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Loran C VNAV Approaches to the Technical Center Heliport

Michael Magrogan

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March 1987

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16. Abstract <p>This report documents the results of Loran C vertical navigation (VNAV) approaches to the Federal Aviation Administration (FAA) Technical Center Heliport. Results of this study show that the three dimensional (3D) Loran C Navigator met the requirements of Advisory Circular (AC) 90-45A for two dimensional (2D) error components of total system crosstrack (TSCT) and flight technical error (FTE). In addition, the 3D error component of vertical flight technical error (VFTE) met the requirements of AC 90-45A.</p>					
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EXECUTIVE SUMMARY

During the summer of 1986, Loran C vertical navigation (VNAV) approaches were conducted at the Federal Aviation Administration (FAA) Technical Center Heliport. In order to conduct these approaches, hardware and software were developed under the FAA's Helicopter Support Contract by Systems Control Technology, Incorporated (SCT). SCT interfaced a Loran C navigator to a commercially available approach guidance computer and altimeter. The motivation behind the development of this three dimensional (3D) Loran C navigator was to be able to conduct instrument approach procedures with let-down guidance at airports which have no instrument landing system (ILS) glide slope equipment and/or microwave landing system (MLS). When this effort was started there were no commercially available Loran C navigators which could provide 3D (VNAV) guidance. Now, there are several such avionics on the market. FAA Technical Center personnel installed and instrumented this 3D Loran C navigator in the Technical Center's Sikorsky S-76 helicopter, conducted flight tests, performed data collection, and data reduction/analysis.

The purpose of these flights was twofold. First, to obtain data on flight technical error (FTE), total system crosstrack error (TSCT), and airborne system errors in both the lateral and vertical domains. Secondly, to obtain the subject pilot's evaluations of the 3D Loran C navigation system. A test matrix was developed which included only straight-in approaches with airspeed and glide slope angle being varied from approach to approach.

The 3D Loran C navigator met the accuracy requirements of Advisory Circular (AC) 90-45A for two dimensional (2D) error components of TSCT and FTE. The 3D error component of vertical flight technical error (VFTE) also met the requirements of AC 90-45A.

INTRODUCTION

PURPOSE.

The purpose of this three dimensional (3D) Loran C navigator test program is twofold. First, to acquire a statistically reliable data base concerning overall 3D Loran C navigator system performance and operational procedures that will assist the Federal Aviation Administration (FAA) and airspace users alike in developing and certifying standard approach procedures and associated weather minimums. Second, to quantify specific 3D Loran C navigator system performance parameters.

OBJECTIVES.

Specific objectives of this project were:

1. To obtain data on lateral and vertical components of: flight technical error (FTE), total system error (TSE), and navigation system error (NSE).
2. To obtain data on the subject pilot's evaluation of the 3D Loran C navigation system.

BACKGROUND.

As helicopters become a more essential transportation mode in support of commerce, remote area all weather navigation and approach capabilities become a necessity. In recognition of this need, the FAA is conducting an ongoing evaluation of the use of Loran C for all phases of helicopter navigation. Consideration of costs, accuracy, availability, dependability, and compatibility with the National Airspace System (NAS) will enter into the evaluation of all navigation systems which meet the user's needs. Loran C meets many of the requirements of helicopter operators because of its cost, weight, accuracy, availability, and the ability to provide area navigation (RNAV) to user defined waypoints at low altitudes in remote areas.

Currently, there are two types of instrument approach procedures: nonprecision and precision. Nonprecision procedures provide only lateral guidance. Vertical approach limitations (altitudes) are derived from time and distance or the intersection of fixed positions; however, no vertical guidance is provided. A precision procedure provides both lateral and vertical guidance.

In order to conduct Loran C vertical navigation (VNAV) approaches, hardware and software were developed under the FAA's Helicopter Support Contract by Systems Control Technology, Incorporated (SCT). SCT interfaced a Loran C navigator to a commercially available approach guidance computer and altimeter. The motivation behind the development of this 3D Loran C navigator was to be able to conduct instrument approach procedures with let-down guidance at airports which have no instrument landing system (ILS) glide slope equipment and/or microwave landing systems (MLS). When this effort was started there were no commercially available Loran C navigators which could provide 3D (VNAV) guidance. Now, there are several such avionics on the market.

The basic concept of the 3D Loran C navigator is to provide 3D approach let-down guidance using Loran C in areas where there are no other navigation aids (NAVAIDS) available. Vertical guidance during approaches in the

aviation world today is a real problem. Presently, two basic types of vertical guidance devices exist, ILS and MLS. There have been some VNAV devices developed for RNAV systems, but most are ineffective in remote areas relying on very high frequency omni-directional ranging/distance measuring equipment (VOR/DME) coverage. The major problem with present day systems is that they require fixed base sites, i.e., vertical navigation can only be accomplished at locations where the equipment is installed.

However, with a 3D Loran C navigator this problem may be overcome. Vertical guidance is supplied to the pilot, at any glide slope angle, in areas where no other NAVAIDS are available. This capability requires the availability of an area coverage navigation sensor with good accuracy and stability, such as Loran C, and other instrumentation required to process altitude and position data in order to calculate descent guidance command(s). In order to demonstrate the 3D Loran C capability, SCT interfaced a popular Loran C navigator (the Teledyne TDL-711) to a commercially-available approach guidance computer (the model 541 VNAV/ALERter, made by Intercontinental Dynamics).

LORAN C OPERATION.

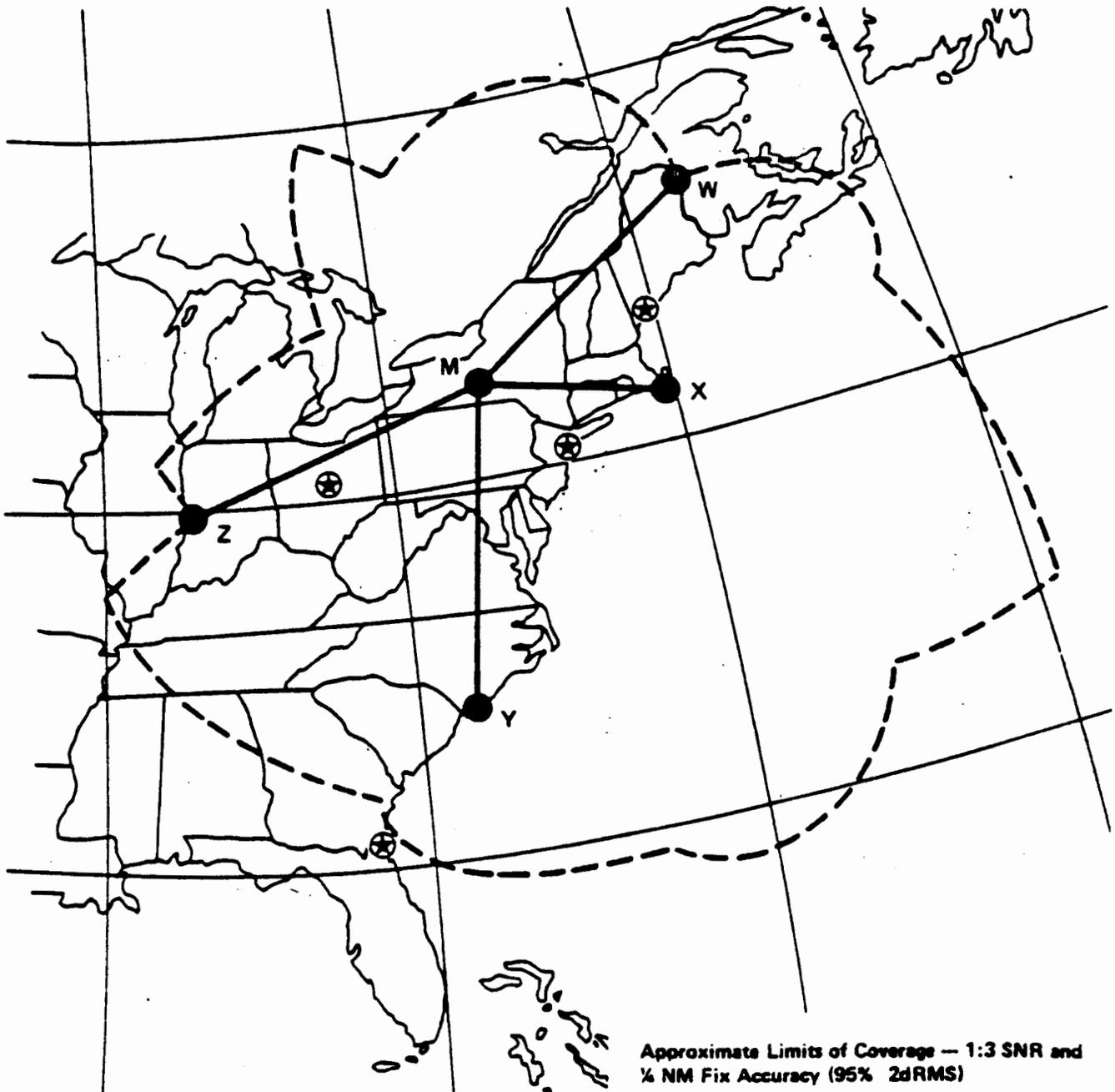
Loran C is a hyperbolic radio navigation system originally created for maritime use, and is becoming more popular with helicopter operators since it can provide wide area coverage in meeting the navigation needs of the helicopter. It is a low frequency (100 kilohertz) system which transmits pulses within strictly controlled parameters. Transmitting stations at specific locations provide coverage over a broad area of the Northern Hemisphere.

Regional coverage is provided by groups of three to six transmitting stations forming a chain. Chains are unique in the time period of the transmission sequence within the chain. This distinguishing characteristic is the group repetition interval (GRI). Each chain consists of a designated master station which transmits a set of coded pulses to identify it as a master station. Within the chain there are two or more secondary stations. All station transmissions are controlled by atomic clocks. Each secondary station's transmission follows the master station's coded pulse transmission. This transmission by the secondary station occurs after a precisely controlled fixed emission time delay in relationship to the master station's transmission.

Receiver position is determined by measuring time differences. Once the master transmission is received by the airborne receiver, an interval clock is started and accurately measures the time a secondary station signal is received. The measured time difference corresponds to the distance the receiver is from the transmitter and lies on a line of position (LOP) of constant time difference. Measured time differences between receipt of the master transmission and receipt of another secondary station's transmission provides a second LOP. The intersection of the LOP's is the Loran C receiver position.

The FAA Technical Center, Atlantic City International Airport, N.J., is covered by Northeast United States Chain GRI 9960 (see figure 1). The master transmitter in this chain is located at Seneca, N.Y., with secondary transmitters in Caribou, Me.; Nantucket, Mass.; Carolina Beach, N.C.; and Dana, Ind.

GRI 9960



Approximate Limits of Coverage — 1:3 SNR and
1/4 NM Fix Accuracy (95% 2dRMS)

LEGEND:

- TRANSMITTING
- ⊕ MONITOR
- ⊕ MONITOR (AUTOMATED)

- M SENECA
- W CARIBOU
- X NANTUCKET
- Y CAROLINA BEACH
- Z DANA

FIGURE 1. NORTHEAST U.S. LORAN C CHAIN

SYSTEM/EQUIPMENT DESCRIPTION

TEST AIRCRAFT.

The aircraft utilized for this flight test is the Sikorsky S-76 (see figure 2), a twin engine, single main rotor helicopter. It is equipped with a Sperry Automatic Flight Control System and a HelCIS Flight Director. However, for this test only raw data information was displayed on the horizontal situation indicator (HSI) (see figure 3). The aircraft is certified for single pilot operations with a minimum Instrument Flight Rules (IFR) airspeed of 60 knots. It is representative of the IFR certified helicopters currently in use.

The two forward bench seats have been removed and replaced with two racks containing a data collection system and an aircraft systems coupler designed specifically for this aircraft. The racks are located in the forward portion of the cabin allowing the system operator and observer to sit on the aft bench seat. The aircraft is normally operated approximately 500 to 1,500 pounds below the maximum gross weight of 10,300 pounds. However, this is not considered to be a critical parameter in this test.

AIRBORNE TEST EQUIPMENT.

The airborne data collection package is a computer driven, general purpose programmable system. A militarized Norden PDP-11/34M minicomputer controls the data collection through software stored on a floppy disk and hardware contained in a UNIBUS[™] compatible expansion chassis. The computer hardware includes a real-time clock, floating point hardware, 32K x 18 bits MOS memory, floppy disk interface, and RS-232 interfaces for the terminal and cartridge recorder. Various aircraft performance data are obtained from sensors and transmitted through the data collection package and recorded on magnetic tape. Among the parameters recorded for this project are: time, airspeed, vertical speed, heading, altitude, vertical deviation, vertical navigation flags, lateral deviation, lateral navigation flags, and TDL-711 Loran C receiver present position. A list of the airborne parameters recorded and used to analyze the performance of the 3D Loran C Navigator is contained in table 1.

TELEDYNE TDL-711 LORAN C RECEIVER/PROCESSOR

The Loran C airborne system used in this flight test program is a Teledyne TDL-711 micronavigator system consisting of an E-field vertical antenna, a receiver/computer unit a control display unit (CDU), and a course deviation/vertical deviation indicator (CDI/VDI) on the subject pilot's instrument panel to display Loran C course deviation. The control display unit is the operator's interface with the Loran C system. It displays position information both in latitude/longitude and time differences. It also shows which waypoint or waypoint pair has been selected, displays all navigation and test modes, and mirrors the information being entered through the keyboard. The output of the Loran C micronavigator drives a CDI, giving linear deviation from the selected "TO" waypoint course. Full scale deflection left or right of center is 1.26 nmi. The "TO" flag indicates that the aircraft is located short of the "TO" waypoint. The "FROM" flag indicates a position beyond the "TO" waypoint. The red "NAV" flag indicates that steering commands are invalid. The Loran C receiver is designed to run a remote display unit (RDU). This information, i.e., distance to waypoint (DTW) and system status, was utilized as inputs to the 3D Loran C interface unit.

