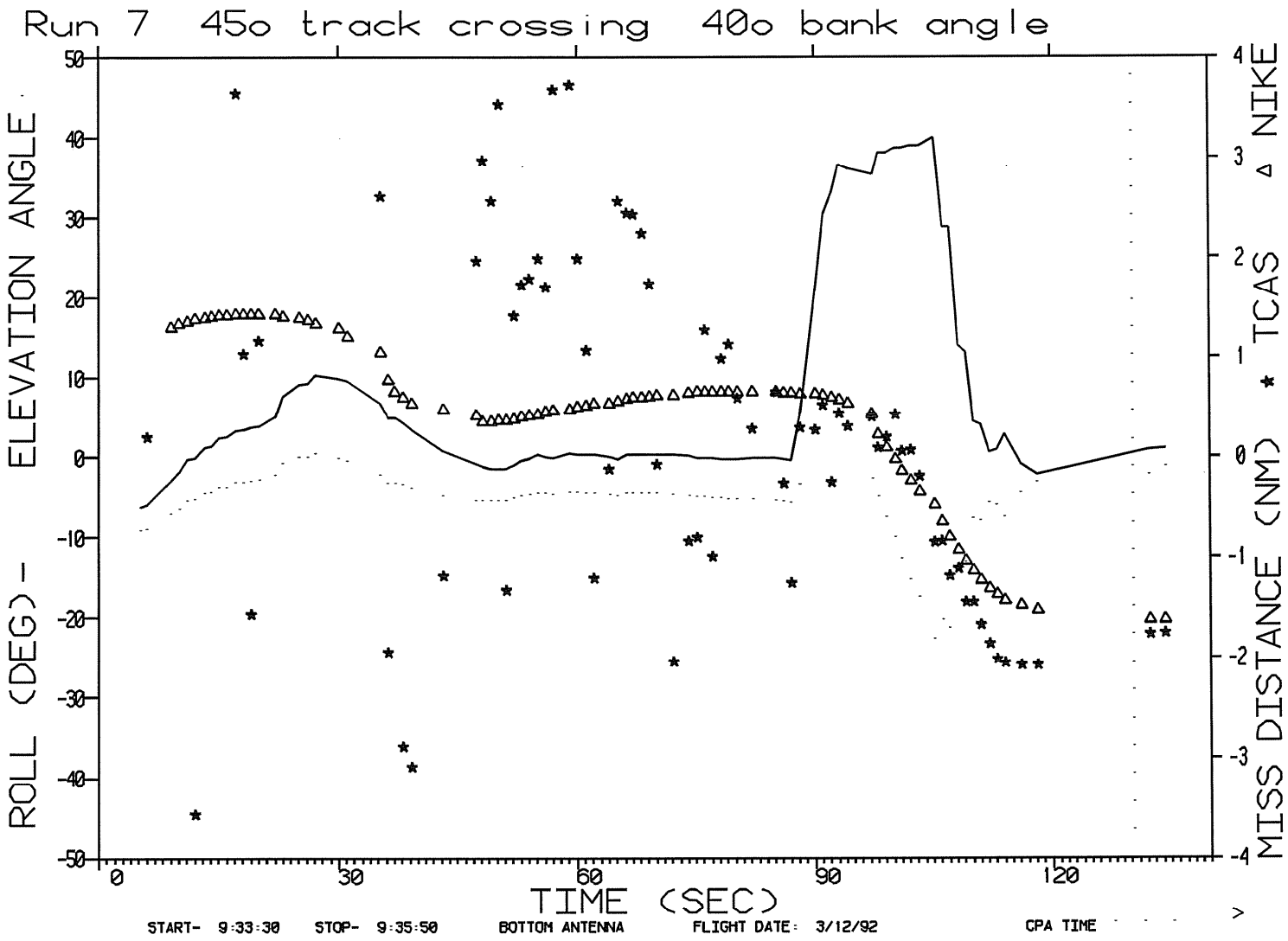

Run 7 45o track crossing 40o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:33:30 STOP- 9:35:50 DIVERSITY TRACK FLIGHT DATE- 3/12/92 FAA Technical Center >

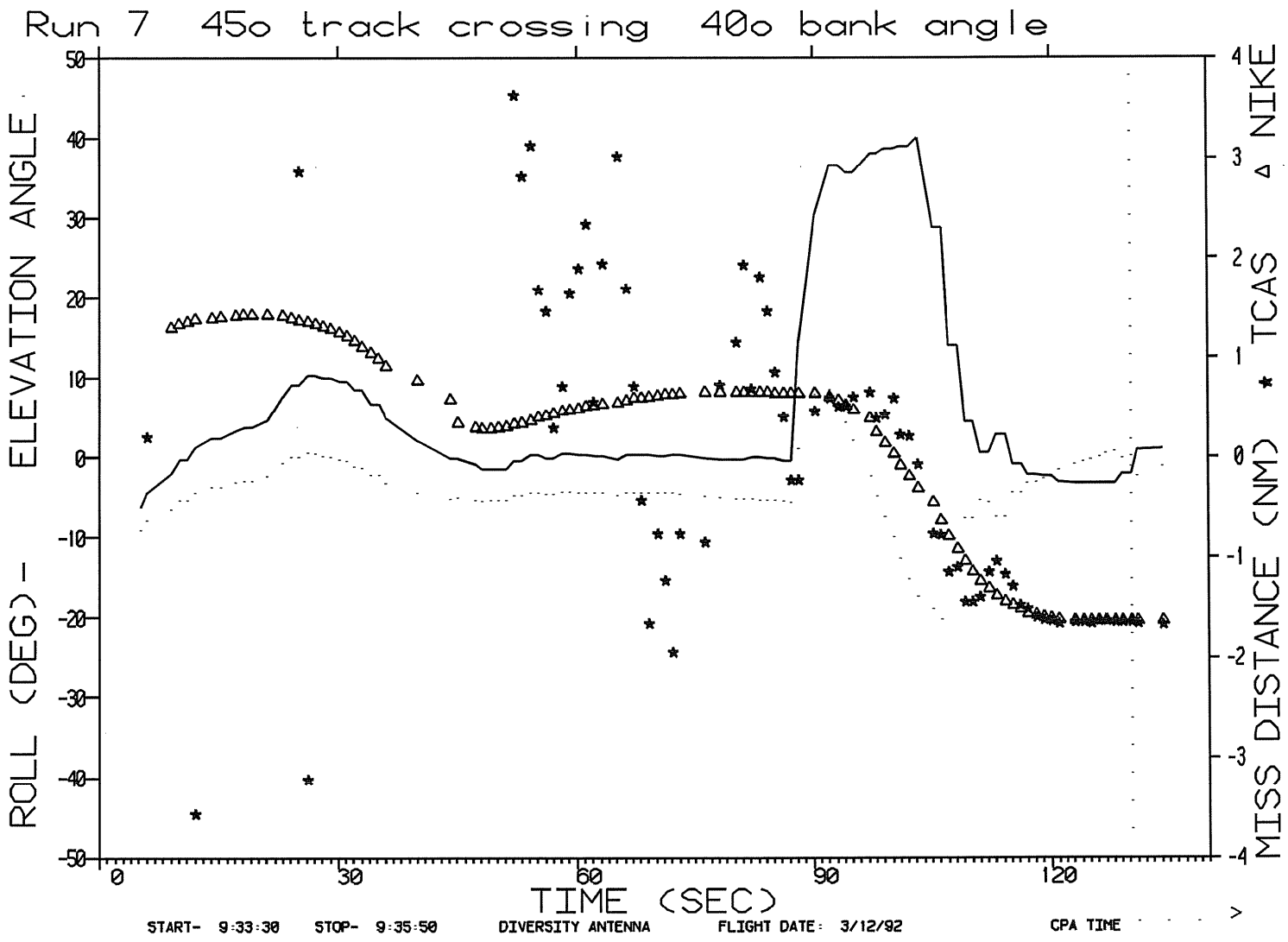

Run 7 45o track crossing 40o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:33:30 STOP- 9:35:50 TOP TRACK FLIGHT DATE- 3/12/92
FAA Technical Center >

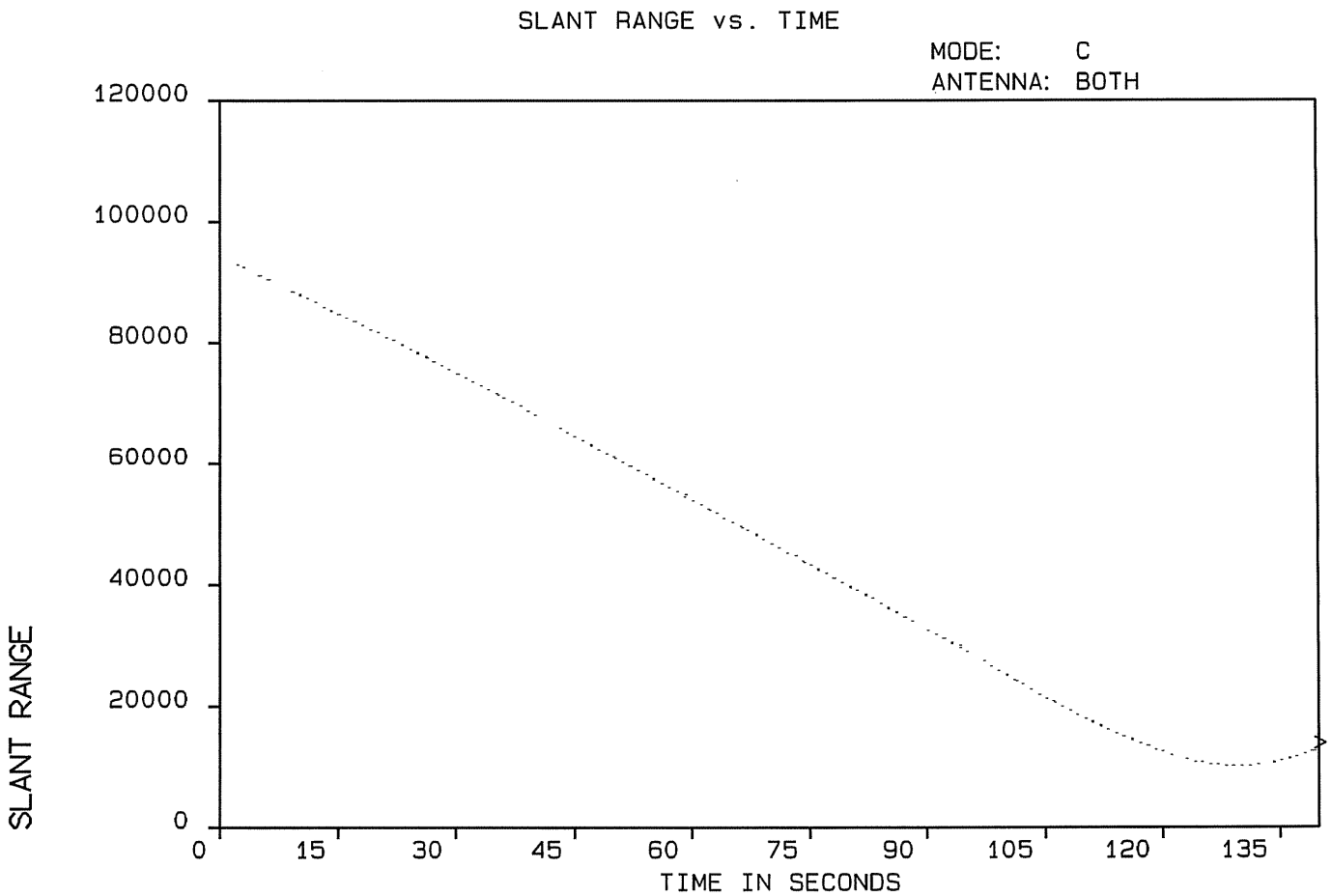

Run 7 45o track crossing 40o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:33:30 STOP- 9:35:50 BOTTOM TRACK FLIGHT DATE- 3/12/92 FAA Technical Center >


Run 7 45o track crossing 40o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:33:30 STOP- 9:35:50 DIVERSITY TRACK FLIGHT DATE- 3/12/92 FAA Technical Center >

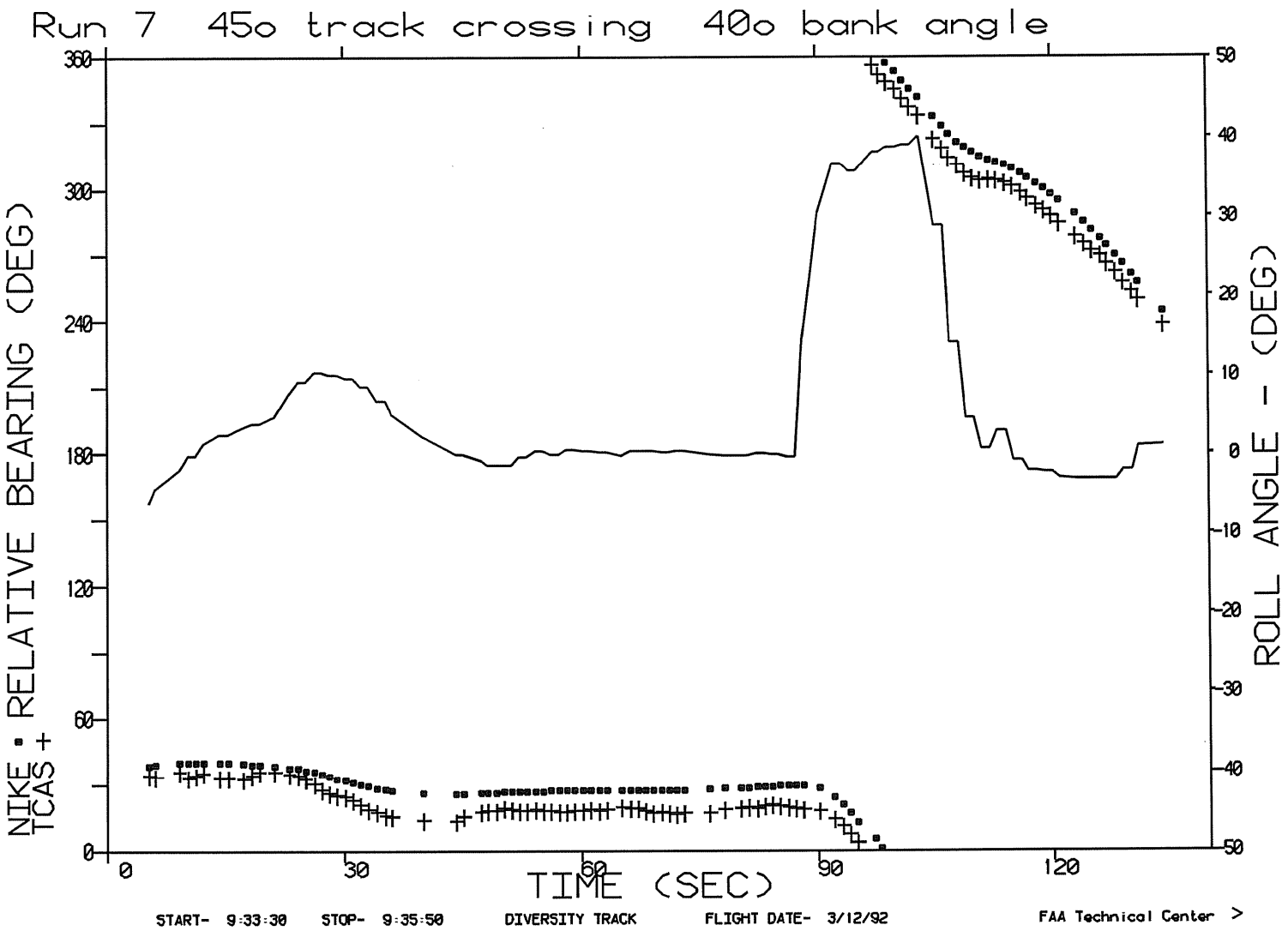

Run 7 45o track crossing 40o bank angle
ROLL (DEG)- ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
START- 9:33:30 STOP- 9:35:50 TOP ANTENNA FLIGHT DATE: 3/12/92 CPA TIME

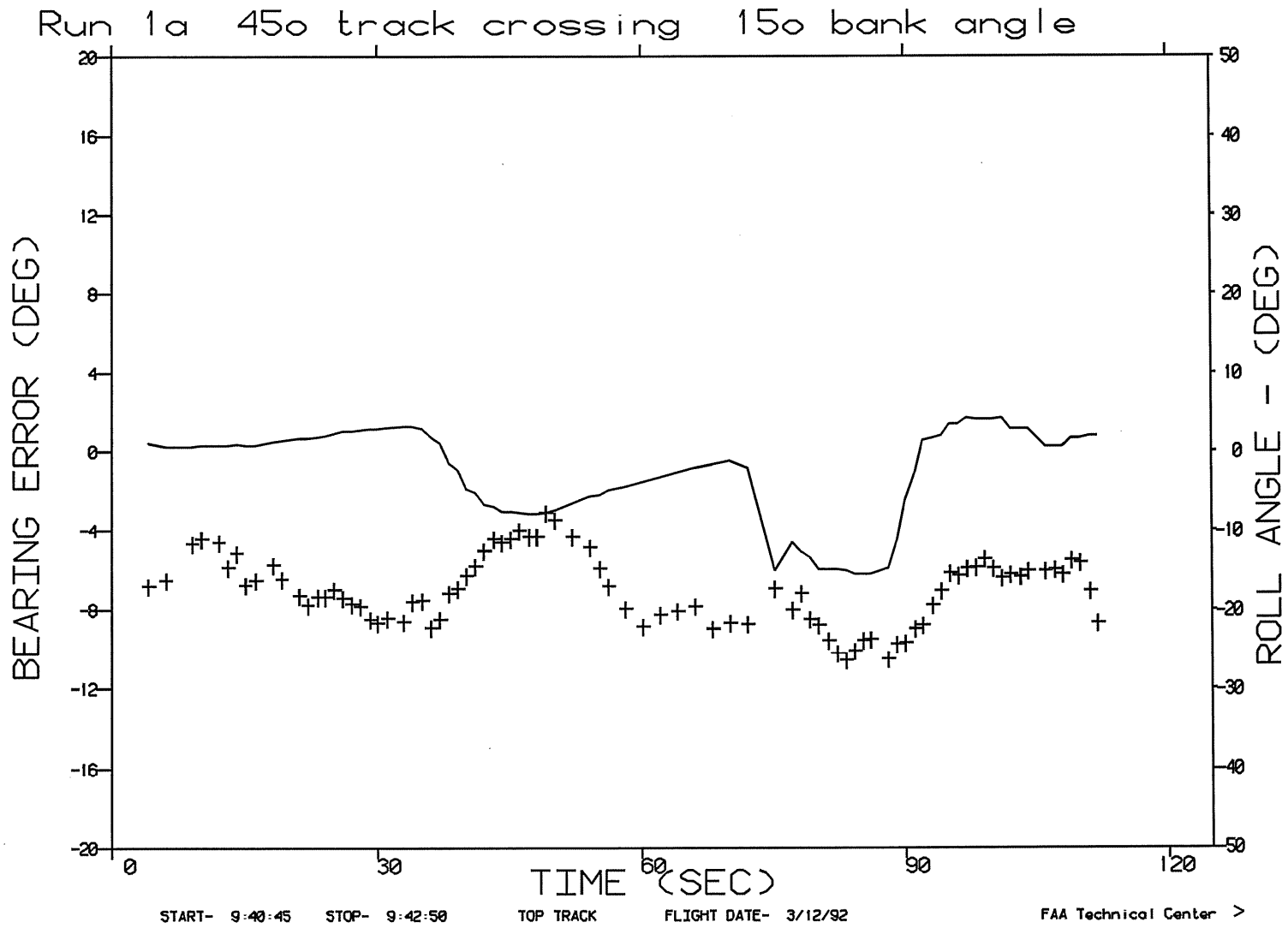

Run 7 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
START- 9:33:30 STOP- 9:35:50 BOTTOM ANTENNA FLIGHT DATE: 3/12/92 CPA TIME

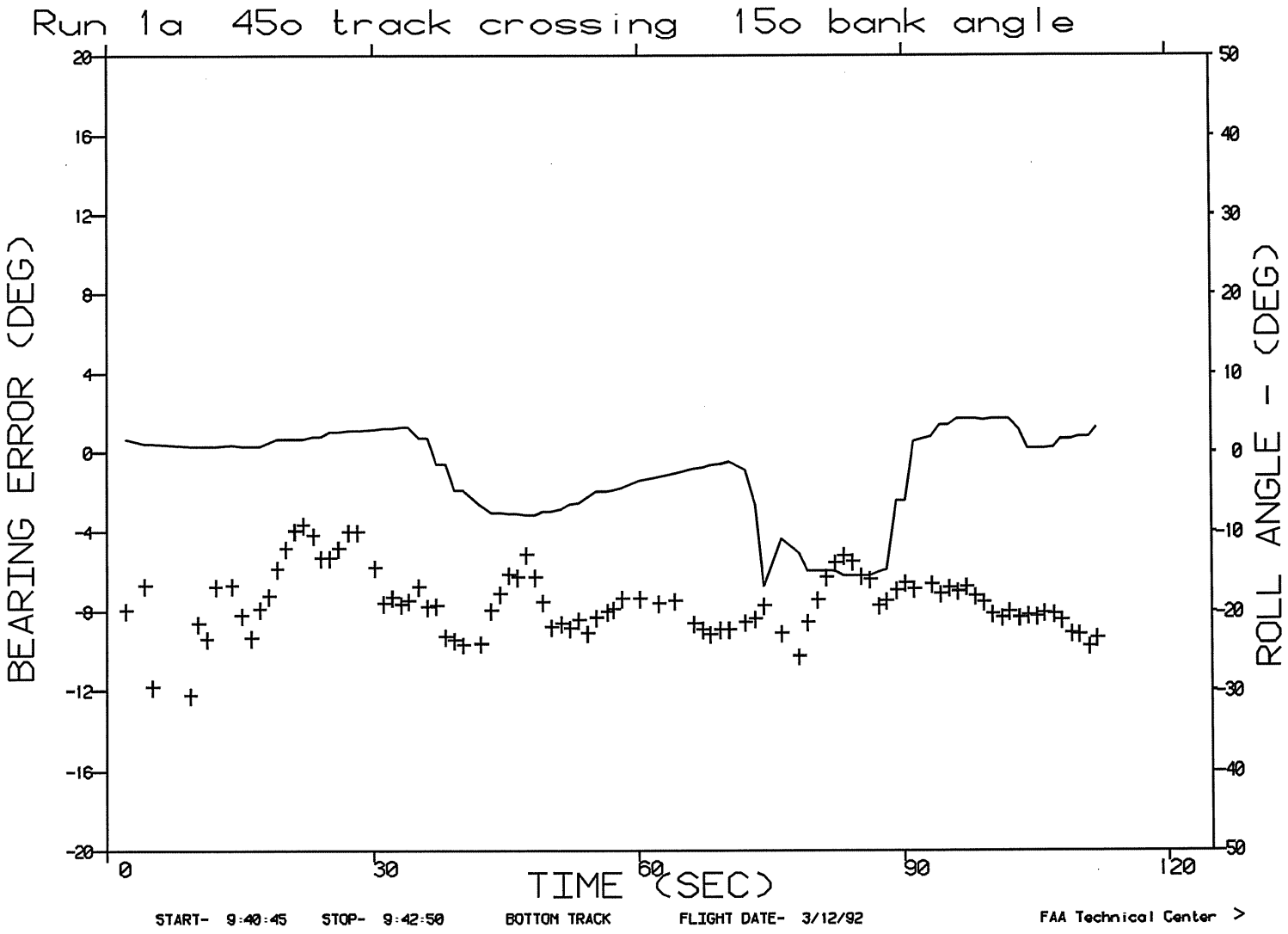

Run 7 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
4
3
2
1
0
-1
-2
-3
-4
0
30
60
90
120
START- 9:33:30 STOP- 9:35:50 DIVERSITY ANTENNA FLIGHT DATE: 3/12/92 CPA TIME

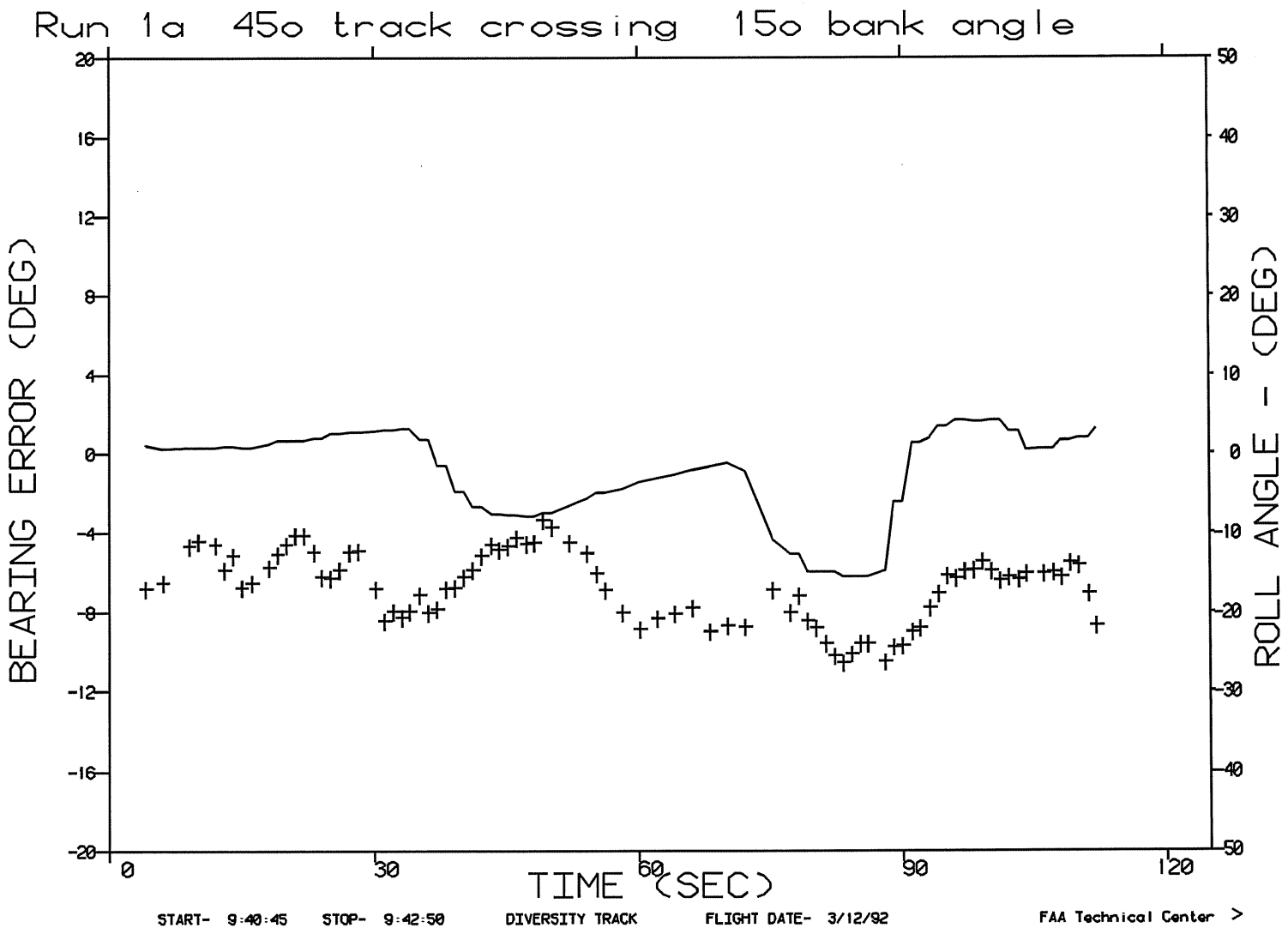


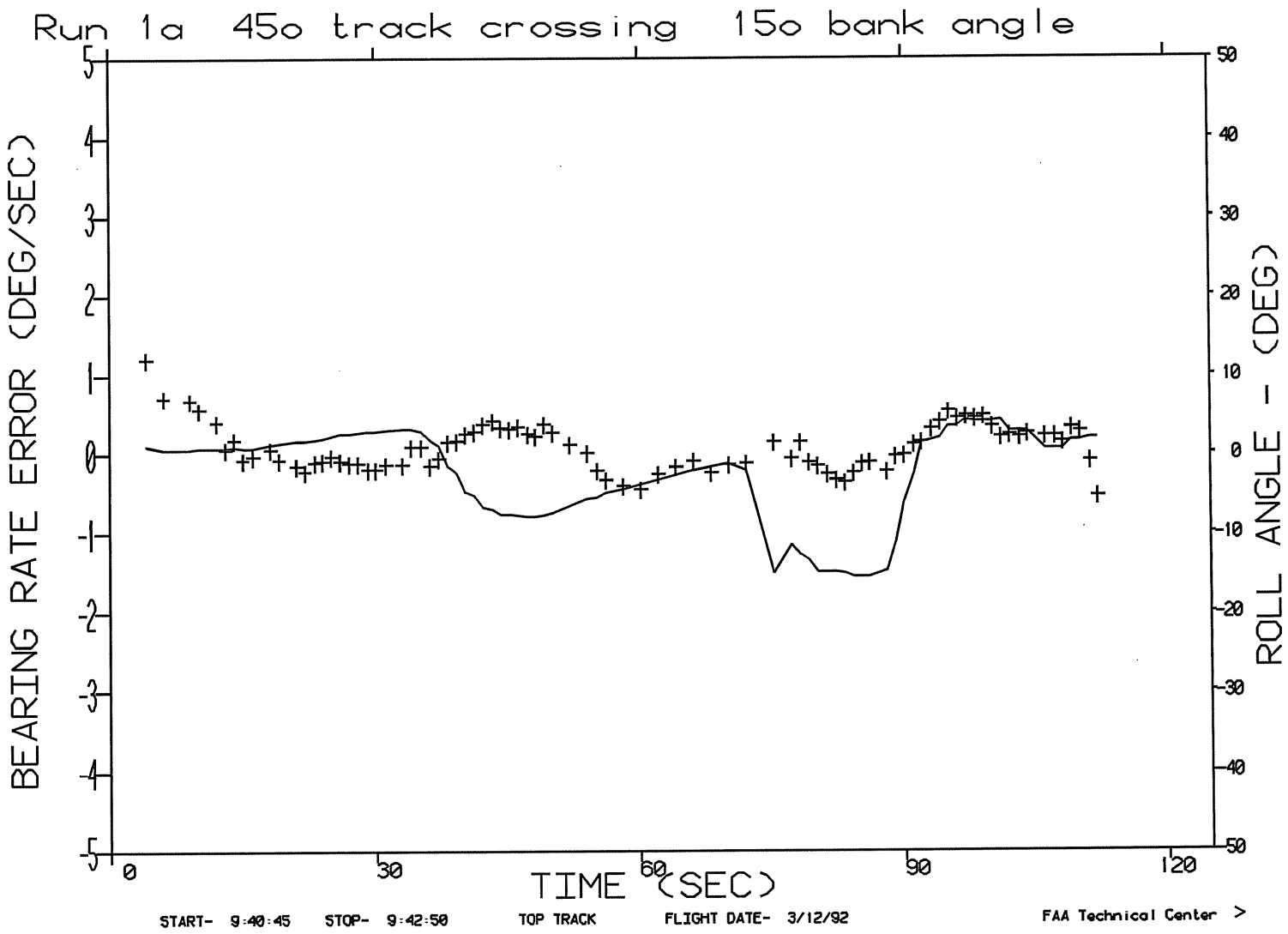
INTERCEPT 43
START TIME: 9: 33: 30 FLIGHT DATE: 3/12/92
STOP TIME: 9: 35: 50 PROCESSED: 4/15/93
ACT-170 FAA Technical Center, ACY, NJ 08405

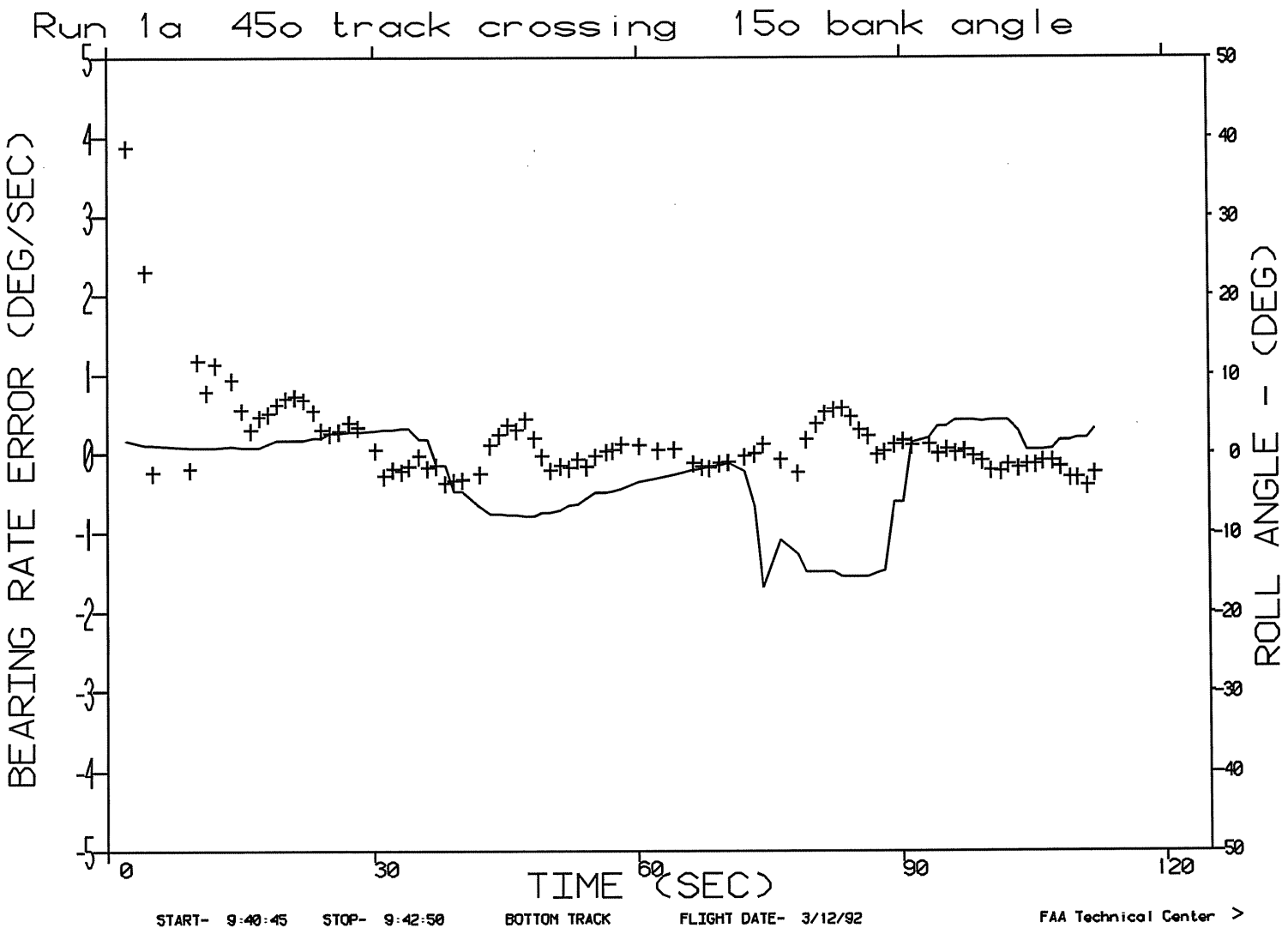

Run 7 45o track crossing 40o bank angle
NIKE ▪ RELATIVE BEARING (DEG)
TCAS +
ROLL ANGLE - (DEG)
TIME (SEC)
0
60
120
180
240
300
360
0
30
60
90
120
50
40
30
20
10
0
-10
-20
-30
-40
-50
START- 9:33:30 STOP- 9:35:50 DIVERSITY TRACK FLIGHT DATE- 3/12/92 FAA Technical Center >

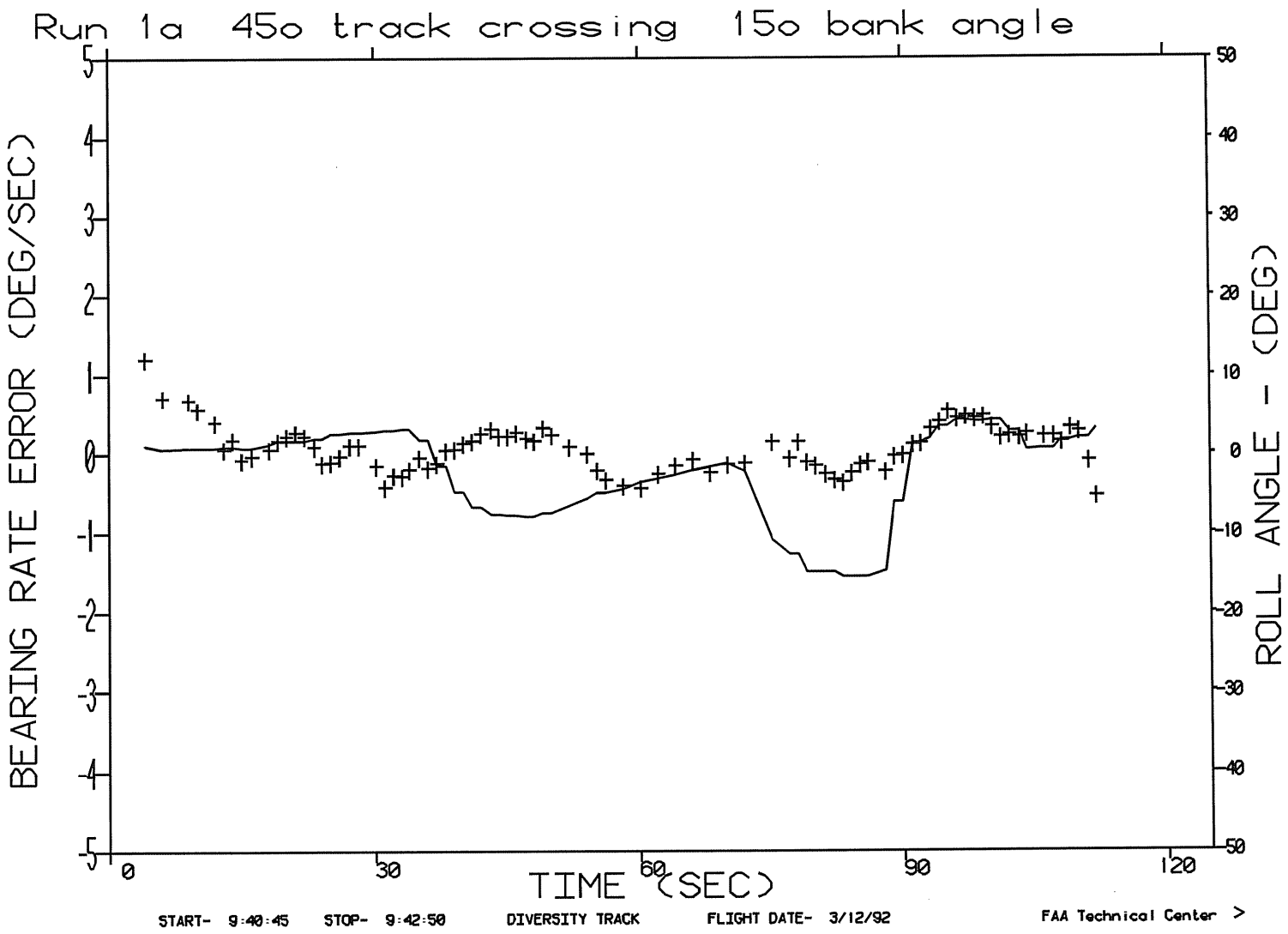

Run 1a 45o track crossing 15o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:40:45
STOP- 9:42:50
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

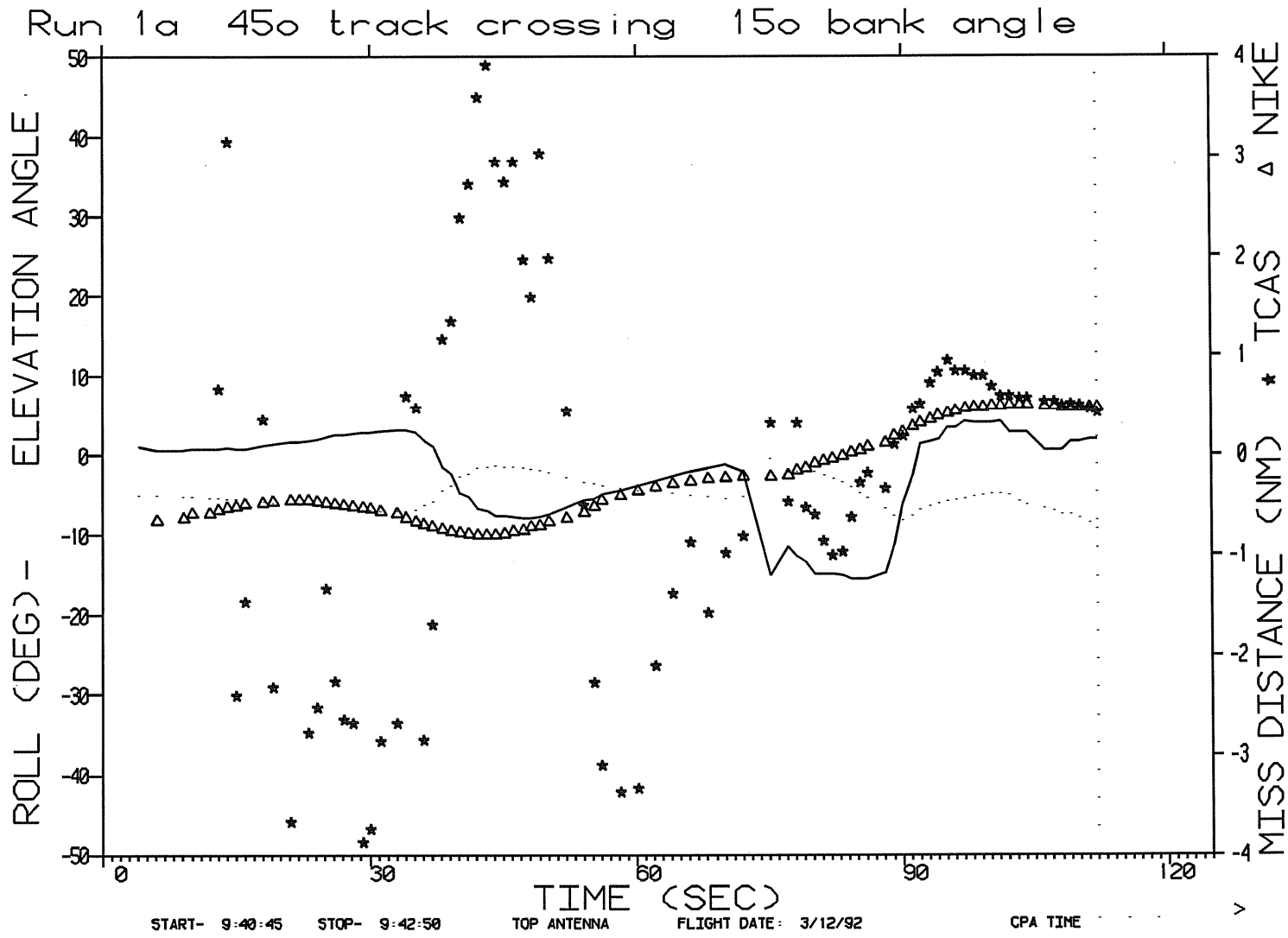

Run 1a 45o track crossing 15o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:40:45 STOP- 9:42:50 BOTTOM TRACK FLIGHT DATE- 3/12/92
FAA Technical Center >

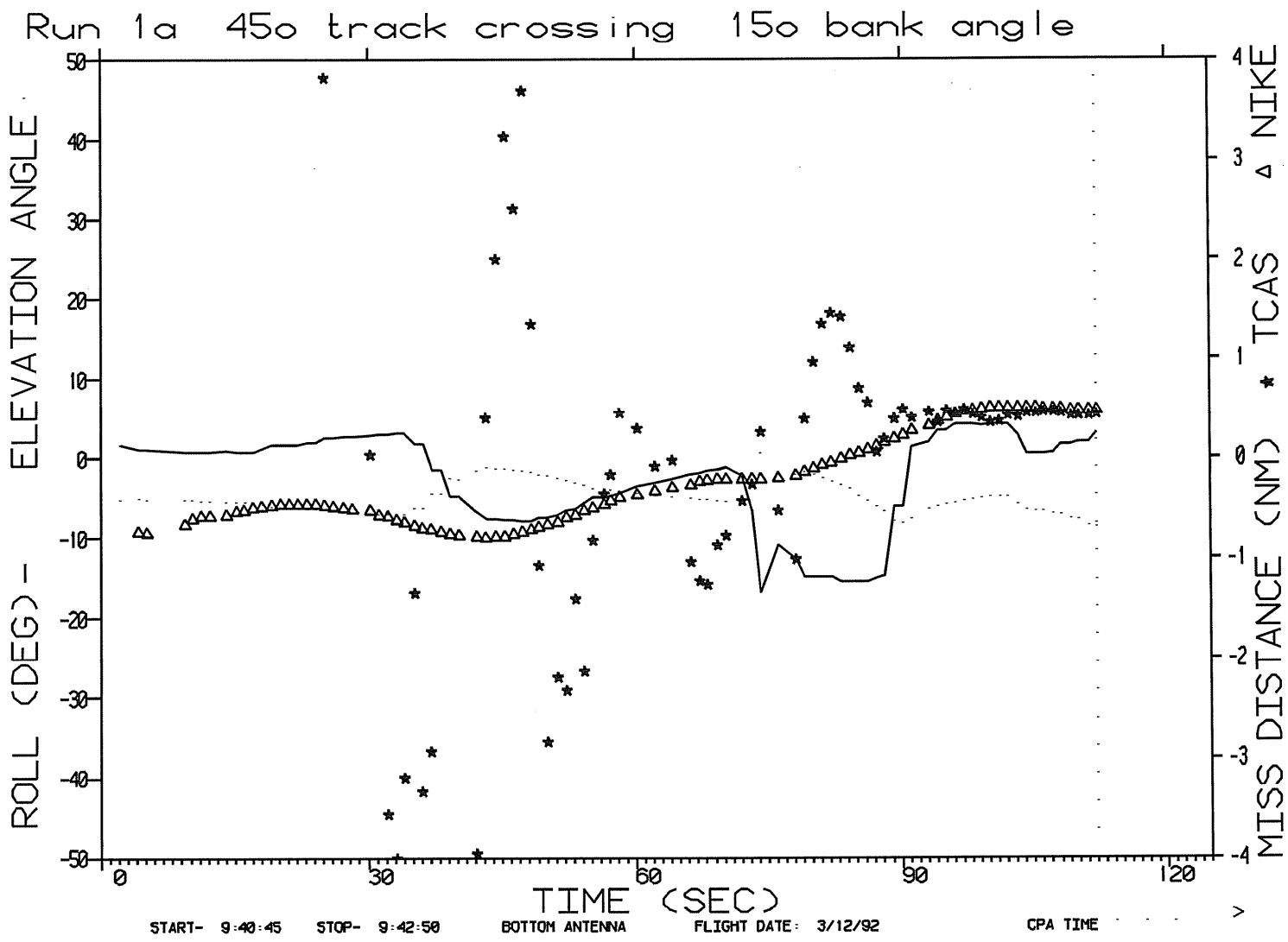

Run 1a 45o track crossing 15o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:40:45
STOP- 9:42:50
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

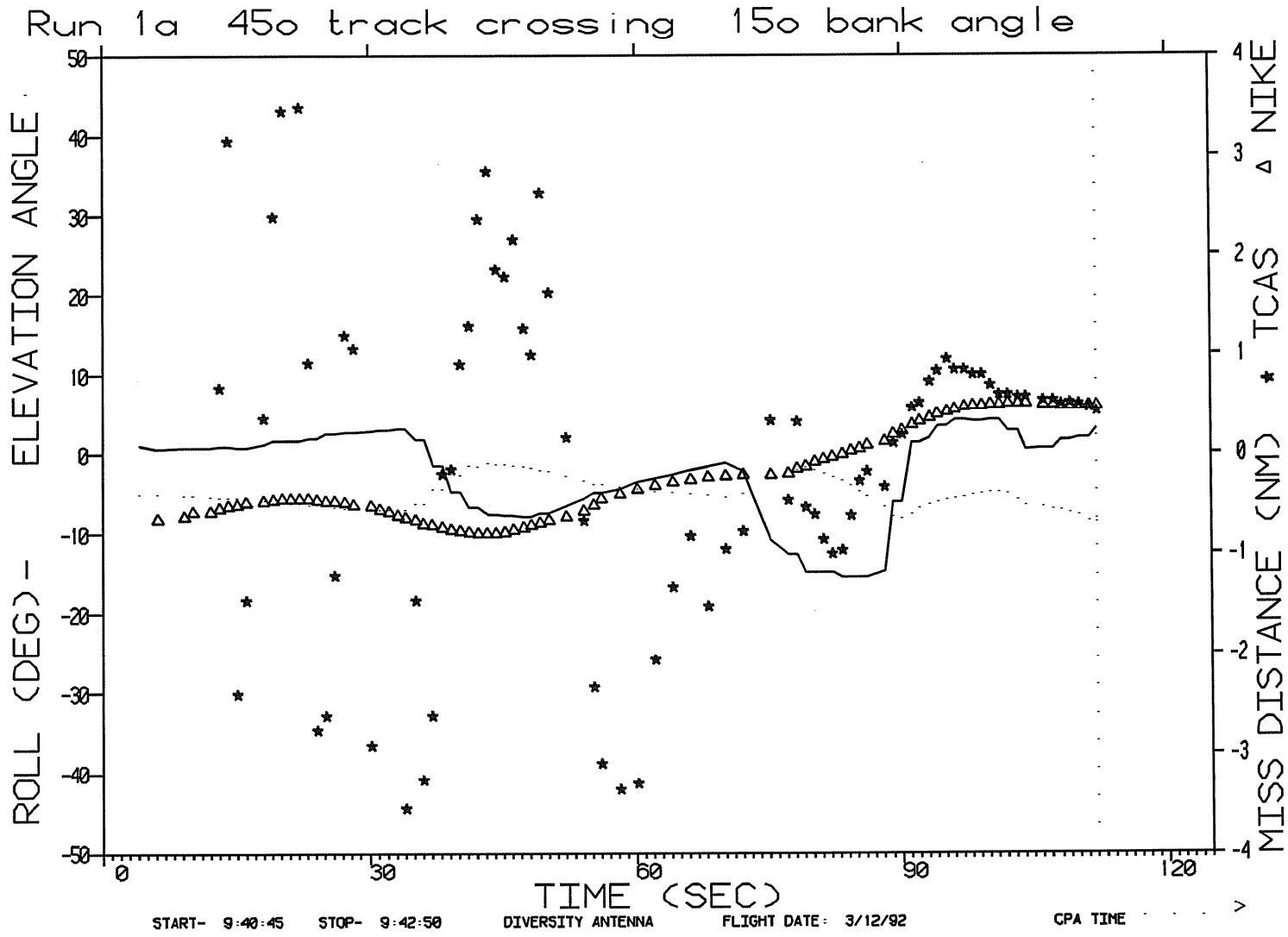

Run 1a 45o track crossing 15o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:40:45
STOP- 9:42:50
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

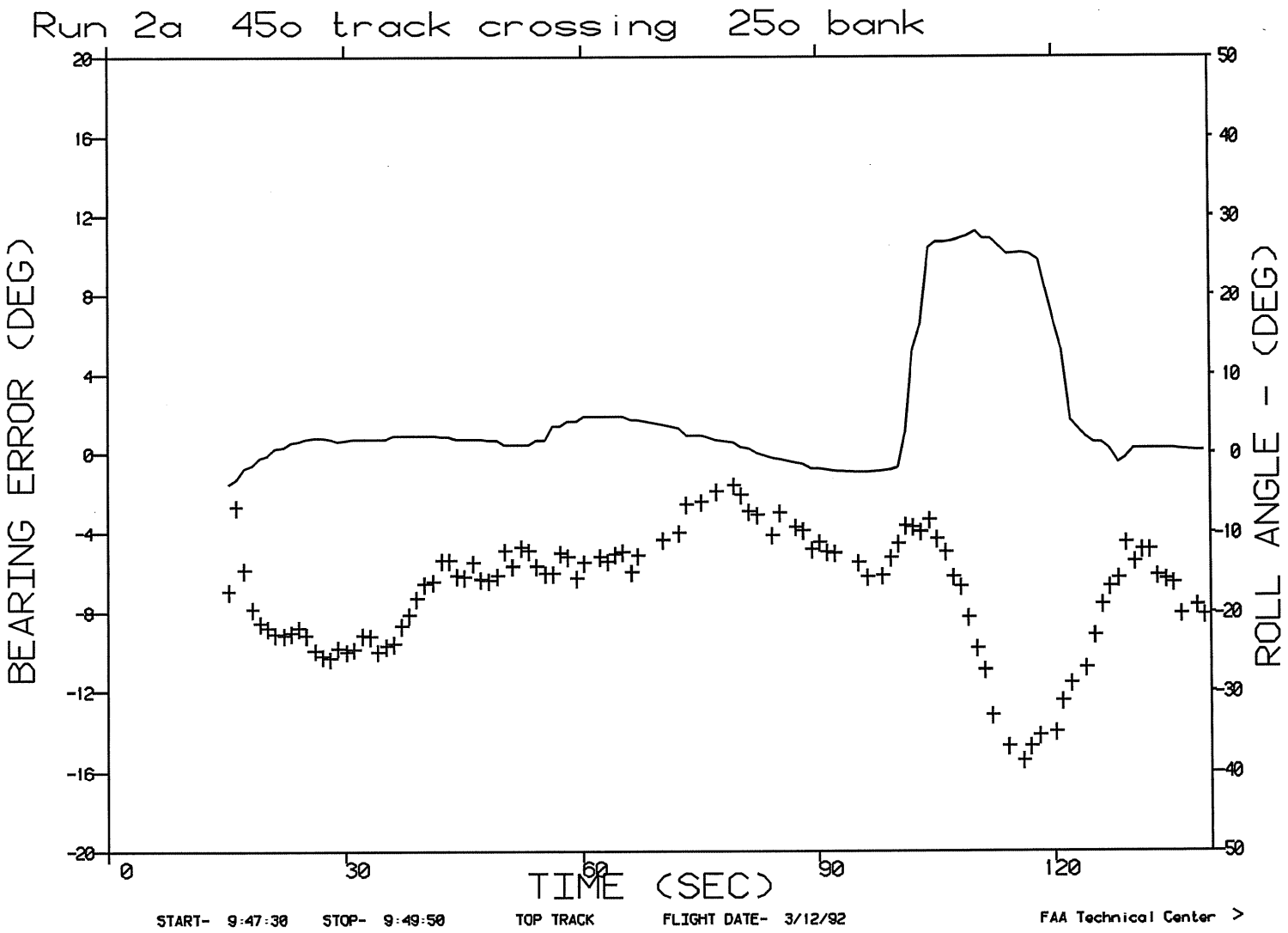

Run 1a 45o track crossing 15o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:40:45 STOP- 9:42:50 BOTTOM TRACK FLIGHT DATE- 3/12/92
FAA Technical Center >

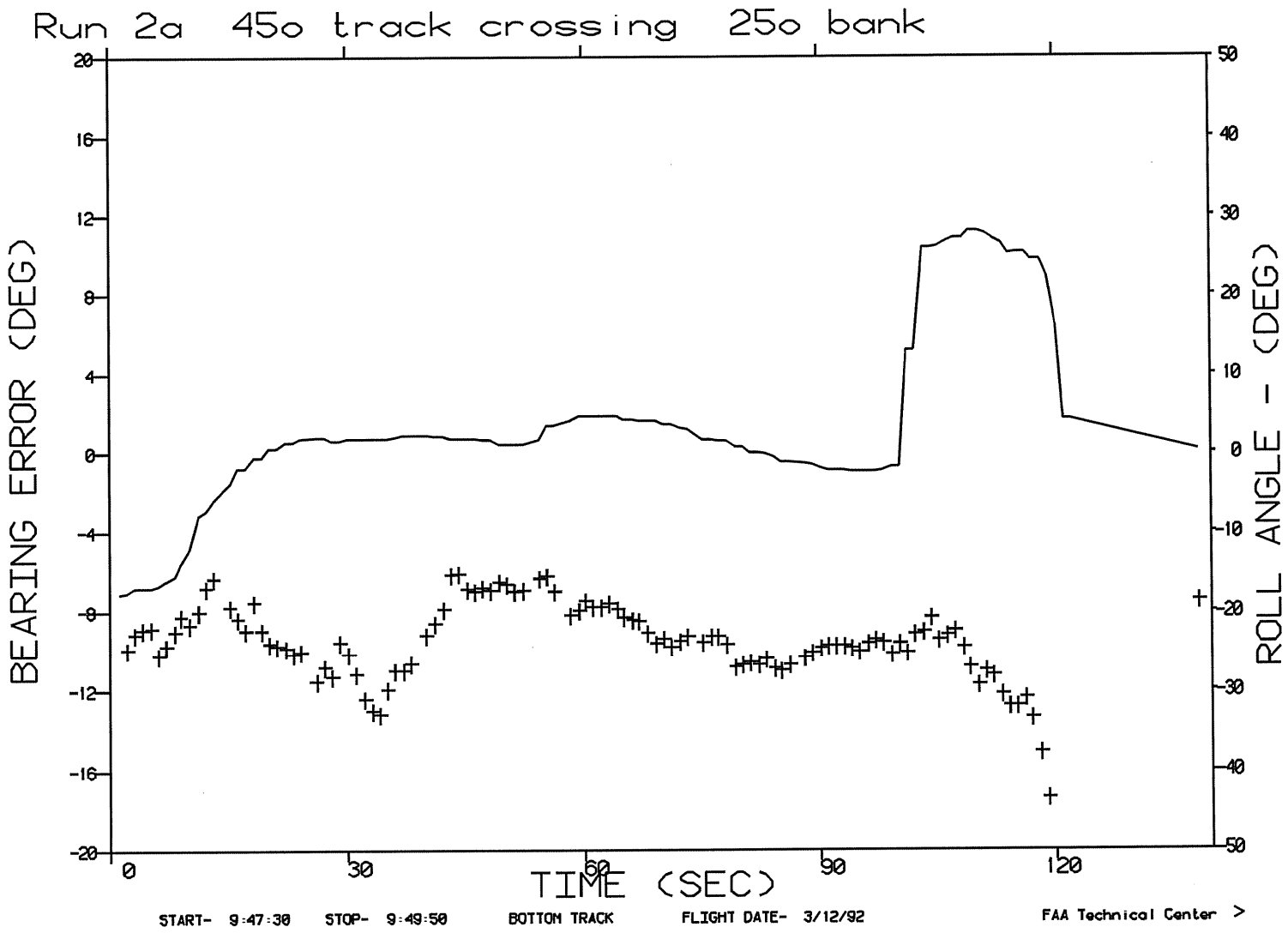

Run 1a 45o track crossing 15o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:40:45
STOP- 9:42:50
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

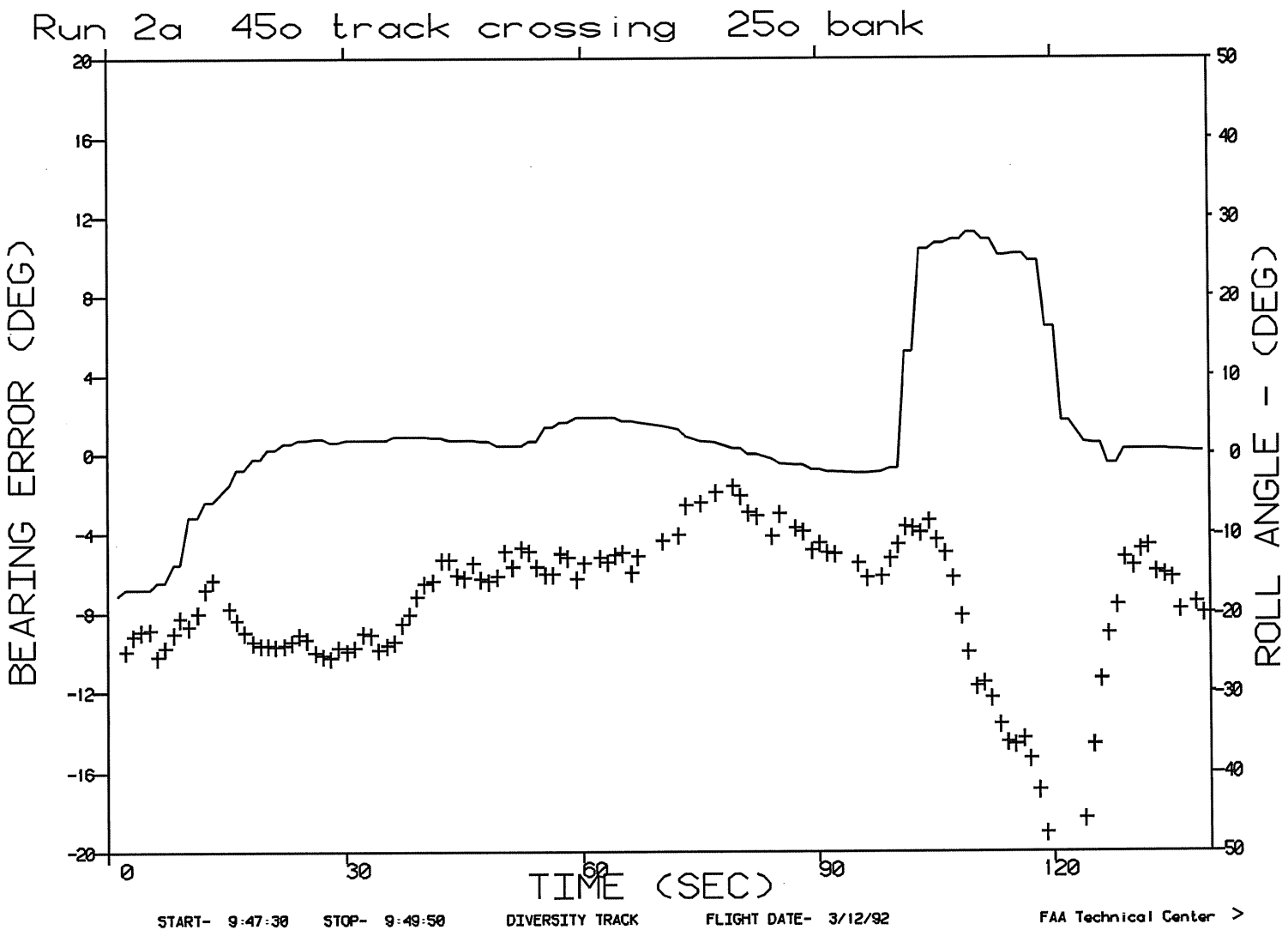

Run 1a 45o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
START- 9:40:45 STOP- 9:42:50 TOP ANTENNA FLIGHT DATE: 3/12/92 CPA TIME

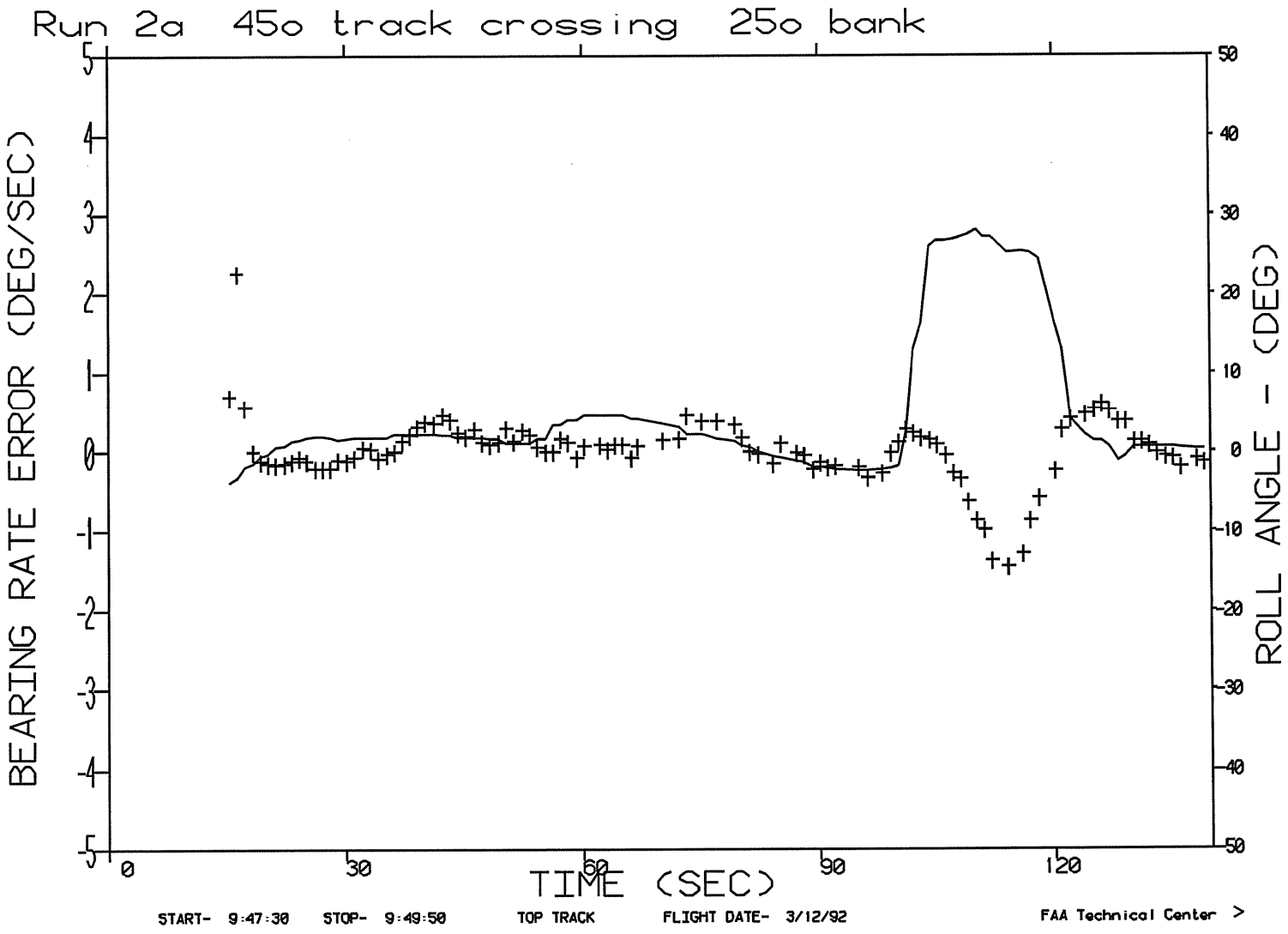

Run 1a 45o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
START- 9:40:45 STOP- 9:42:50 BOTTOM ANTENNA FLIGHT DATE: 3/12/92 CPA TIME

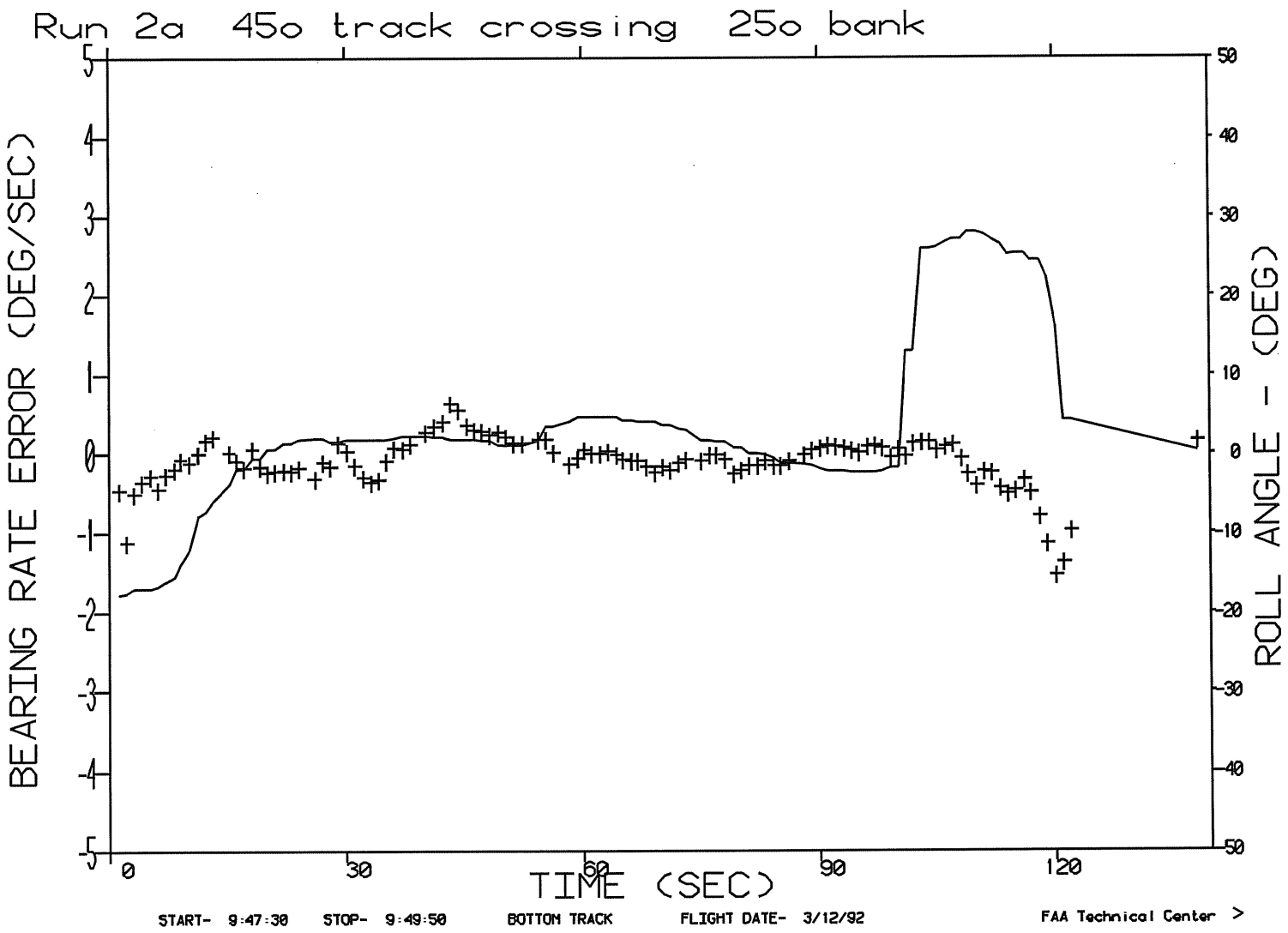

Run 1a 45o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
4
3
2
1
0
-1
-2
-3
-4
0
30
60
90
120
START- 9:40:45 STOP- 9:42:50 DIVERSITY ANTENNA FLIGHT DATE: 3/12/92 CPA TIME

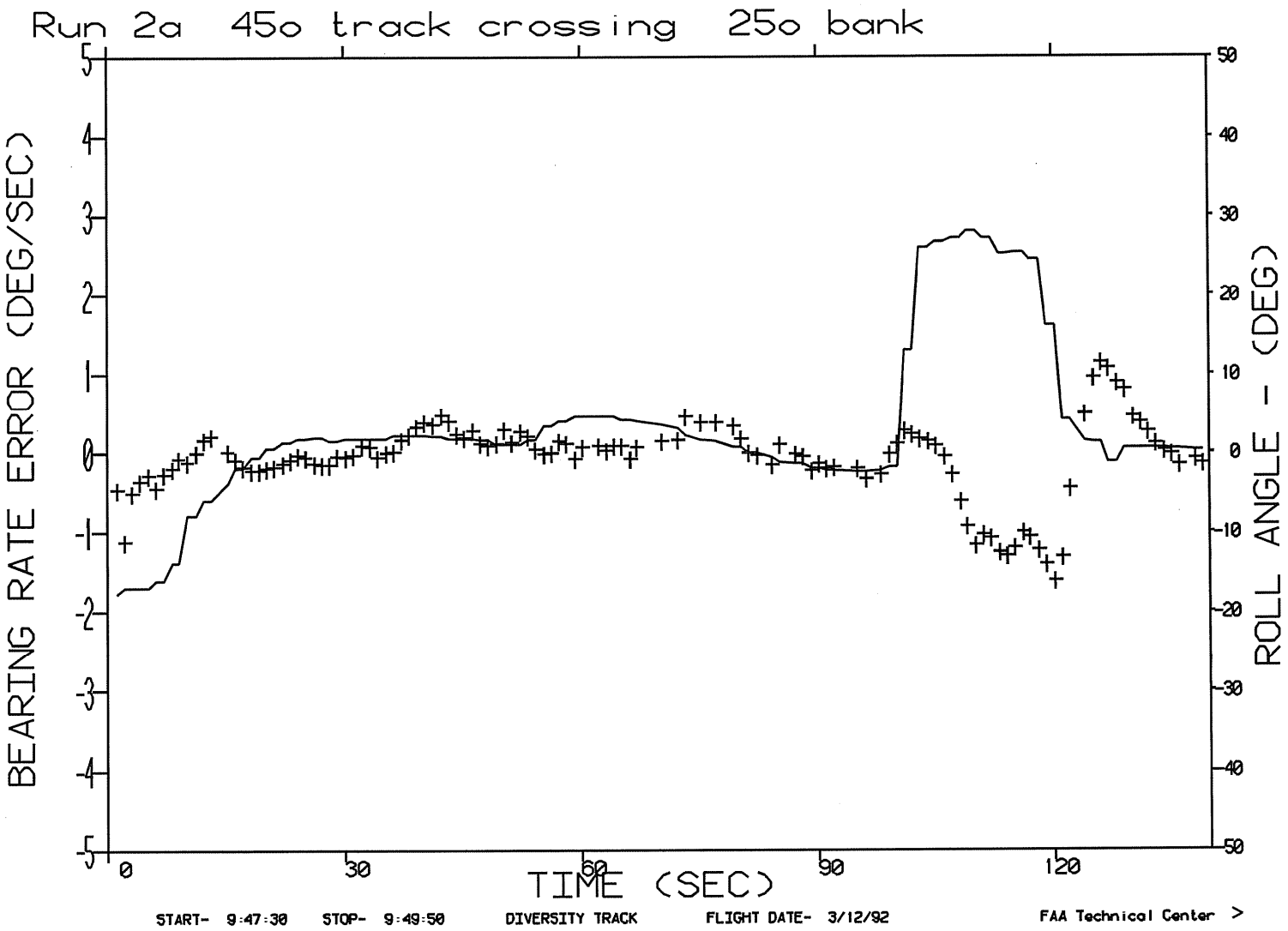

Run 2a 45o track crossing 25o bank
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:47:30 STOP- 9:49:50 TOP TRACK FLIGHT DATE- 3/12/92
FAA Technical Center >

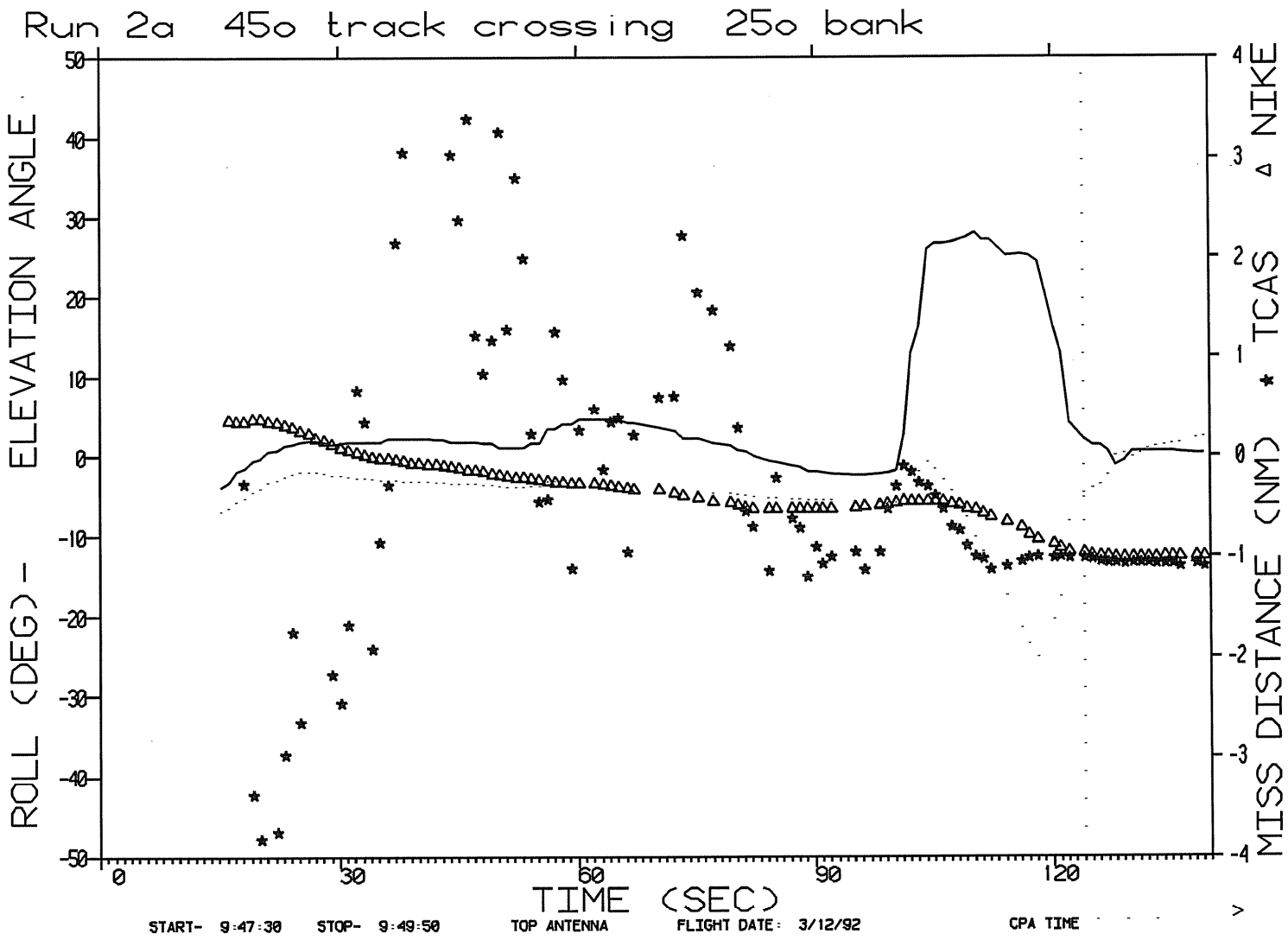

Run 2a 45o track crossing 25o bank
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:47:30 STOP- 9:49:50 BOTTOM TRACK FLIGHT DATE- 3/12/92 FAA Technical Center >

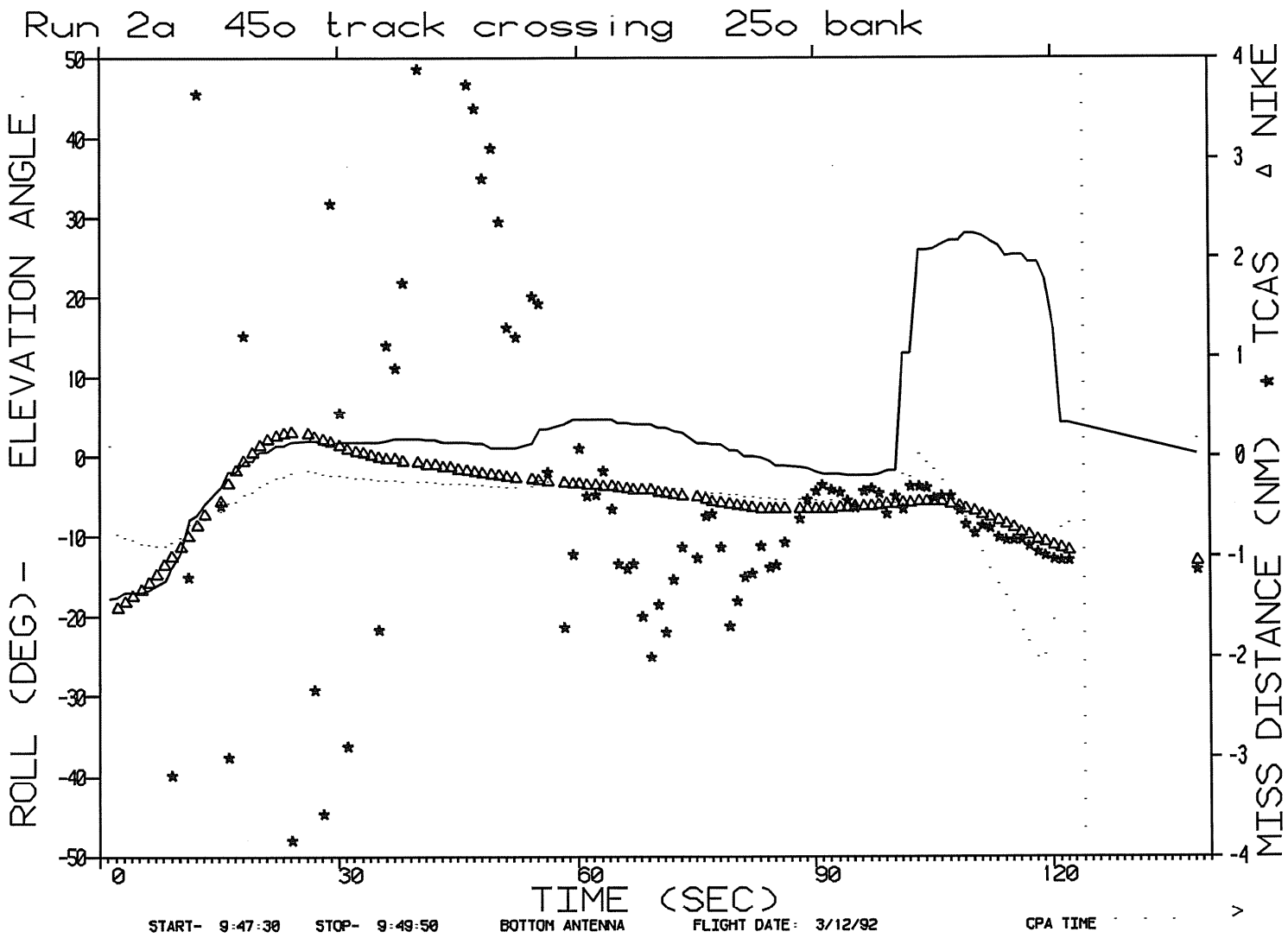

Run 2a 45o track crossing 25o bank
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:47:30
STOP- 9:49:50
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

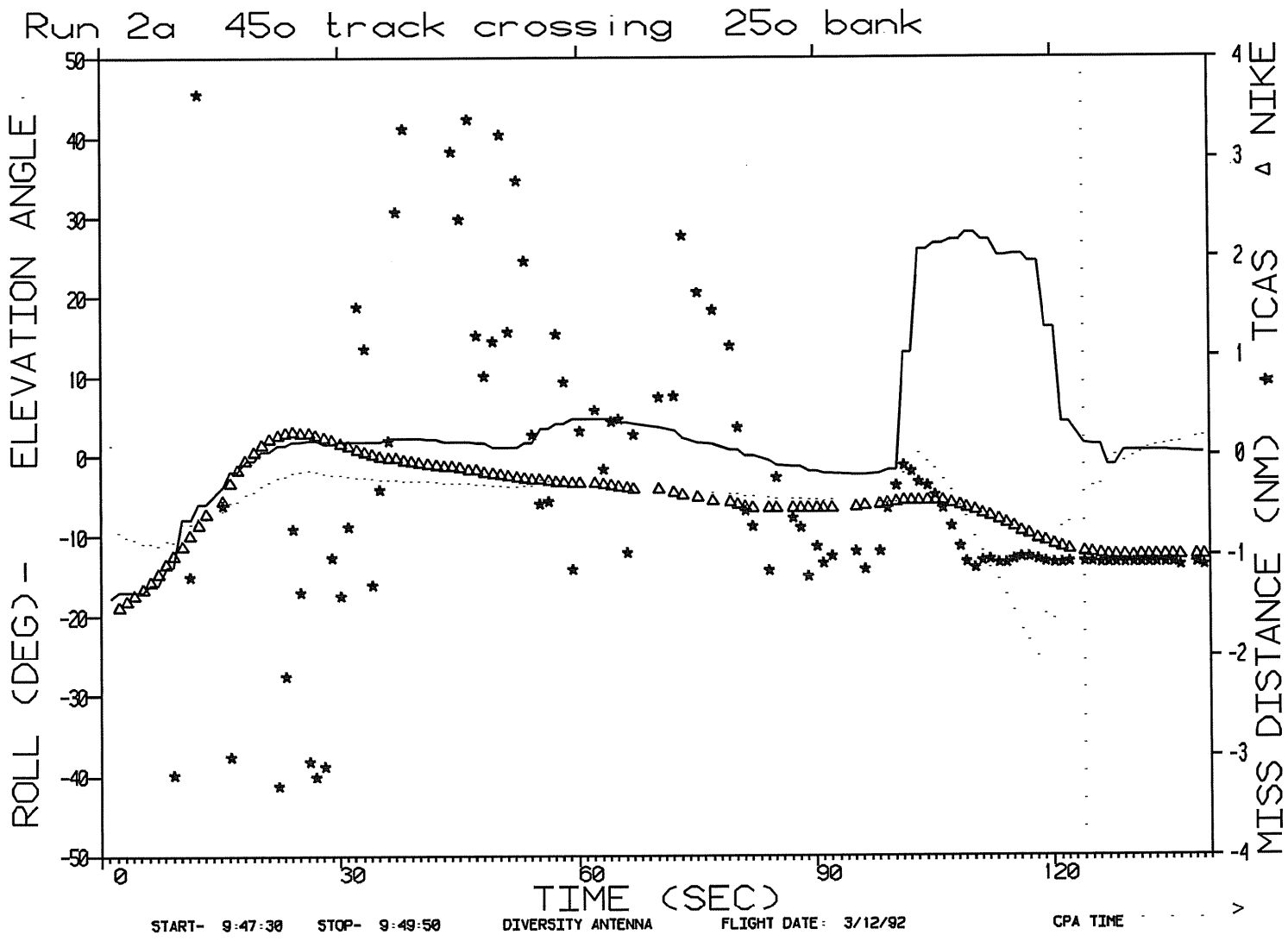

Run 2a 45o track crossing 25o bank
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:47:30 STOP- 9:49:50 TOP TRACK FLIGHT DATE- 3/12/92
FAA Technical Center >

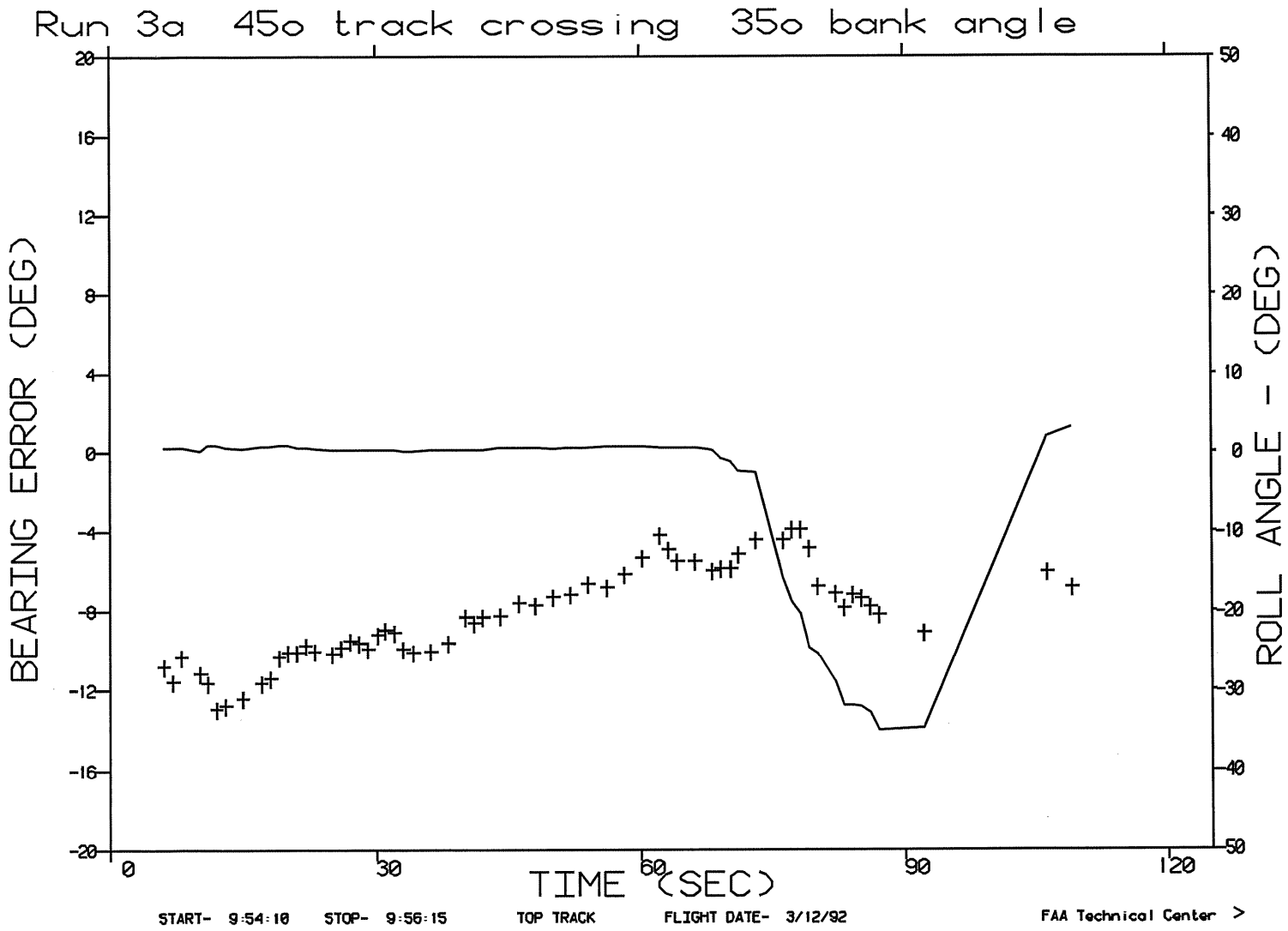

Run 2a 45o track crossing 25o bank
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:47:30 STOP- 9:49:50 BOTTOM TRACK FLIGHT DATE- 3/12/92
FAA Technical Center >