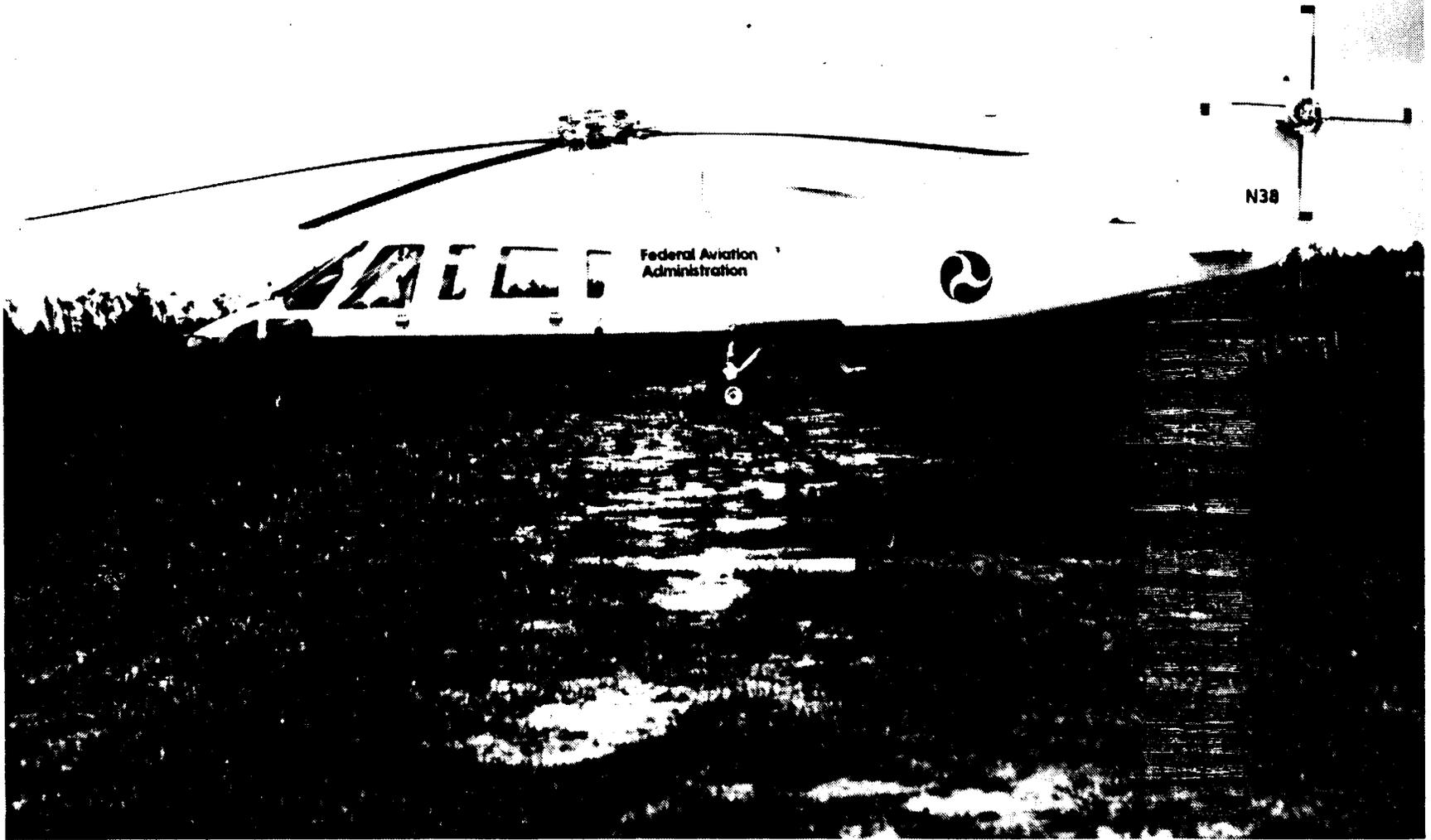


FIGURE 2. SIKORSKY S-76 HELICOPTER (SHEET 1 OF 2)

SIKORSKY S-76 HELICOPTER

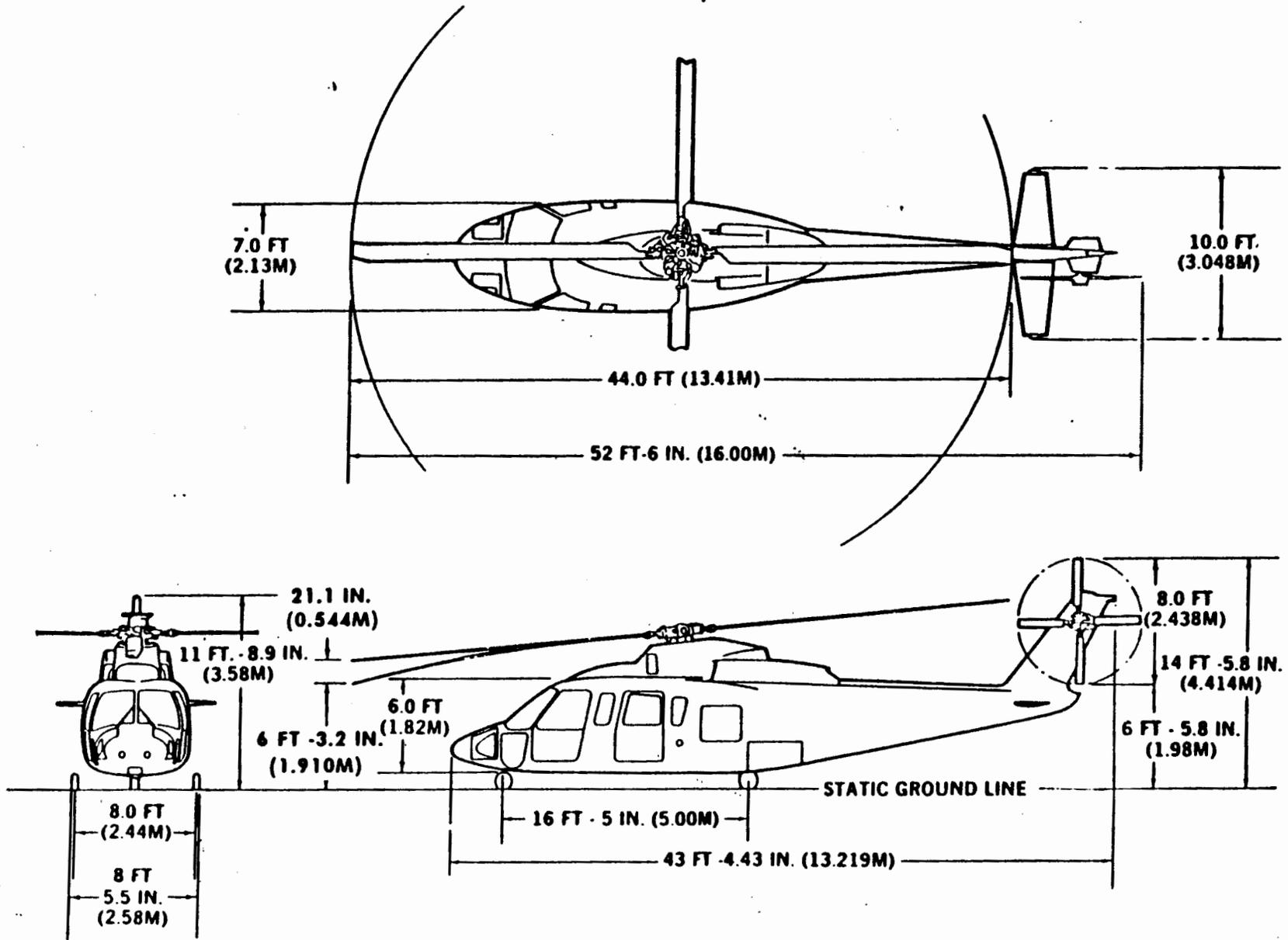


FIGURE 2. SIKORSKY S-76 HELICOPTER (SHEET 2 OF 2)

HSI INDICATOR

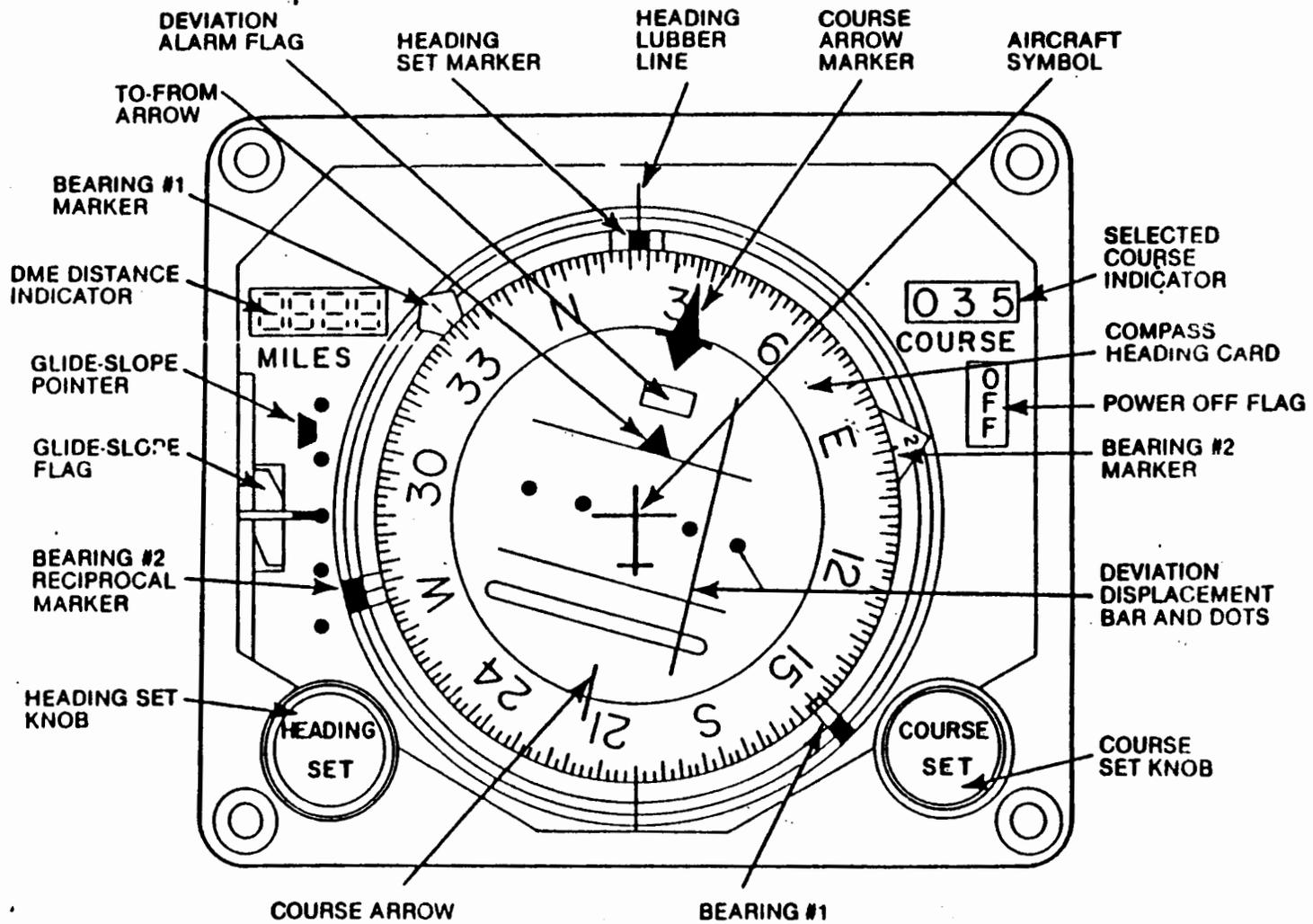


FIGURE 3. HSI INDICATOR

TABLE 1. AIRBORNE DATA COLLECTION PARAMETERS

<u>Parameter</u>	<u>Units</u>	<u>Resolution</u>
Time	Hrs/mins/secs/millisecs	0.001 sec
TDL-711		
Delta Latitude	Degrees	0.0001 deg
Base Latitude	Degrees	0.0001 deg
Delta Longitude	Degrees	0.0001 deg
Base Longitude	Degrees	0.0001 deg
Lateral Deviation from Approach Centerline	Nautical miles (nmi)	0.001 nmi
Lateral Flags		n/a
Vertical Deviation from Approach Glidepath	Feet	0.001 ft
Vertical Flags		n/a

3D LORAN C INTERFACE UNIT.

The 3D Loran C navigator unit is connected to three major components in the aircraft: the TDL-711 receiver processing unit (RPU), Intercontinental Dynamics VNAV ALERT unit, and the digital glide slope switch. The 3D Loran C interface unit receives DTW and system status (flag) from the TDL-711 RPU. The DTW information is in turn filtered, smoothed, and converted to an analog output signal by the 3D Loran C interface unit. This analog output signal is transmitted directly to the VNAV ALERT unit which, in turn, drives the VDI needle and its associated flag. In addition to receiving DTW analog signals, the VNAV ALERT unit also receives altitude information from the barometric altimeter, which is part of the VNAV system. Glidepath descent angle information is supplied to the 3D Loran C navigator by a digital switch mounted on the data acquisition rack.

Block diagrams of the 3D Loran C navigator and the airborne data collection system are contained in figures 4 and 5.

RNAV APPROACH REQUIREMENTS.

RNAV approaches may provide navigational guidance in both the horizontal and vertical planes (i.e., 3D). Accuracy requirements for equipment used for conducting 3D RNAV approaches are identified in Advisory Circular (AC) 90-45A. The 2D requirements are stated in terms of the 95 percent limits (2 standard deviations about the mean) for the distribution of errors derived from several different sources. The 3D requirements are stated in terms of the 99.7 percent limits (3 standard deviations about the mean). The errors pertinent to this study are defined in the following paragraphs.

2D ERROR COMPONENTS.

1. FTE - Flight technical error refers to the accuracy with which the pilot controls the aircraft as measured by his success in causing the aircraft position to match the commanded position. FTE is measured in the horizontal plane perpendicular to the desired approach path.
2. NAT - Navigation error alongtrack component is the error in the aircraft position along the desired flightpath to be flown. NAT results only from error contributions due to airborne or ground equipment. FTE is not included in NAT.
3. NCT - Navigation error crosstrack component is the difference between the true crosstrack position perpendicular to the desired flightpath and the crosstrack position determined by the navigation equipment.
4. TSCT - Total system crosstrack error is the position error to the left or right from the desired track to the present position, measured perpendicular to the desired track. The error includes airborne equipment, ground equipment, and FTE.

Figure 6 presents the above errors graphically. As shown in figure 6, three system error terms combine in the direction perpendicular to the desired track. Statistically, NCT and FTE are combined in a root sum square (rss) manner to produce TSCT. The mathematical expression is:

$$TSCT = \sqrt{NCT^2 + FTE^2}$$

Algebraic manipulation yields an expression by which NCT may be derived when FTE and TSCT are specified:

$$NCT = \sqrt{TSCT^2 - FTE^2}$$

Table 2 presents the error limits identified in AC 90-45A.

TABLE 2. AC 90-45A 2D ERROR COMPONENTS LIMITS

	95% Confidence Limit	
<u>Error</u>	<u>(nmi)</u>	
TSCT	0.6	
FTE	0.5	
NCT	0.3	
NAT	0.3	

3D ERROR COMPONENTS.

1. VFTE - Vertical flight technical error refers to the accuracy with which the pilot controls the aircraft as measured by his success in causing the aircraft position to match the commanded or desired position. VFTE is measured in the vertical plane perpendicular to the desired approach glidepath.

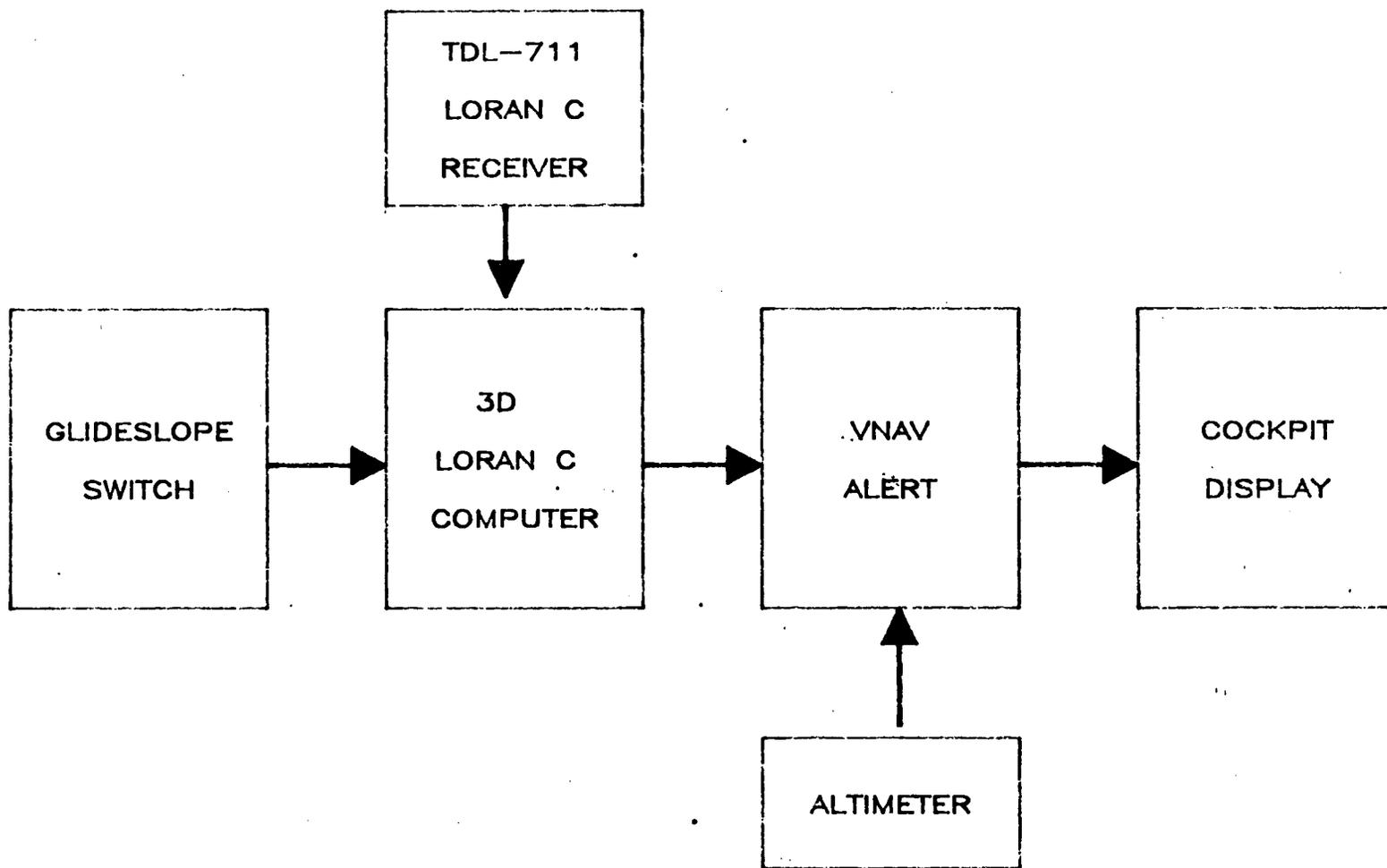


FIGURE 4. 3D LORAN C NAVIGATOR

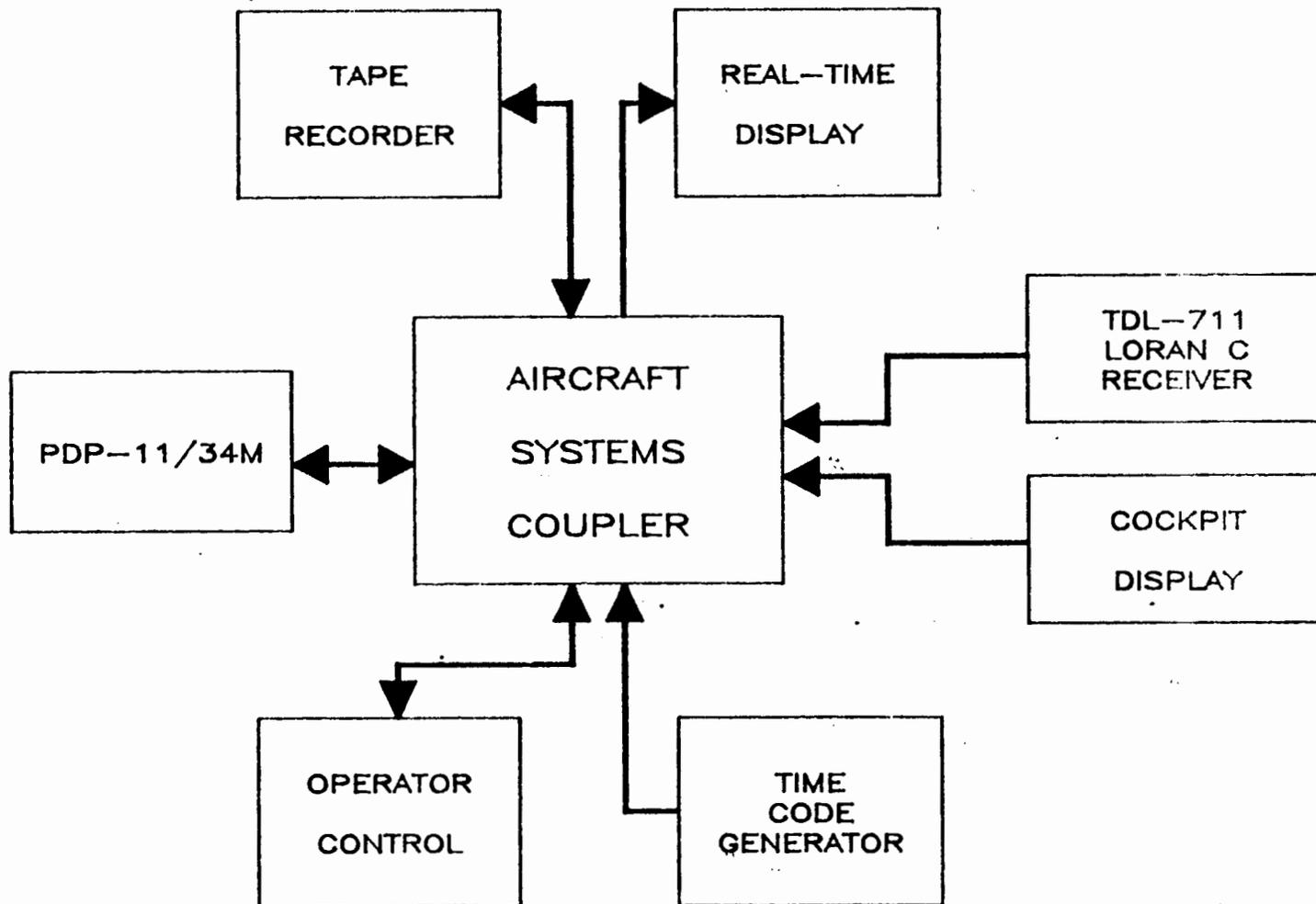
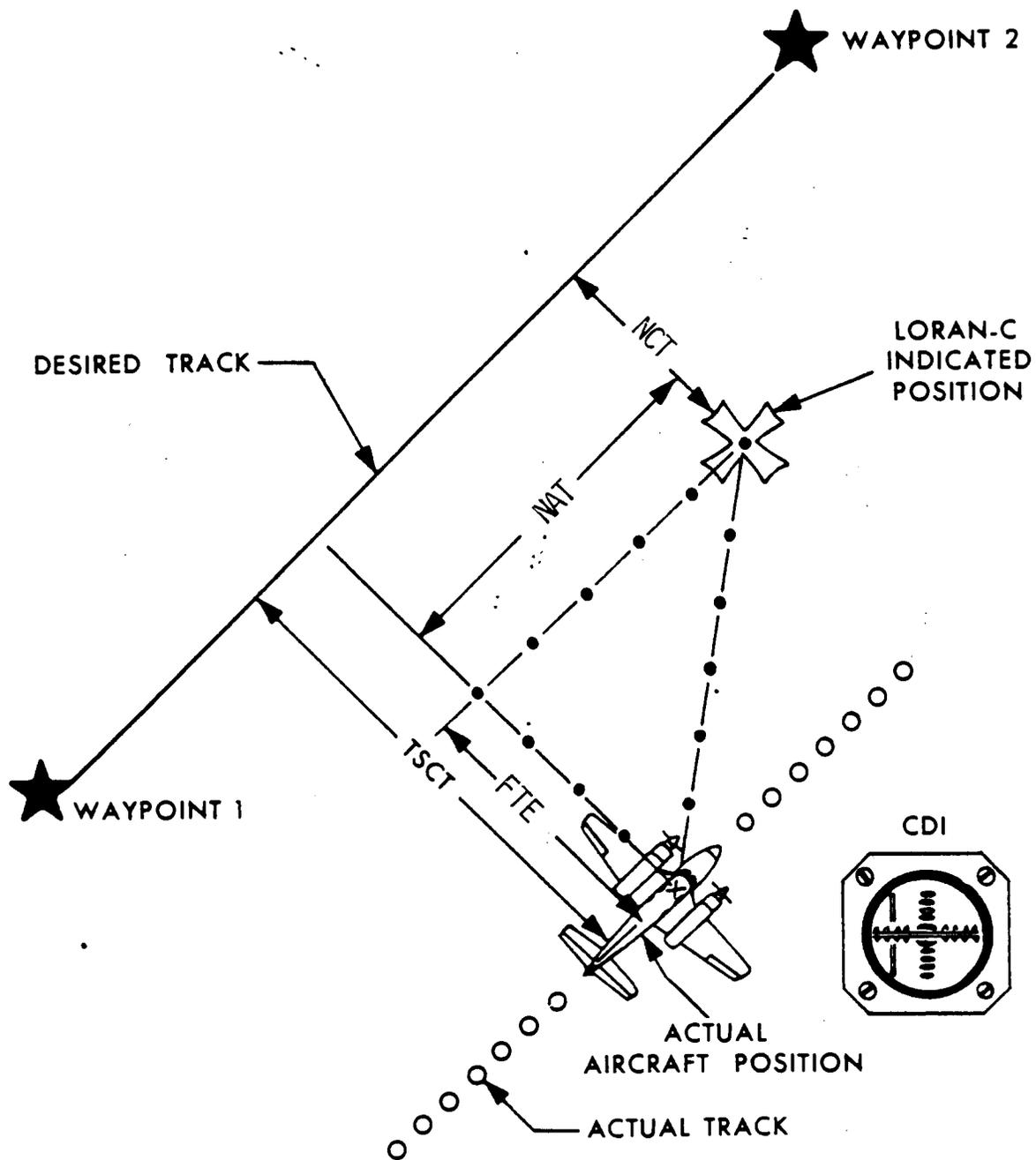


FIGURE 5. AIRBORNE DATA COLLECTION SYSTEM



TSCT = TOTAL SYSTEM CROSS TRACK ERROR
 NAT = AIRBORNE EQUIPMENT ALONG TRACK ERROR
 NCT = AIRBORNE EQUIPMENT CROSS TRACK ERROR
 FTE = FLIGHT TECHNICAL ERROR

FIGURE 6. NAVIGATION SYSTEM 2D ERROR TERMS

2. NVT - Navigation error vertical component is the difference between the true vertical position perpendicular to the desired glidepath and the vertical position determined by the navigation equipment.

3. TSVT - Total system vertical error is the position error above or below the intended glidepath measured perpendicular to the desired glidepath. The error includes airborne equipment, ground equipment, and VFTE.

Table 3 presents the 3D limits identified in AC 90-45A.

TABLE 3. AC 90-45A 3D ERROR COMPONENTS LIMITS

99.7% Confidence Limit

<u>Error</u>	<u>(Feet)</u>
VFTE	200
NVT	100
TSVT	265

NIKE/HERCULES TRACKING.

The FAA Technical Center's position standard for measuring the 3D Loran C navigator's system performance was obtained using a modified Nike/Hercules radar system. Modifications to the standard Nike/Hercules radar have resulted in a very accurate system for obtaining measurements on navigation system performance. During the flight tests the Nike/Hercules radar tracked the S-76. Tracking data were converted to latitude, longitude, and altitude. The converted tracking data were time merged with the airborne data that were collected. The merged data file provided the basis for determining the 3D Loran C navigator system errors:

DATA COLLECTION METHODOLOGY.