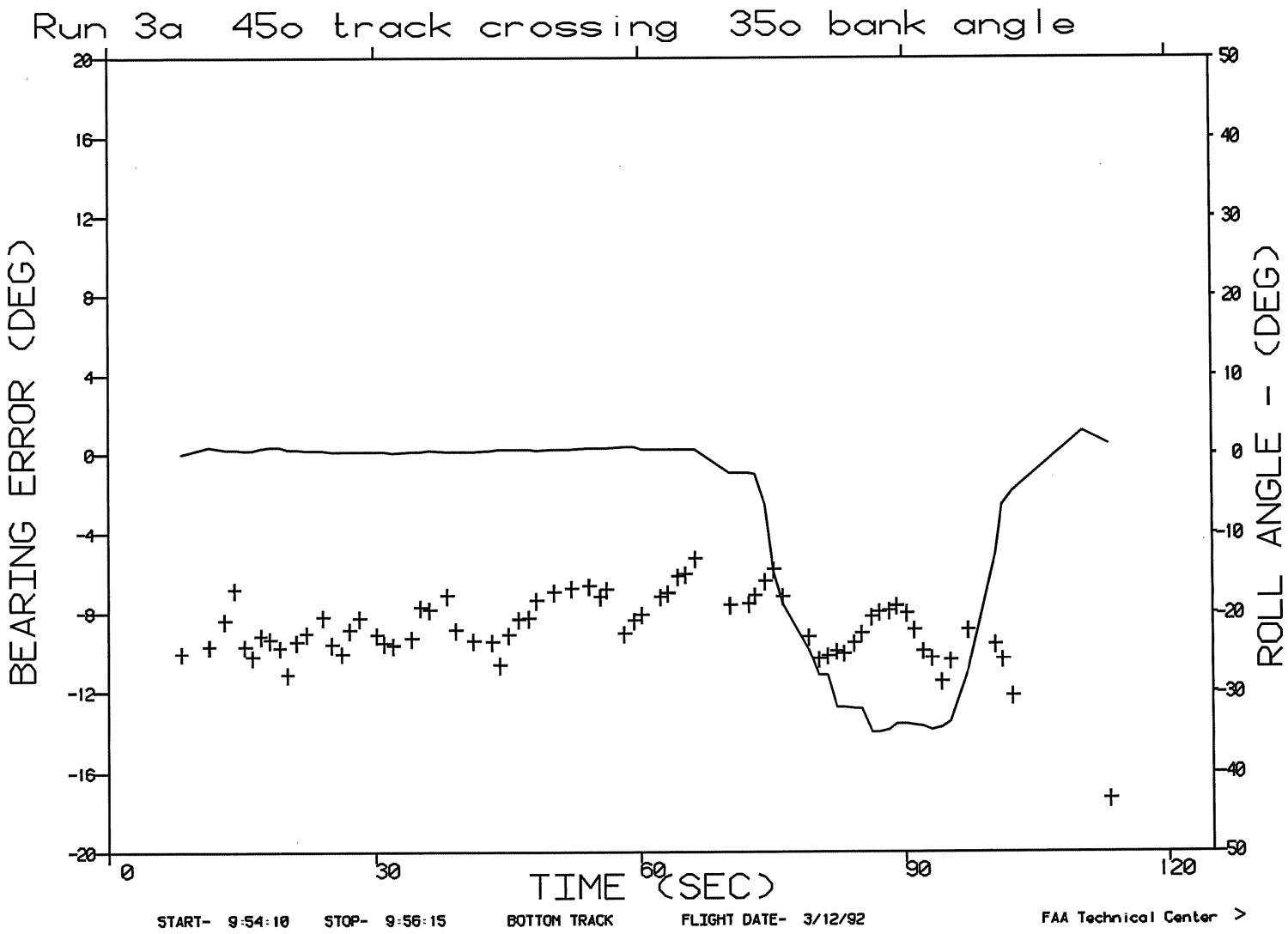

Run 2a 45o track crossing 25o bank
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:47:30 STOP- 9:49:50 DIVERSITY TRACK FLIGHT DATE- 3/12/92 FAA Technical Center >

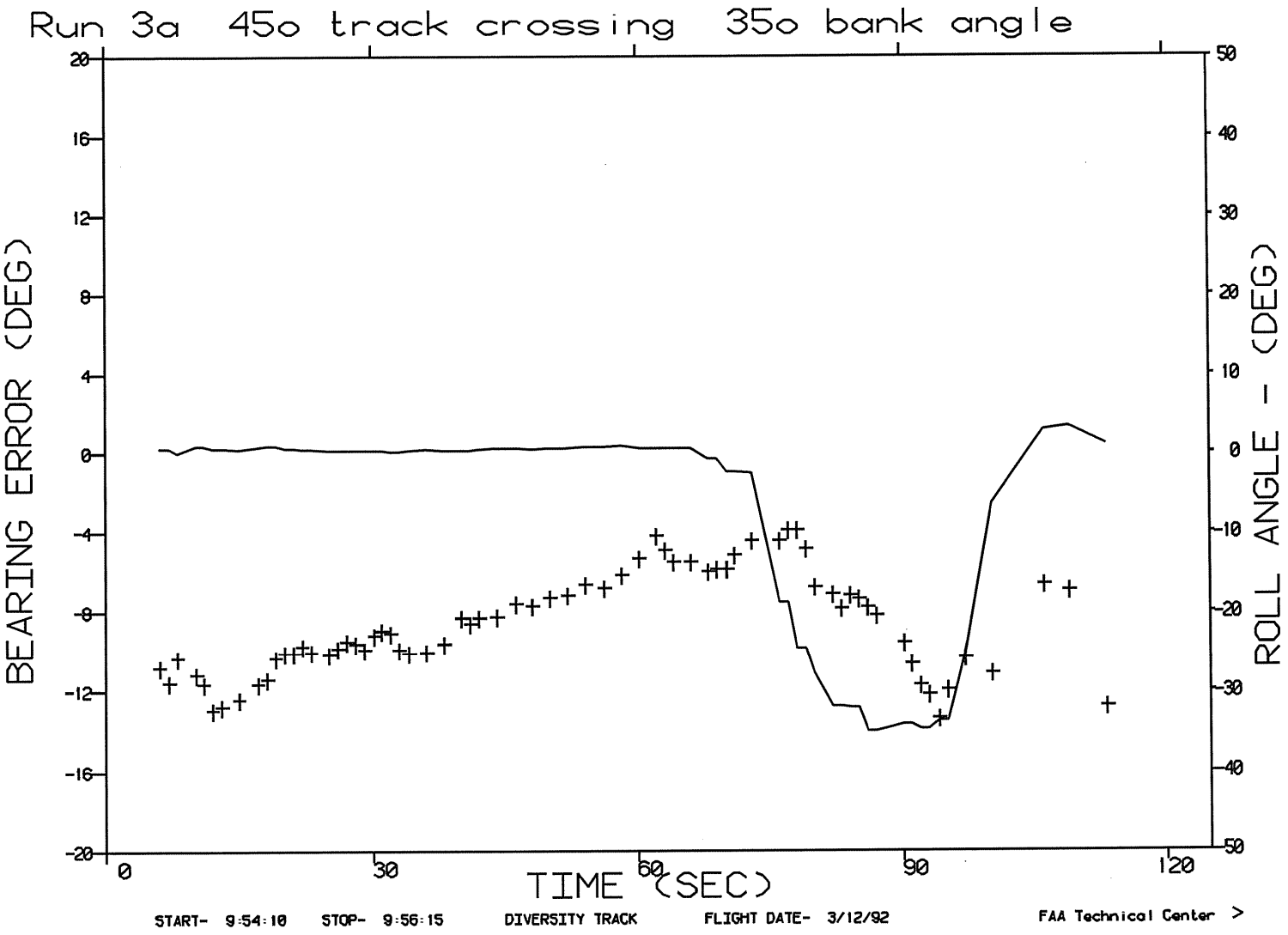

Run 2a 45o track crossing 25o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
START- 9:47:30 STOP- 9:49:50 TOP ANTENNA FLIGHT DATE: 3/12/92 CPA TIME

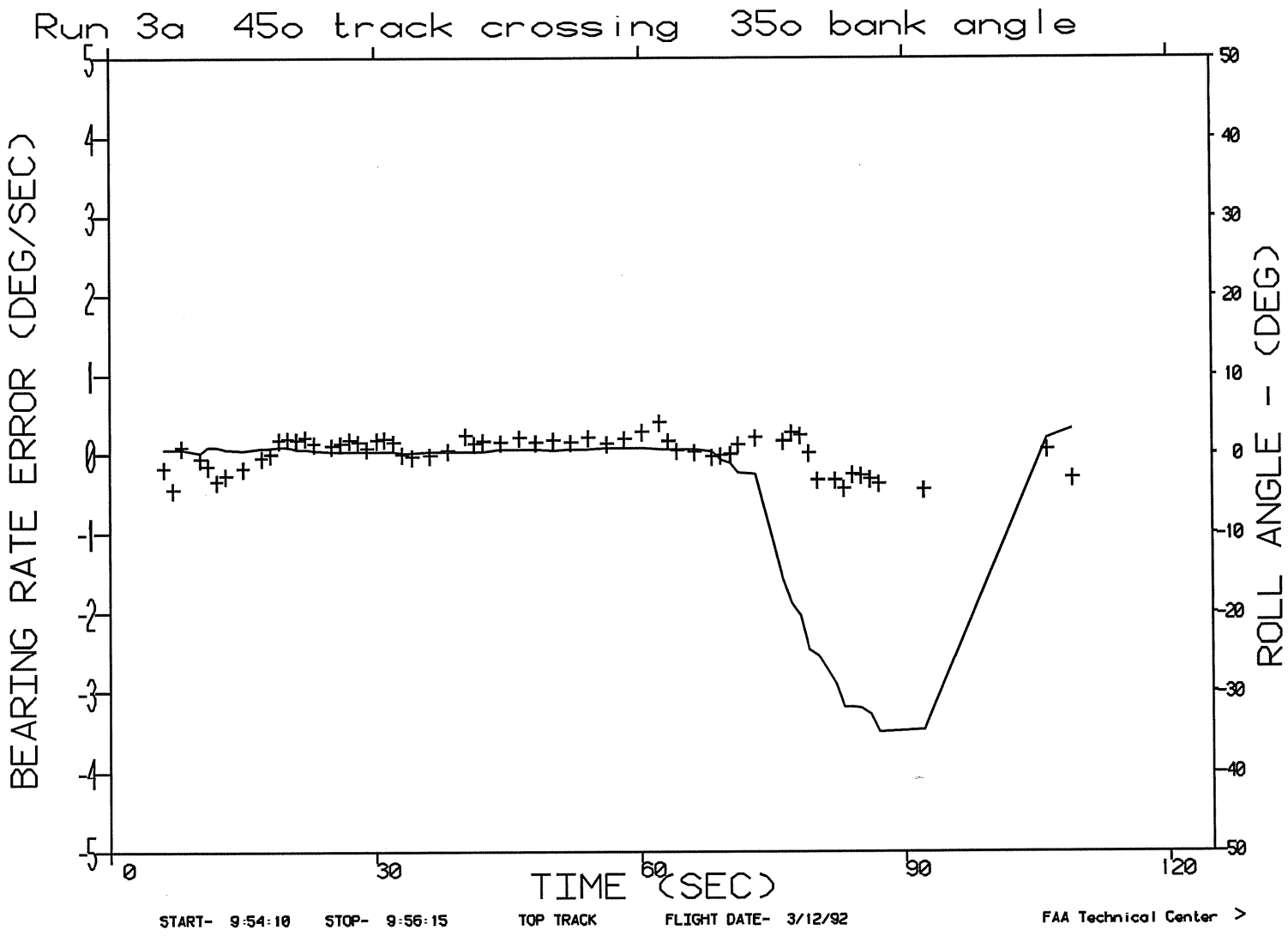

Run 2a 45o track crossing 25o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
4
3
2
1
0
-1
-2
-3
-4
0
30
60
90
120
START- 9:47:30 STOP- 9:49:50 BOTTOM ANTENNA FLIGHT DATE: 3/12/92 CPA TIME

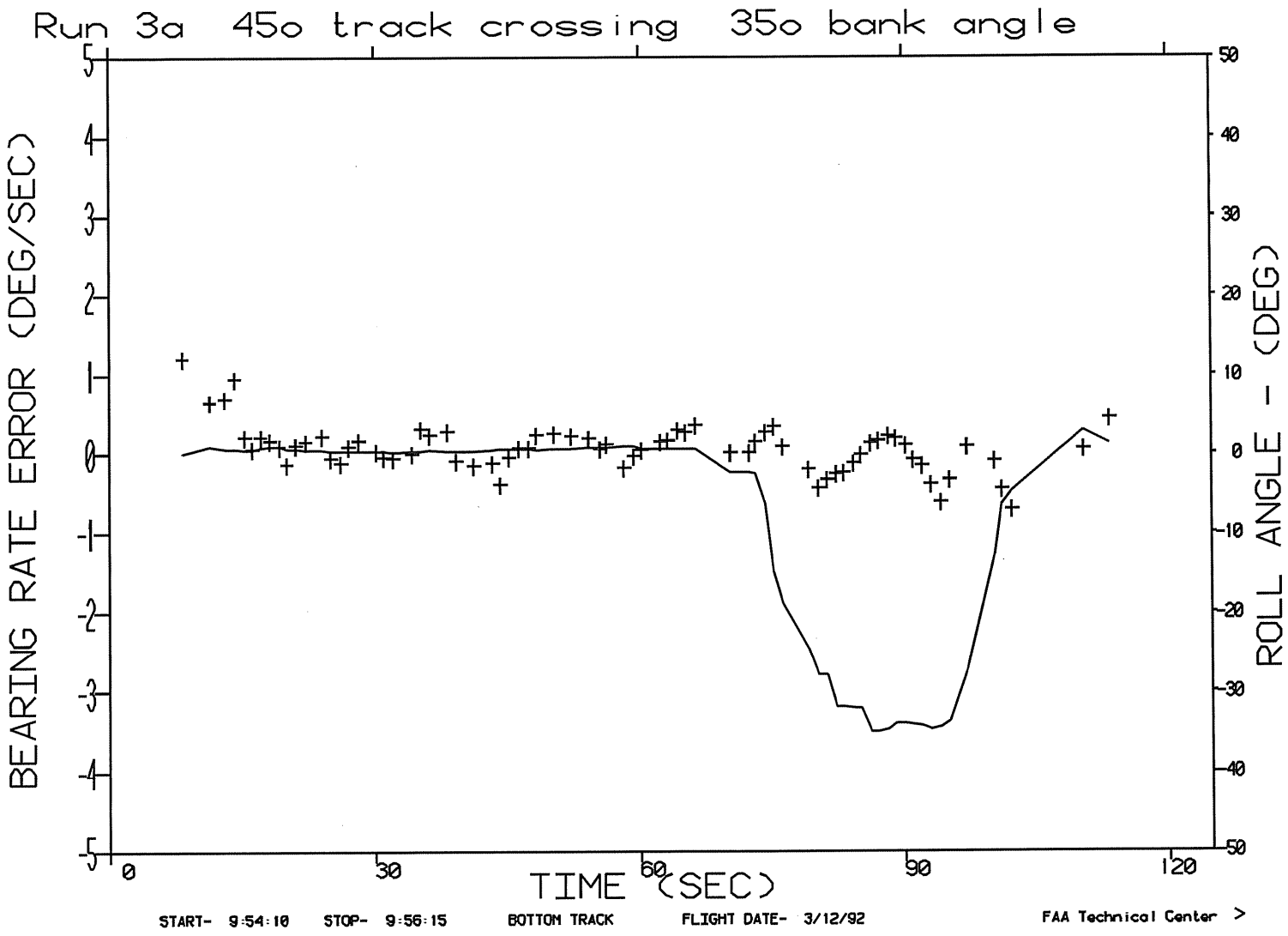

Run 2a 45o track crossing 25o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
4
3
2
1
0
-1
-2
-3
-4
0
30
60
90
120
START- 9:47:30 STOP- 9:49:50 DIVERSITY ANTENNA FLIGHT DATE: 3/12/92 CPA TIME

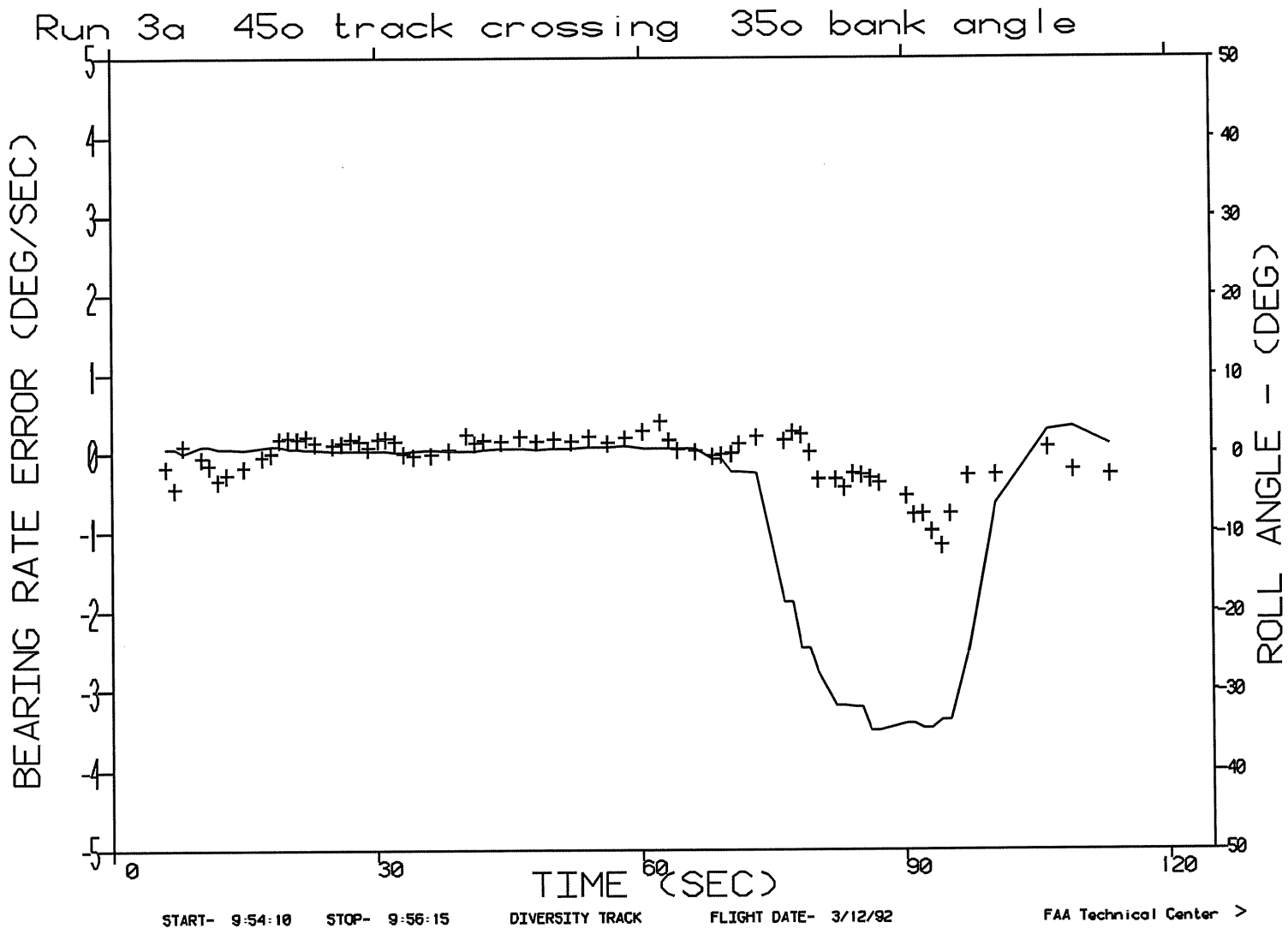

Run 3a 45o track crossing 35o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:54:10 STOP- 9:56:15 TOP TRACK FLIGHT DATE- 3/12/92
FAA Technical Center >

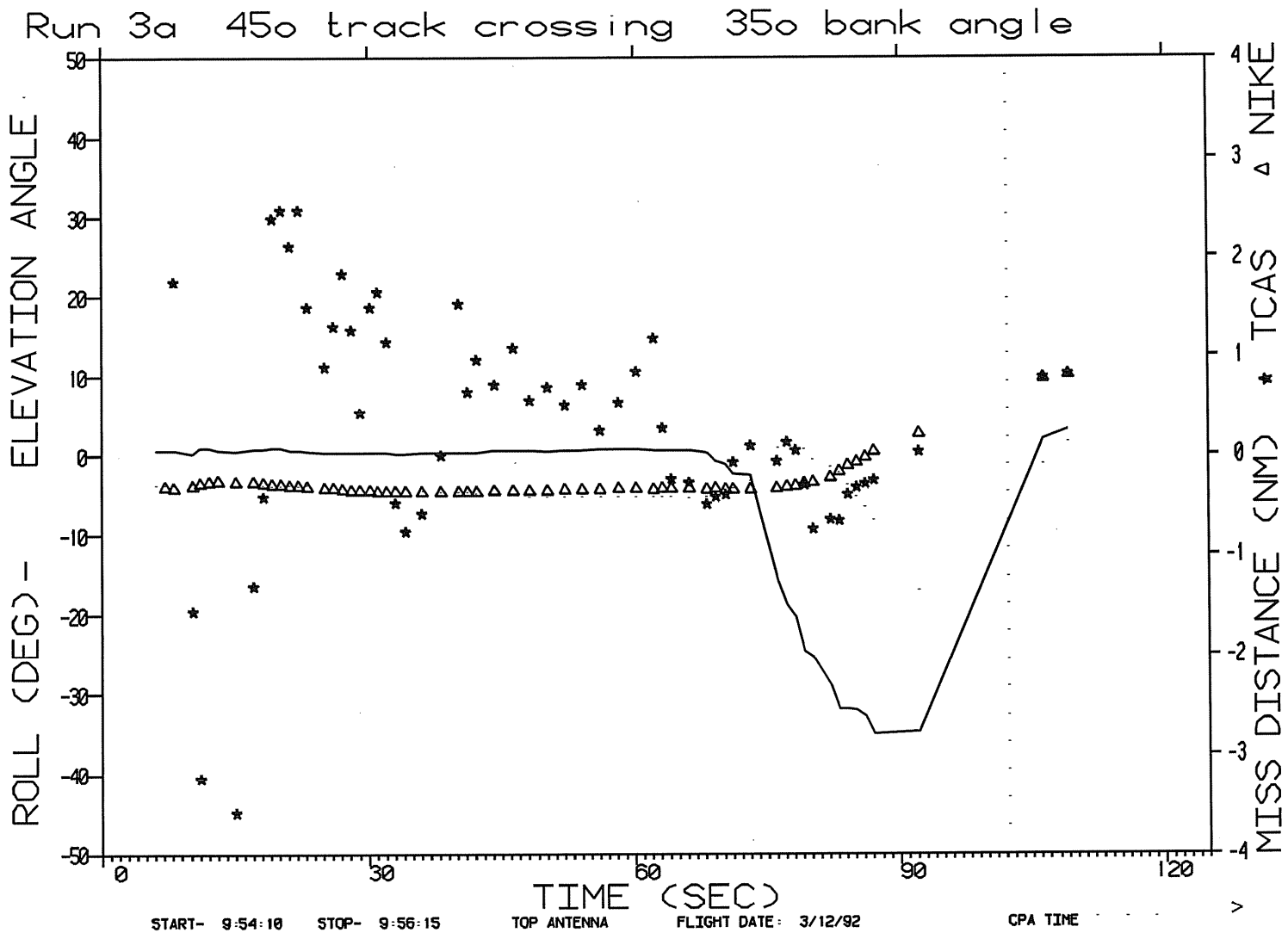

Run 3a 45o track crossing 35o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:54:10
STOP- 9:56:15
BOTTOM TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

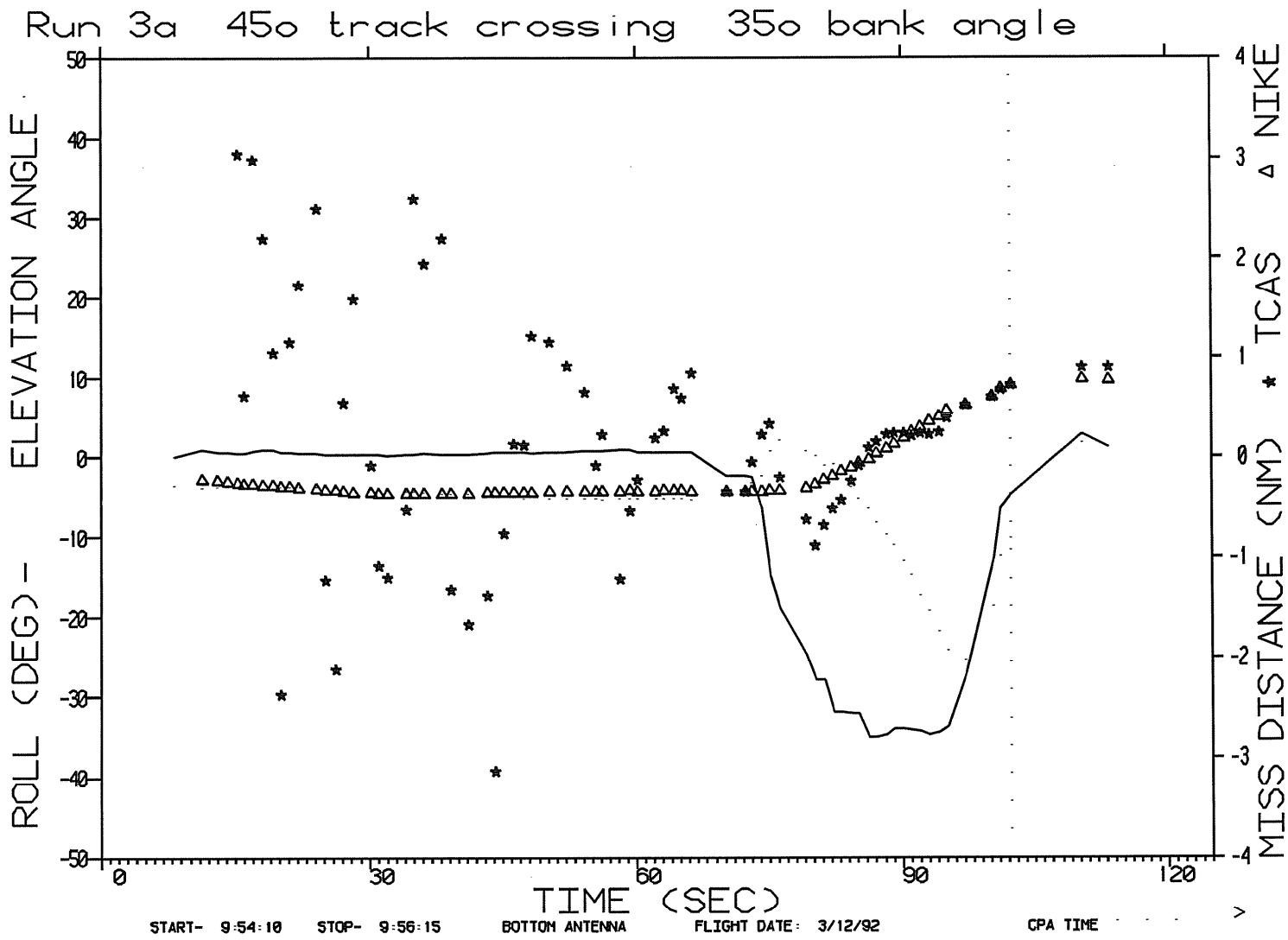

Run 3a 45o track crossing 35o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:54:10
STOP- 9:56:15
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

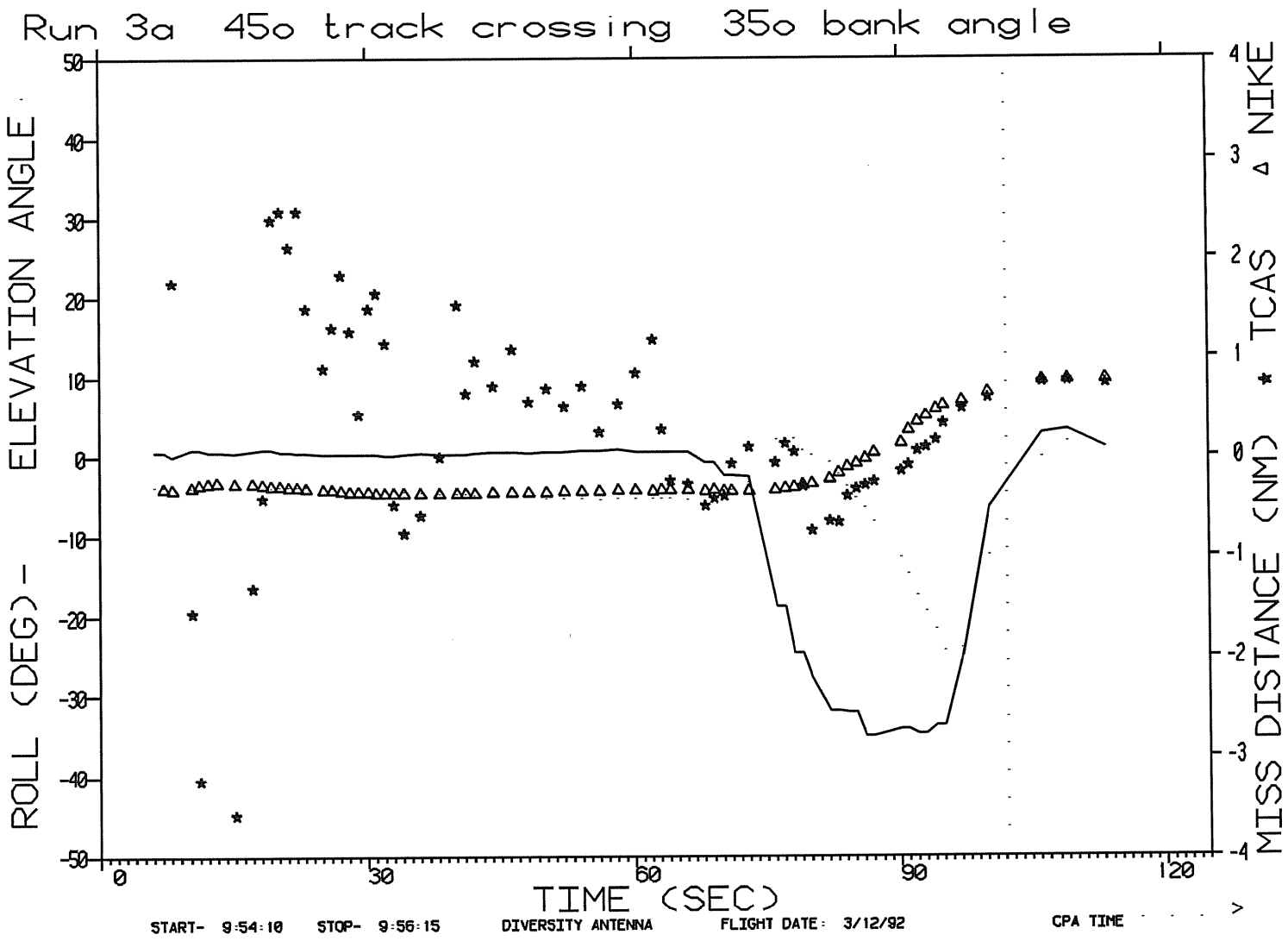

Run 3a 45o track crossing 35o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:54:10
STOP- 9:56:15
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

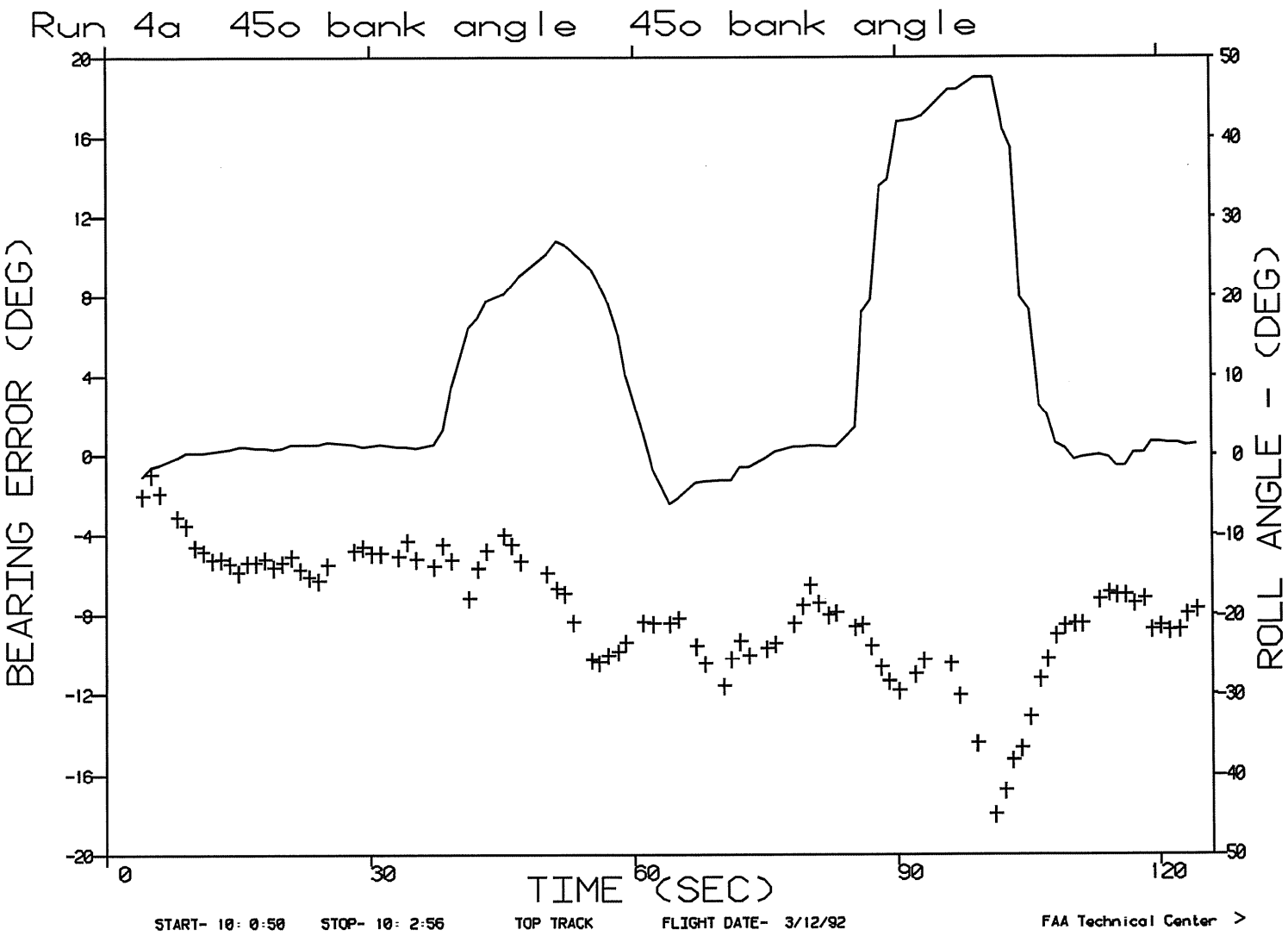

Run 3a 45o track crossing 35o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:54:10
STOP- 9:56:15
BOTTOM TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

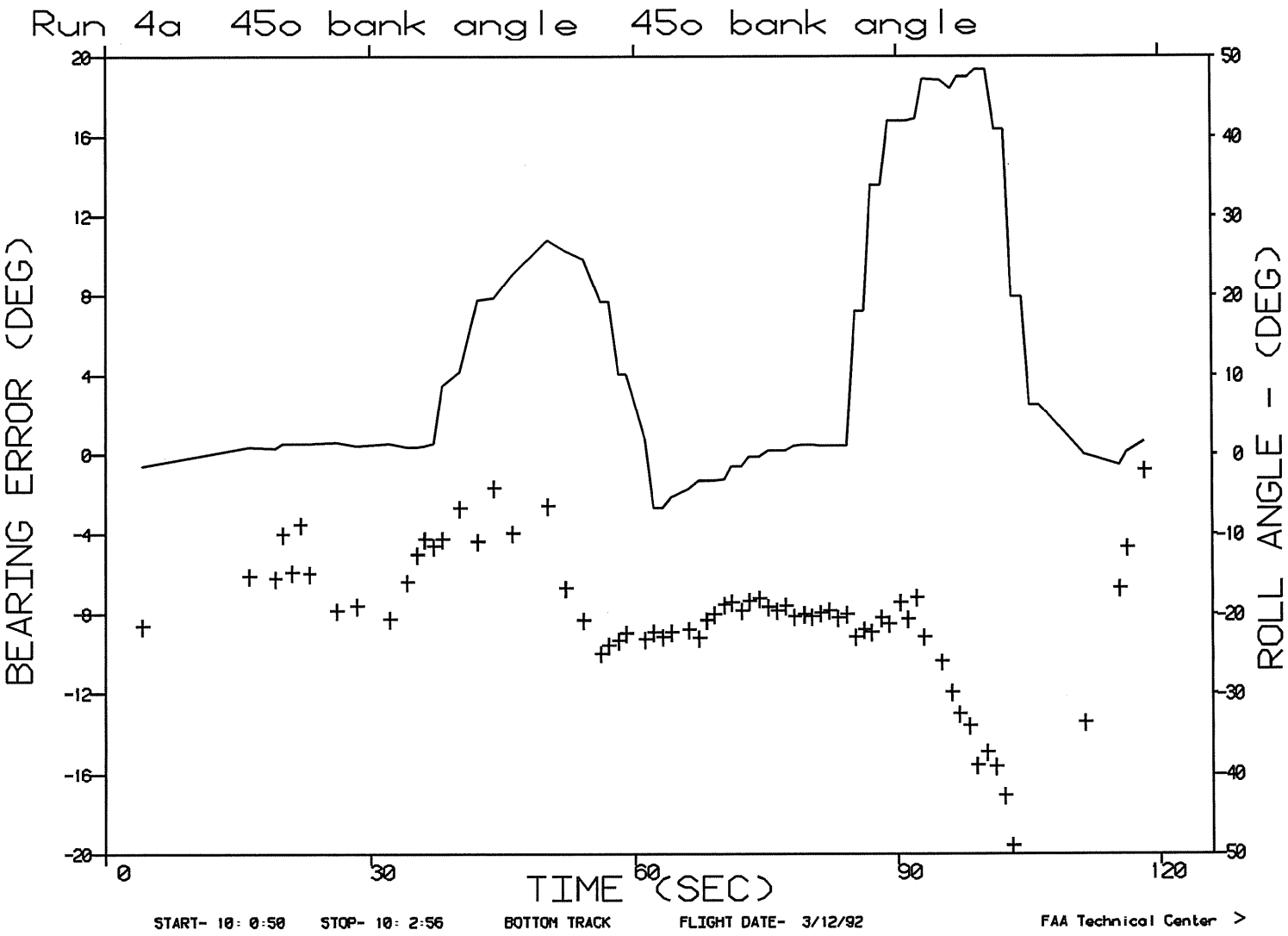

Run 3a 45o track crossing 35o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 9:54:10
STOP- 9:56:15
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 3a 45o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
4
3
2
1
0
-1
-2
-3
-4
0
30
60
90
120
START- 9:54:10 STOP- 9:56:15 TOP ANTENNA FLIGHT DATE: 3/12/92 CPA TIME


Run 3a 45o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
4
3
2
1
0
-1
-2
-3
-4
0
30
60
90
120
START- 9:54:10 STOP- 9:56:15 BOTTOM ANTENNA FLIGHT DATE: 3/12/92 CPA TIME


Run 3a 45o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
4
3
2
1
0
-1
-2
-3
-4
0
30
60
90
120
START- 9:54:10 STOP- 9:56:15 DIVERSITY ANTENNA FLIGHT DATE: 3/12/92 CPA TIME


Run 4a 45o bank angle 45o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
30
60
90
120
START- 10: 0:50
STOP- 10: 2:56
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 4a 45o bank angle 45o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
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4
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-4
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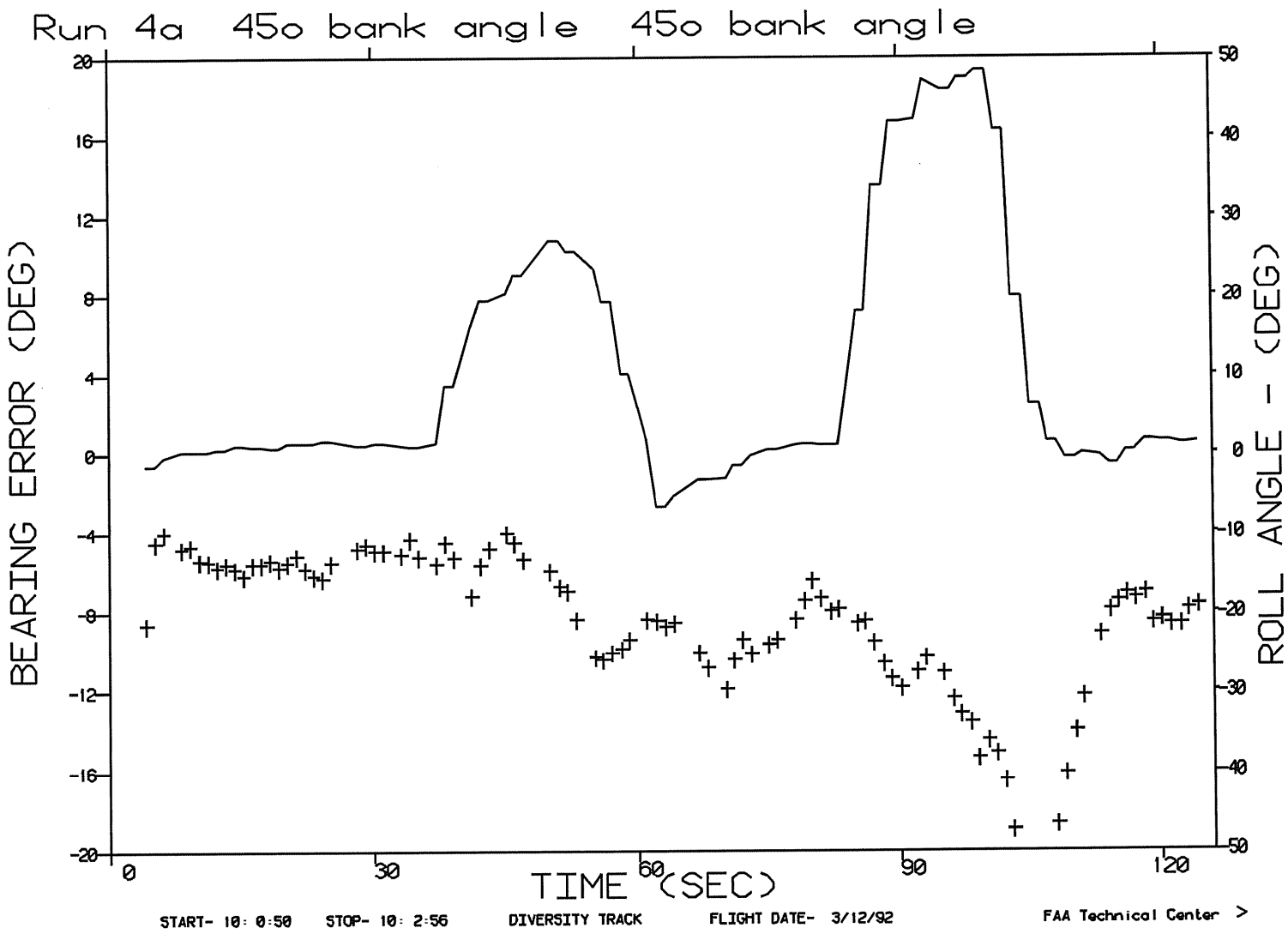
-30
-40
-50
0
30
60
90
120
START- 10: 0:50
STOP- 10: 2:56
BOTTOM TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 4a 45o bank angle 45o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
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-4
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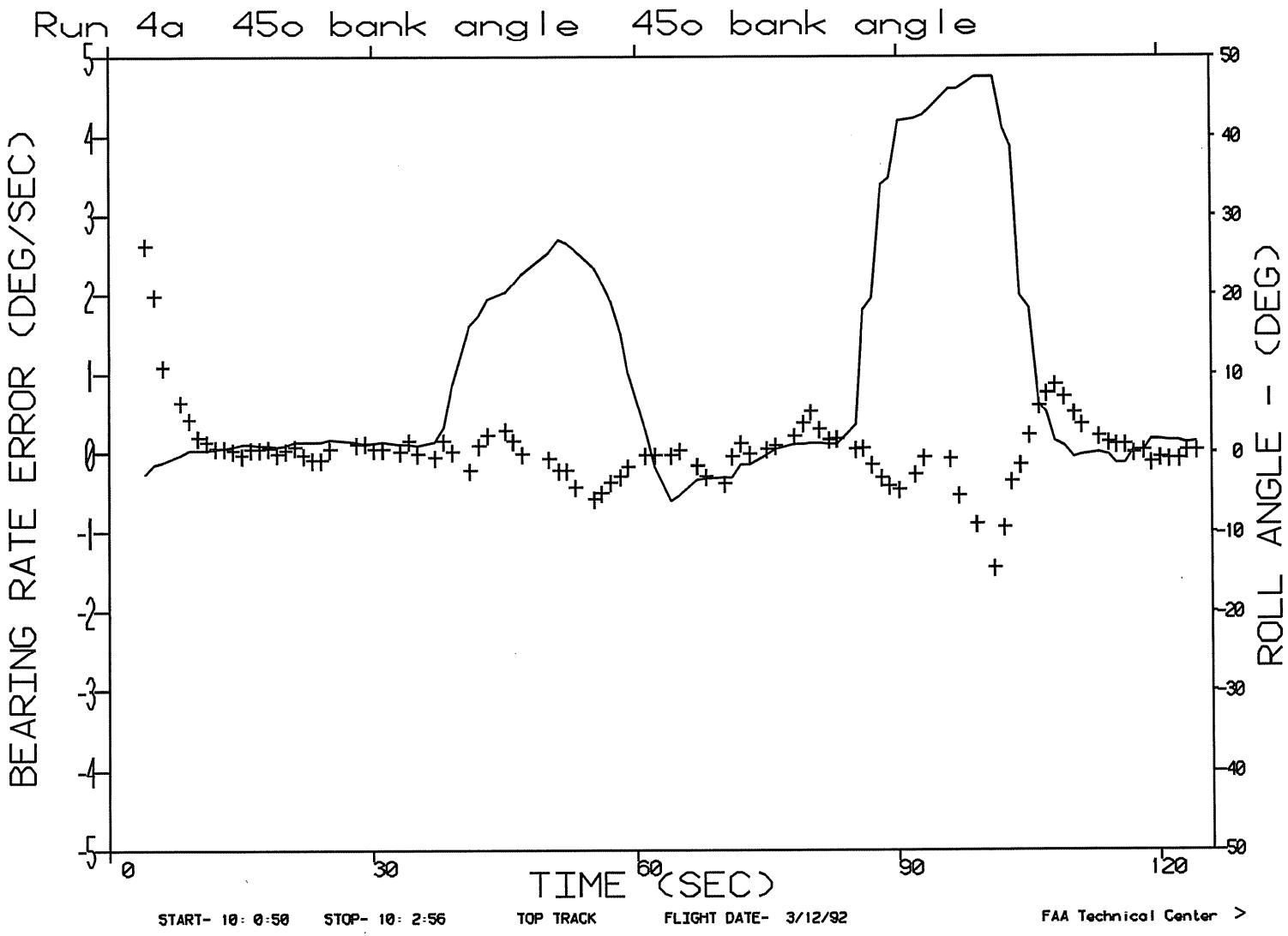
START- 10: 0:50
STOP- 10: 2:56
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 4a 45o bank angle 45o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
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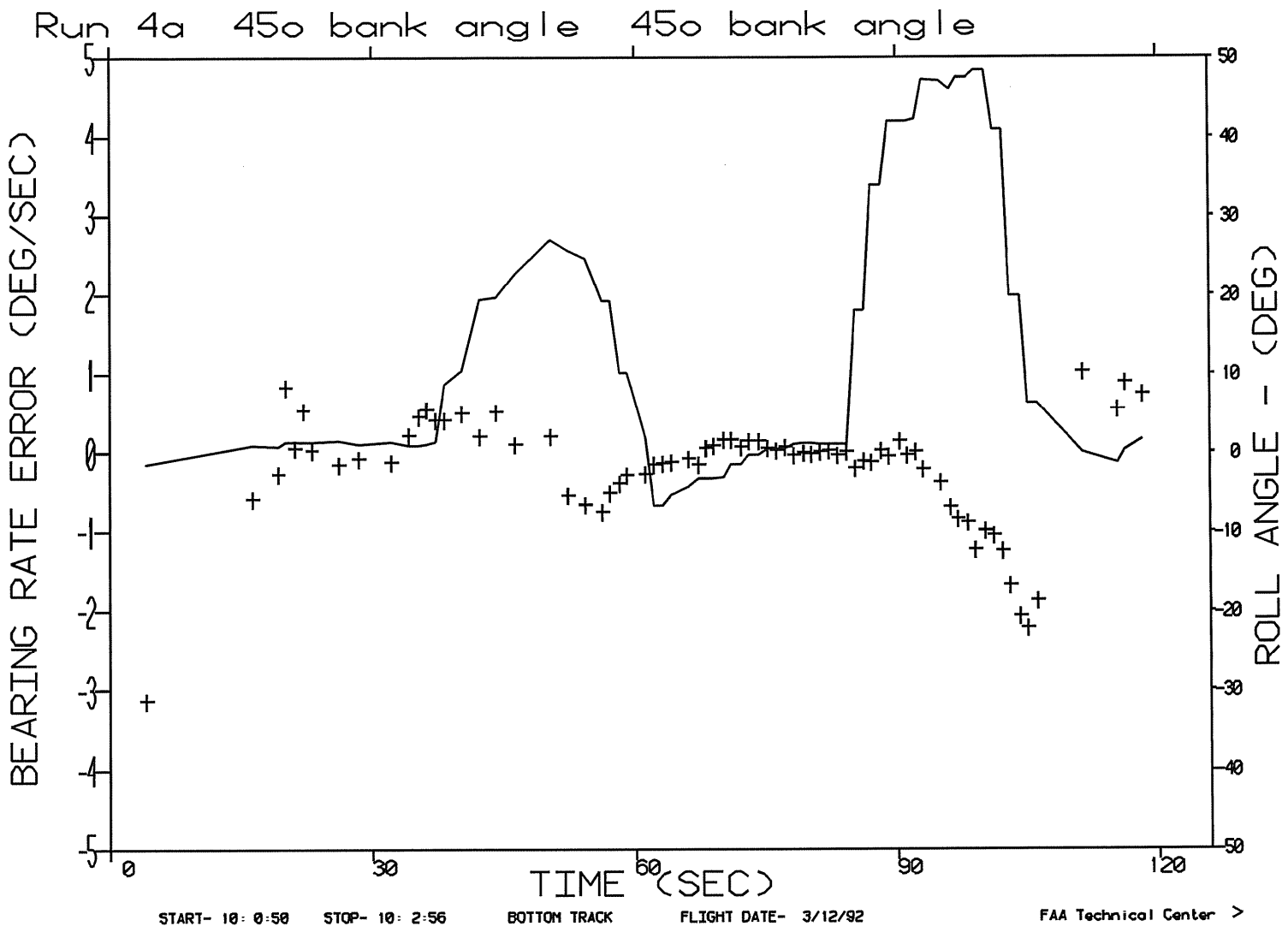
START- 10: 0:50
STOP- 10: 2:56
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 4a 45o bank angle 45o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
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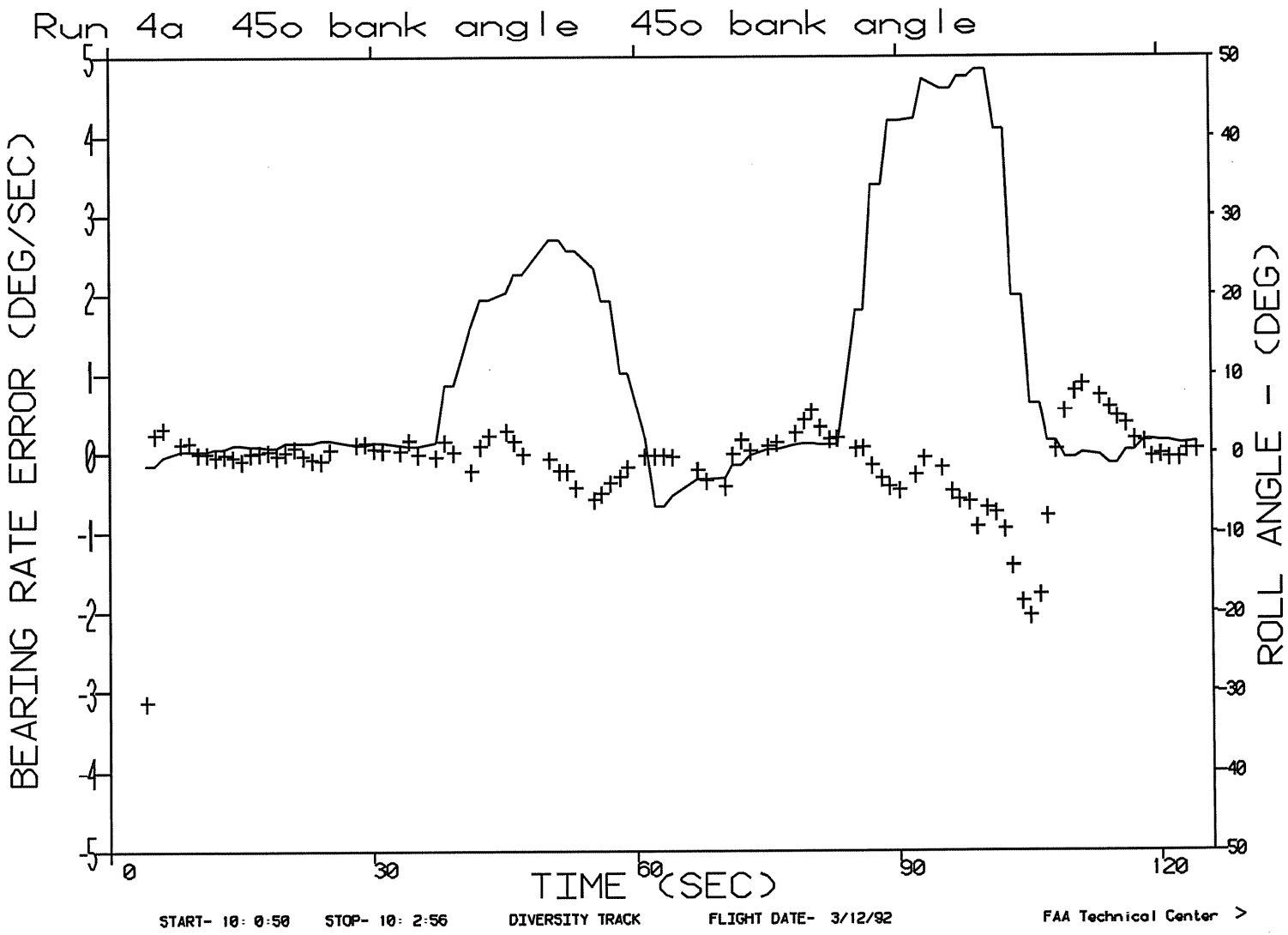
START- 10: 0:50
STOP- 10: 2:56
BOTTOM TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 4a 45o bank angle 45o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
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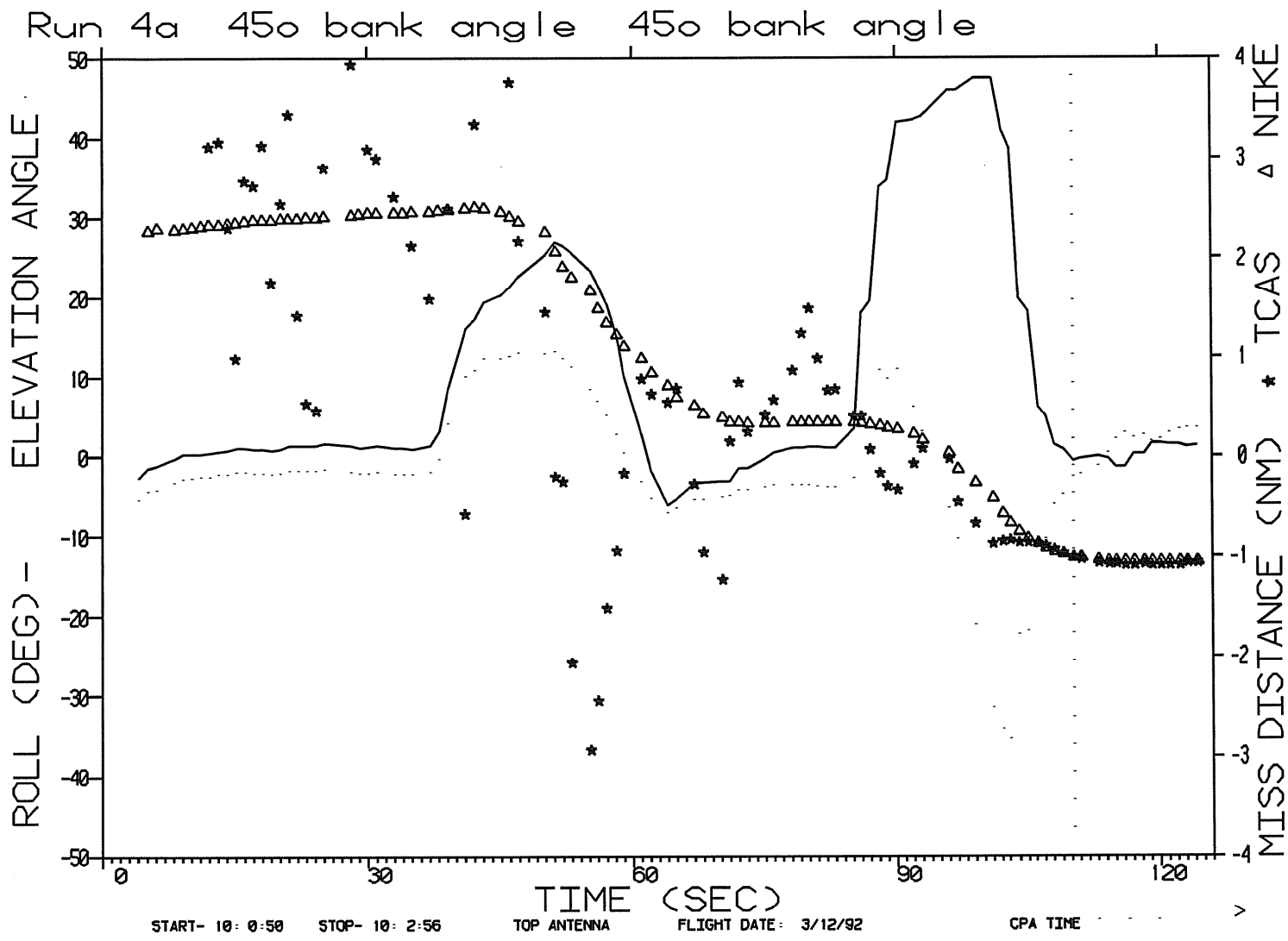
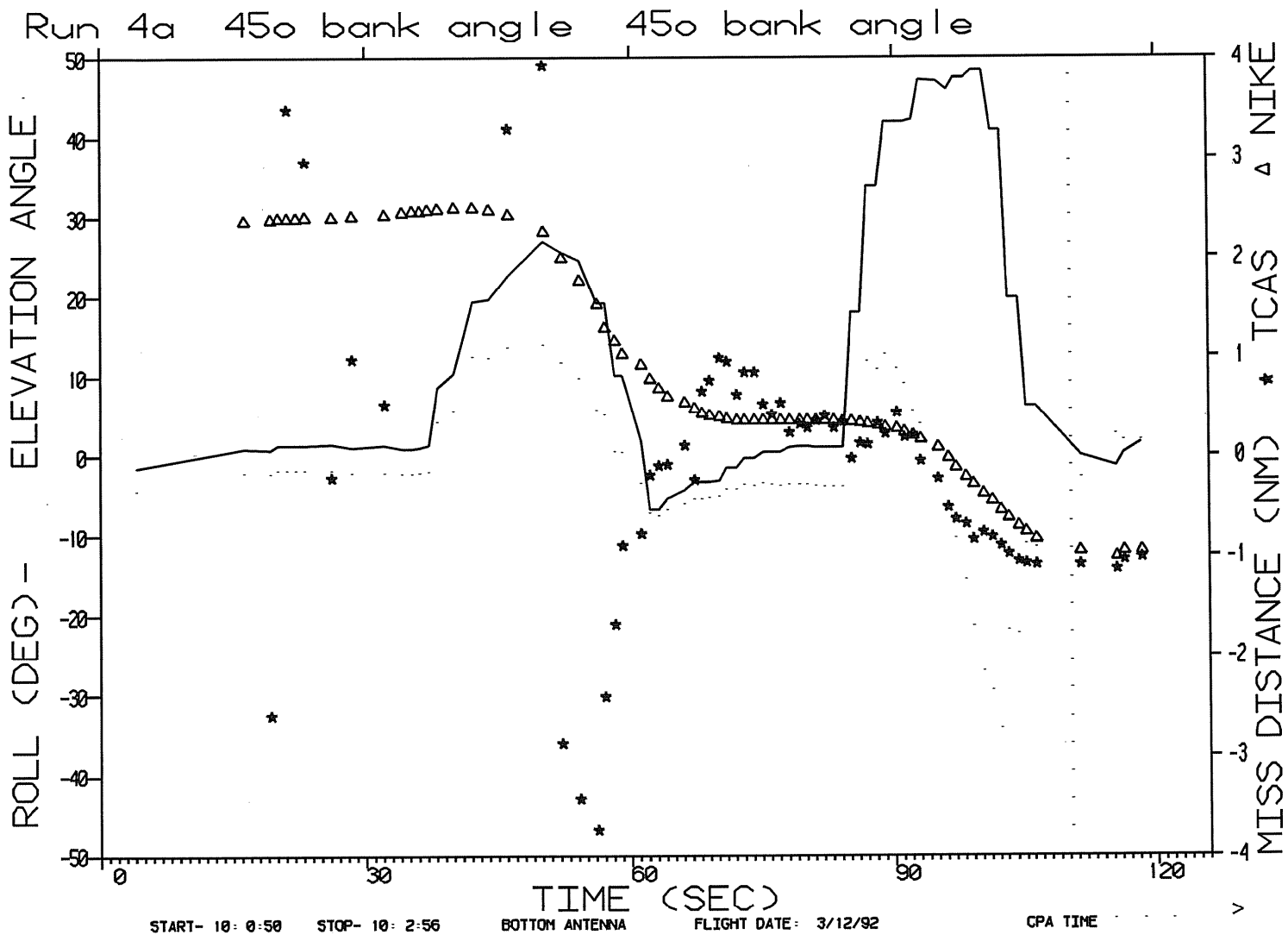
START- 10: 0:50
STOP- 10: 2:56
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 4a 45o bank angle 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
START- 10: 0:50 STOP- 10: 2:56 TOP ANTENNA FLIGHT DATE: 3/12/92 CPA TIME


Run 4a 45o bank angle 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
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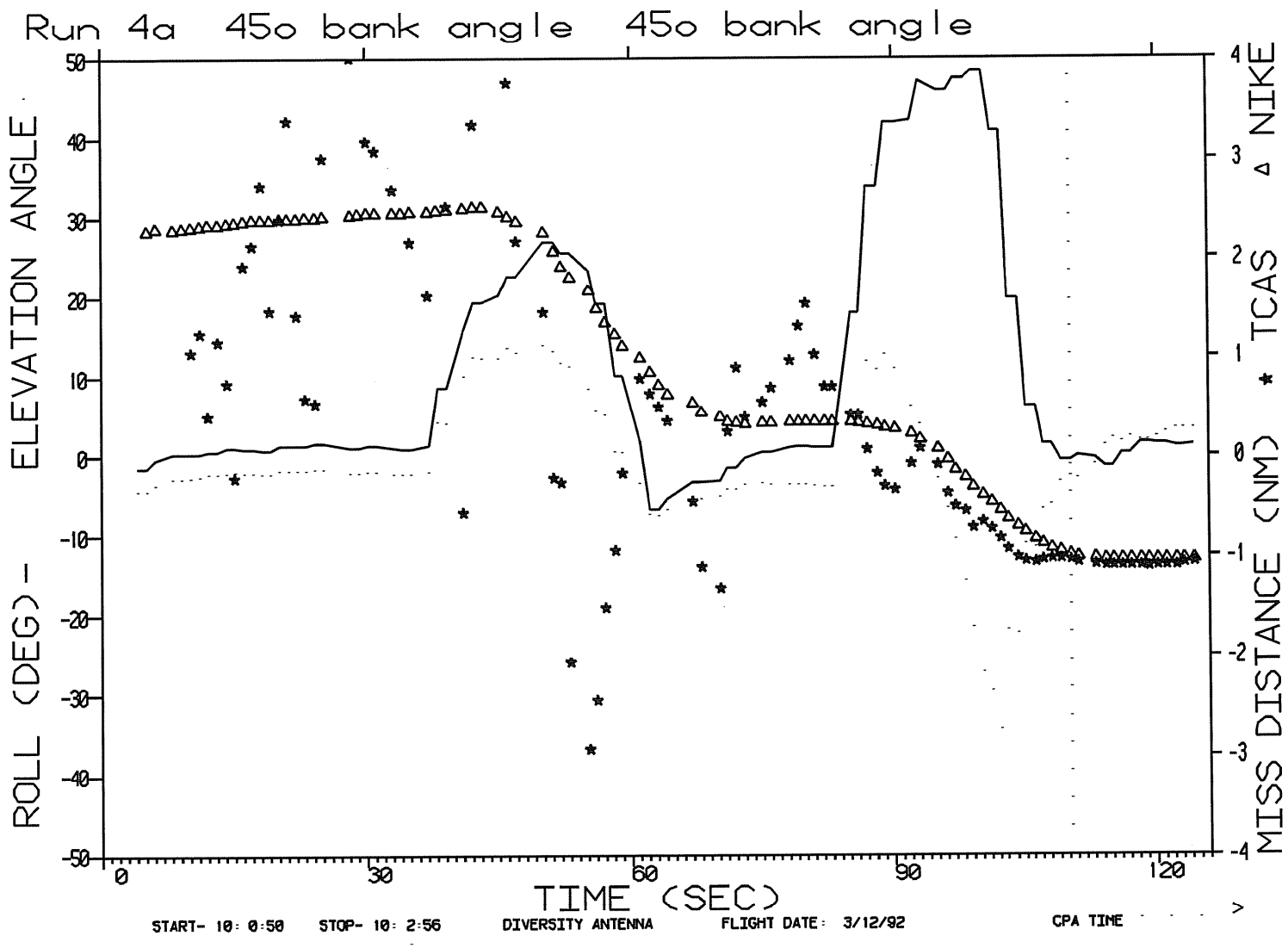
START- 10: 0:50
STOP- 10: 2:56
BOTTOM ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME


Run 4a 45o bank angle 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
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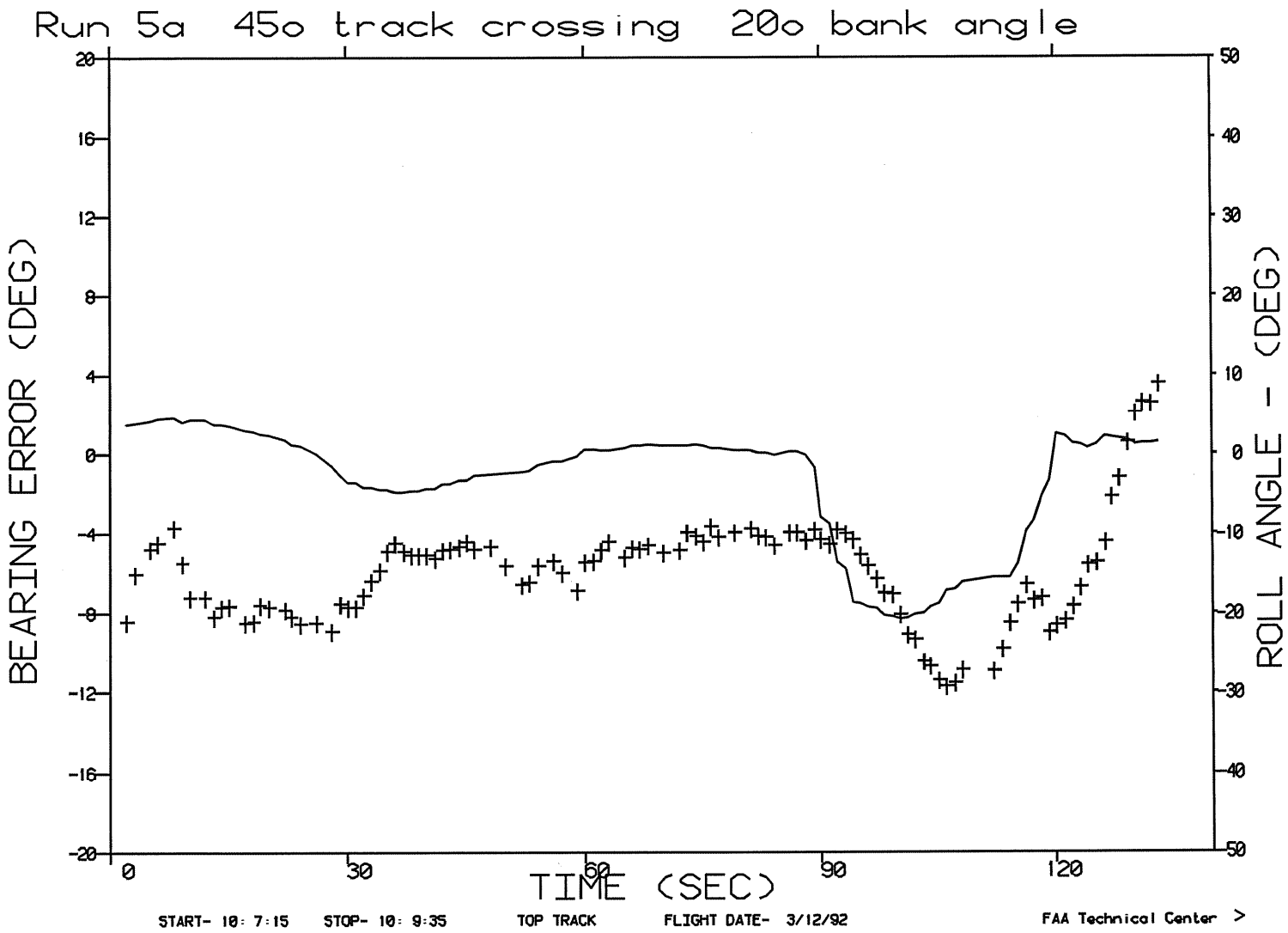
START- 10: 0:50
STOP- 10: 2:56
DIVERSITY ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME


Run 5a 45o track crossing 20o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
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4
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-4
-8
-12
-16
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-10
-20
-30
-40
-50
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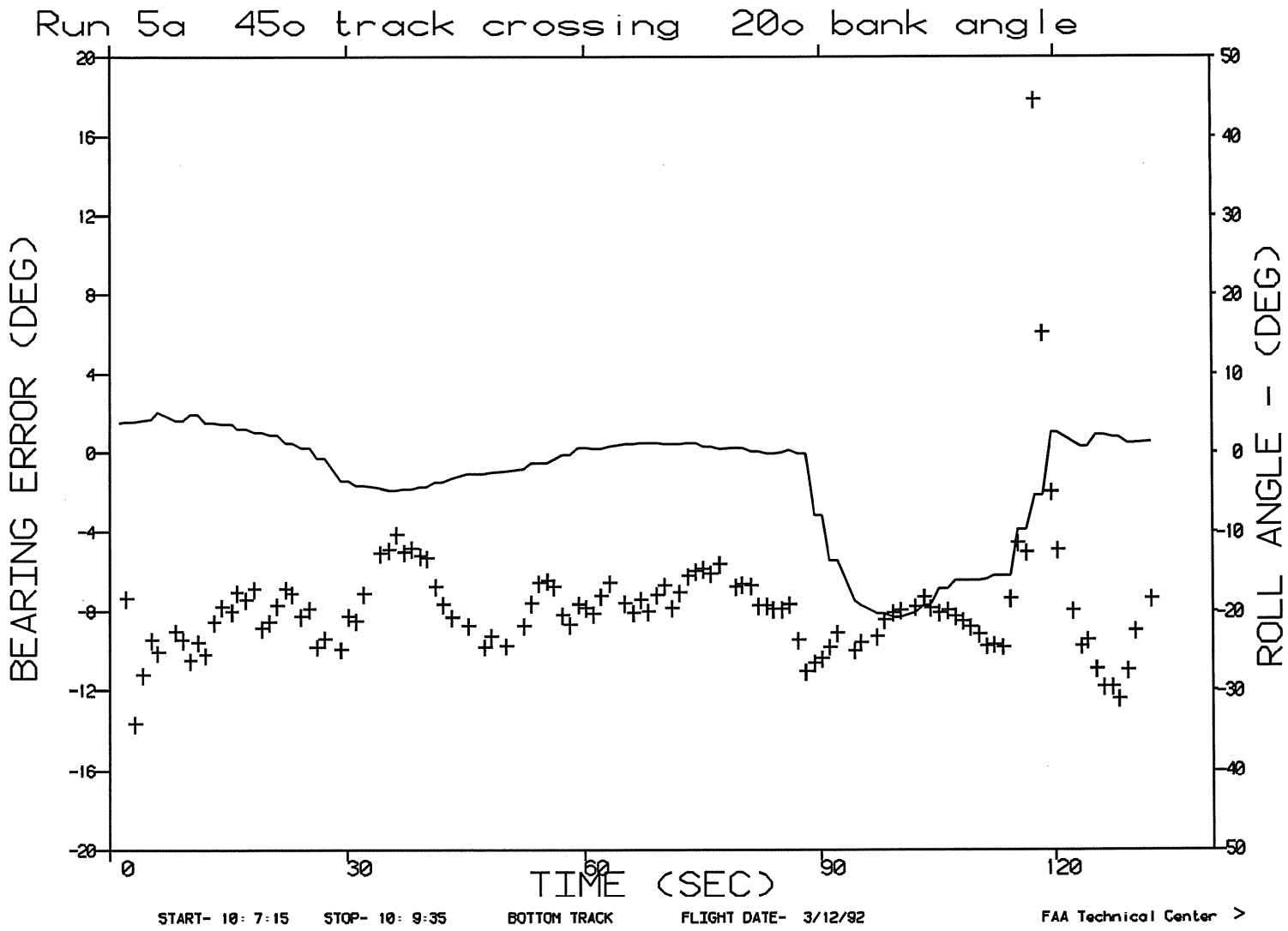
120
START- 10: 7:15
STOP- 10: 9:35
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 5a 45o track crossing 20o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
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-40
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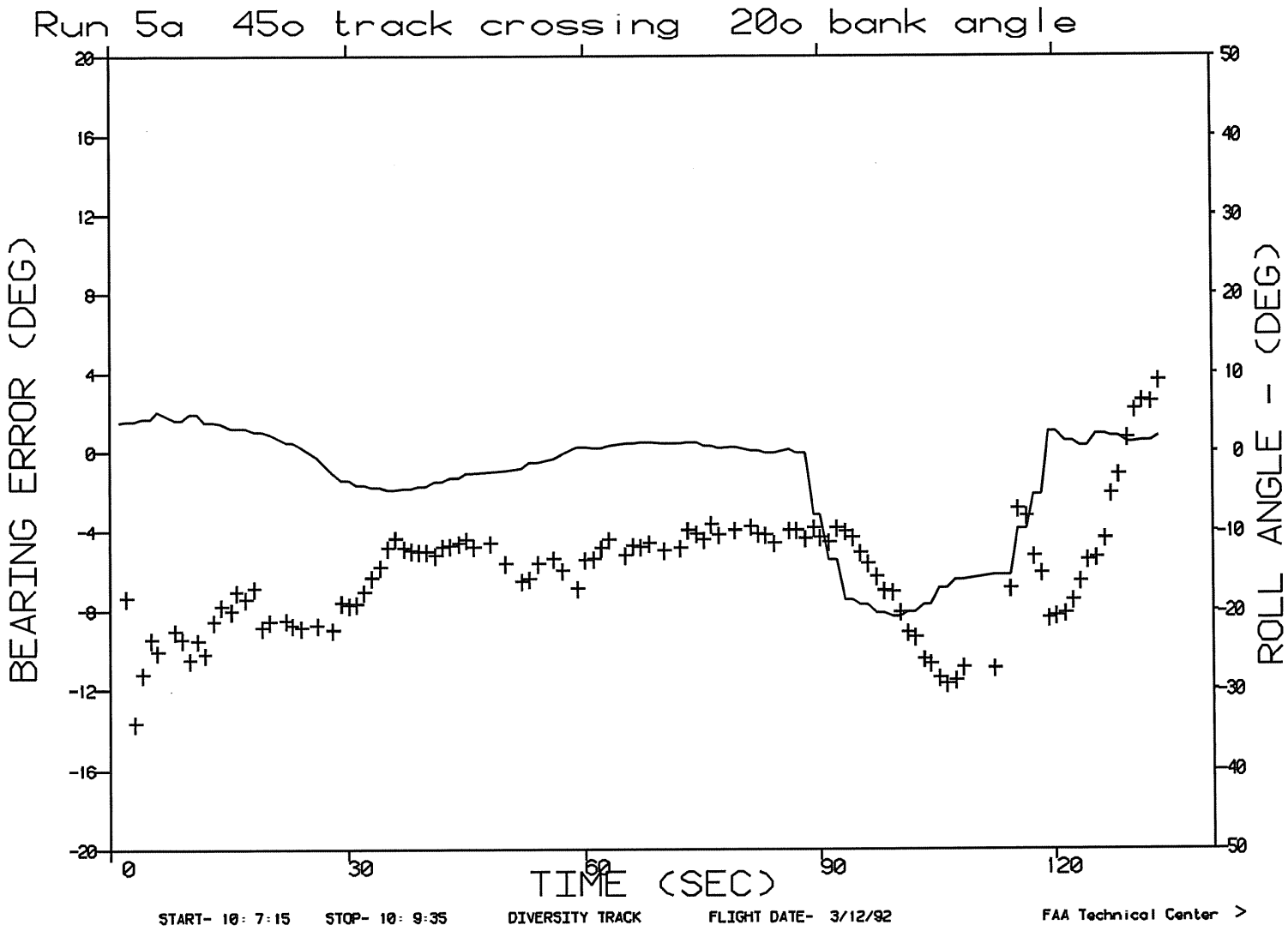
120
START- 10: 7:15
STOP- 10: 9:35
BOTTOM TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 5a 45o track crossing 20o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
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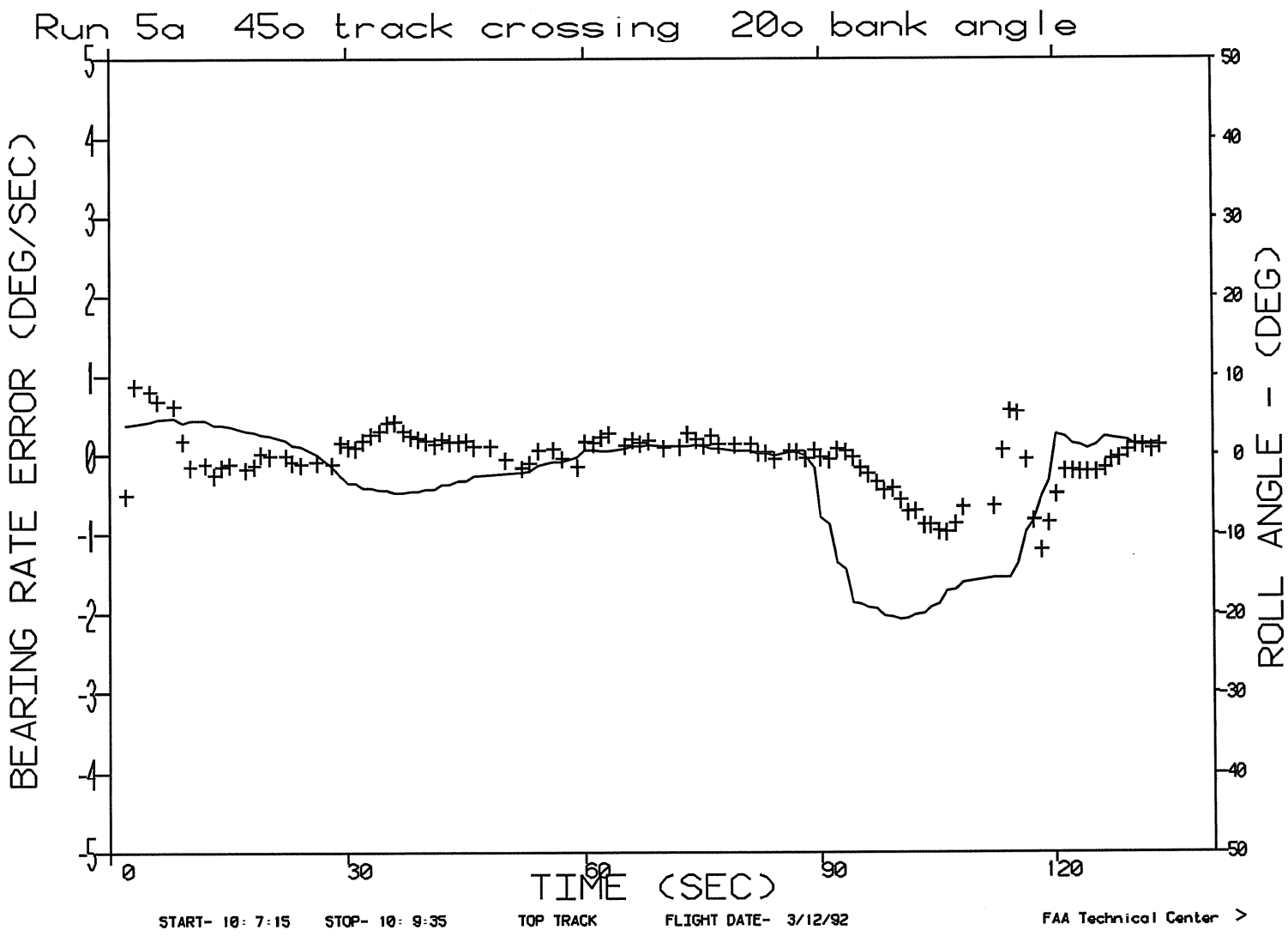
START- 10: 7:15
STOP- 10: 9:35
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 5a 45o track crossing 20o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
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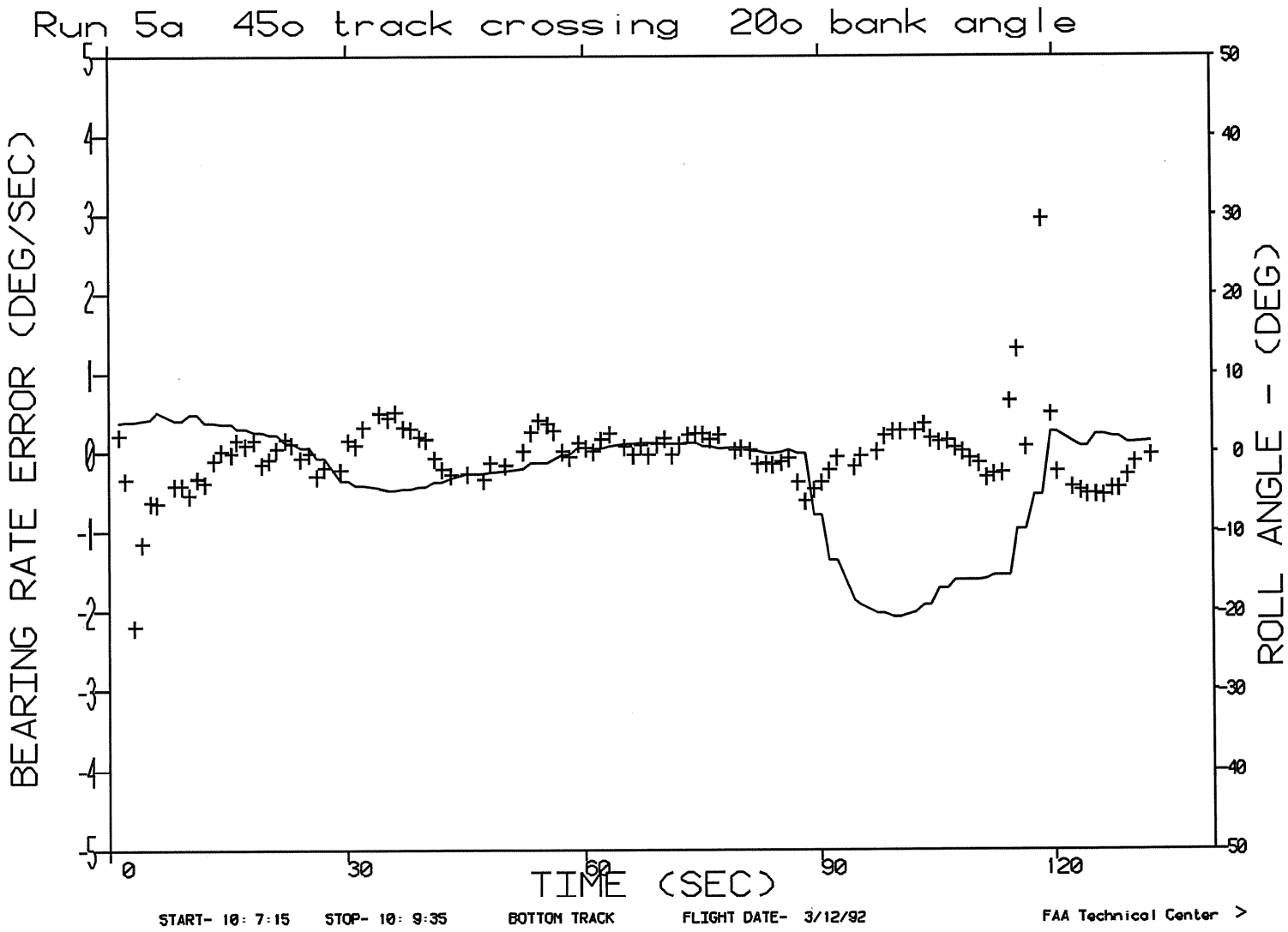
START- 10: 7:15
STOP- 10: 9:35
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 5a 45o track crossing 20o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
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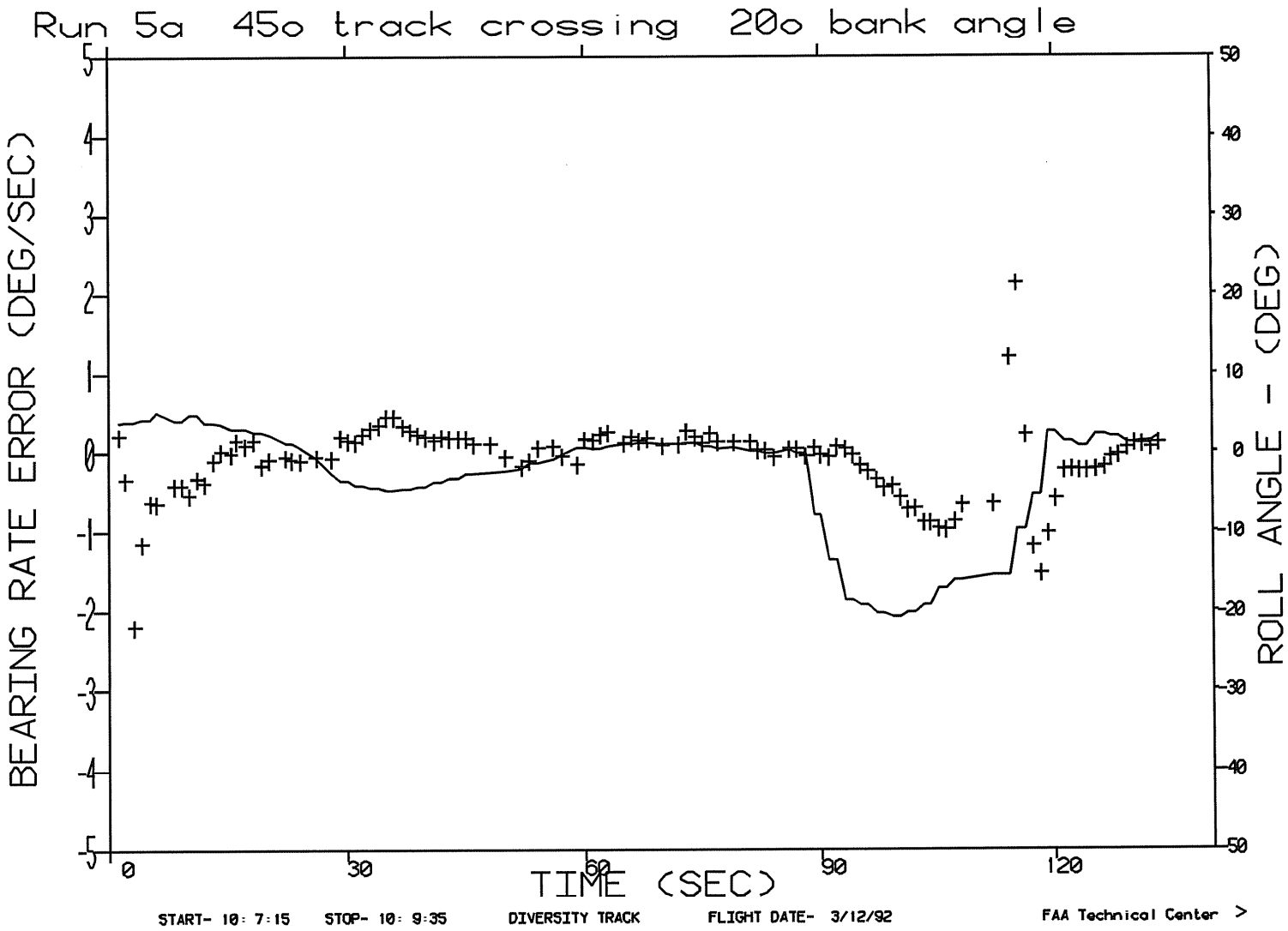
START- 10: 7:15
STOP- 10: 9:35
BOTTOM TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 5a 45o track crossing 20o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
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4
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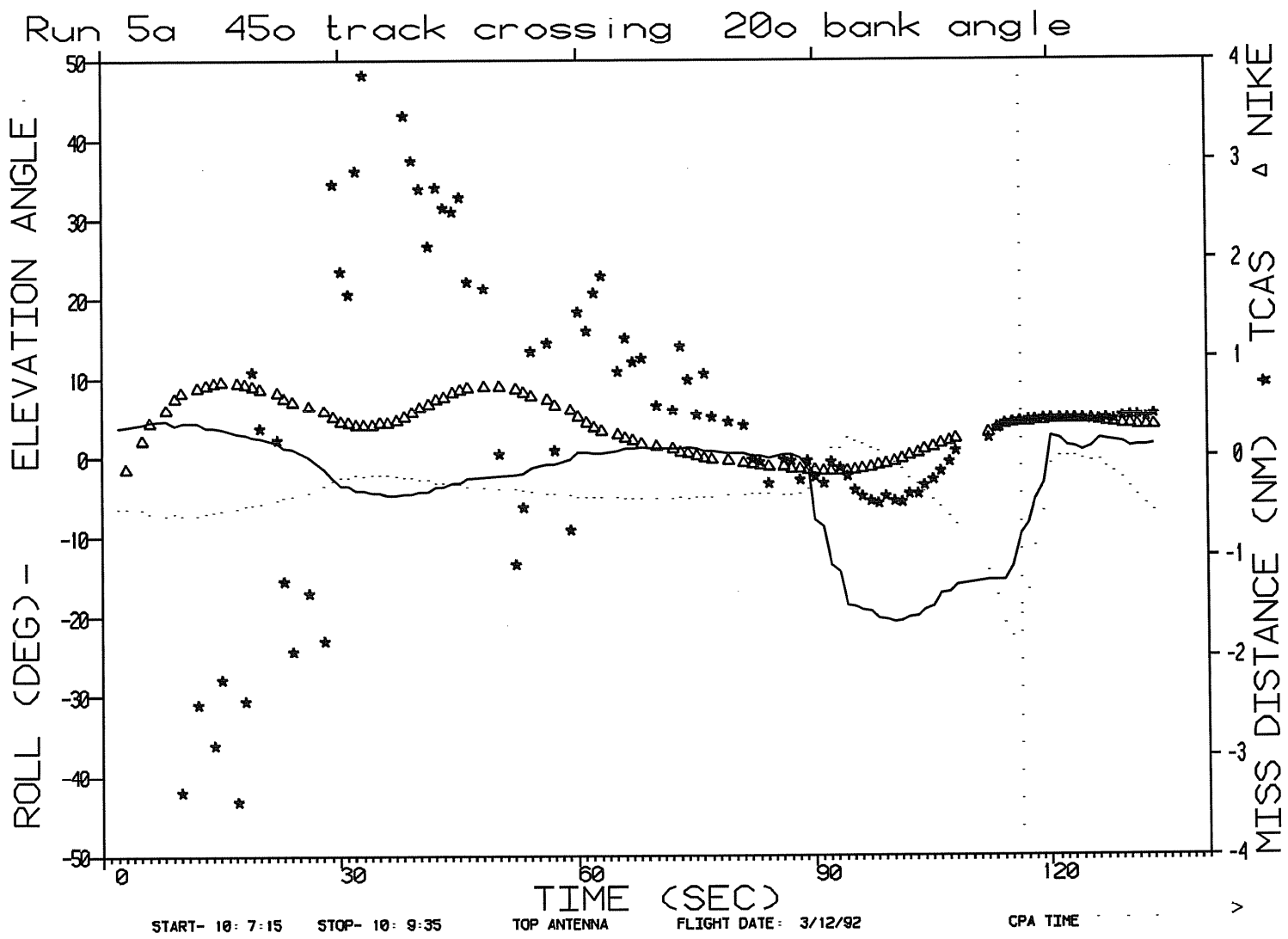
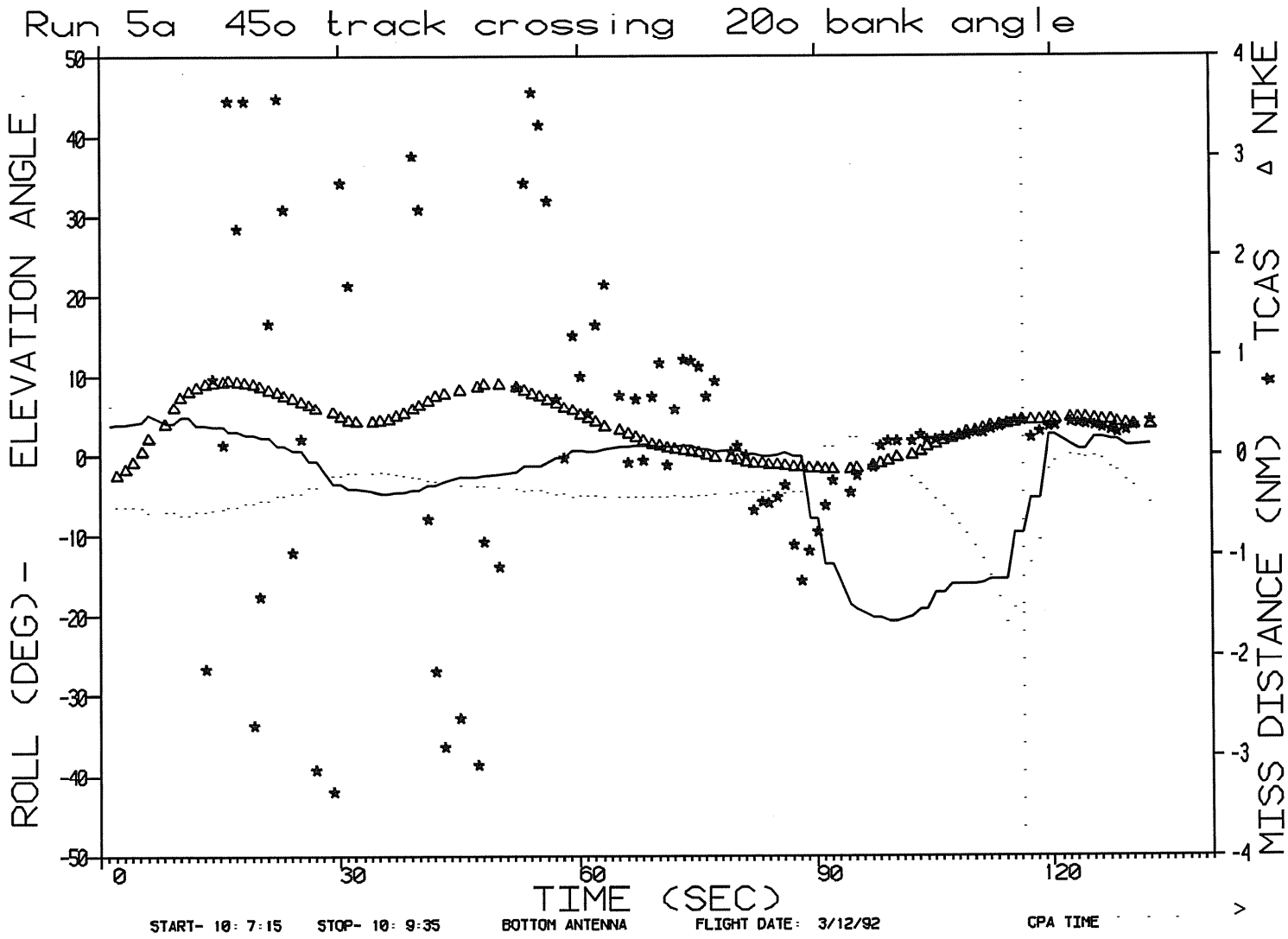
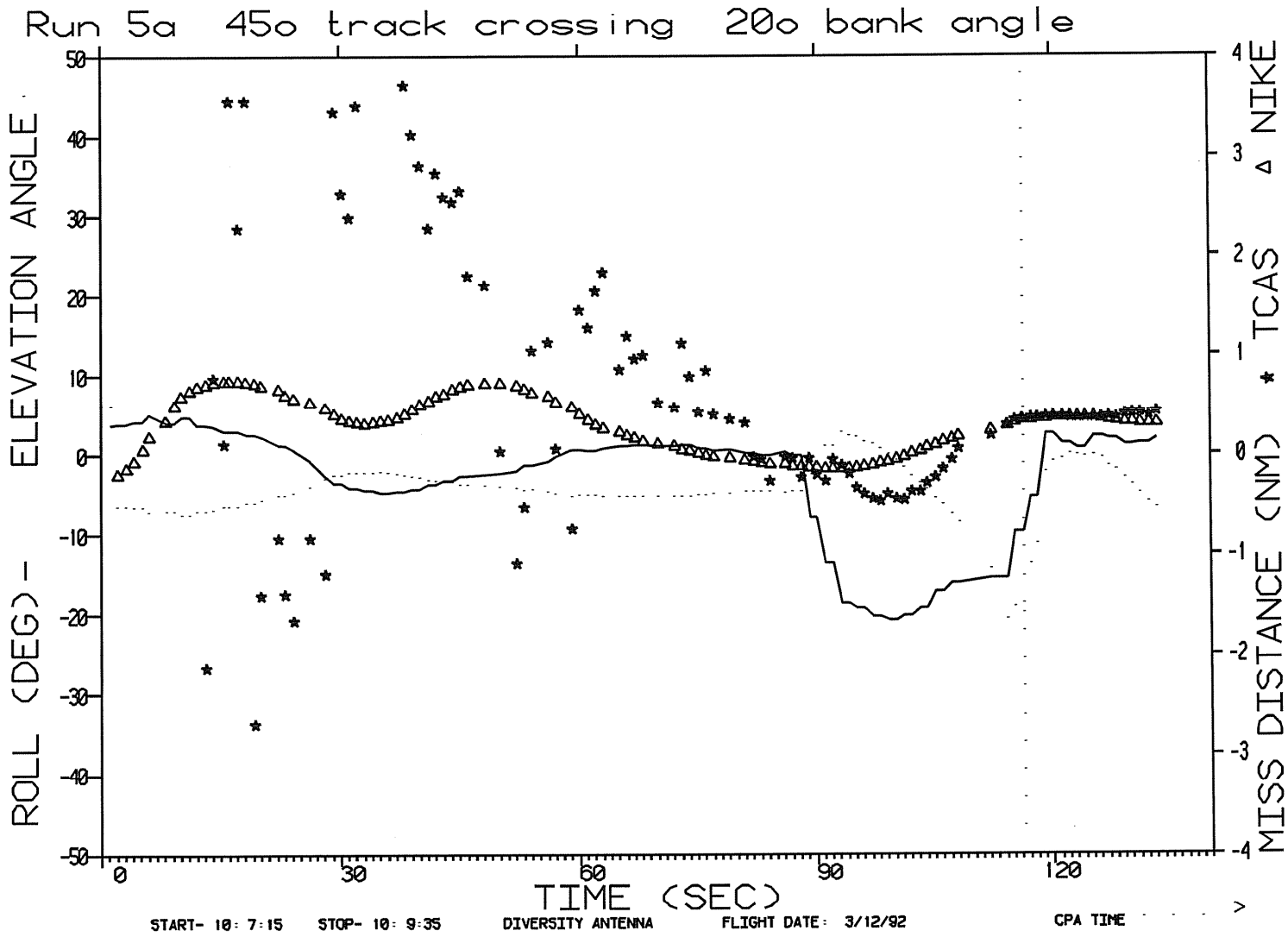
120
START- 10: 7:15
STOP- 10: 9:35
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 5a 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
START- 10: 7:15
STOP- 10: 9:35
TOP ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME


Run 5a 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
START- 10: 7:15
STOP- 10: 9:35
BOTTOM ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME


Run 5a 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
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-40
-50
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-1
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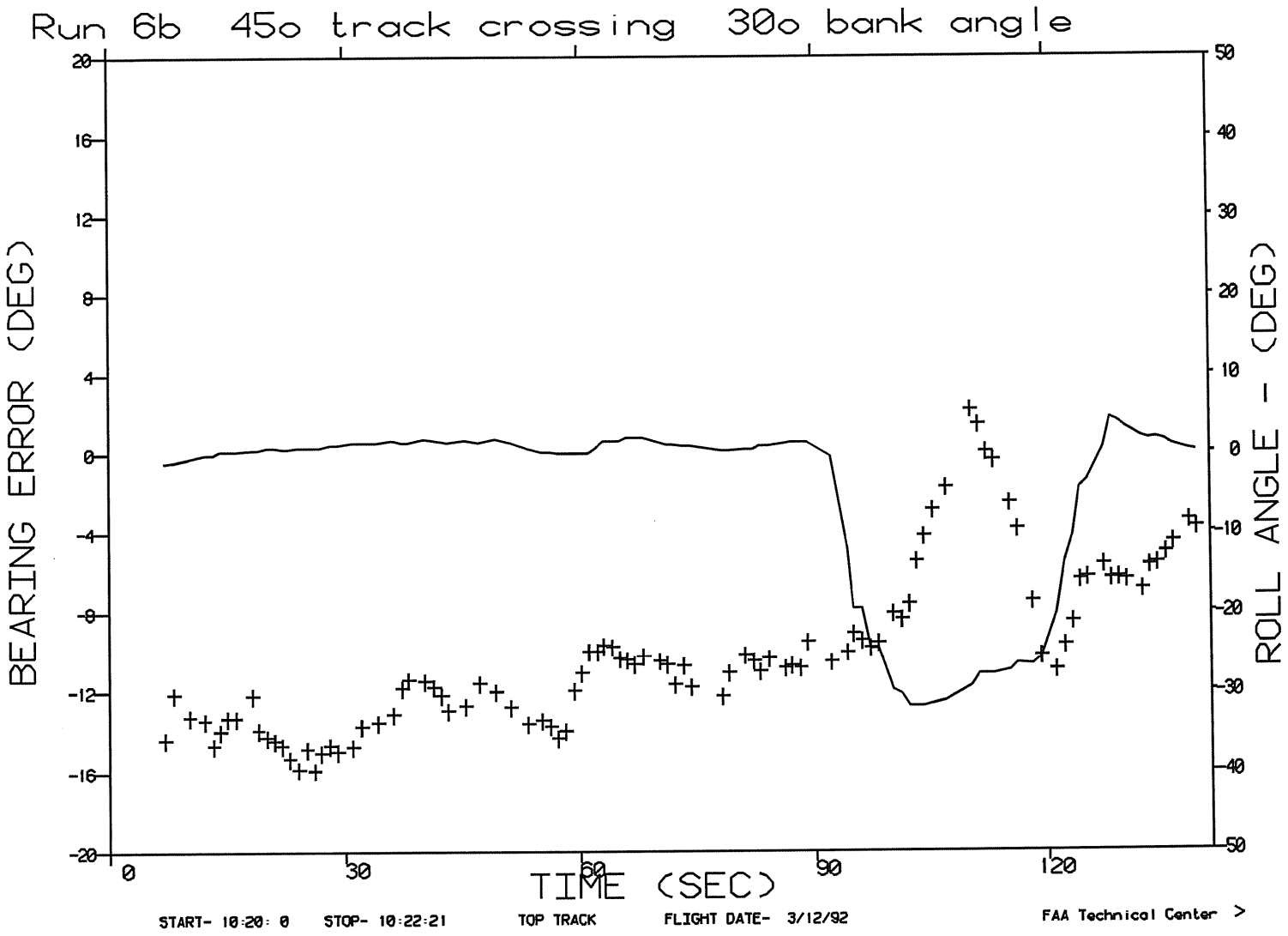
90
120
START- 10: 7:15
STOP- 10: 9:35
DIVERSITY ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME


Run 6b 45o track crossing 30o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
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-4
-8
-12
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-20
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10
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-10
-20
-30
-40
-50
0
30
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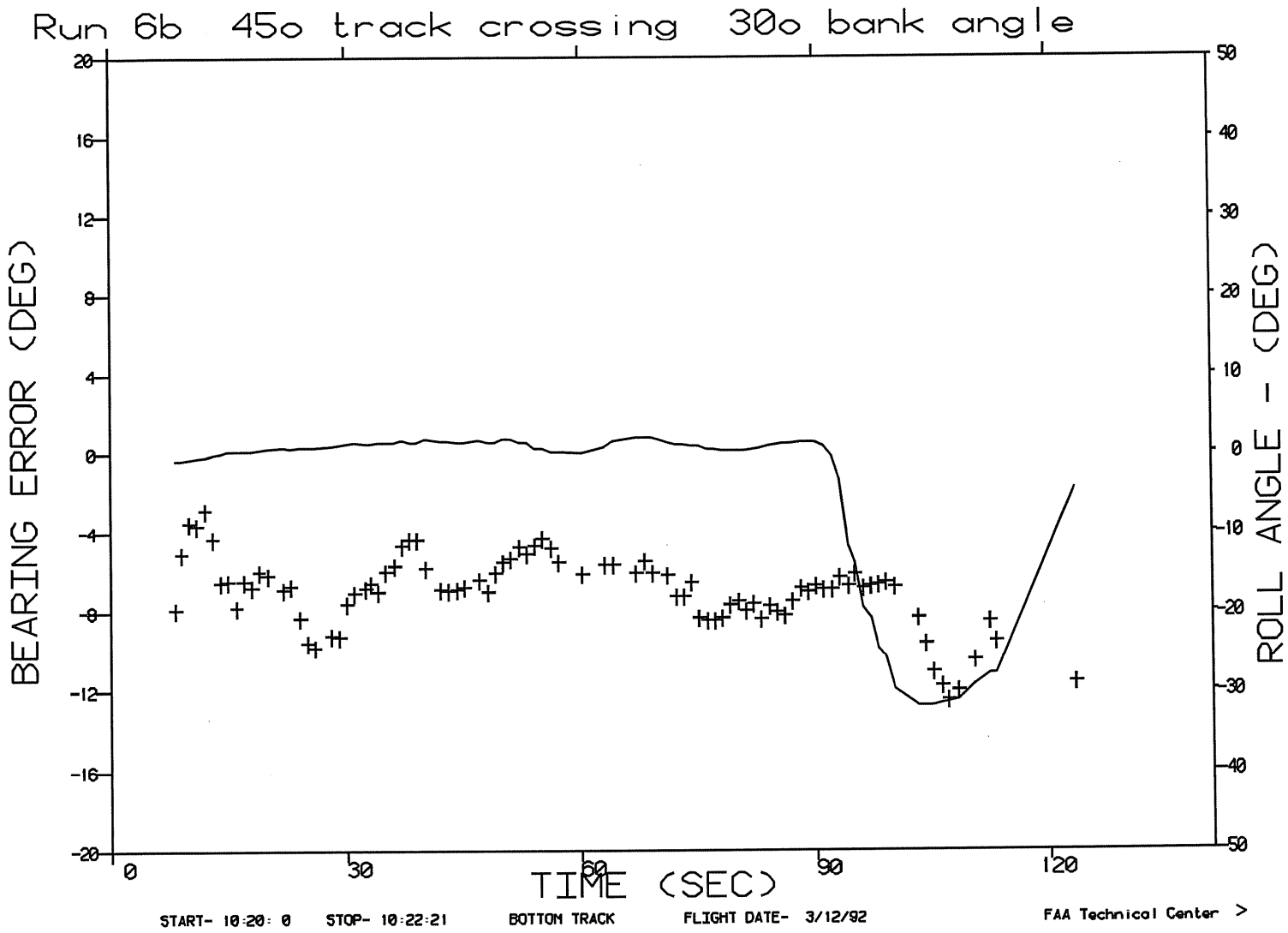
90
120
START- 10:20: 0
STOP- 10:22:21
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 6b 45o track crossing 30o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
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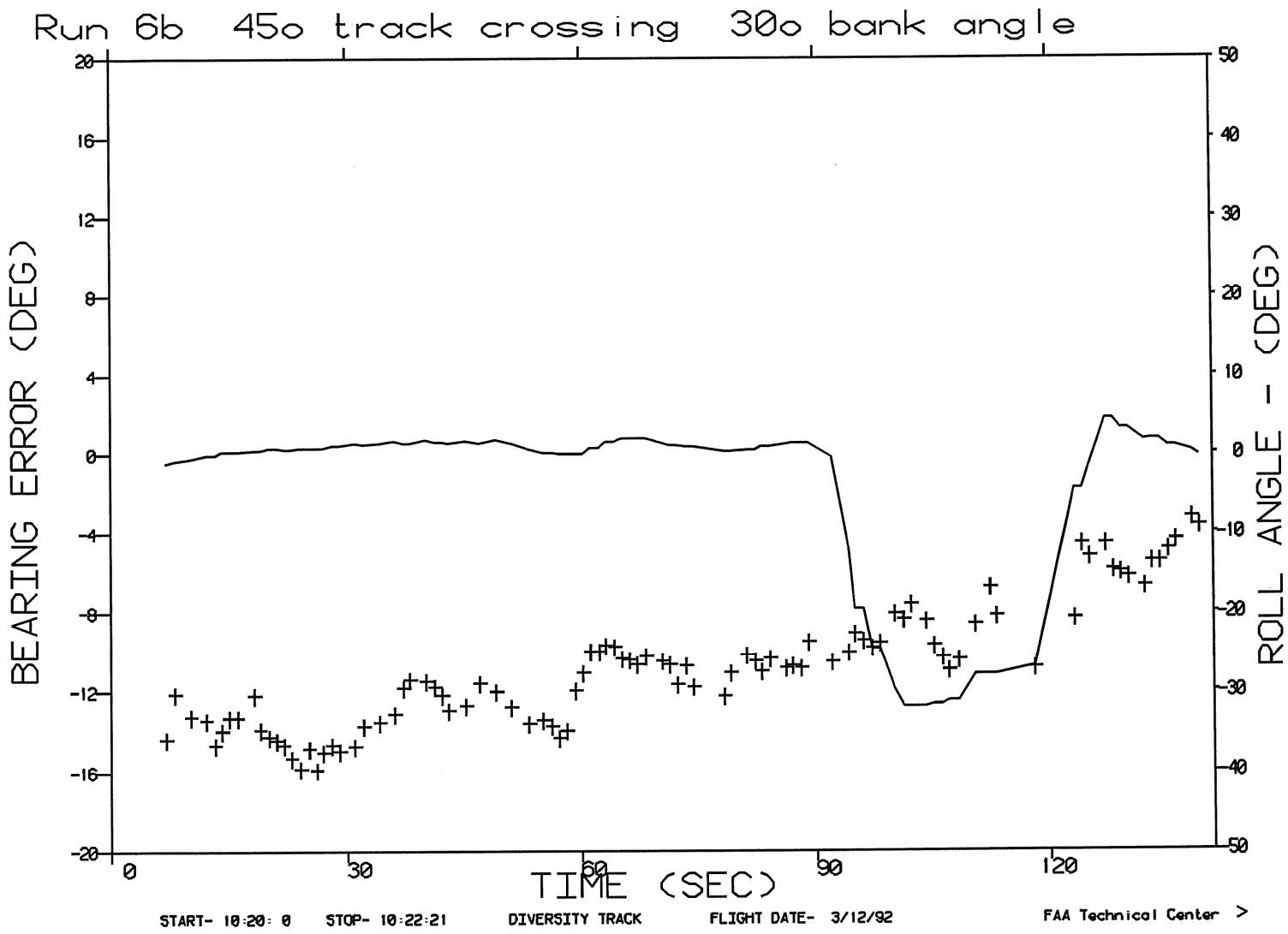
-30
-40
-50
0
30
60
90
120
START- 10:20: 0
STOP- 10:22:21
BOTTOM TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 6b 45o track crossing 30o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
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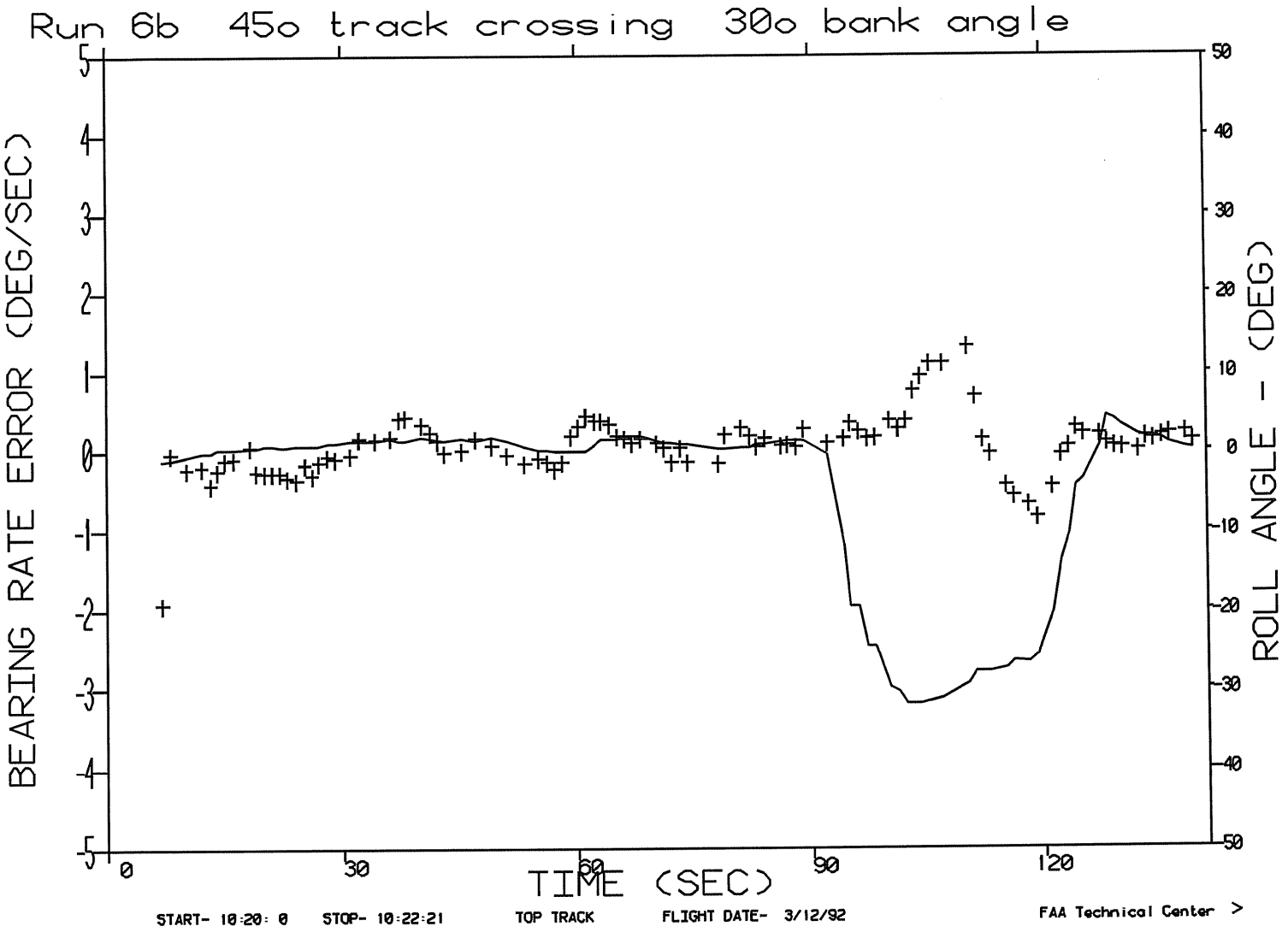
120
START- 10:20: 0
STOP- 10:22:21
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 6b 45o track crossing 30o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
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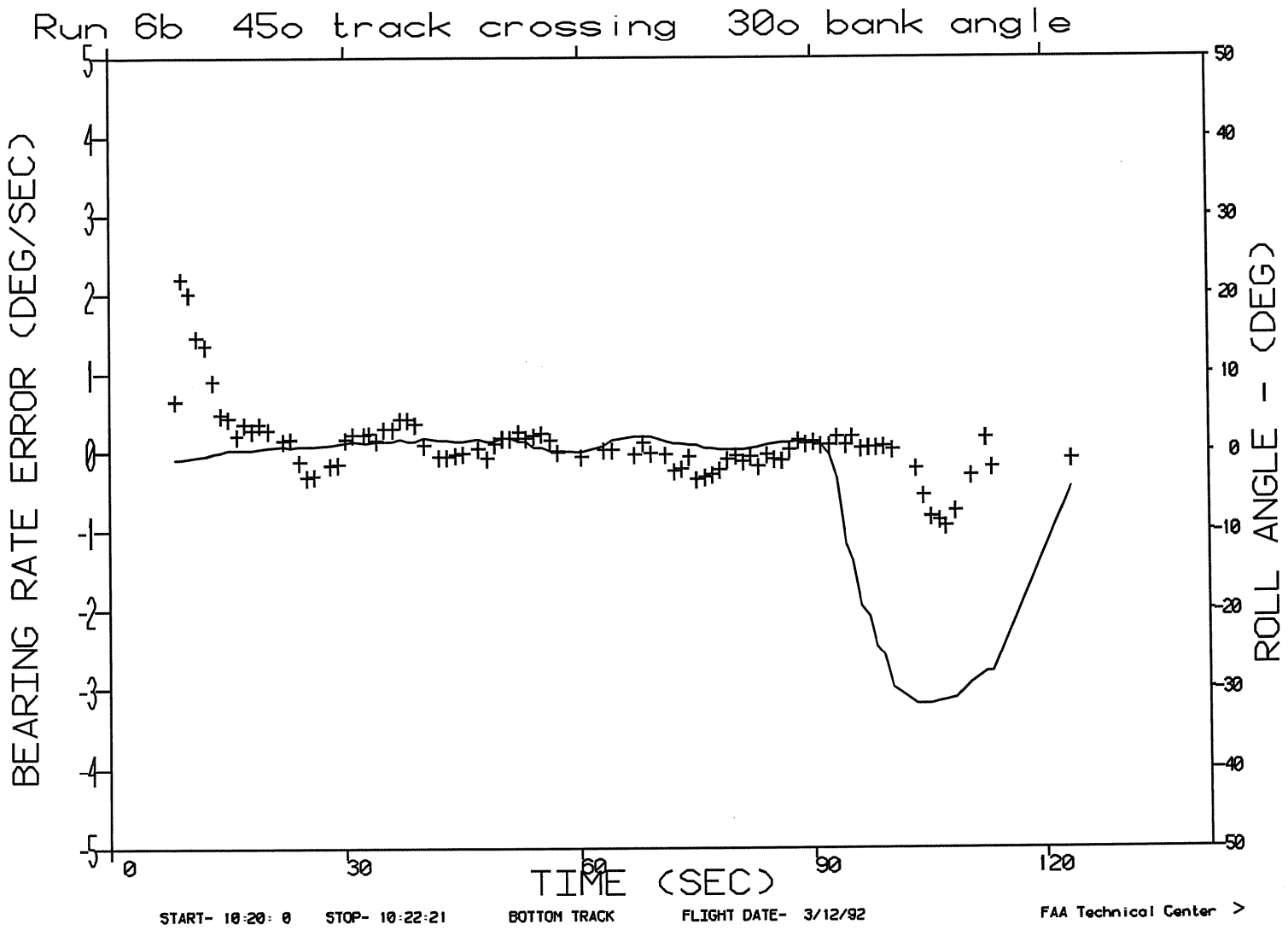
120
START- 10:20: 0
STOP- 10:22:21
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 6b 45o track crossing 30o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
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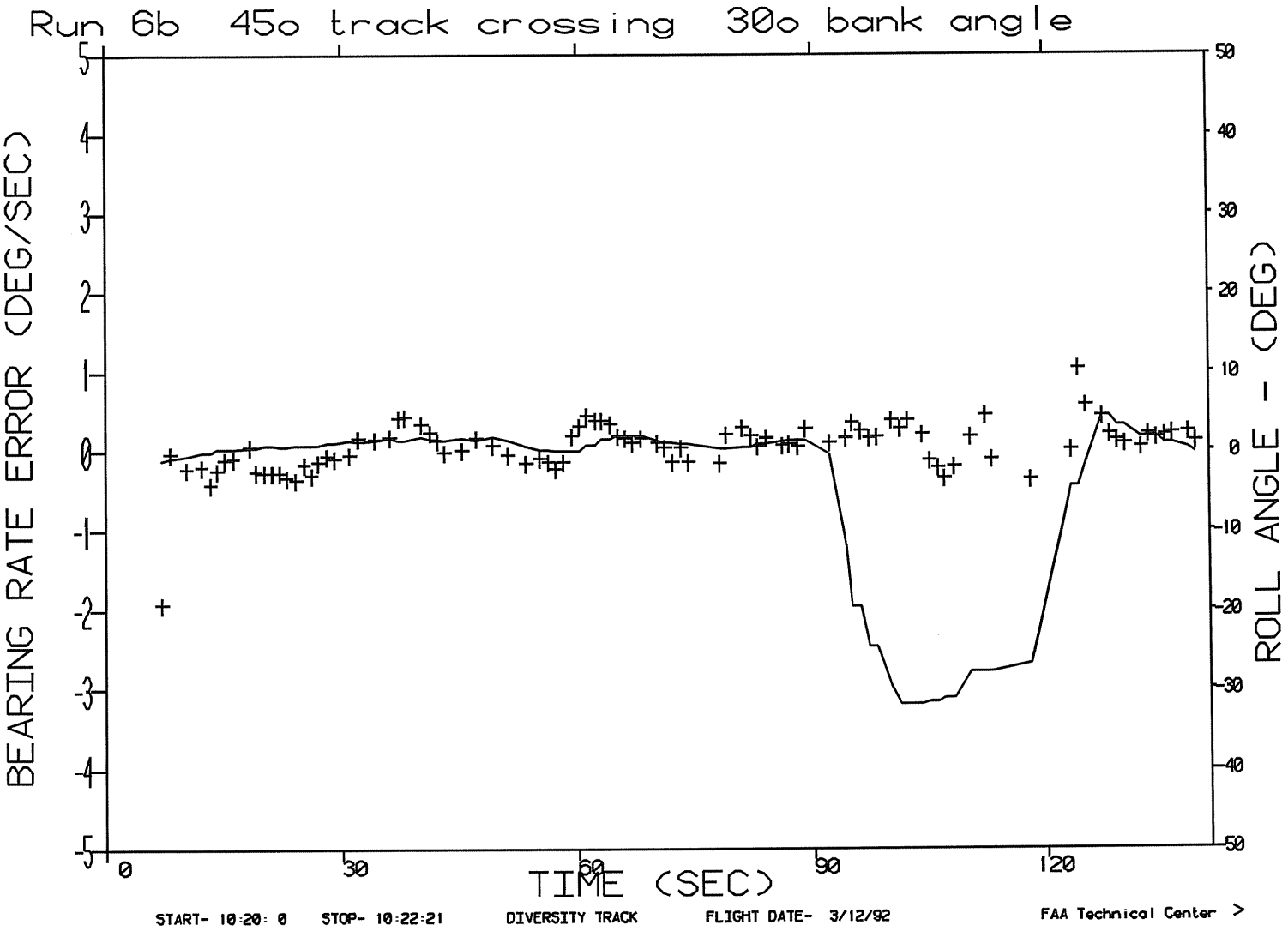
START- 10:20: 0
STOP- 10:22:21
BOTTOM TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 6b 45o track crossing 30o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
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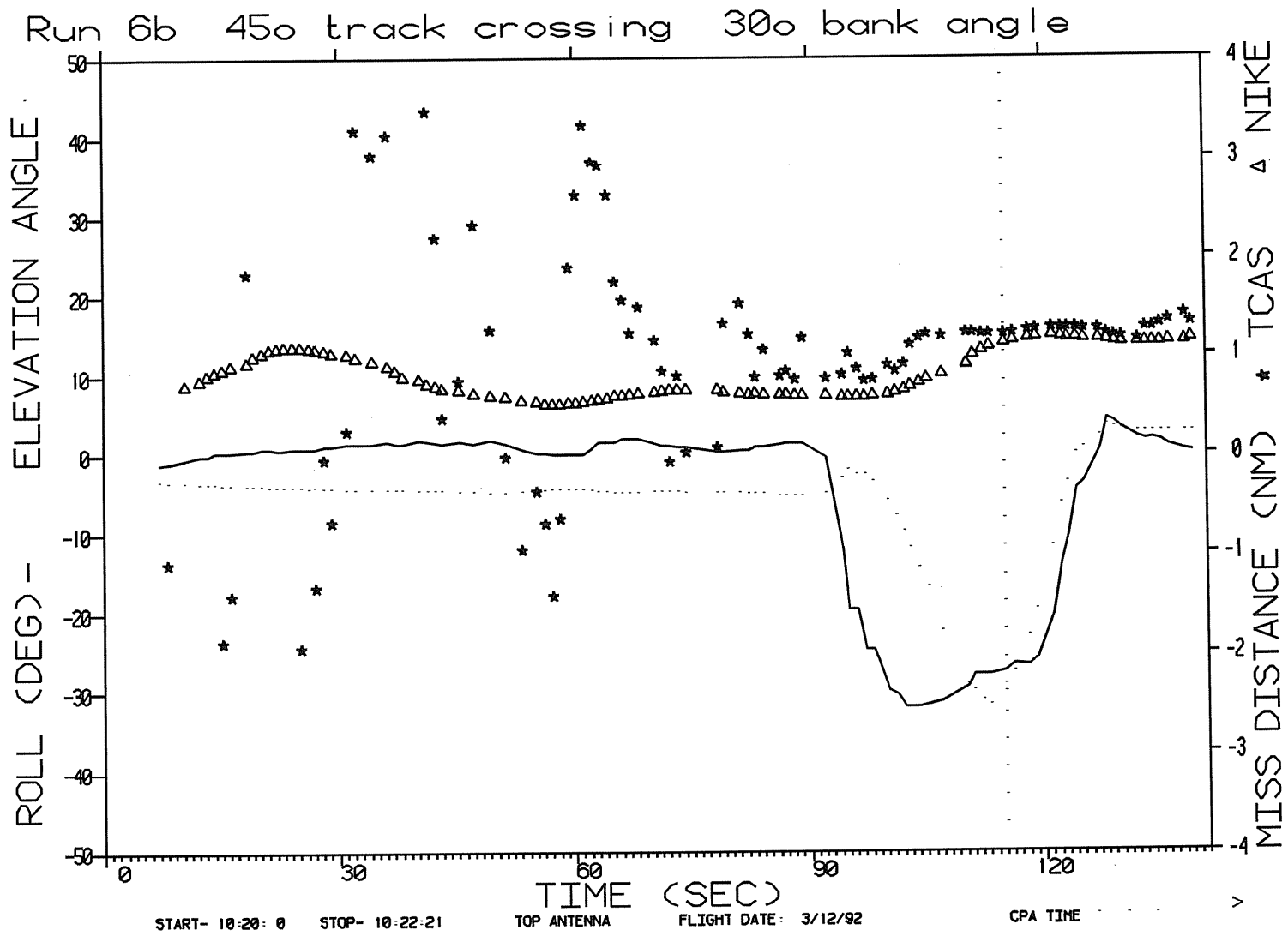
START- 10:20: 0
STOP- 10:22:21
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 6b 45o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
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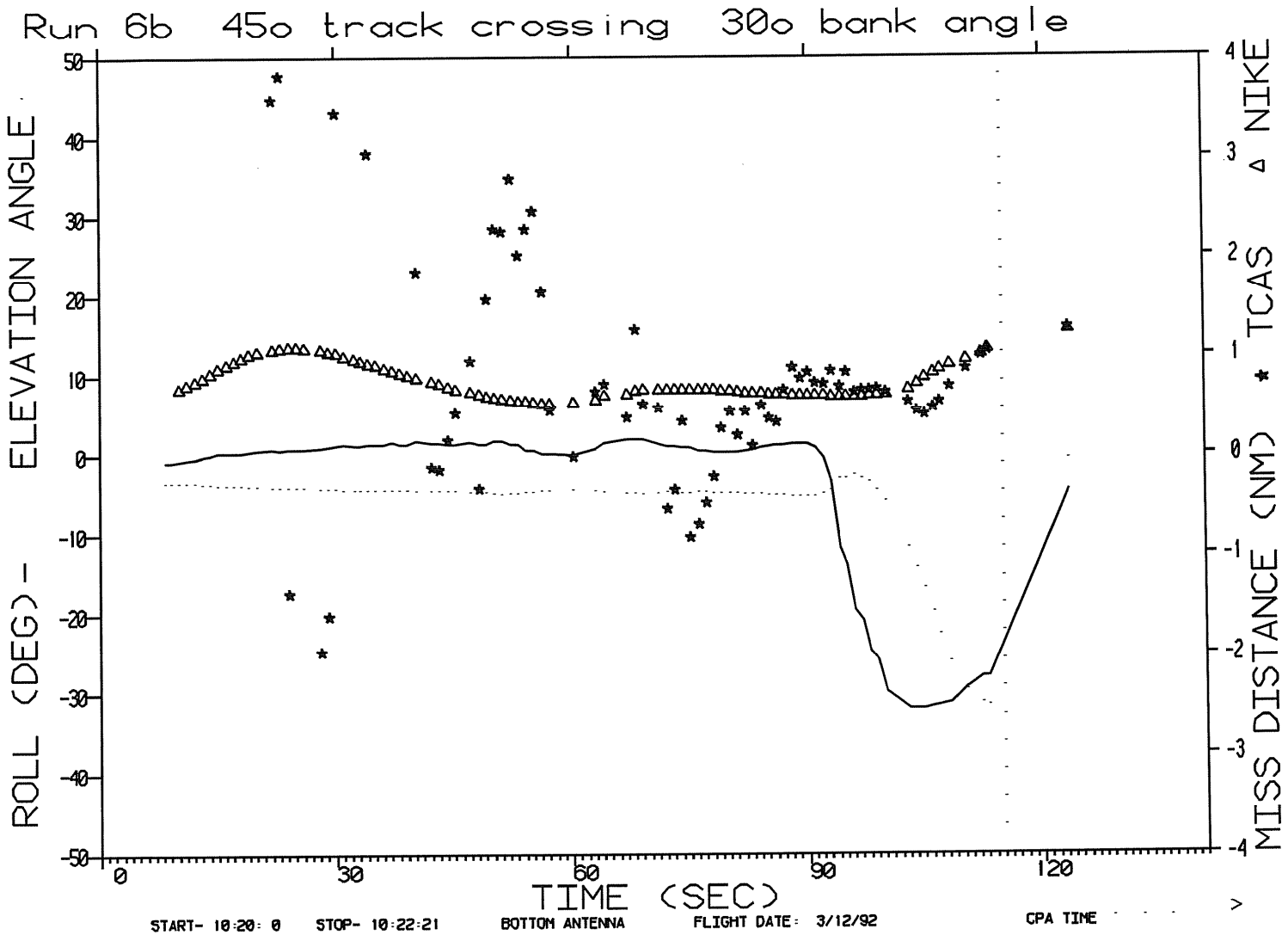
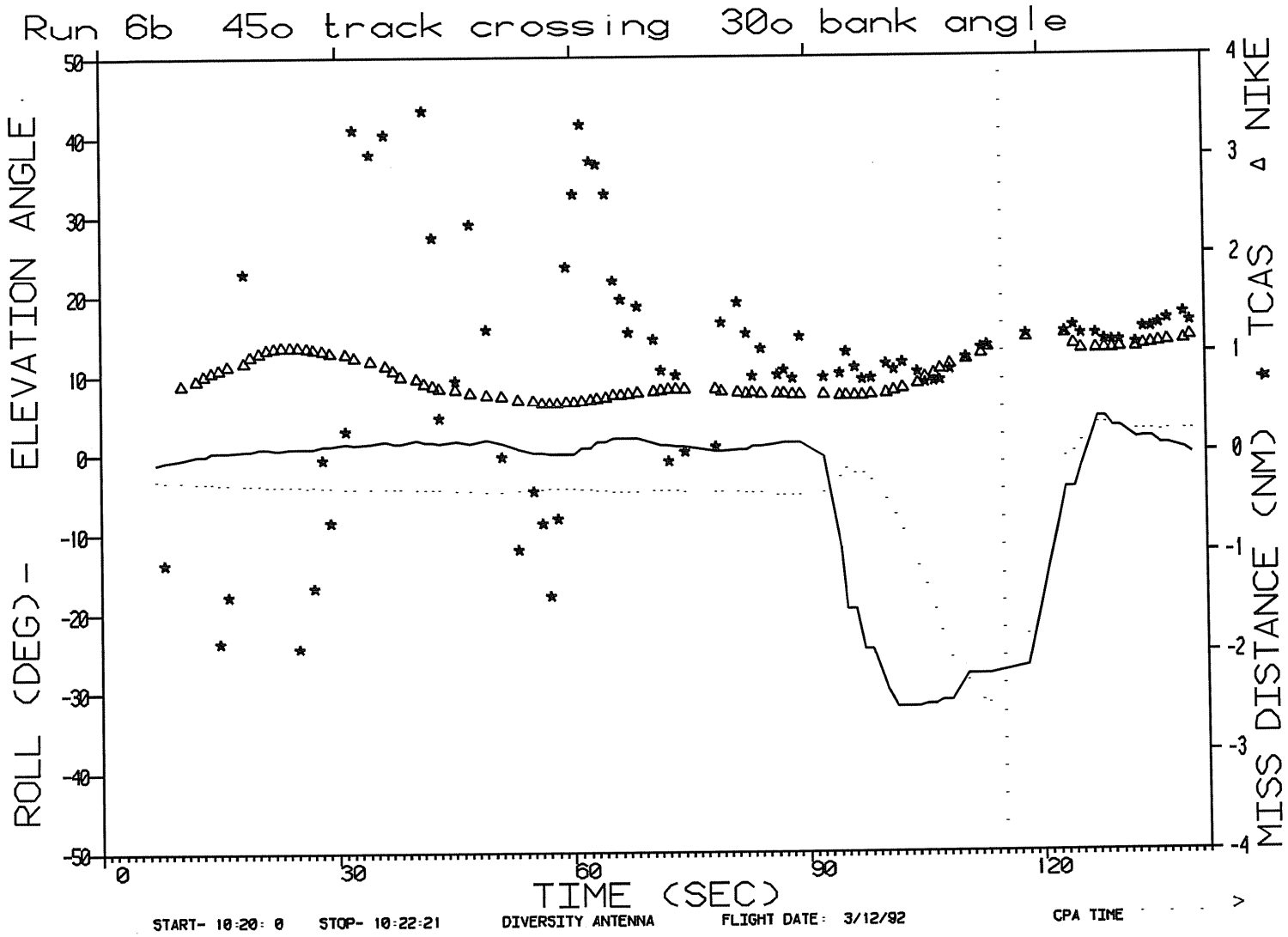
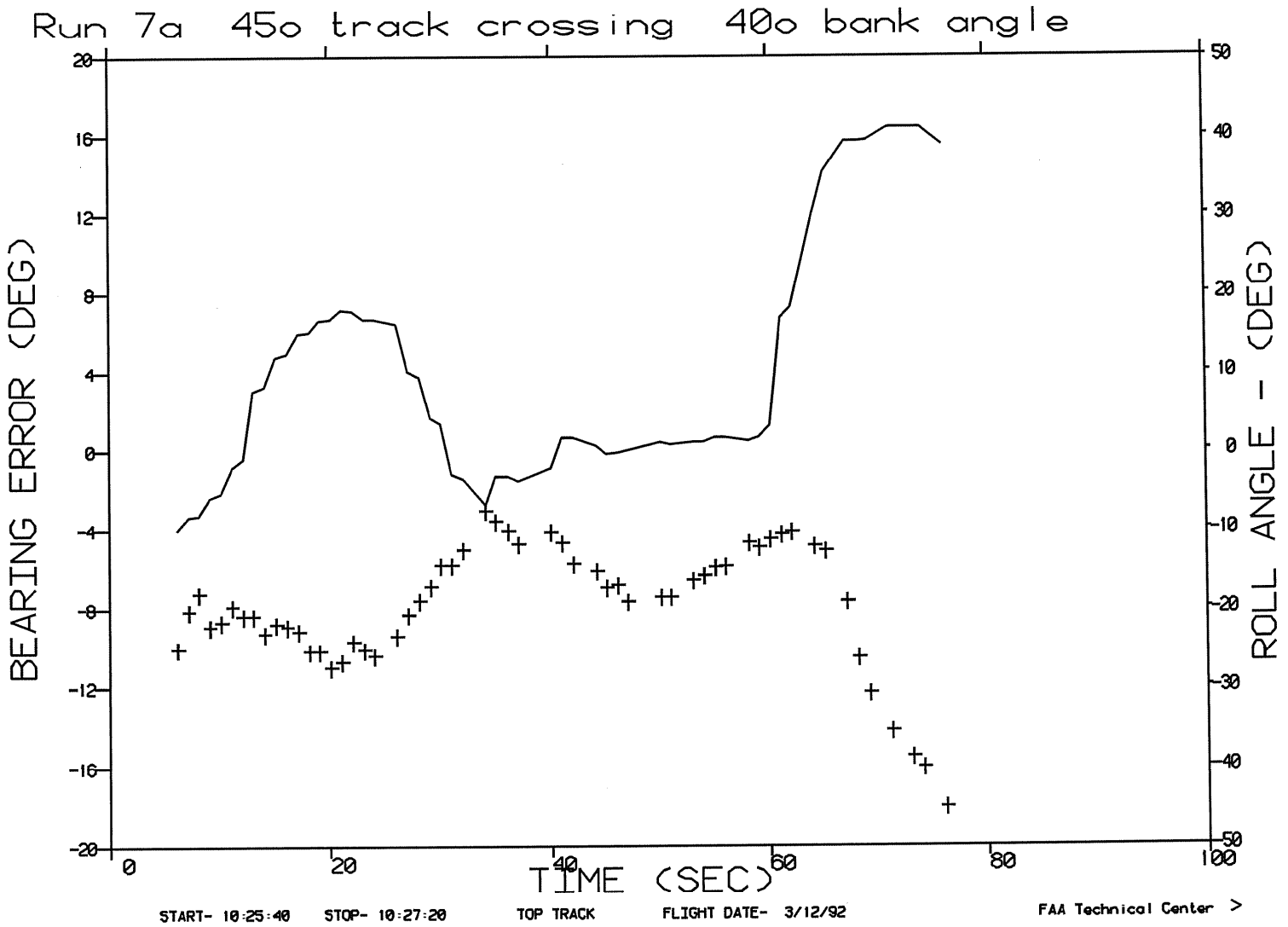
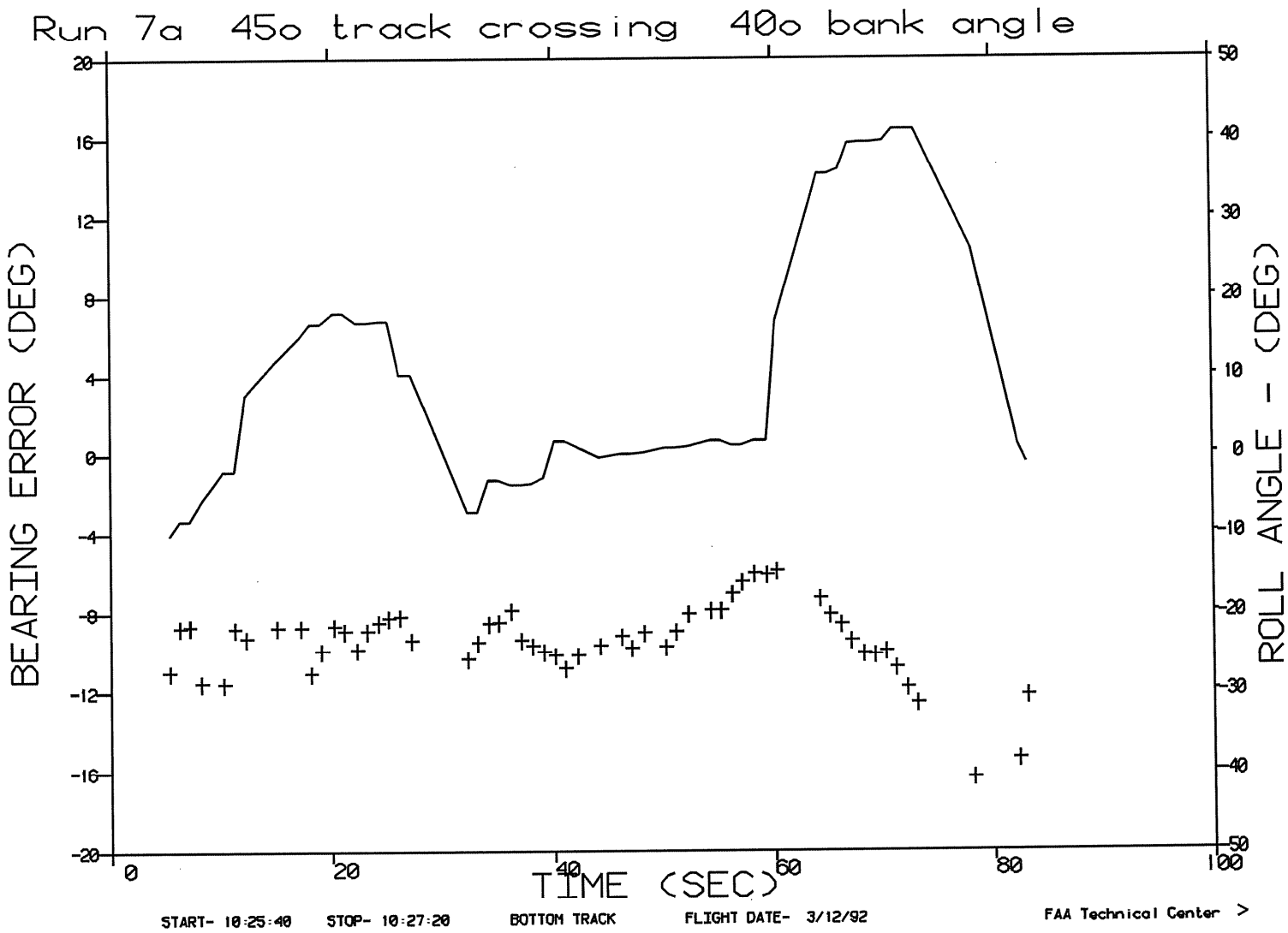
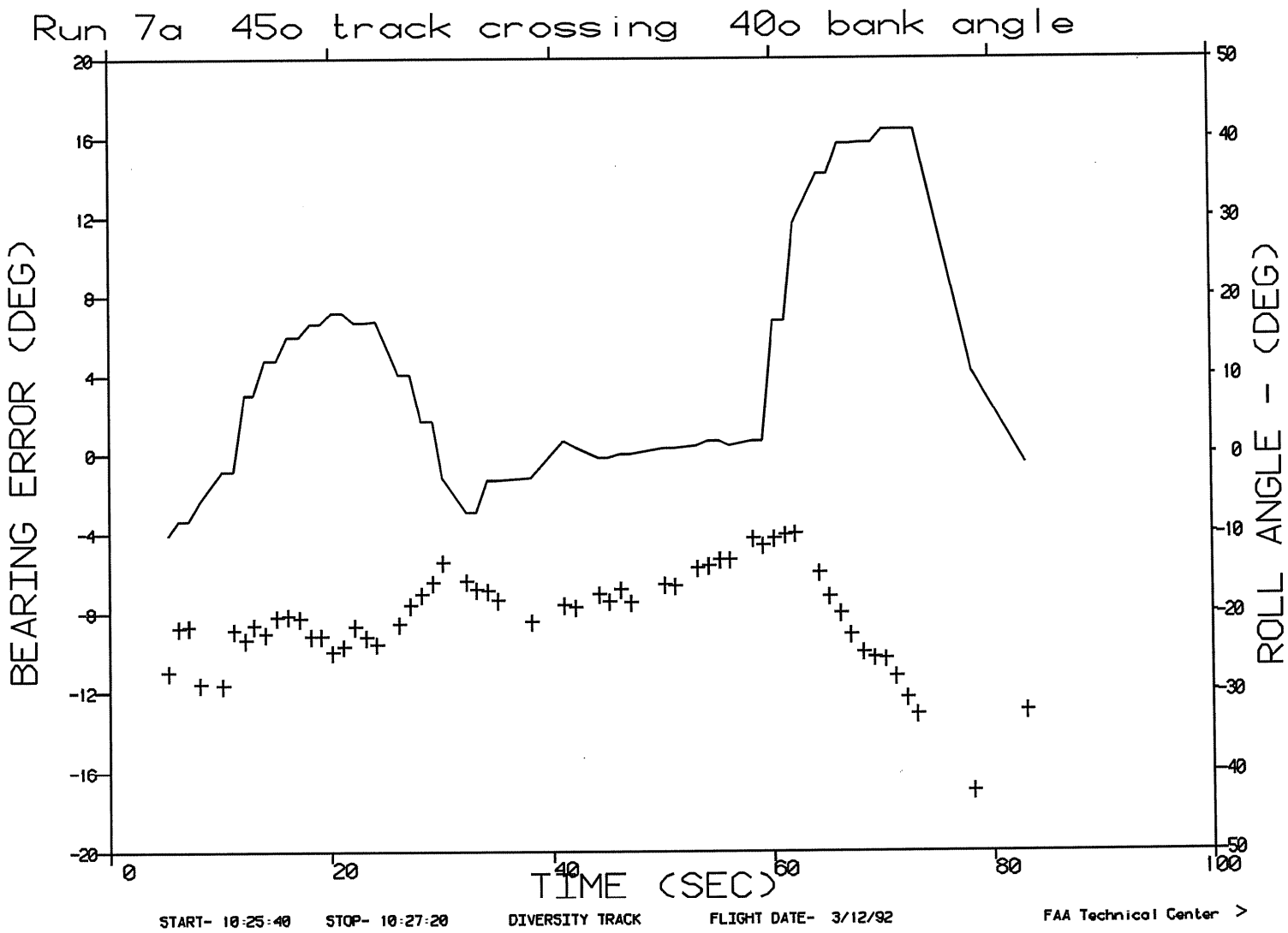
-2
-3
-4
0
30
60
90
120
START- 10:20: 0
STOP- 10:22:21
TOP ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME

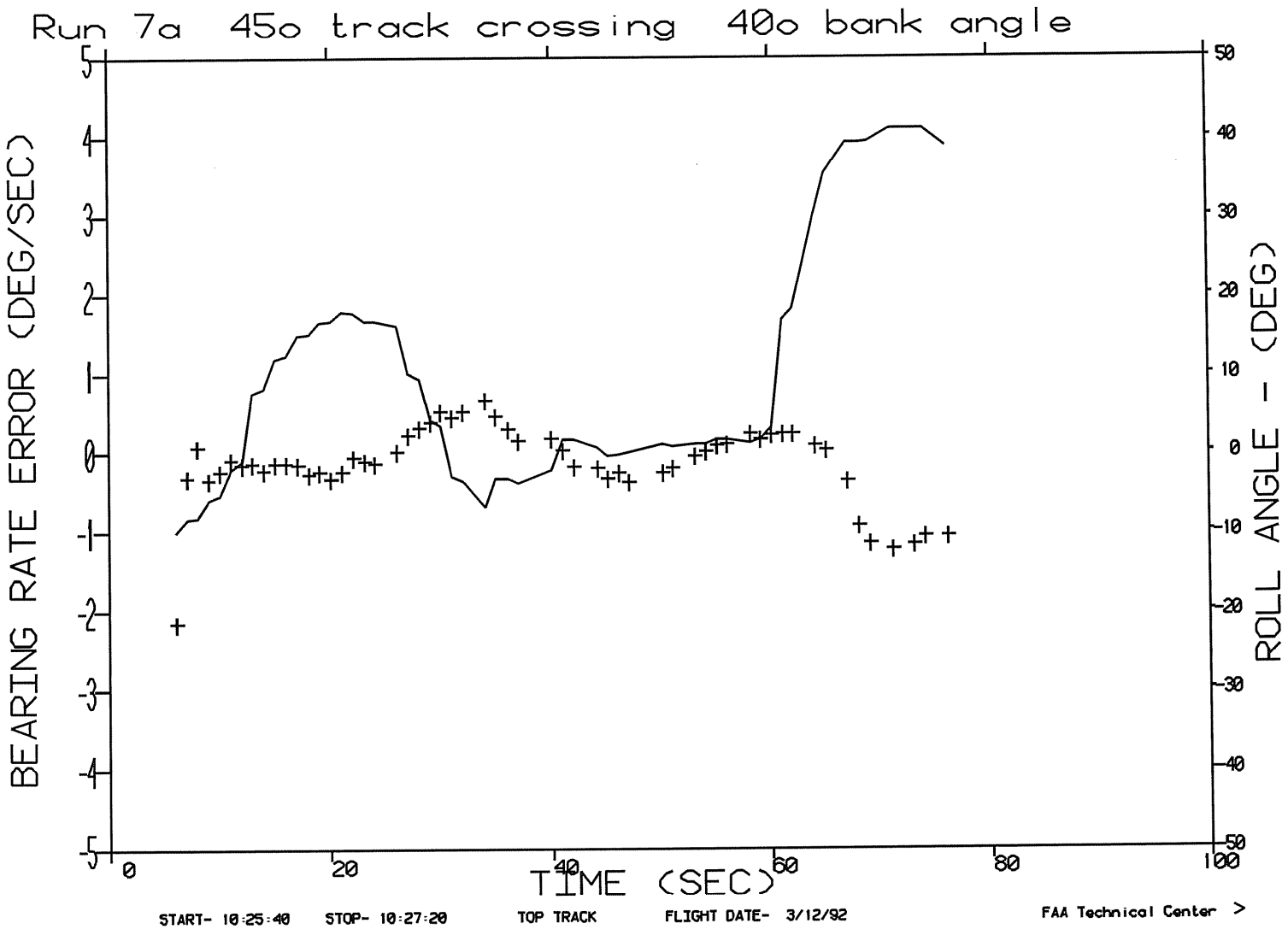

Run 6b 45o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
START- 10:20: 0
STOP- 10:22:21
BOTTOM ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME

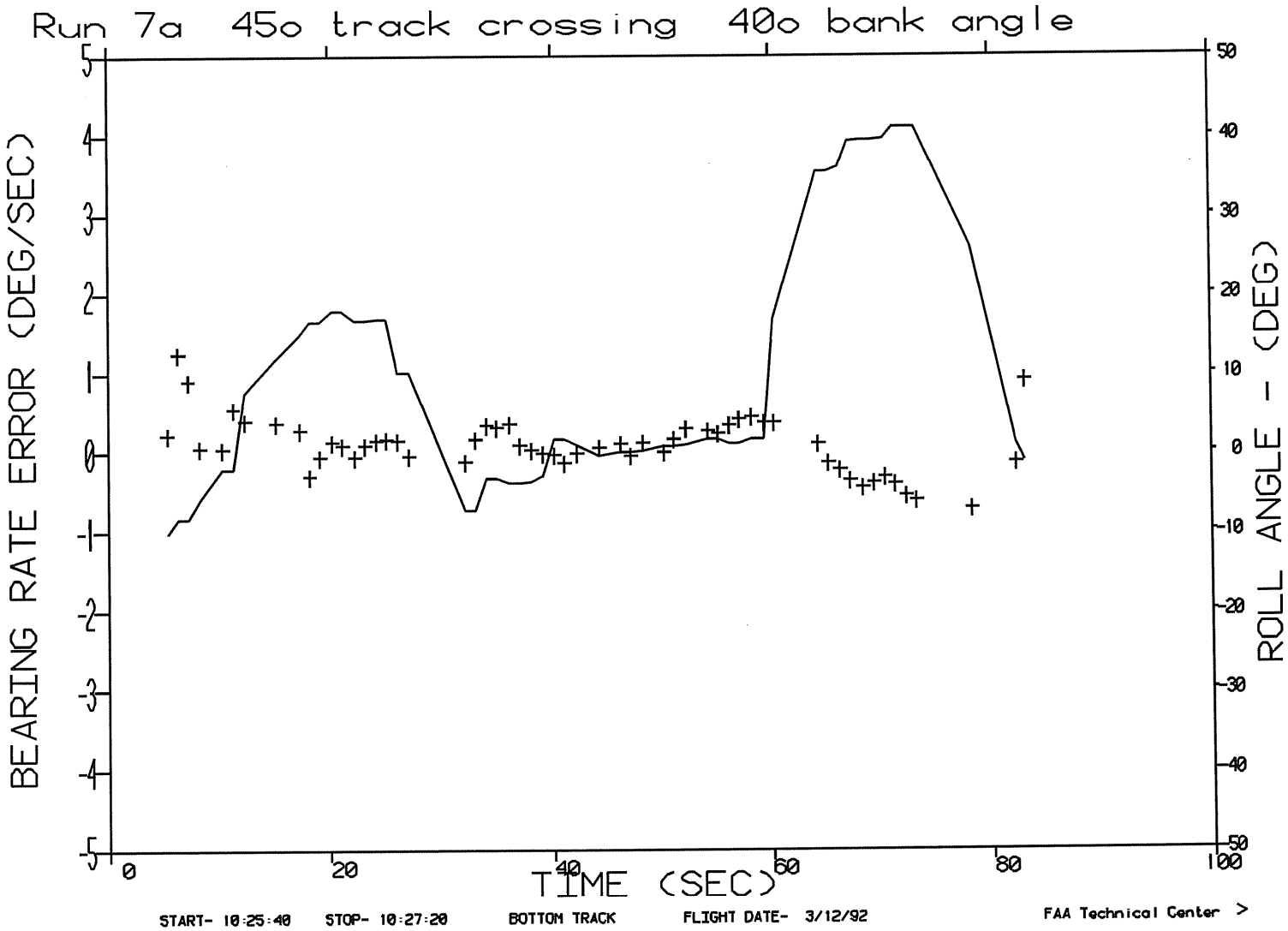

Run 6b 45o track crossing 30o bank angle
ELEVATION ANGLE
ROLL (DEG) -
MISS DISTANCE (NM)
* TCAS
Δ NIKE
TIME (SEC)
START- 10:20: 0
STOP- 10:22:21
DIVERSITY ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME

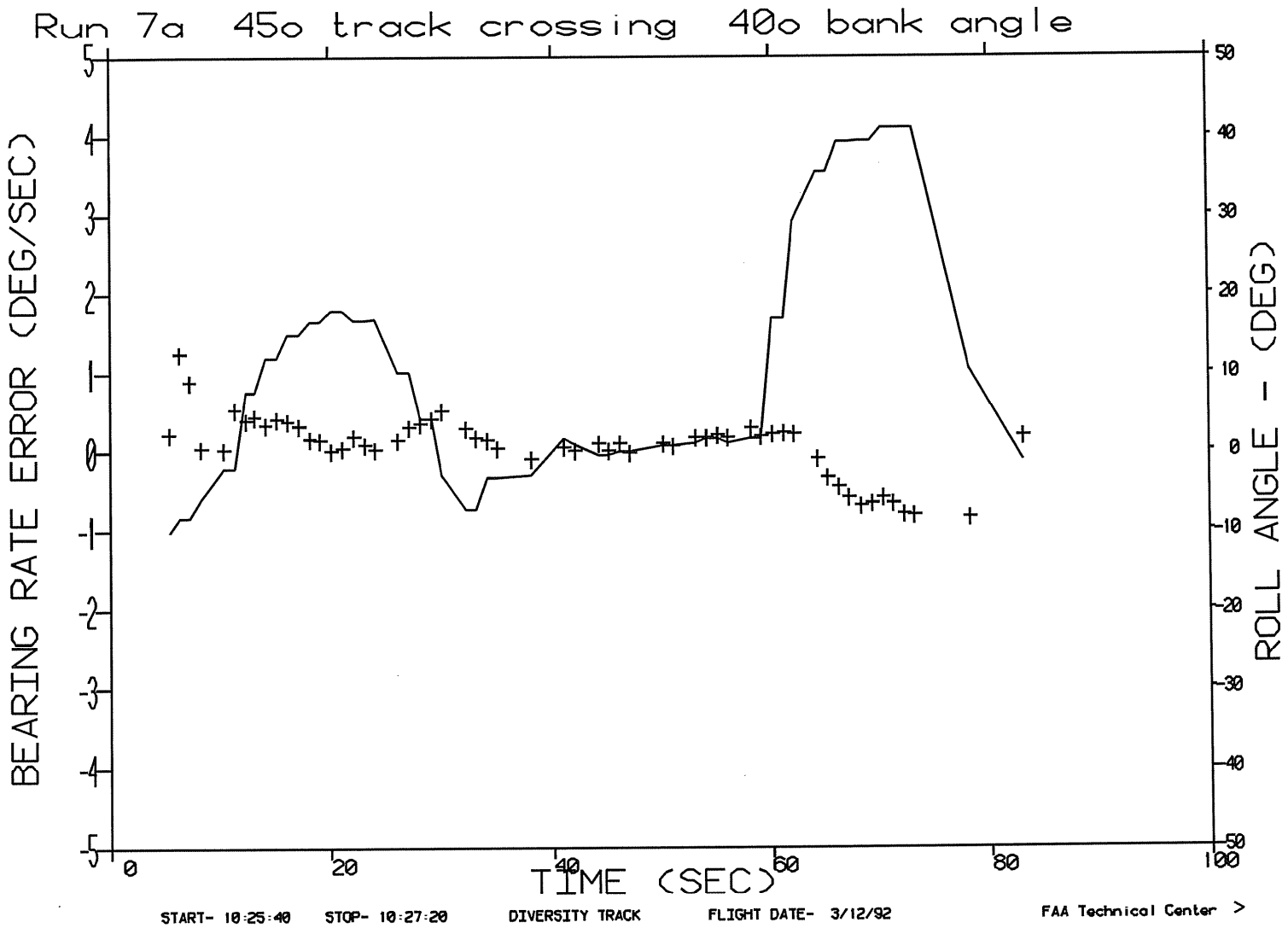

Run 7a 45o track crossing 40o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
20
40
60
80
100
START- 10:25:40
STOP- 10:27:20
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

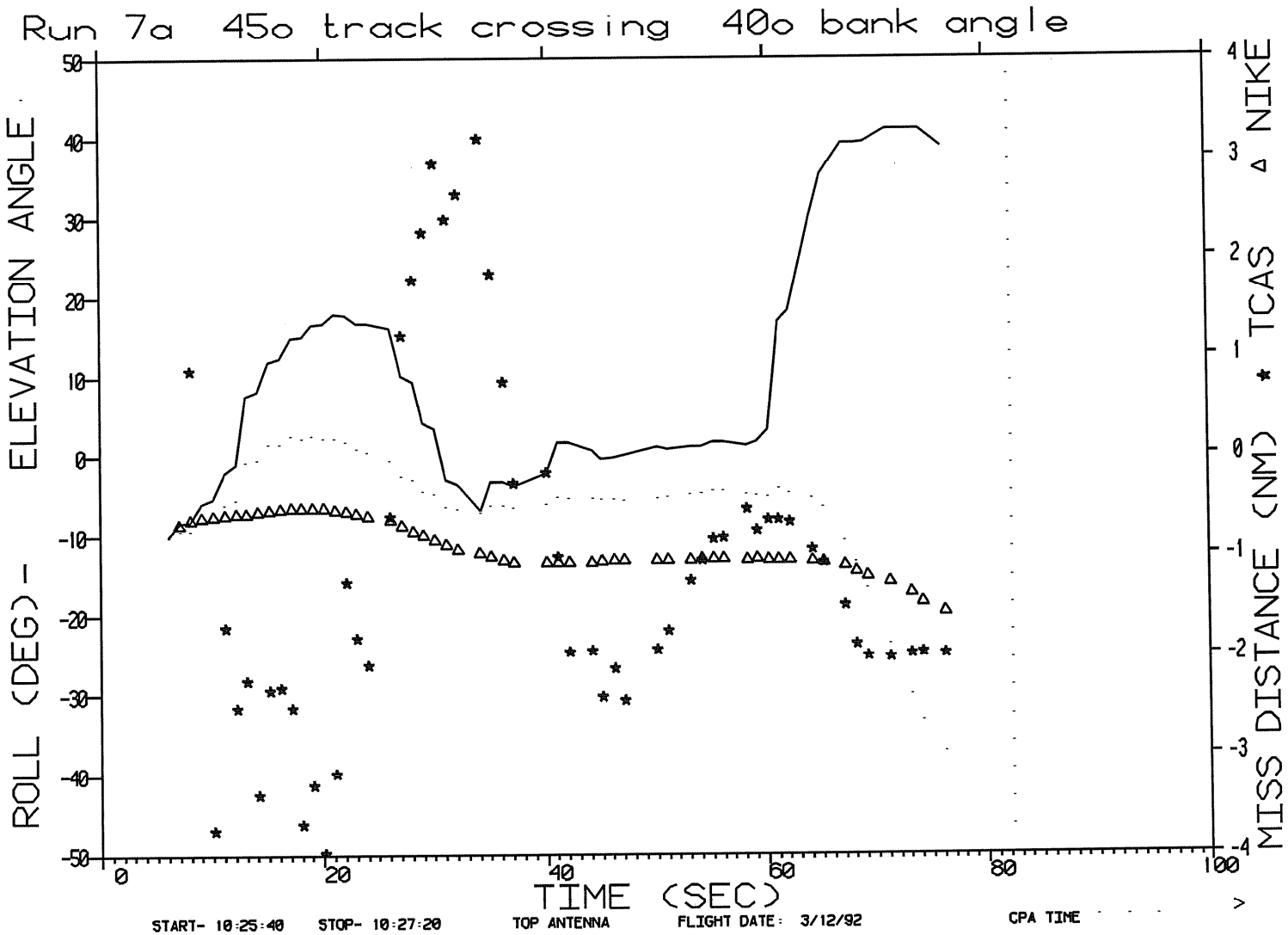

Run 7a 45o track crossing 40o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
20
40
60
80
100
START- 10:25:40
STOP- 10:27:20
BOTTOM TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

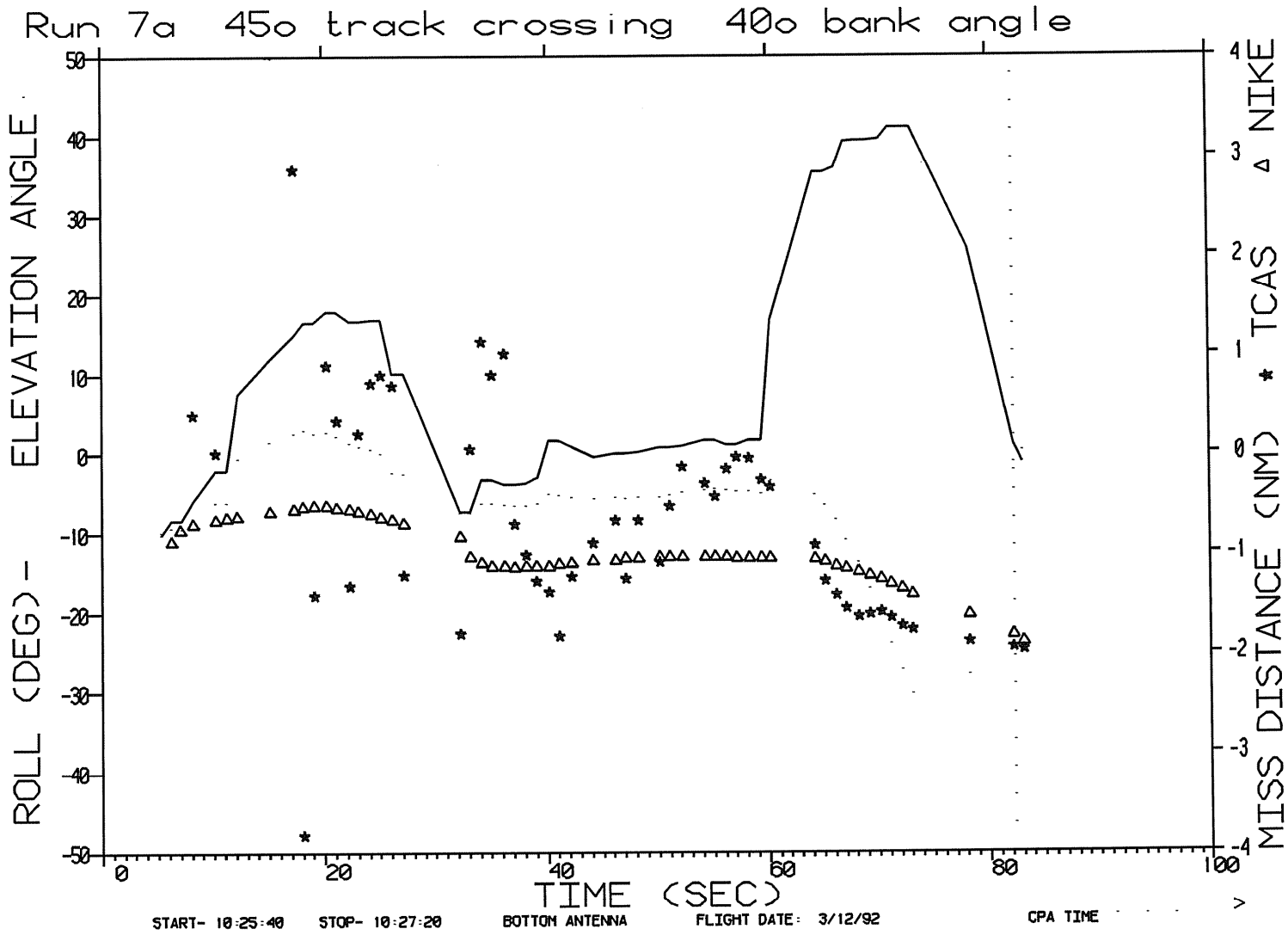

Run 7a 45o track crossing 40o bank angle
BEARING ERROR (DEG)
ROLL ANGLE - (DEG)
TIME (SEC)
20
16
12
8
4
0
-4
-8
-12
-16
-20
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
20
40
60
80
100
START- 10:25:40
STOP- 10:27:20
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >

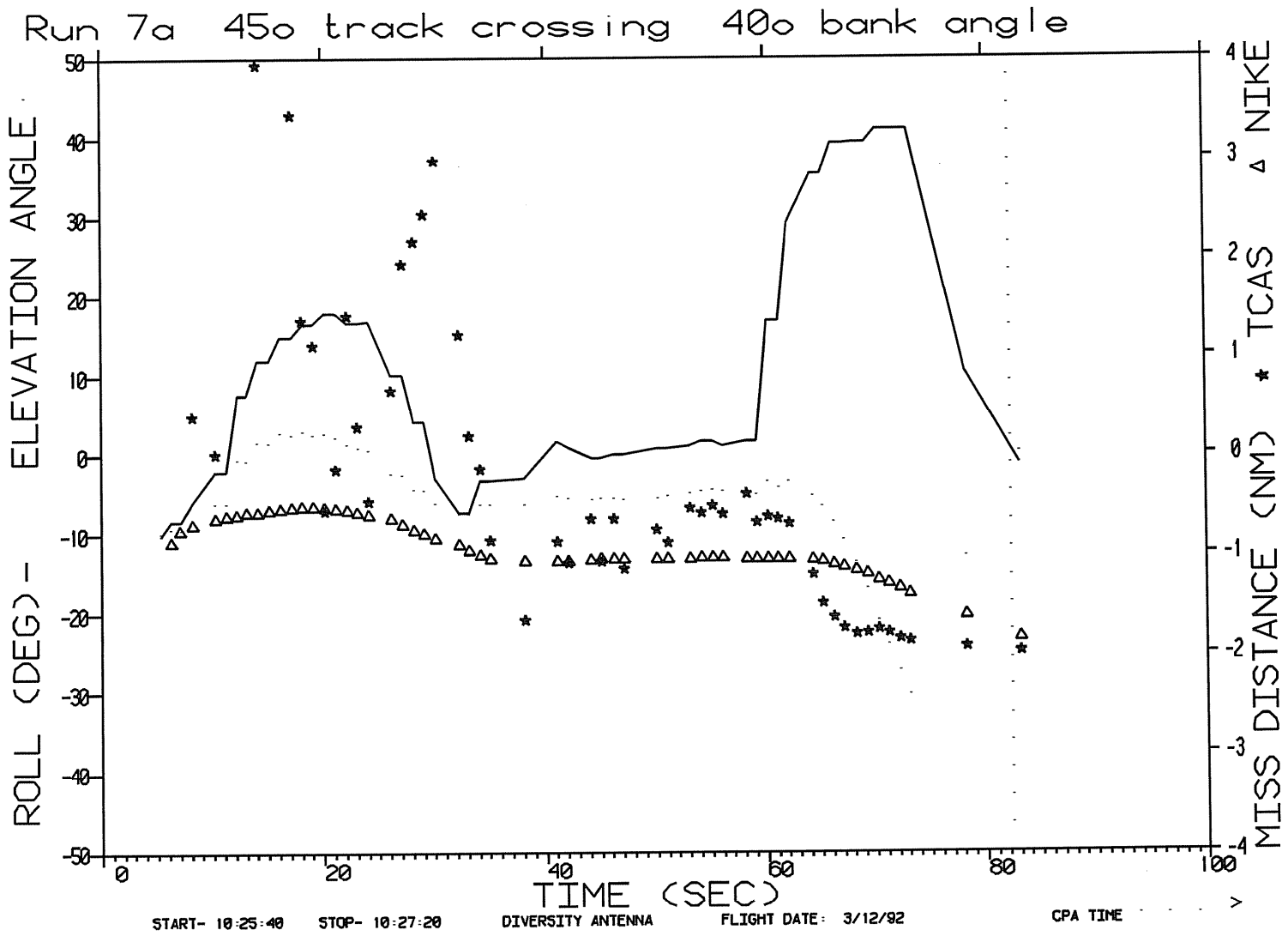

Run 7a 45o track crossing 40o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
20
40
60
80
100
START- 10:25:40
STOP- 10:27:20
TOP TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 7a 45o track crossing 40o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
20
40
60
80
100
START- 10:25:40
STOP- 10:27:20
BOTTOM TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 7a 45o track crossing 40o bank angle
BEARING RATE ERROR (DEG/SEC)
ROLL ANGLE - (DEG)
TIME (SEC)
5
4
3
2
1
0
-1
-2
-3
-4
-5
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
20
40
60
80
100
START- 10:25:40
STOP- 10:27:20
DIVERSITY TRACK
FLIGHT DATE- 3/12/92
FAA Technical Center >


Run 7a 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
START- 10:25:40
STOP- 10:27:20
TOP ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME


Run 7a 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
4
3
2
1
0
-1
-2
-3
-4
0
20
40
60
80
100
START- 10:25:40
STOP- 10:27:20
BOTTOM ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME


Run 7a 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (NM) * TCAS Δ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
4
3
2
1
0
-1
-2
-3
-4
0
20
40
60
80
100
START- 10:25:40
STOP- 10:27:20
DIVERSITY ANTENNA
FLIGHT DATE: 3/12/92
CPA TIME

Appendix D - Miss Distance Plots

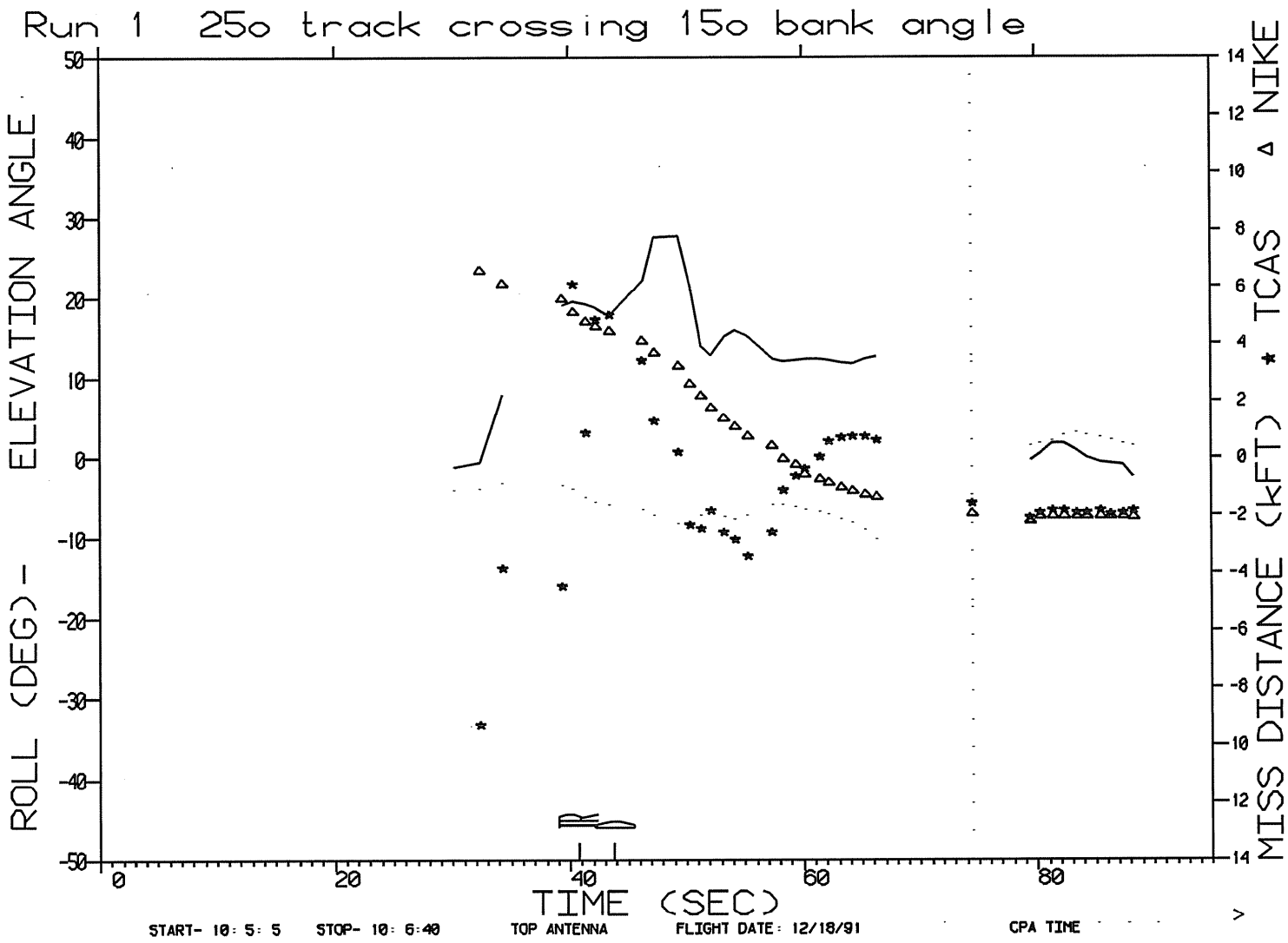
Flight Dates:

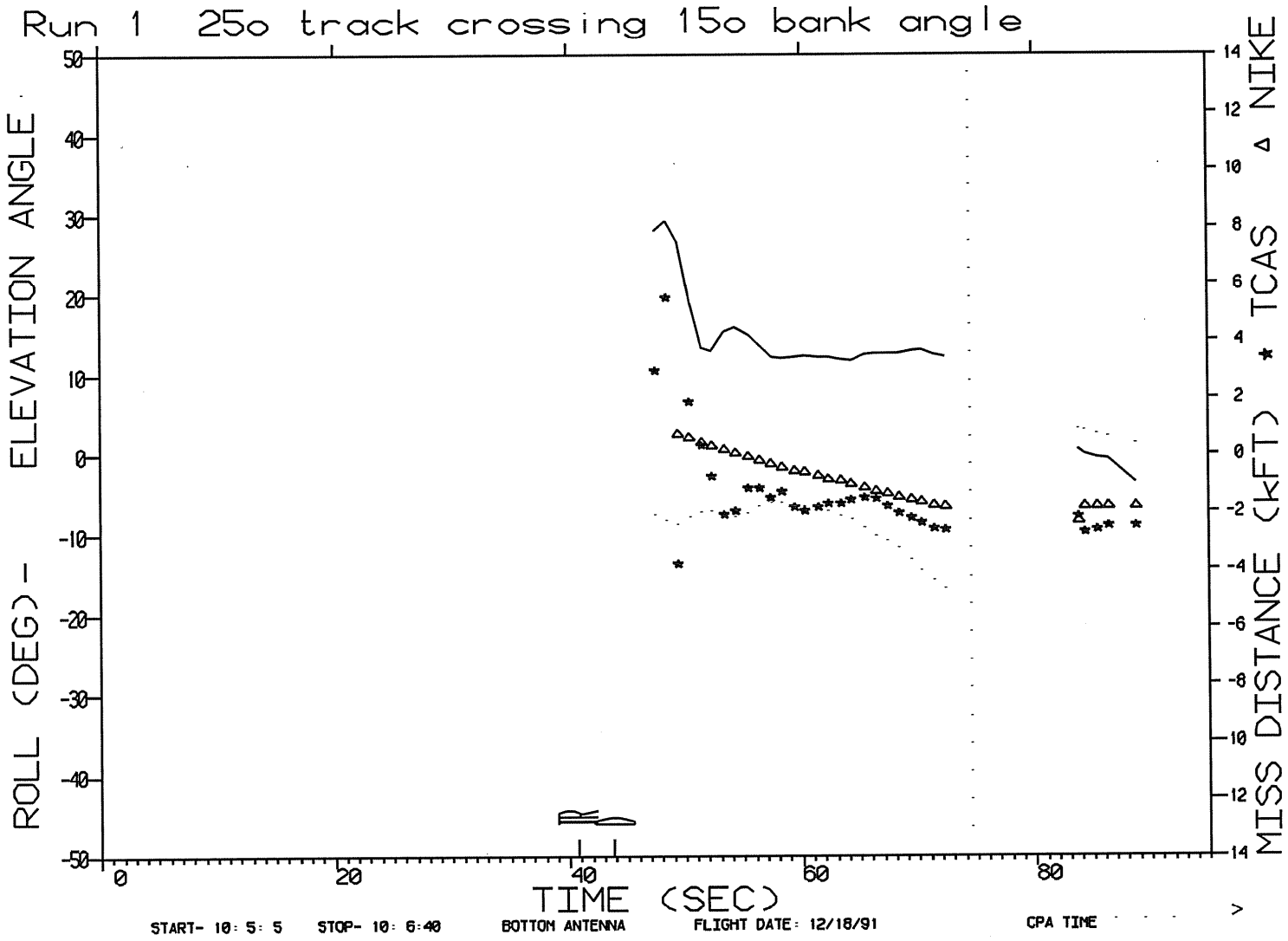
December 18, 1991
March 10, 1992
March 13, 1992
March 25, 1992
June 8, 1992
June 23, 1992
July 23, 1992

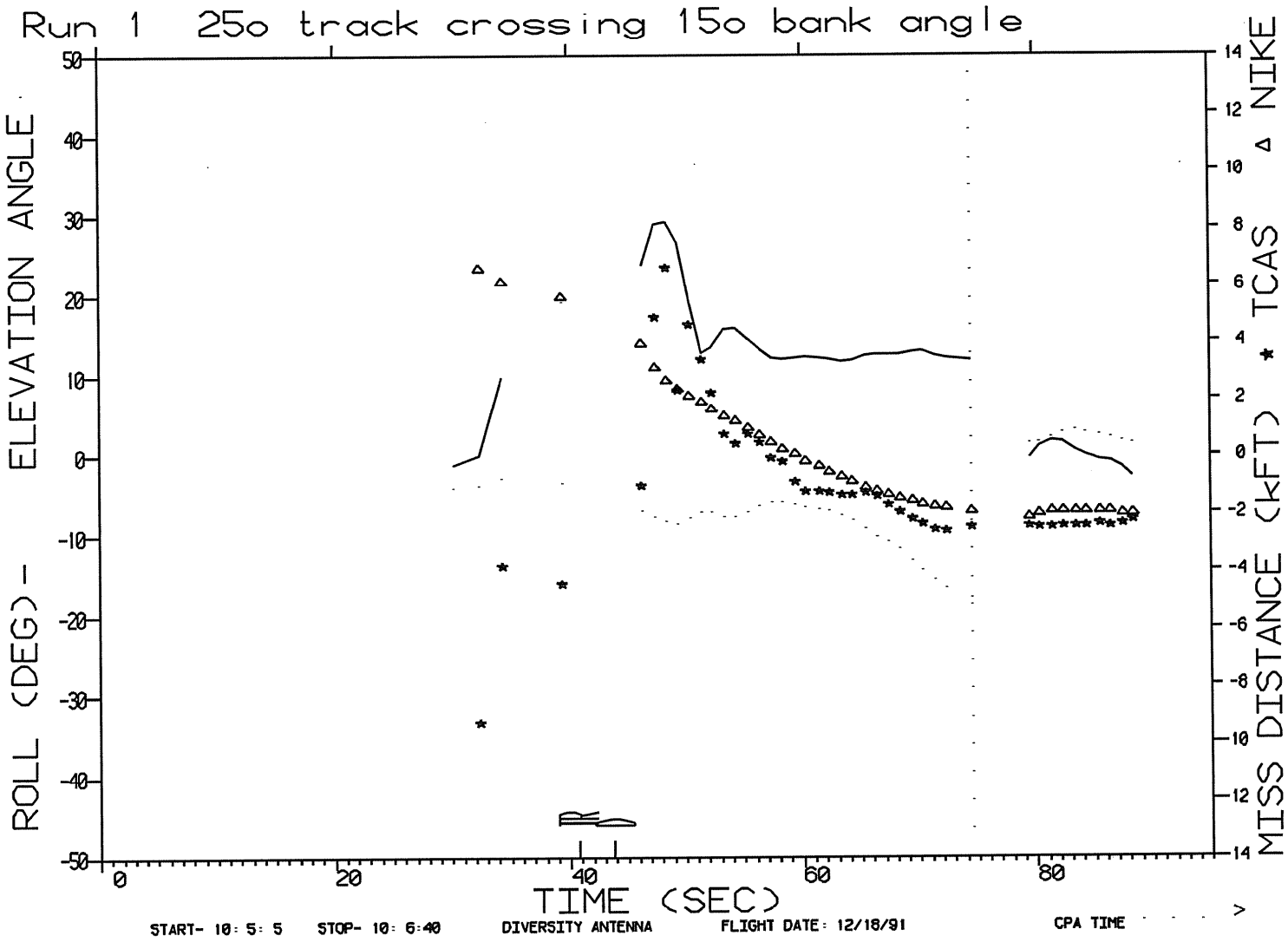
Plots include:

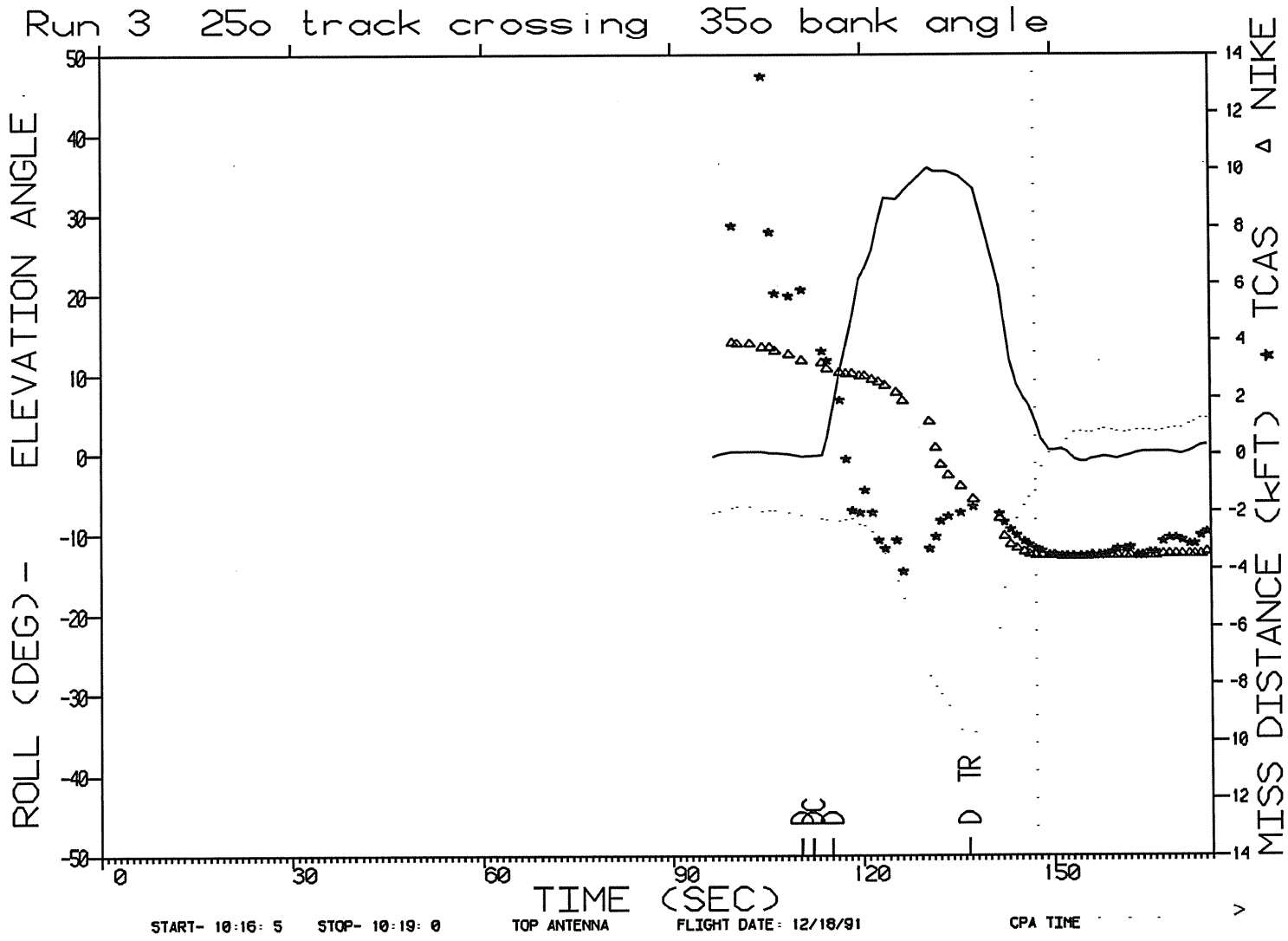
Miss Distance Top, Bottom, Diversity antenna (when available)

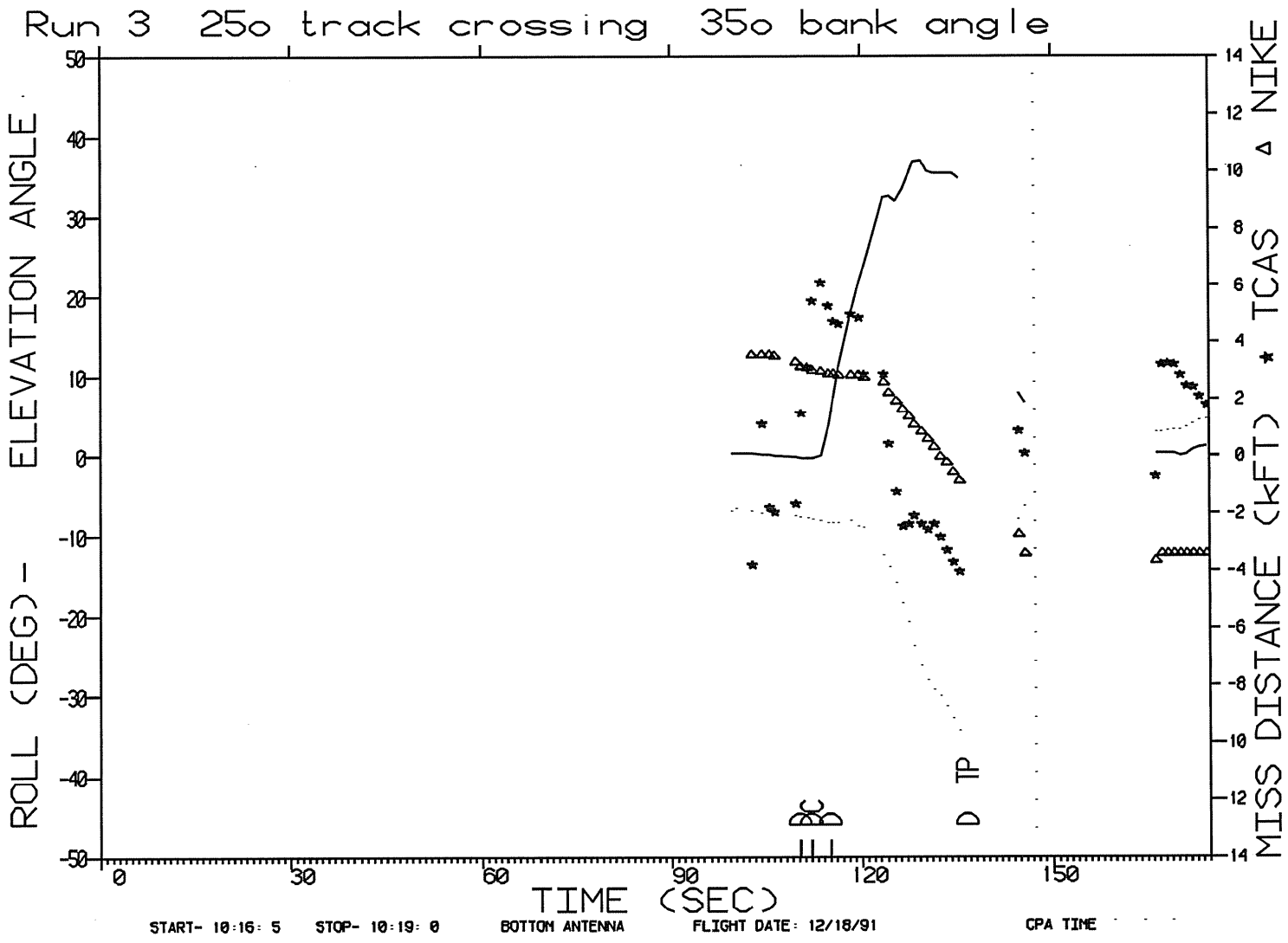
See Appendix B for plot descriptions.