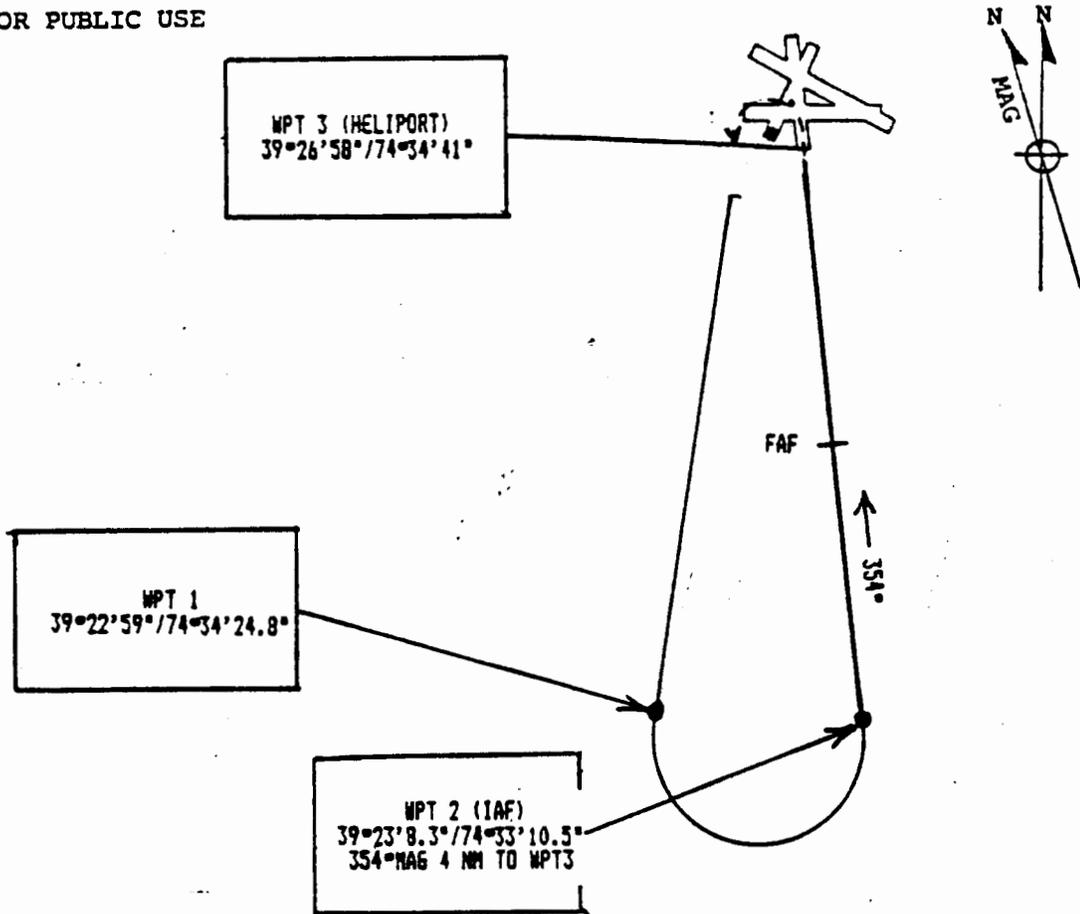
The 3D Loran C navigator flight tests were flown under simulated IFR conditions. Each flight consisted of a series of eight approaches to the Technical Center's Heliport. In all cases, the final approach fix (FAF) was 2.0 nmi from the helipad. All approaches were straight-in approach profiles. The profile and plan view of this approach procedure is depicted in figure 7. The flights were conducted in visual meteorological conditions (VMC).

The flight crew consisted of the subject pilot, the safety pilot, and a flight technician. The subject pilot made all approaches with reference to navigation deviation information provided on his HSI. Throughout the flight, instrument meteorological conditions were simulated by restricting the subject pilot's field of vision.

Northeast Chain (9960)
 Triad: Seneca-Nantucket-
 Carolina Beach-(Dana)
 Apt. Elev. 76'

Atlantic City, N.J.
 FAA Technical Center
 3D Loran-C 3°-5°-7°
 Approaches

EXPERIMENTAL CHART
 NOT FOR PUBLIC USE



Missed Approach: Climbing Turn to IAF Altitude, Direct to IAF WPT

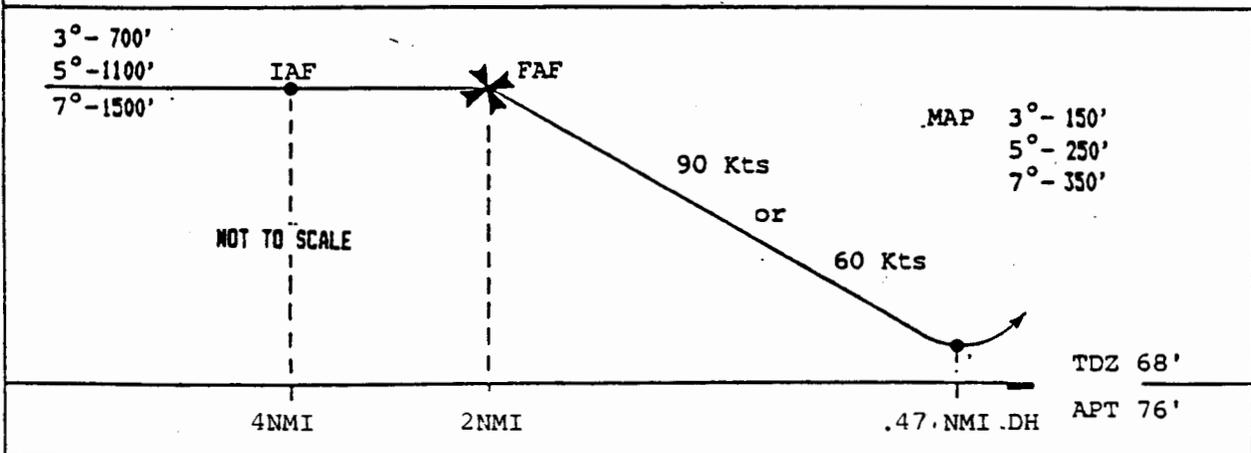


FIGURE 7. 3D LORAN C NAVIGATOR APPROACH PLATE

MODIFIED COOPER-HARPER RATING SCALE

ACCEPTABILITY OF SAFETY MARGINS, TASK PERFORMANCE, AND PILOT WORKLOAD

GENERAL CHARACTERISTICS

SAFETY MARGINS

DEMANDS ON THE PILOT

PILOT RATING

Acceptable for routine operations?

NO

Acceptable for rare occasions, e.g. FCS failure or severe atmospheric conditions?

NO

Controllable?

NO

Pilot Decisions

Excellent Highly Desirable	Clearly adequate	Pilot compensation not a factor for desired performance	1
Good Negligible Deficiencies	Clearly adequate	Pilot compensation not a factor for desired performance	2
Fair - Some Mildly Unpleasant Deficiencies	Clearly adequate	Minimal pilot compensation required for desired performance	3
Minor but annoying deficiencies	Clearly adequate	Desired performance requires moderate pilot compensation	4
Moderately objectionable deficiencies	Adequate	Adequate performance requires considerable pilot compensation	5
Very objectionable but tolerable deficiencies	Marginal	Adequate performance requires extensive pilot compensation	6
Major deficiencies	Inadequate	Adequate performance not attainable with maximum tolerable pilot compensation. Controllability not in question	7
Major deficiencies	Inadequate	Considerable pilot compensation is required for control	8
Major deficiencies	Inadequate	Intense pilot compensation is required to retain control	9
Major deficiencies	None	Control will be lost during some portion of required operation	10

FIGURE 8. MODIFIED COOPER - HARPER RATING SCALE

The helicopter was taxied for Nike/Hercules radar calibration. After confirming Nike calibration, the pilot departed and proceeded directly to waypoint No. 1 (lat 39° 22' 59.1" long 74° 34' 24.8") while climbing to the appropriate altitude for the next approach. Upon reaching waypoint No. 1, the subject pilot turned left and intercepted the inbound course at waypoint No. 2 (lat 39° 23' 8.3" long 74° 33' 10.5"). The pilot proceeded inbound along the 354° heading to the FAF at 2 nmi from waypoint No. 3, which is the heliport (lat 39° 26' 58" long 74° 34' 41"). Beyond the FAF, the subject followed glide slope commands to decision height (DH). Upon reaching DH the subject announced DH, then the safety pilot instructed him to land or go-around. The go-around was a climb straight ahead to 500 feet mean sea level (m.s.l.), then turn left and proceed to waypoint No. 1 while climbing to the Initial Approach Fix (IAF) altitude for the next approach. Figure 7 depicts the instrument approach procedure.

The subject pilot's vision was restricted after initial level off until DH or missed approach, whichever was appropriate. The safety pilot performed copilot duties. These duties included the scanning for visual flight rules (VFR) traffic, monitoring aircraft performance, and communicating with air traffic control (ATC). The flight technician monitored receiver performance, coordinated range tracking, and maintained a flight test log. After landing or missed approach, the data technician asked the subject pilot three questions: to rate the approach, landing, or missed approach. The subject used the modified Cooper-Harper rating scale (figure 8) to rate the maneuvers.

Although a single type of approach was utilized, two parameters were varied in the test matrix (table 4): airspeed and glide slope angle. The decision was made to limit this test series to only two parameters for two primary reasons:

1. Due to budget considerations the test was limited to 15 flight hours: 12 hours for data collection and 3 hours for system checkout and pilot training.
2. Using several approach parameters, the sample size would be too small to provide meaningful statistical analysis results.

FLIGHT TEST CONDITIONS.

Data were collected for two flights with two different subject pilots. For the first flight, 2D and 3D error component data were available for seven of the eight approaches. Error component data were available for all eight approaches in the second flight. Pilot ratings of the approaches, landings, or missed approaches were available for all eight approaches of both flights. The barometric pressure for the first flight was 30.26 inches of mercury (Hg) and the second was 30.16 inches of Hg. The wind conditions were 12 knots at 220° during the first flight, resulting in a near maximum tail wind component during the approaches. During the second flight the wind conditions were 18 knots at 010°.

TABEL 4. 3D LORAN C APPROACH MATRIX

<u>Run No.</u>	<u>Airspeed (kts)</u>	<u>Glideslope (deg)</u>	<u>Intercept Alt (ft)</u>	<u>Termination</u>
1	90	3	700	Landing
2	60	7	1500	Missed approach
3	60	5	1100	Missed approach
4	90	3	700	Missed approach
5	60	3	700	Landing
6	60	5	1100	Landing
7	60	3	700	Missed approach
8	60	7	1500	Landing

DATA ANALYSIS

Data analysis consisted of statistical and graphical characterization of both 2D and 3D error components associated with the 3D Loran C navigation system. Statistical data reduction was accomplished on a per second basis by summing the various error terms for each data sample over an entire approach, and expressing each as a mean and standard deviation. A Calcomp 1051 drum plotter was also used to plot error sequences versus range. The plots permitted patterns and trends in performance to be detected more easily. The first step in post-processing the data was to calculate actual aircraft position at each data point by converting the raw Nike/Hercules tracking data to World Geodetic Survey of 1972 (WGS-72) latitude, longitude, and altitude. TSCT was determined by computing the desired course from waypoint coordinates and calculating aircraft deviation perpendicular to this course. FTE was obtained by converting the data recorded in microamps to nmi based on a constant course width of 1.26 nmi. All of the statistics, except FTE and VFTE, were computed using WGS-72 latitude, longitude, and altitude. NCT and NAT were determined by taking differences in the latitude and longitude between the TDL-711 computed position and the actual position. These differences were resolved along the direction of the desired course to determine distance between the actual aircraft position and the desired aircraft position based on the descent angle of the approach. VFTE was obtained by converting the data recorded in microamps to feet based on a vertical course width of 60 feet. NVT was obtained by taking the square root of the difference of the squares of TSVT and VFTE.

Ninety-five percent limits were calculated for the 2D error components by adding the mean error and two times the standard deviation. Three standard deviation (99.7 percent) limits were calculated for the 3D error components by adding the mean error and three times the standard deviation.

3D RVAV CONSIDERATIONS

By adding a third dimension of vertical guidance to a 2D RNAV system, the Loran C navigator can achieve significant operational advantages. Briefly, a 3D RNAV capability permits altitude change by following vertical routes (tubes) of known dimensions; thus, vertical guidance is available for stabilized descent in instrument approach procedures using computed glidepath information.

To provide vertical guidance during ascent or descent, the 3D RNAV equipment compares the indicated altitude with the desired altitude and presents the computer correction instrumentally; typically in the form of fly up/fly down cross pointer information. The computation and comparison process produces vertical position errors which are additional to those affecting the aircraft in level flight (figure 9).

The along track error also (ATE) has significance in vertically guided flight. When an aircraft is ahead or behind its assumed position, it will be either above or below its intended path (figure 10).

The angle at which climb or descent is made also affects the required obstacle clearance because as the vertical angle increases, there is a corresponding increase in the effect of the ATE on the thickness of the tube (figure 11).

RESULTS

Accuracy results identifying the performance characteristics of the 3D Loran C navigator are presented in tables 5 through 8. Tables 9 through 12 present the calculated 95 percent limits for the 2D error components and the 99.7 percent limits for the 3D error components. The sign convention used presents TSCT and NCT errors to the left of course as negative values. NAT errors are negative when the TDL-711 receiver identified along-track position is in front of the actual along-track position. FTE is positive for a fly right command, indicating that the pilot is left of course. TSVT and NVT errors are negative when the actual position is below the desired position. VFTE is positive for a fly up command, indicating that the pilot is below the desired descent angle. Plots of navigation error parameters versus range are contained in appendices A through G.

2D ERROR COMPONENT RESULTS.

For flight No.1 the 95 percent confidence limits in AC 90-45A were met for all approaches. For flight No.2 the limits for TSCT and FTE were met for all approaches. The limit for NCT was met for the first seven runs but not the eighth. The limit for NAT was exceeded on runs 2, 4, and 8.

3D ERROR COMPONENT RESULTS.

For flight No.1 the 99.7 percent confidence limits in AC 90-45A for TSVT and NVT were exceeded on all runs. The VFTE limit was met on six of the seven runs for which data were available. For flight No.2 the limits for TSVT and NVT were exceeded on all runs. The VFTE limit was met on seven of the eight runs.

SUBJECT PILOT EVALUATIONS

The subject pilot evaluations of the individual approaches are presented in tables 13 and 14. The subject used the Modified Cooper-Harper Rating Scale (Figure 8) to rate the maneuvers.

ADDITIONAL VERTICAL CONTRIBUTION USING YNAV

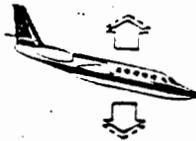


FIGURE 9. ADDITIONAL ERROR ALLOWANCE FOR ASCENDING/DESCENDING FLIGHT

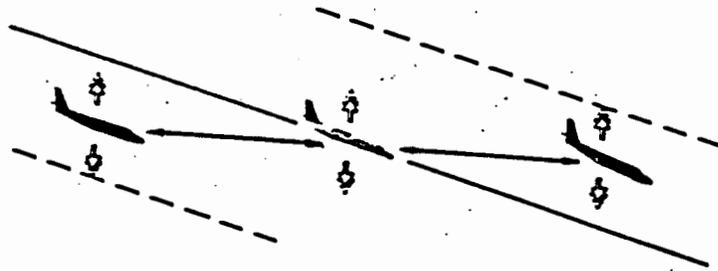


FIGURE 10. EFFECTS OF ALONG-TRACK ERROR

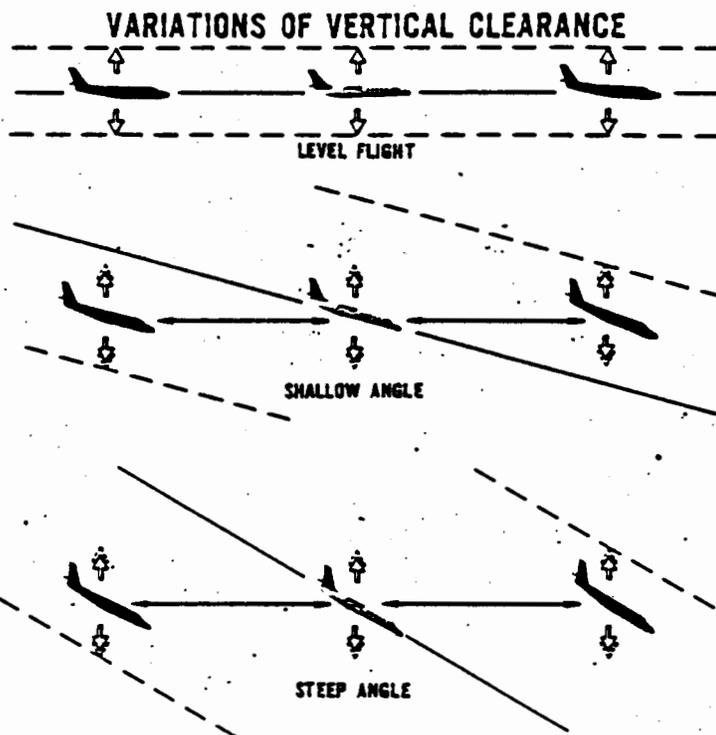


FIGURE 11. VARIATIONS OF TUBE SIZE TO CONTAIN POSITION ERRORS as VERTICAL ANGLE INCREASES

TABLE 5. FLIGHT NO. 1 2D ERROR COMPONENTS

Run No.	Sample Size	TSCT (nmi)		FTE (nmi)		NCT (nmi)		NAT (nmi)	
		Mean	Std	Mean	Std	Mean	Std	Mean	Std
1	132	0.04	0.10	-0.02	0.07	0.03	0.04	0.17	0.06
2	199	0.03	0.05	-0.02	0.05	0.04	0.02	0.11	0.04
3	184	0.05	0.04	-0.01	0.04	0.04	0.02	0.12	0.03
4	146	0.09	0.09	0.01	0.07	0.04	0.04	0.17	0.06
5	154	0.07	0.08	0.00	-0.06	0.04	0.03	0.11	0.04
6	175	0.04	0.04	-0.01	0.04	0.03	0.02	0.11	0.04
7	-	-	-	-	-	-	-	-	-
8	180	-0.03	0.06	-0.06	0.05	0.03	0.02	0.11	0.03

TABLE 6. FLIGHT NO. 2 2D ERROR COMPONENTS

Run No.	Sample Size	TSCT (nmi)		FTE (nmi)		NCT (nmi)		NAT (nmi)	
		Mean	Std	Mean	Std	Mean	Std	Mean	Std
1	182	0.00	0.06	-0.04	0.05	0.03	0.02	0.15	0.07
2	326	0.17	0.09	0.08	0.07	0.02	0.02	0.10	0.10
3	351	0.13	0.05	0.06	0.04	0.02	0.02	0.08	0.02
4	172	0.15	0.05	0.05	0.05	0.03	0.03	0.17	0.09
5	263	0.17	0.09	0.07	0.07	0.02	0.01	0.10	0.04
6	342	0.04	0.07	-0.01	0.05	0.02	0.01	0.09	0.03
7	274	0.06	0.04	0.01	0.03	0.02	0.01	0.11	0.04
8	285	0.22	0.13	0.12	0.10	-0.12	2.07	0.50	6.80

TABLE 7. FLIGHT NO. 1 3D ERROR COMPONENTS

Run No.	Sample Size	TSVT (ft)		VFTE (ft)		NVT (ft)	
		Mean	Std	Mean	Std	Mean	Std
1	132	-125.86	192.33	28.29	43.96	-118.69	188.01
2	199	-273.81	484.63	33.16	56.51	-279.22	481.09
3	184	-172.39	329.57	38.40	47.95	-167.82	326.20
4	146	-67.02	215.65	30.49	42.32	-61.04	210.47
5	154	-137.32	180.32	27.91	41.91	-130.91	175.23
6	175	-211.97	283.42	32.81	46.05	-207.96	279.85
7	-	-	-	-	-	-	-
8	180	-276.84	389.61	37.81	51.00	-275.09	385.69

TABLE 8. FLIGHT NO. 2 3D ERROR COMPONENTS

Run No.	Sample Size	TSVT (ft)		VFTE (ft)		NVT (ft)	
		Mean	Std	Mean	Std	Mean	Std
1	182	-151.94	214.65	39.98	44.62	-142.10	212.28
2	326	-362.05	511.88	35.22	53.25	-359.35	509.82
3	351	-277.32	389.83	42.71	52.93	-273.23	386.79
4	172	-169.82	219.96	21.05	57.11	-163.59	215.31
5	263	-133.78	158.94	28.14	42.63	-126.19	154.26
6	342	-275.35	336.27	-35.58	54.26	-269.00	334.41
7	274	-158.39	213.80	31.81	54.58	-150.98	209.03
8	285	-321.58	377.38	-20.97	73.42	-319.74	372.44

TABLE 9. FLIGHT NO. 1 2D ERROR COMPONENTS 95 PERCENT LIMITS

Run No.	Sample Size	TSCT (nmi)	FTE (nmi)	NCT (nmi)	NAT (nmi)
1	132	0.24	0.11	0.12	0.29
2	199	0.12	0.07	0.08	0.19
3	184	0.13	0.06	0.07	0.18
4	146	0.27	0.15	0.12	0.28
5	154	0.24	0.13	0.09	0.19
6	175	0.13	0.06	0.07	0.19
7	-	-	-	-	-
8	180	0.08	0.04	0.07	0.17

TABLE 10. FLIGHT NO. 2 2D ERROR COMPONENTS 95 PERCENT LIMITS

Run No.	Sample Size	TSCT (nmi)	FTE (nmi)	NCT (nmi)	NAT (nmi)
1	182	0.13	0.06	0.08	0.29
2	326	0.35	0.22	0.07	0.31
3	351	0.24	0.13	0.05	0.13
4	172	0.26	0.15	0.10	0.36
5	263	0.35	0.21	0.04	0.18
6	342	0.18	0.09	0.05	0.16
7	274	0.13	0.06	0.04	0.18
8	285	0.48	0.32	4.01	14.11

TABLE 11. FLIGHT NO. 1 3D ERROR COMPONENTS 99.7 PERCENT LIMITS

<u>Run No.</u>	<u>Sample Size</u>	<u>TSVT (ft)</u>	<u>VFTE (ft)</u>	<u>NVT (ft)</u>
1	132	451.13	160.18	445.33
2	199	1180.08	202.67	1171.04
3	184	816.33	182.24	810.79
4	146	579.93	157.45	570.38
5	154	403.63	153.65	394.79
6	175	638.30	170.97	631.59
7	-	-	-	-
8	180	891.98	190.80	881.96

TABLE 12. FLIGHT NO. 2 3D ERROR COMPONENTS 99.7 PERCENT LIMITS

<u>Run No.</u>	<u>Sample Size</u>	<u>TSVT (ft)</u>	<u>VFTE (ft)</u>	<u>NVT (ft)</u>
1	182	492.02	173.84	494.75
2	326	1173.59	194.96	1170.11
3	351	892.15	201.49	887.14
4	172	490.07	192.37	482.34
5	263	343.06	156.04	336.58
6	342	733.44	127.21	734.22
7	274	482.99	195.54	476.12
8	285	810.56	199.30	797.58

TABLE 13. SUBJECT PILOT EVALUATION - FLIGHT NO. 1

<u>Run No.</u>	<u>Approach</u>	<u>Landing</u>	<u>Missed Approach</u>	<u>Remarks</u>
1	7	4	-	
2	2	-	3	
3	2	-	2	
4	3	-	4	Didn't like the airspeed at low alt
5	1	2	-	
6	2	2	-	Best final approach
7	2	-	2	
8	2	2	-	

TABLE 14. SUBJECT PILOT EVALUATION - FLIGHT NO. 2

<u>Run No.</u>	<u>Approach</u>	<u>Landing</u>	<u>Missed Approach</u>	<u>Remarks</u>
1	2	9	-	Would not land without head wind
2	3	-	3	
3	2	-	2	
4	3	-	2	Would not land without head wind
5	2	6	-	
6	2	5	-	
7	2	-	2	
8	2	2	-	

CONCLUSIONS

Based on operational evaluation and the data analysis presented in this report the following conclusions can be made with respect to the three dimensional (3D) Loran C navigator system performance:

1. The 3D Loran C navigator performed within the limits identified in Advisory Circular (AC) 90-45A for two dimensional (2D) error components of total system cross-track (TSCT) and flight technical error (FTE).
2. The 3D Loran C navigator performed within the limits identified in AC 90-45A for the 3D error component vertical flight technical error (VFTE) only.
3. The lack of distance information in the cockpit eliminates the ability of the pilot to cross-check his along-track position during the approach.
4. Different altitude sources were used for vertical navigation (VNAV). The navigation system had its own altimeter while the pilot flew the aircraft referencing a different altimeter. Discrepancies of up to 100 feet have been noted between the VNAV altimeter and aircraft altimeters.
5. The integrity of the displayed vertical guidance was unreliable. Vertical guidance often was flagged at low altitudes. The vertical display indicator (VDI) did not always indicate the correct sense at the beginning of an approach.
6. The TDL-711 is a Loran C receiver which has not been approved for nonprecision approaches. Several Loran receivers have recently entered or completed the certification process and may be used for nonprecision approach guidance. The TDL-711 used for VNAV flight testing was not, and is not representative of Loran receivers which could be used for 3D approach guidance.
7. The TDL-711 receiver has a fixed lateral display sensitivity of 1.26 nautical miles (nmi) full scale. The subject pilots have noted that this provides a "sluggish," overdamped needle response and does not take advantage of the full accuracy capability of Loran.

8. The vertical flag appears to give erroneous and conflicting information. This flag should always be in view when the lateral flag is in view for the system as currently implemented. However, this was not the case with the designed equipment.

9. Inherent lags in the barometric altimeter make the system less responsive than other altitude references would be. Either an air data computer, which is already aboard many Instrument Flight Rules (IFR) certified helicopters, or a complementary filter using barometric and radar altitude inputs would improve the performance of the system.

10. The implementation of the alpha-beta filter for distance to go does not provide for vertical guidance while climbing (outbound), only while descending (inbound). This implementation prevents vertical guidance during missed approach.

11. This flight testing was conducted with prototype avionics. A number of the vagaries noted above can be attributed to this fact. Very little can be done with this prototype avionics to modify or optimize it. It is not suited for use with a flight director, which would be a natural extension of the current VNAV project. And, as noted previously, there is no distance display to the pilot. If additional tests are envisioned, this work should be done with production hardware (currently on the market) or modifications of such equipment.

12. In the loop pilot testing of commercially available Loran C vertical navigators should be conducted.

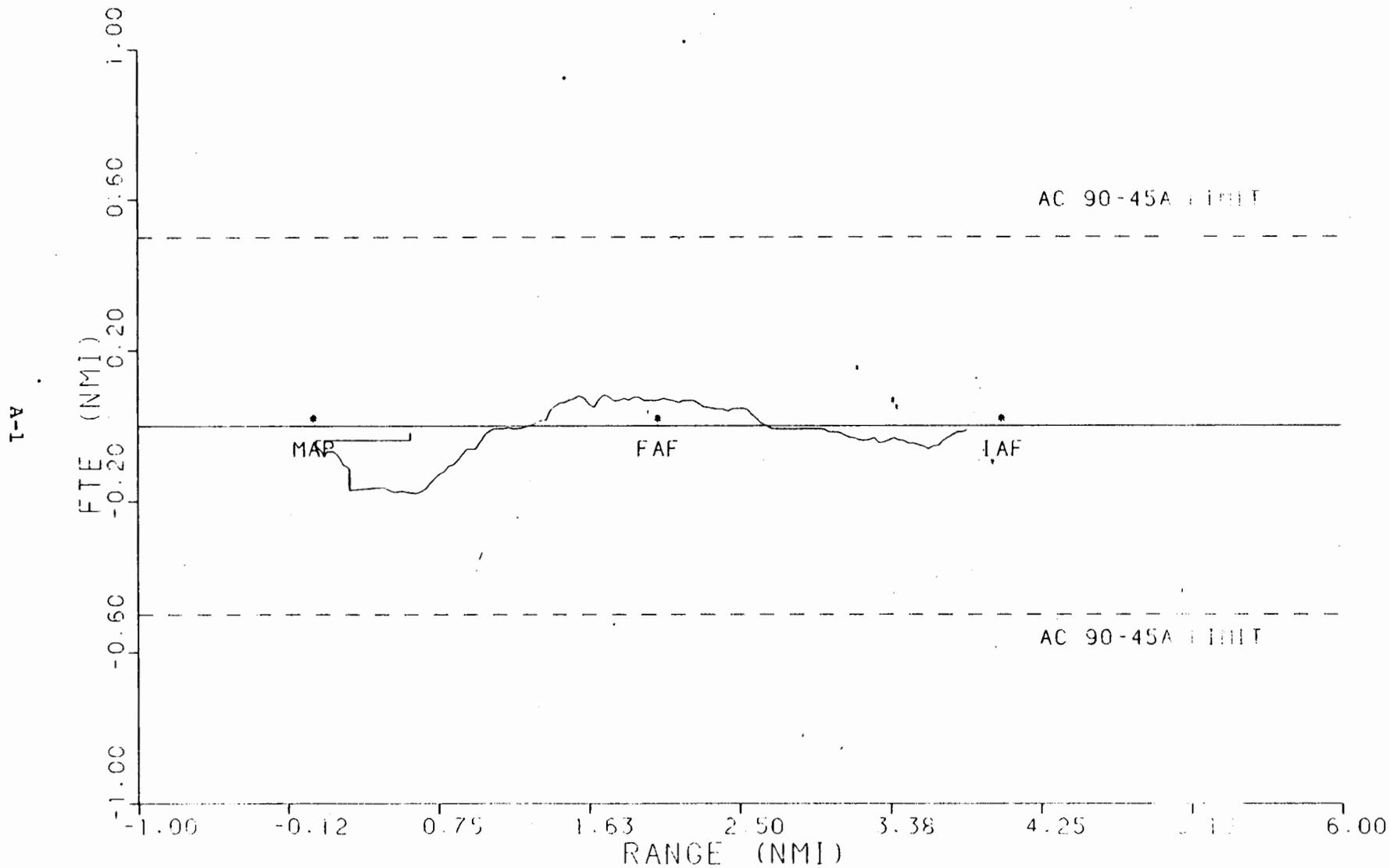
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2. Bolz, E. H. and King, L. D., 3D Loran-C Navigator Documentation, prepared by Systems Control Technology, Inc., West Palm Beach, Florida, prepared for Department of Transportation, Federal Aviation Administration, Washington, D.C., Report No. DOT/FAA/RD-82/16, January 1982.
3. King, L. D., 3D Loran-C Navigator Flight Test Plan, Program Engineering Maintenance Service, Washington, D.C., October 1983.
4. Lorge, F., Loran C Nonprecision Approaches in the Northeast Corridor, FAA-RD-82/78, June 1983.
5. Advisory Circular AC 90-45A, Approval of Area Navigation Systems for Use in Aviation Administration, February 1980.
6. Luciani, V., NAFEC Range Instrumentation Systems, FAA-NA-79-32, February 1980.