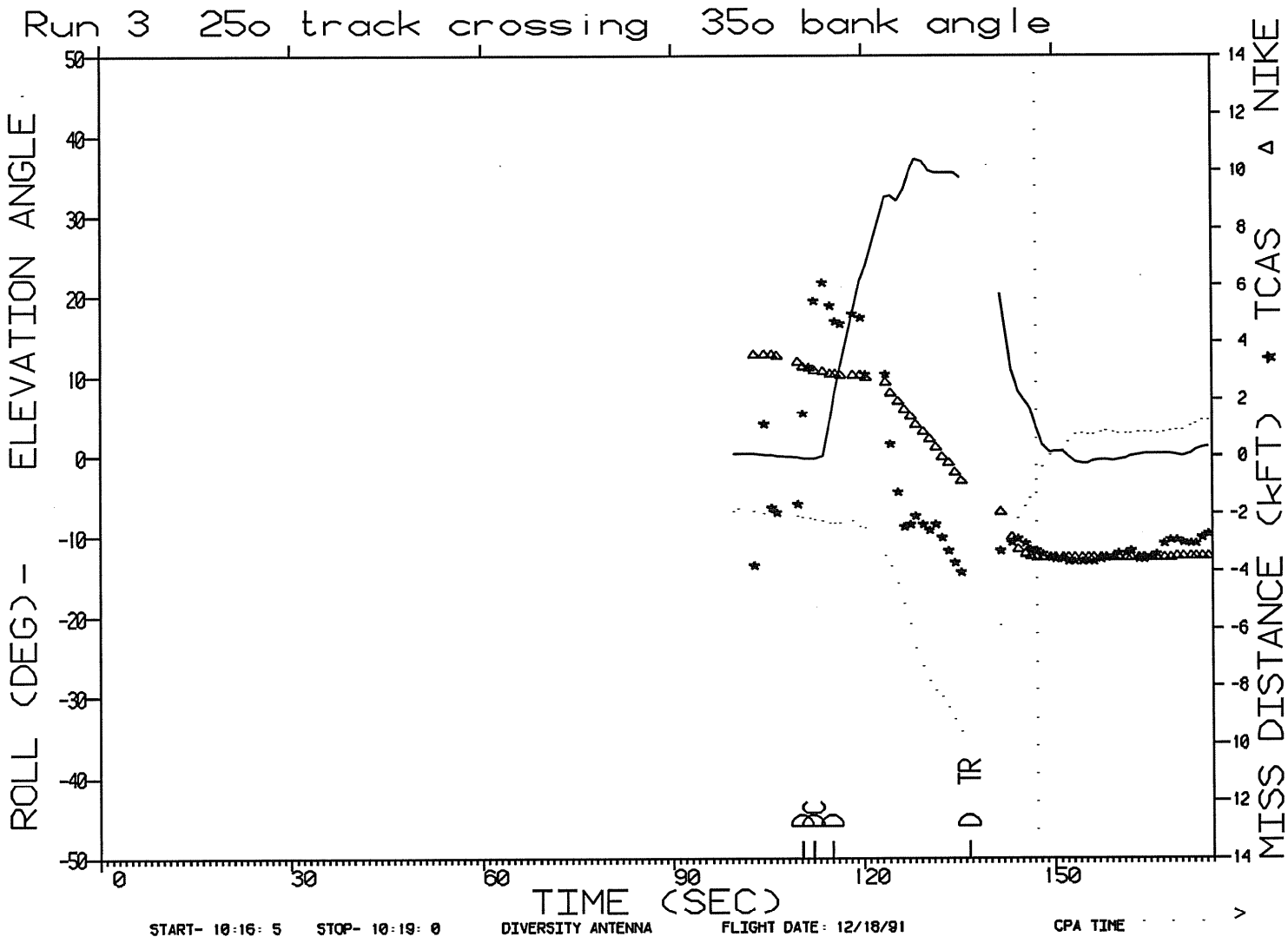

Run 1 25o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10: 5: 5
STOP- 10: 6:40
TOP ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

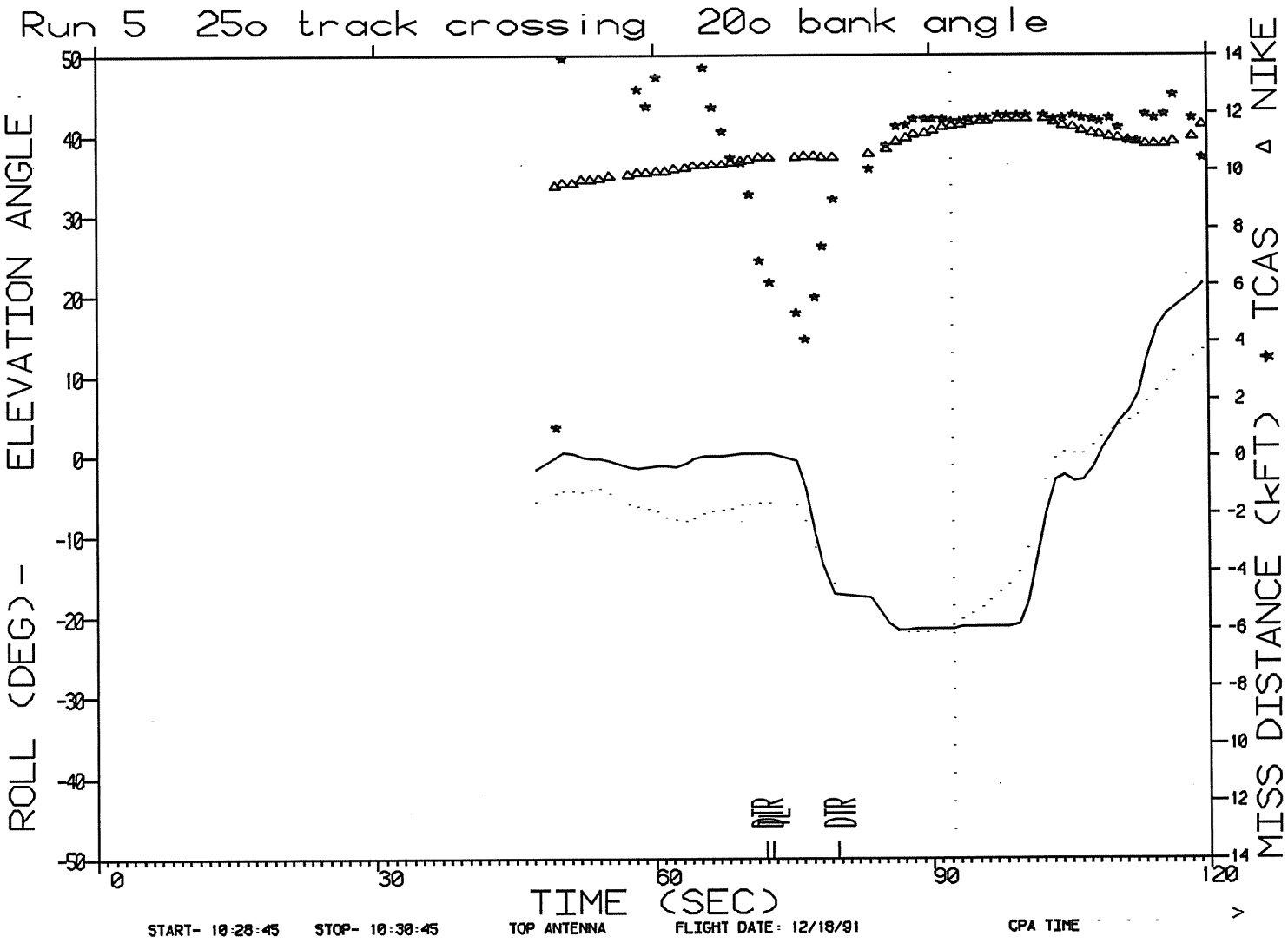

Run 1 25o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10: 5: 5
STOP- 10: 6:40
BOTTOM ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

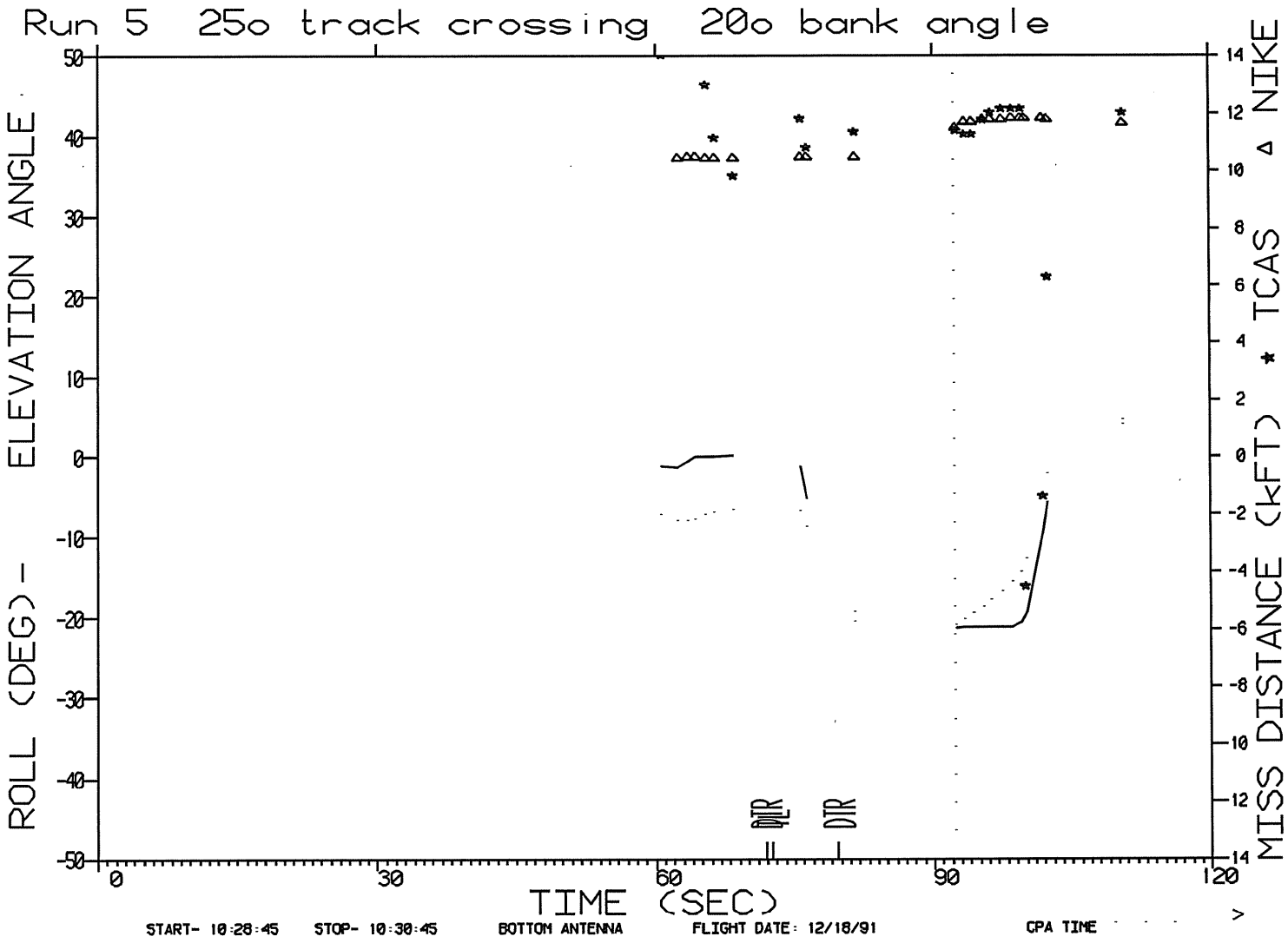

Run 1 25o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
20
40
60
80
START- 10: 5: 5
STOP- 10: 6:40
DIVERSITY ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

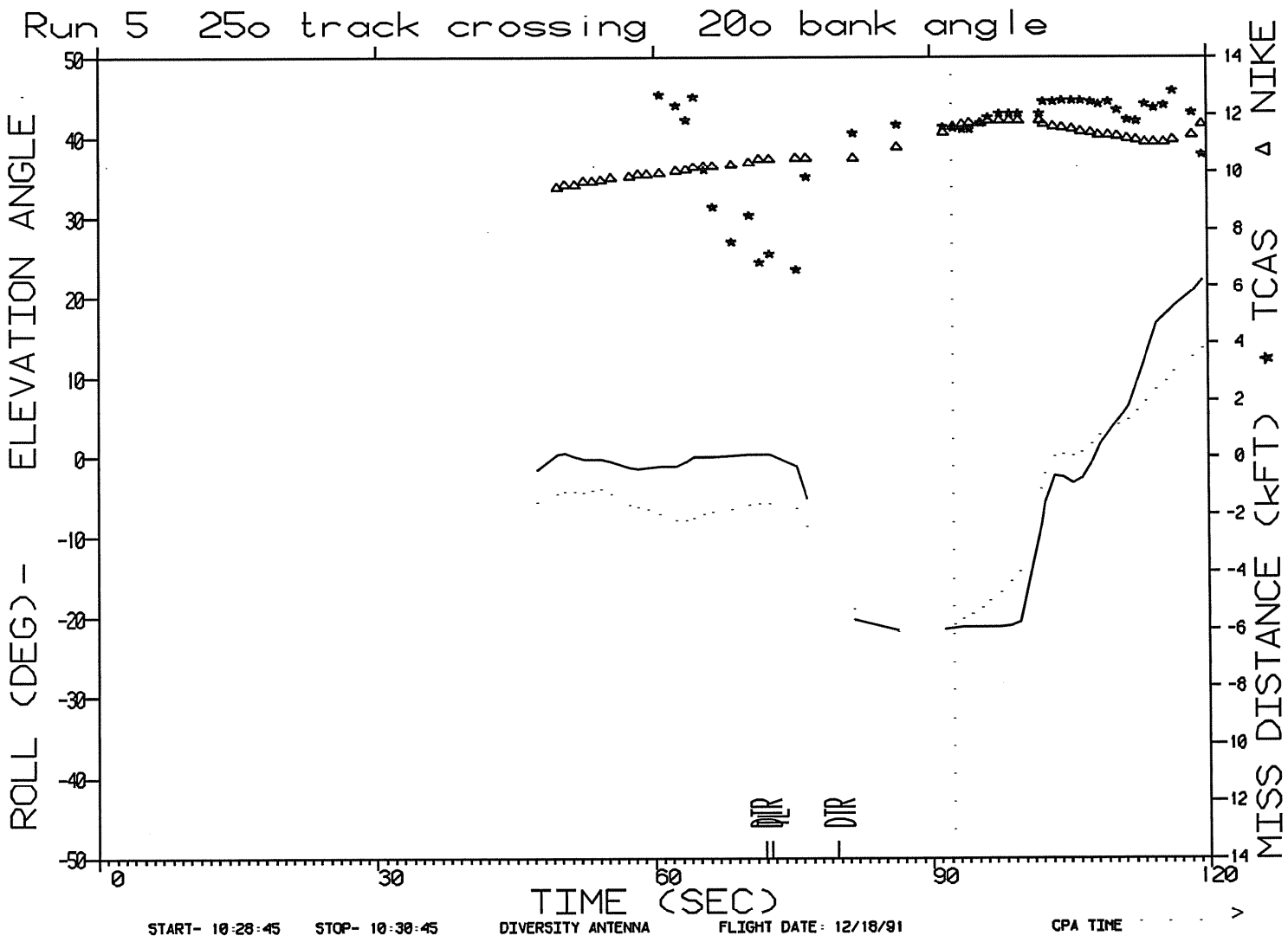

Run 3 25o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D TR
START- 10:16: 5
STOP- 10:19: 0
TOP ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

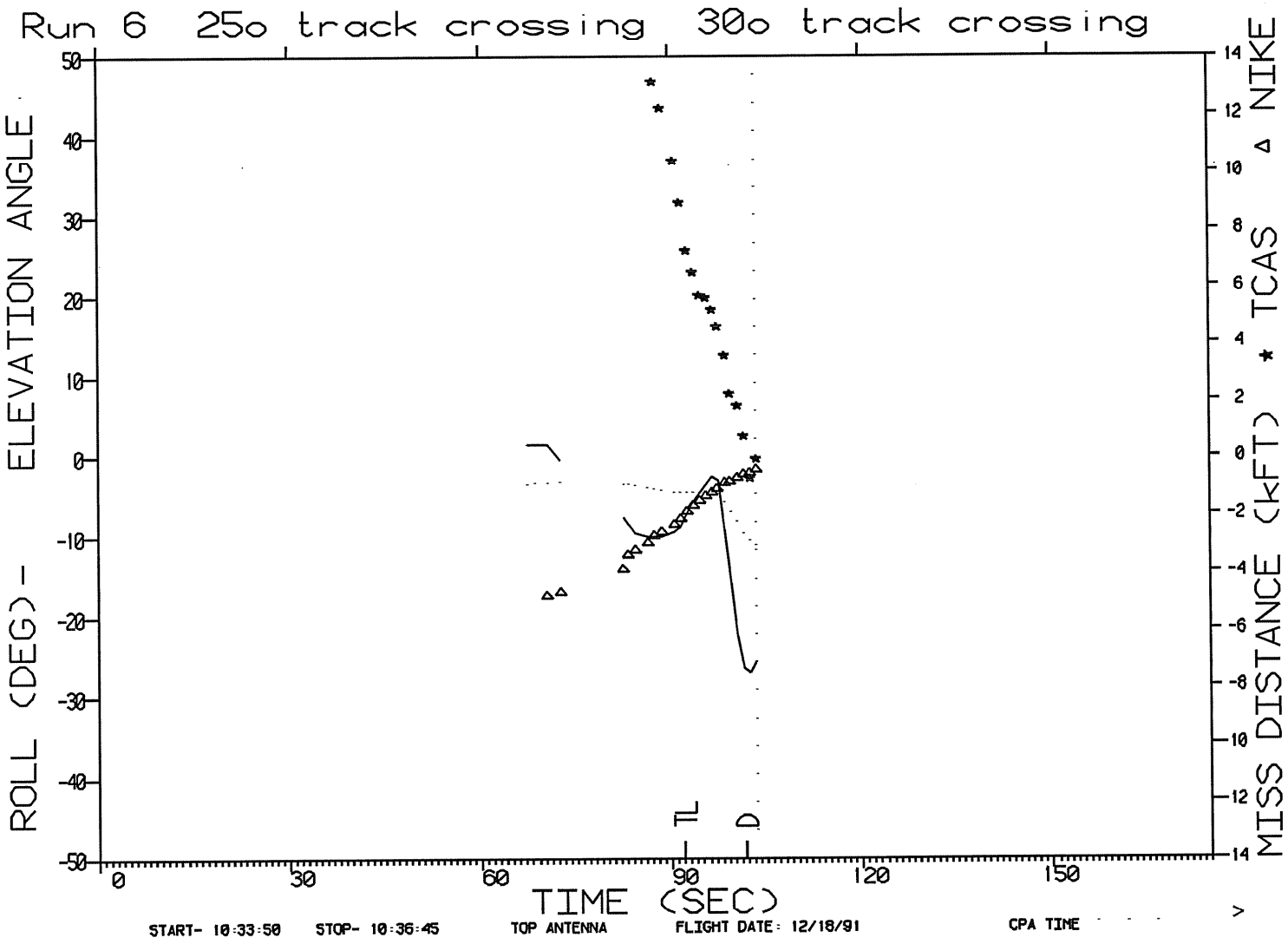

Run 3 25o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
TP
START- 10:16: 5
STOP- 10:19: 0
BOTTOM ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

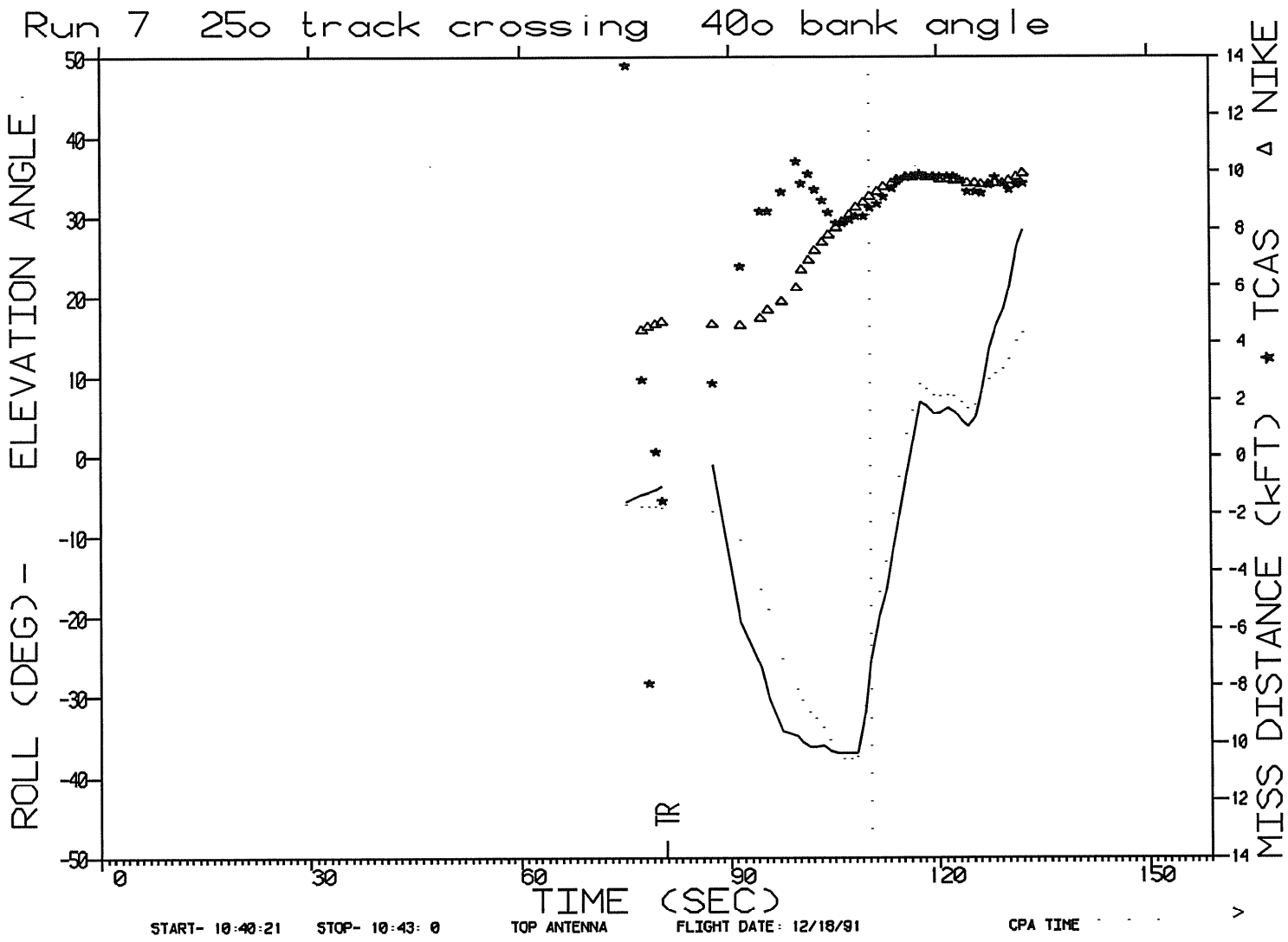

Run 3 25o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D TR
START- 10:16: 5 STOP- 10:19: 0 DIVERSITY ANTENNA FLIGHT DATE: 12/18/91 CPA TIME

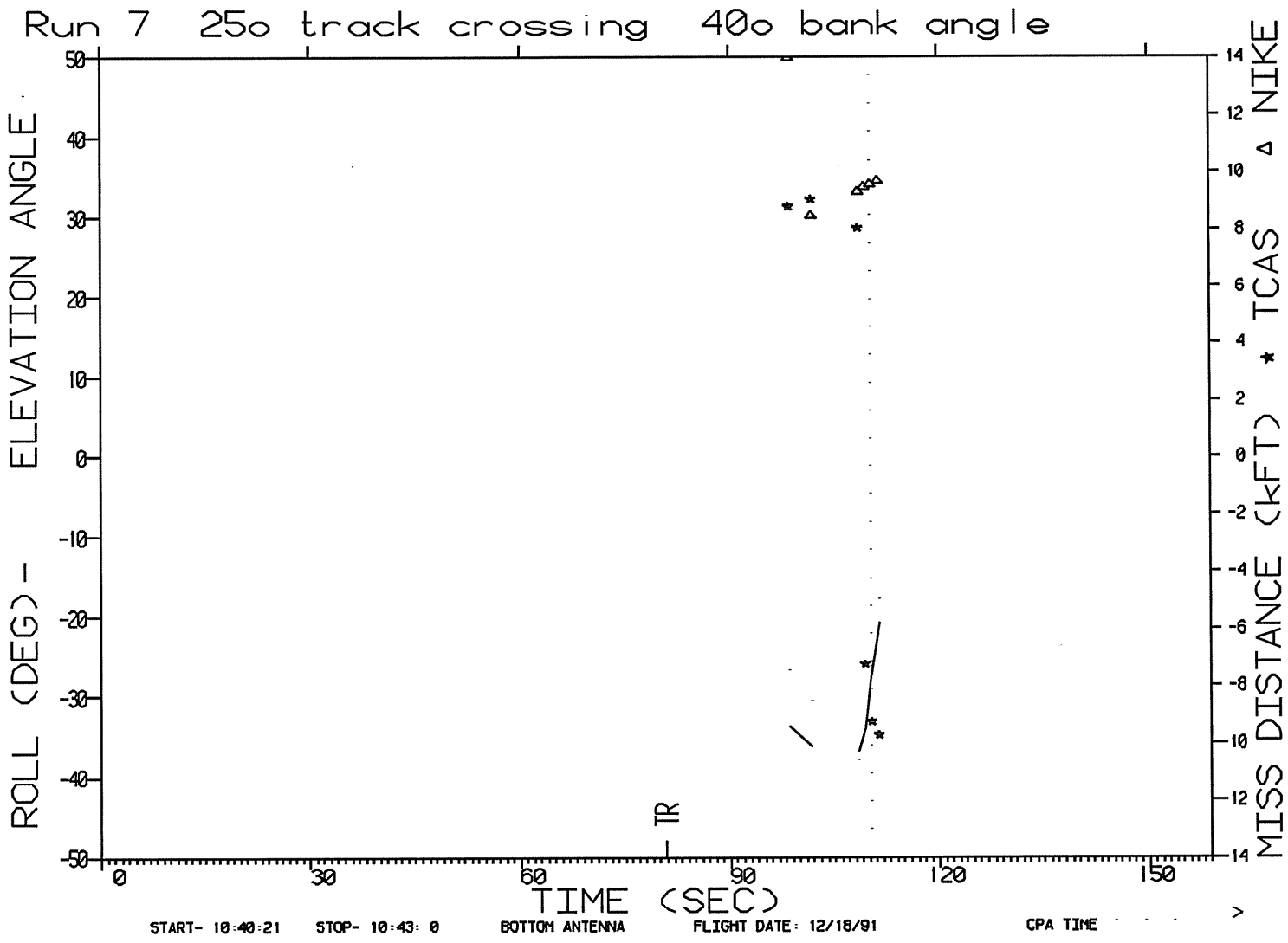

Run 5 25o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
30
60
90
120
DIR
DIR
START- 10:28:45
STOP- 10:30:45
TOP ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

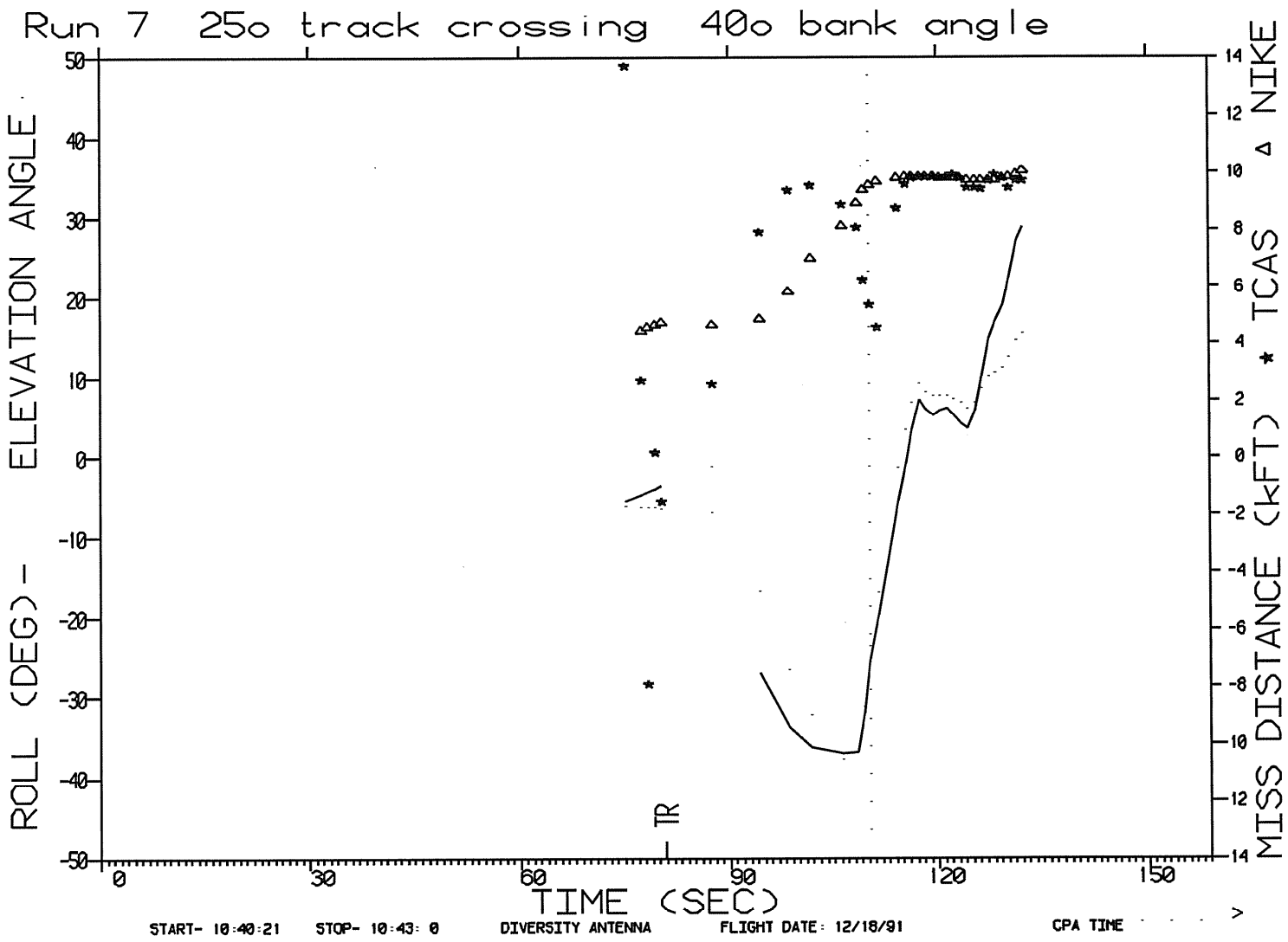

Run 5 25o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
DIR
DIR
START- 10:28:45
STOP- 10:30:45
BOTTOM ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

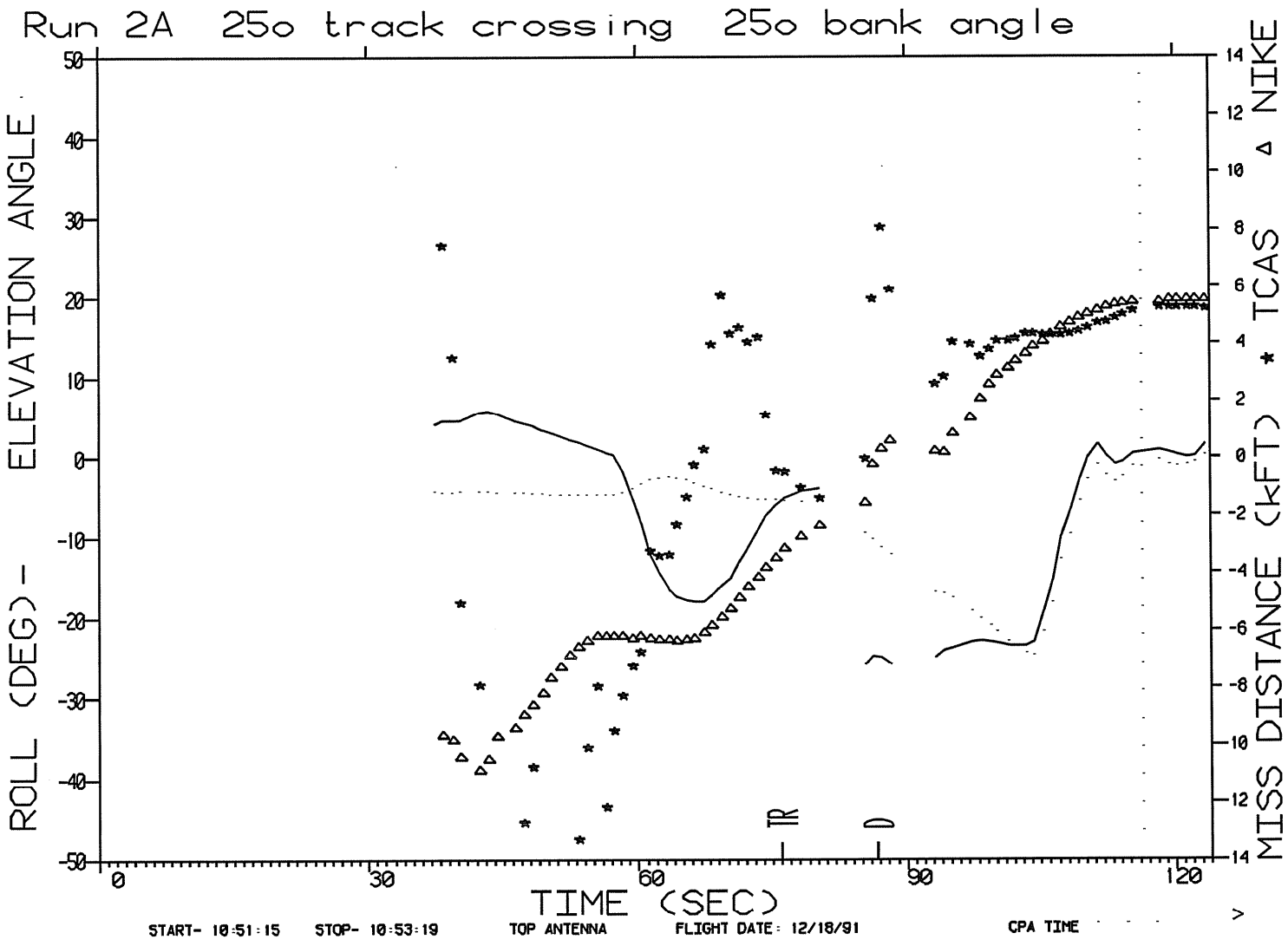

Run 5 25o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
START- 10:28:45 STOP- 10:30:45 DIVERSITY ANTENNA FLIGHT DATE: 12/18/91 CPA TIME

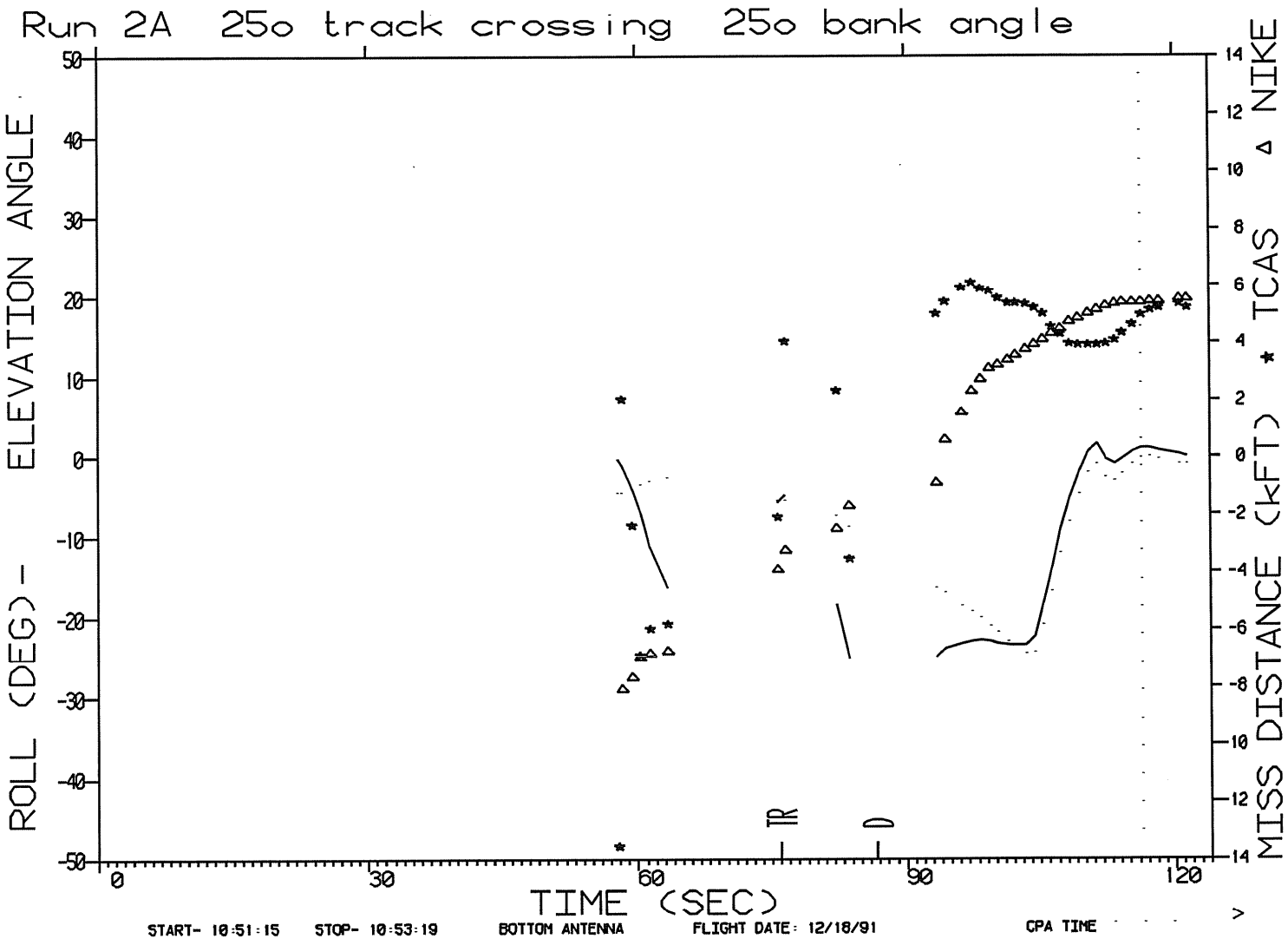

Run 6 25o track crossing 30o track crossing
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TL
D
START- 10:33:50 STOP- 10:36:45 TOP ANTENNA FLIGHT DATE: 12/18/91 CPA TIME

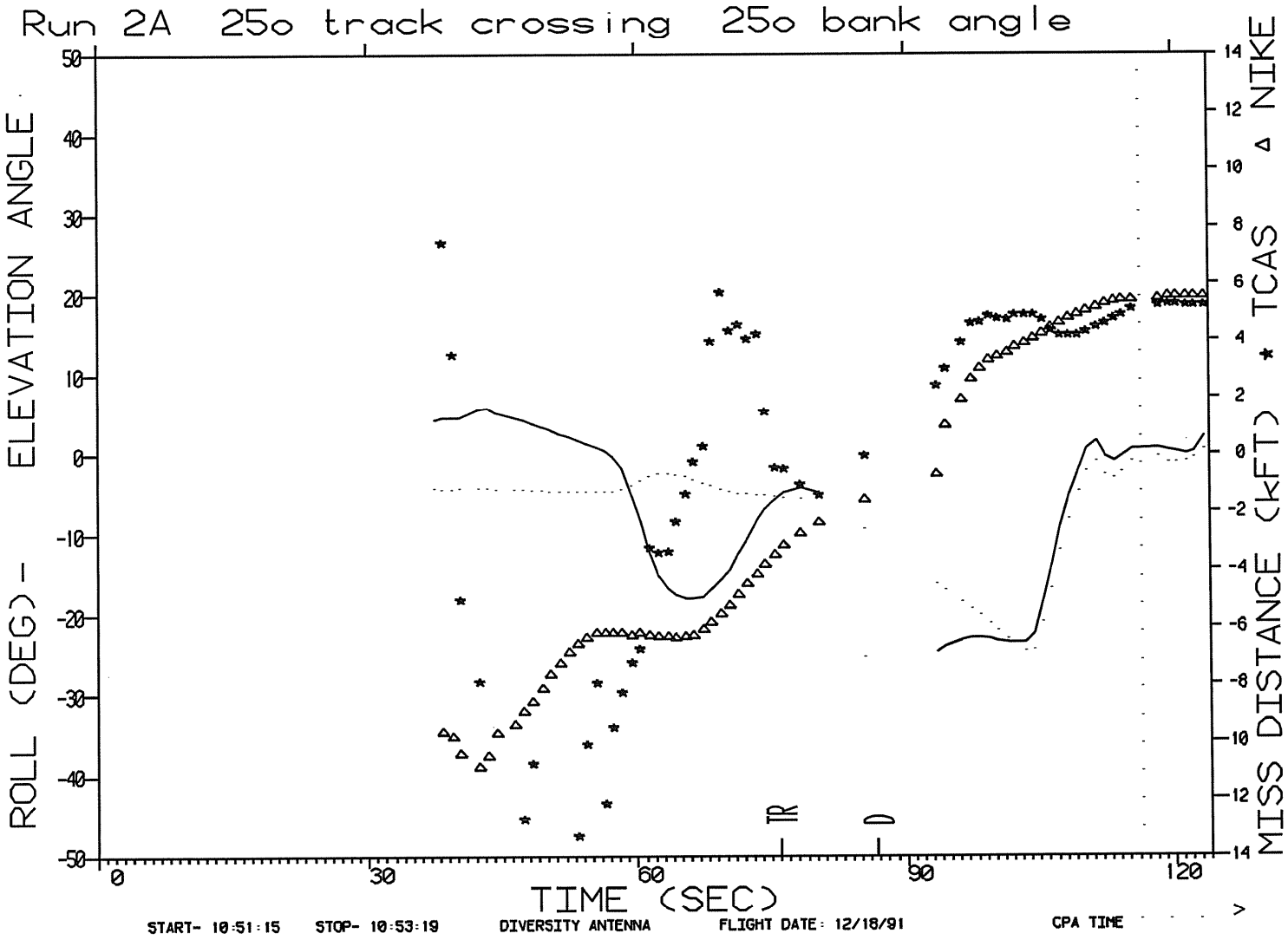

Run 7 25o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
START- 10:40:21
STOP- 10:43: 0
TOP ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

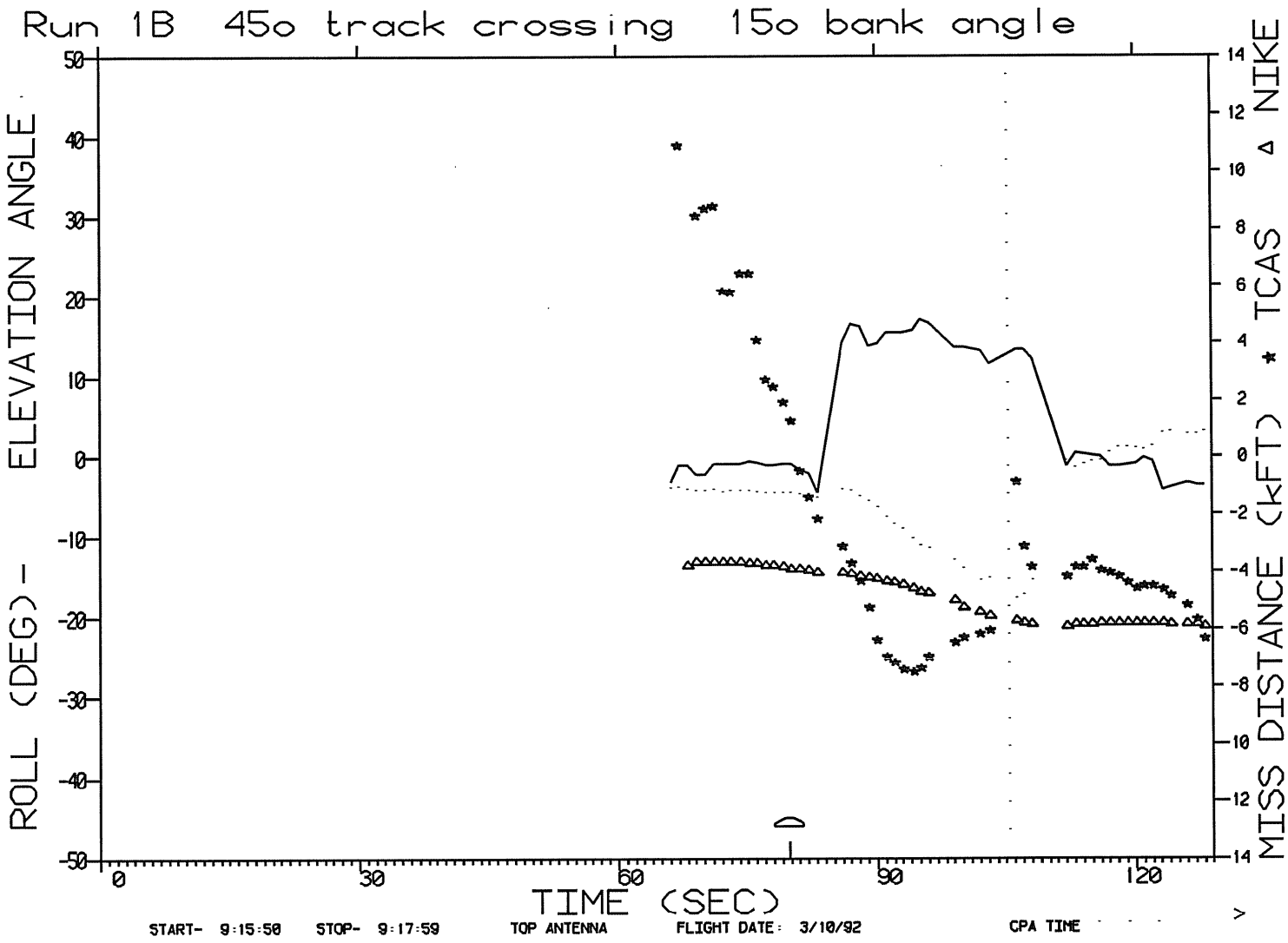

Run 7 25o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
START- 10:40:21
STOP- 10:43: 0
BOTTOM ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

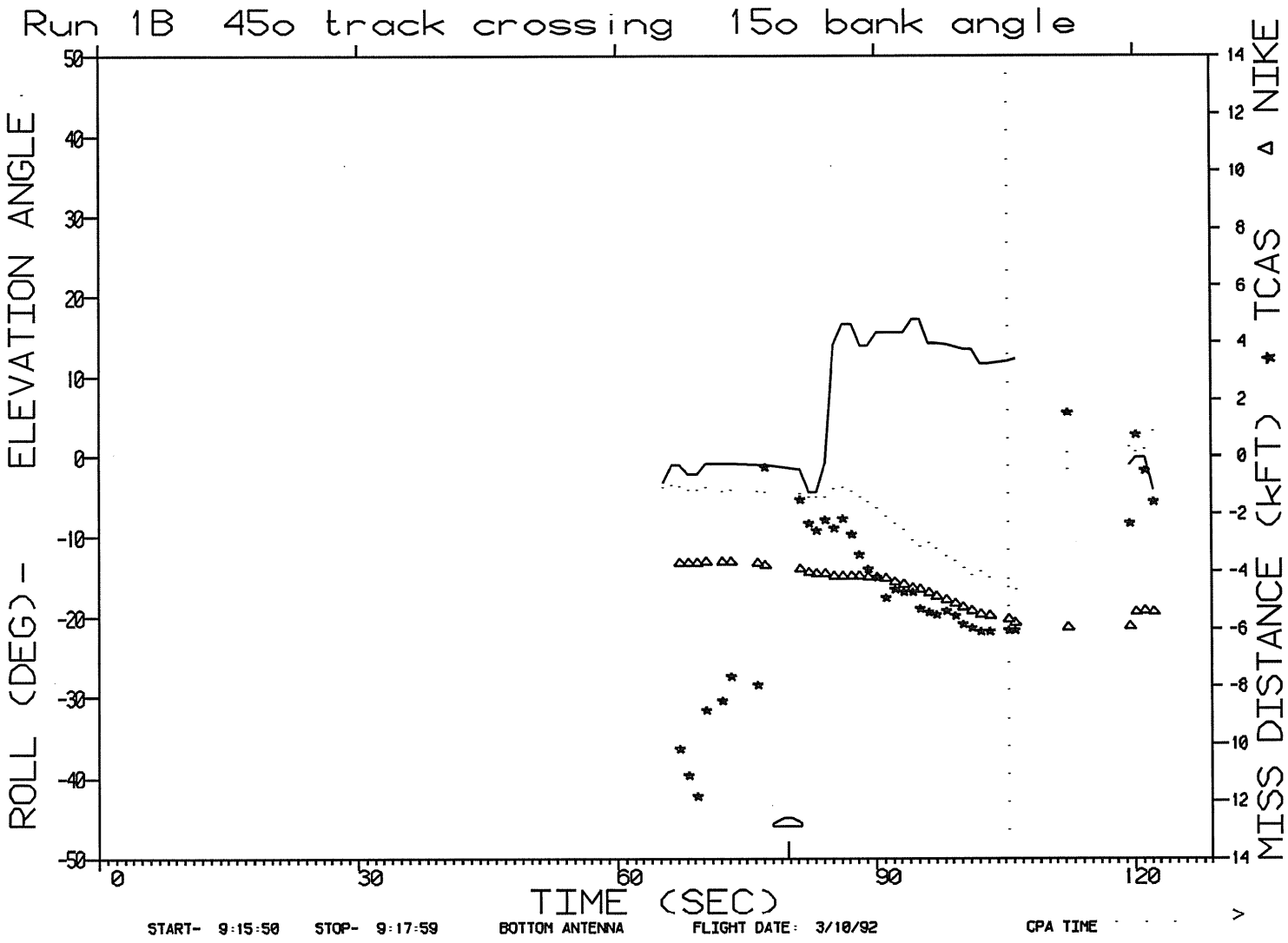

Run 7 25o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
START- 10:40:21 STOP- 10:43: 0 DIVERSITY ANTENNA FLIGHT DATE: 12/18/91 CPA TIME

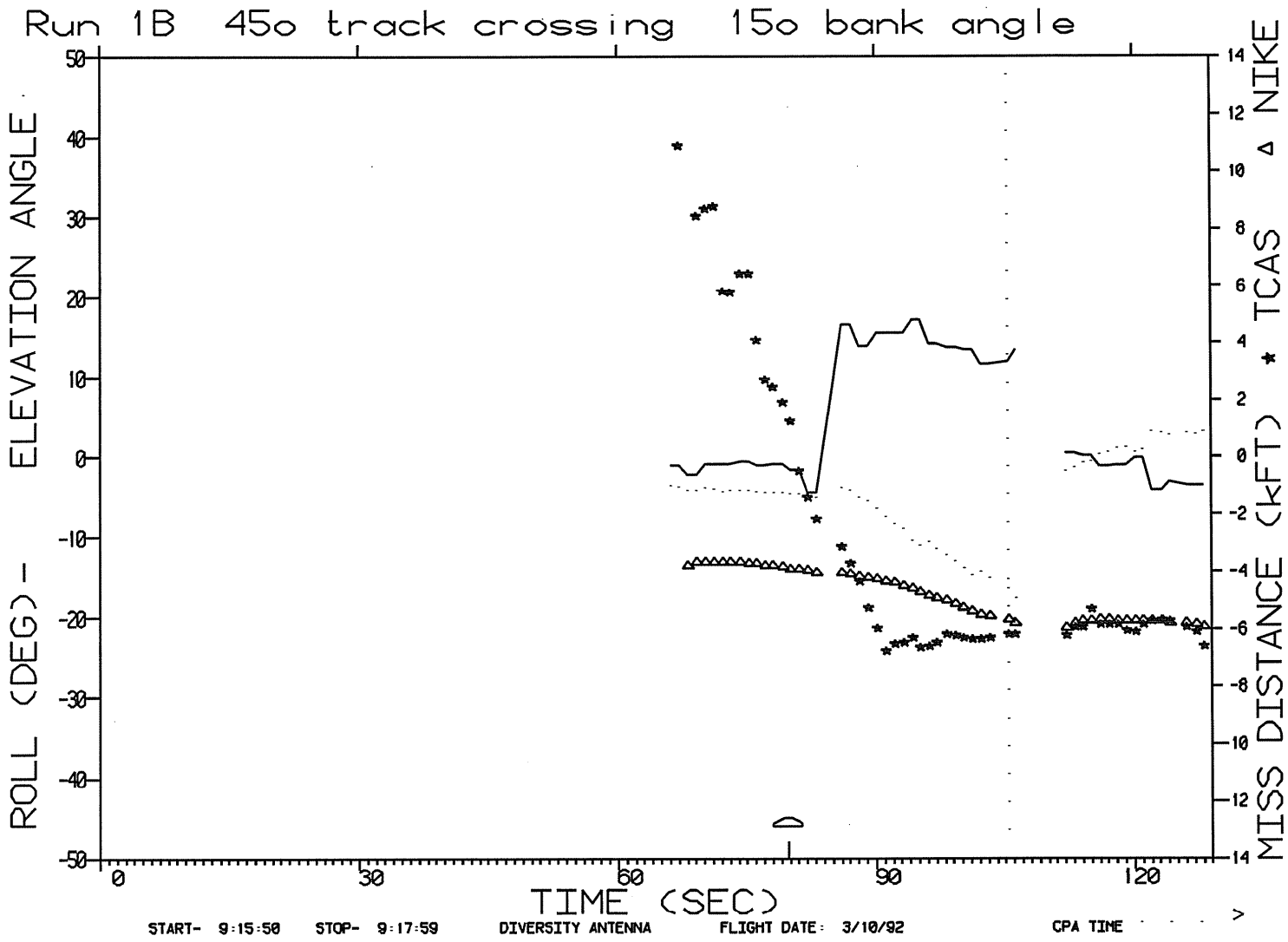

Run 2A 25o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
D
START- 10:51:15
STOP- 10:53:19
TOP ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

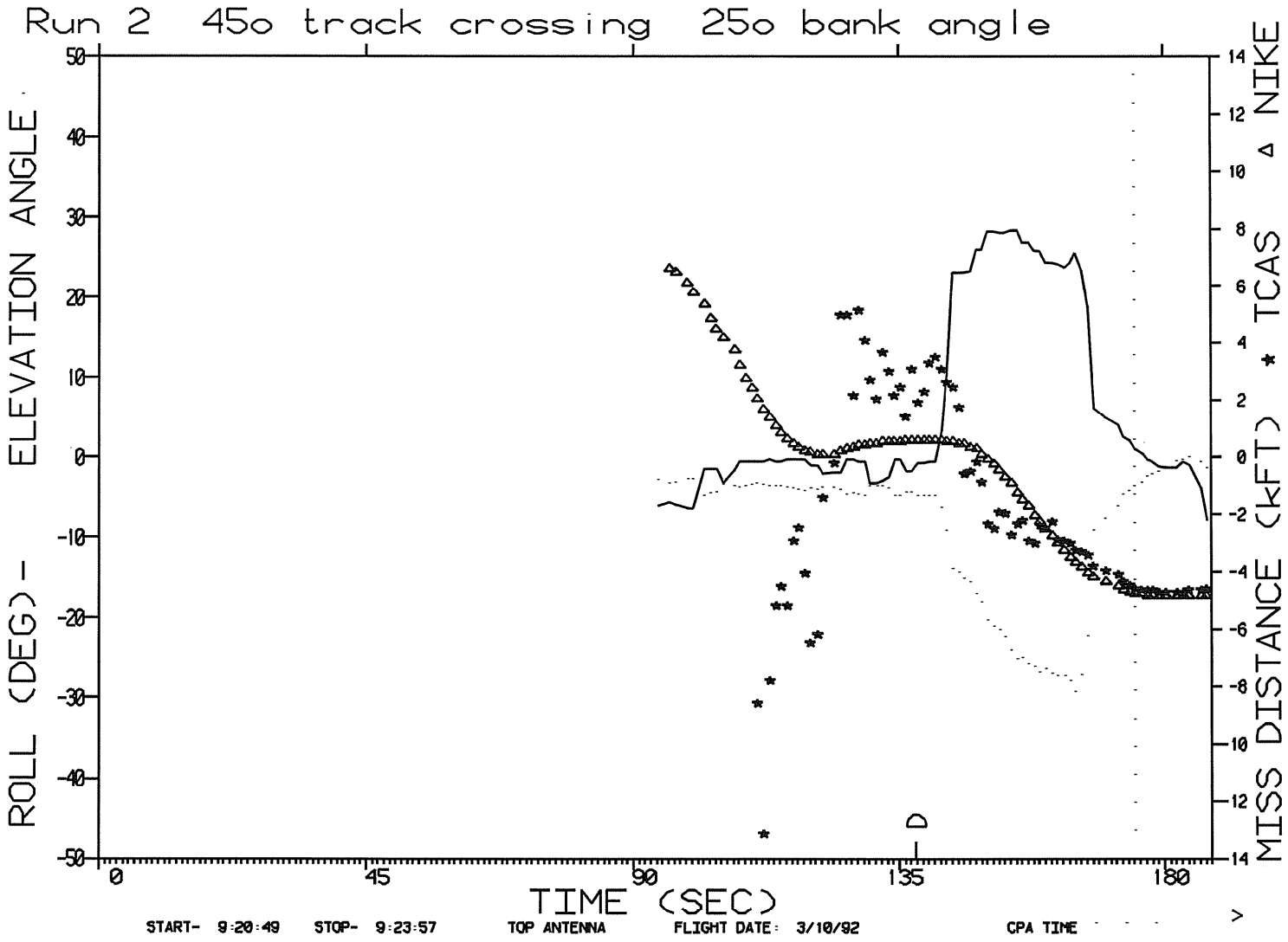

Run 2A 25o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
TR
D
START- 10:51:15
STOP- 10:53:19
BOTTOM ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME

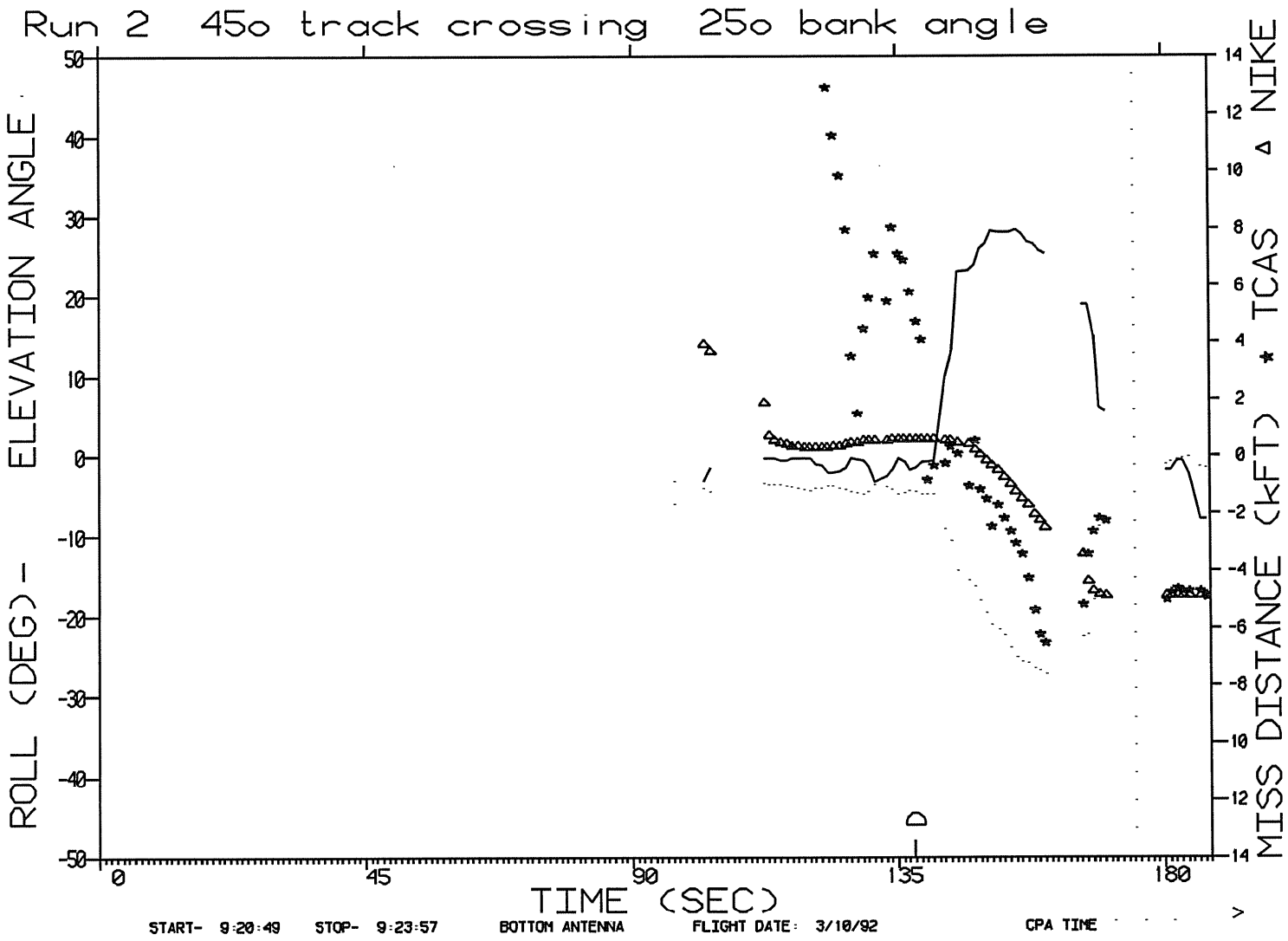

Run 2A 25o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
TR
D
START- 10:51:15
STOP- 10:53:19
DIVERSITY ANTENNA
FLIGHT DATE: 12/18/91
CPA TIME


Run 1B 45o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:15:50 STOP- 9:17:59 TOP ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 1B 45o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:15:50 STOP- 9:17:59 BOTTOM ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 1B 45o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:15:50 STOP- 9:17:59 DIVERSITY ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 2 45o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
45
90
135
180
START- 9:20:49
STOP- 9:23:57
TOP ANTENNA
FLIGHT DATE: 3/10/92
CPA TIME


Run 2 45o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
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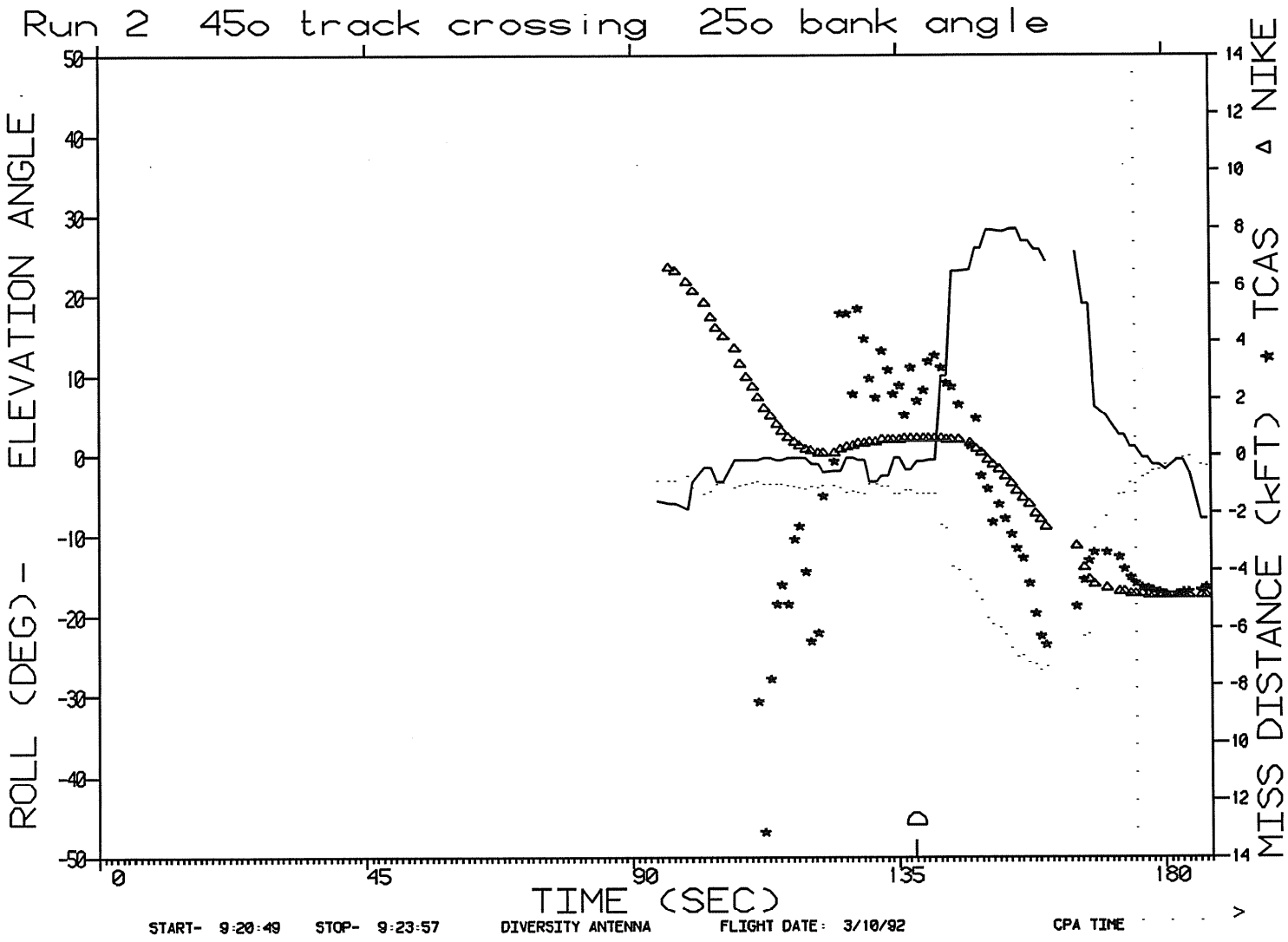
-10
-12
-14
0
45
90
135
180
START- 9:20:49
STOP- 9:23:57
BOTTOM ANTENNA
FLIGHT DATE: 3/10/92
CPA TIME


Run 2 45o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
50
40
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10
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-10
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-30
-40
-50
14
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10
8
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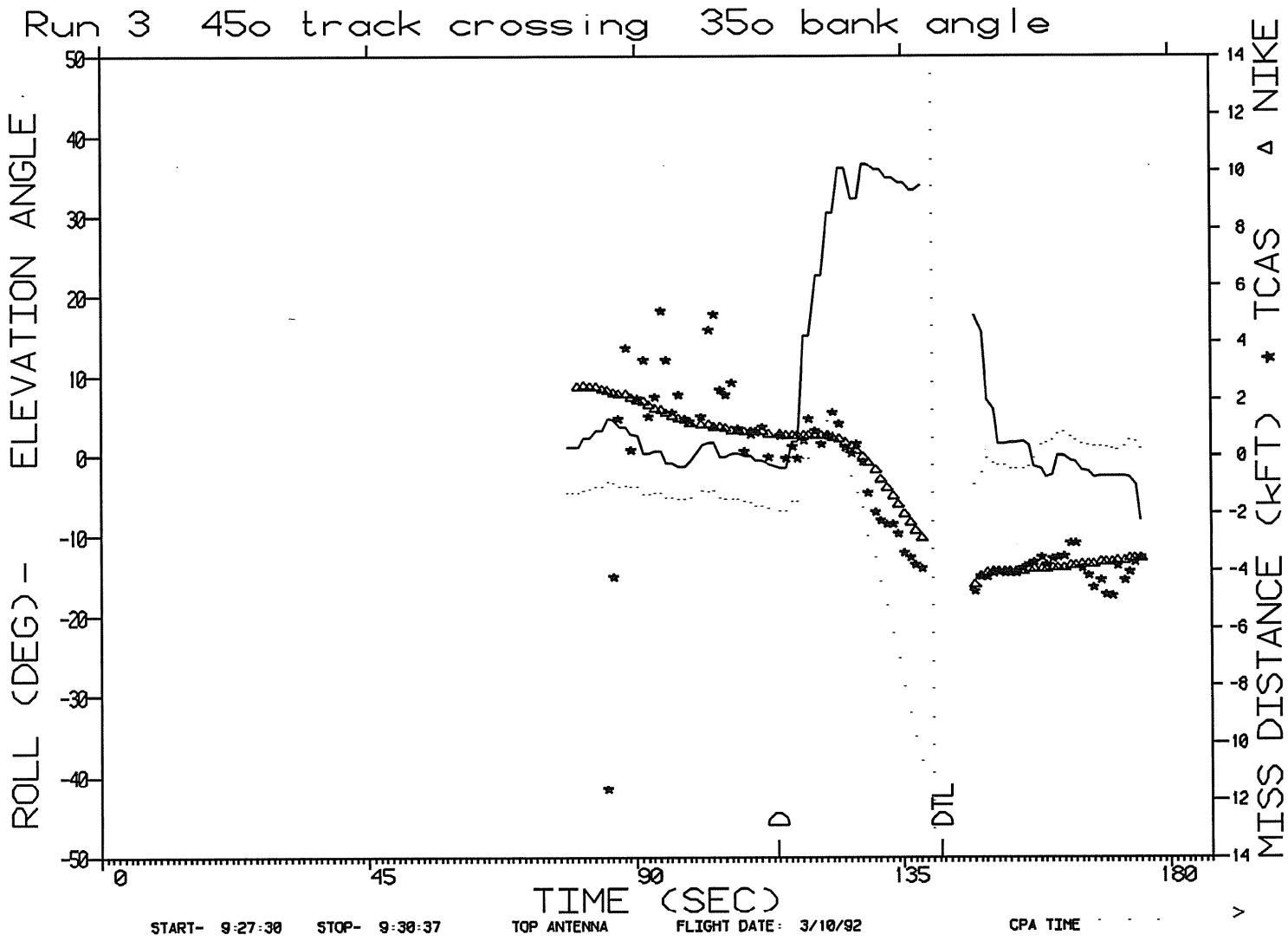
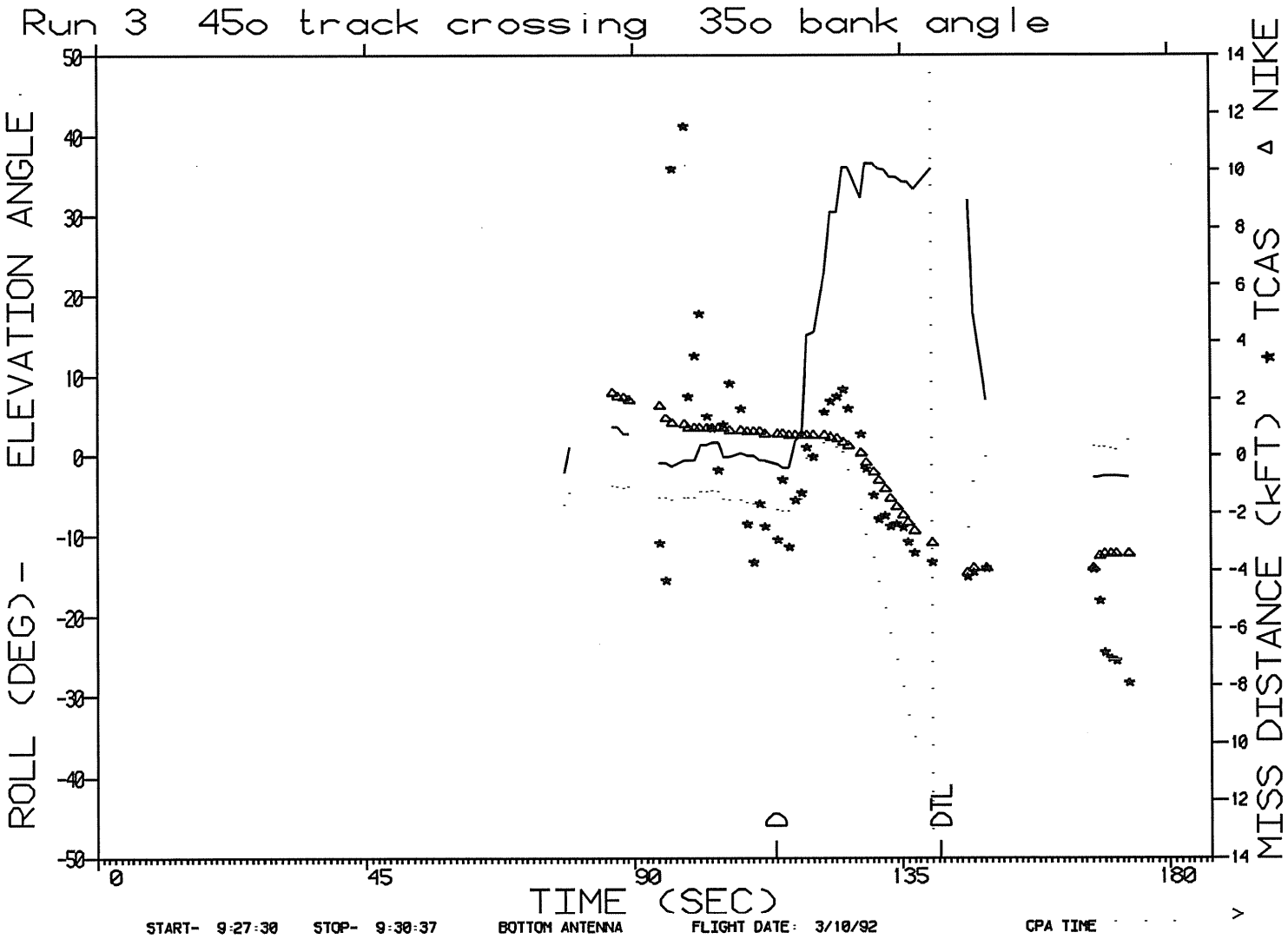
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
45
90
135
180
START- 9:20:49
STOP- 9:23:57
DIVERSITY ANTENNA
FLIGHT DATE: 3/10/92
CPA TIME


Run 3 45o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
DTL
START- 9:27:30 STOP- 9:30:37 TOP ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 3 45o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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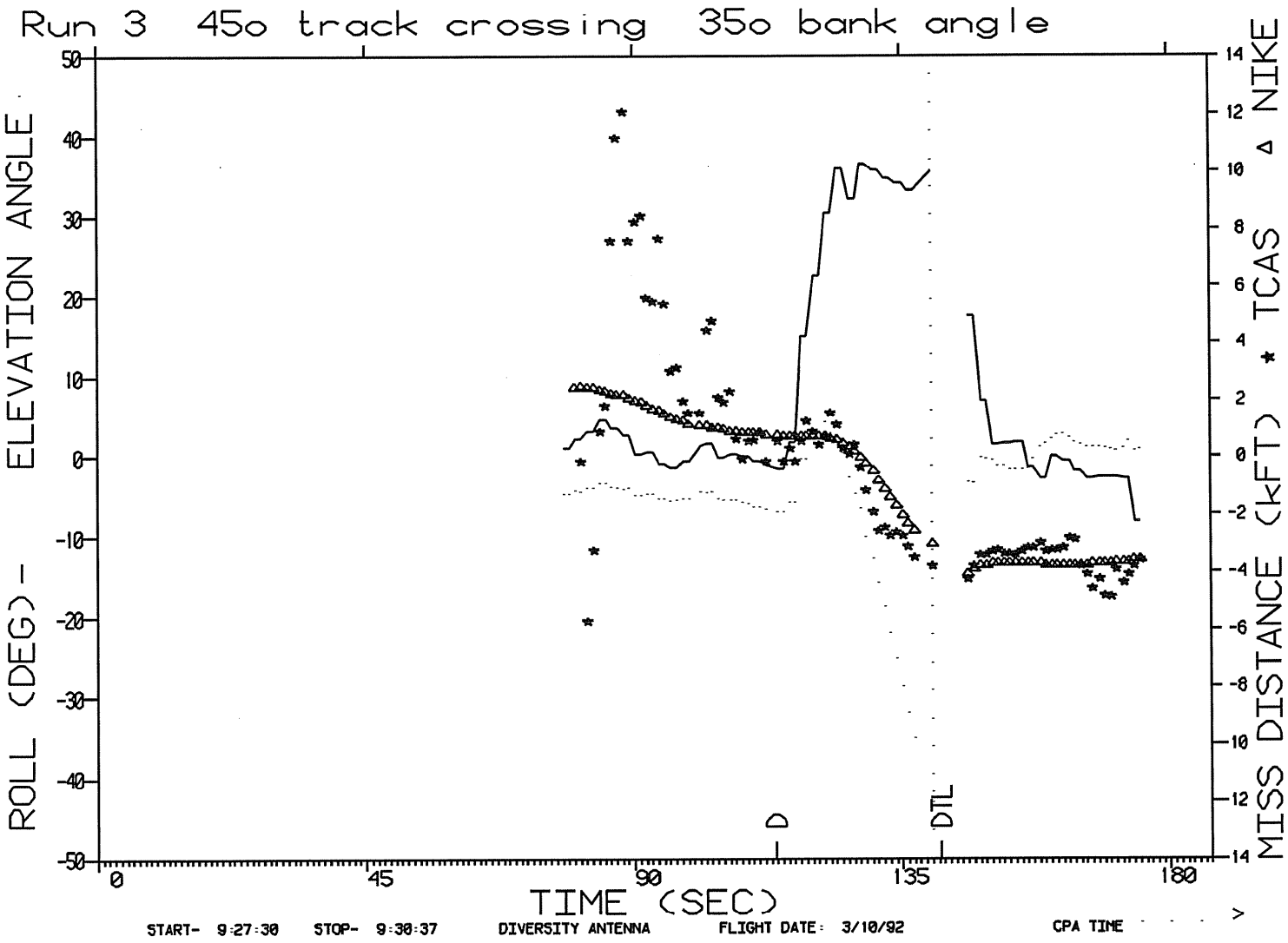
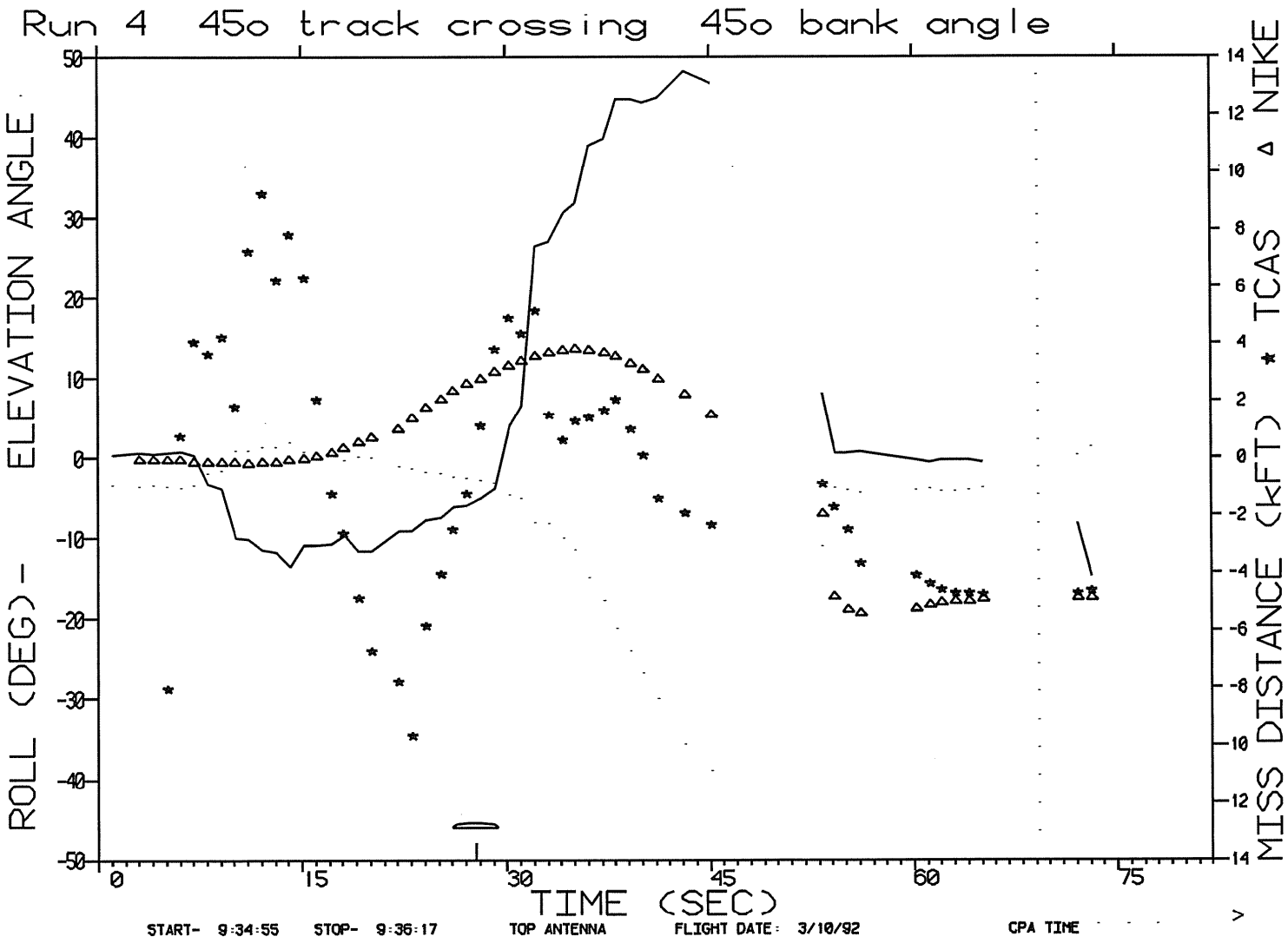
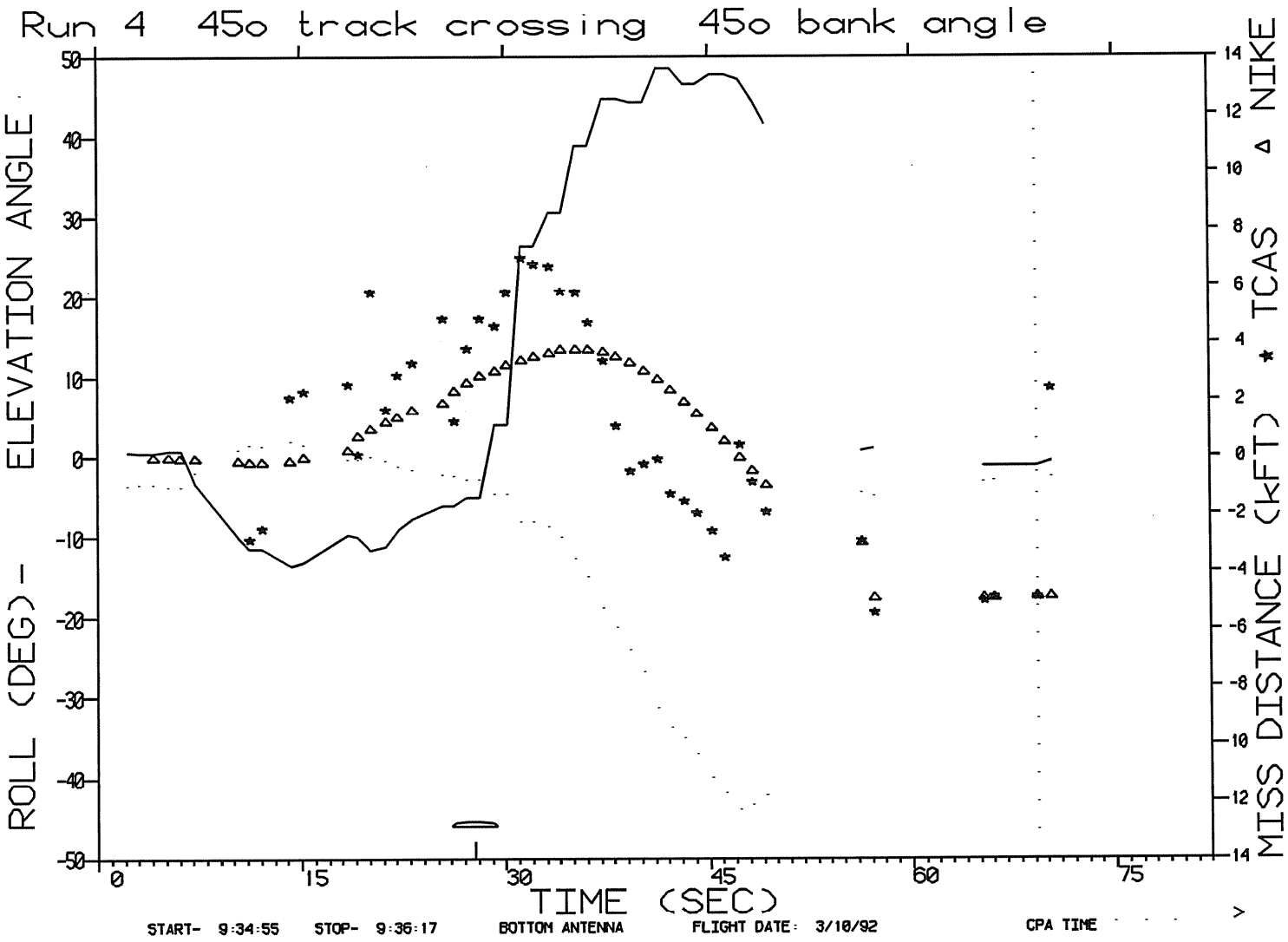
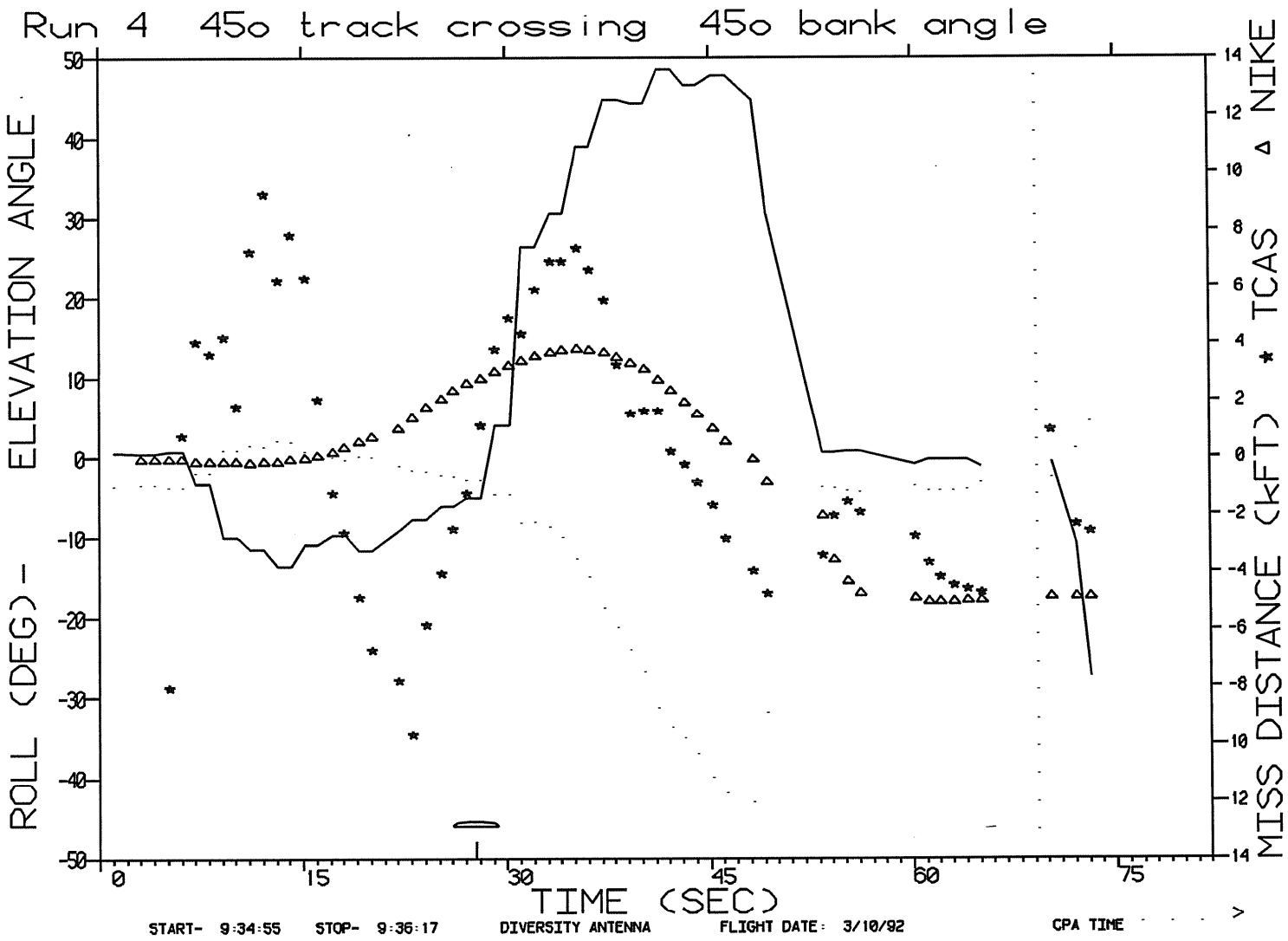
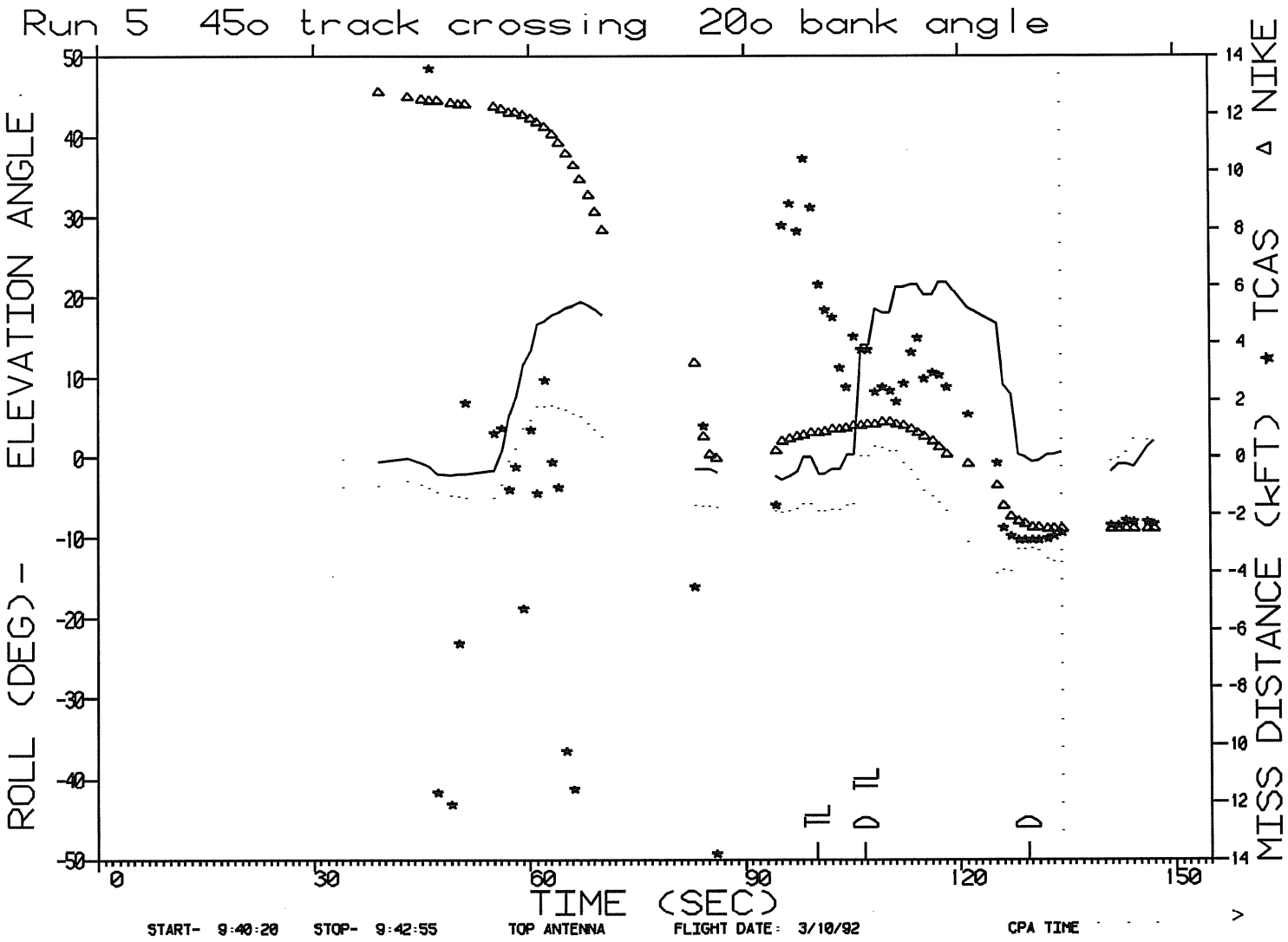
DTL
START- 9:27:30 STOP- 9:30:37 BOTTOM ANTENNA FLIGHT DATE: 3/10/92 CPA TIME