APPENDIX A
TSCT VERSUS RANGE PLOTS

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RUN # 1

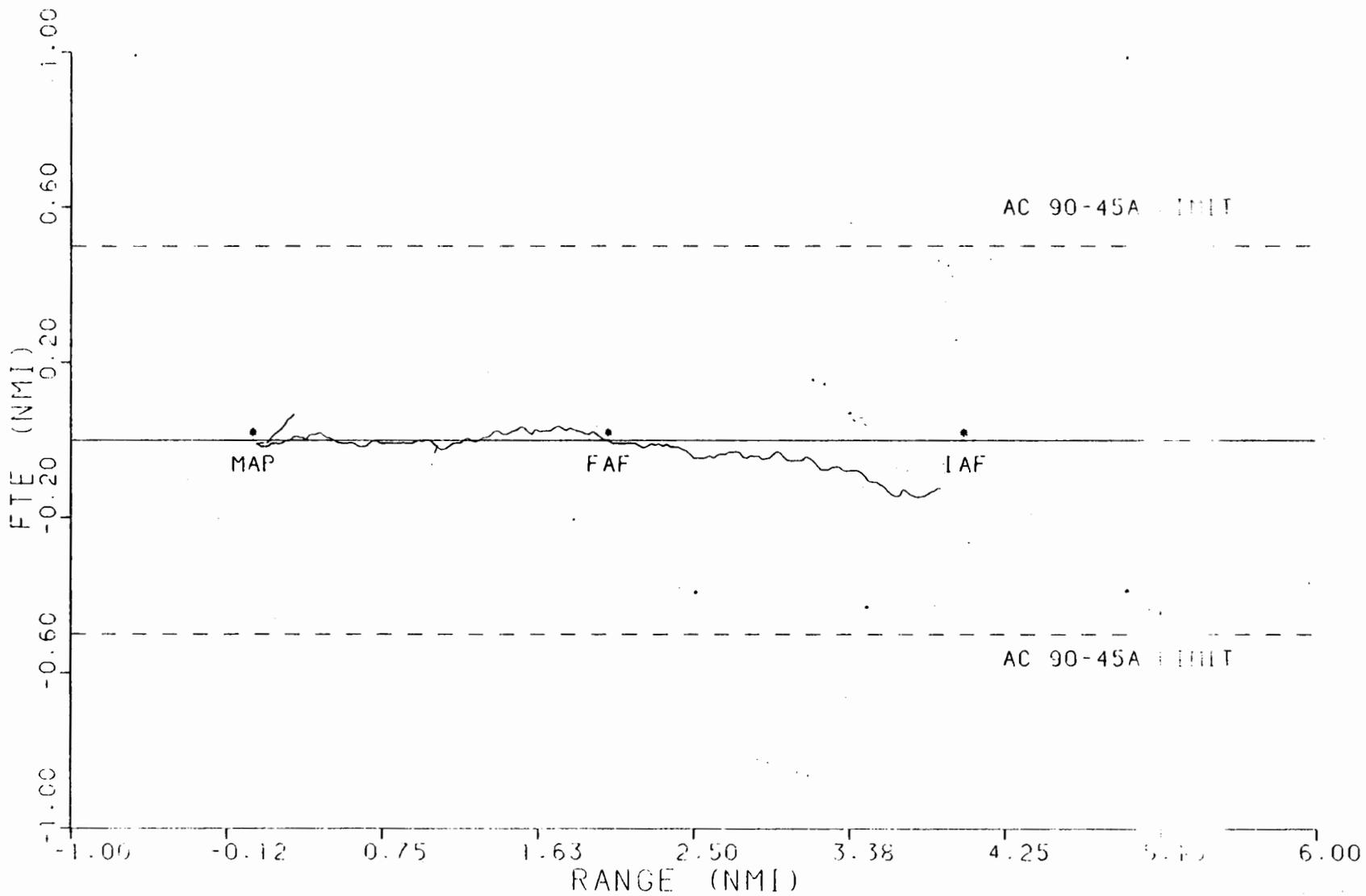
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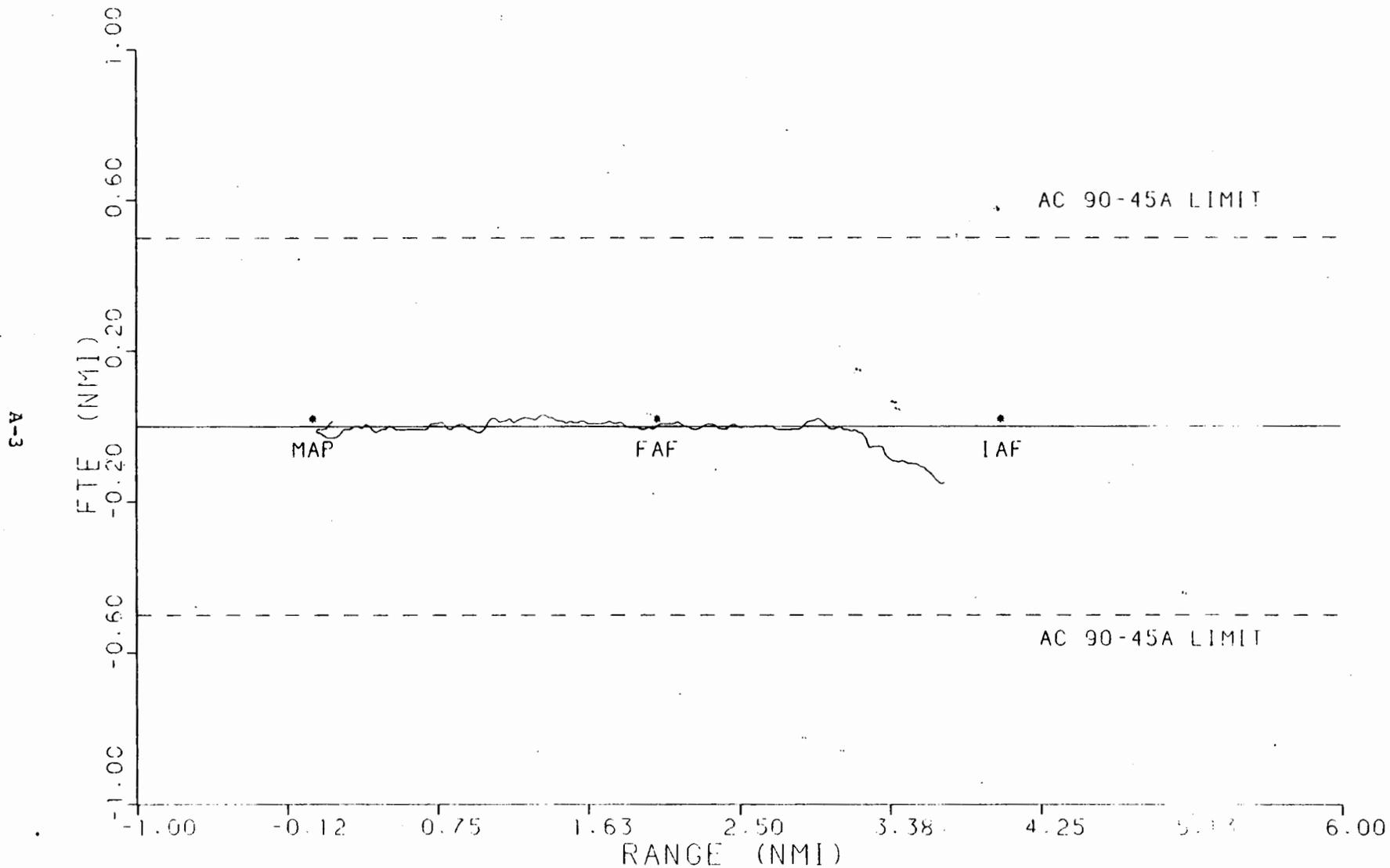
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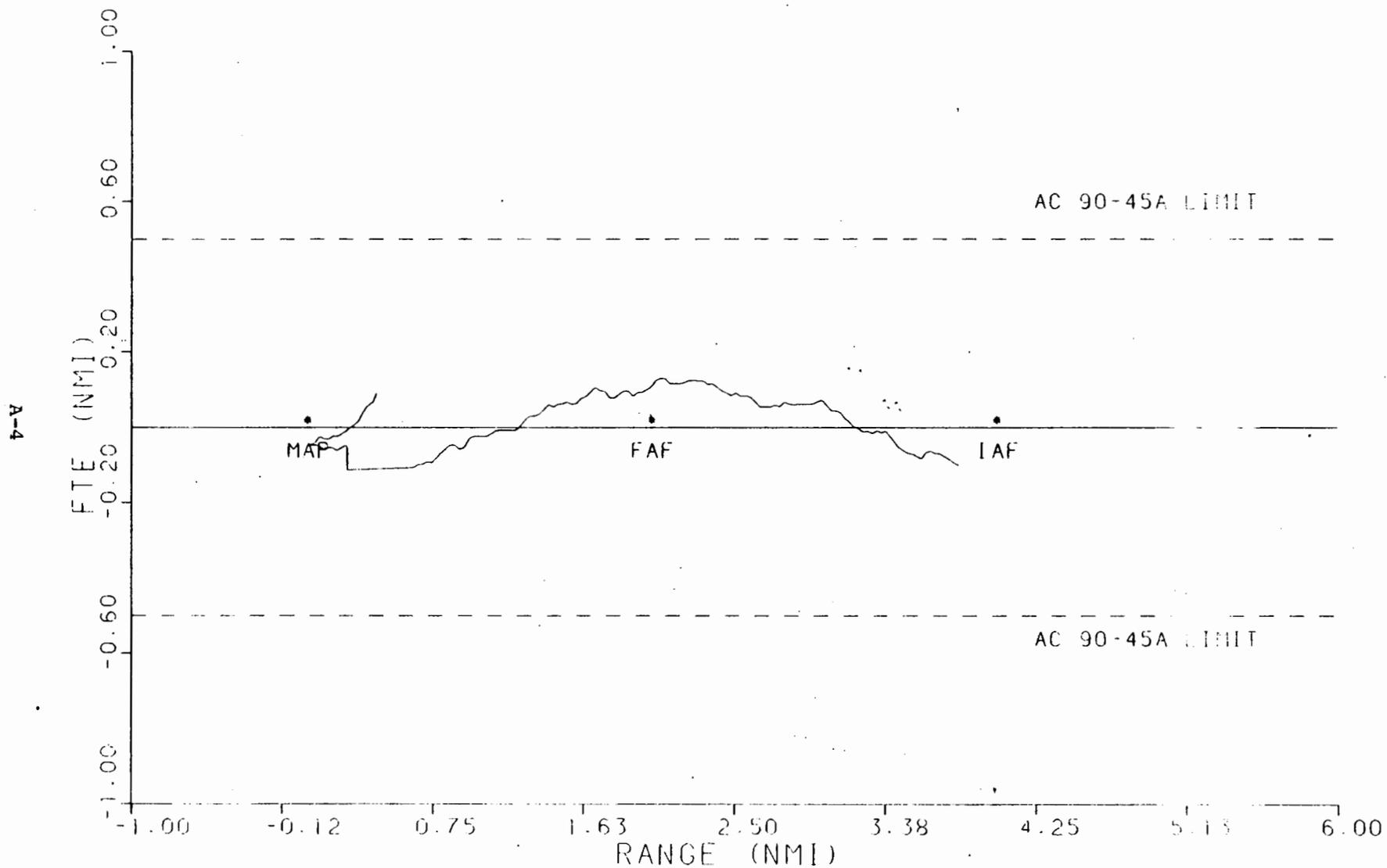
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RUN # 3

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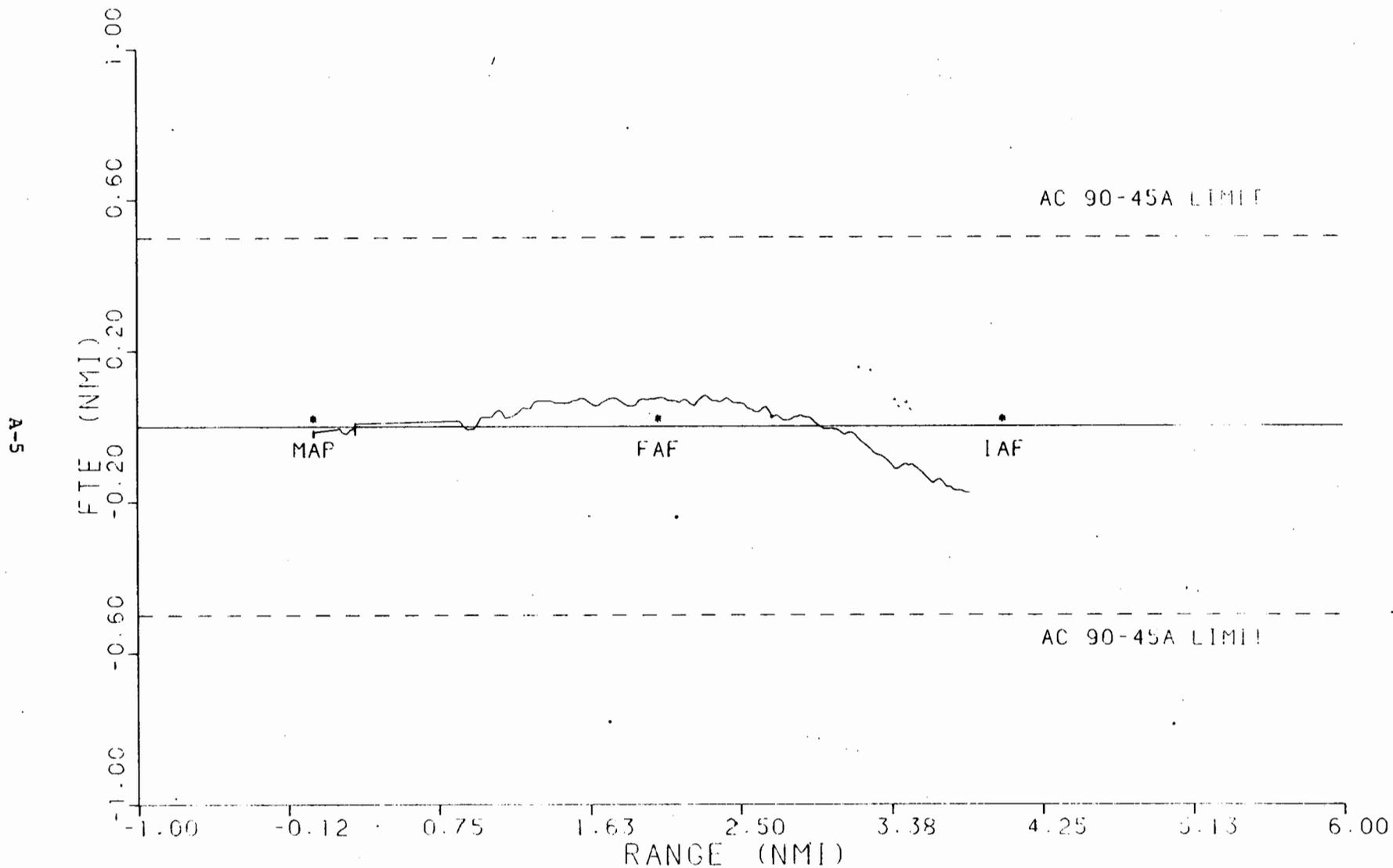
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RUN # 4

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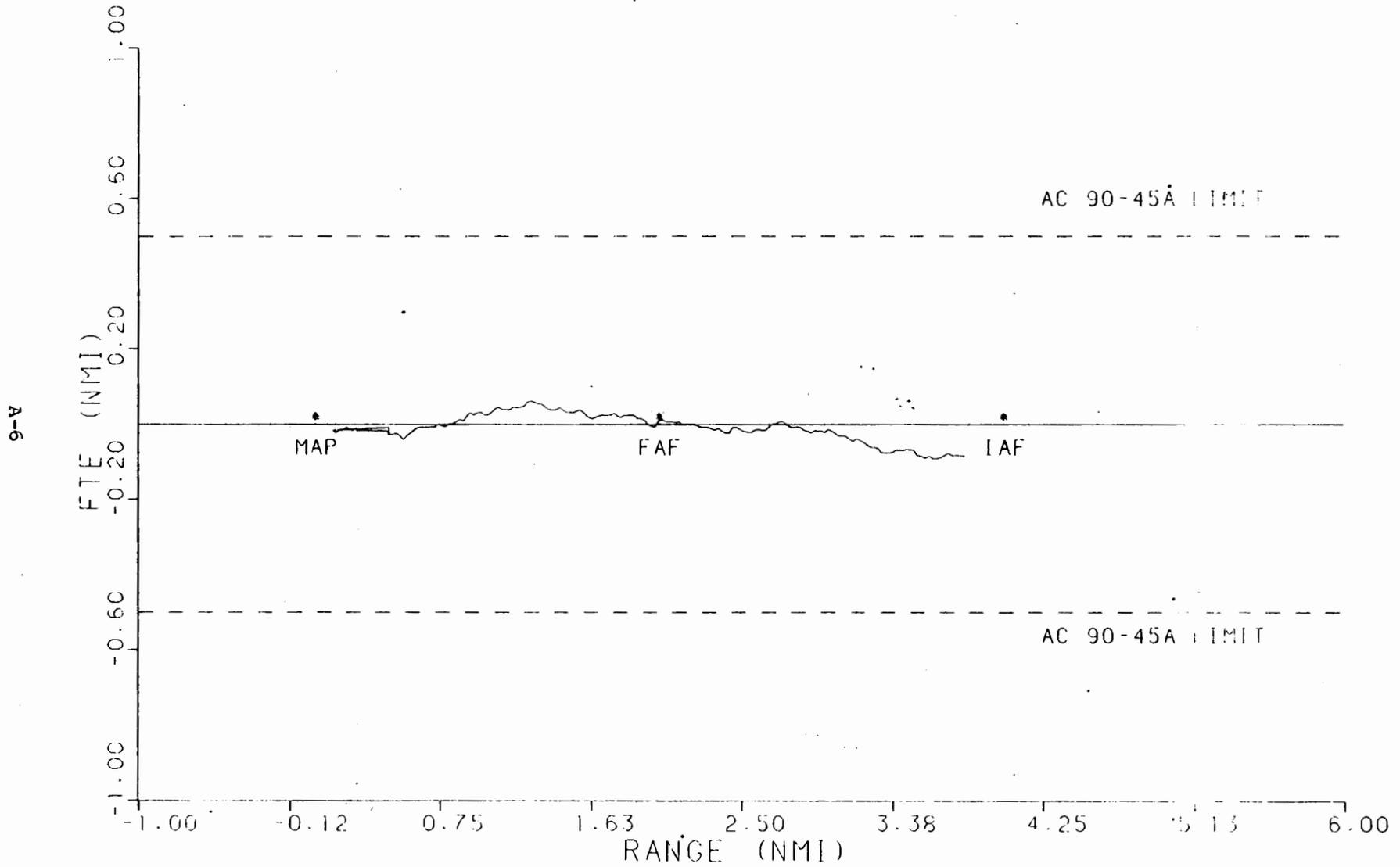
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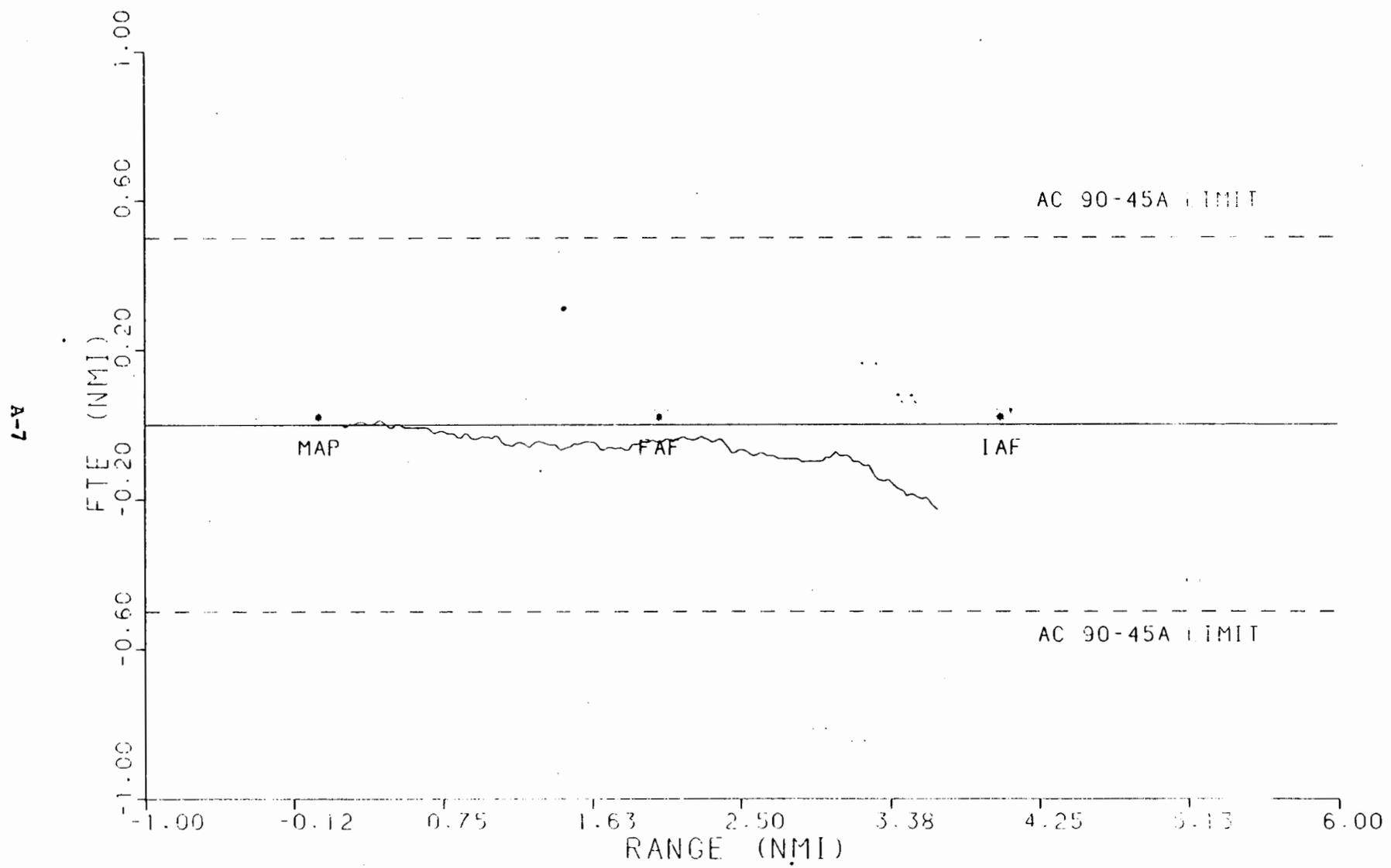
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RUN # 6

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RUN # 8

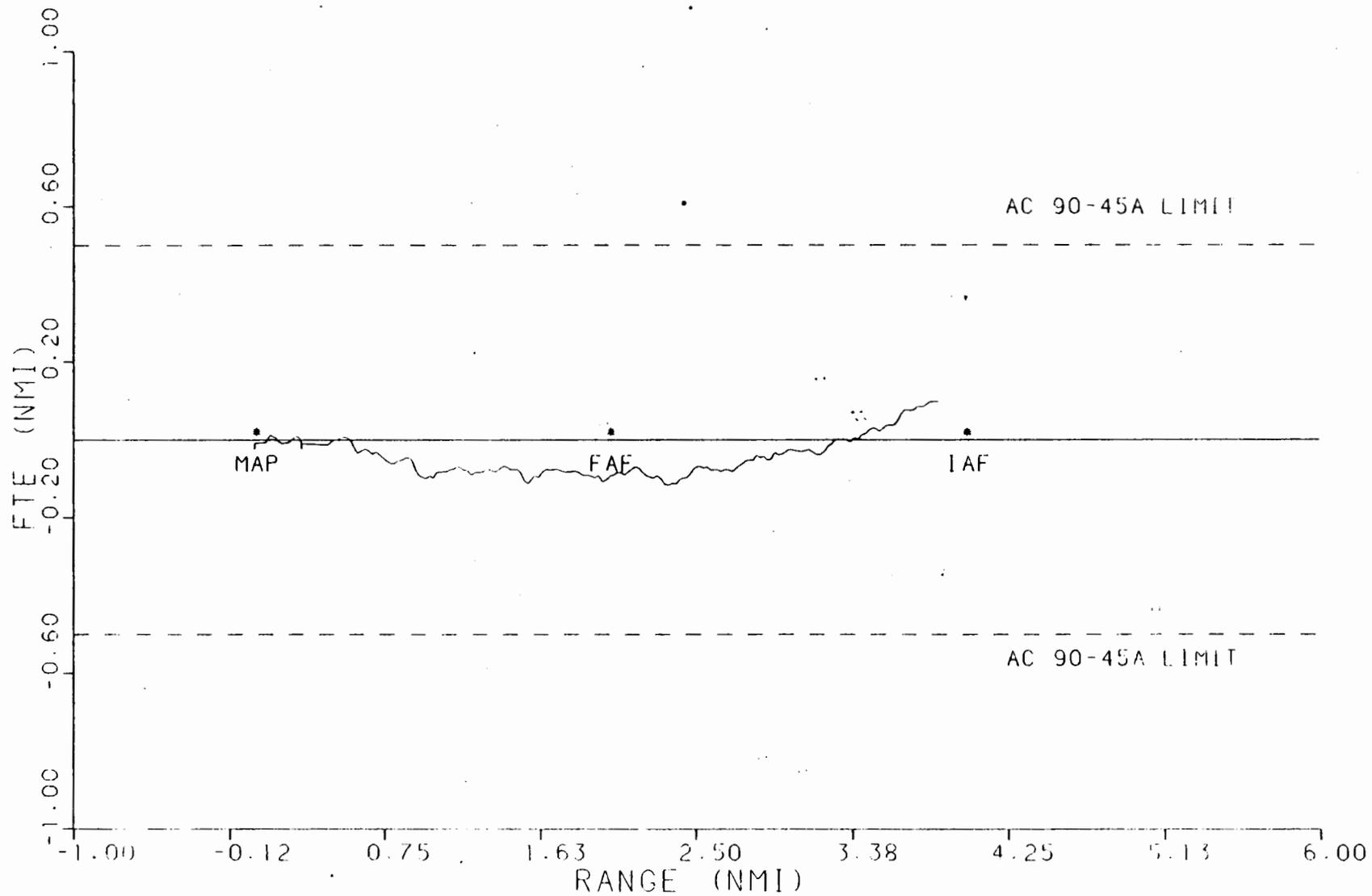
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FLIGHT #2 WITH SUBJECT PILOT #2
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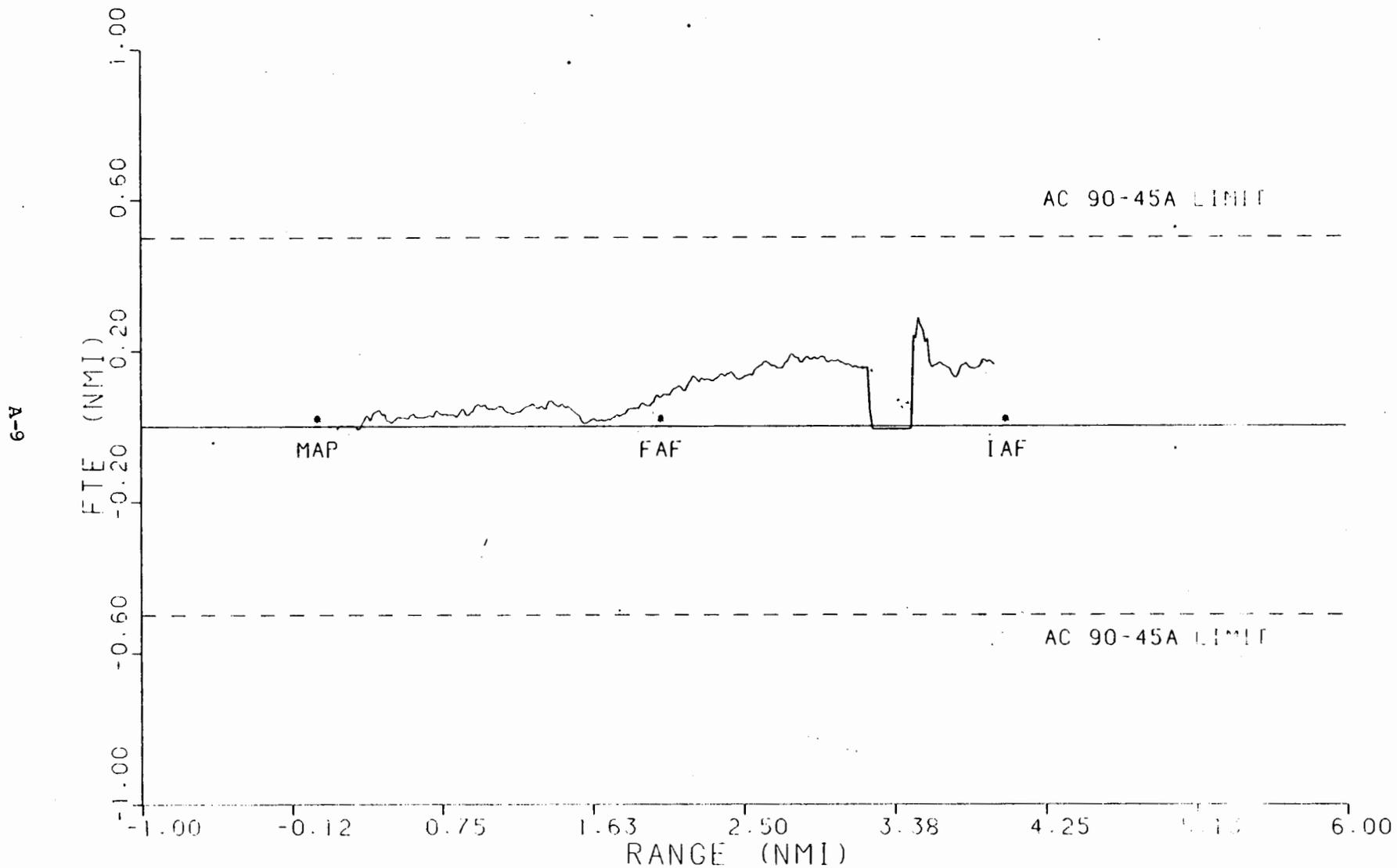
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A-8