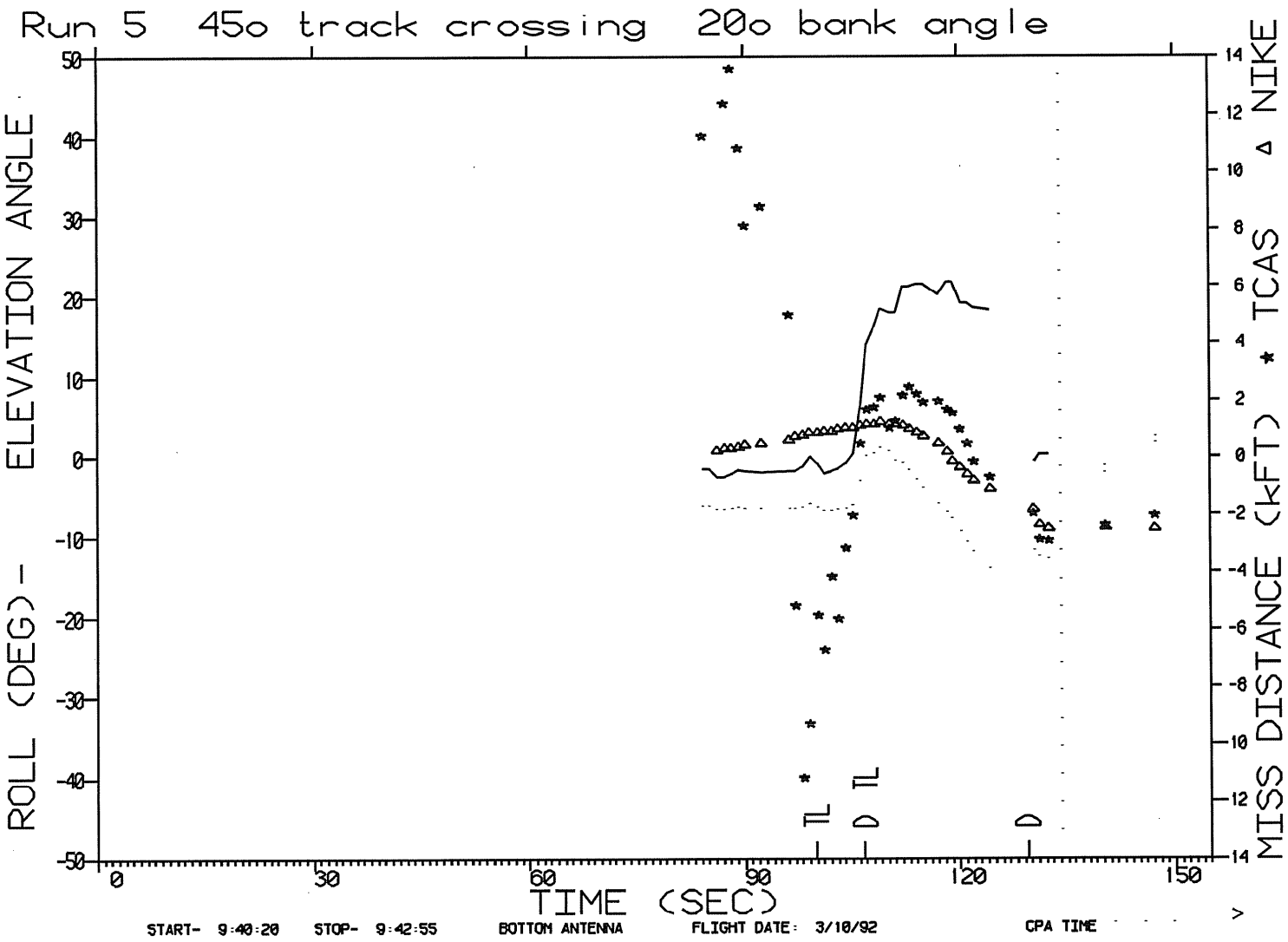

Run 3 45o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
DTL
START- 9:27:30 STOP- 9:30:37 DIVERSITY ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 4 45o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:34:55 STOP- 9:36:17 TOP ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 4 45o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:34:55 STOP- 9:36:17 BOTTOM ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 4 45o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:34:55 STOP- 9:36:17 DIVERSITY ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 5 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:40:20 STOP- 9:42:55 TOP ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 5 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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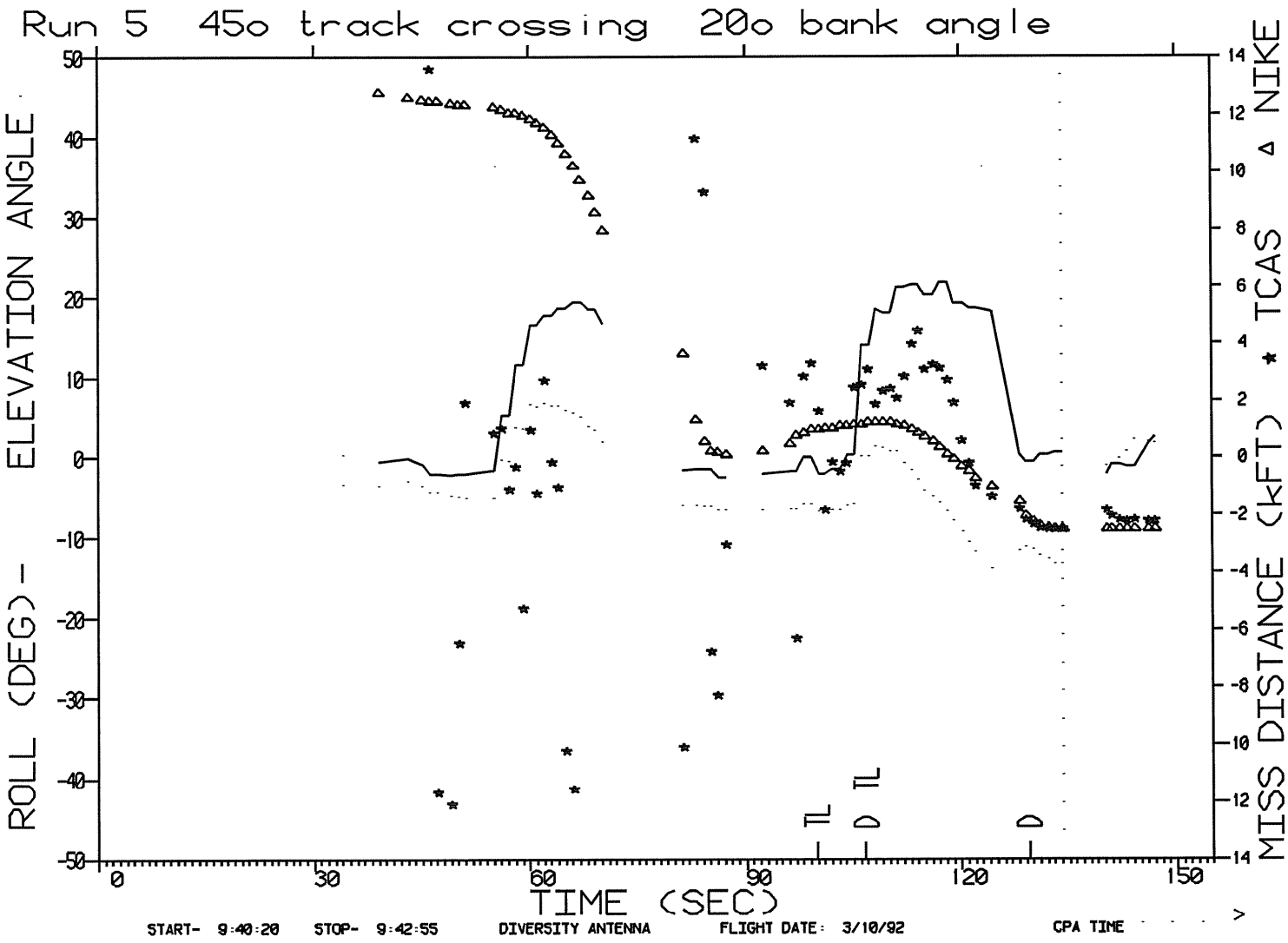
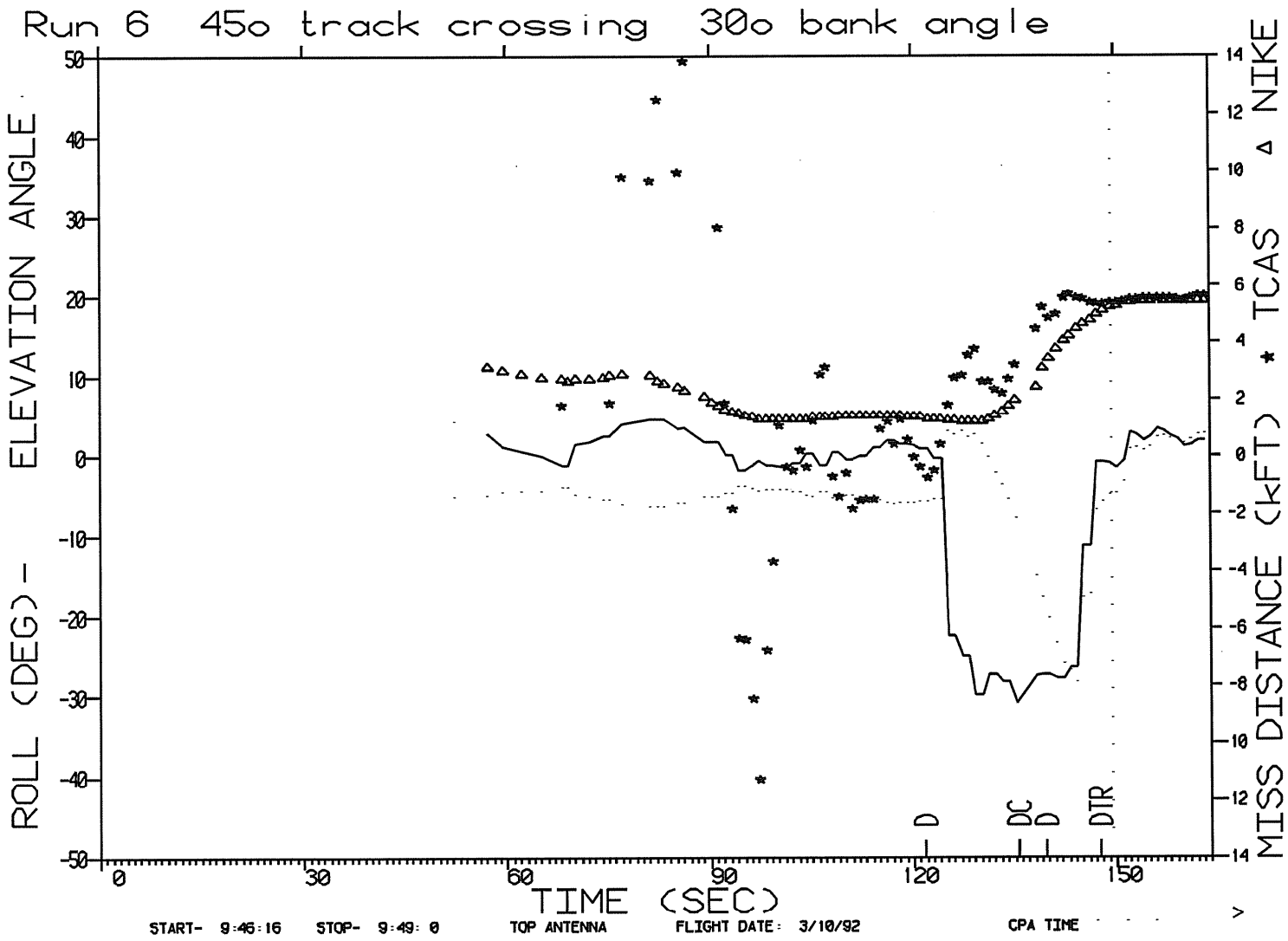
START- 9:40:20 STOP- 9:42:55 BOTTOM ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 5 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:40:20 STOP- 9:42:55 DIVERSITY ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 6 45o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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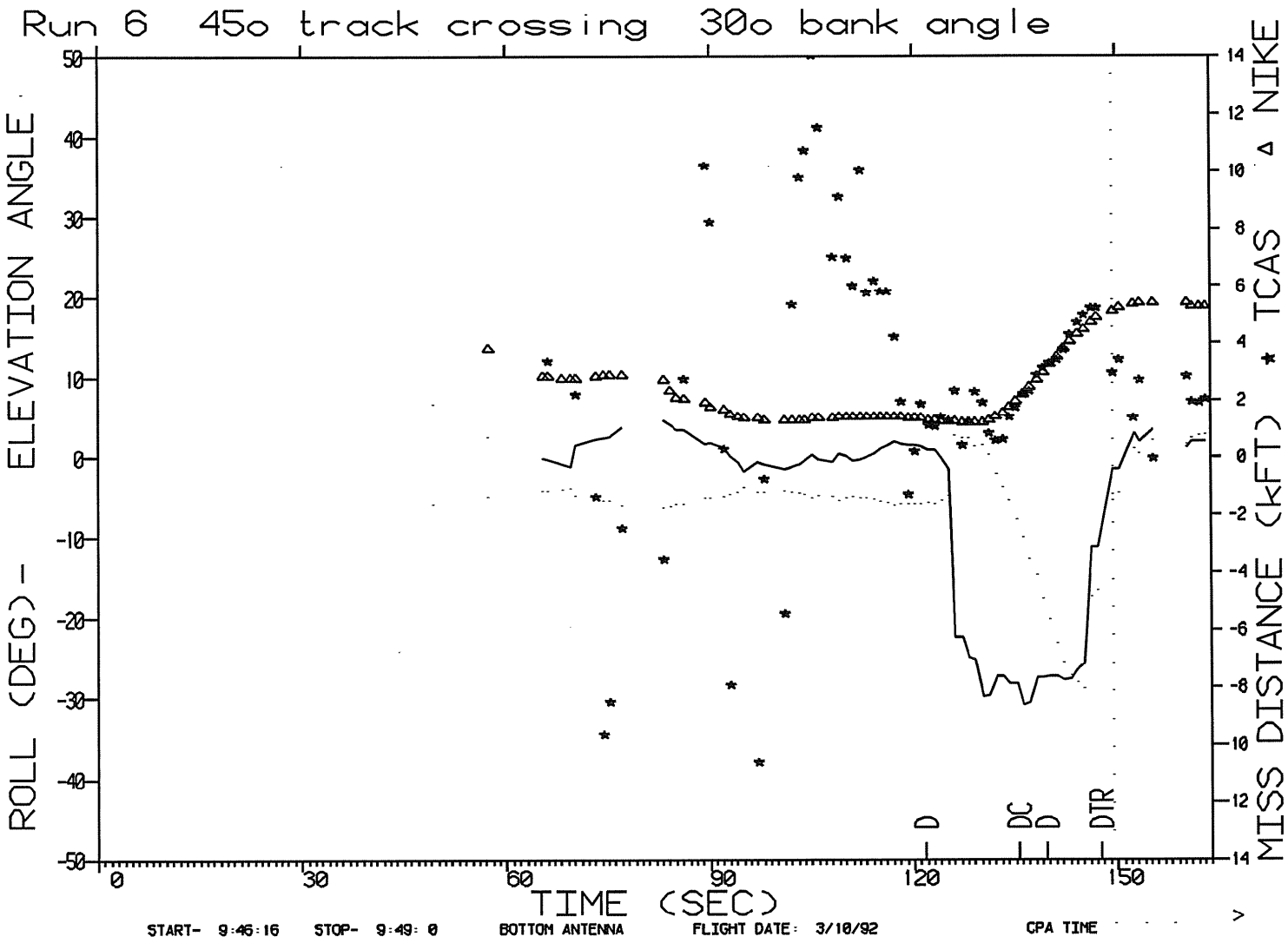
DTR
START- 9:46:16 STOP- 9:49: 0 TOP ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 6 45o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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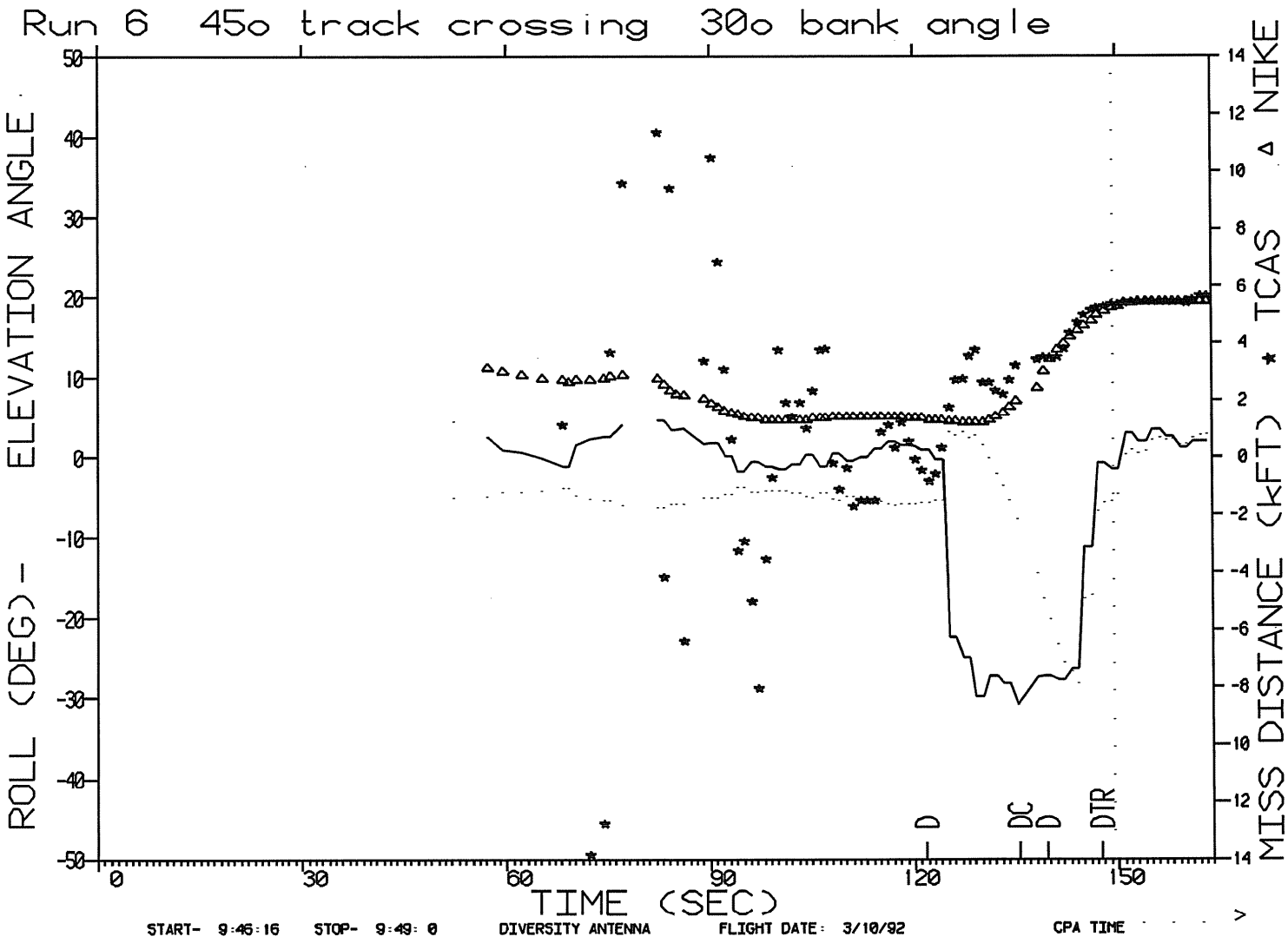
START- 9:46:16 STOP- 9:49: 0 BOTTOM ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 6 45o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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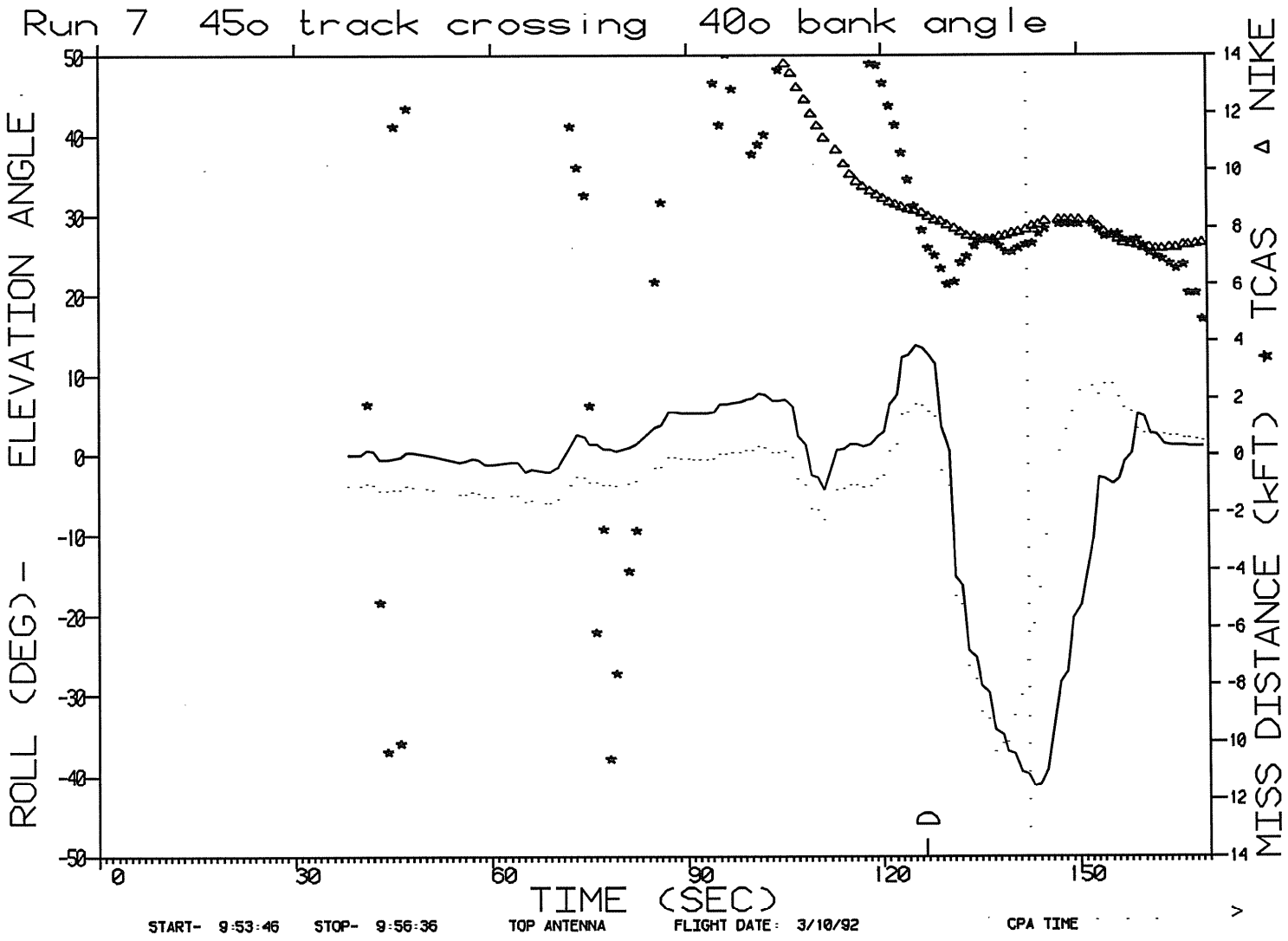
START- 9:46:16 STOP- 9:49: 0 DIVERSITY ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 7 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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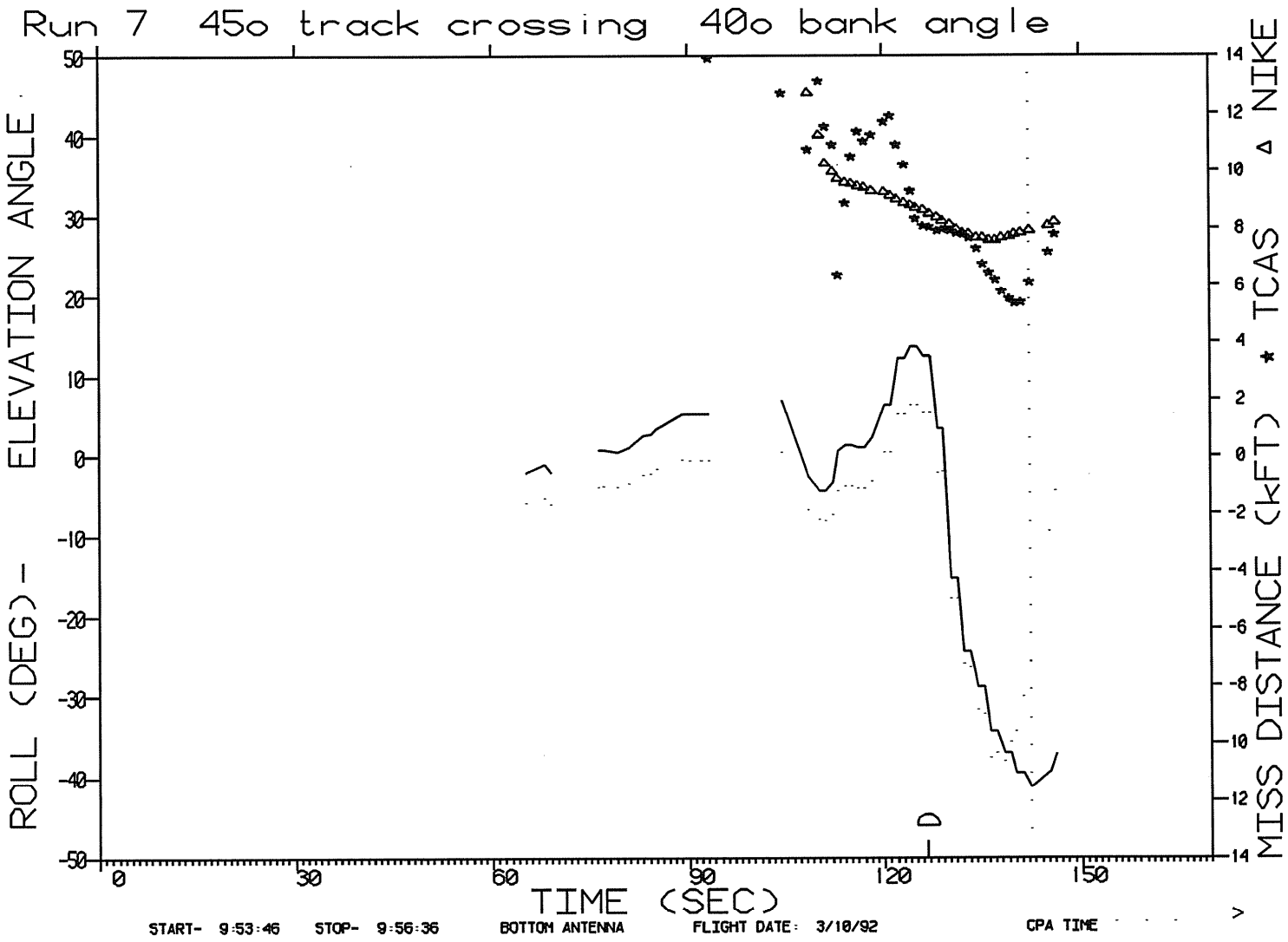
START- 9:53:46
STOP- 9:56:36
TOP ANTENNA
FLIGHT DATE: 3/10/92
CPA TIME


Run 7 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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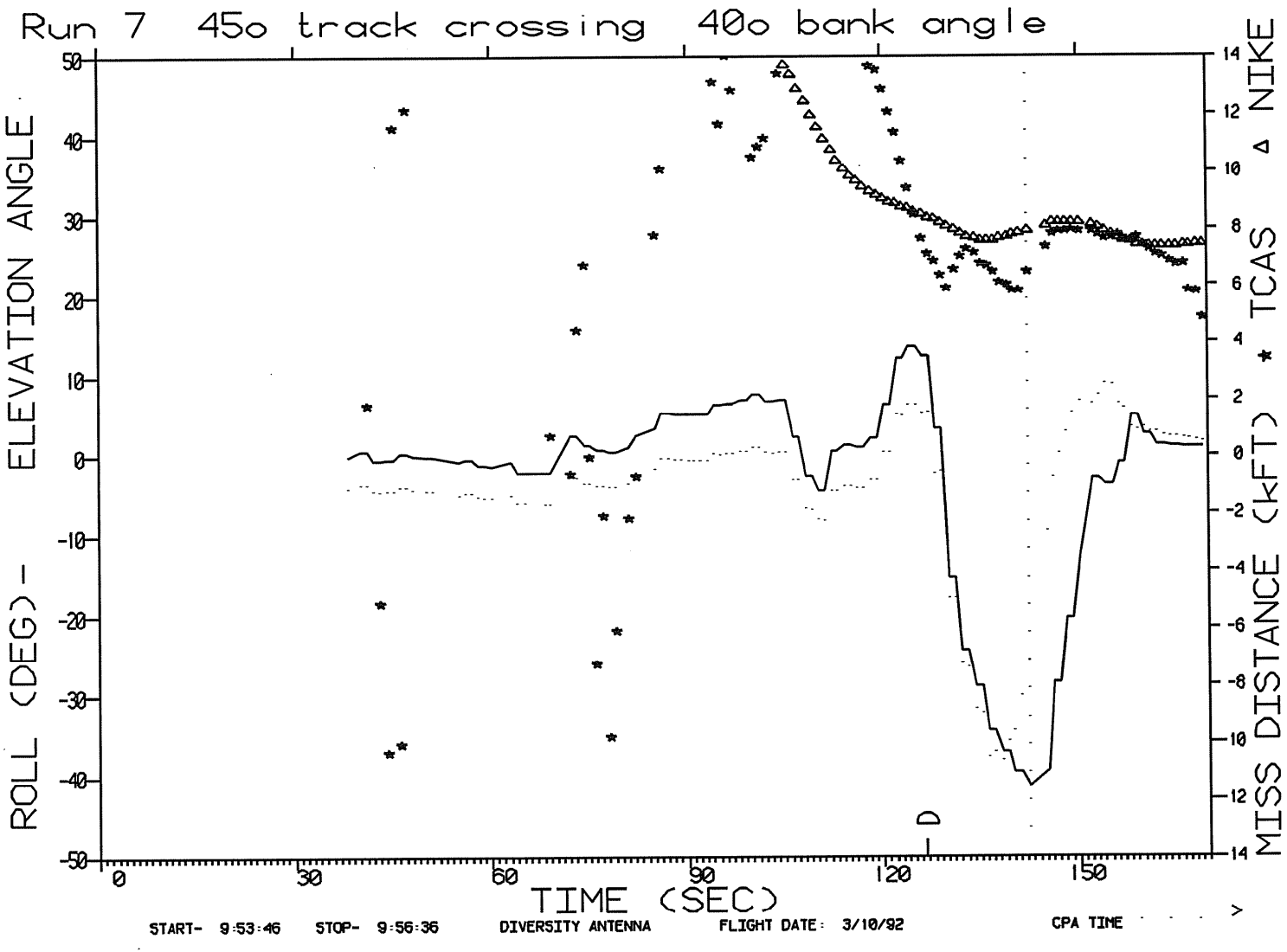
START- 9:53:46 STOP- 9:56:36 BOTTOM ANTENNA FLIGHT DATE: 3/10/92 CPA TIME


Run 7 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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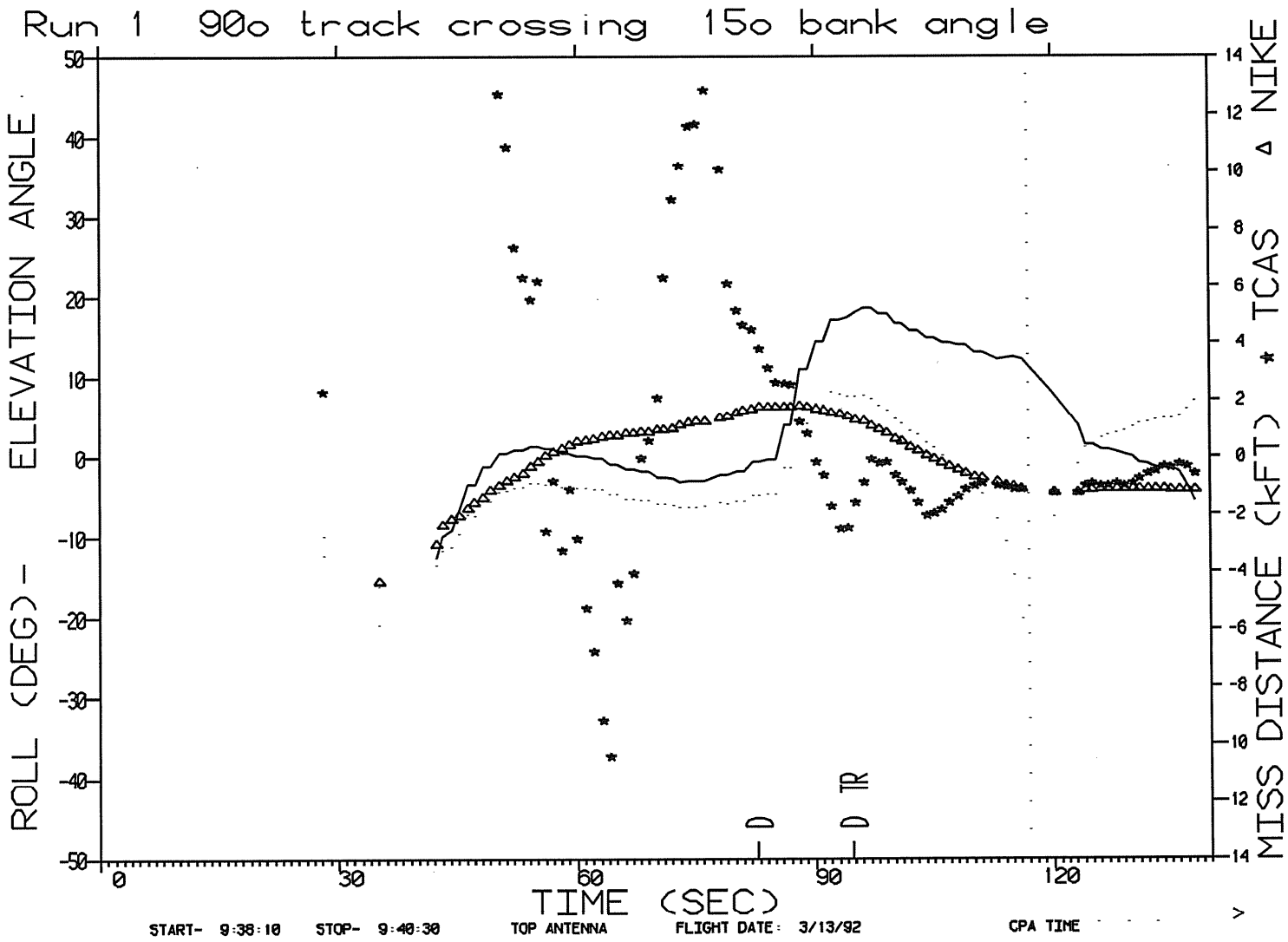
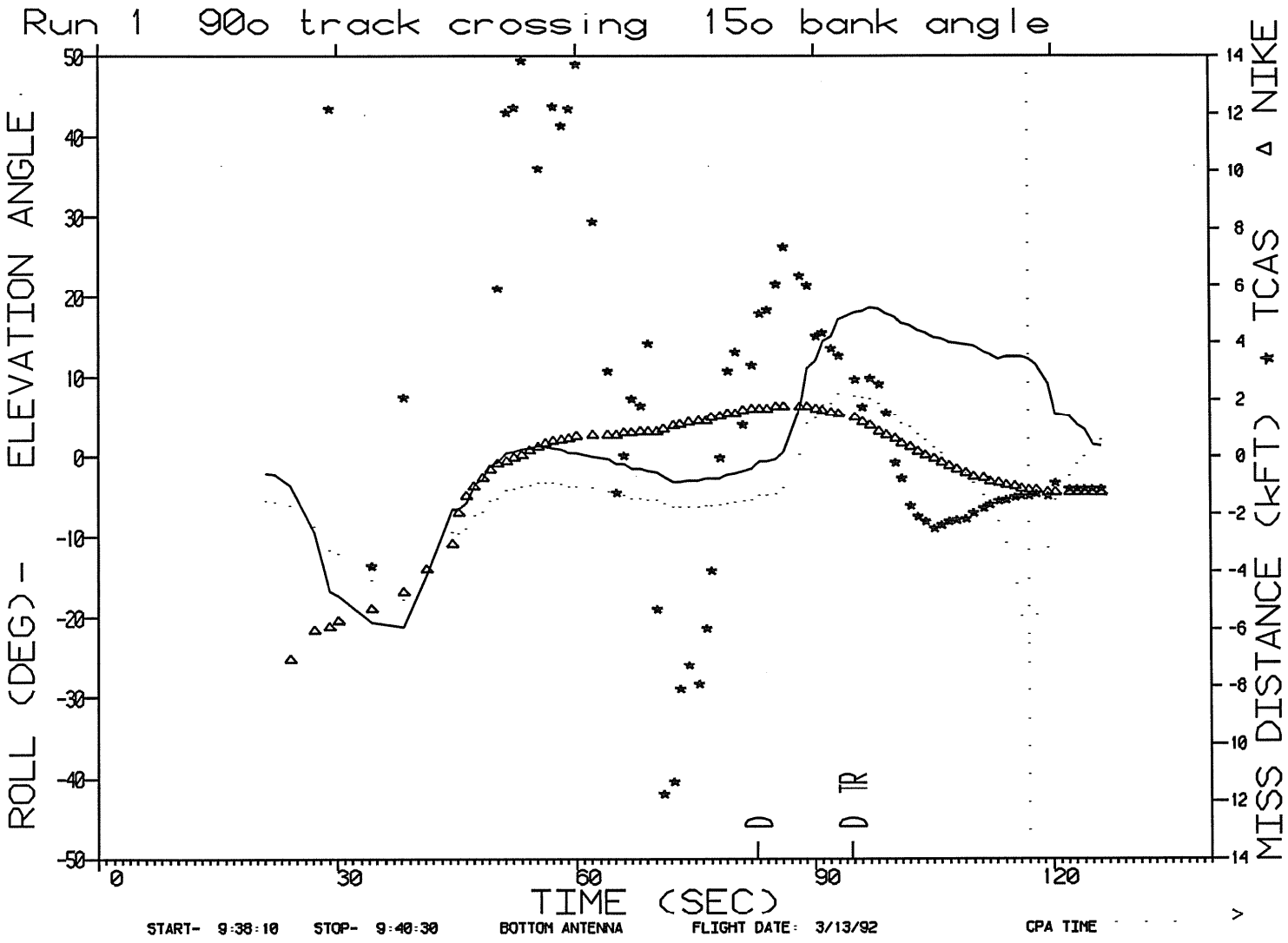
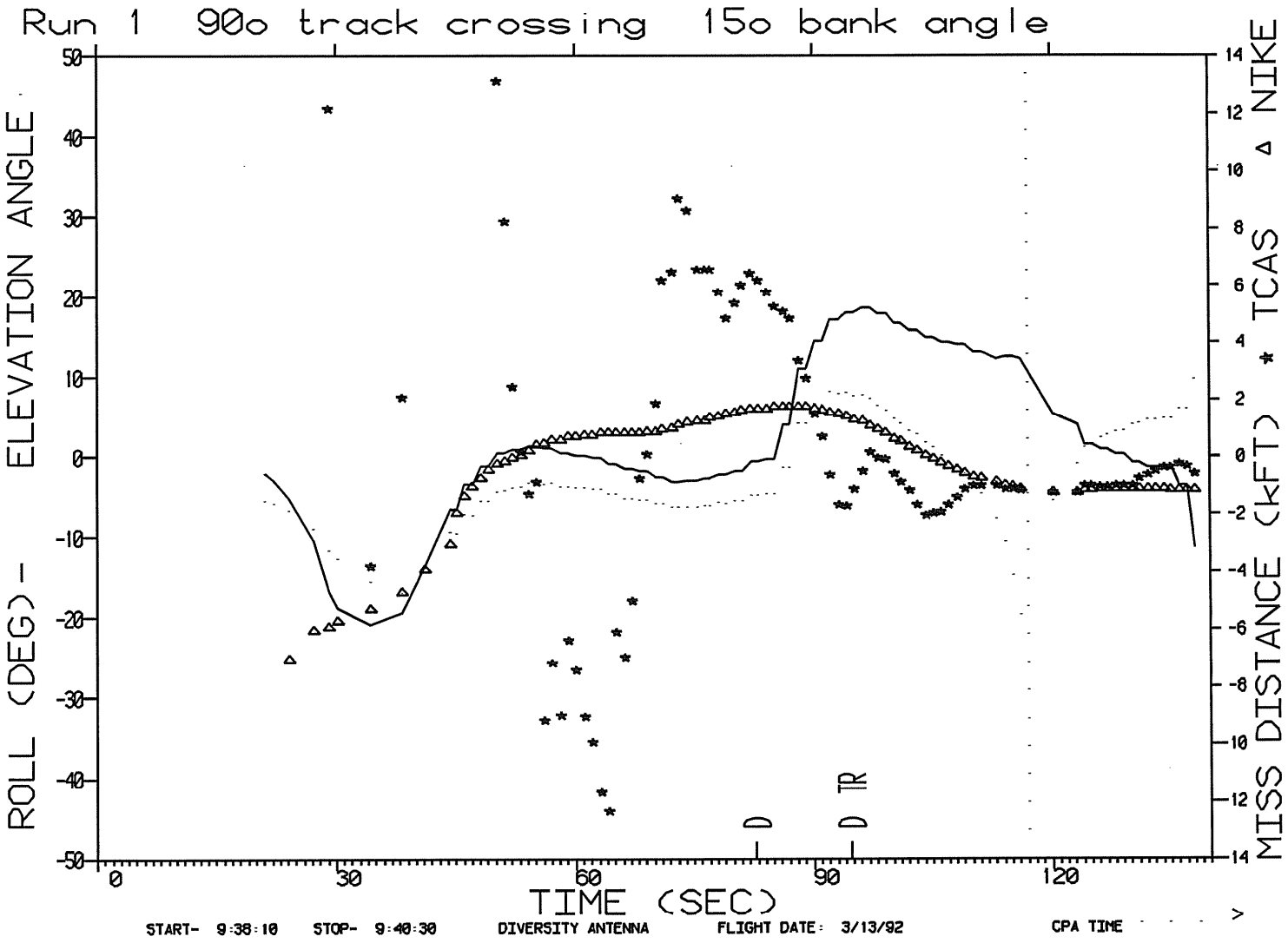
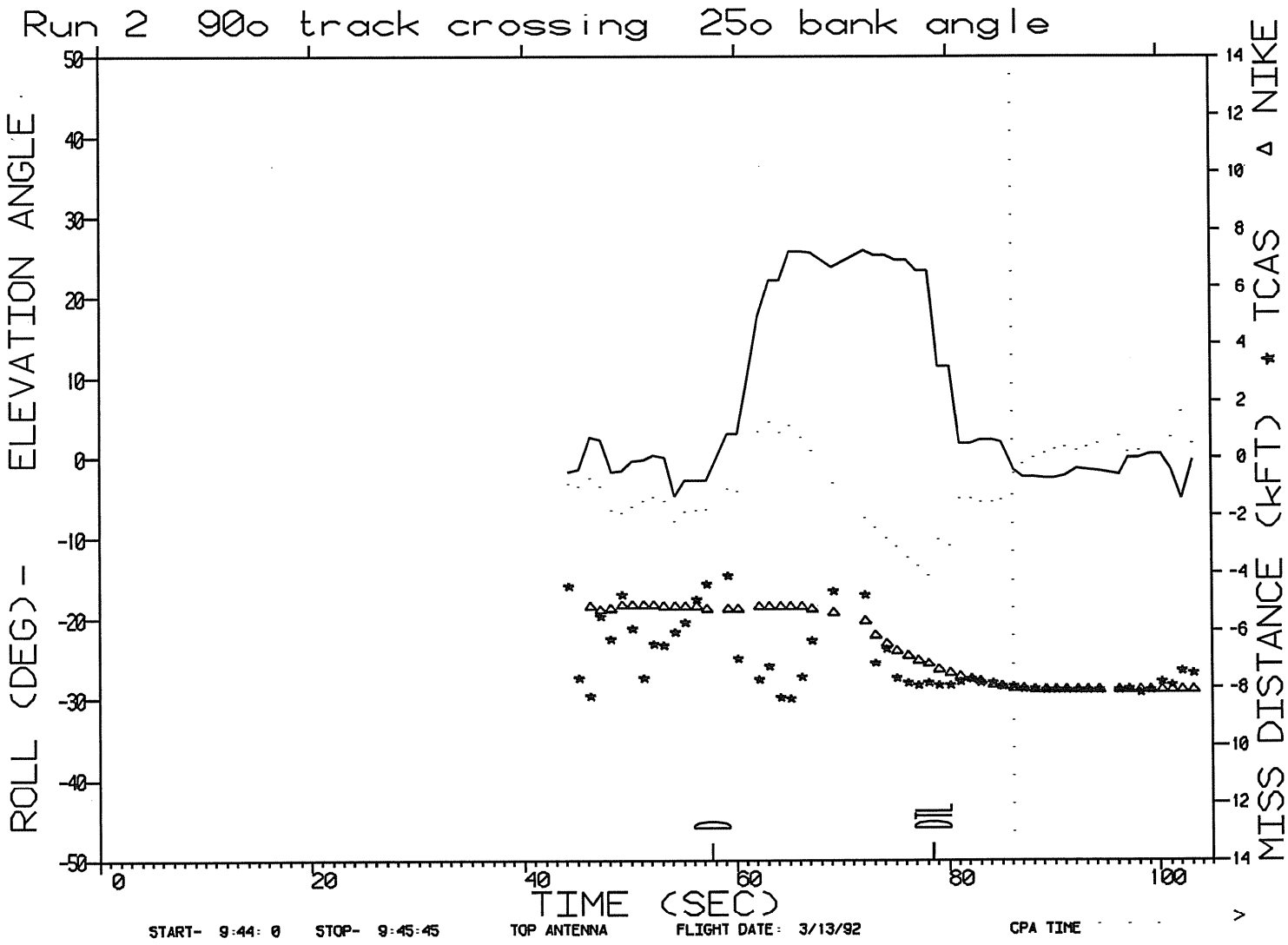
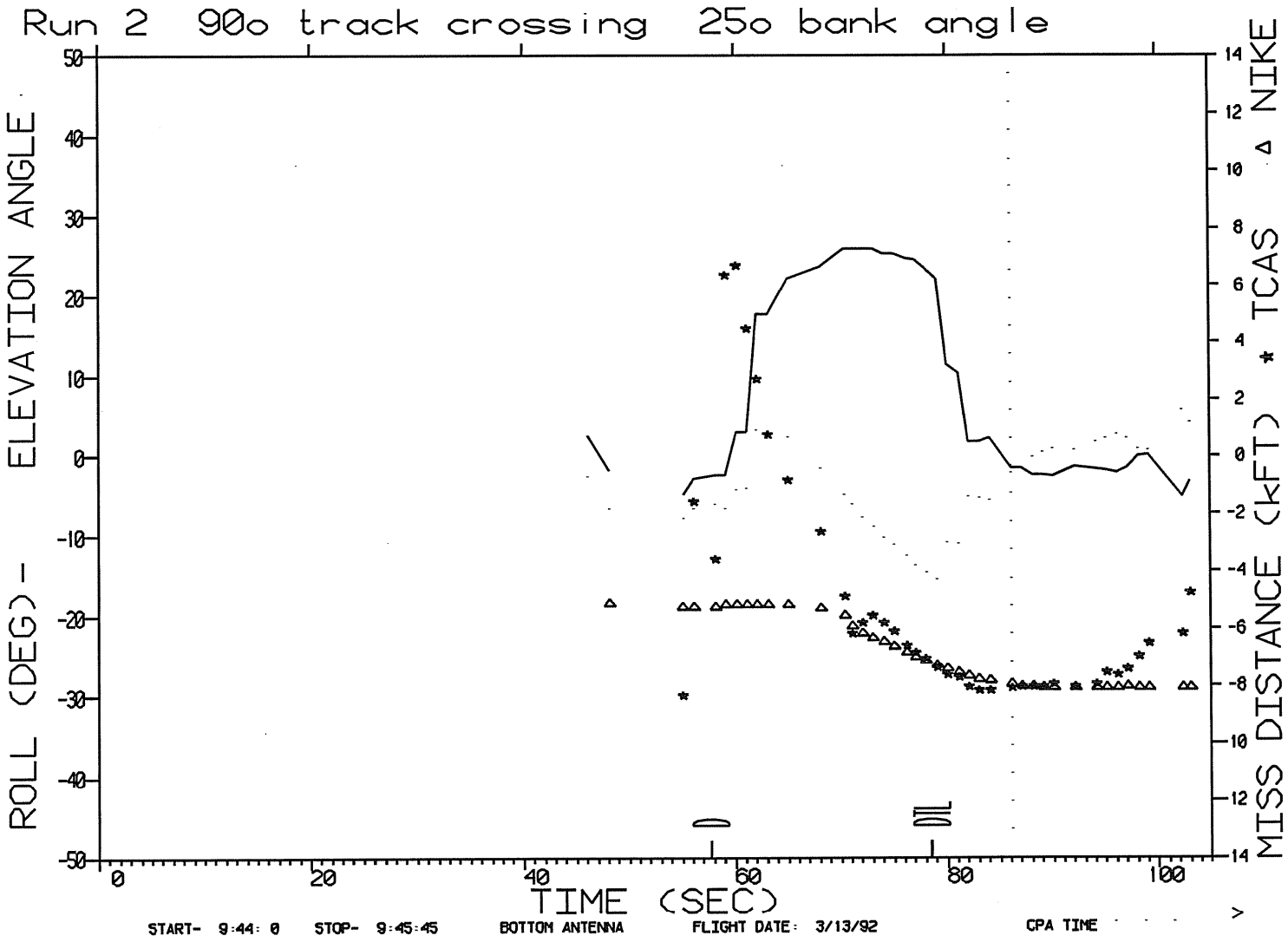
START- 9:53:46
STOP- 9:56:36
DIVERSITY ANTENNA
FLIGHT DATE: 3/10/92
CPA TIME

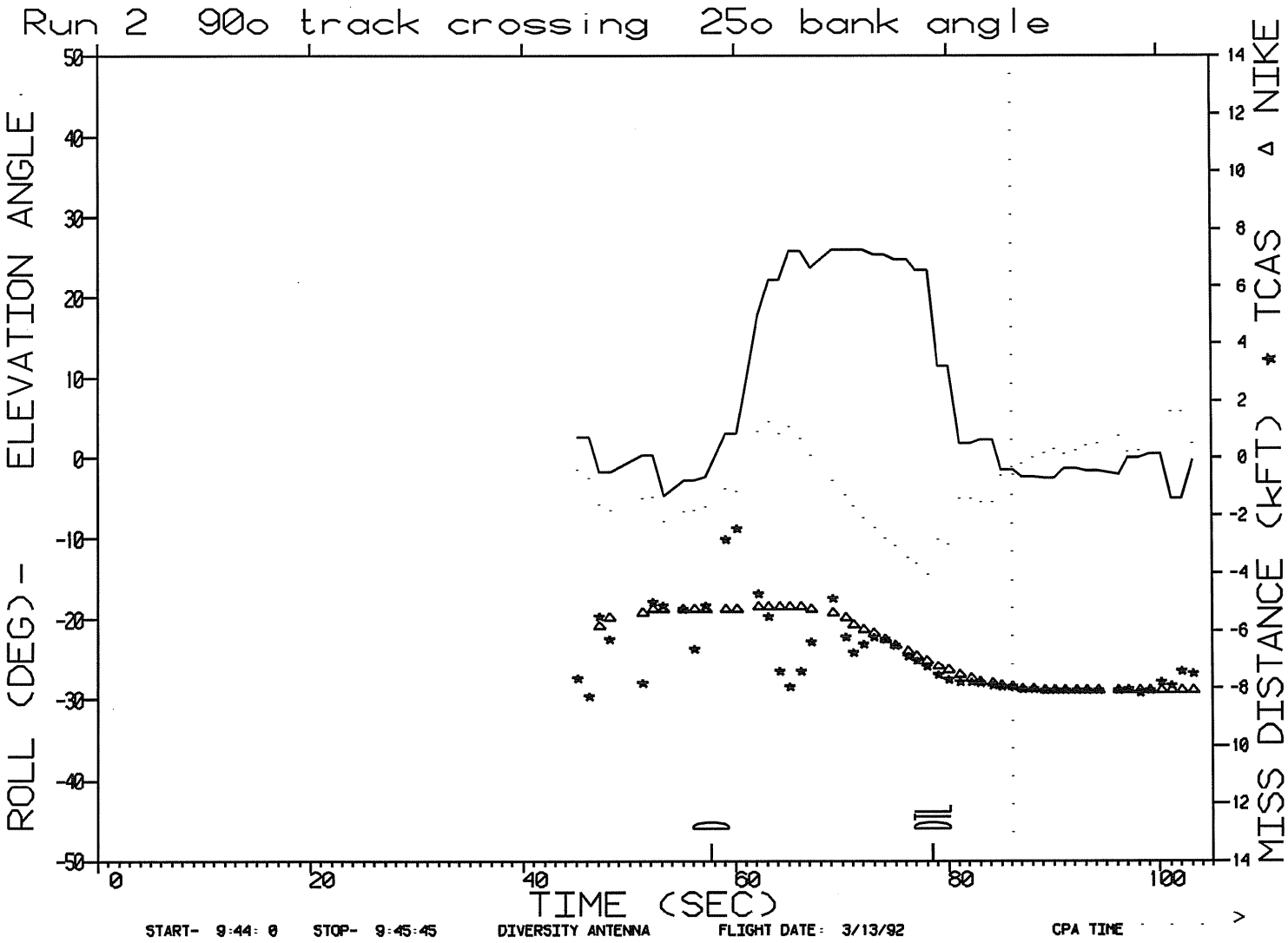

Run 1 90o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
D TR
START- 9:38:10 STOP- 9:40:30 TOP ANTENNA FLIGHT DATE: 3/13/92 CPA TIME

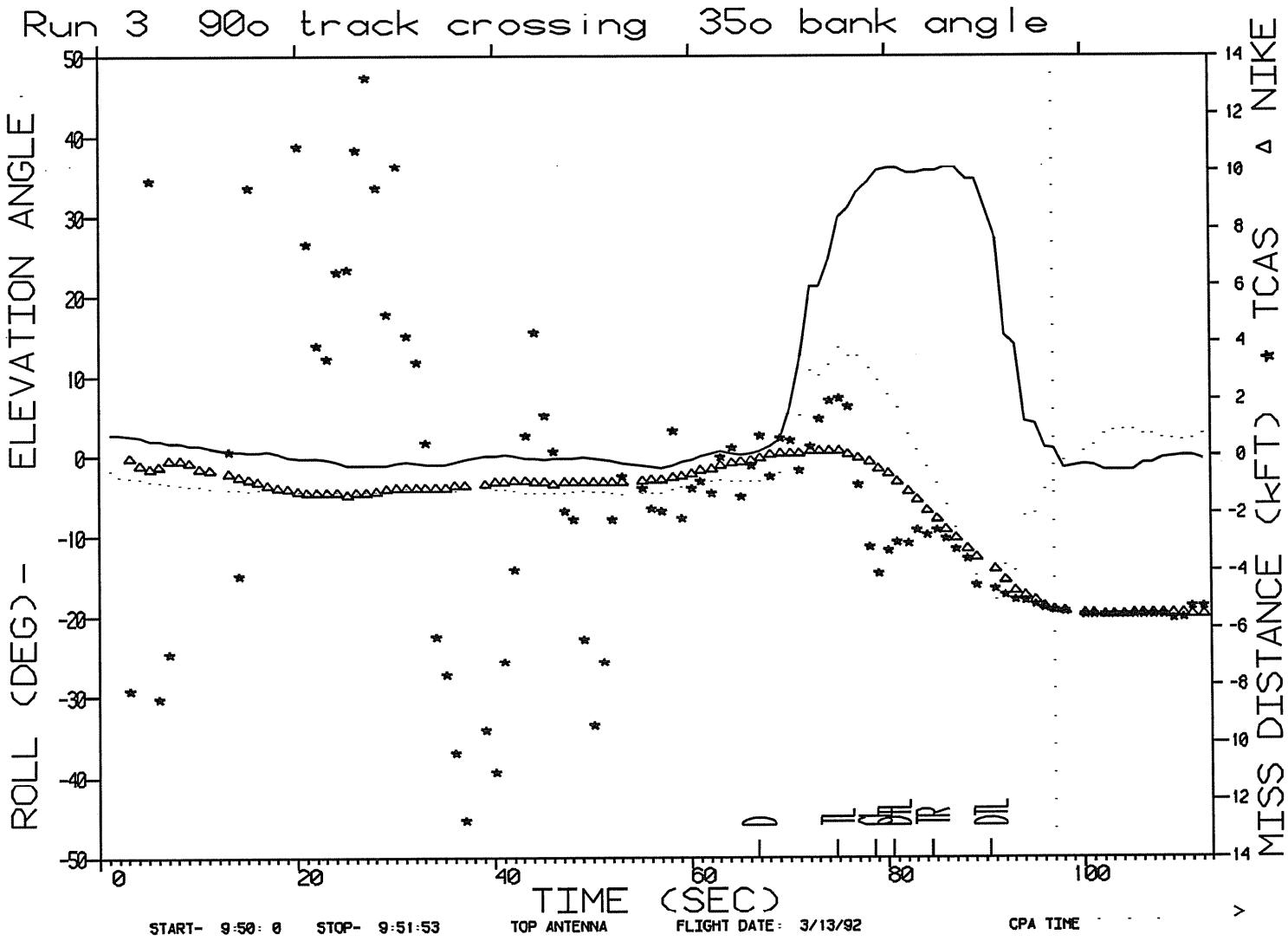

Run 1 90o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
D TR
START- 9:38:10 STOP- 9:40:30 BOTTOM ANTENNA FLIGHT DATE: 3/13/92 CPA TIME

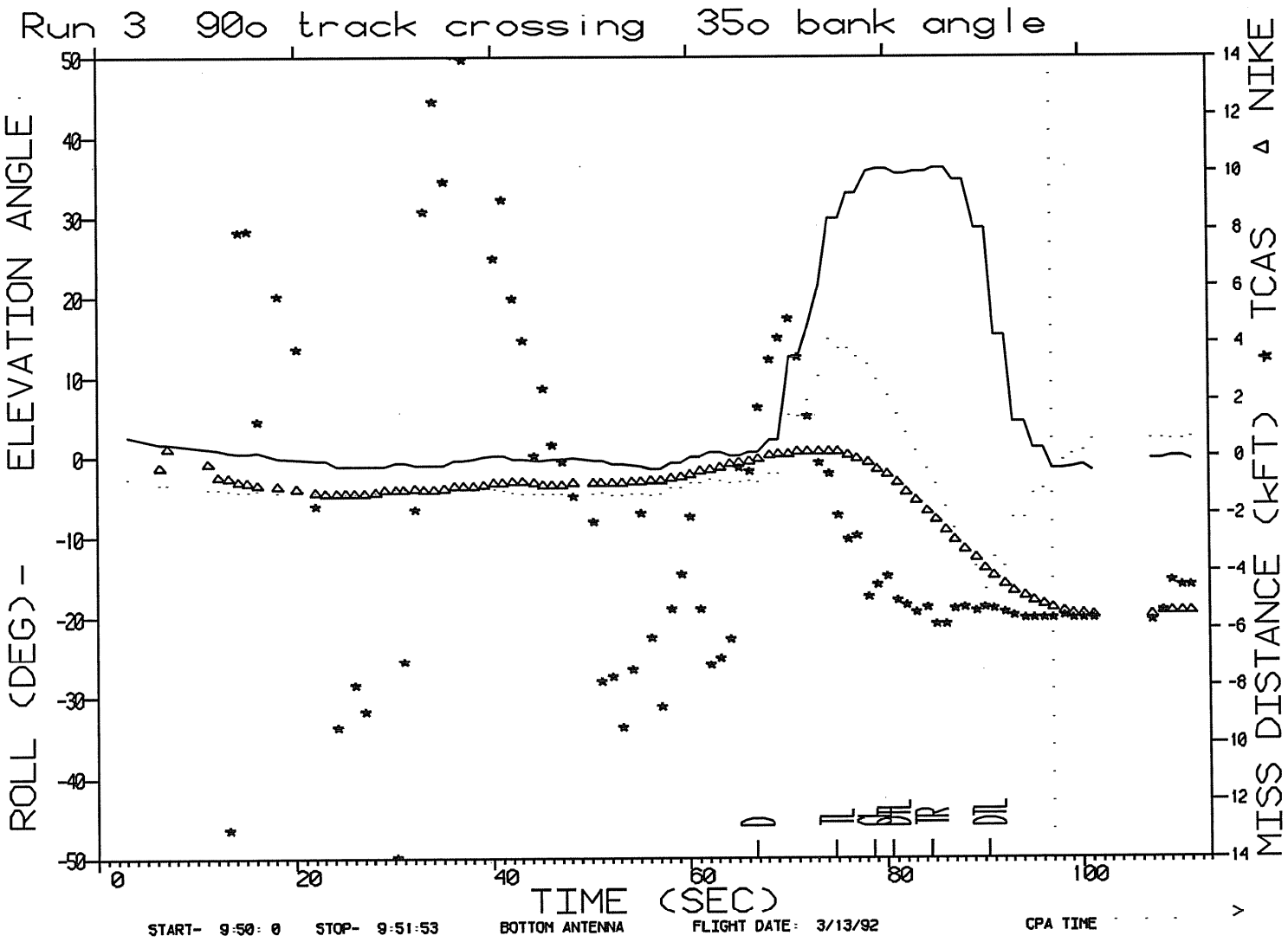

Run 1 90o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
D TR
START- 9:38:10 STOP- 9:40:30 DIVERSITY ANTENNA FLIGHT DATE: 3/13/92 CPA TIME

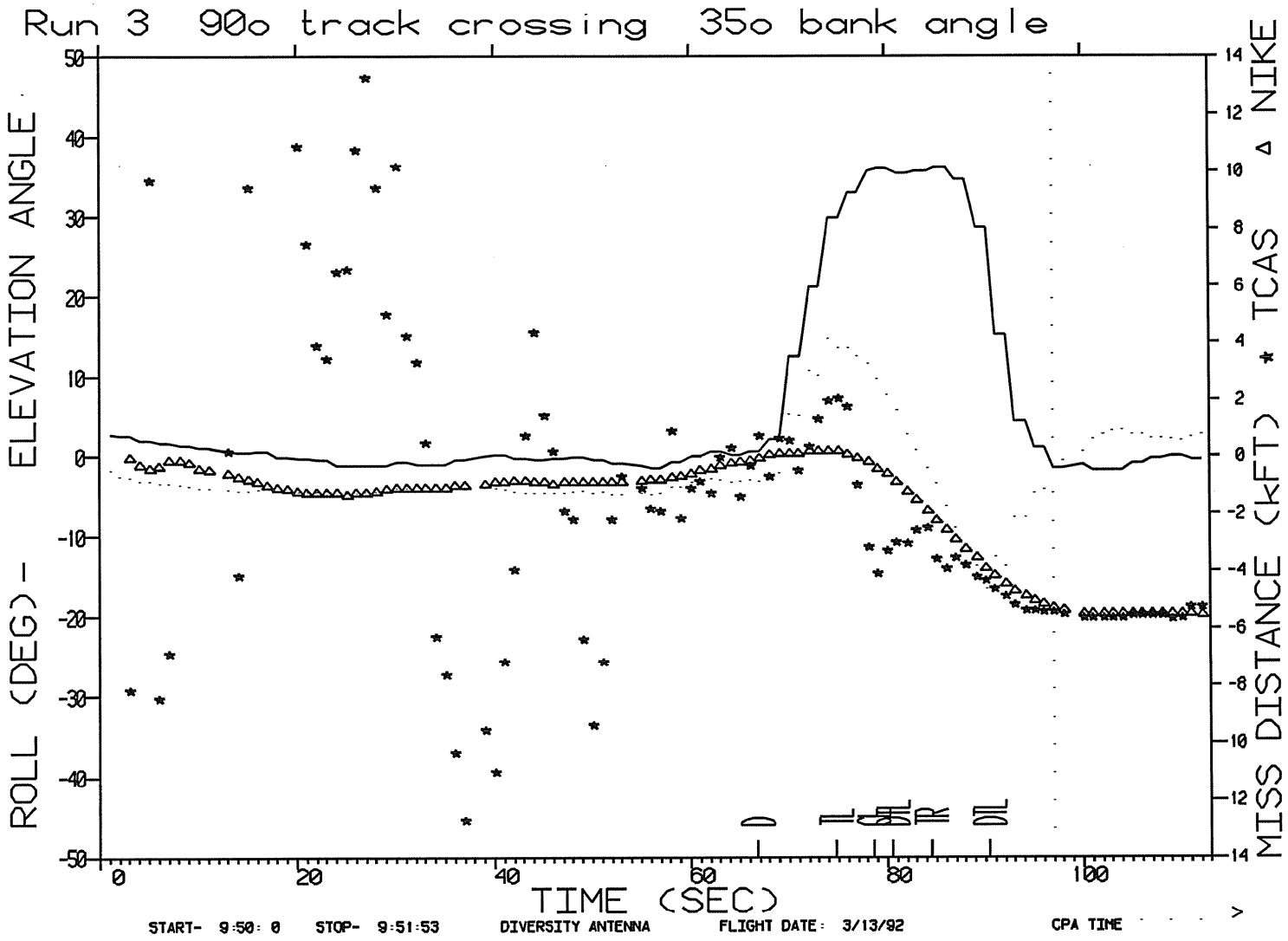

Run 2 90o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:44: 0
STOP- 9:45:45
TOP ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

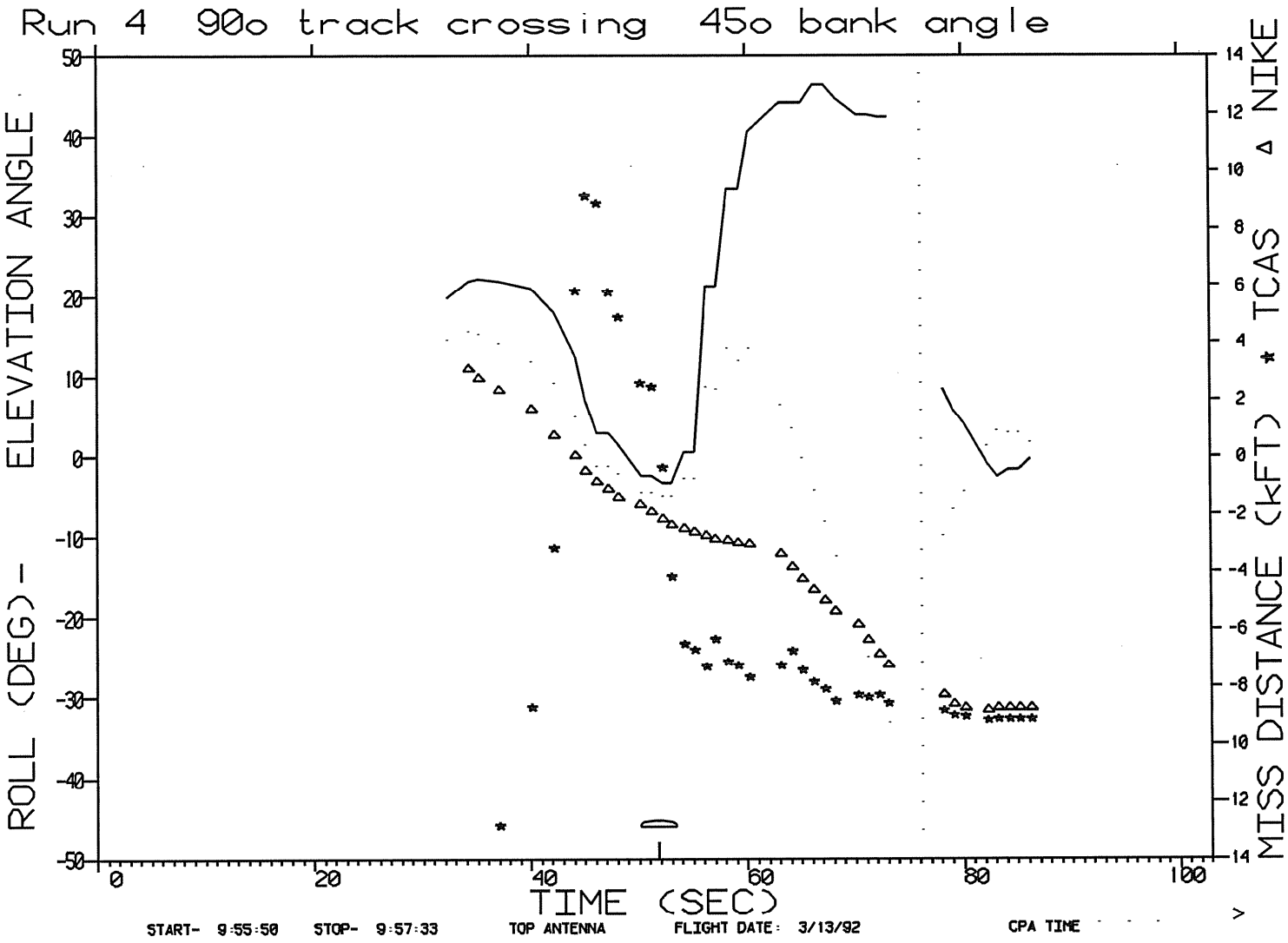

Run 2 90o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:44: 0
STOP- 9:45:45
BOTTOM ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME


Run 2 90o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:44: 0
STOP- 9:45:45
DIVERSITY ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME


Run 3 90o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:50: 0
STOP- 9:51:53
TOP ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME


Run 3 90o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:50: 0
STOP- 9:51:53
BOTTOM ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME


Run 3 90o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:50: 0
STOP- 9:51:53
DIVERSITY ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME


Run 4 90o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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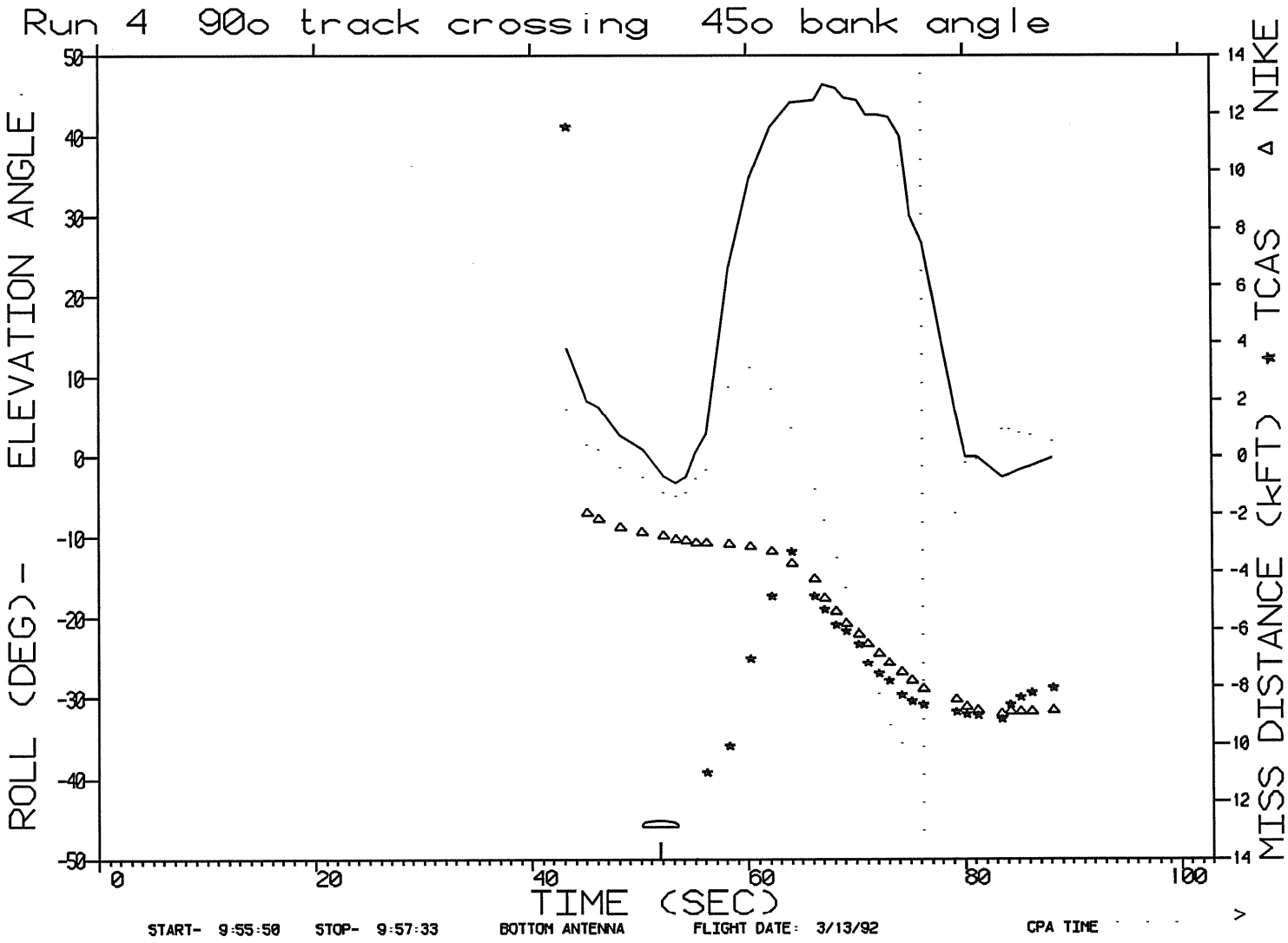
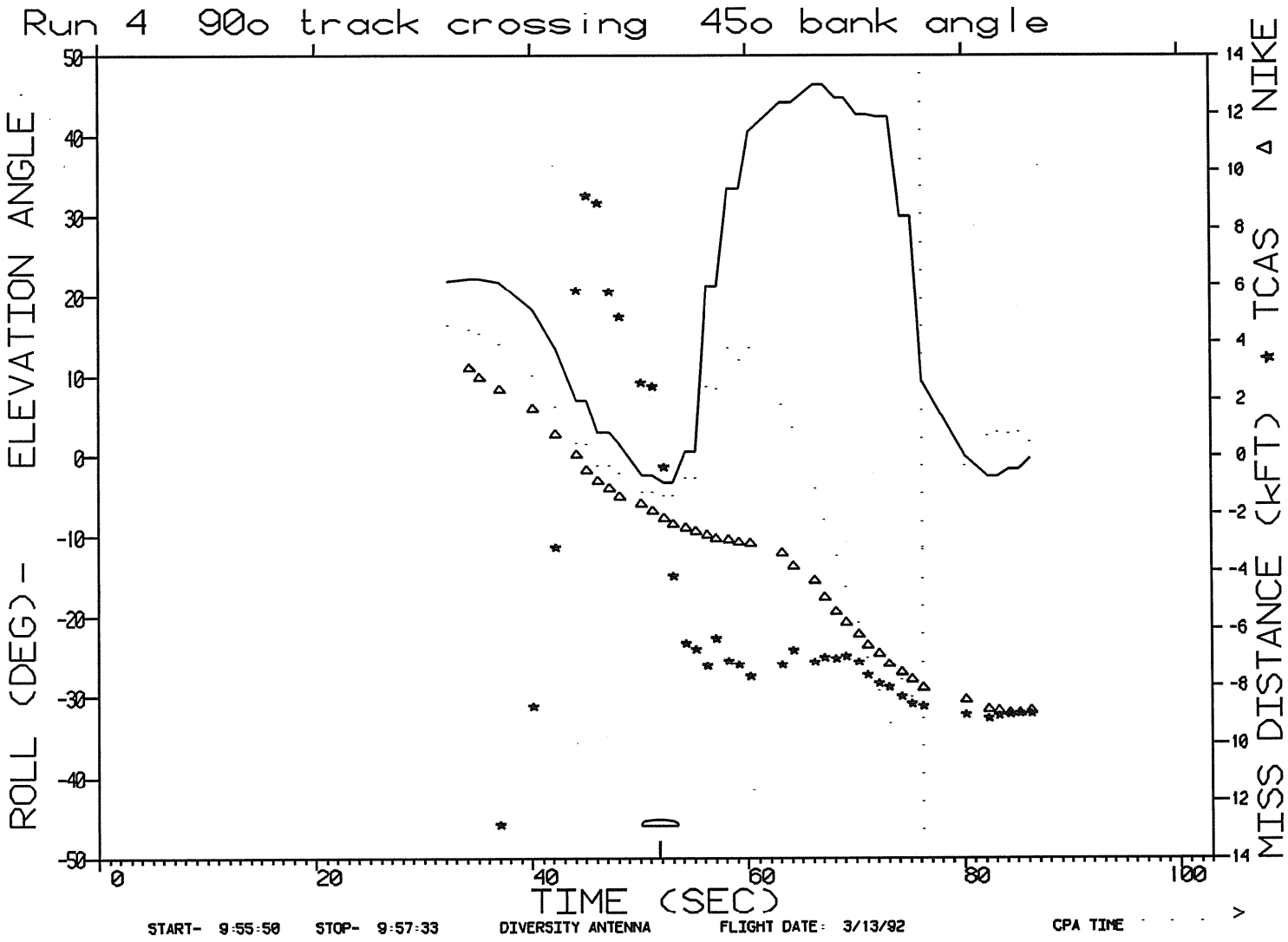
100
START- 9:55:50
STOP- 9:57:33
TOP ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME


Run 4 90o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 9:55:50 STOP- 9:57:33 BOTTOM ANTENNA FLIGHT DATE: 3/13/92 CPA TIME


Run 4 90o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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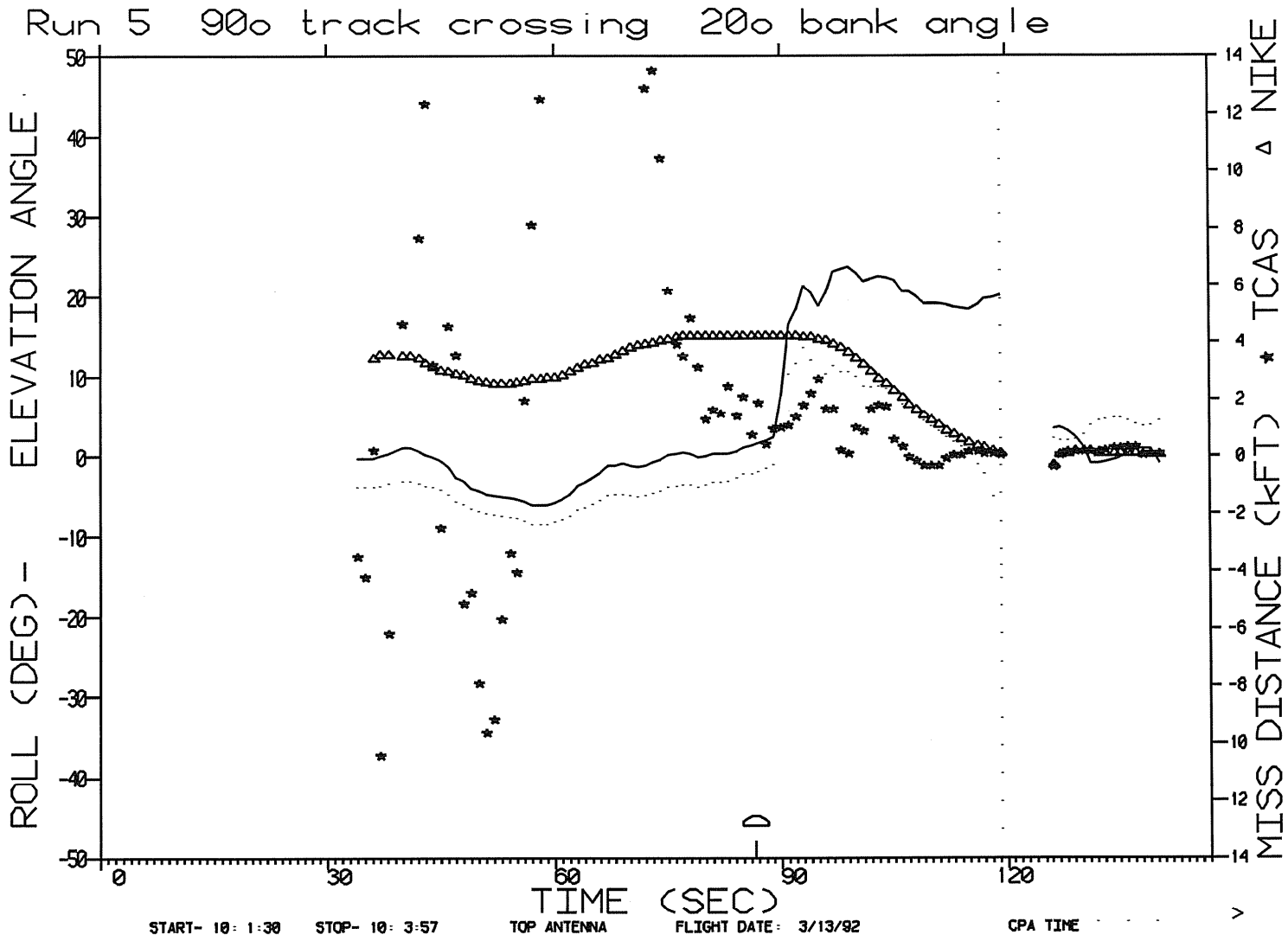
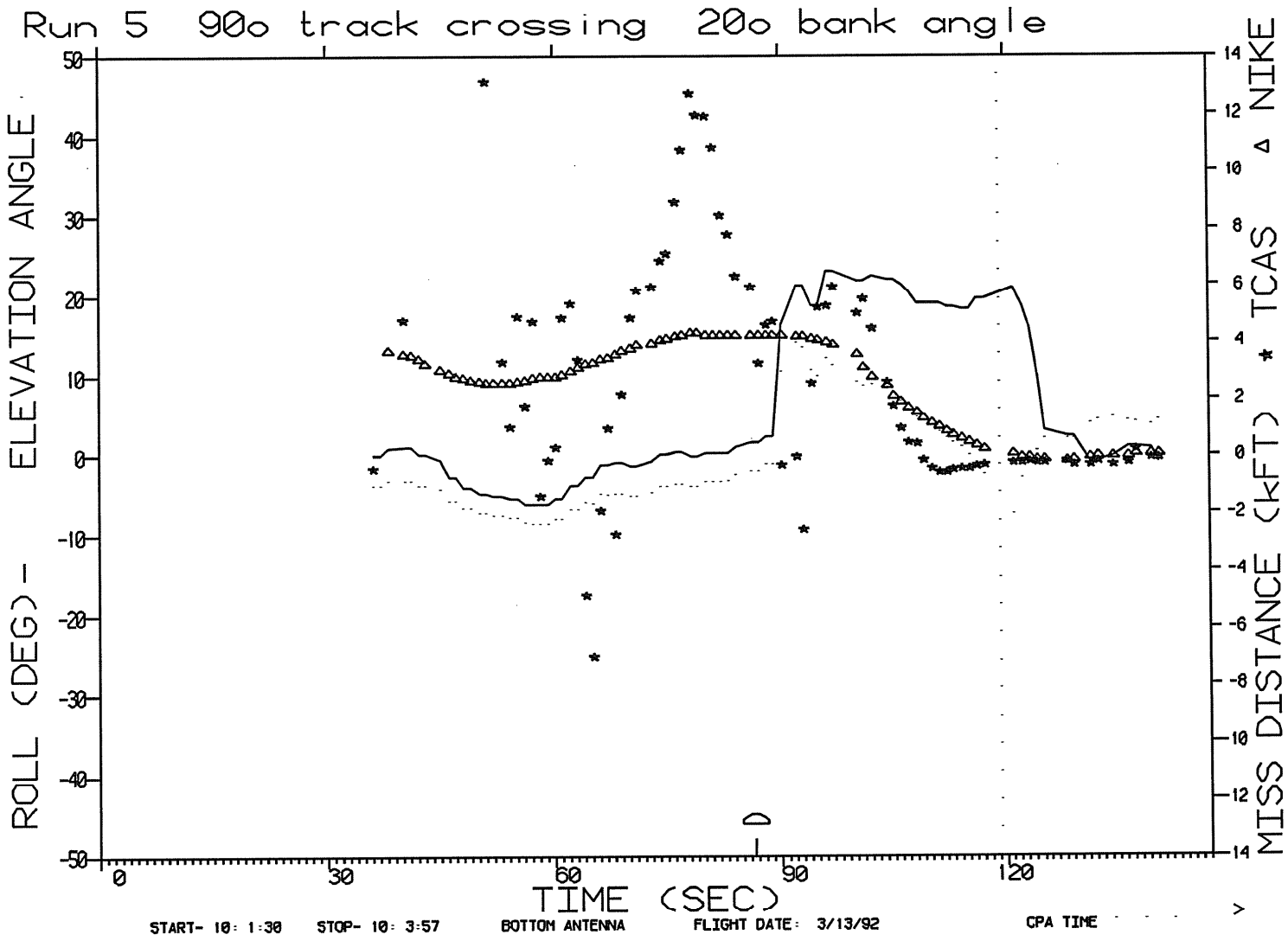
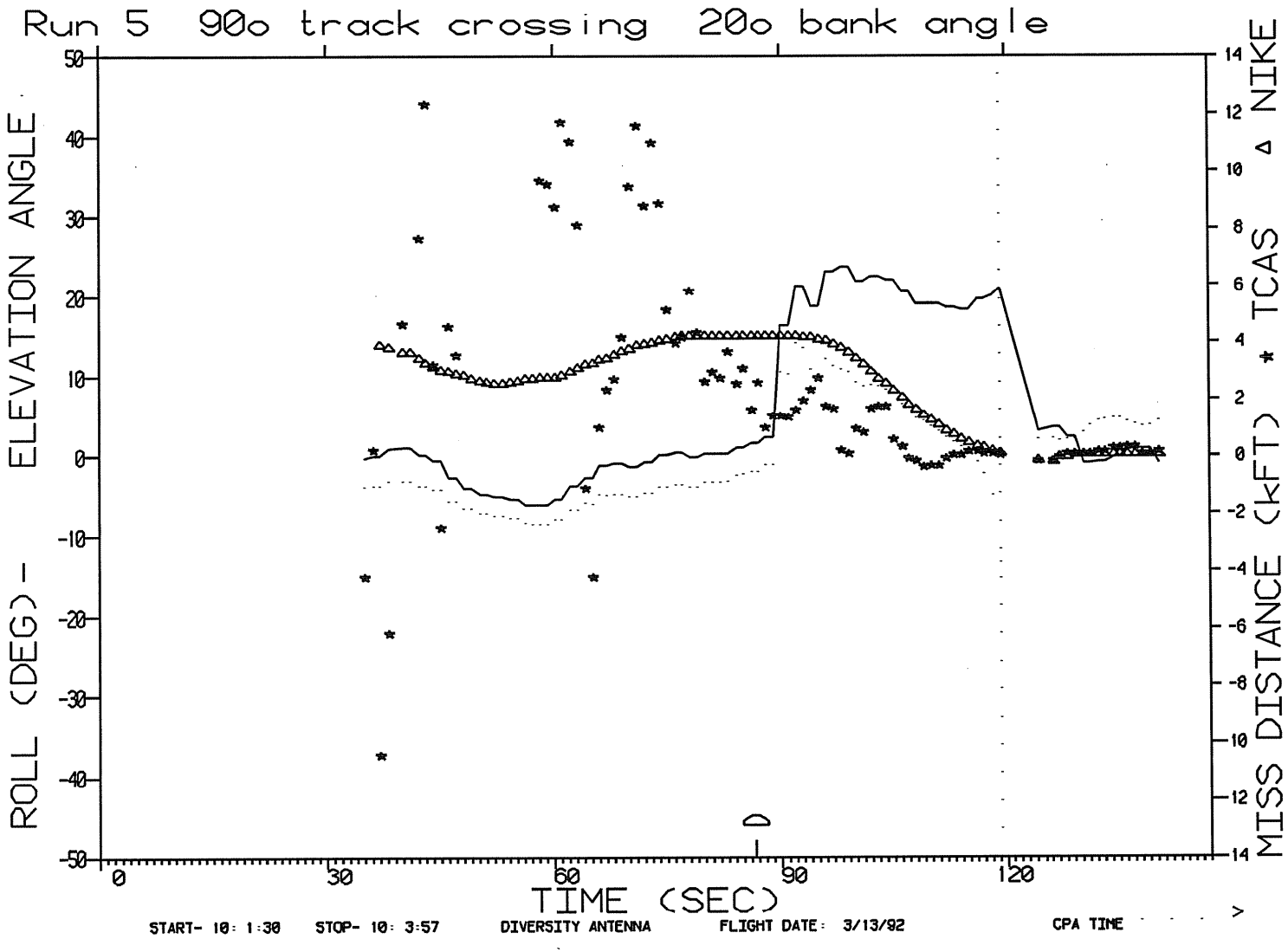
START- 9:55:50 STOP- 9:57:33 DIVERSITY ANTENNA FLIGHT DATE: 3/13/92 CPA TIME


Run 5 90o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10: 1:30
STOP- 10: 3:57
TOP ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME


Run 5 90o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10: 1:30
STOP- 10: 3:57
BOTTOM ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME


Run 5 90o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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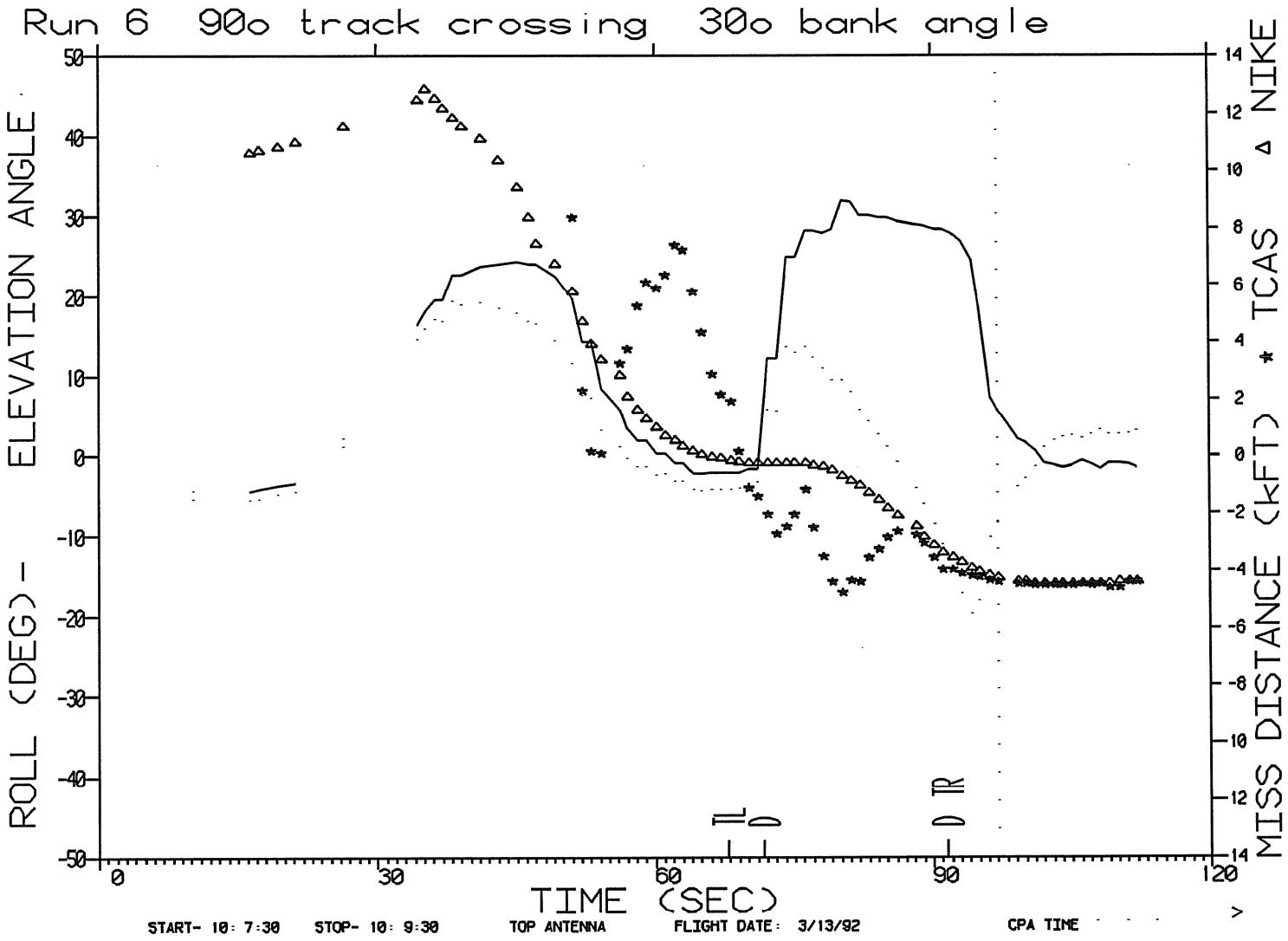
120
START- 10: 1:30
STOP- 10: 3:57
DIVERSITY ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME


Run 6 90o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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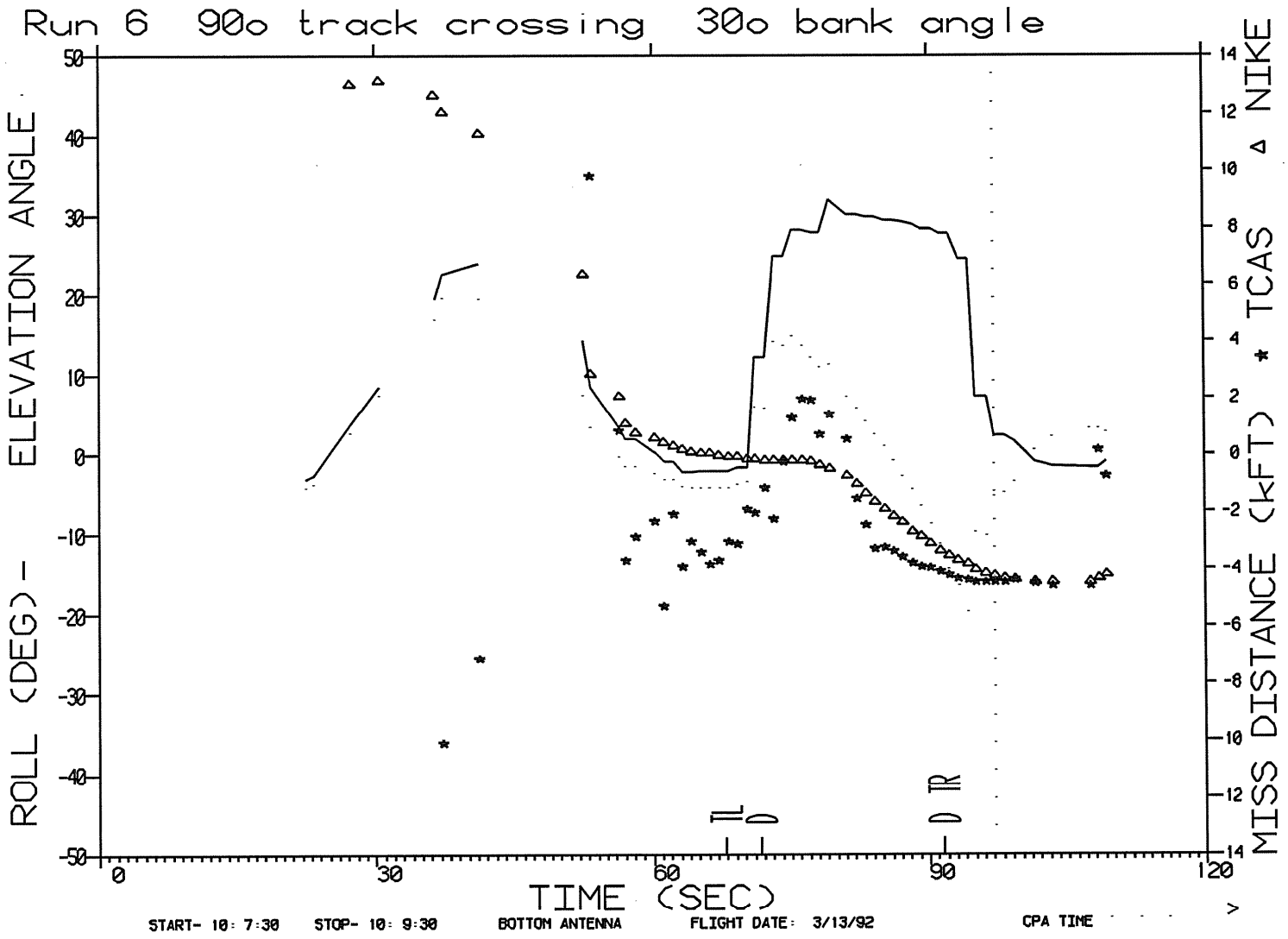
TR
START- 10: 7:30
STOP- 10: 9:30
TOP ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME


Run 6 90o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
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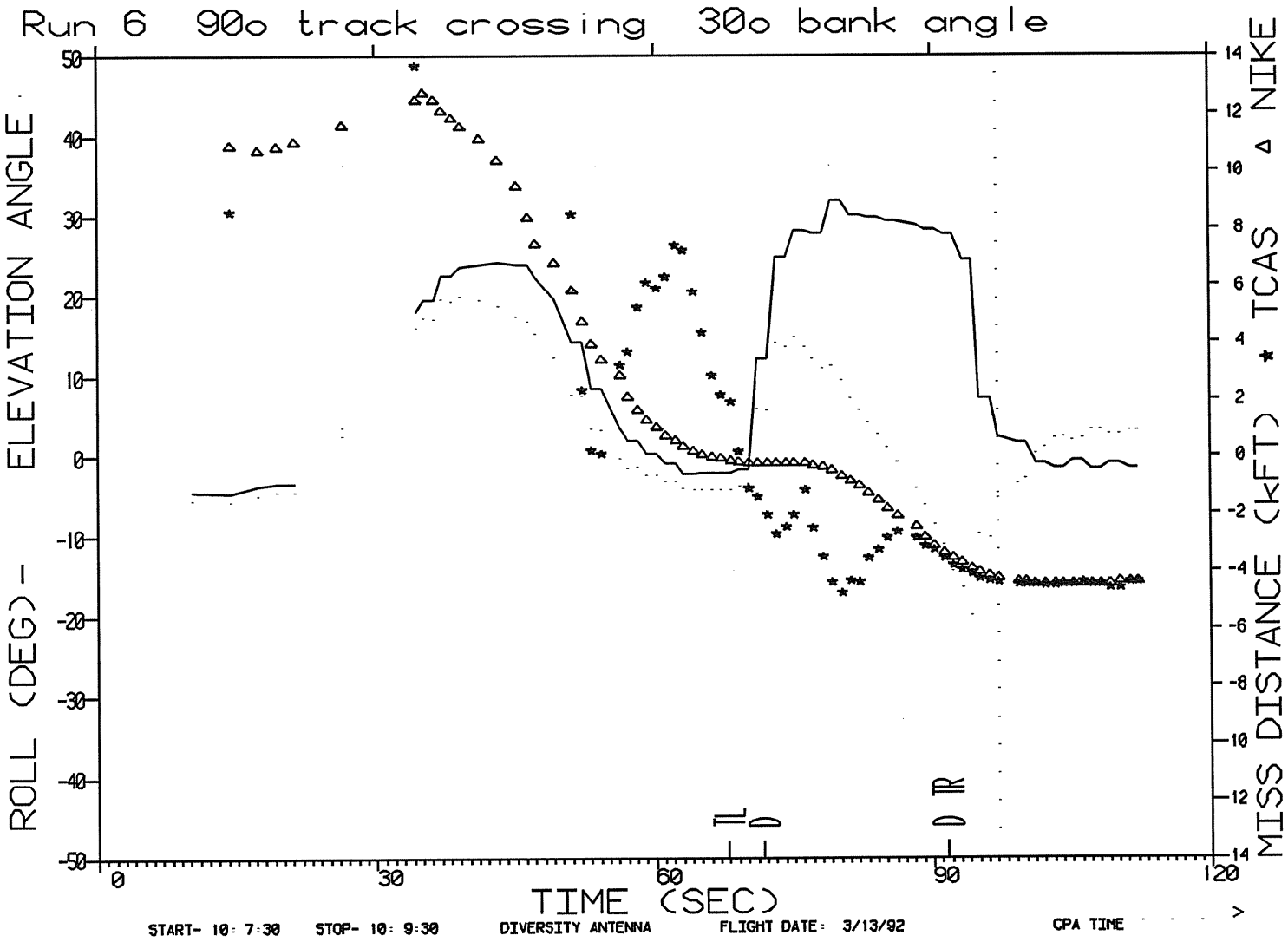
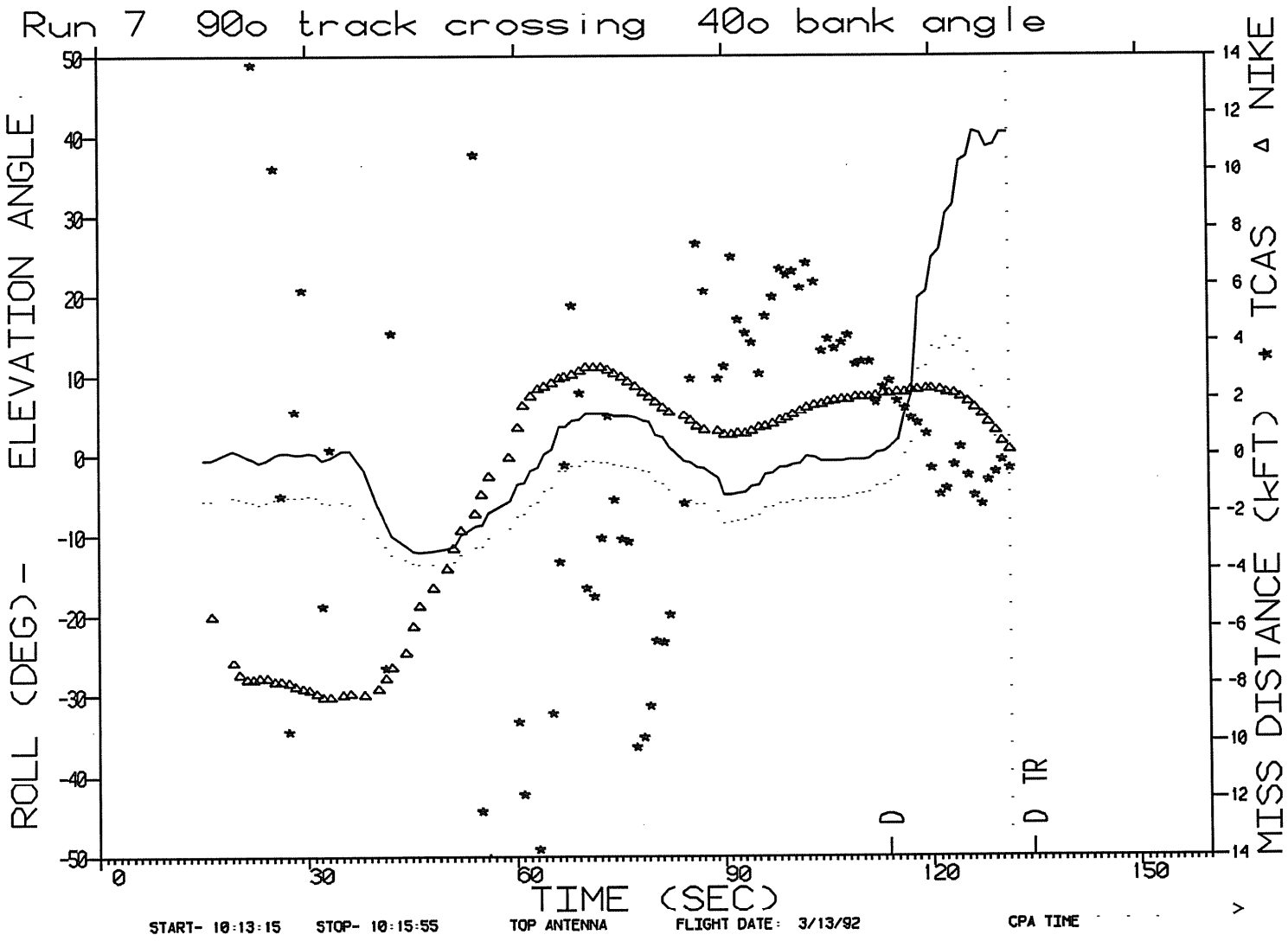
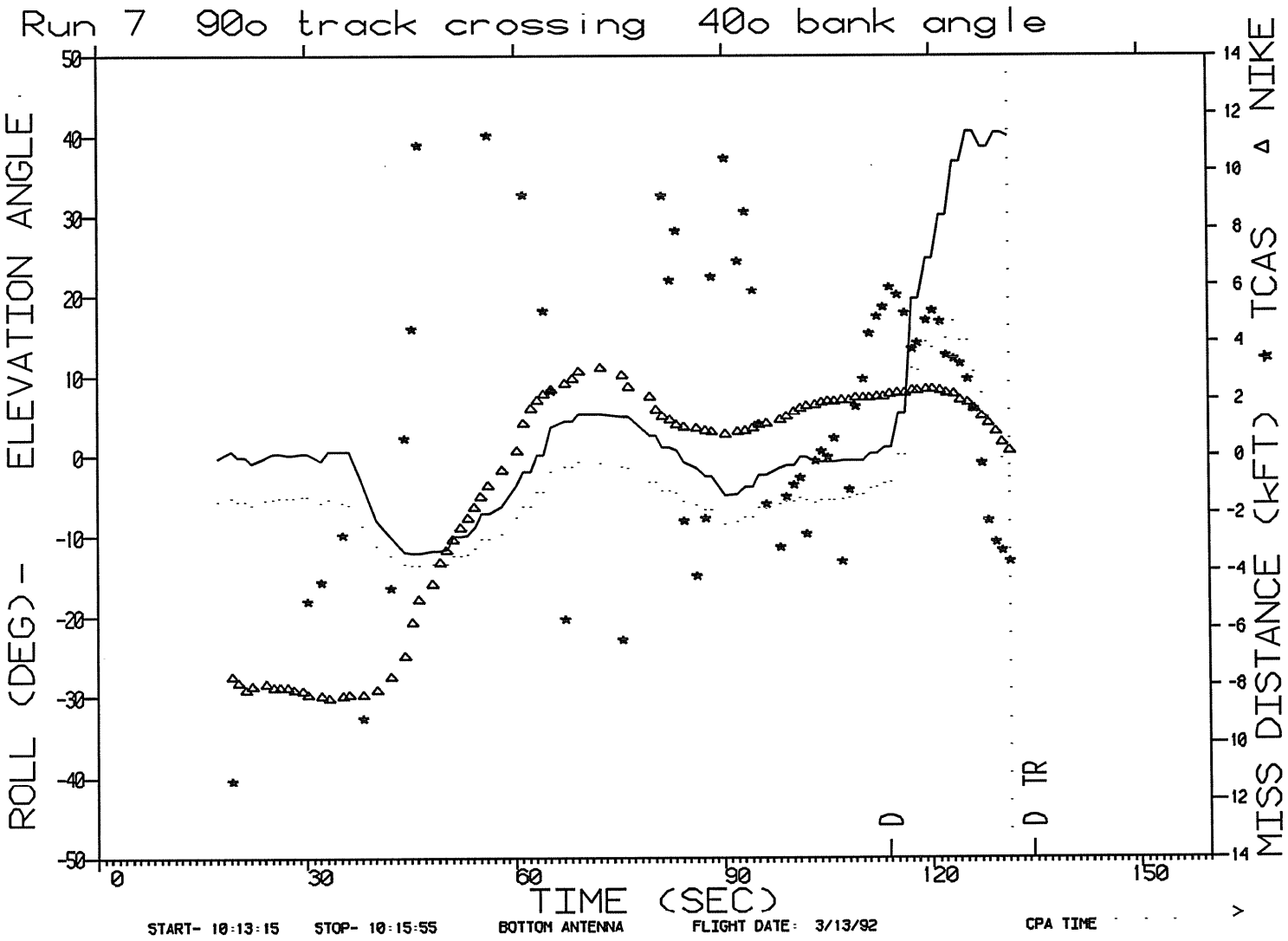
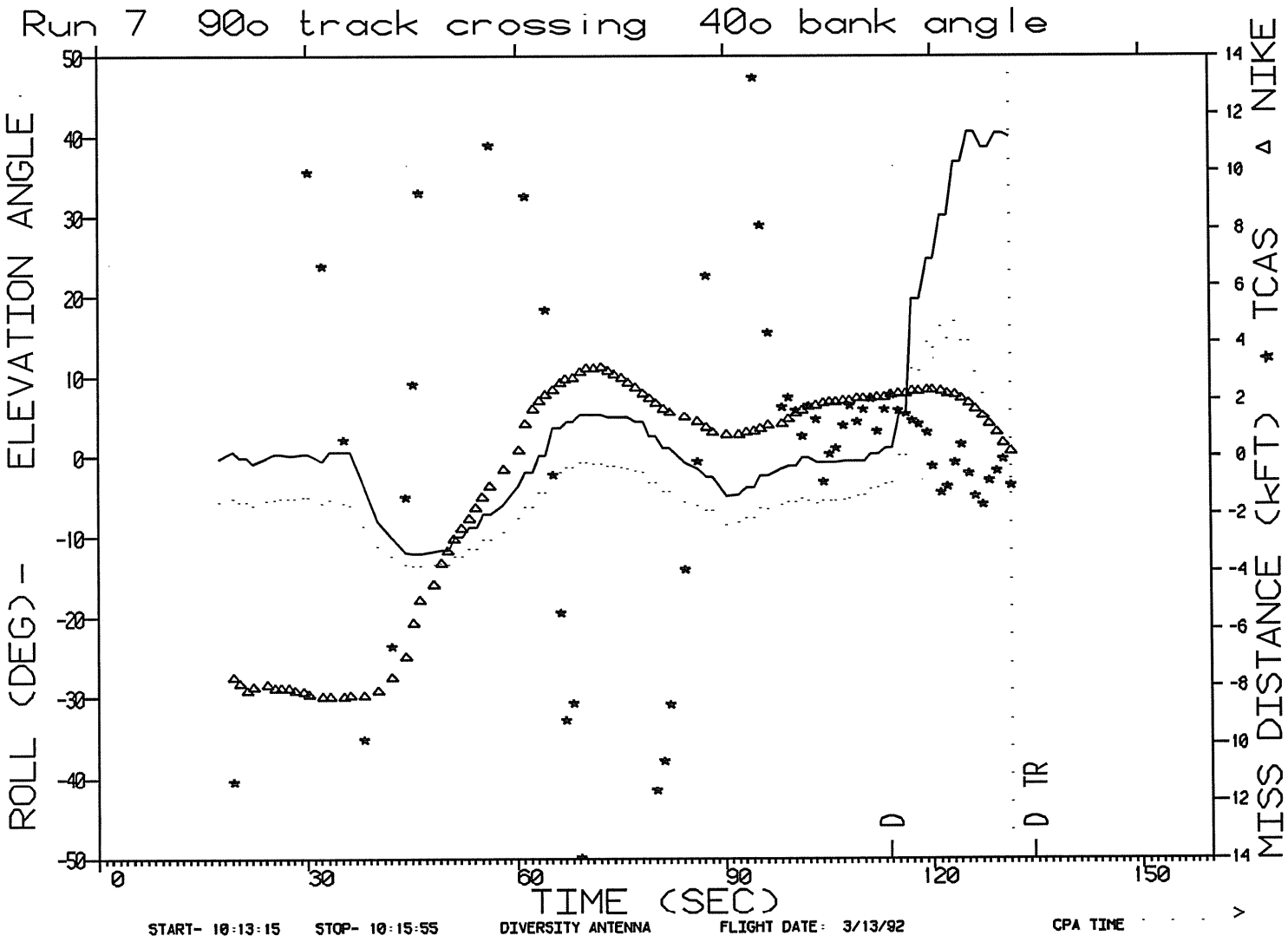
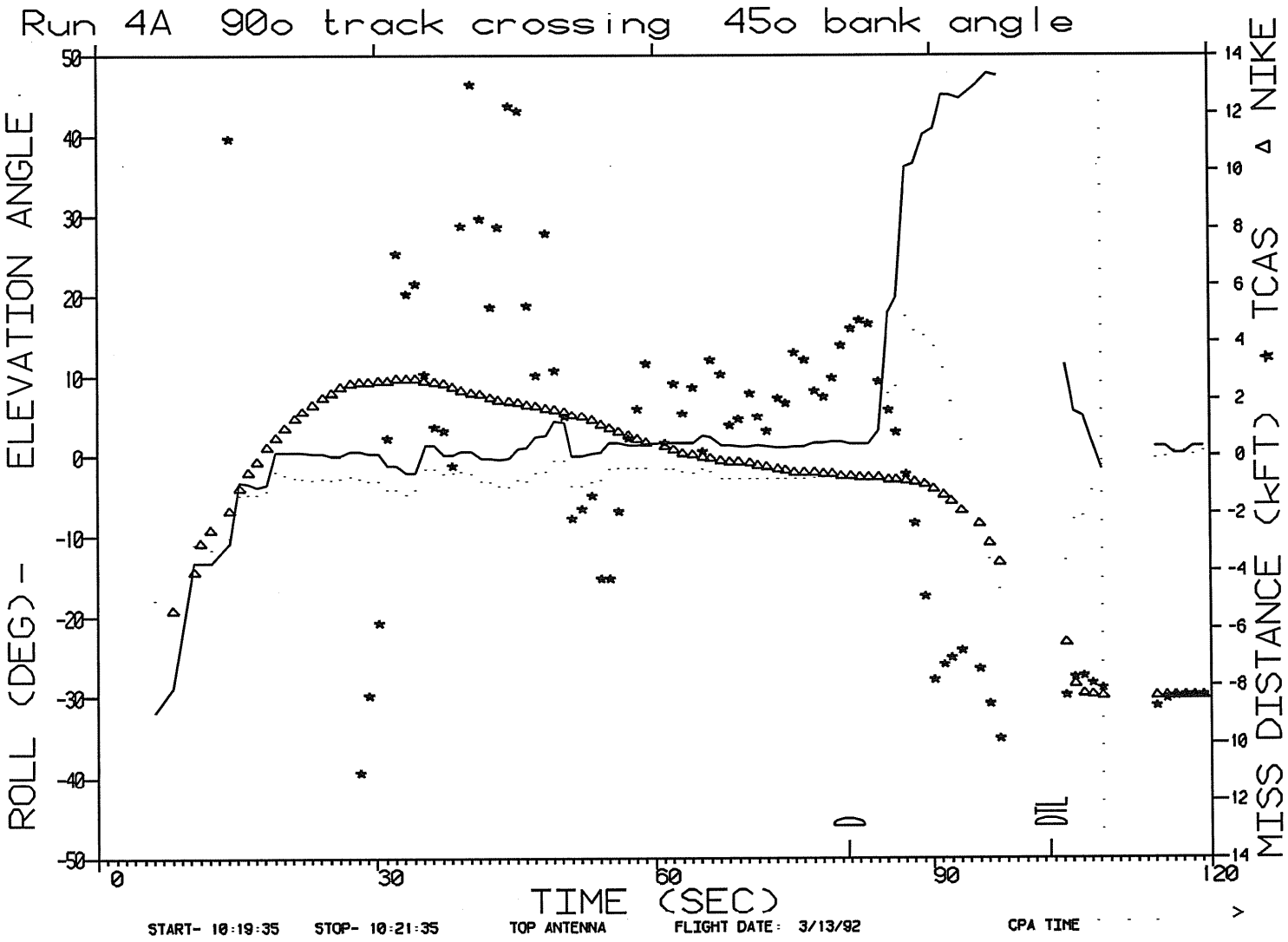
START- 10: 7:30
STOP- 10: 9:30
BOTTOM ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

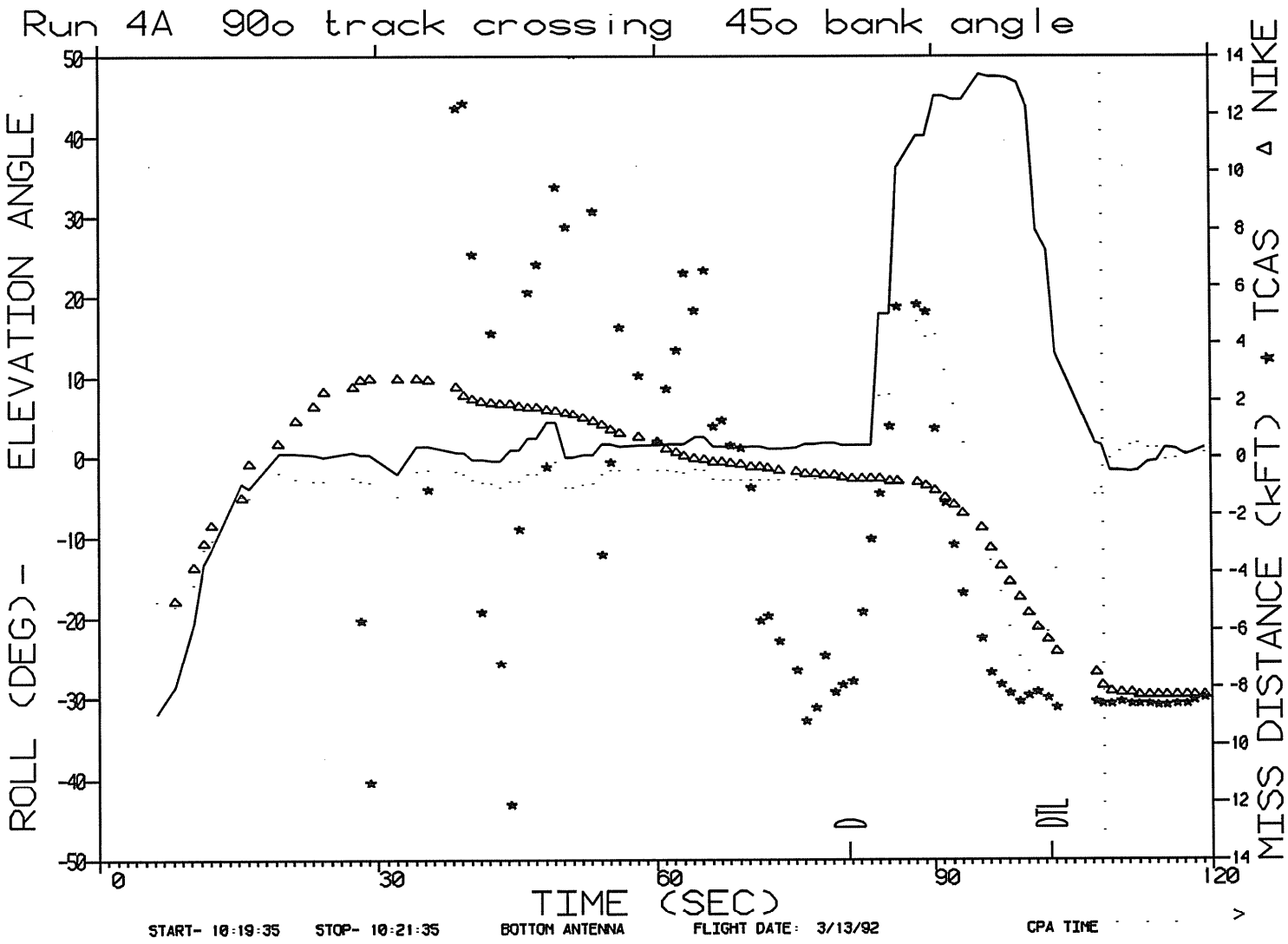

Run 6 90o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TL
D
D R
START- 10: 7:30
STOP- 10: 9:30
DIVERSITY ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

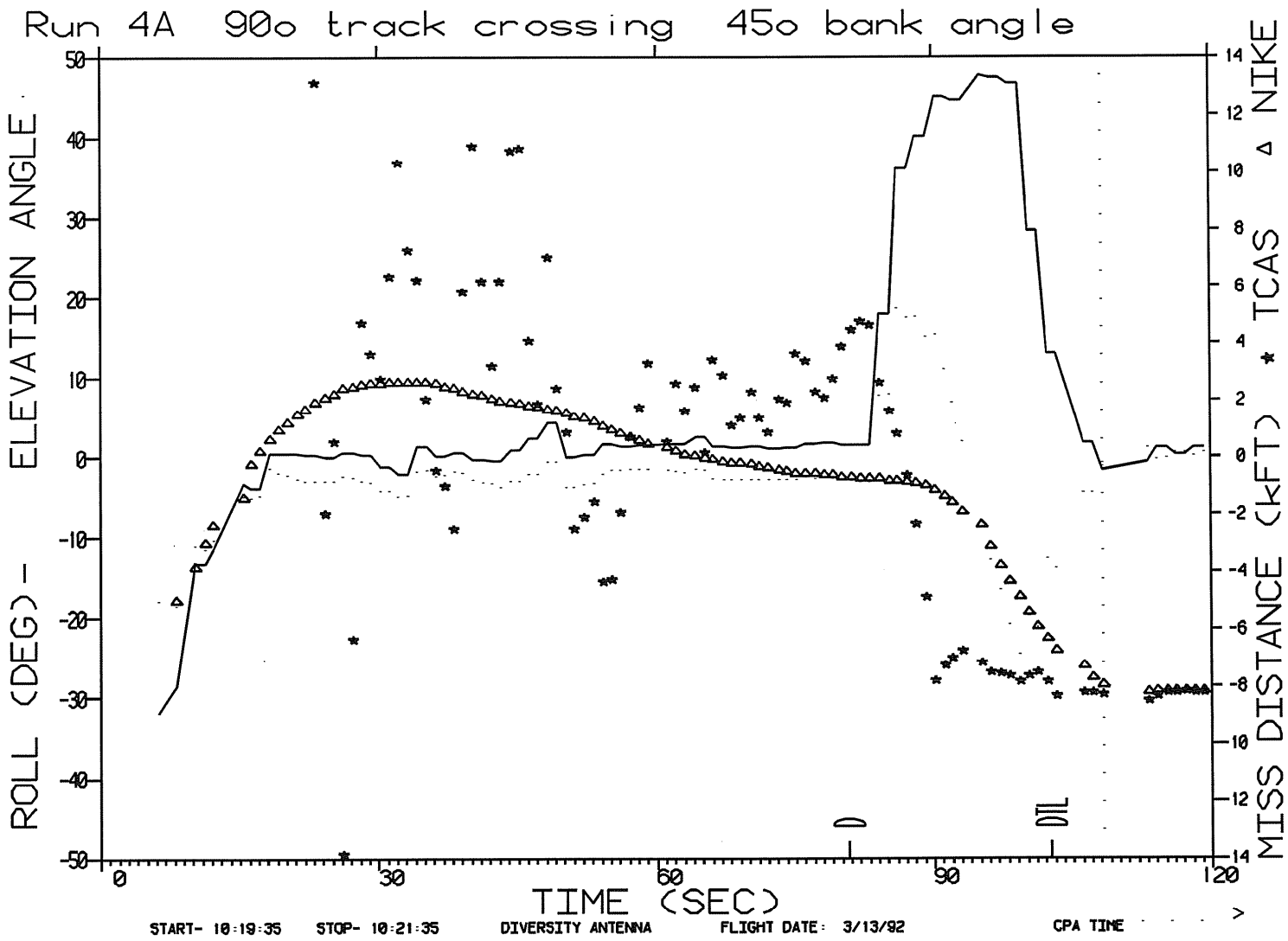

Run 7 90o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
D TR
START- 10:13:15
STOP- 10:15:55
TOP ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

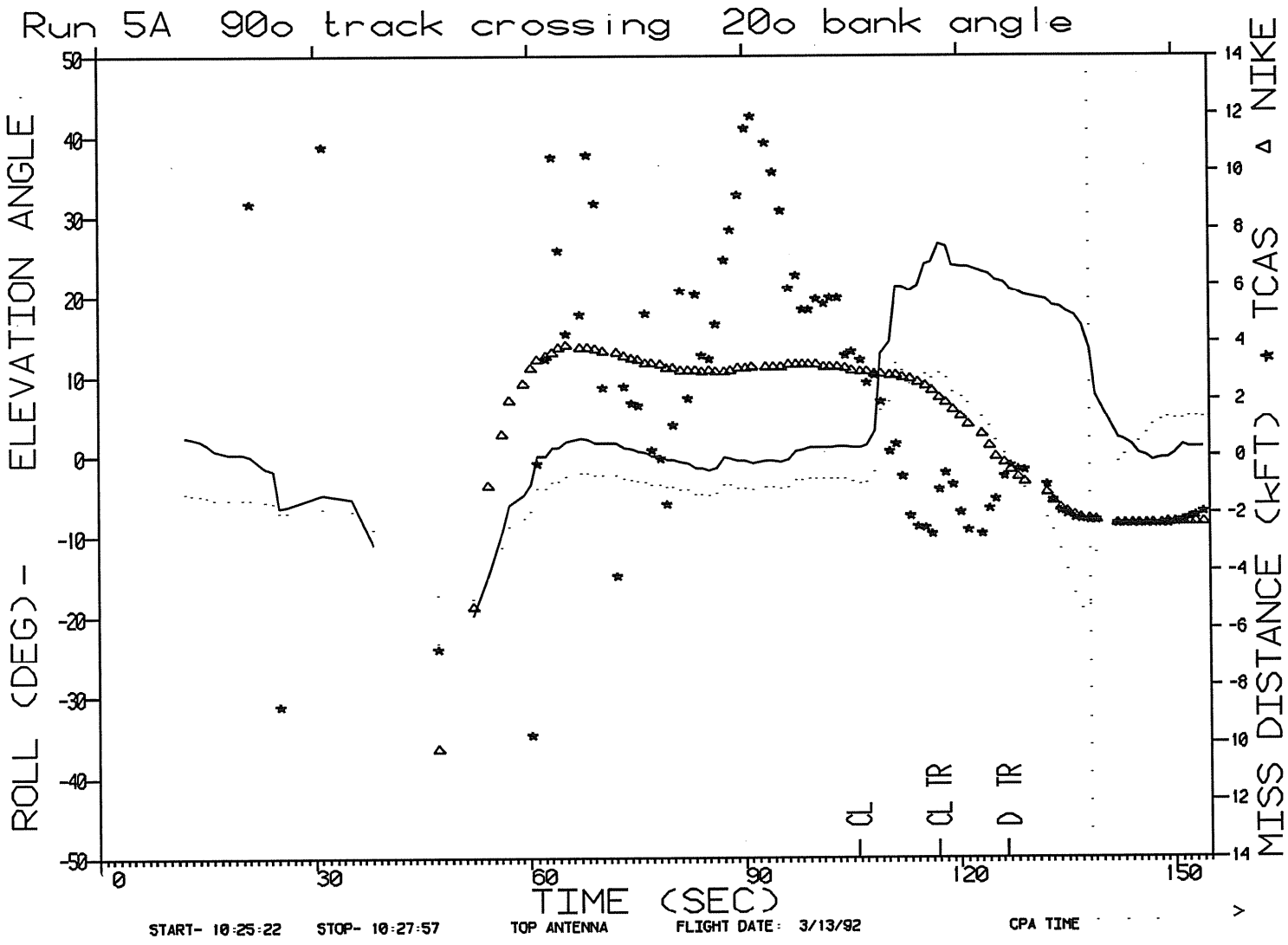

Run 7 90o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
D TR
START- 10:13:15
STOP- 10:15:55
BOTTOM ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

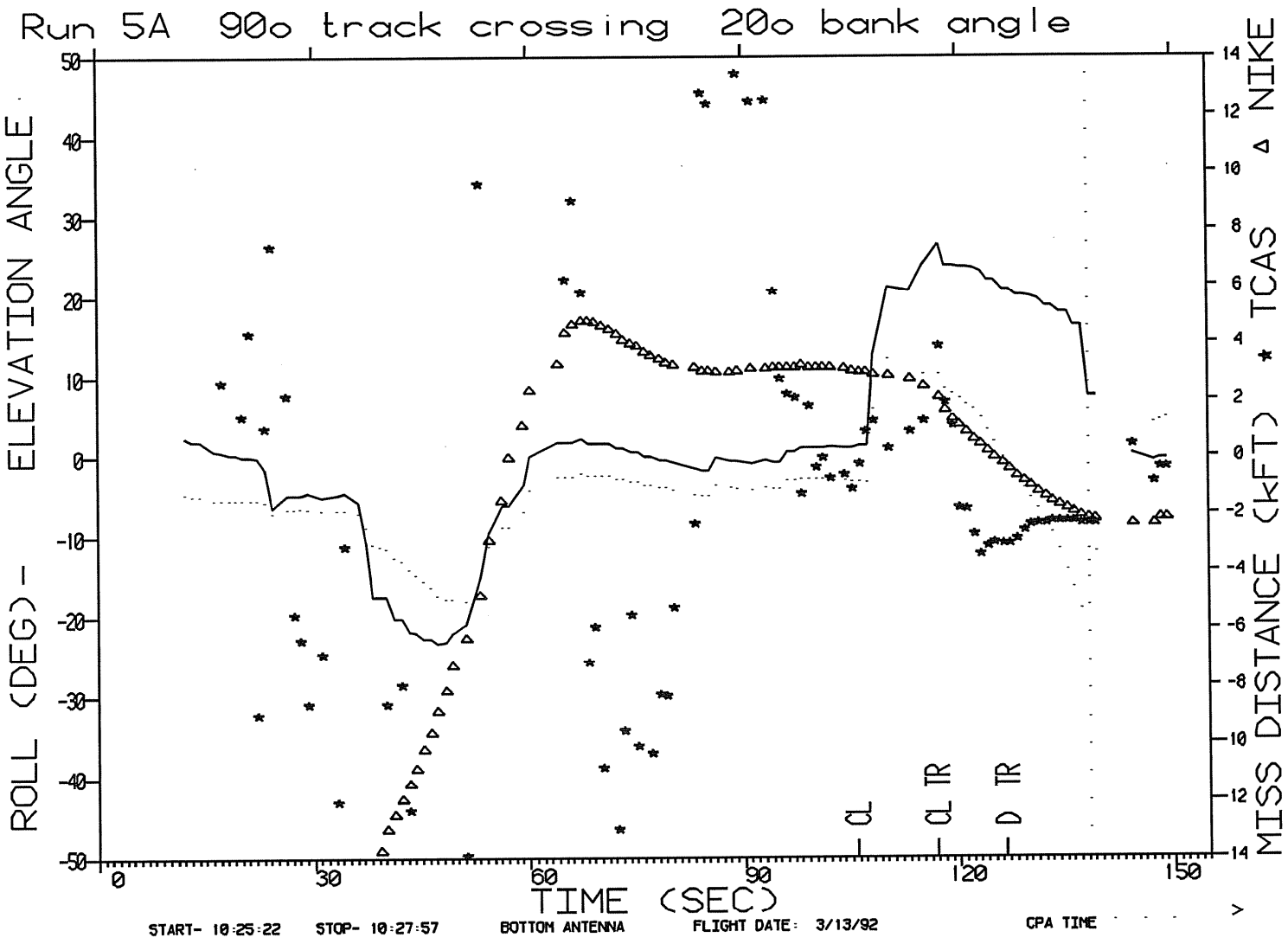

Run 7 90o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
D TR
START- 10:13:15
STOP- 10:15:55
DIVERSITY ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

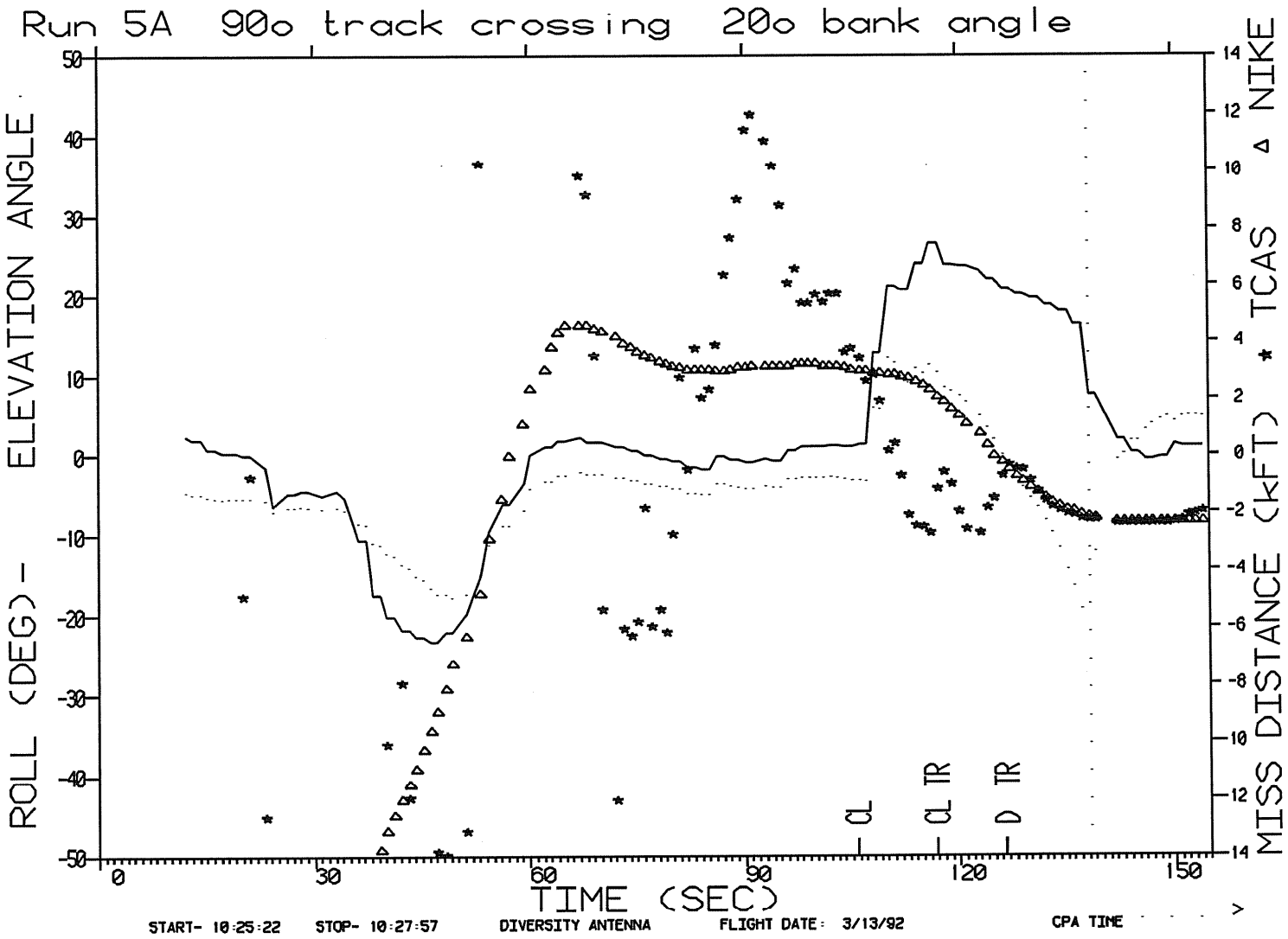

Run 4A 90o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10:19:35
STOP- 10:21:35
TOP ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME
DIL

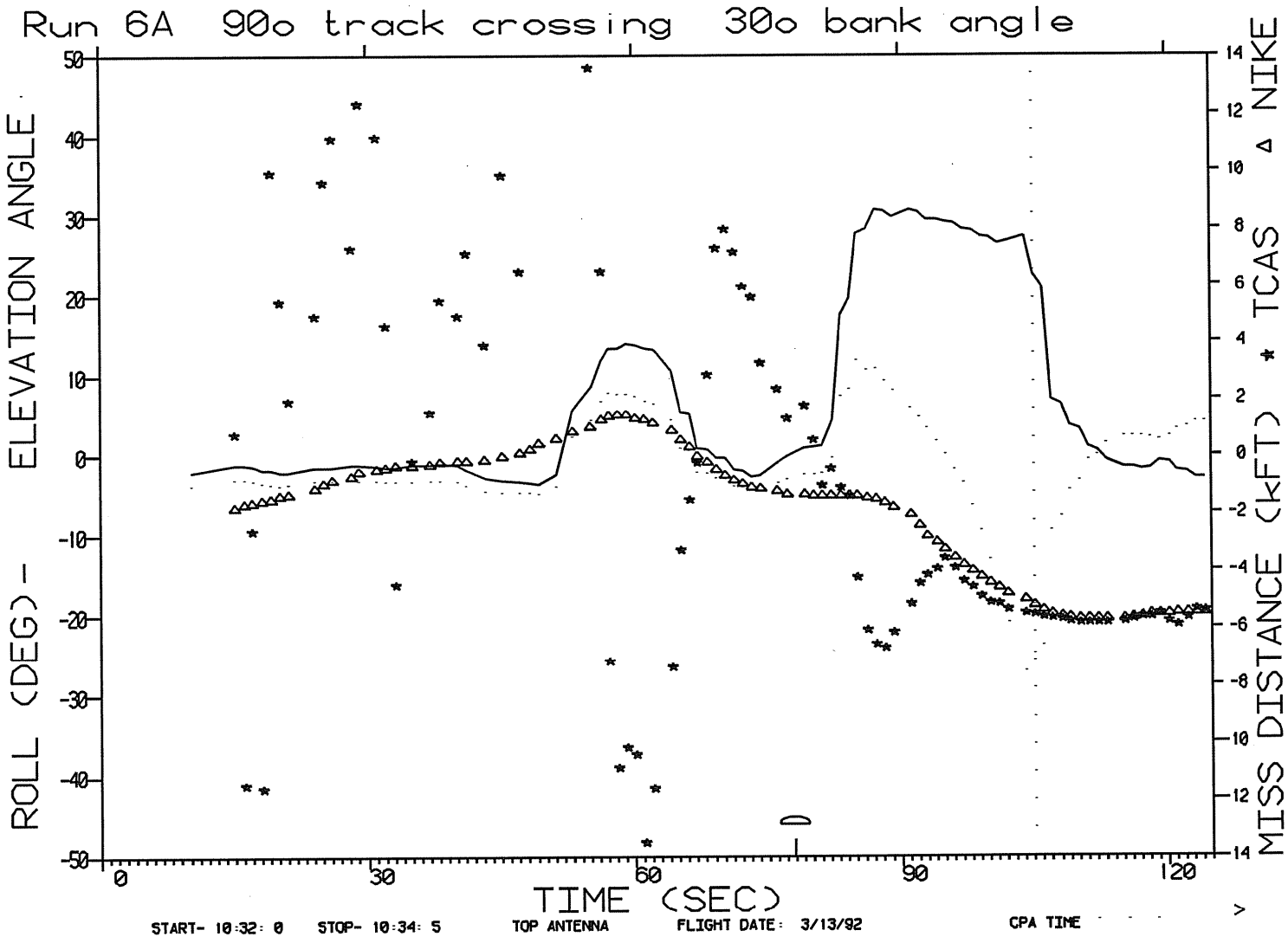

Run 4A 90o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10:19:35
STOP- 10:21:35
BOTTOM ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME
DTL

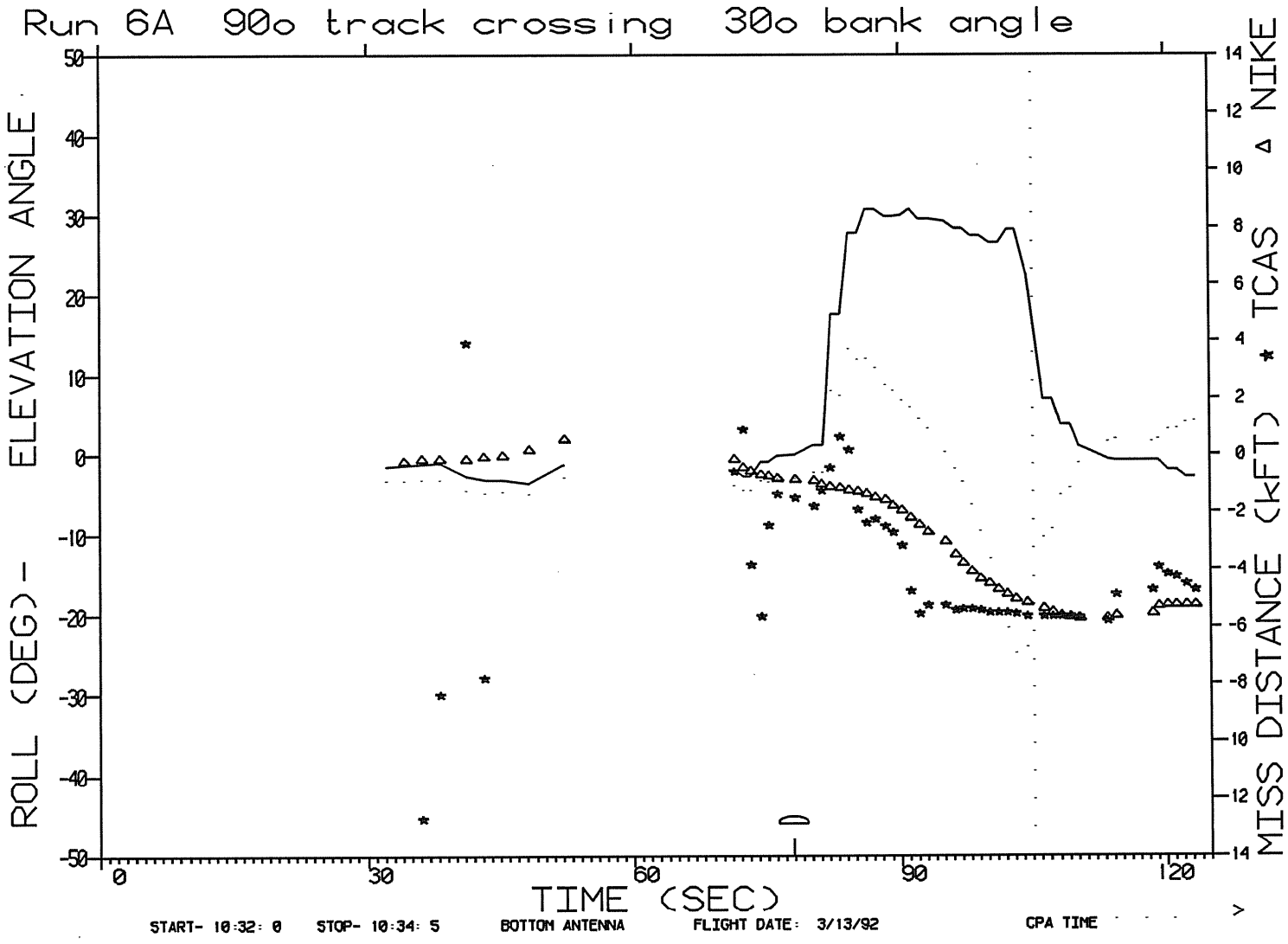

Run 4A 90o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10:19:35
STOP- 10:21:35
DIVERSITY ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME
DIL

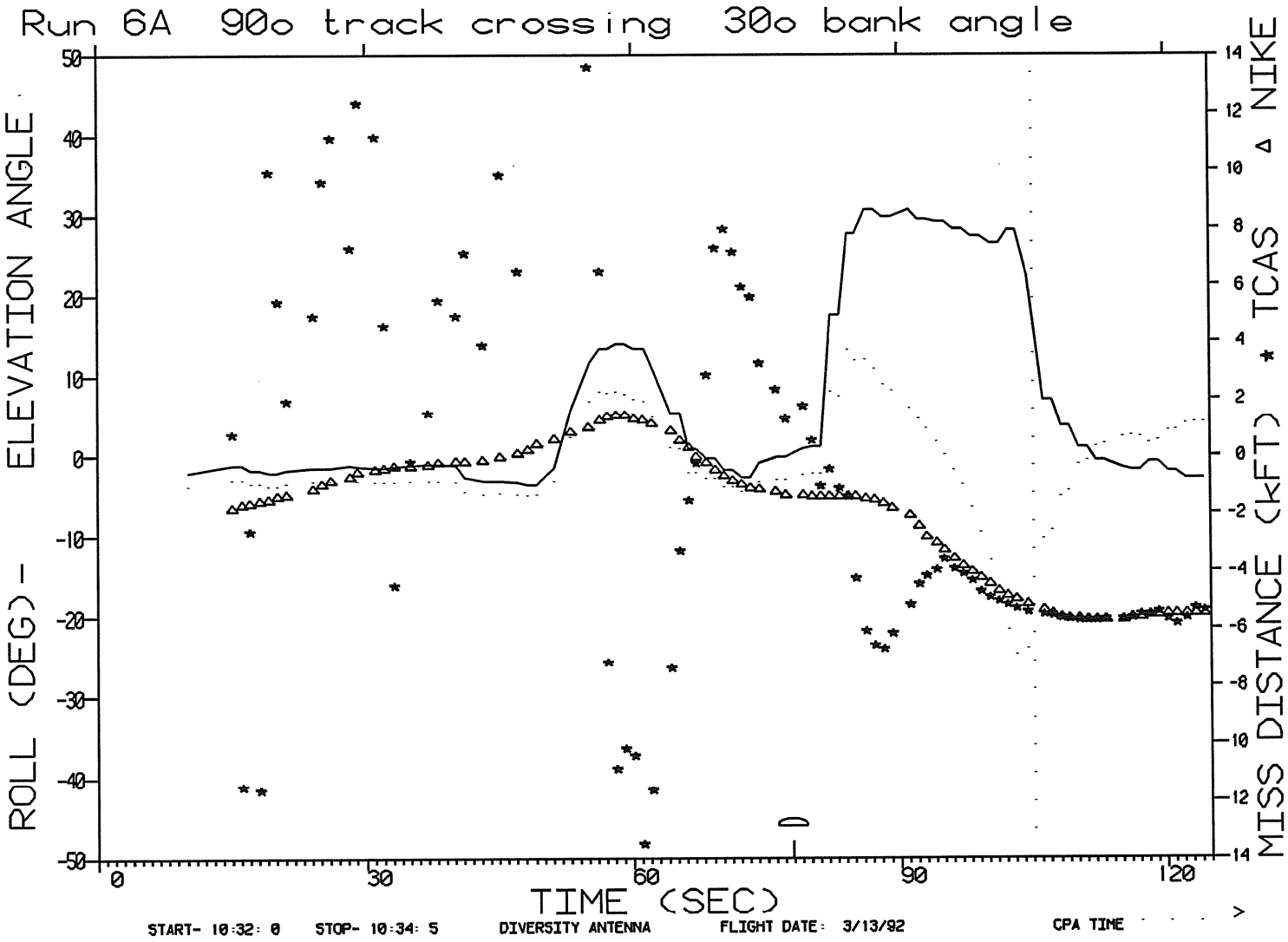

Run 5A 90o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
CL
CL TR
D TR
START- 10:25:22
STOP- 10:27:57
TOP ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

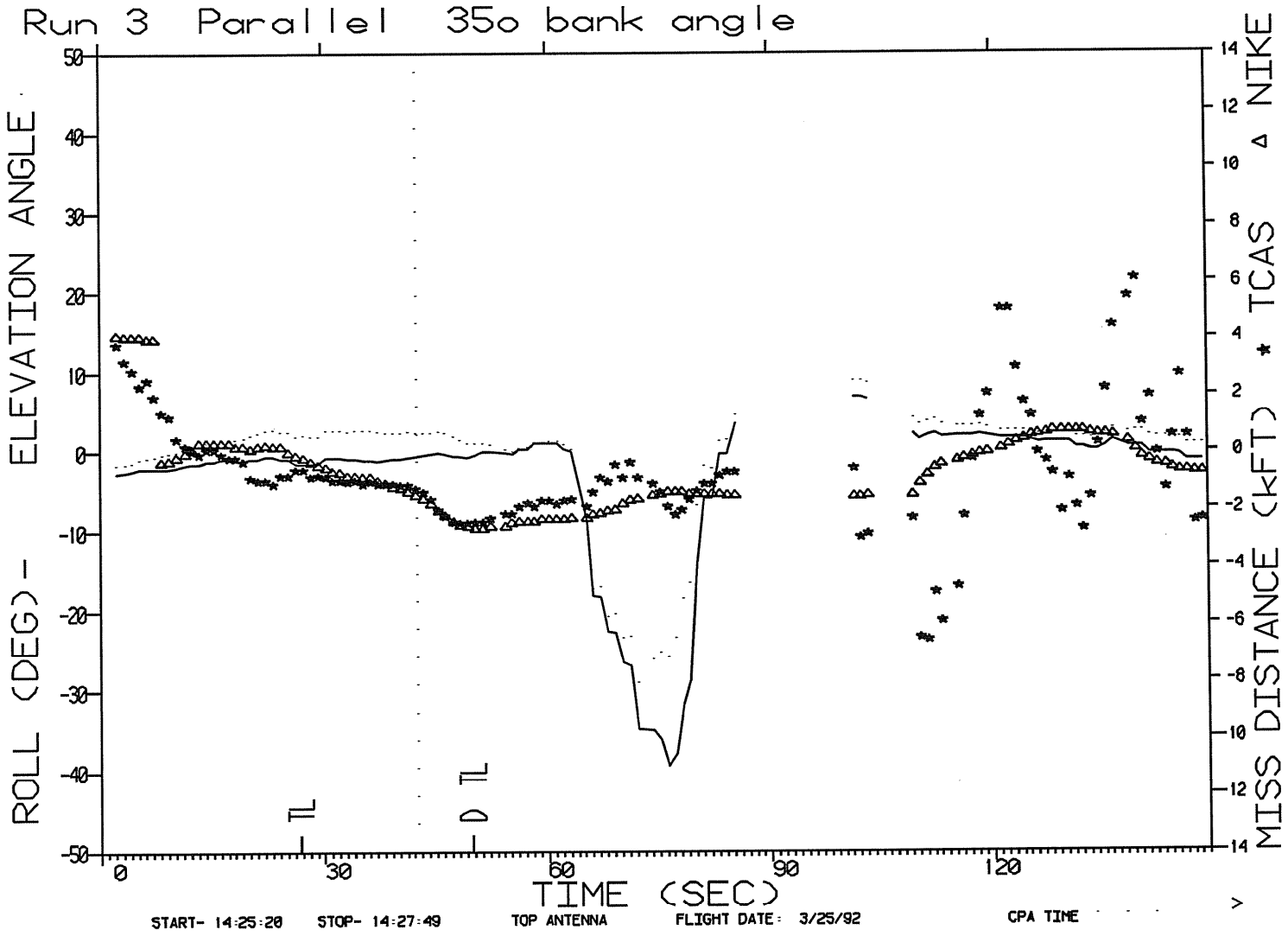

Run 5A 90o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
CL
CL TR
D TR
START- 10:25:22
STOP- 10:27:57
BOTTOM ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

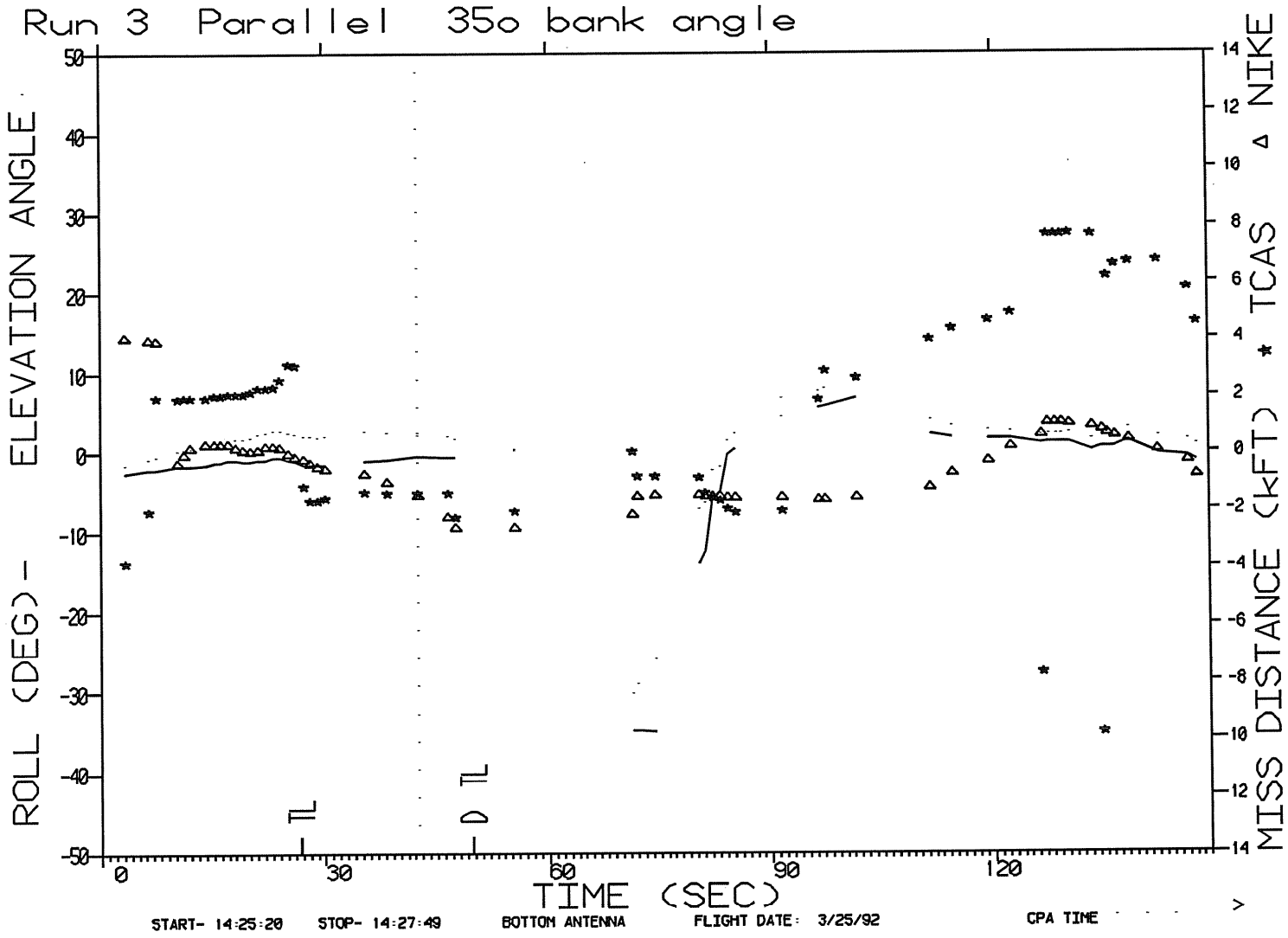

Run 5A 90o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
CL
CL TR
D TR
START- 10:25:22
STOP- 10:27:57
DIVERSITY ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

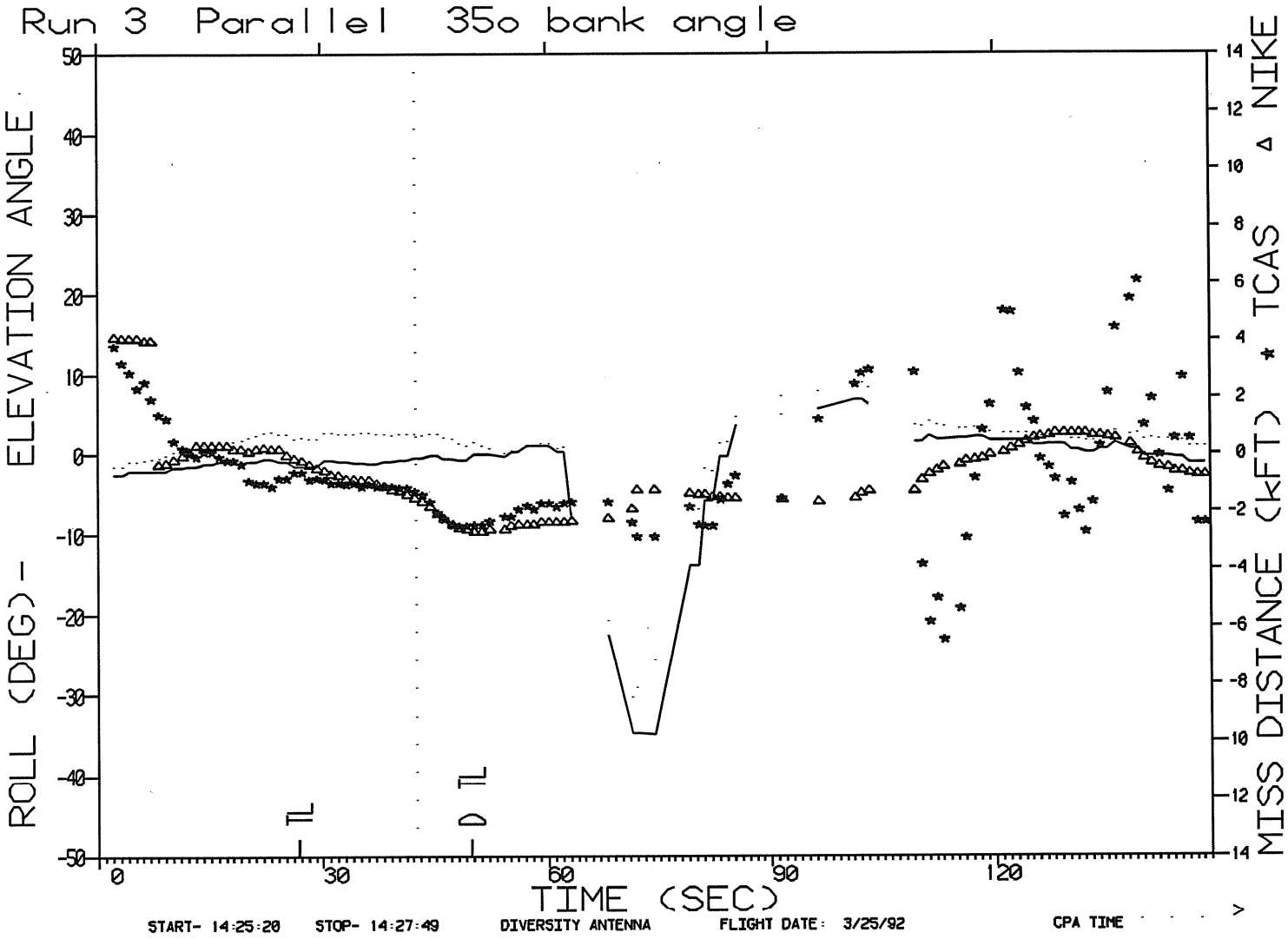

Run 6A 90o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10:32: 0
STOP- 10:34: 5
TOP ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

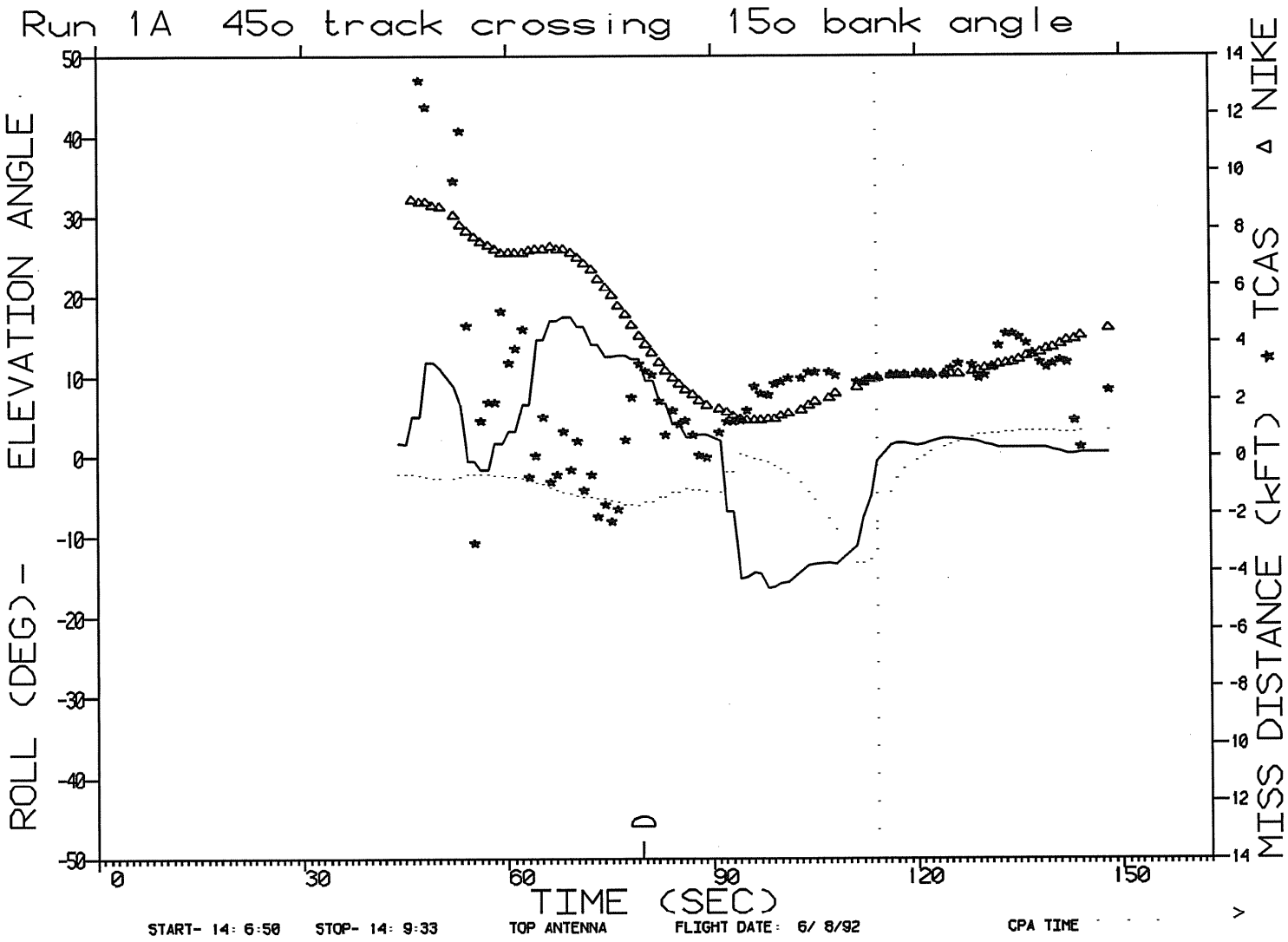

Run 6A 90o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10:32: 0
STOP- 10:34: 5
BOTTOM ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

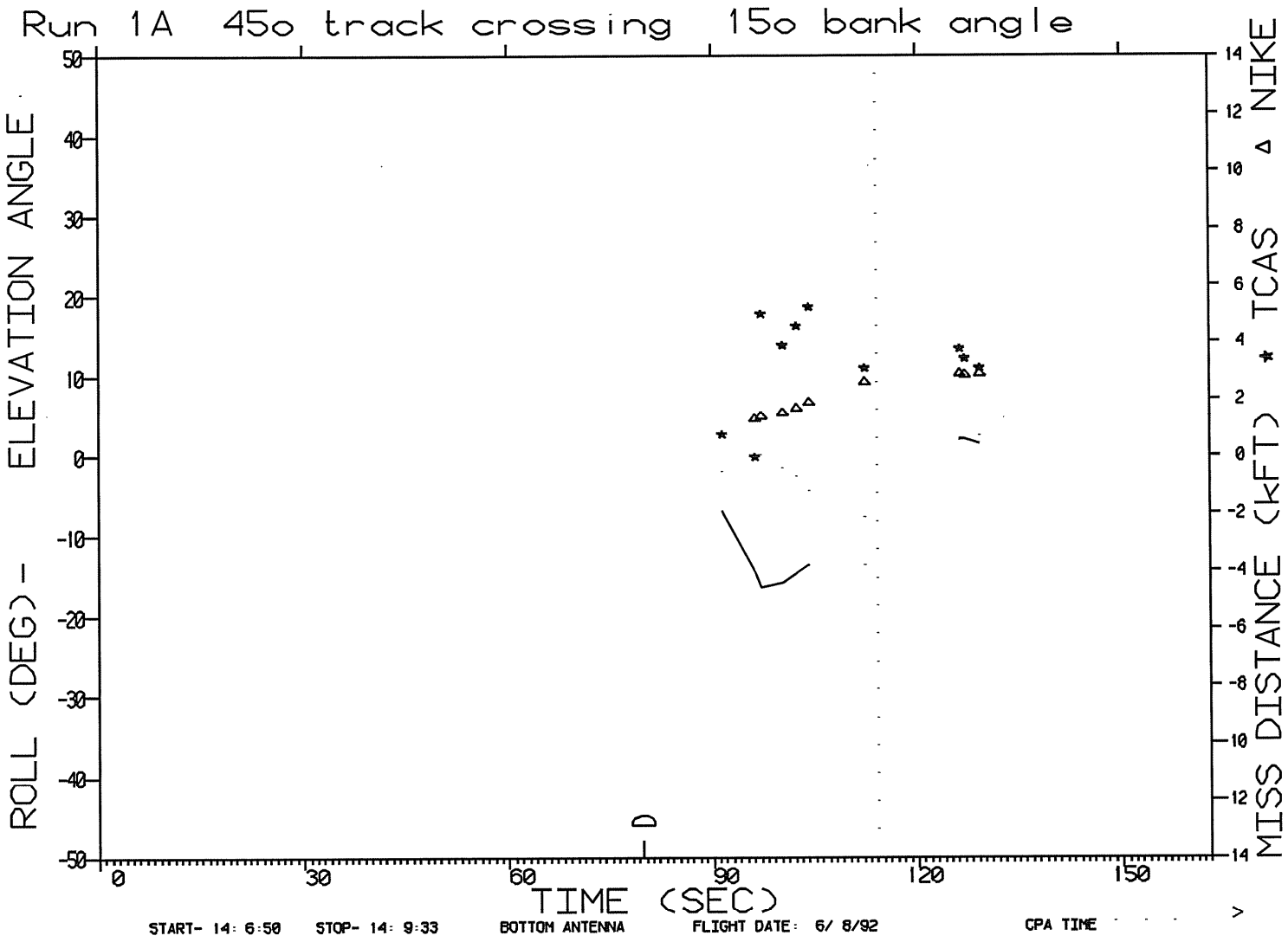

Run 6A 90o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10:32: 0
STOP- 10:34: 5
DIVERSITY ANTENNA
FLIGHT DATE: 3/13/92
CPA TIME

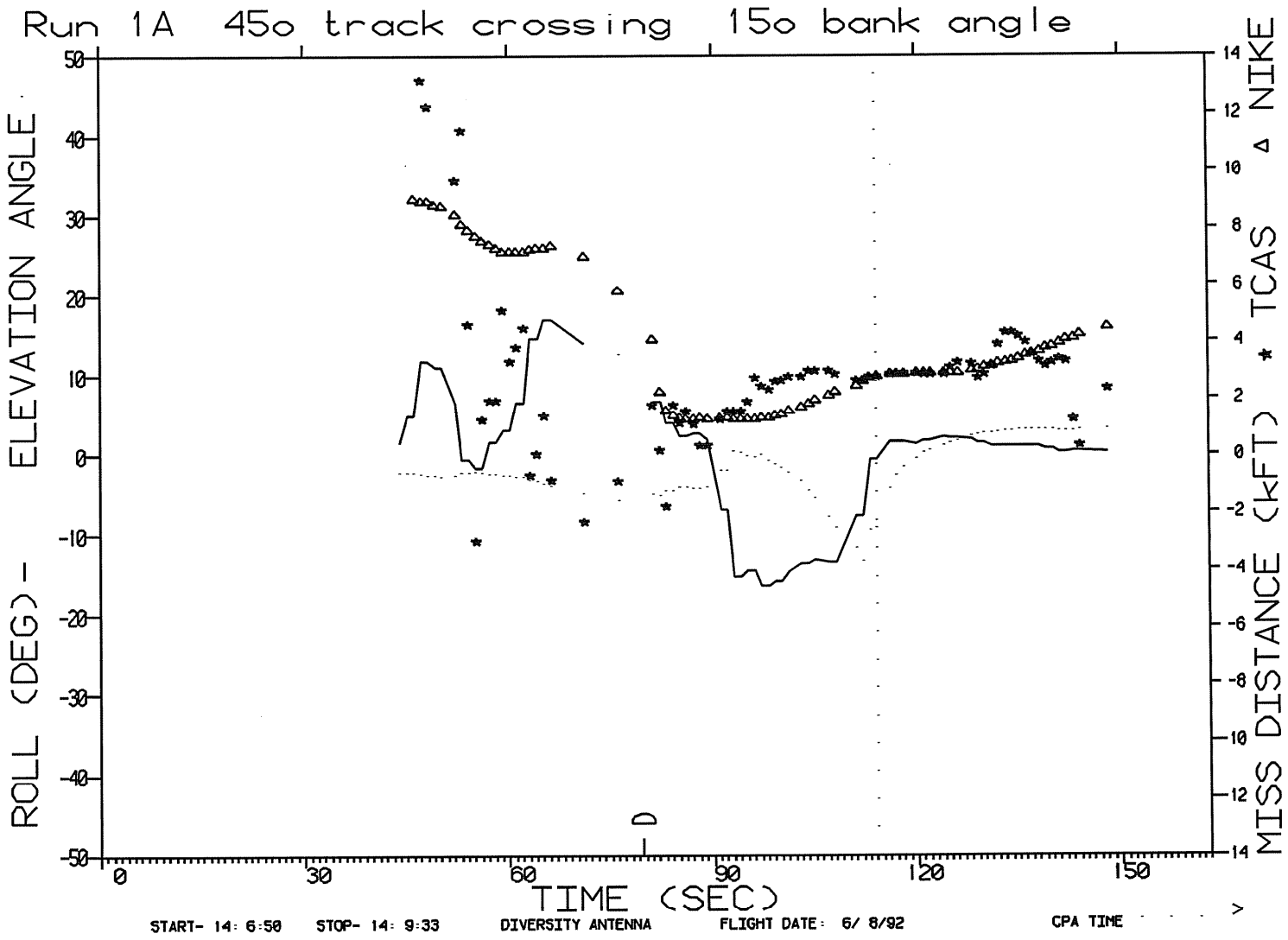

Run 3 Parallel 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TL
D TL
START- 14:25:20
STOP- 14:27:49
TOP ANTENNA
FLIGHT DATE: 3/25/92
CPA TIME

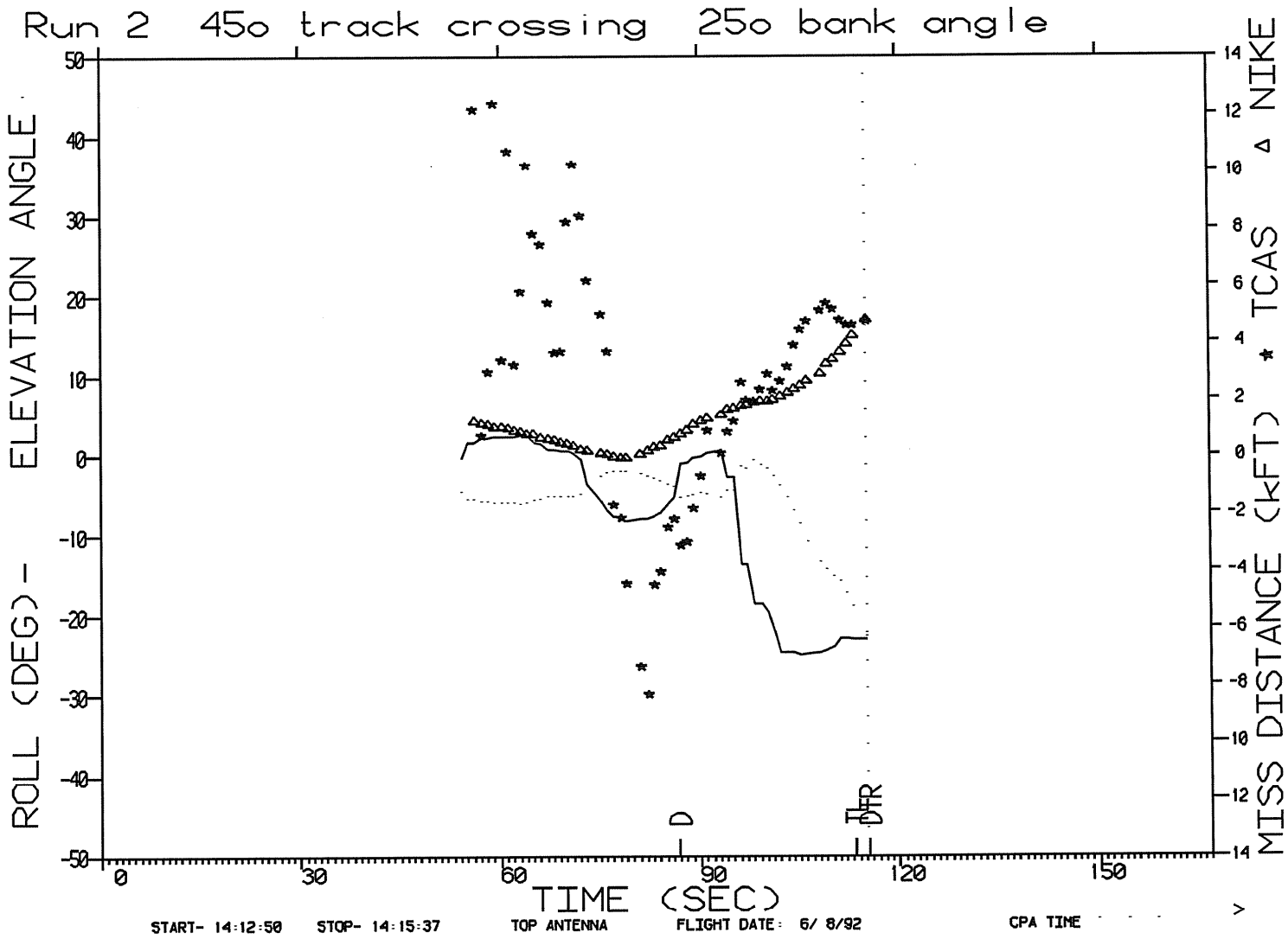

Run 3 Parallel 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TL
D TL
START- 14:25:20
STOP- 14:27:49
BOTTOM ANTENNA
FLIGHT DATE: 3/25/92
CPA TIME

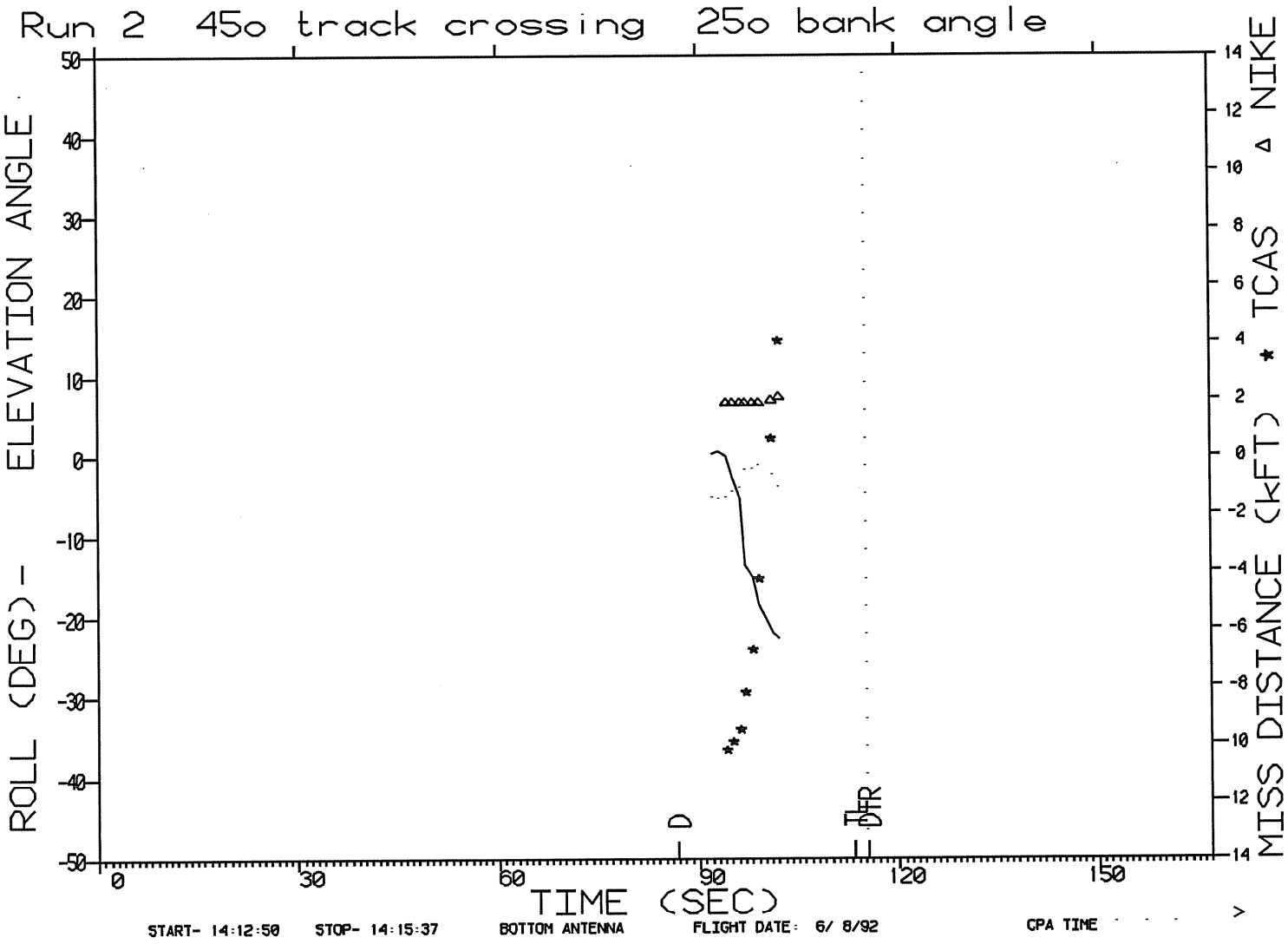

Run 3 Parallel 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TL
D TL
START- 14:25:20
STOP- 14:27:49
DIVERSITY ANTENNA
FLIGHT DATE: 3/25/92
CPA TIME

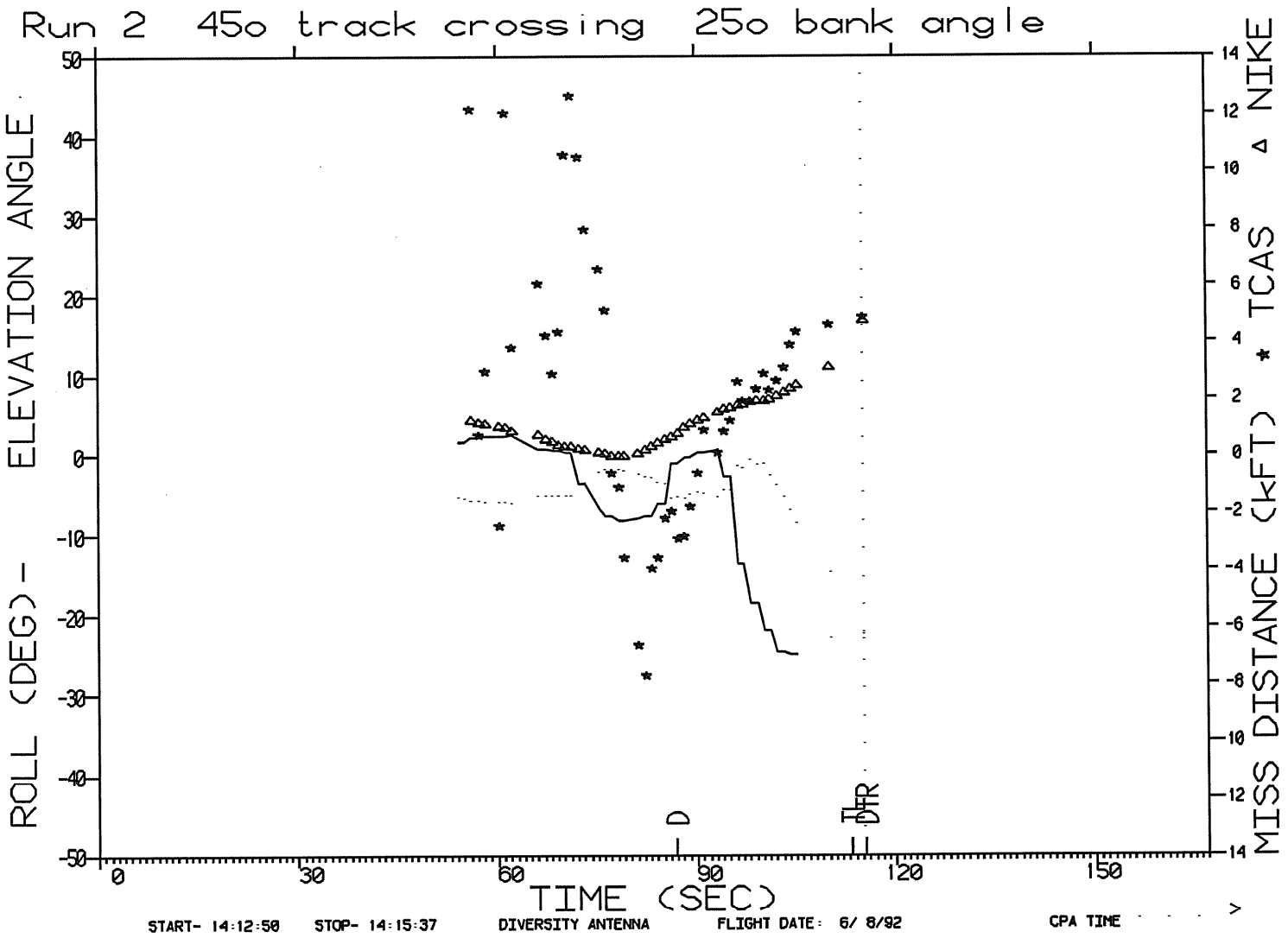

Run 1A 45o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 14: 6:50
STOP- 14: 9:33
TOP ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

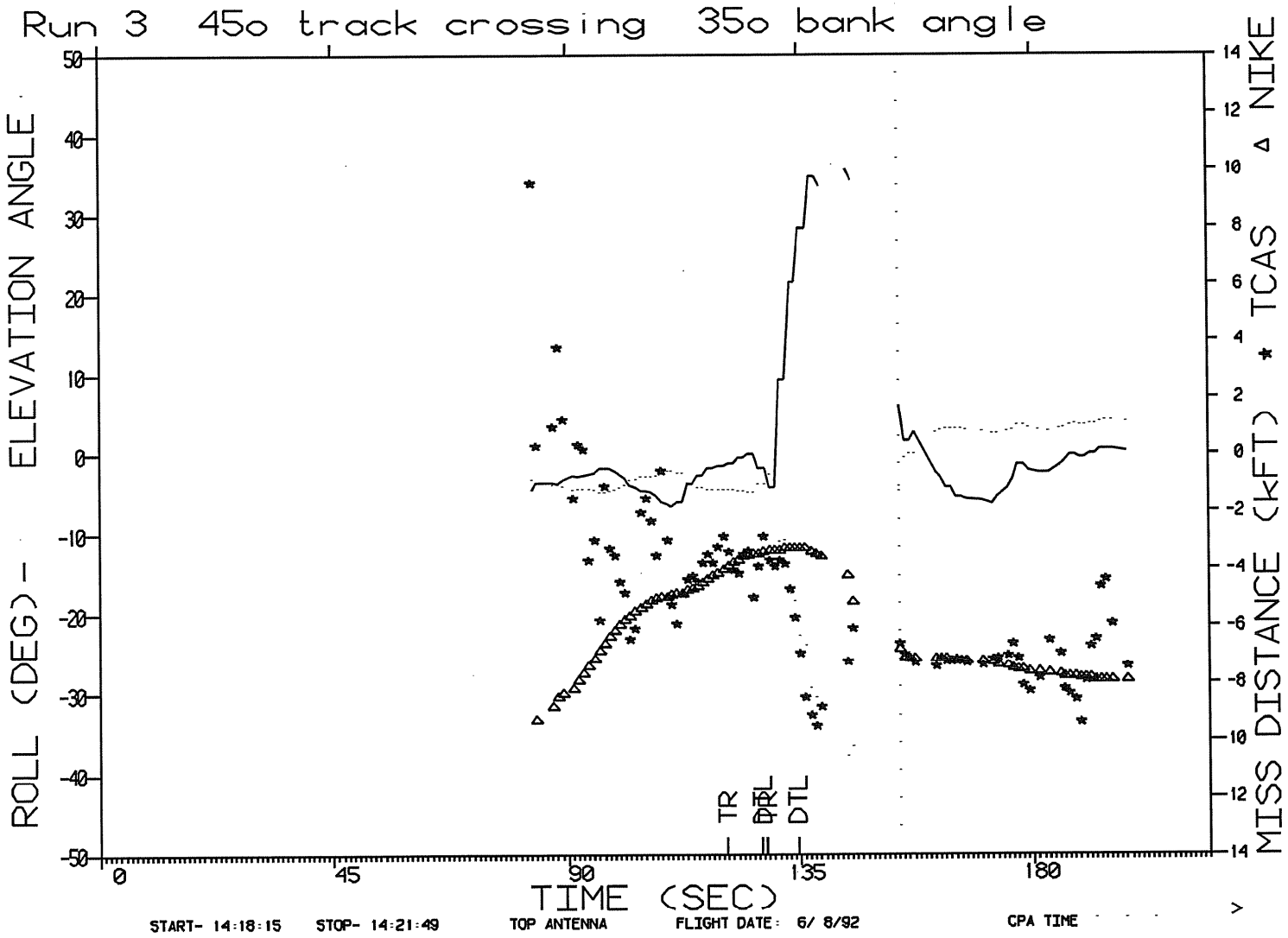

Run 1A 45o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 14: 6:50
STOP- 14: 9:33
BOTTOM ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

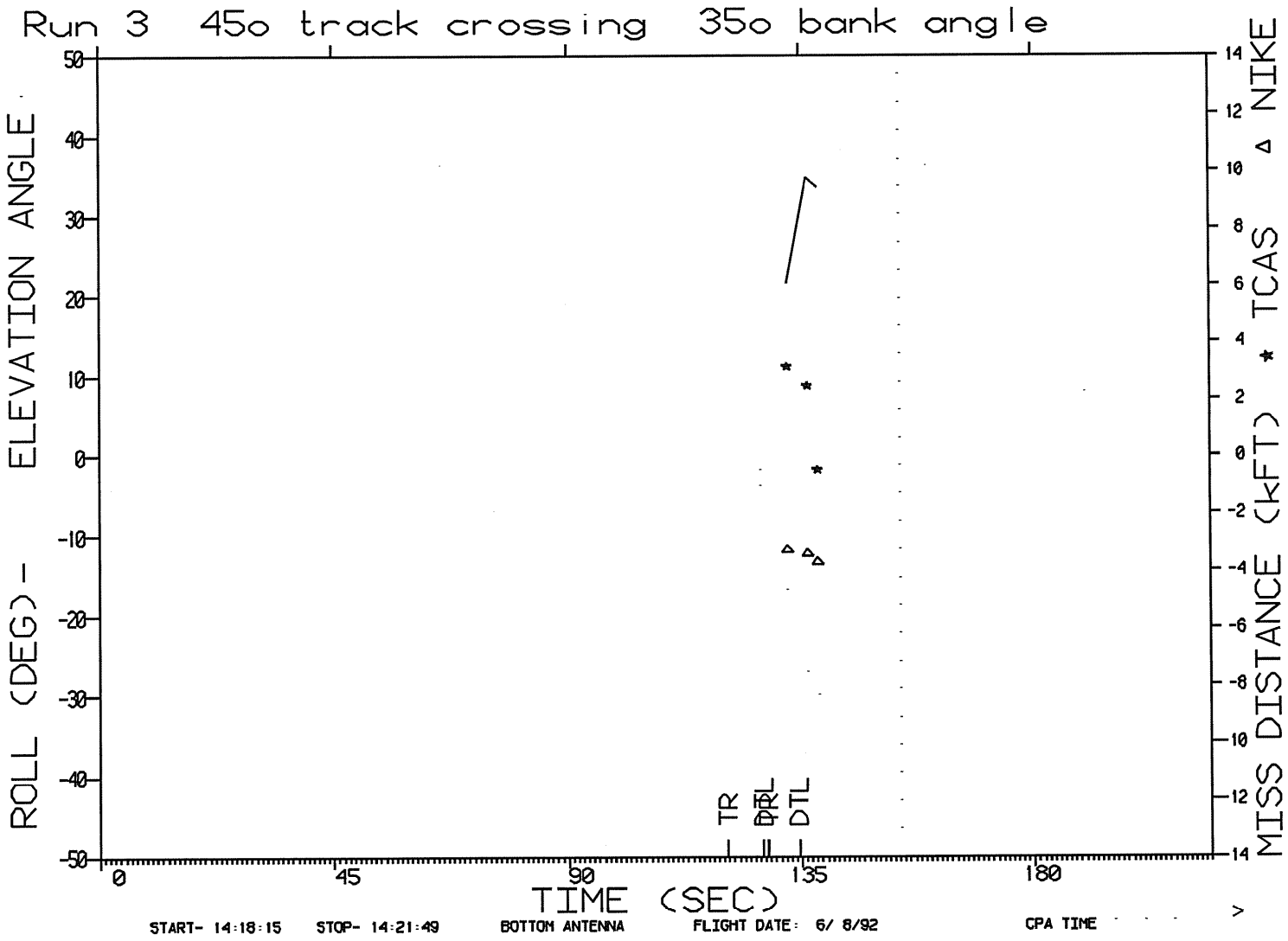

Run 1A 45o track crossing 15o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 14: 6:50
STOP- 14: 9:33
DIVERSITY ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

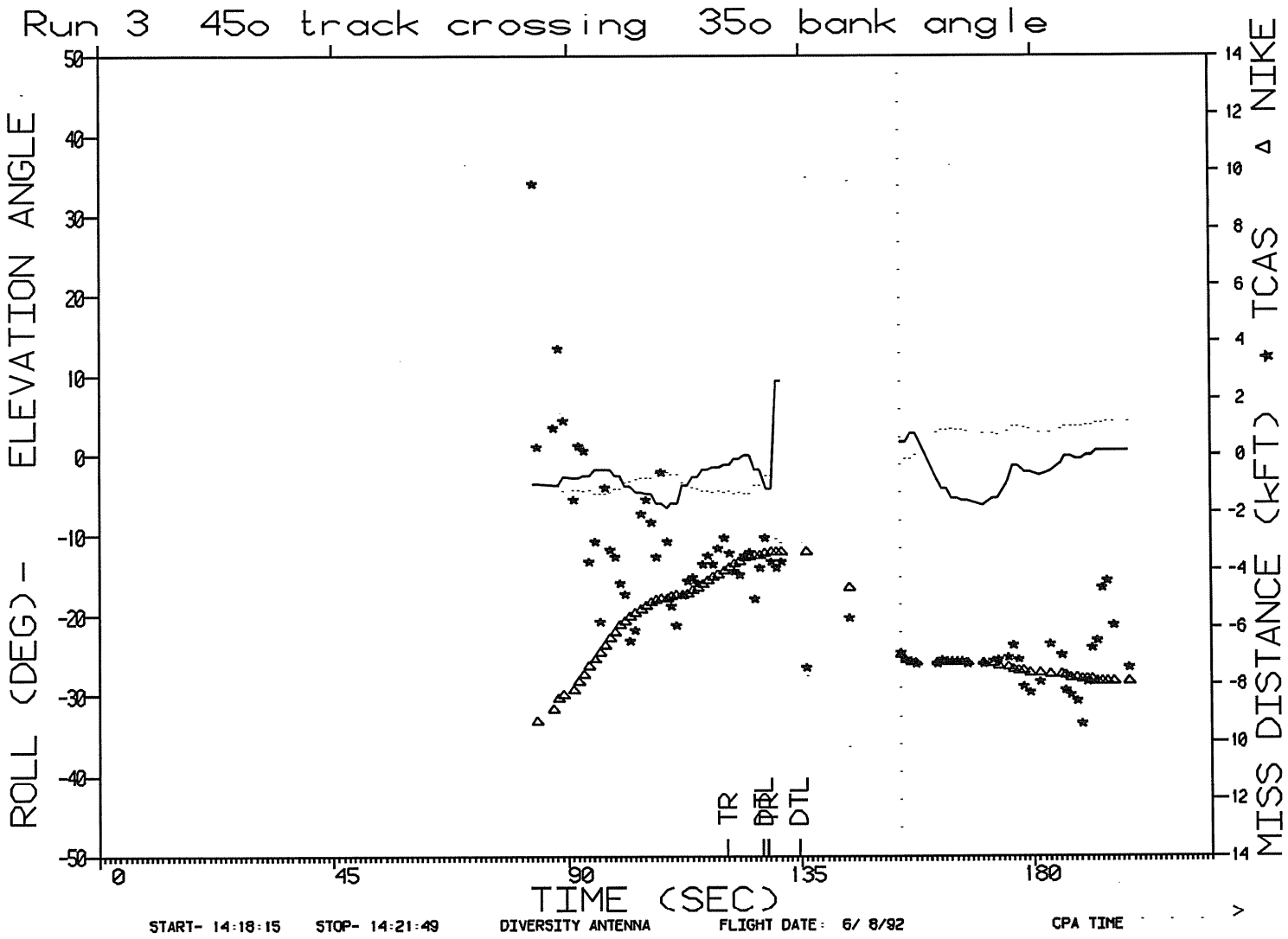

Run 2 45o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
DHR
START- 14:12:50
STOP- 14:15:37
TOP ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

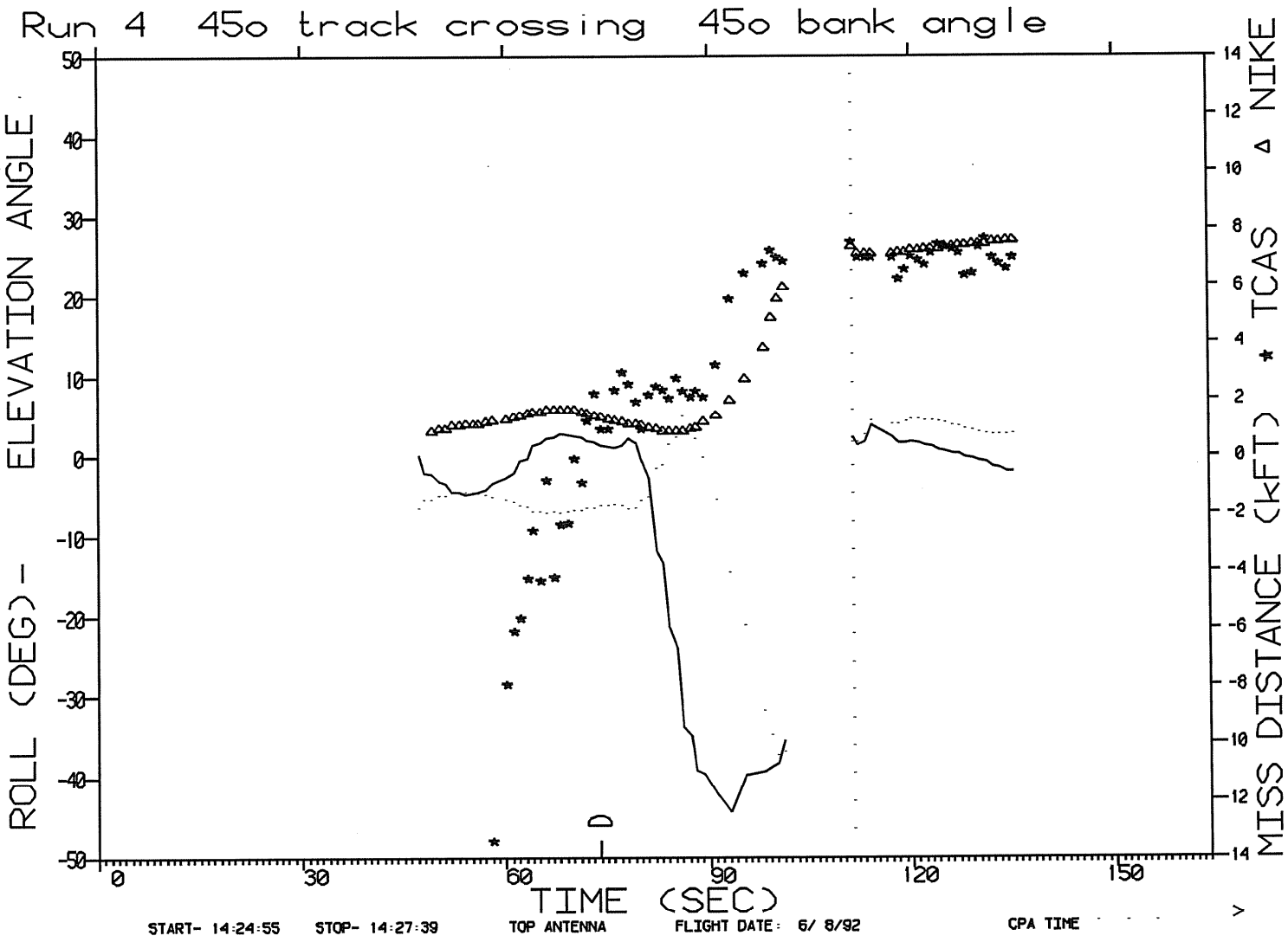

Run 2 45o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
TL
DTR
START- 14:12:50
STOP- 14:15:37
BOTTOM ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

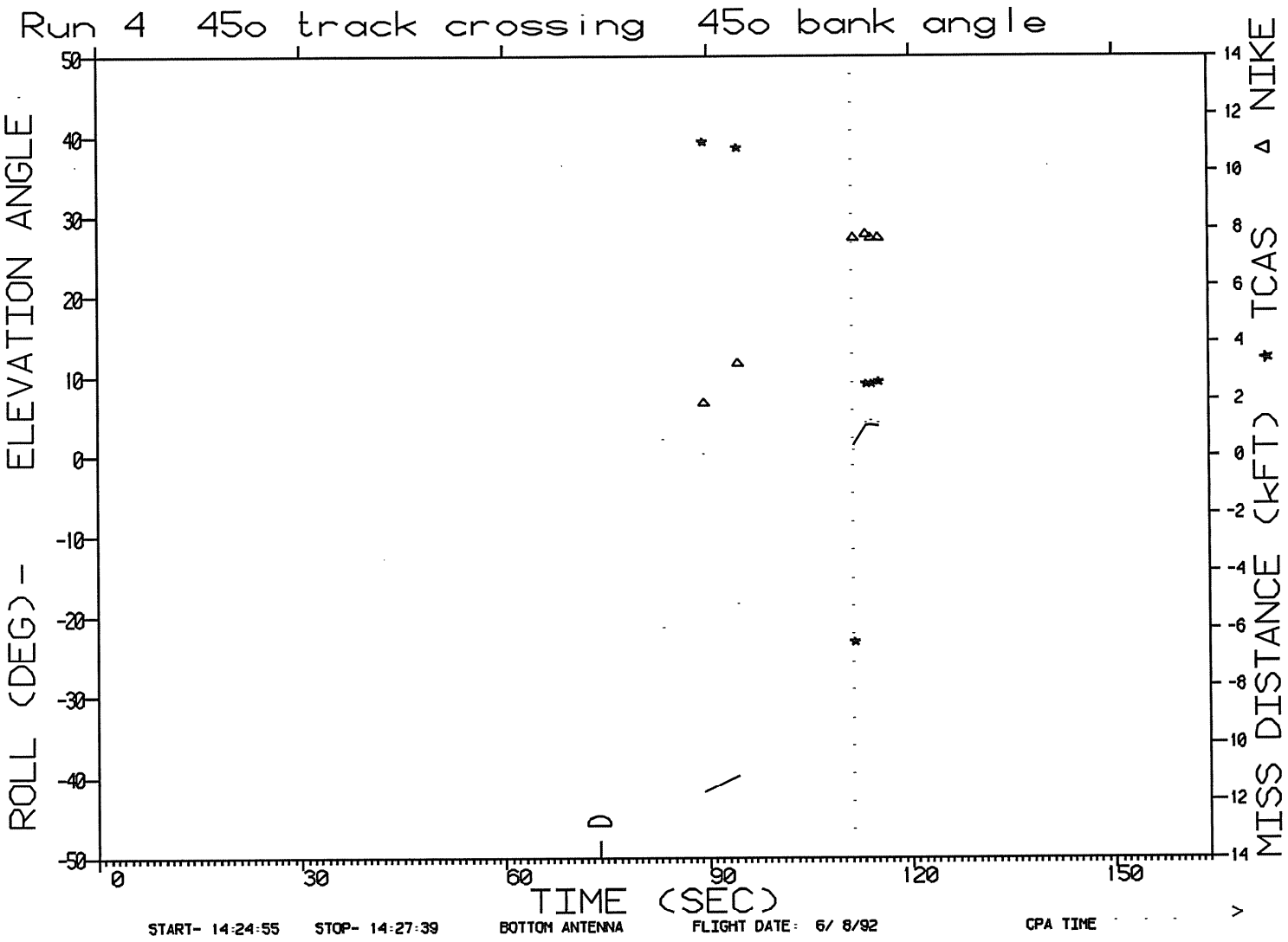

Run 2 45o track crossing 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
TL
DTR
START- 14:12:50 STOP- 14:15:37 DIVERSITY ANTENNA FLIGHT DATE: 6/ 8/92 CPA TIME

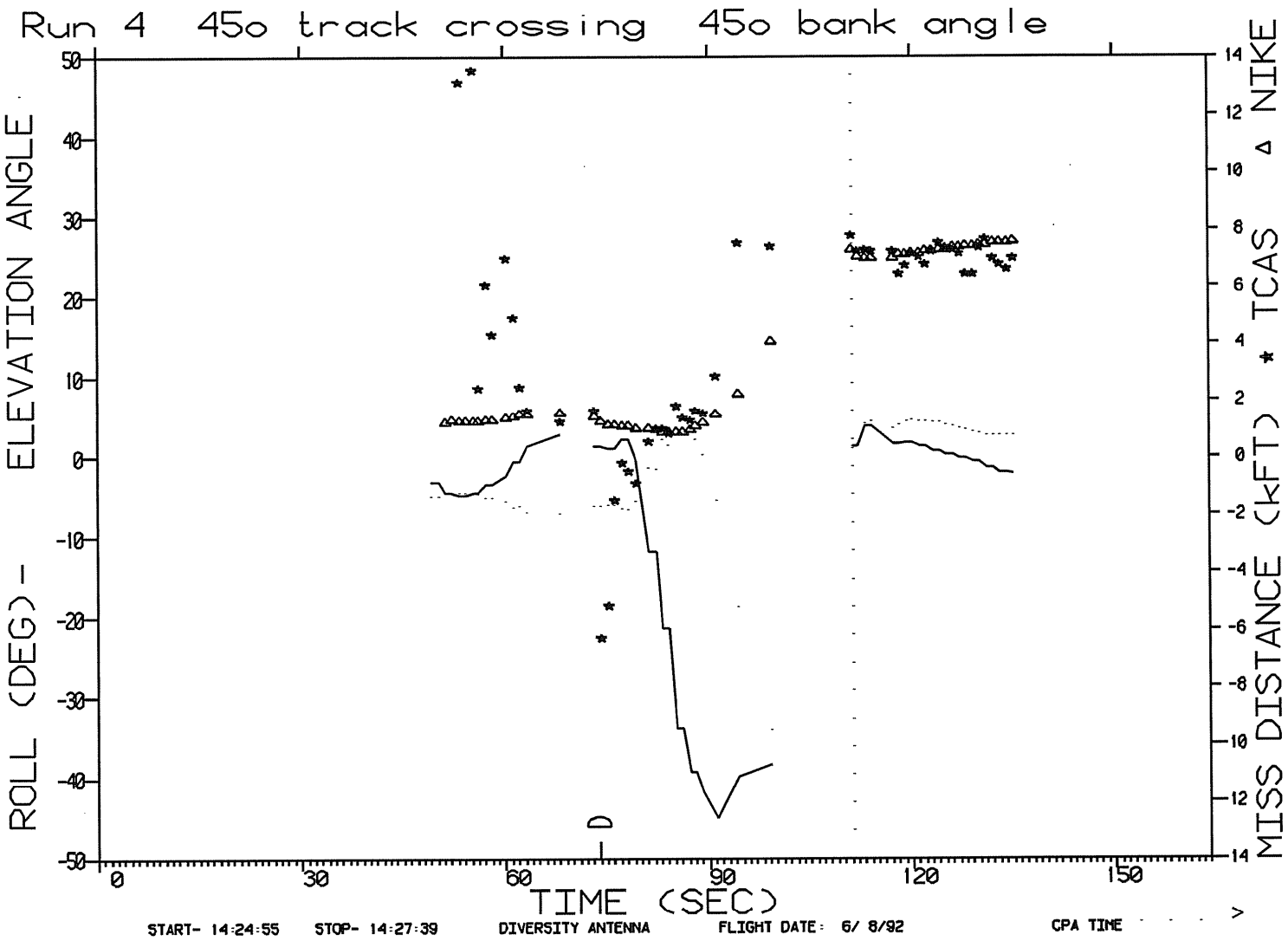

Run 3 45o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
DTL
START- 14:18:15
STOP- 14:21:49
TOP ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

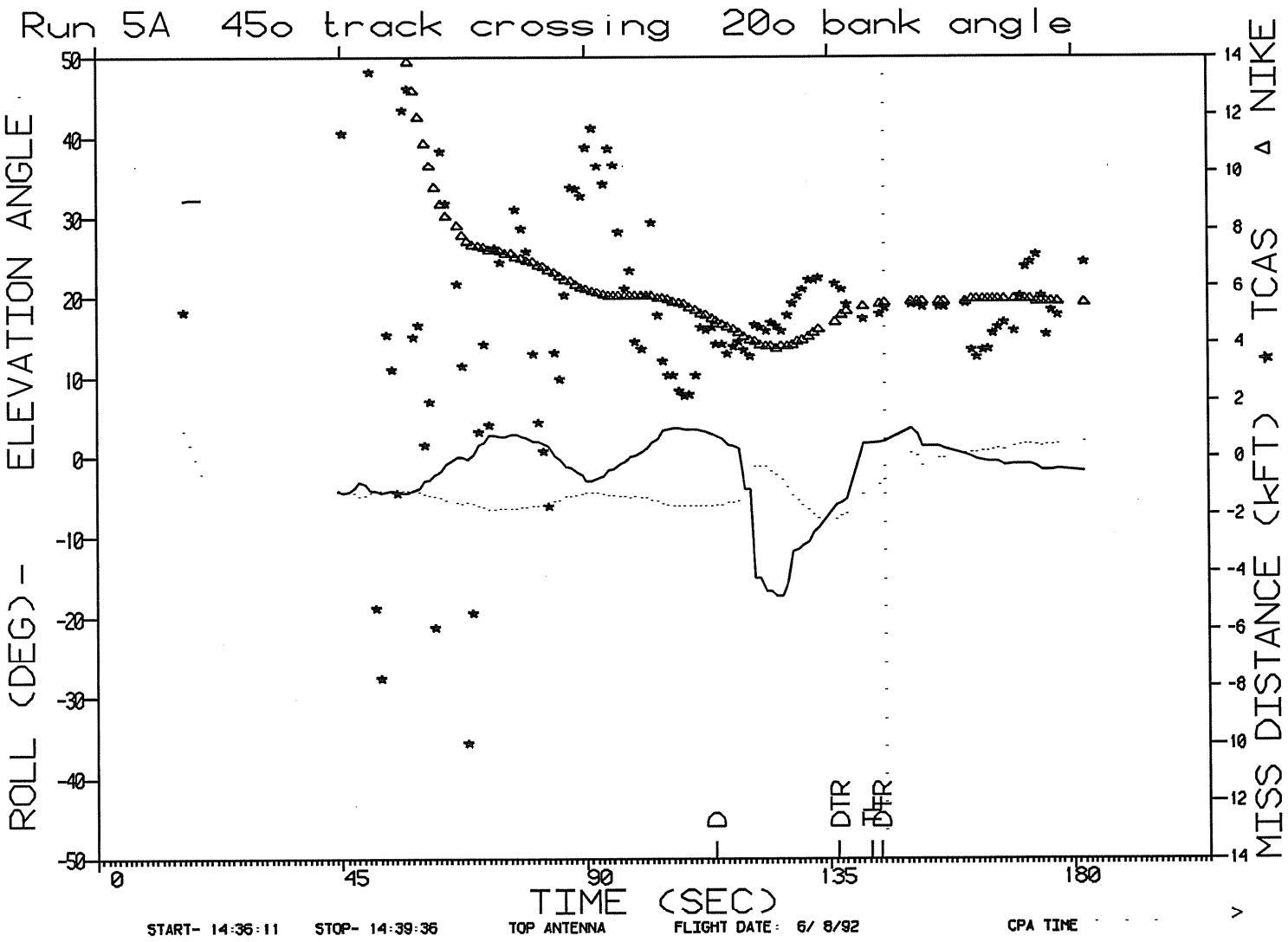

Run 3 45o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
DTL
START- 14:18:15
STOP- 14:21:49
BOTTOM ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

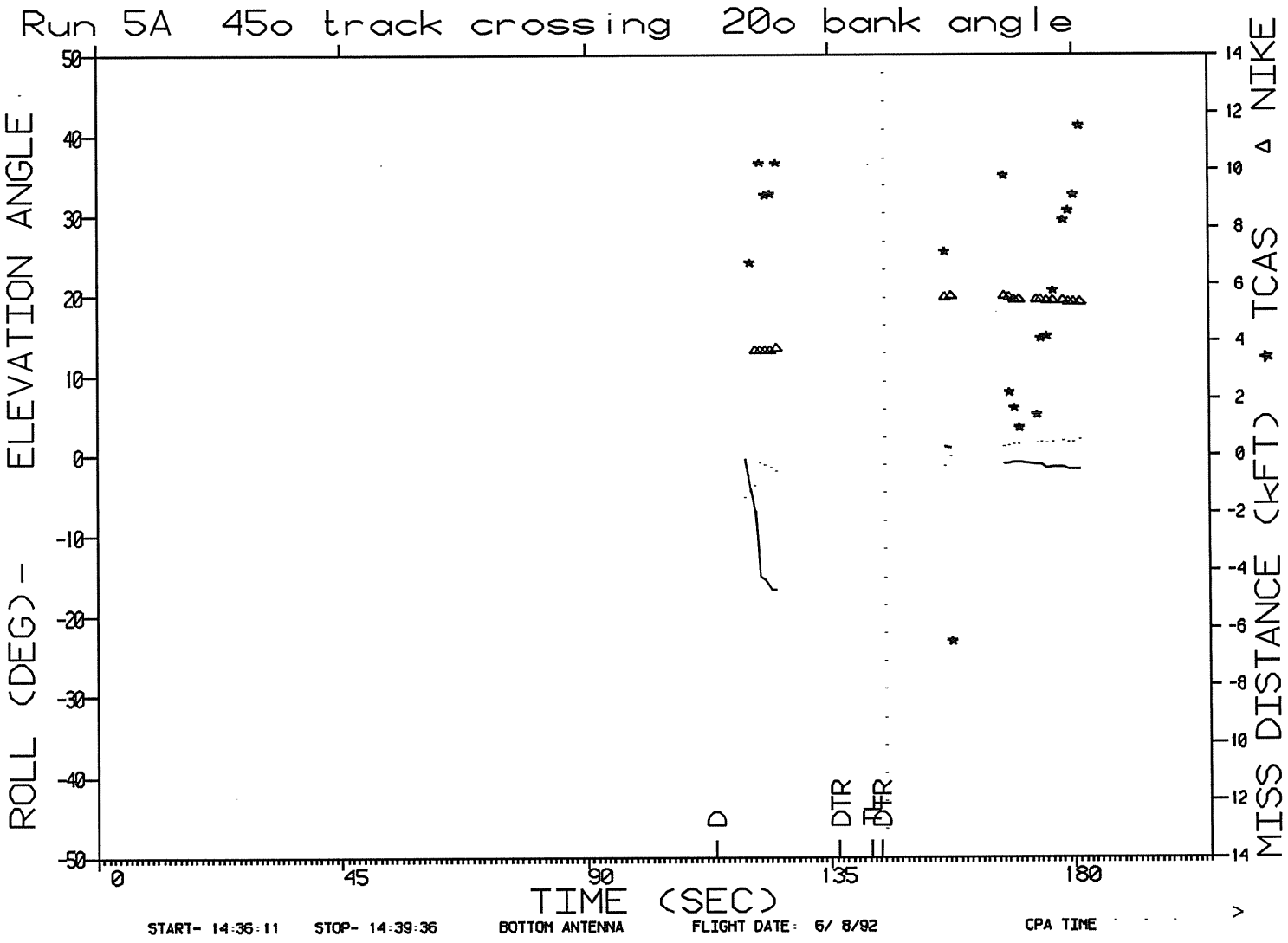

Run 3 45o track crossing 35o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
DTL
START- 14:18:15
STOP- 14:21:49
DIVERSITY ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

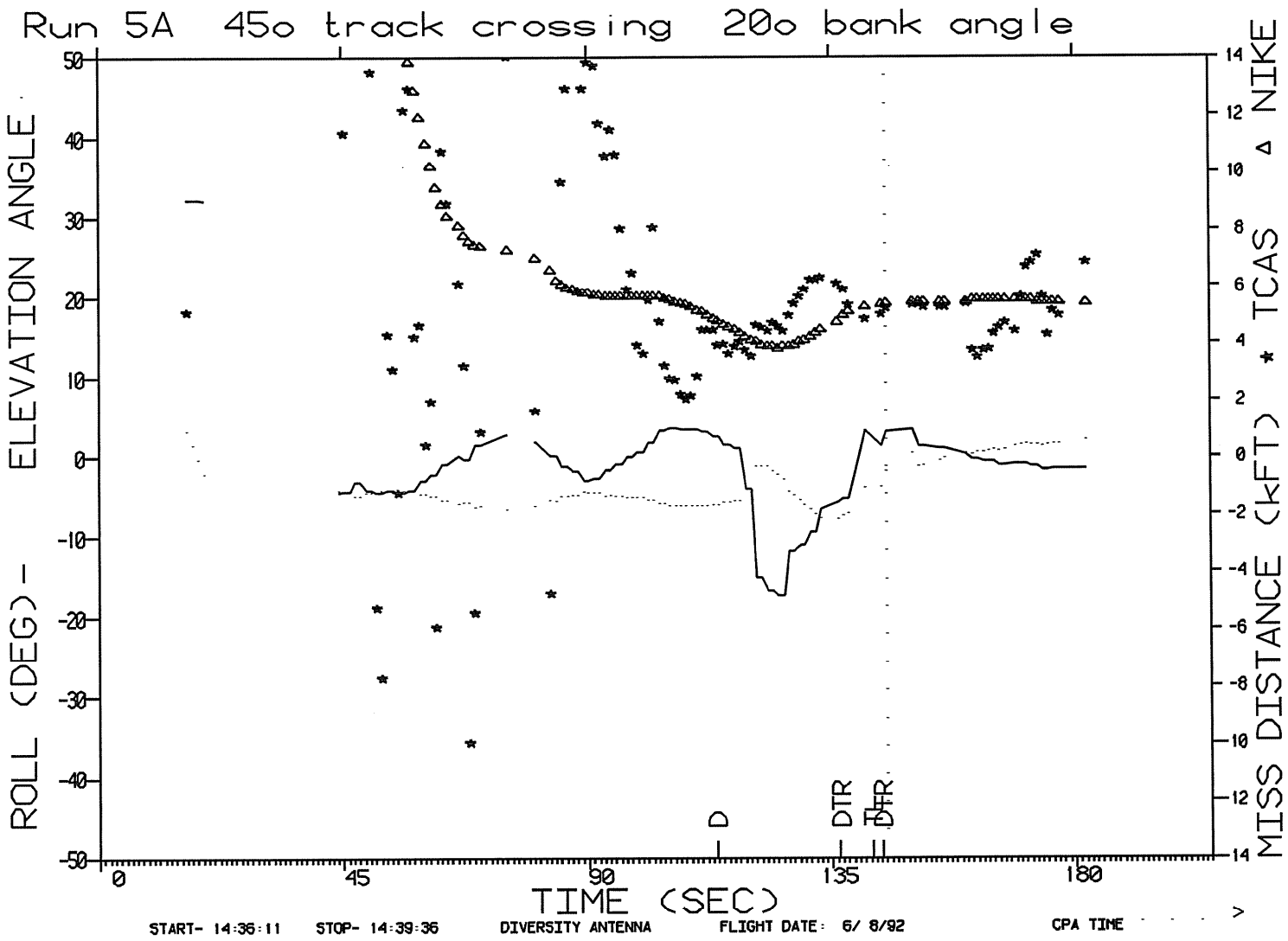

Run 4 45o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 14:24:55
STOP- 14:27:39
TOP ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

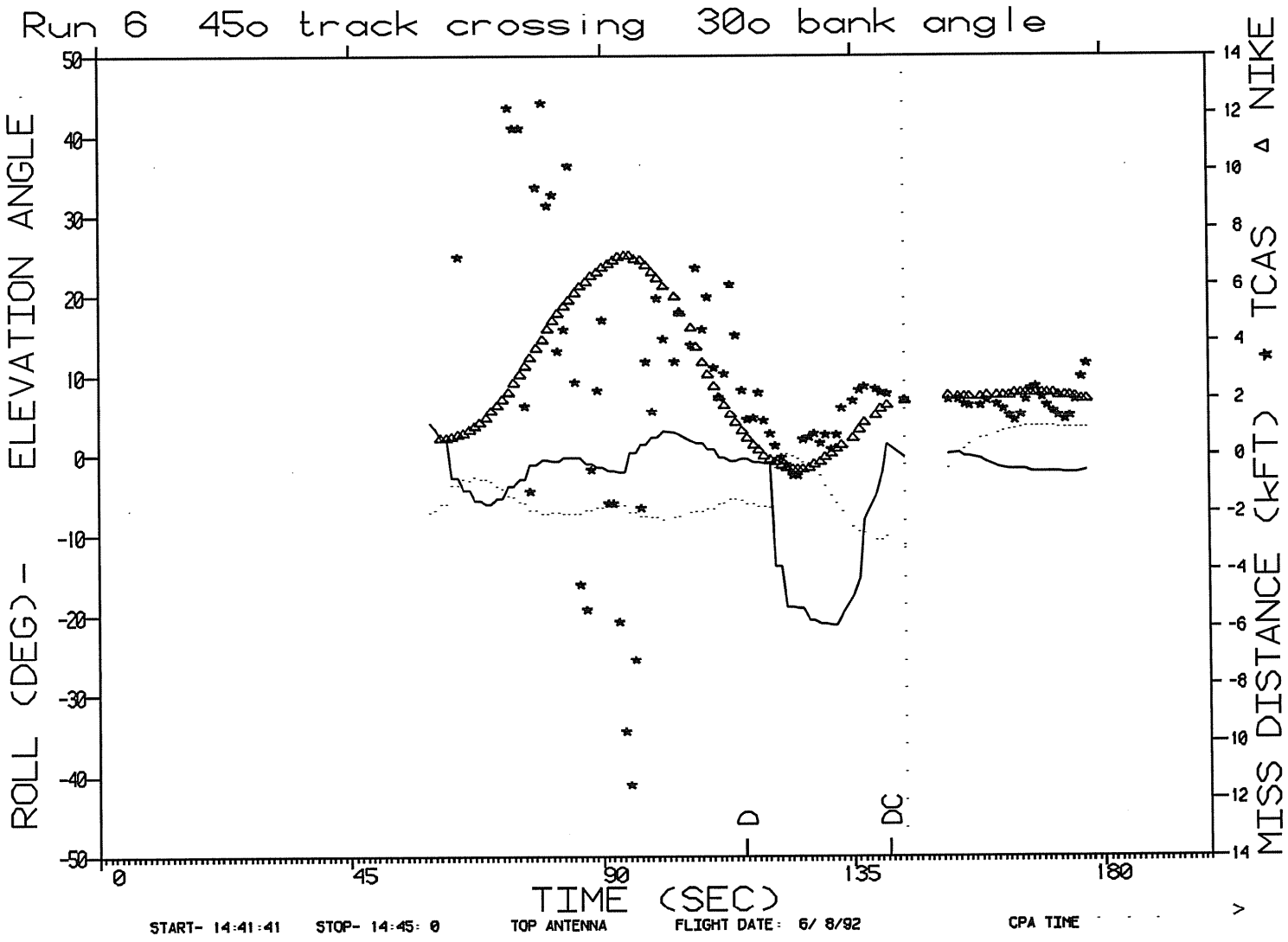

Run 4 45o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
30
60
90
120
150
START- 14:24:55
STOP- 14:27:39
BOTTOM ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

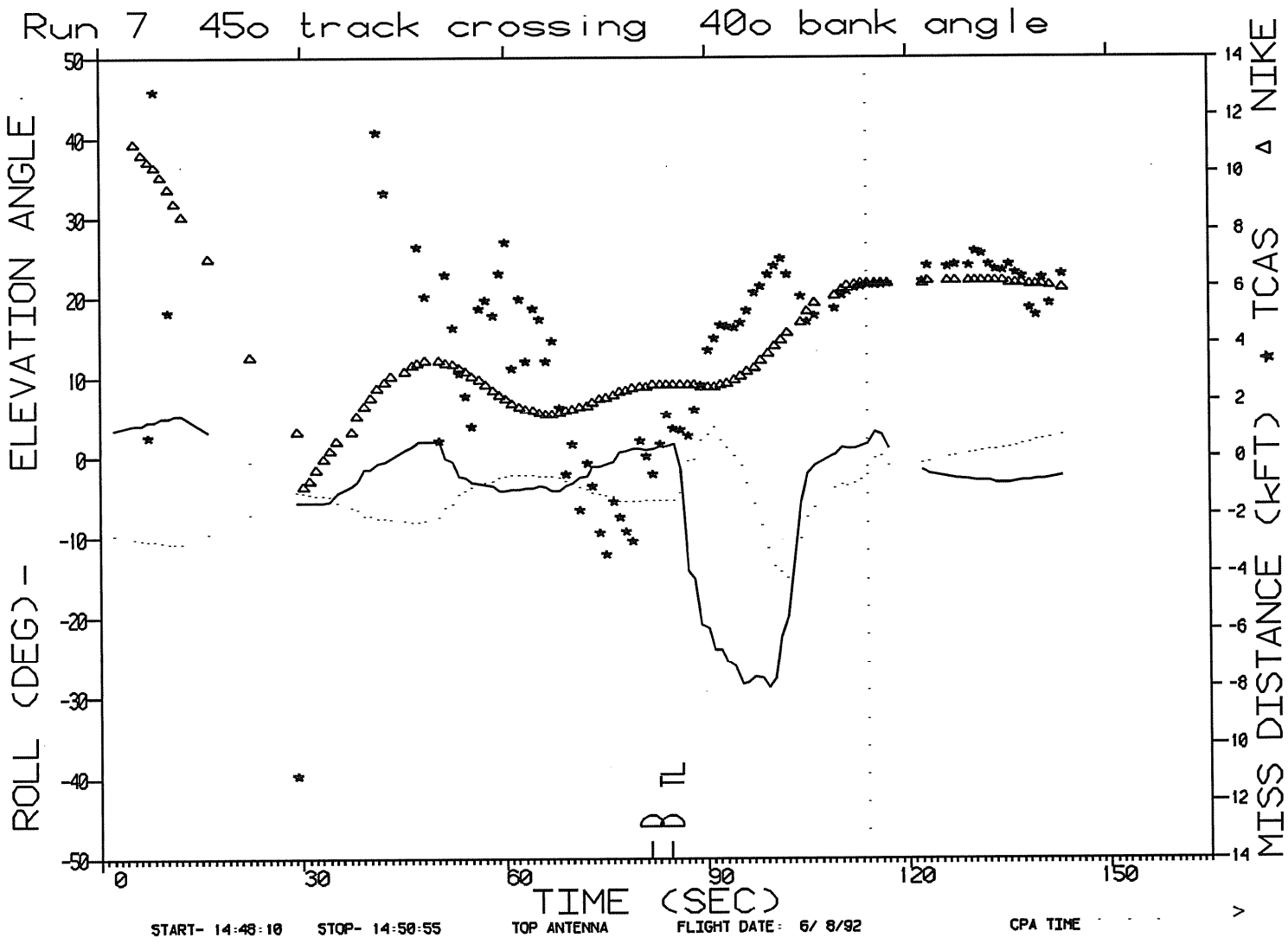

Run 4 45o track crossing 45o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 14:24:55
STOP- 14:27:39
DIVERSITY ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

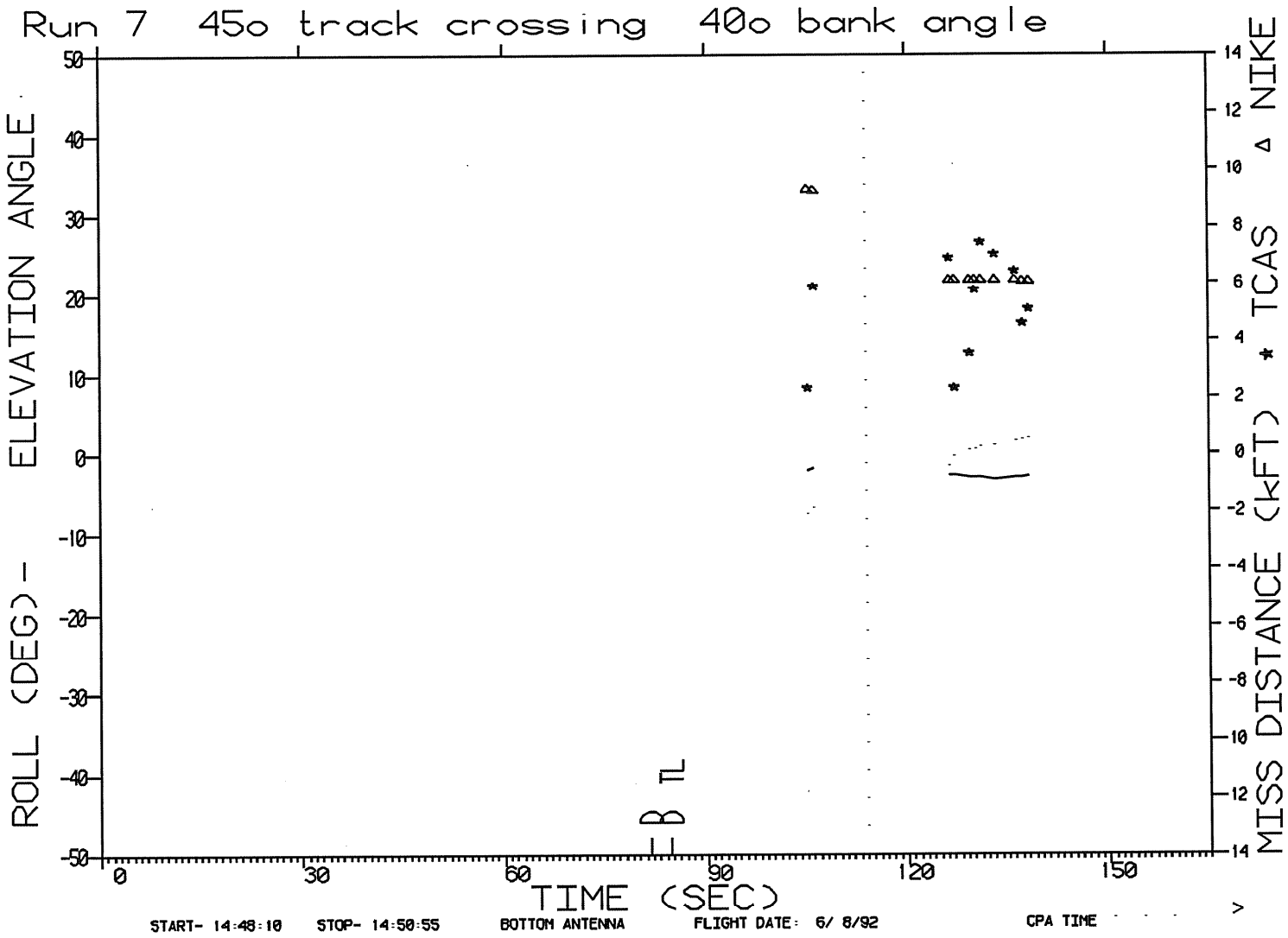

Run 5A 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
DTR
START- 14:36:11
STOP- 14:39:36
TOP ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

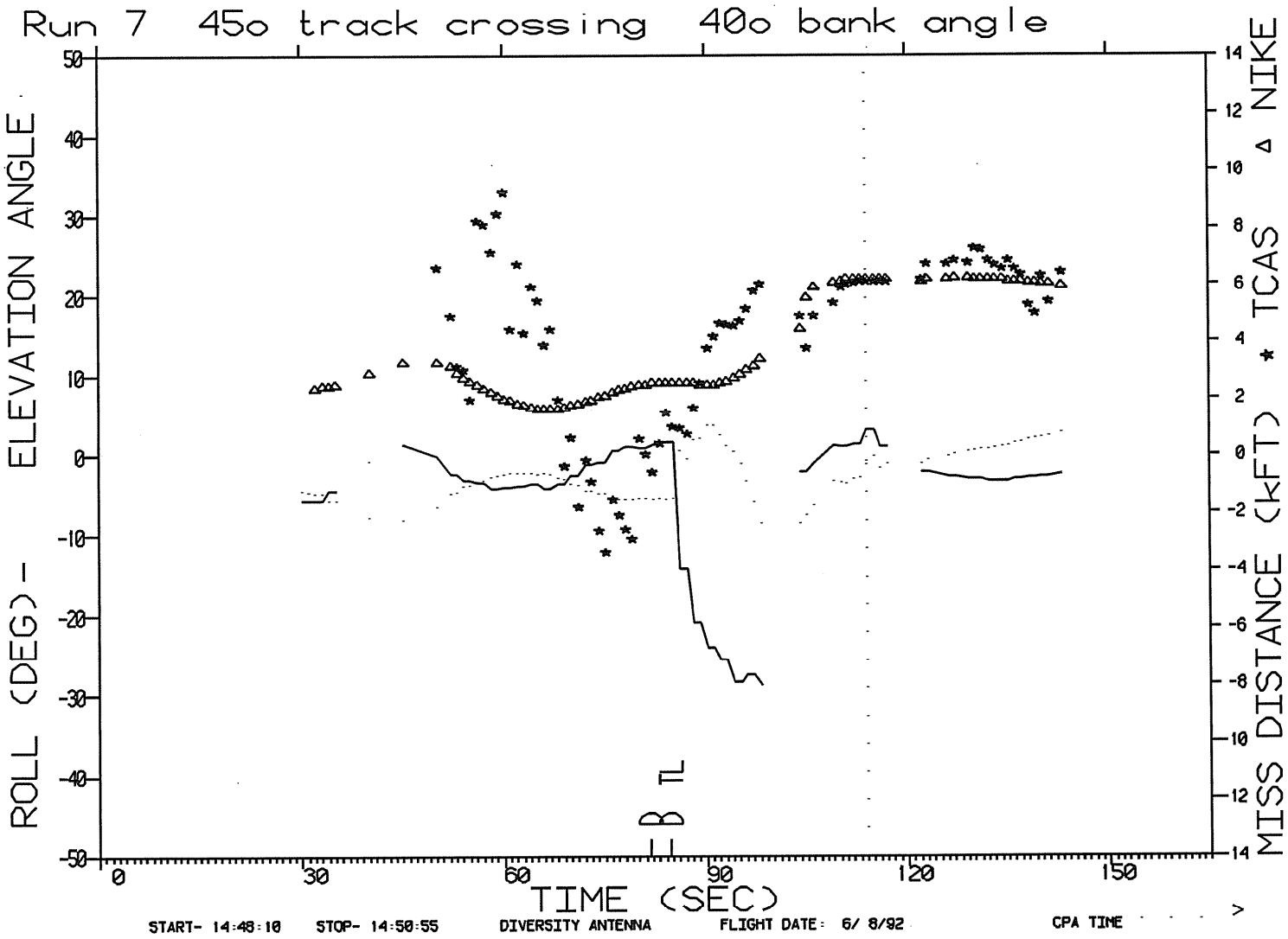

Run 5A 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
DTR
START- 14:36:11
STOP- 14:39:36
BOTTOM ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

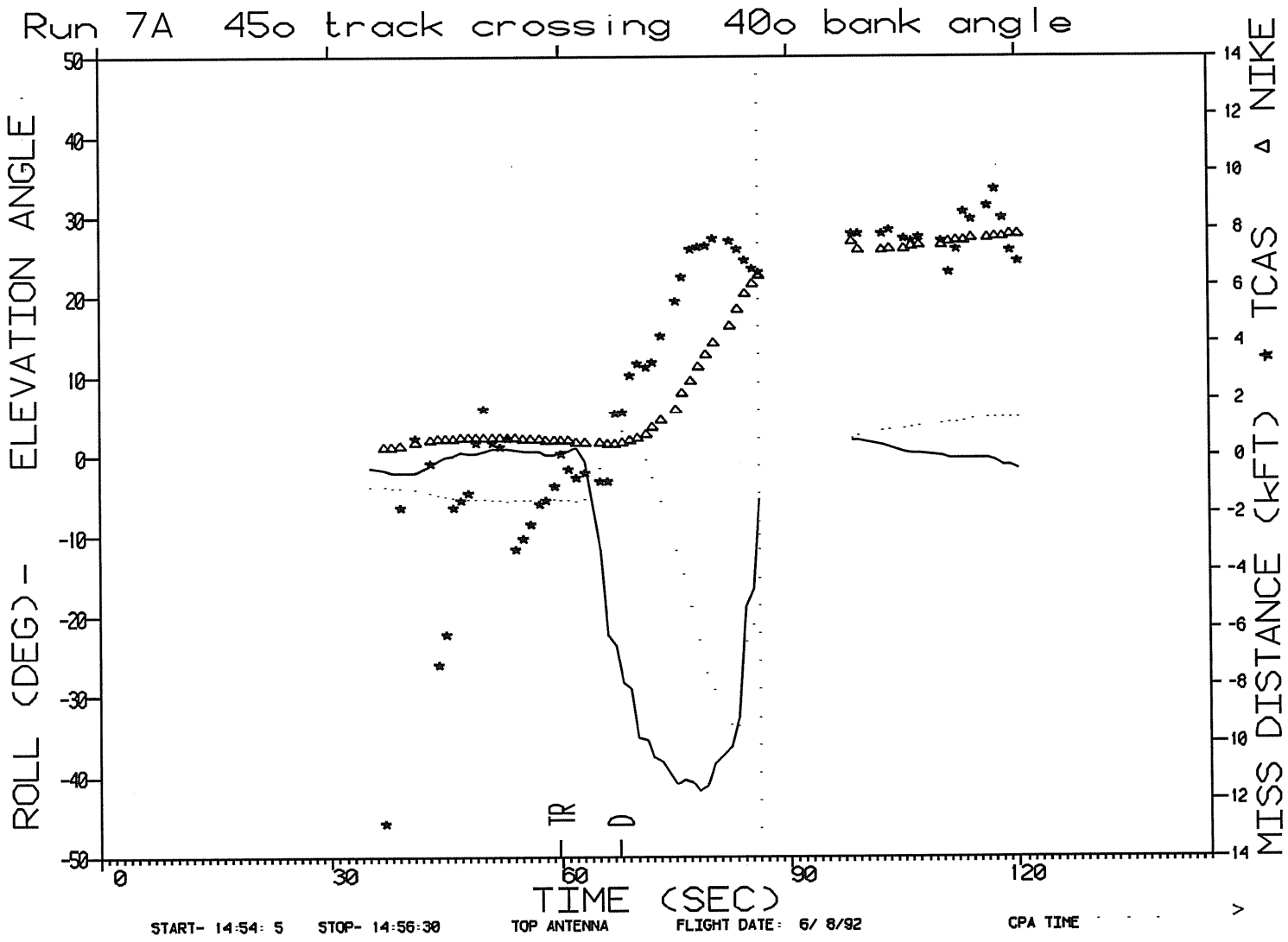

Run 5A 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
DTR
DTR
START- 14:36:11
STOP- 14:39:36
DIVERSITY ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

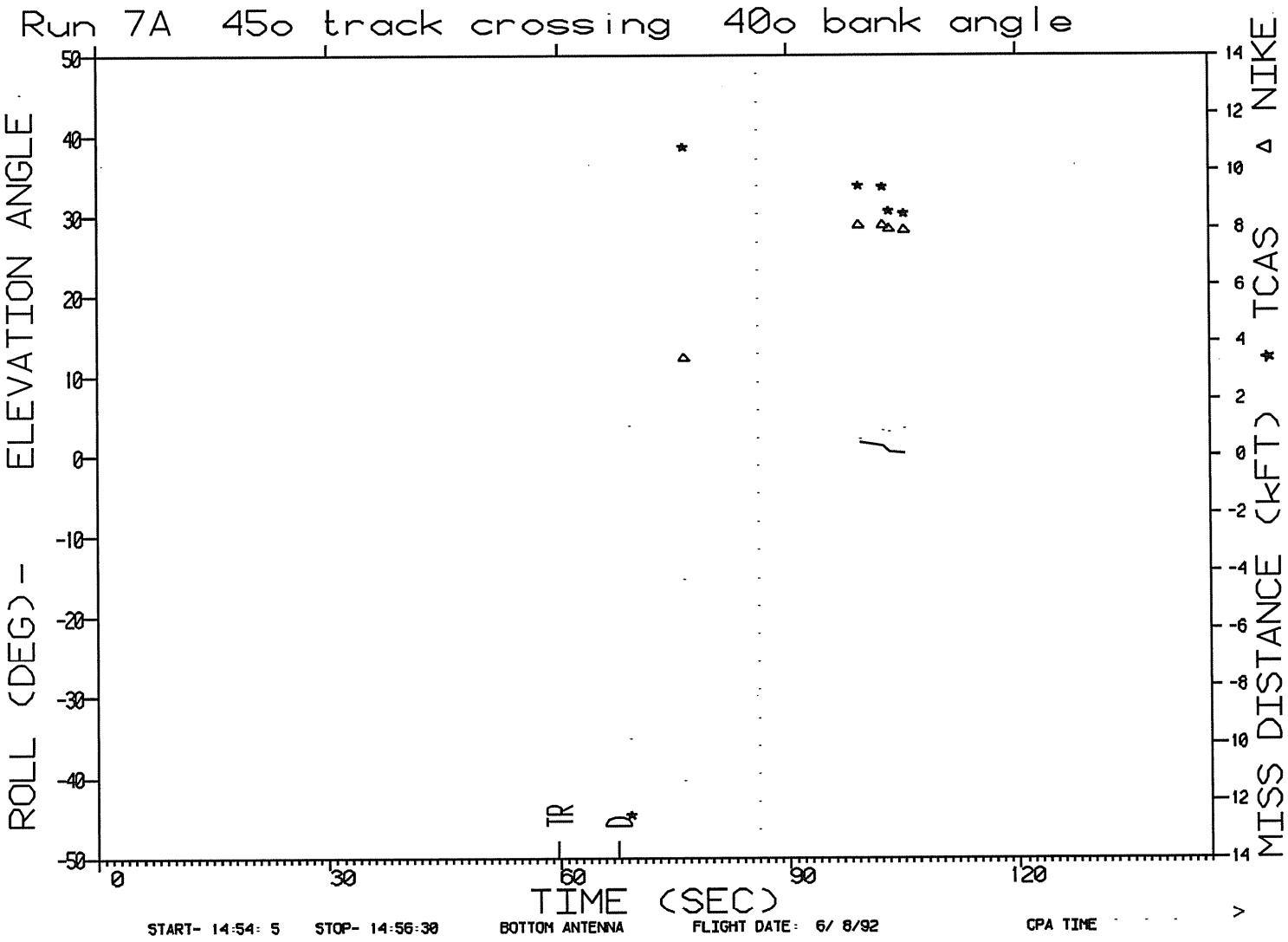

Run 6 45o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
DC
START- 14:41:41 STOP- 14:45: 0 TOP ANTENNA FLIGHT DATE: 6/ 8/92 CPA TIME

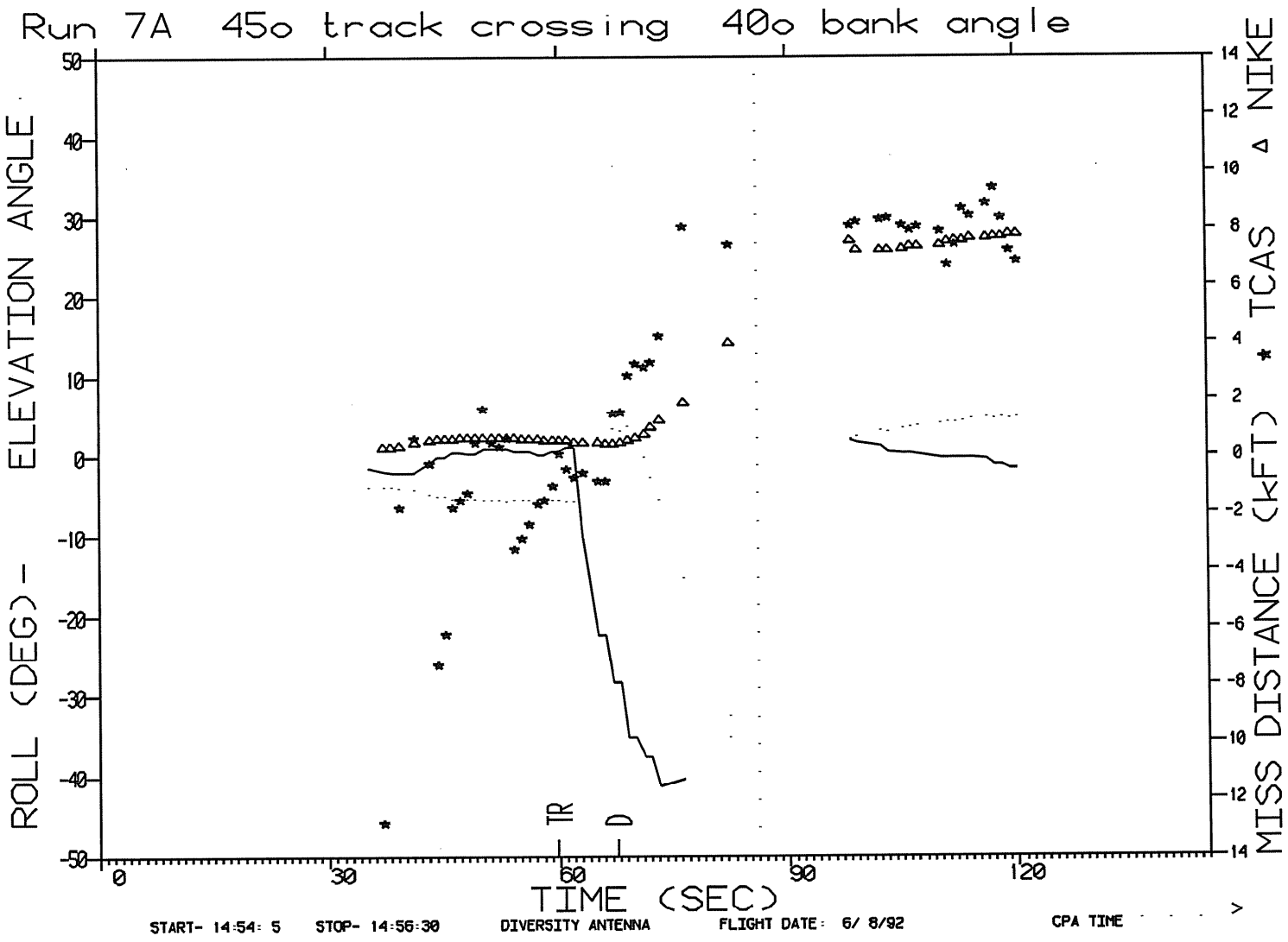

Run 7 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
B
TL
START- 14:48:10
STOP- 14:50:55
TOP ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

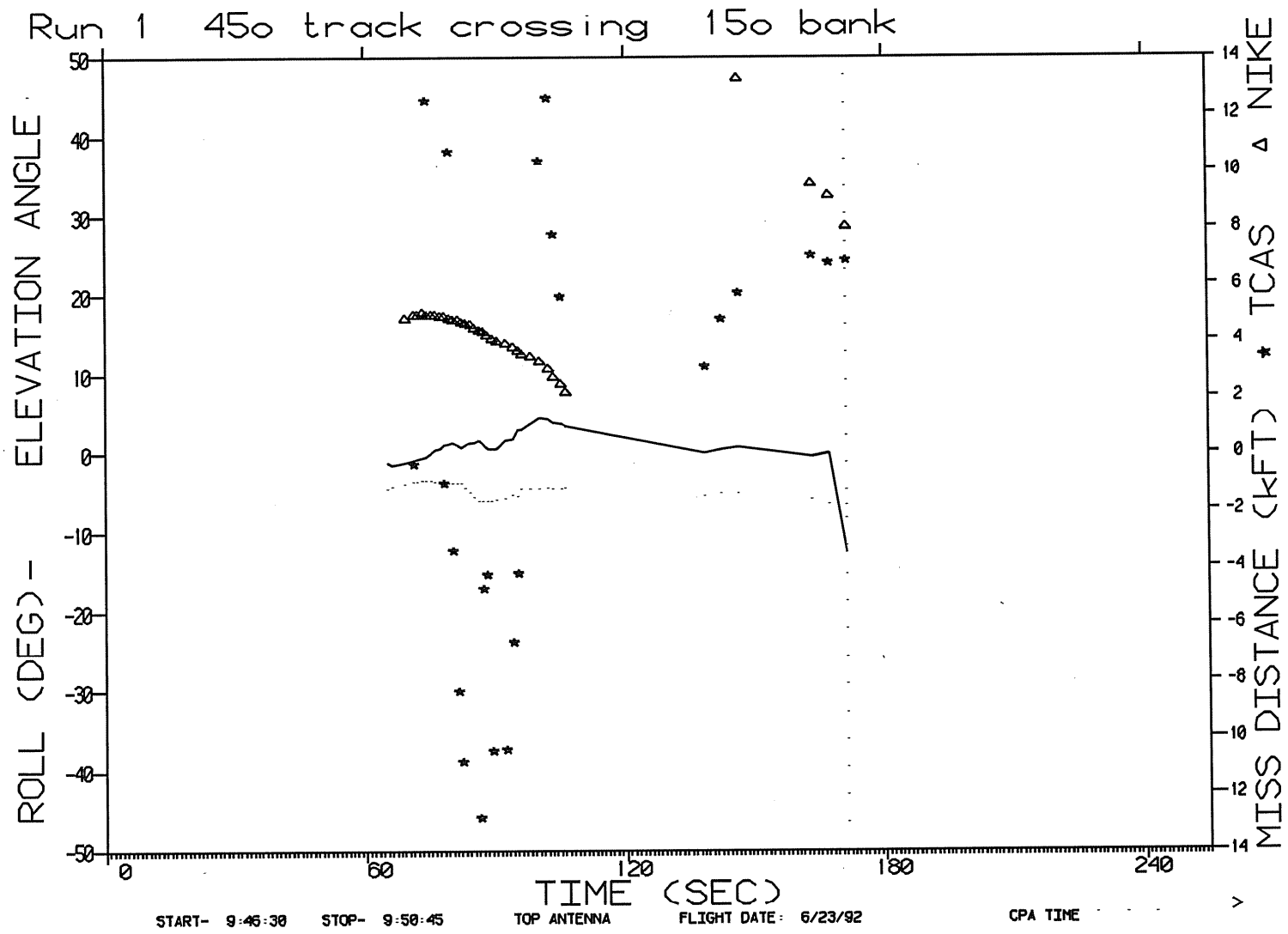

Run 7 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
B TL
START- 14:48:10 STOP- 14:50:55 BOTTOM ANTENNA FLIGHT DATE: 6/ 8/92 CPA TIME

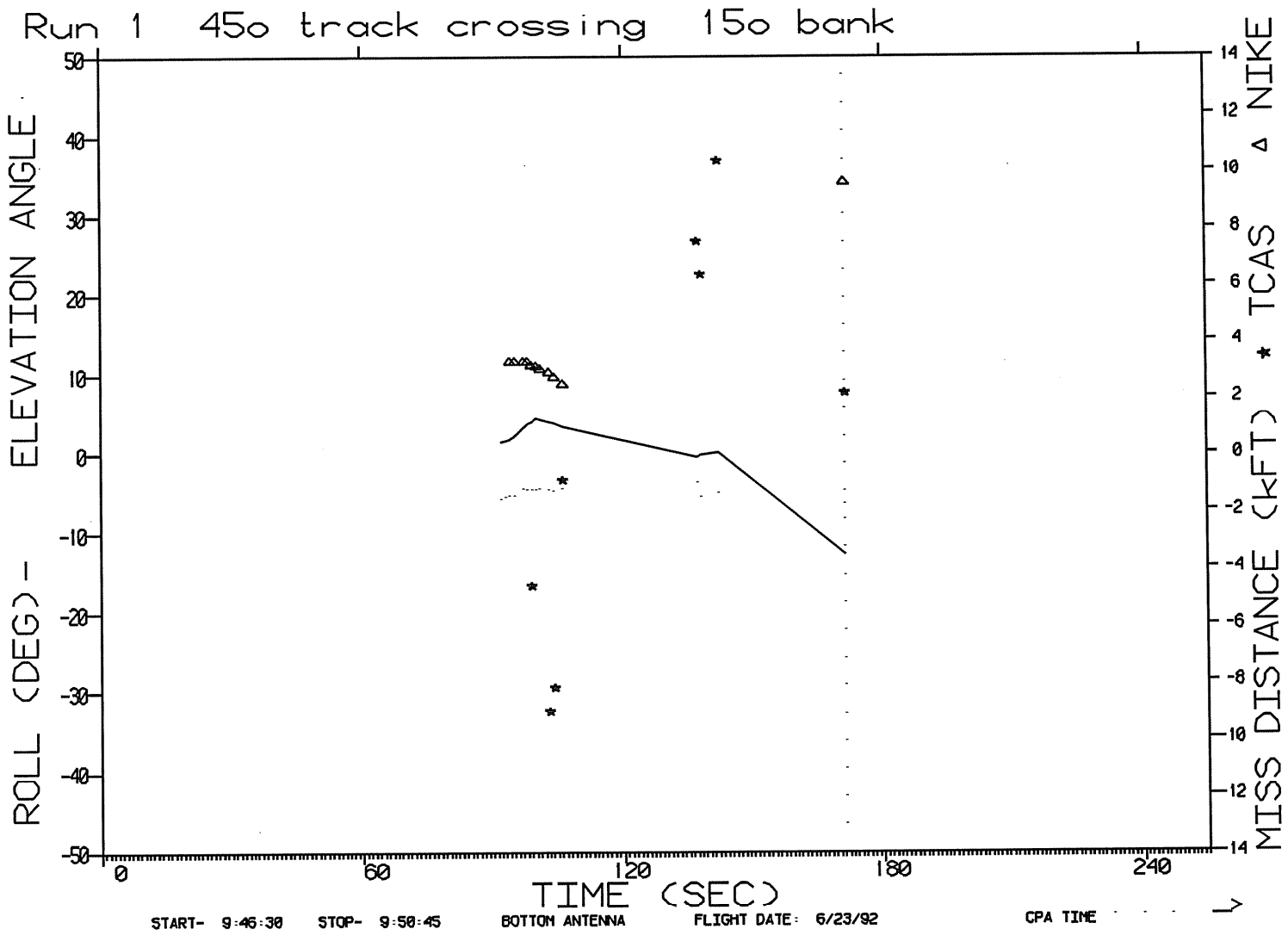

Run 7 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
B TL
START- 14:48:10
STOP- 14:50:55
DIVERSITY ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

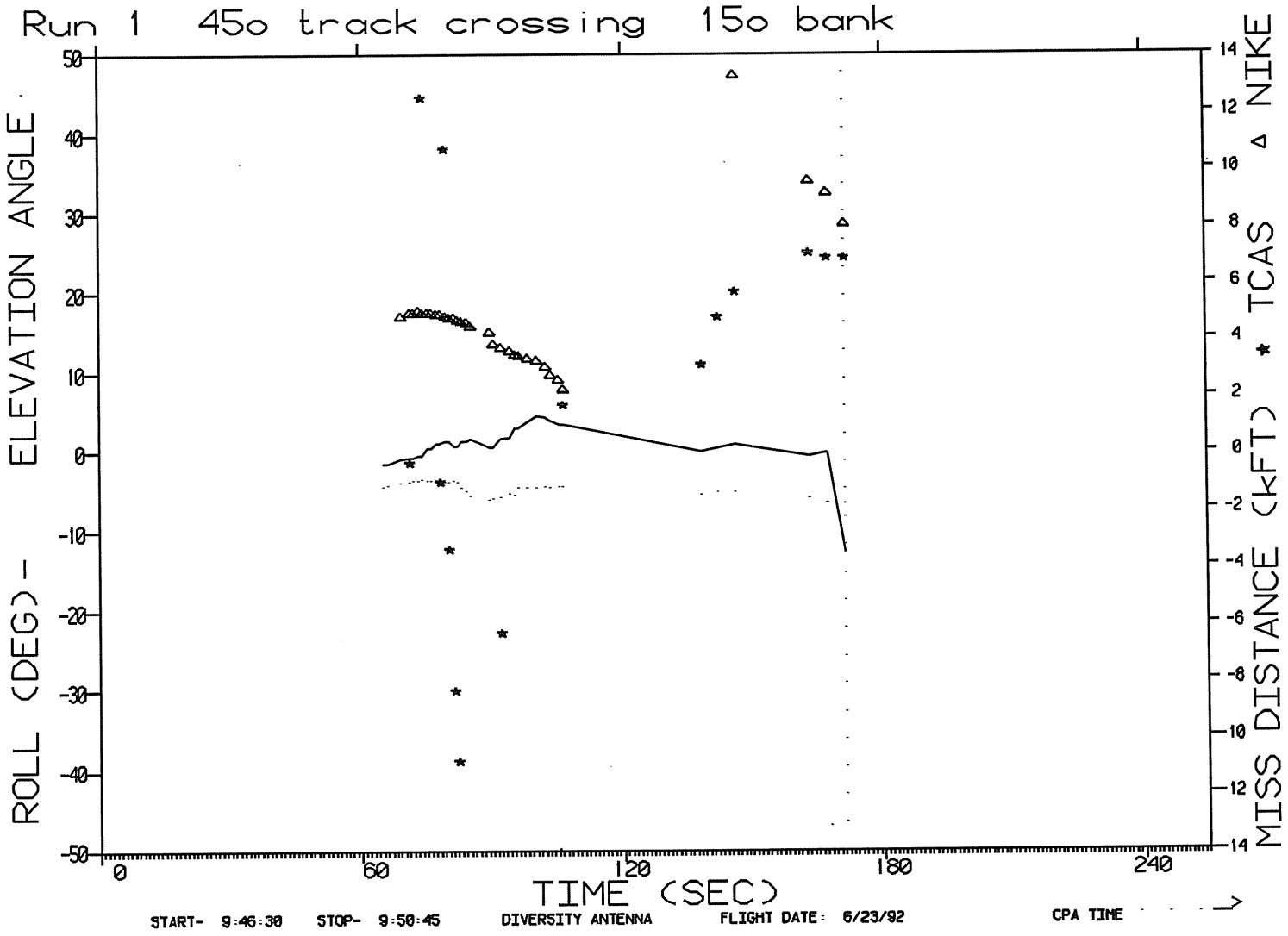

Run 7A 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
D
START- 14:54: 5
STOP- 14:56:30
TOP ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

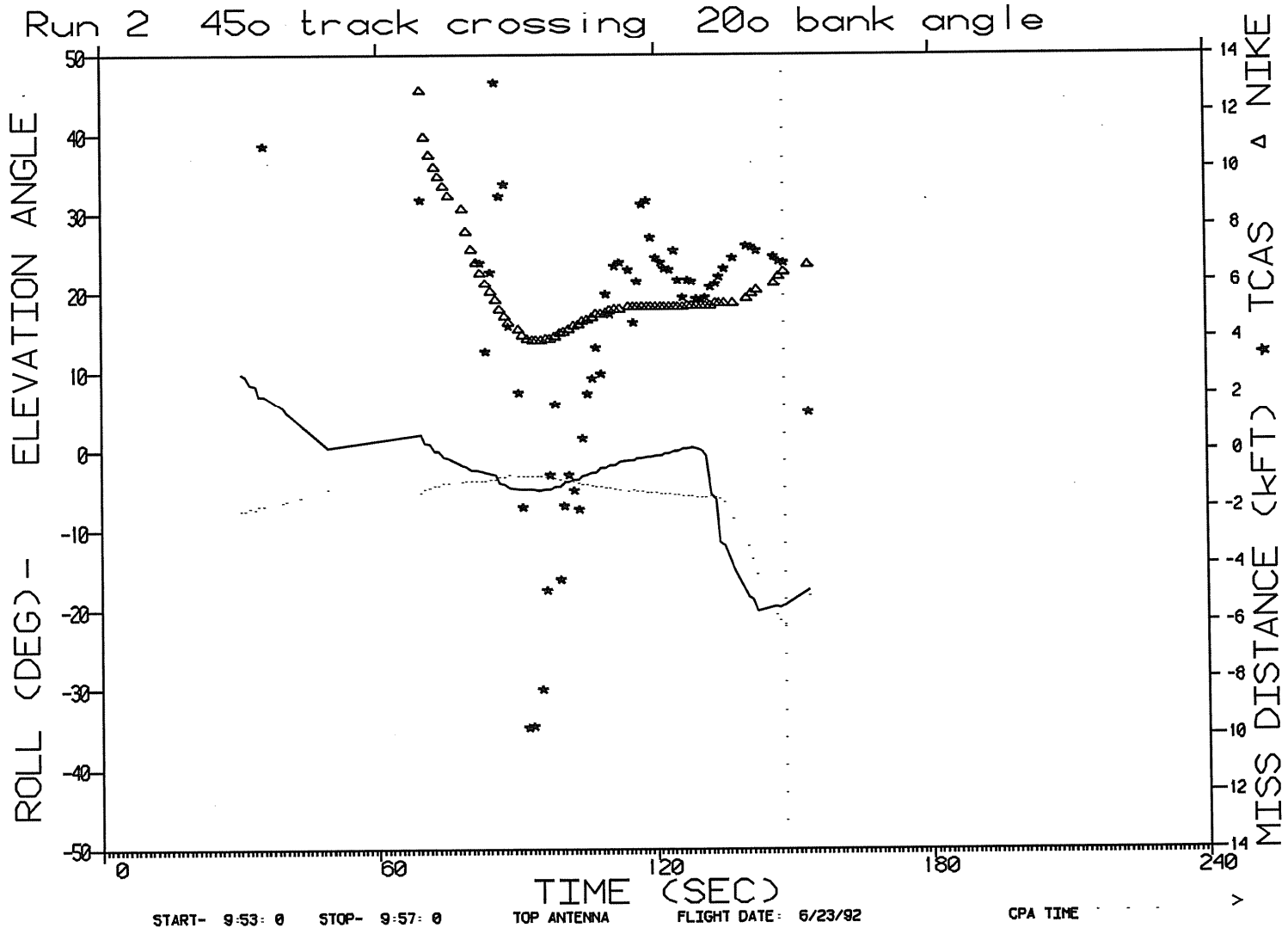

Run 7A 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
D*
START- 14:54: 5
STOP- 14:56:30
BOTTOM ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

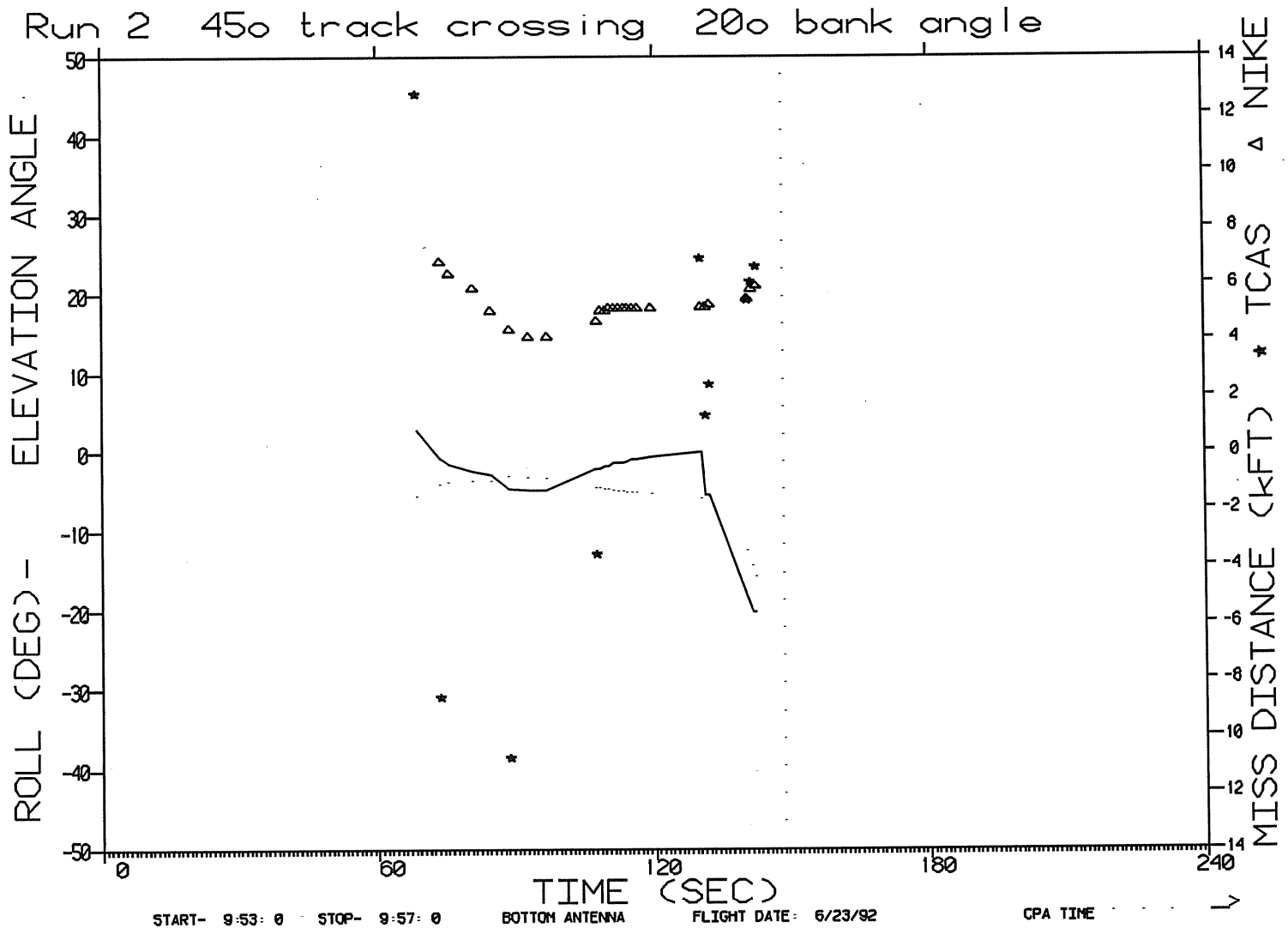

Run 7A 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
D
START- 14:54: 5
STOP- 14:56:30
DIVERSITY ANTENNA
FLIGHT DATE: 6/ 8/92
CPA TIME

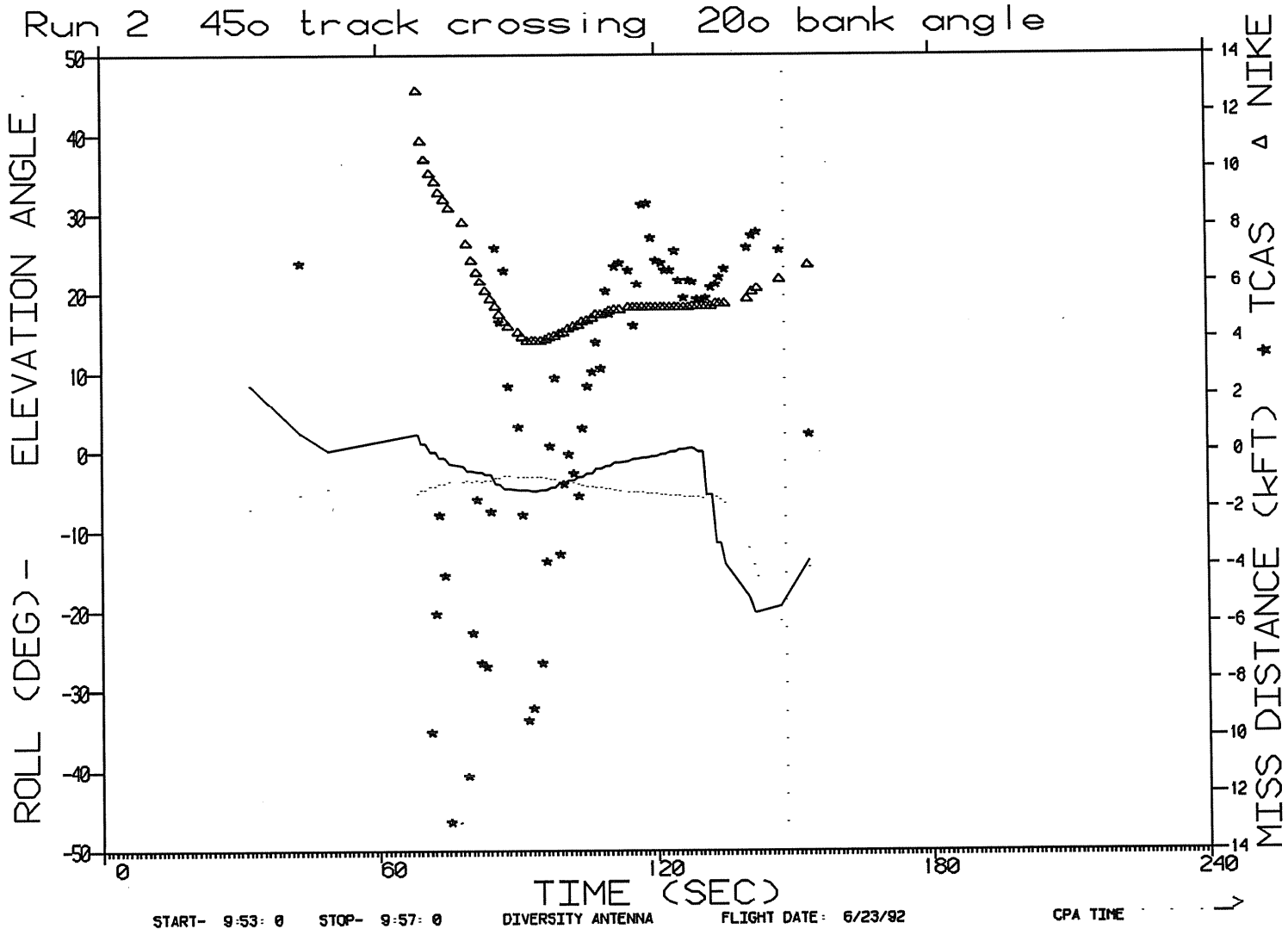

Run 1 45o track crossing 15o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
START- 9:46:30 STOP- 9:50:45 TOP ANTENNA FLIGHT DATE: 6/23/92 CPA TIME

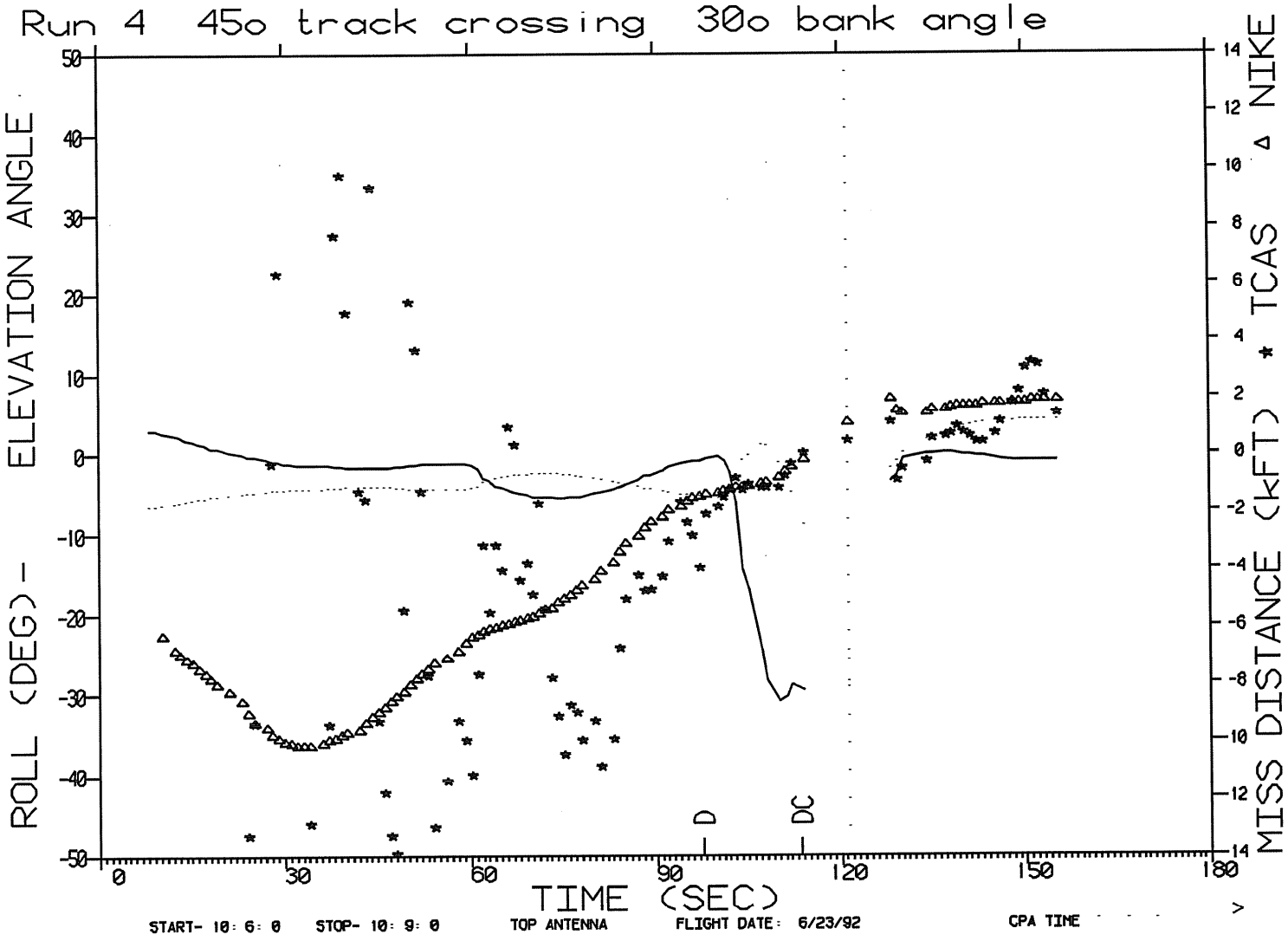

Run 1 45o track crossing 15o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
60
120
180
240
START- 9:46:30 STOP- 9:50:45 BOTTOM ANTENNA FLIGHT DATE: 6/23/92 CPA TIME

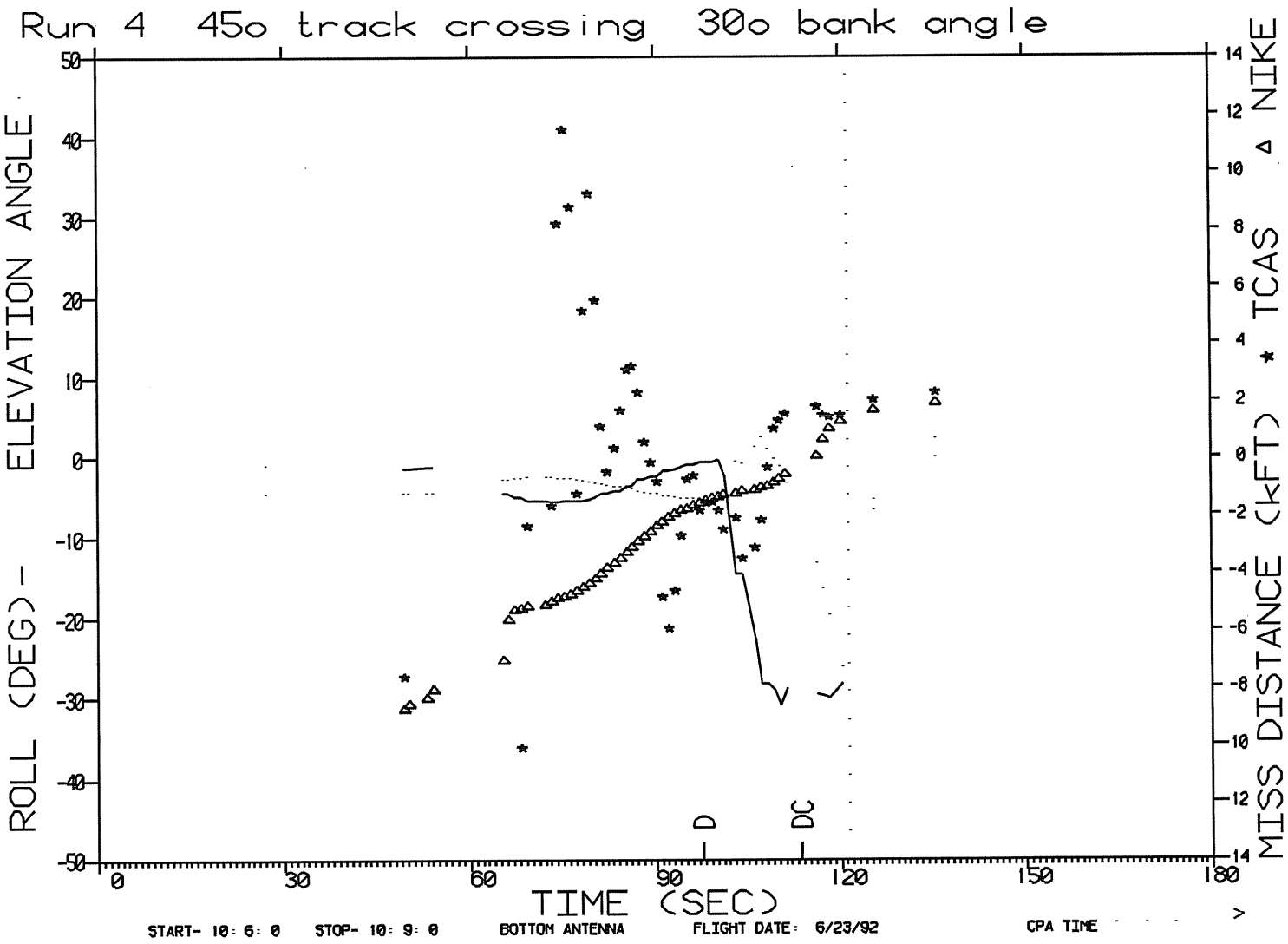

Run 1 45o track crossing 15o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
60
120
180
240
START- 9:46:30 STOP- 9:50:45 DIVERSITY ANTENNA FLIGHT DATE: 6/23/92 CPA TIME

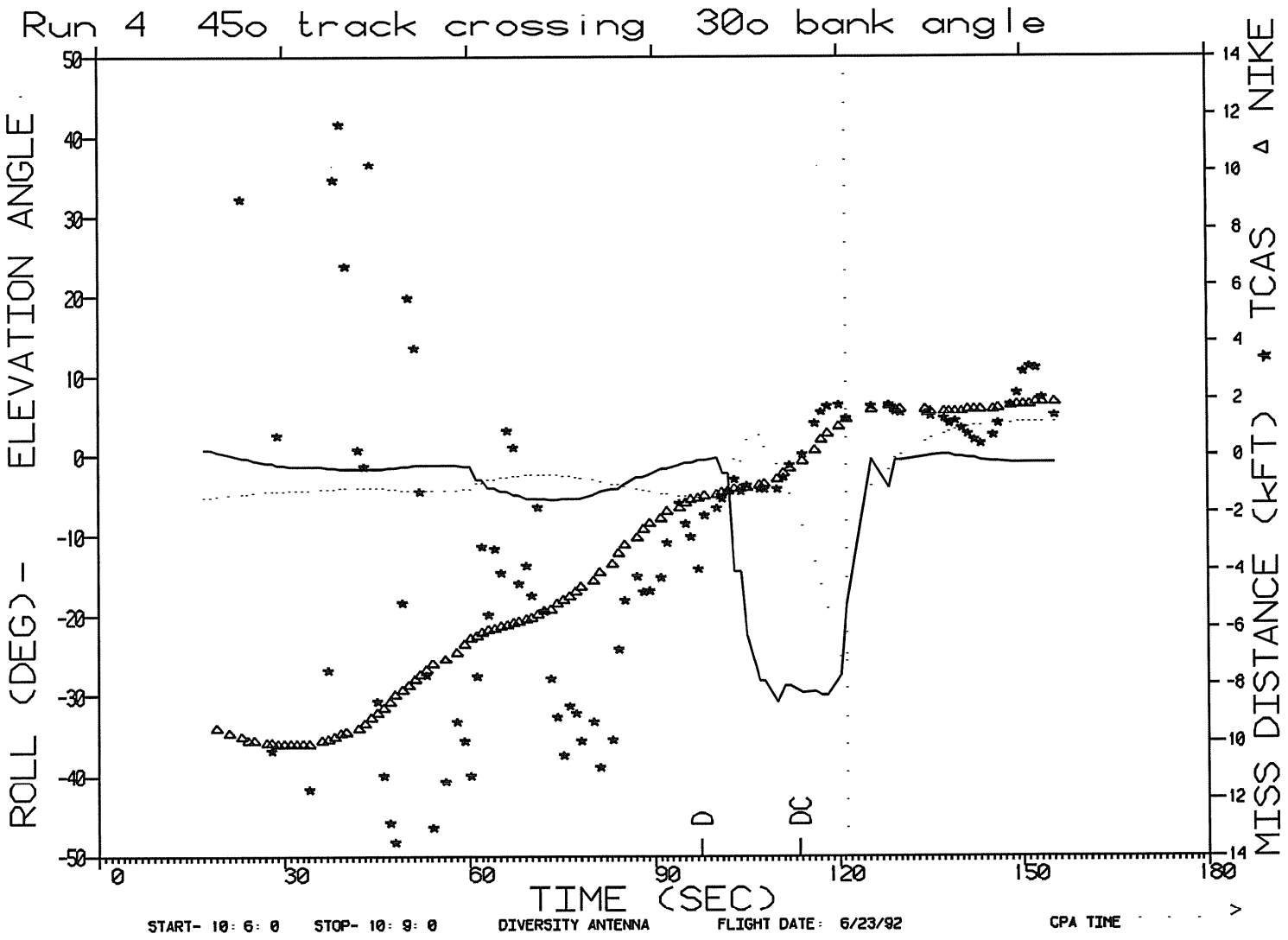

Run 2 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
START- 9:53: 0 STOP- 9:57: 0 TOP ANTENNA FLIGHT DATE: 6/23/92 CPA TIME

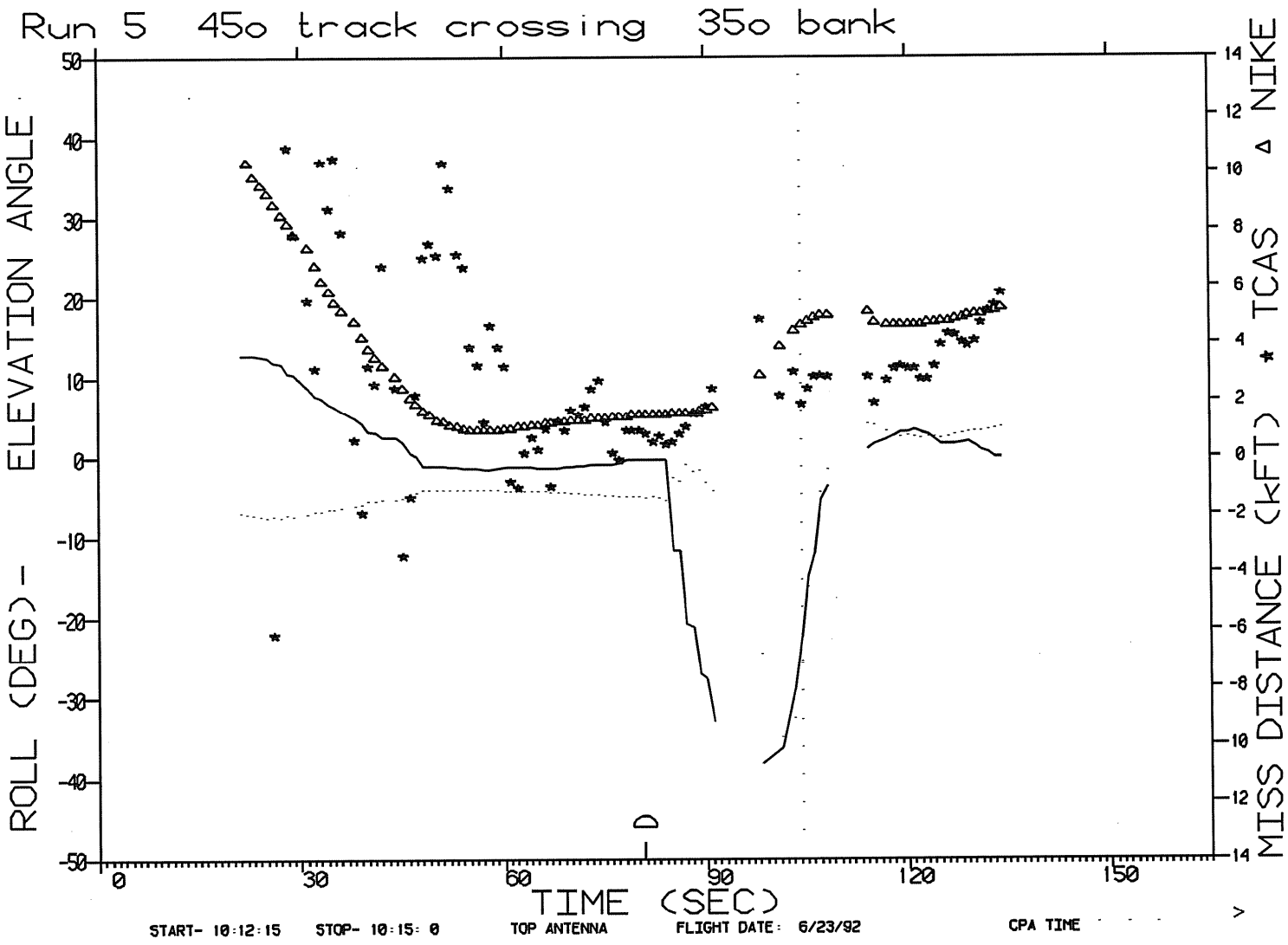

Run 2 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
60
120
180
240
START- 9:53: 0
STOP- 9:57: 0
BOTTOM ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

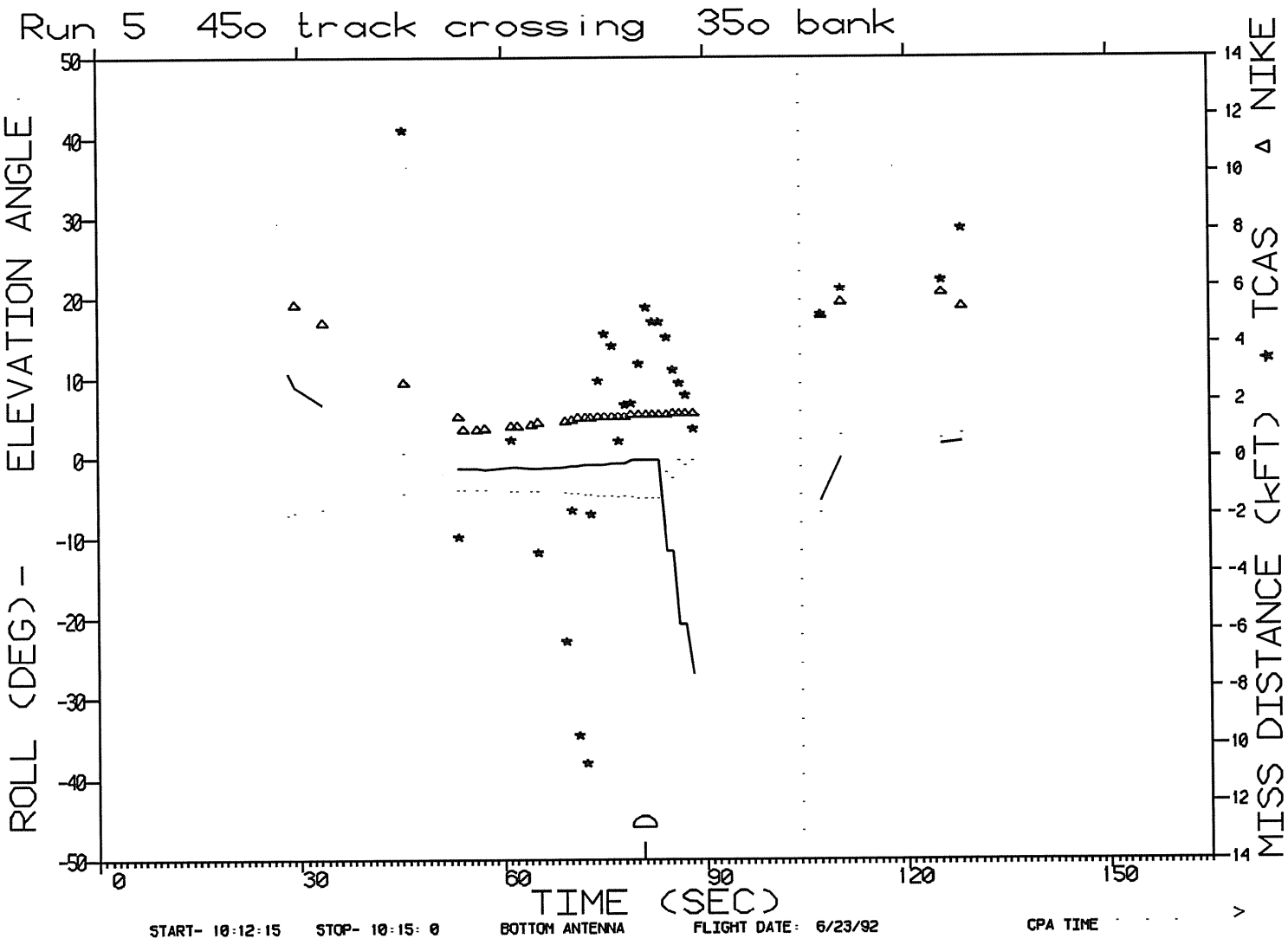

Run 2 45o track crossing 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
60
120
180
240
START- 9:53: 0
STOP- 9:57: 0
DIVERSITY ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

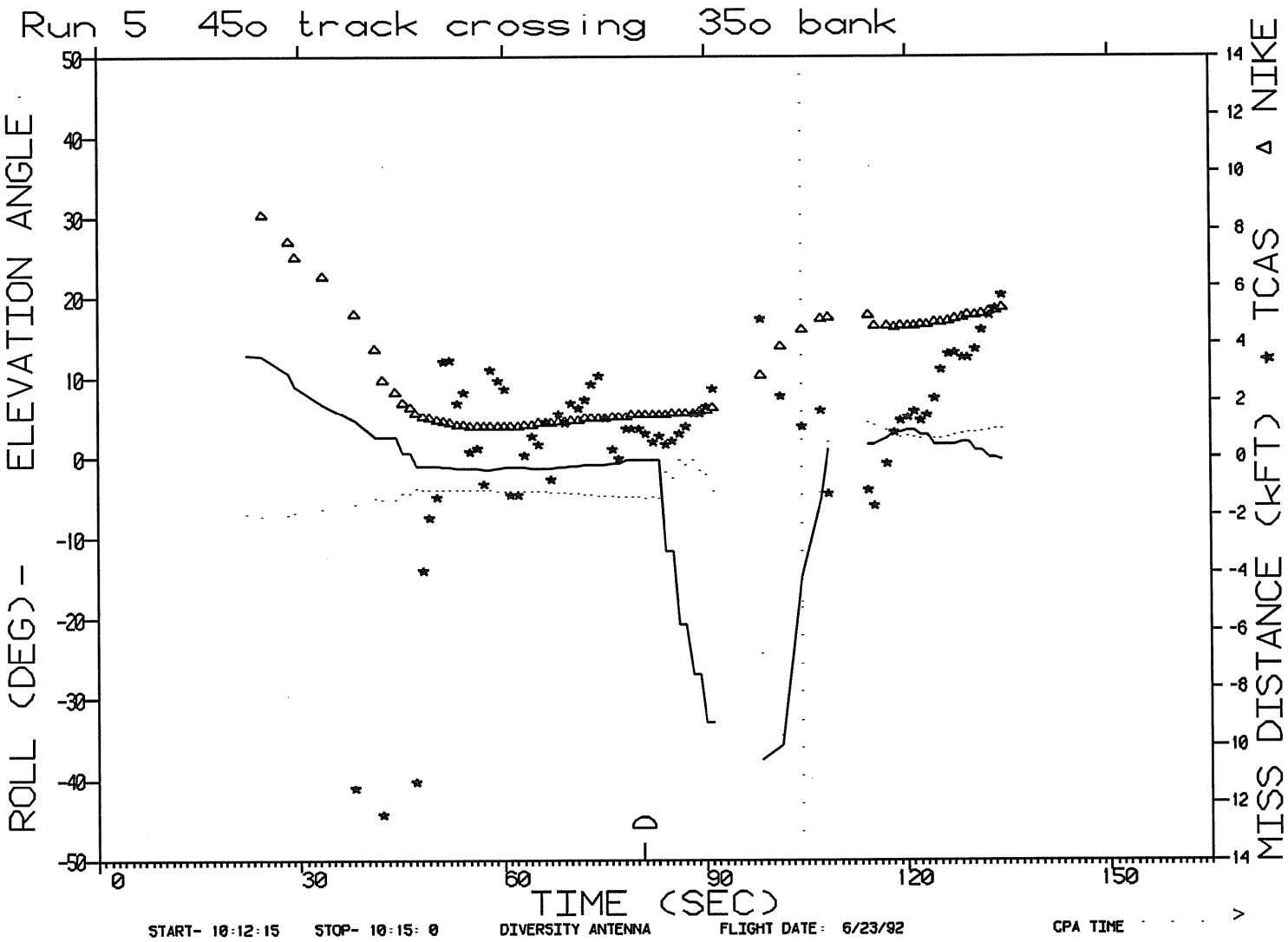

Run 4 45o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
DC
START- 10: 6: 0
STOP- 10: 9: 0
TOP ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

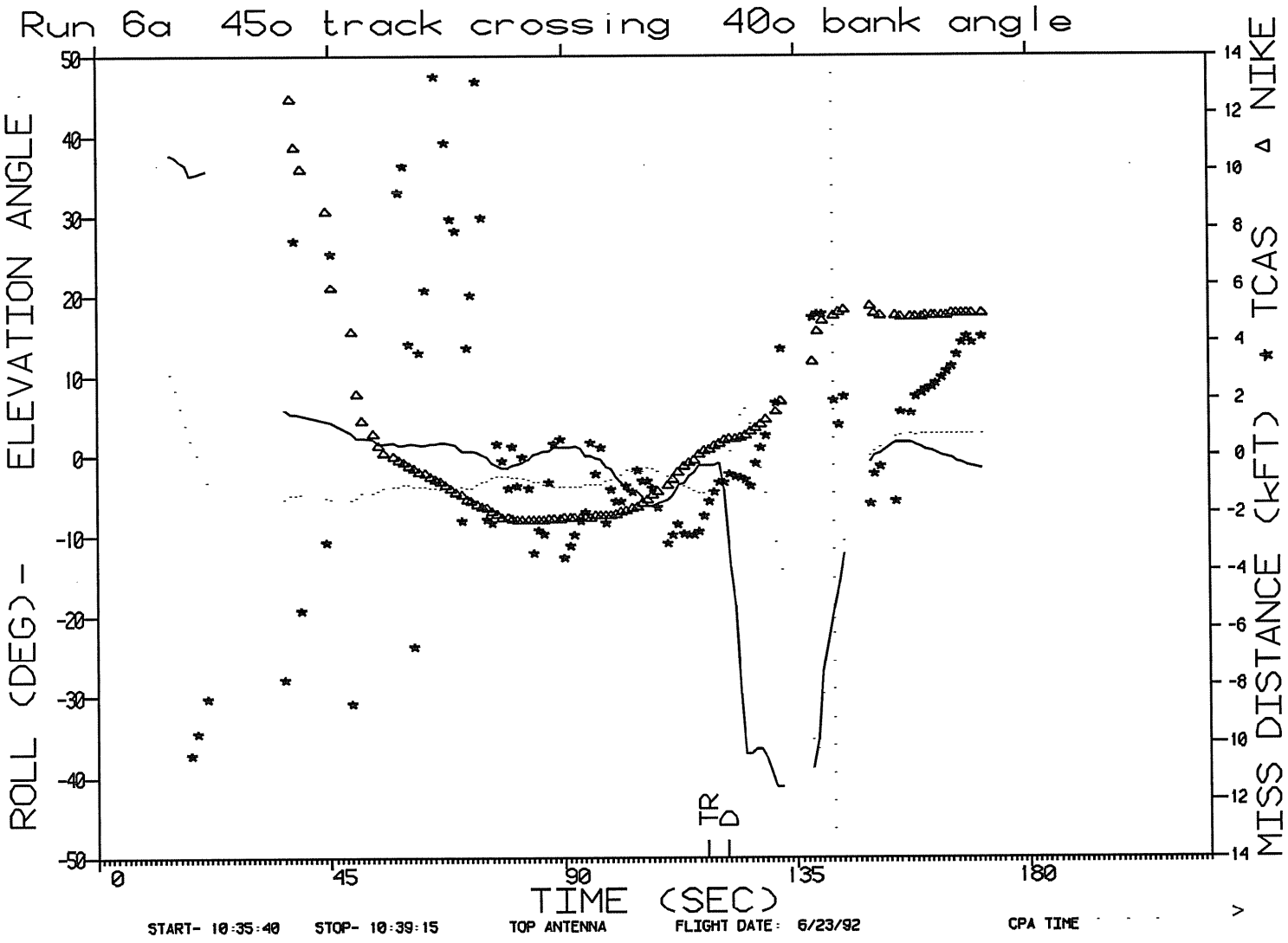

Run 4 45o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
DC
START- 10: 6: 0
STOP- 10: 9: 0
BOTTOM ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

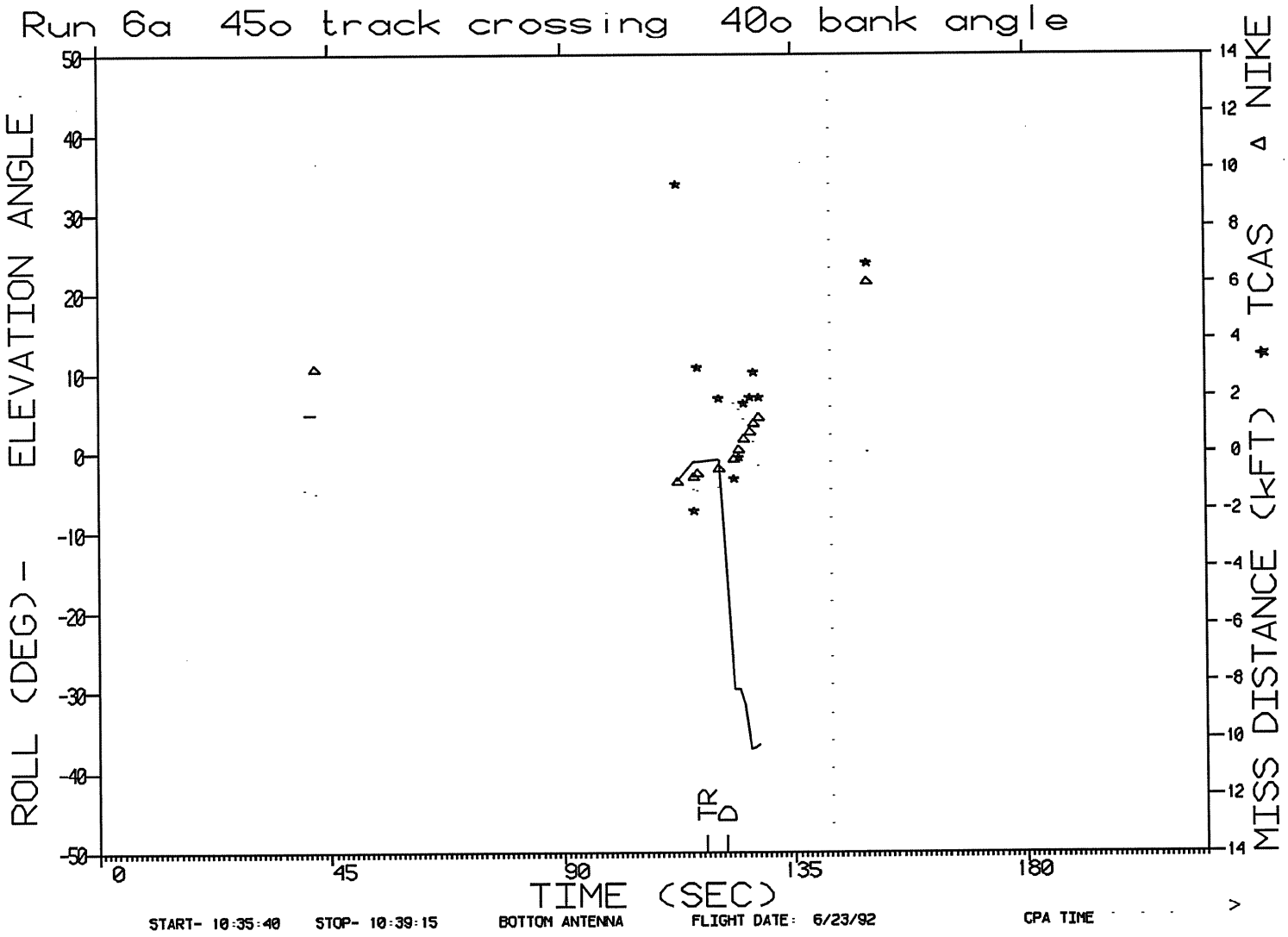

Run 4 45o track crossing 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
DC
START- 10: 6: 0
STOP- 10: 9: 0
DIVERSITY ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

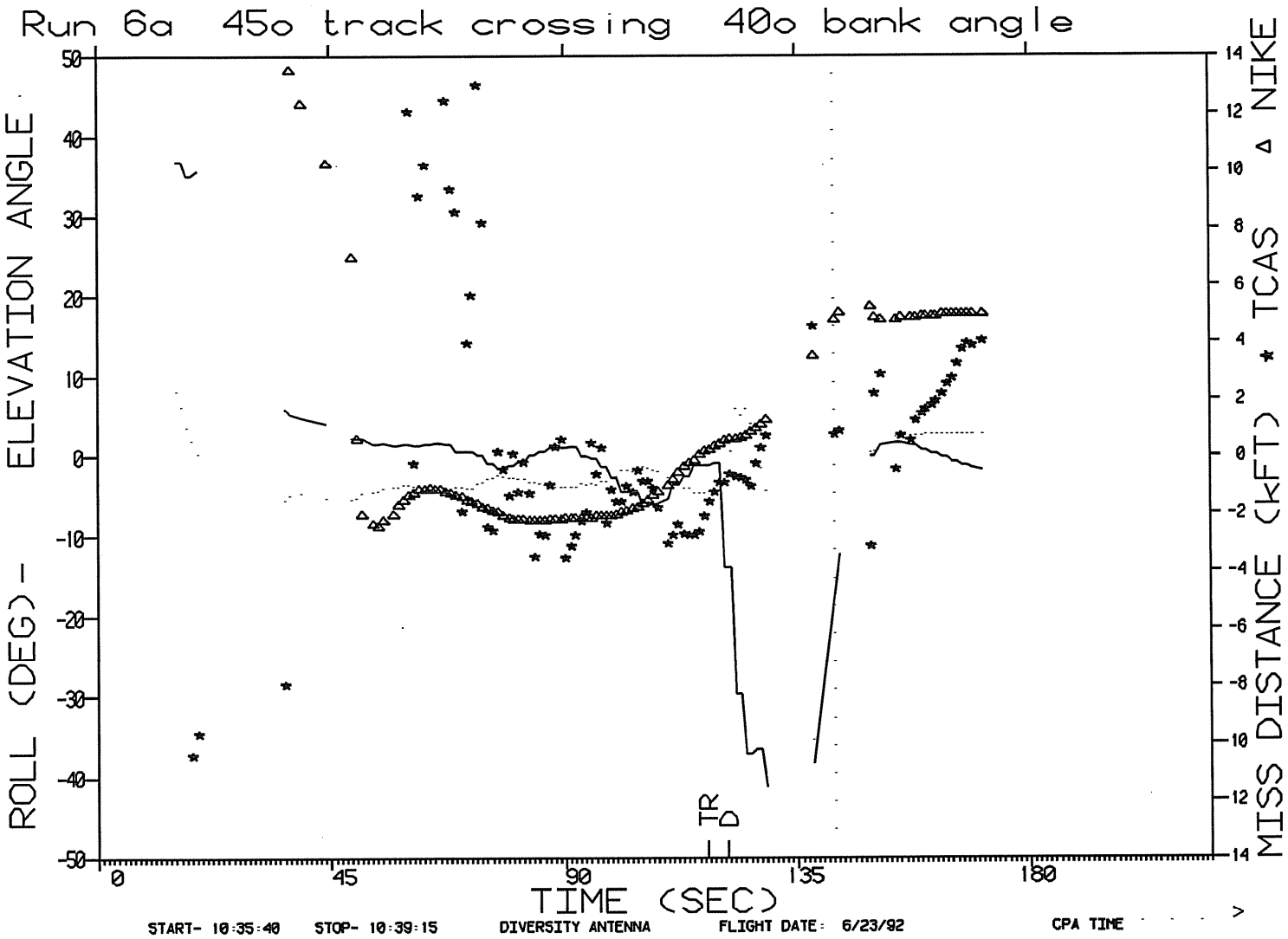

Run 5 45o track crossing 35o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10:12:15 STOP- 10:15: 0 TOP ANTENNA FLIGHT DATE: 6/23/92 CPA TIME

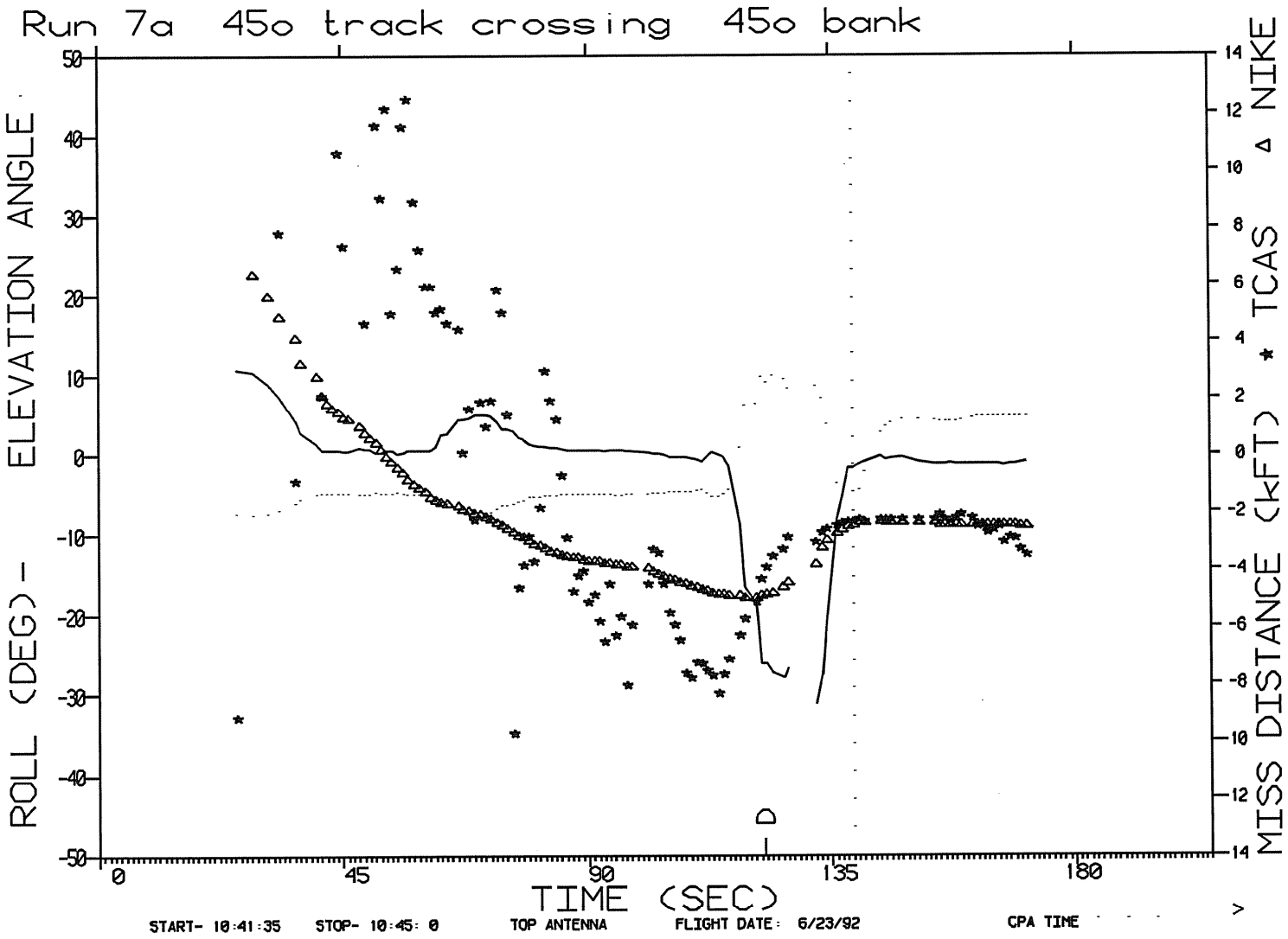

Run 5 45o track crossing 35o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
30
60
90
120
150
D
START- 10:12:15
STOP- 10:15: 0
BOTTOM ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

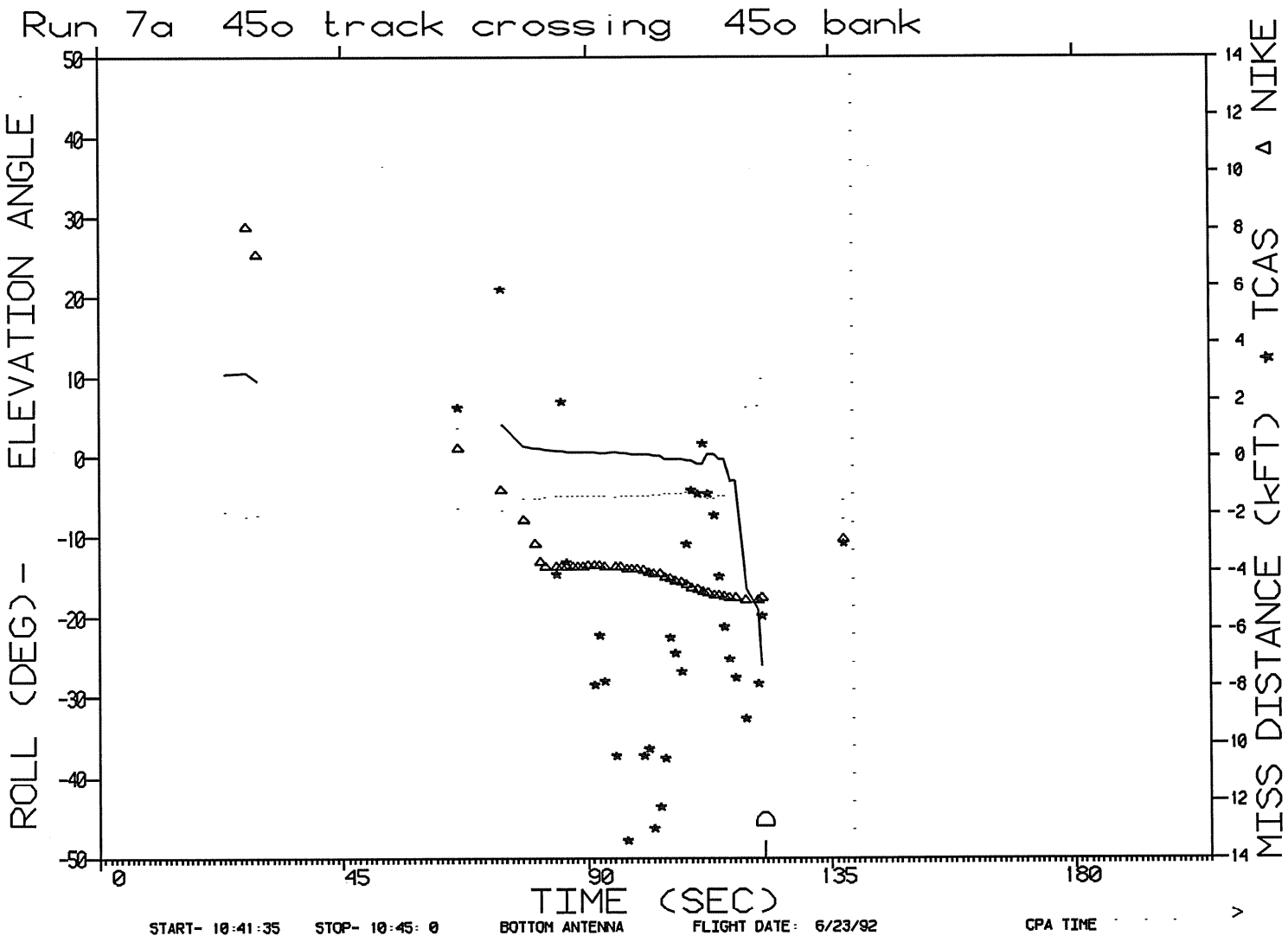

Run 5 45o track crossing 35o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
30
60
90
120
150
D
START- 10:12:15
STOP- 10:15: 0
DIVERSITY ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

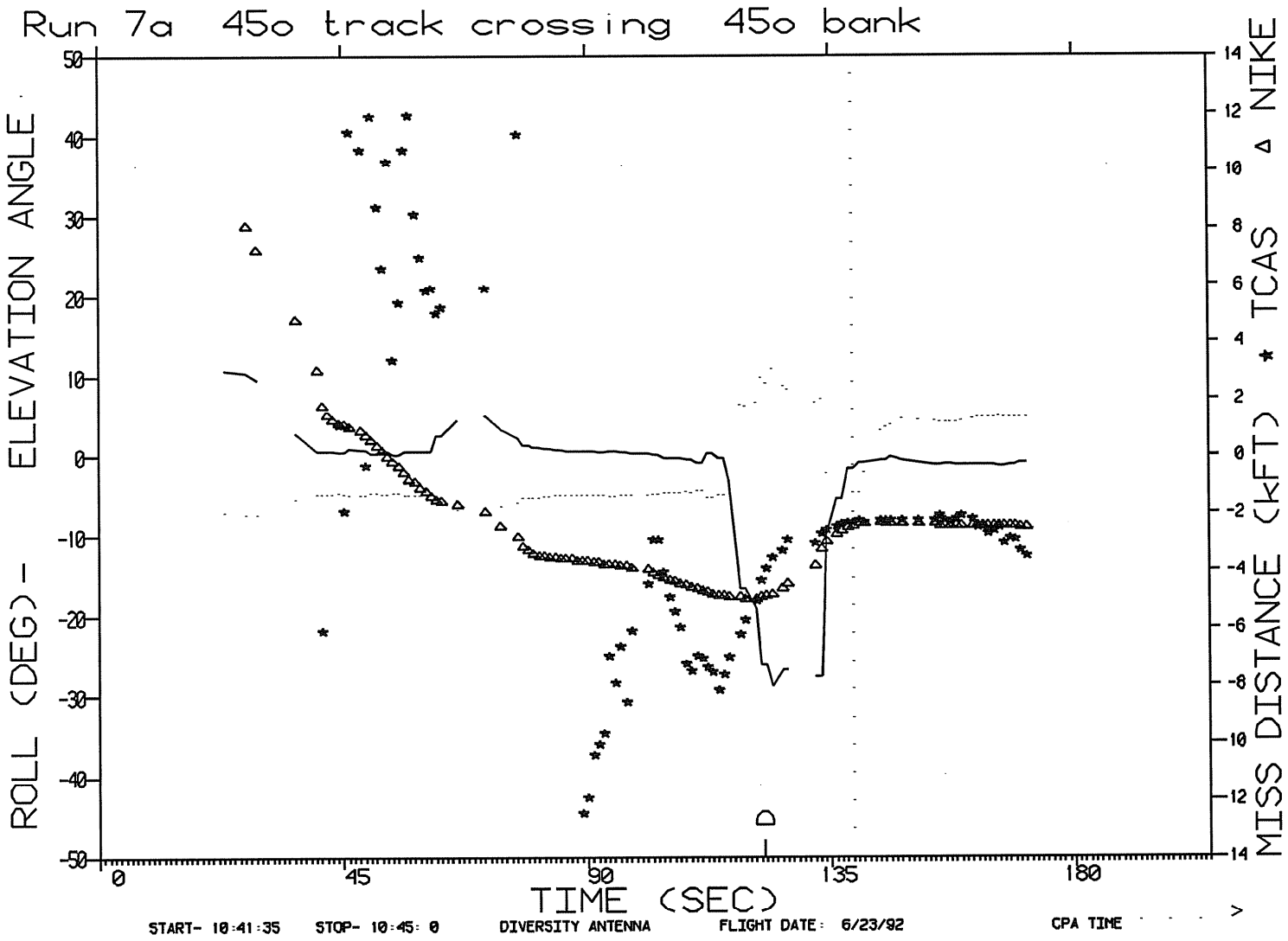

Run 6a 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
D
START- 10:35:40
STOP- 10:39:15
TOP ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

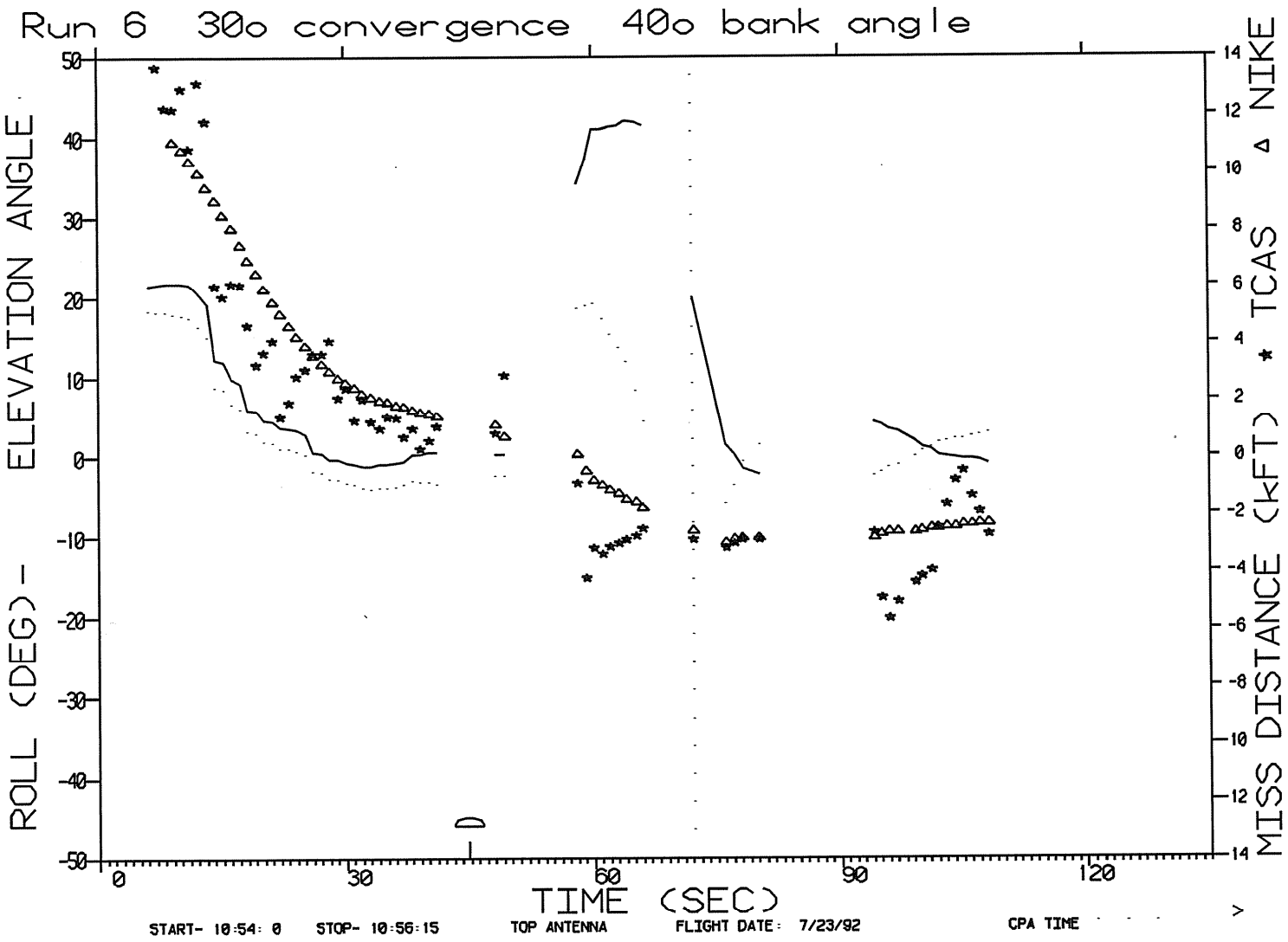

Run 6a 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
D
START- 10:35:40
STOP- 10:39:15
BOTTOM ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

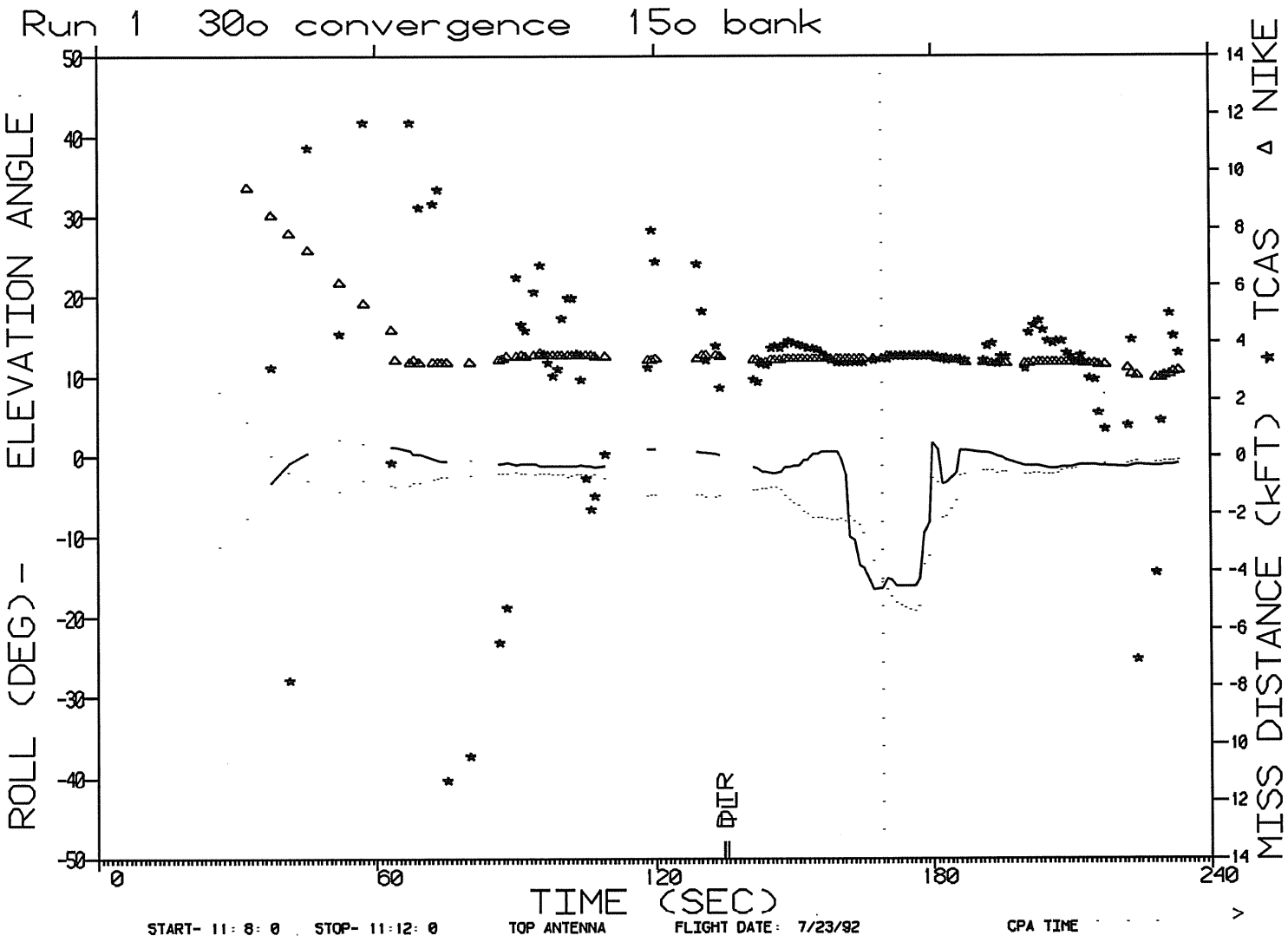

Run 6a 45o track crossing 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
TR
D
START- 10:35:40
STOP- 10:39:15
DIVERSITY ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

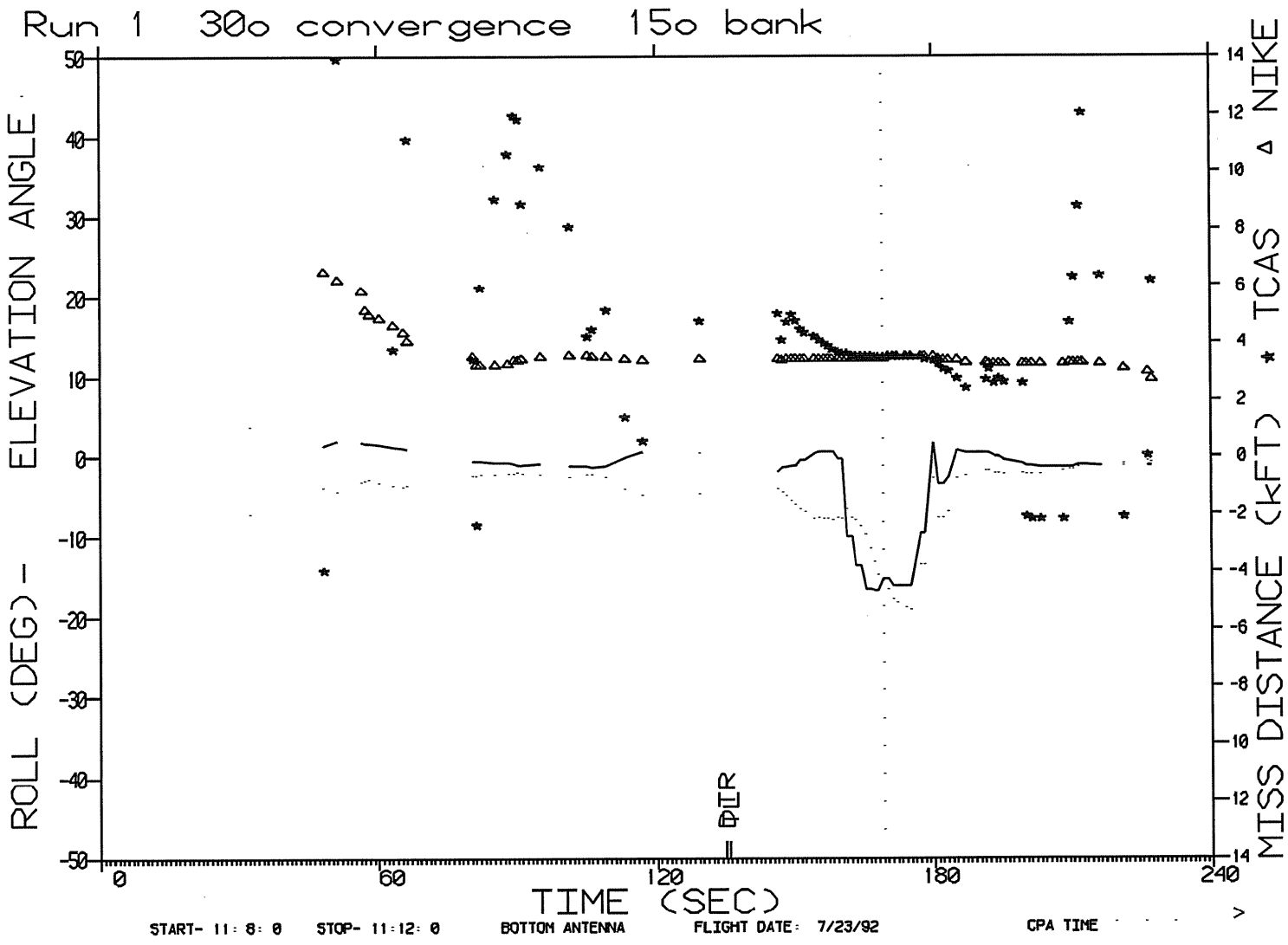

Run 7a 45o track crossing 45o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
START- 10:41:35 STOP- 10:45: 0 TOP ANTENNA FLIGHT DATE: 6/23/92 CPA TIME

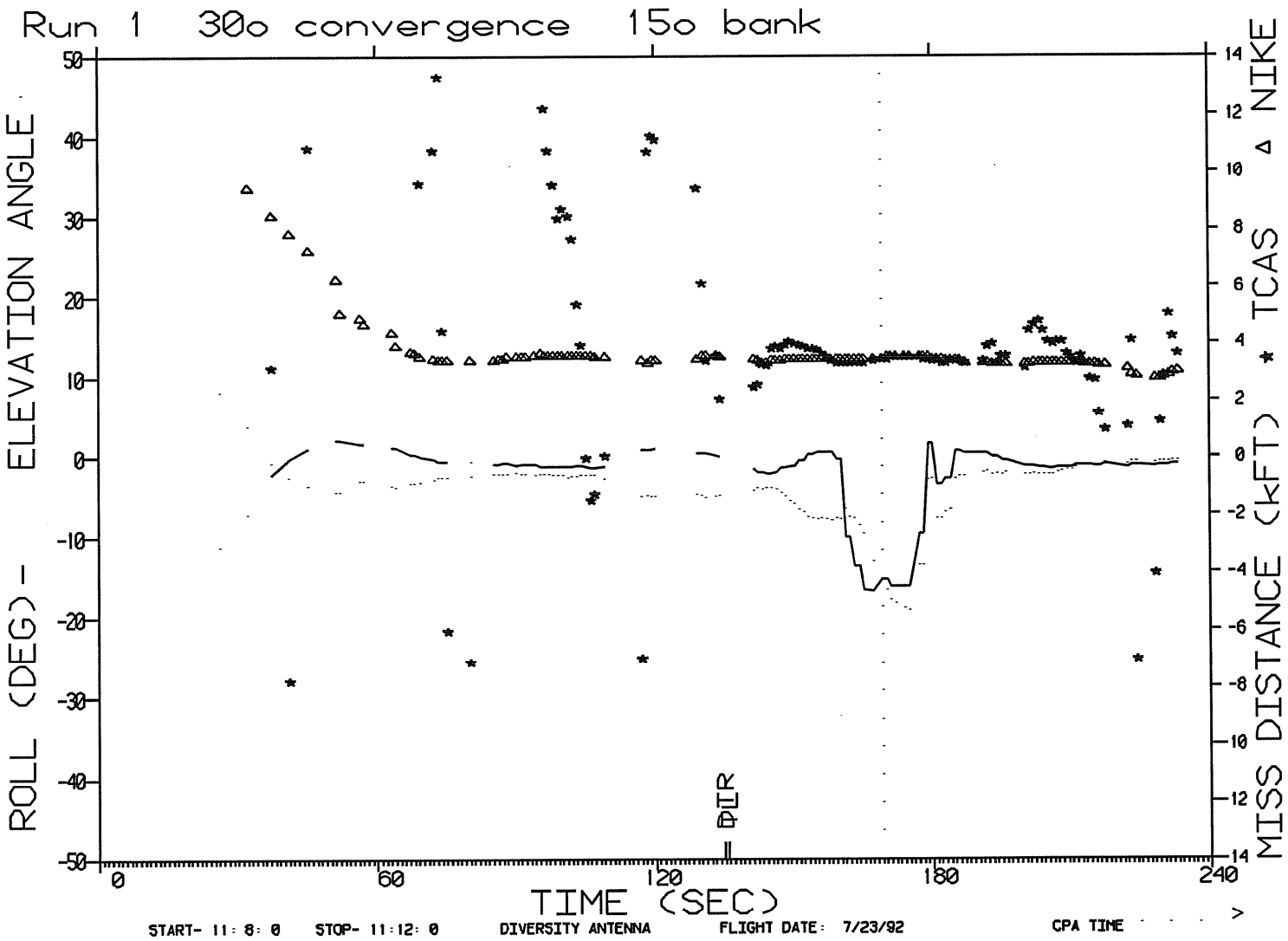

Run 7a 45o track crossing 45o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS △ NIKE
TIME (SEC)
START- 10:41:35 STOP- 10:45: 0 BOTTOM ANTENNA FLIGHT DATE: 6/23/92 CPA TIME

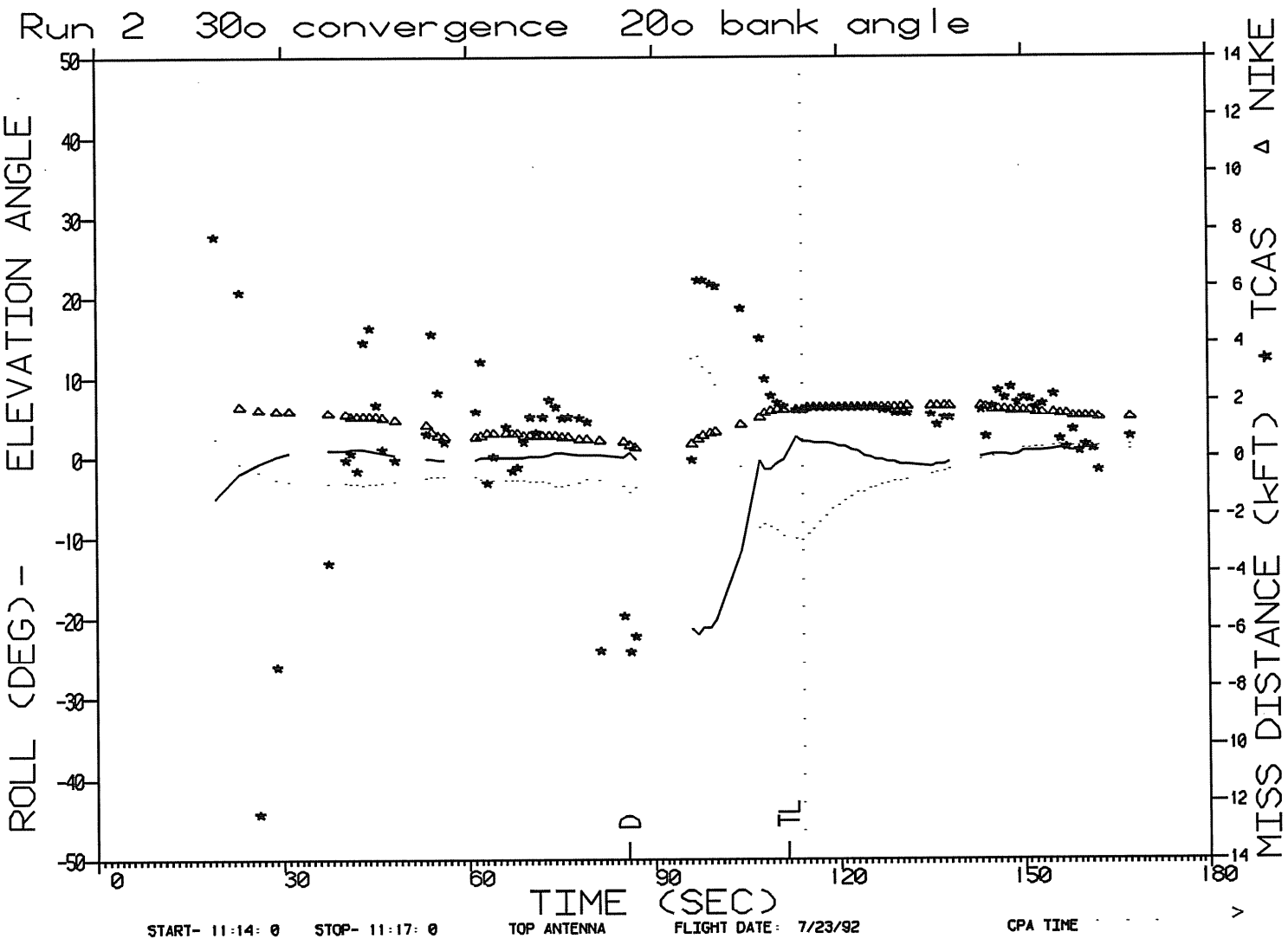

Run 7a 45o track crossing 45o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
45
90
135
180
D
START- 10:41:35
STOP- 10:45: 0
DIVERSITY ANTENNA
FLIGHT DATE: 6/23/92
CPA TIME

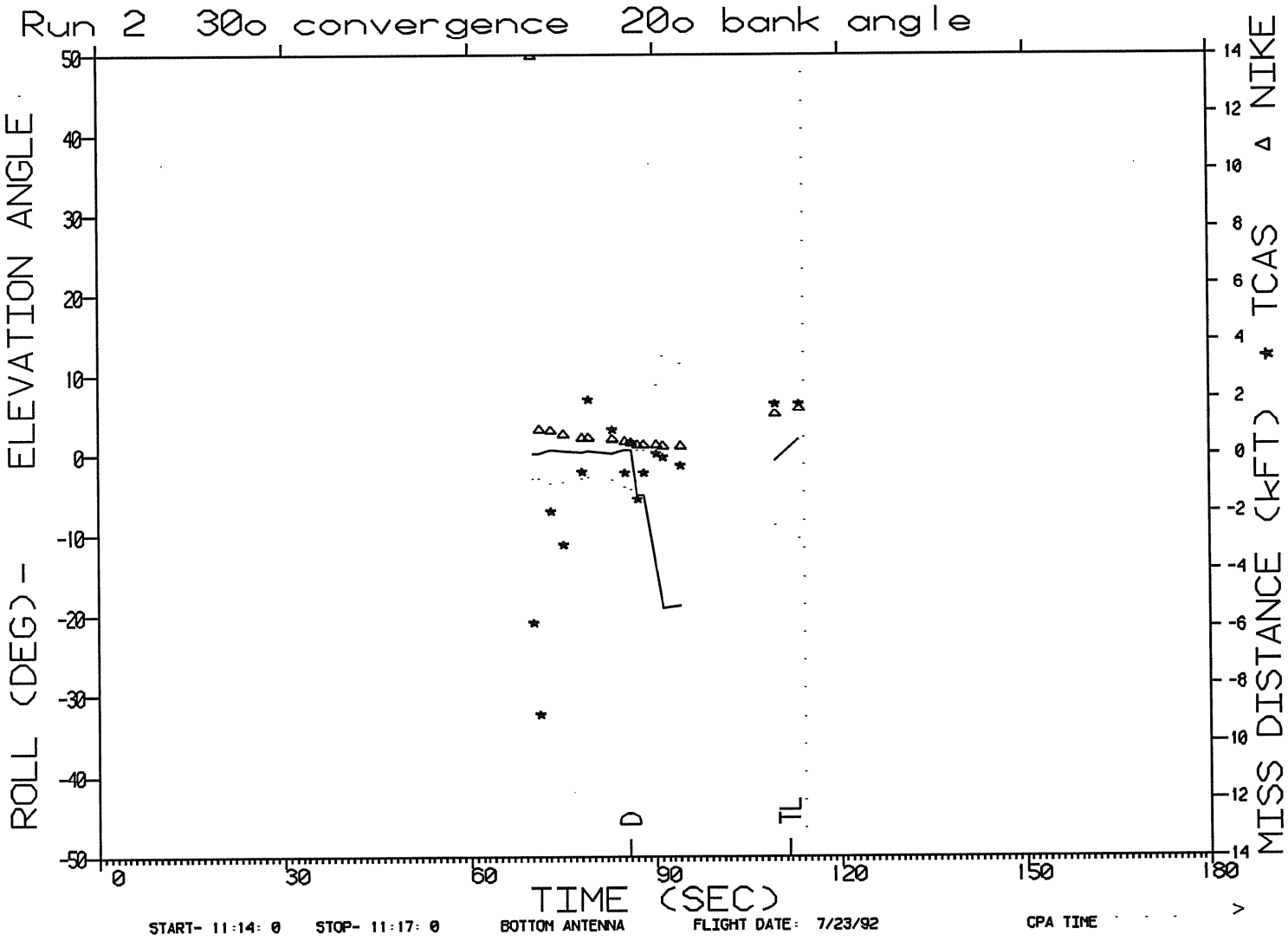

Run 6 30o convergence 40o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 10:54: 0
STOP- 10:56:15
TOP ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME

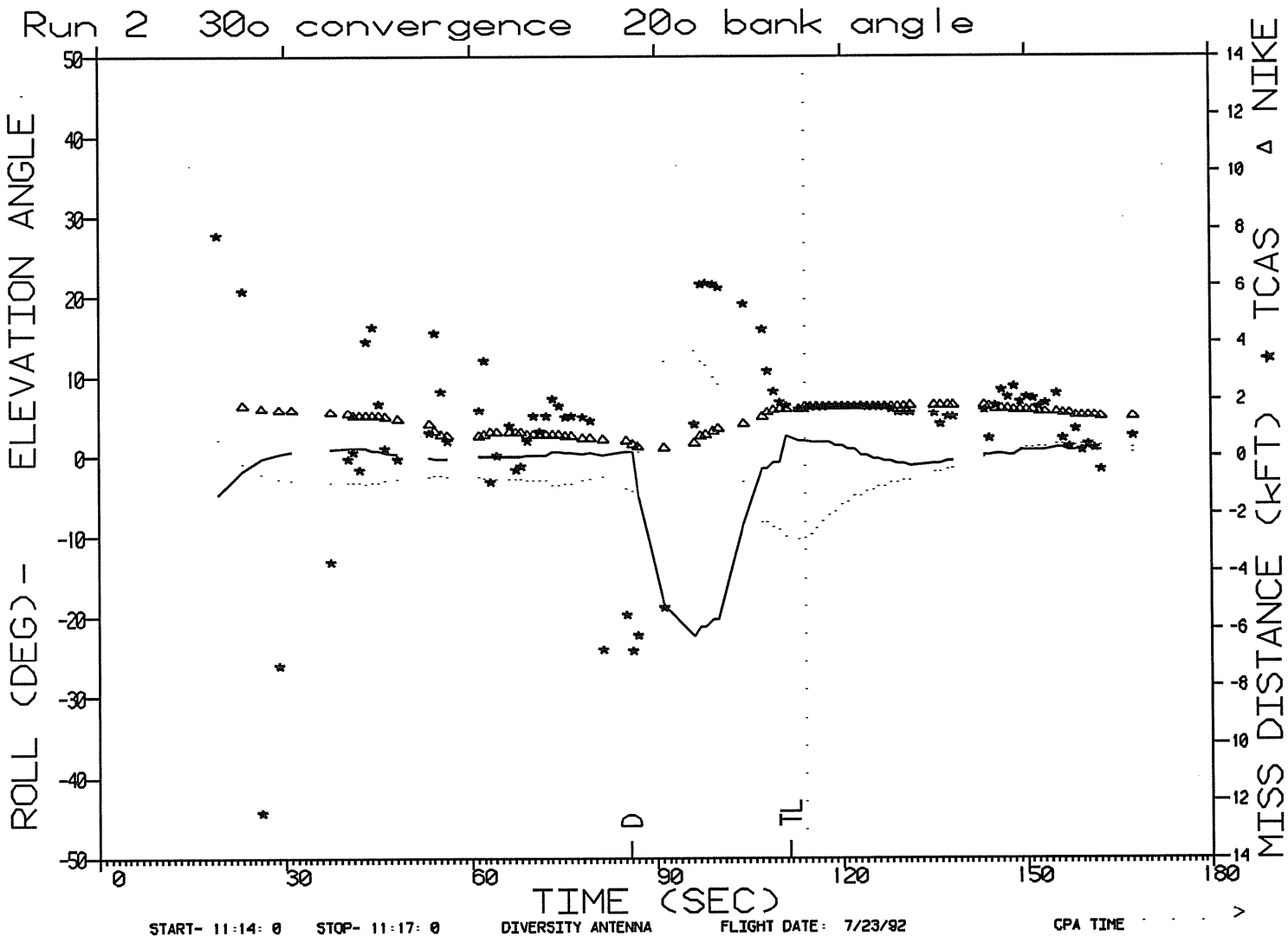

Run 1 30o convergence 15o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
0
60
120
180
240
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
START- 11: 8: 0
STOP- 11:12: 0
TOP ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME

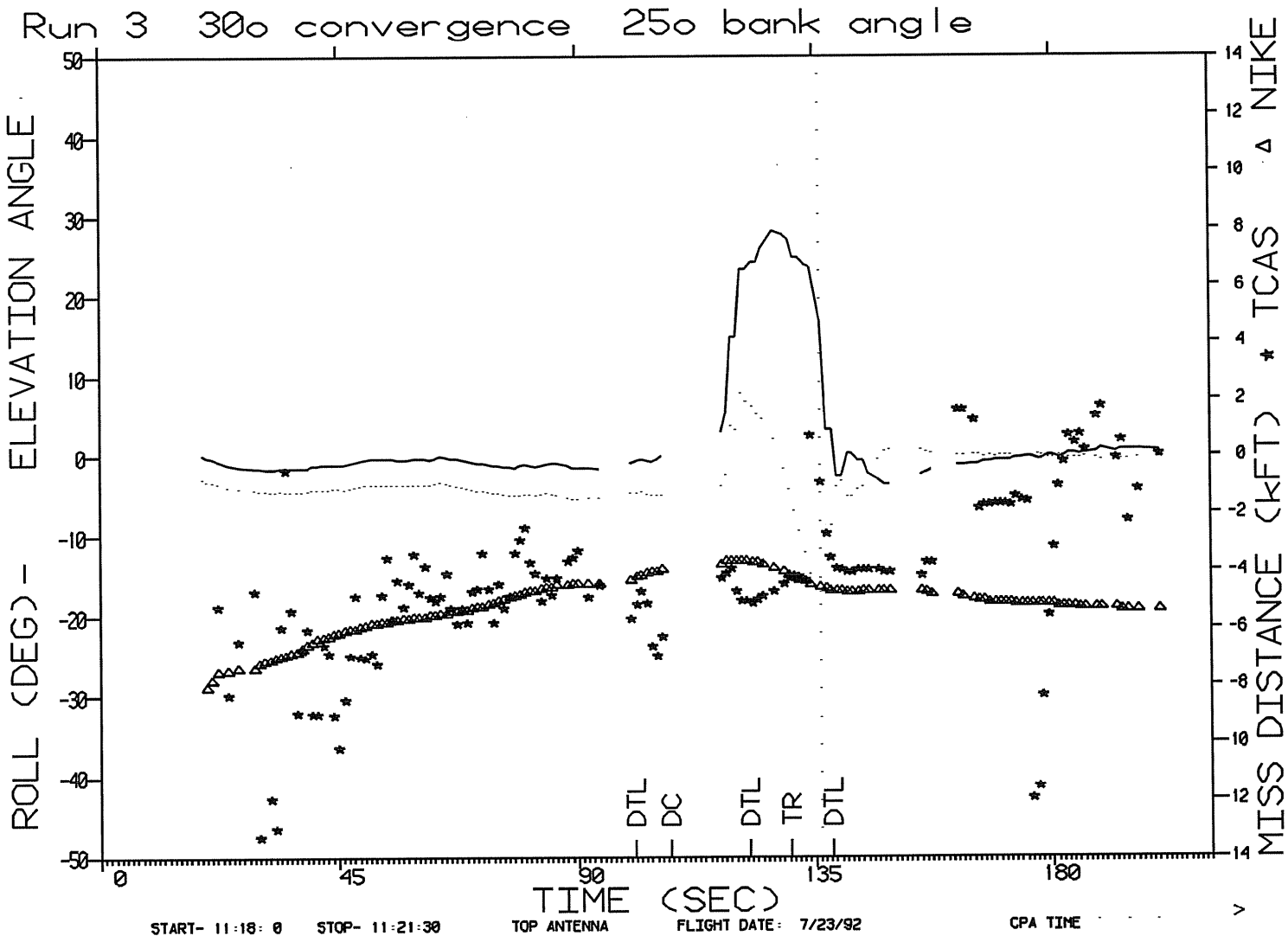

Run 1 30o convergence 15o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
PILR
START- 11: 8: 0
STOP- 11:12: 0
BOTTOM ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME

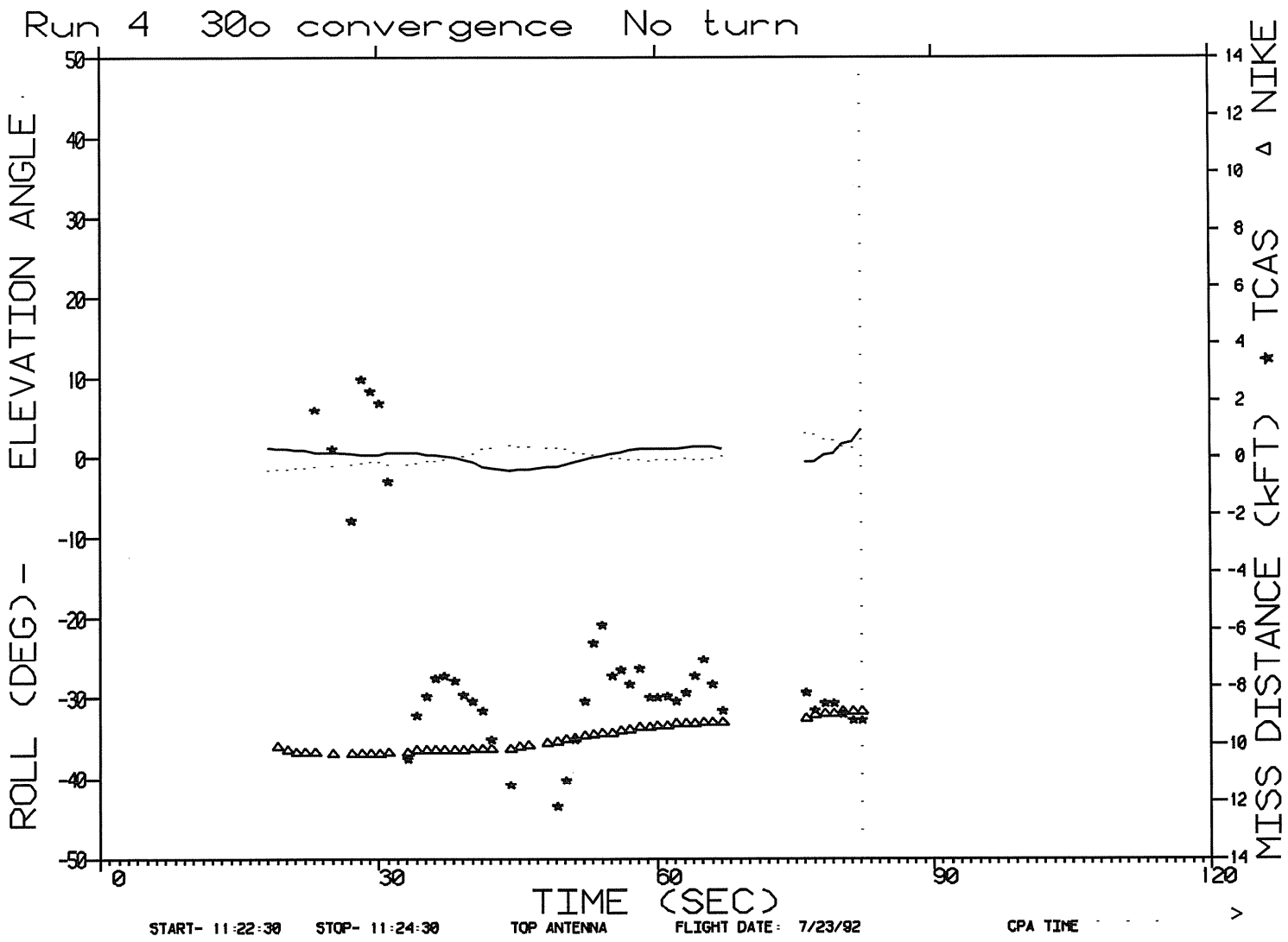

Run 1 30o convergence 15o bank
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
0
60
120
180
240
50
40
30
20
10
0
-10
-20
-30
-40
-50
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
START- 11: 8: 0
STOP- 11:12: 0
DIVERSITY ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME

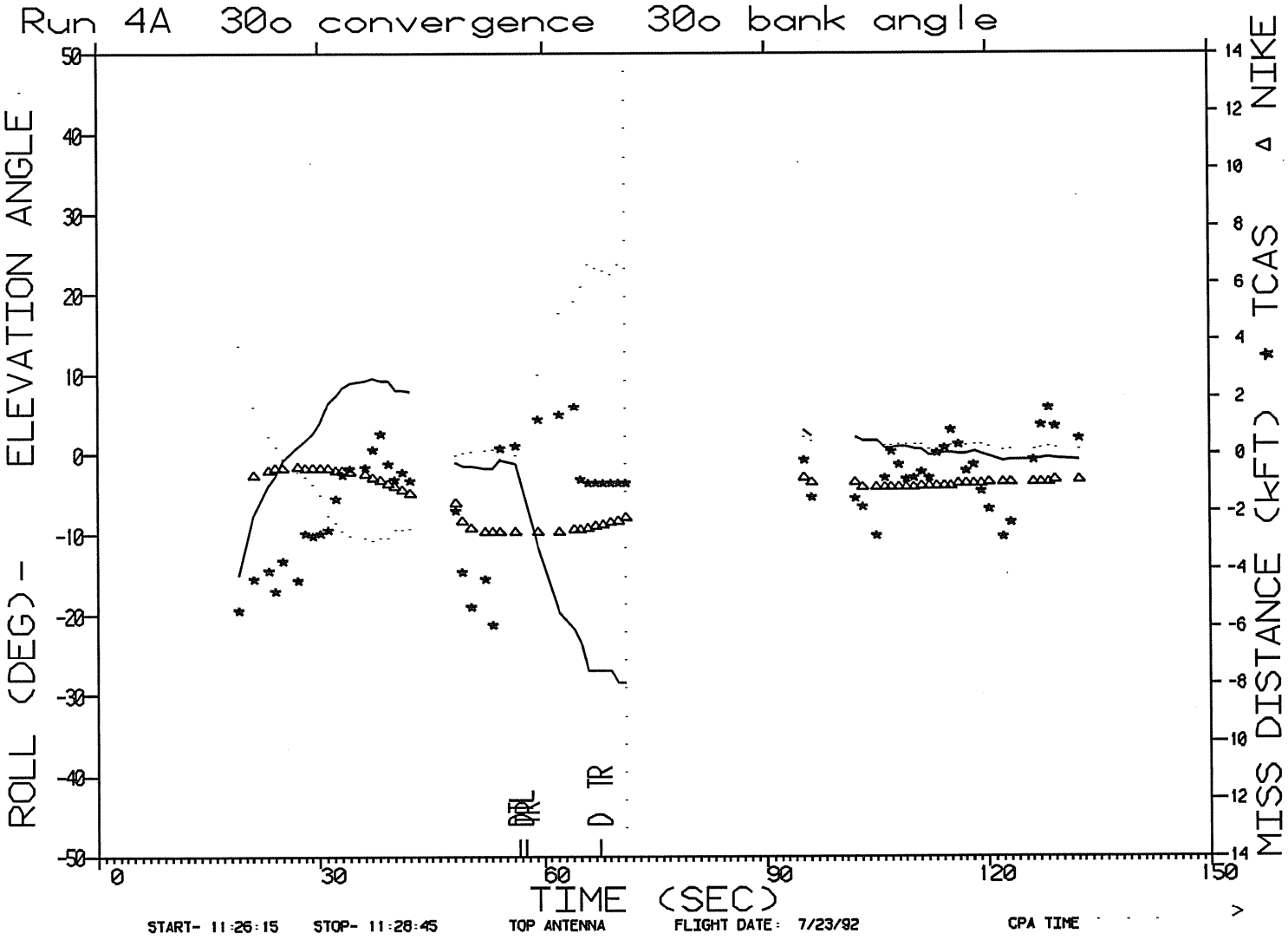

Run 2 30o convergence 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
TL
START- 11:14: 0
STOP- 11:17: 0
TOP ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME

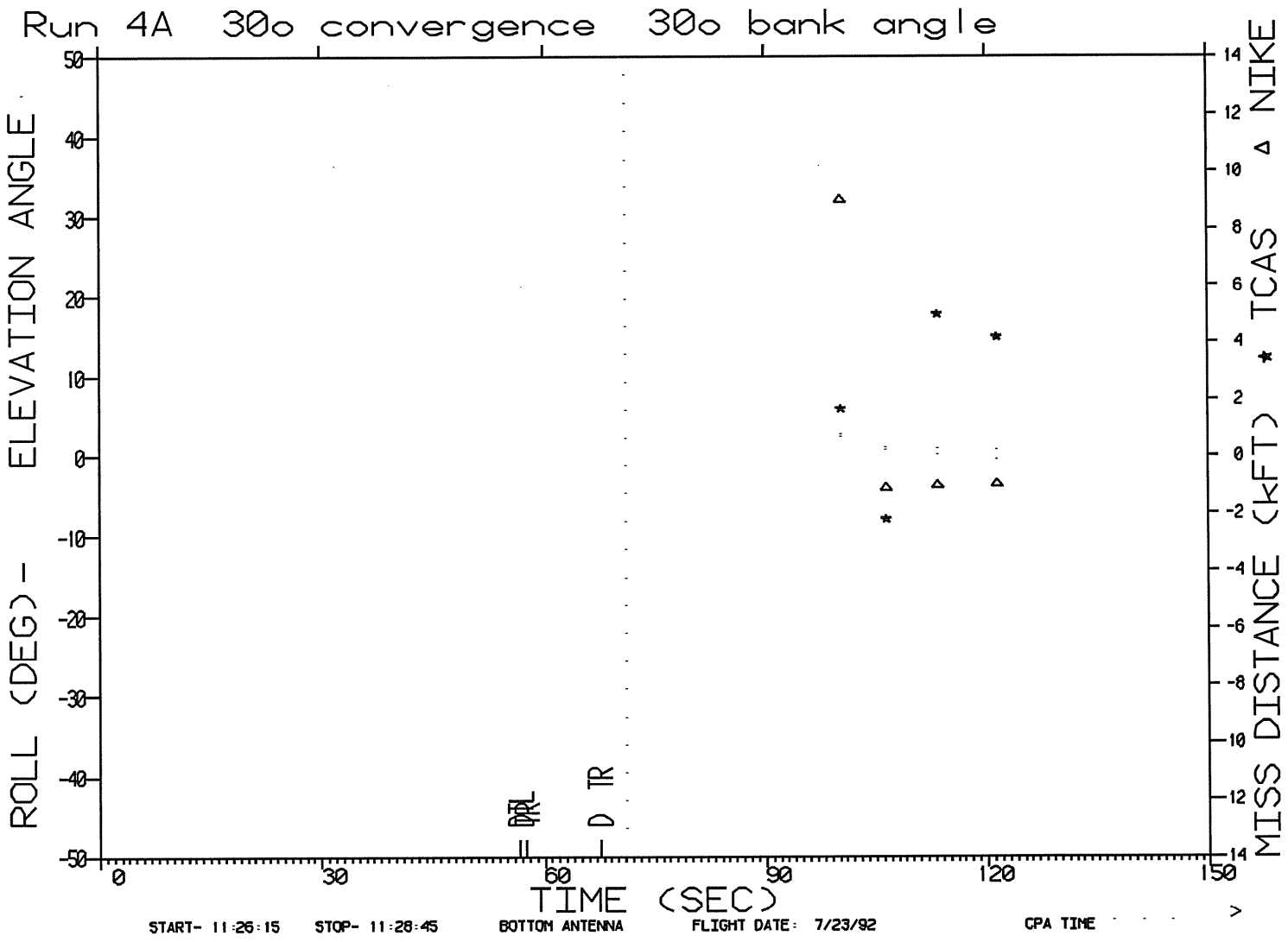

Run 2 30o convergence 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
TL
START- 11:14: 0
STOP- 11:17: 0
BOTTOM ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME

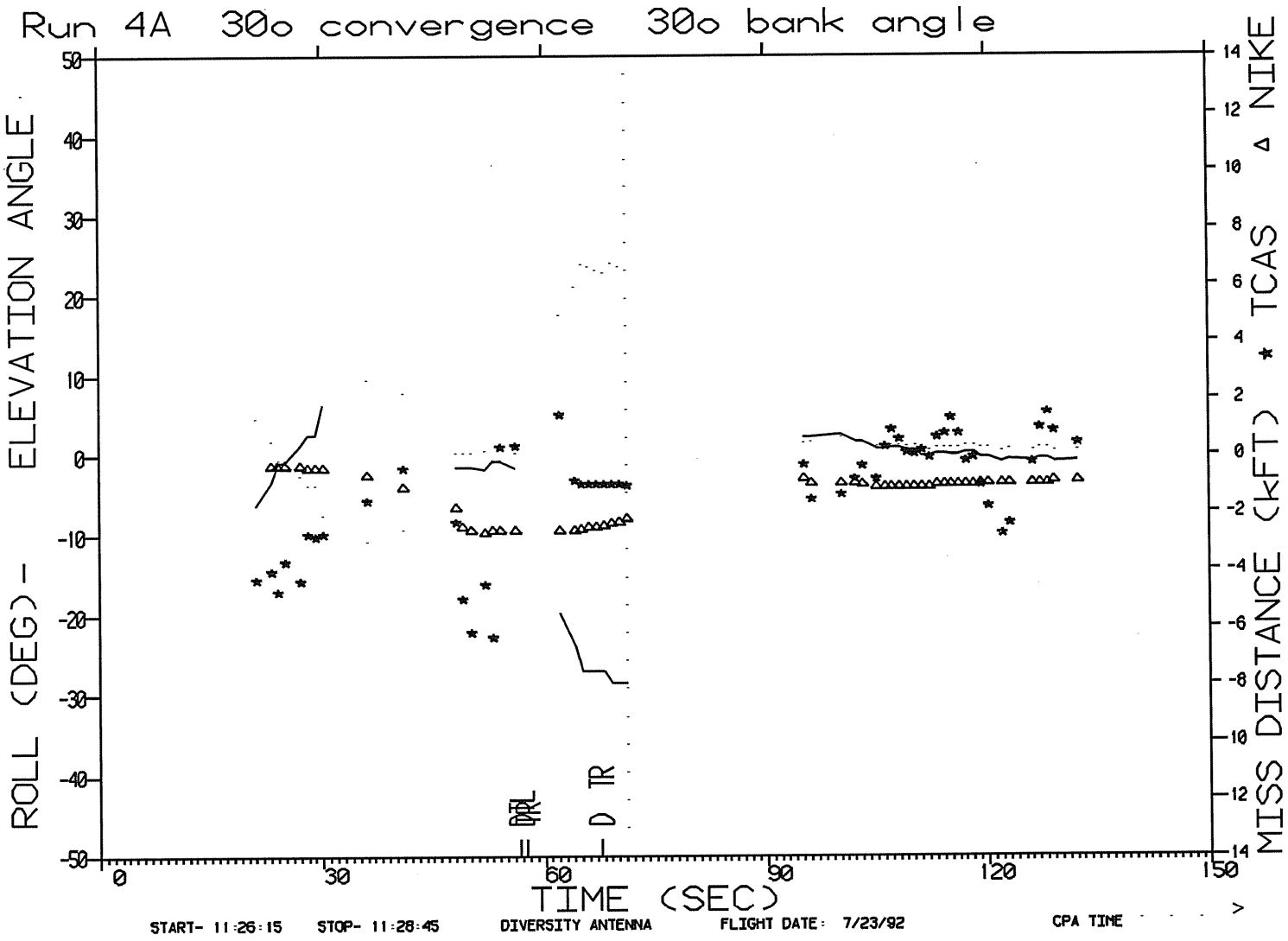

Run 2 30o convergence 20o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D
TL
START- 11:14: 0
STOP- 11:17: 0
DIVERSITY ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME


Run 3 30o convergence 25o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
DTL
DC
DTL
TR
DTL
START- 11:18: 0
STOP- 11:21:30
TOP ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME


Run 4 30o convergence No turn
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
START- 11:22:30
STOP- 11:24:30
TOP ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME


Run 4A 30o convergence 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
DRL
D TR
START- 11:26:15
STOP- 11:28:45
TOP ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME


Run 4A 30o convergence 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D TR
START- 11:26:15
STOP- 11:28:45
BOTTOM ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME


Run 4A 30o convergence 30o bank angle
ROLL (DEG) - ELEVATION ANGLE
MISS DISTANCE (kFT) * TCAS Δ NIKE
TIME (SEC)
D TR
START- 11:26:15
STOP- 11:28:45
DIVERSITY ANTENNA
FLIGHT DATE: 7/23/92
CPA TIME