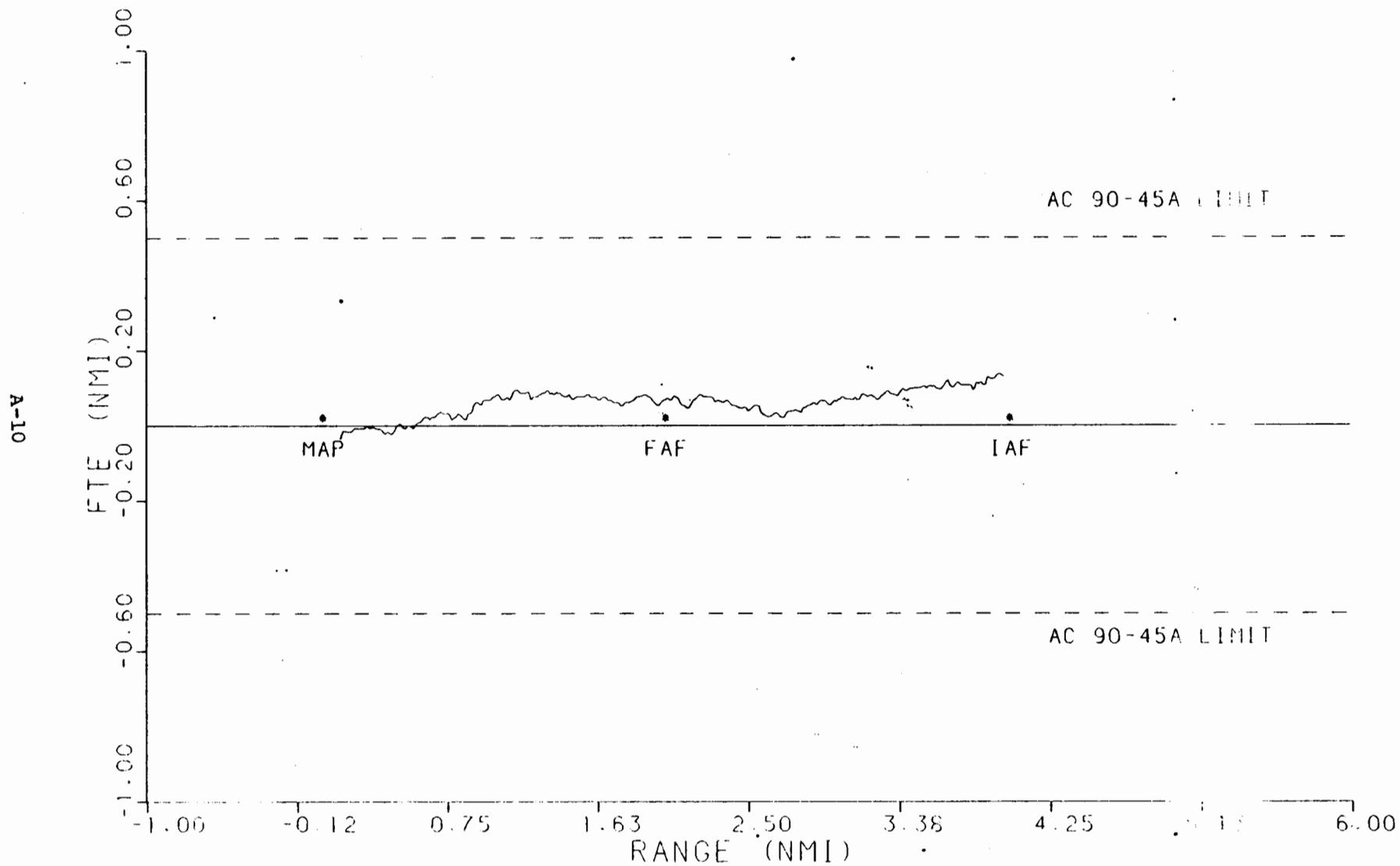
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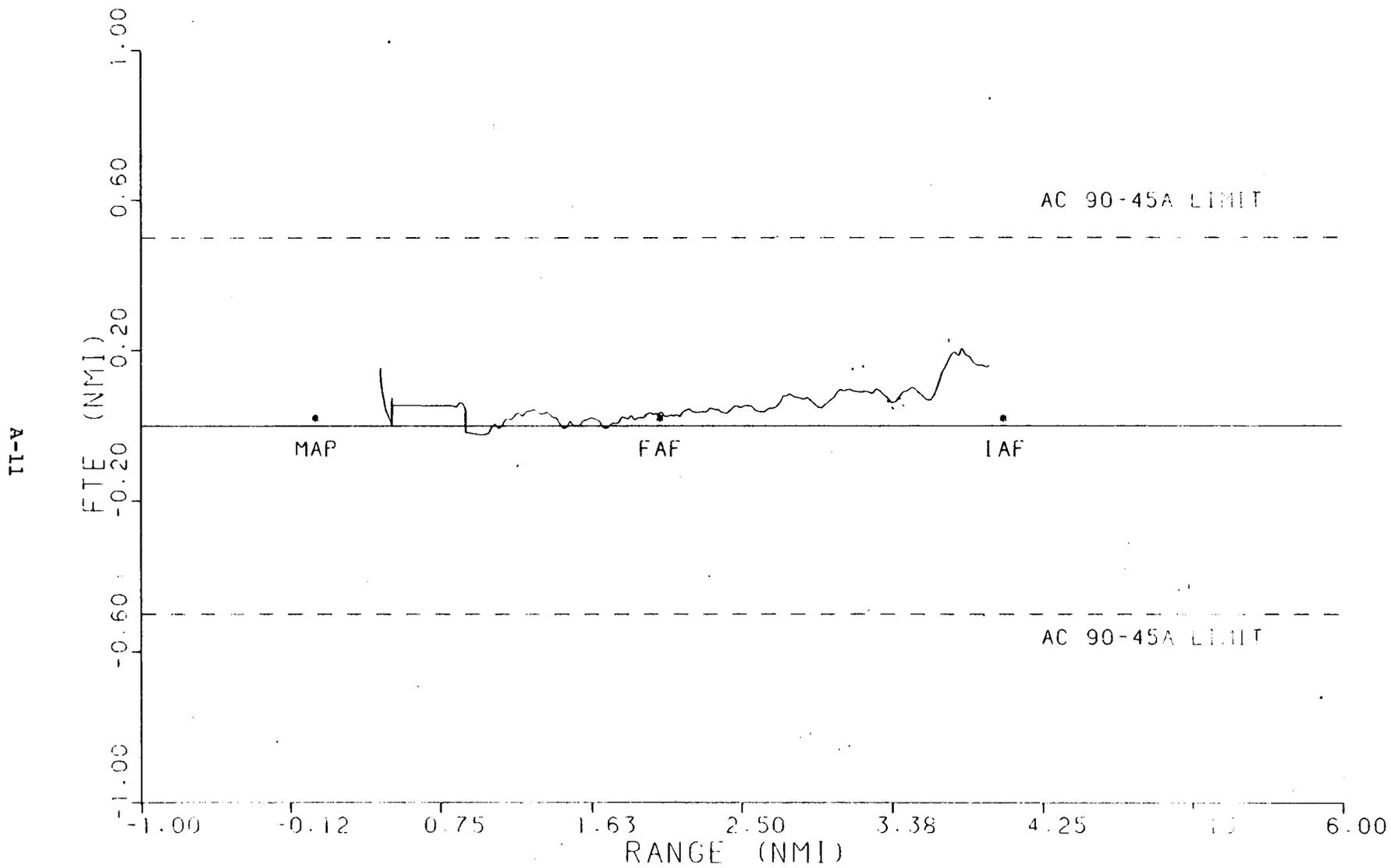
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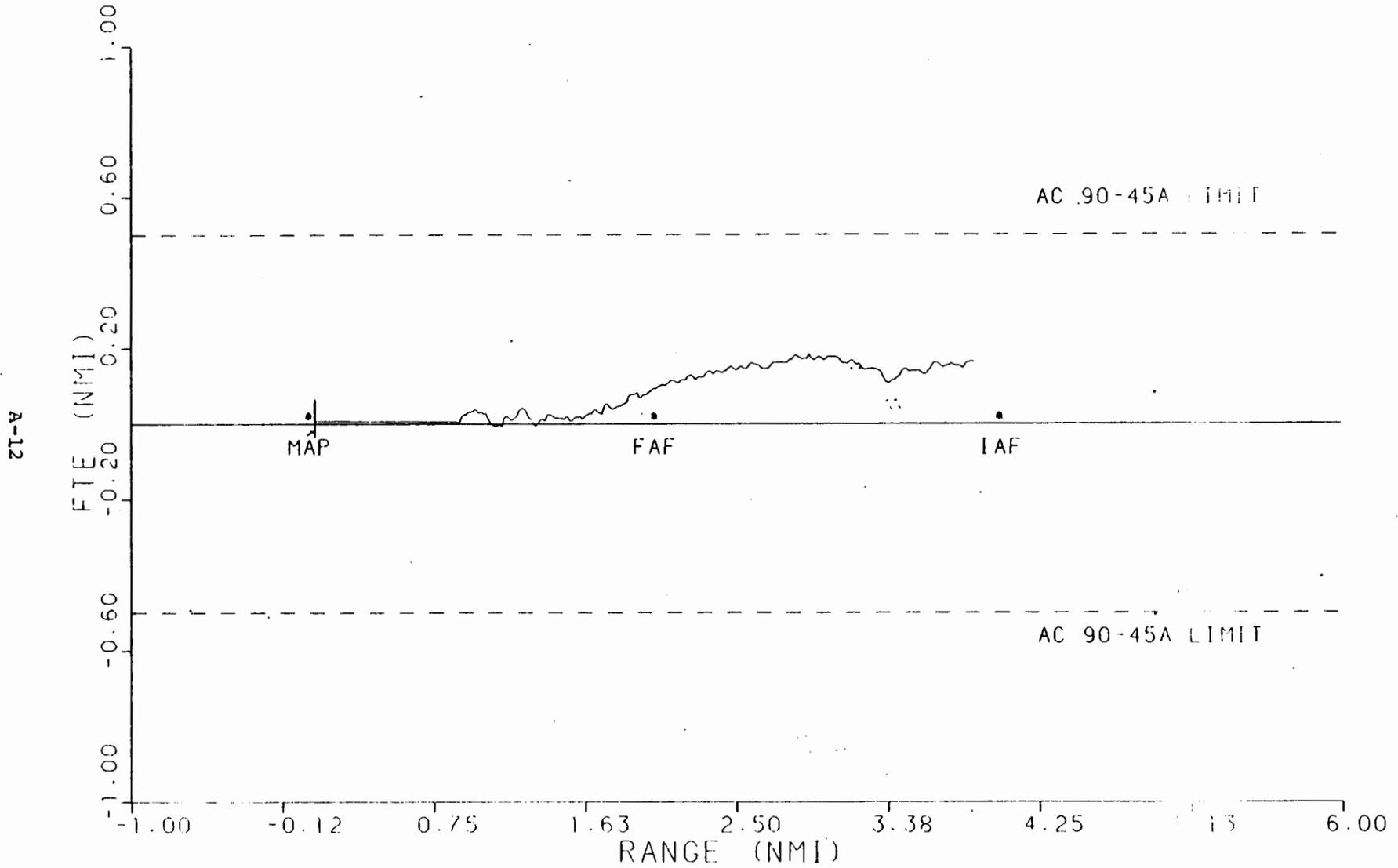
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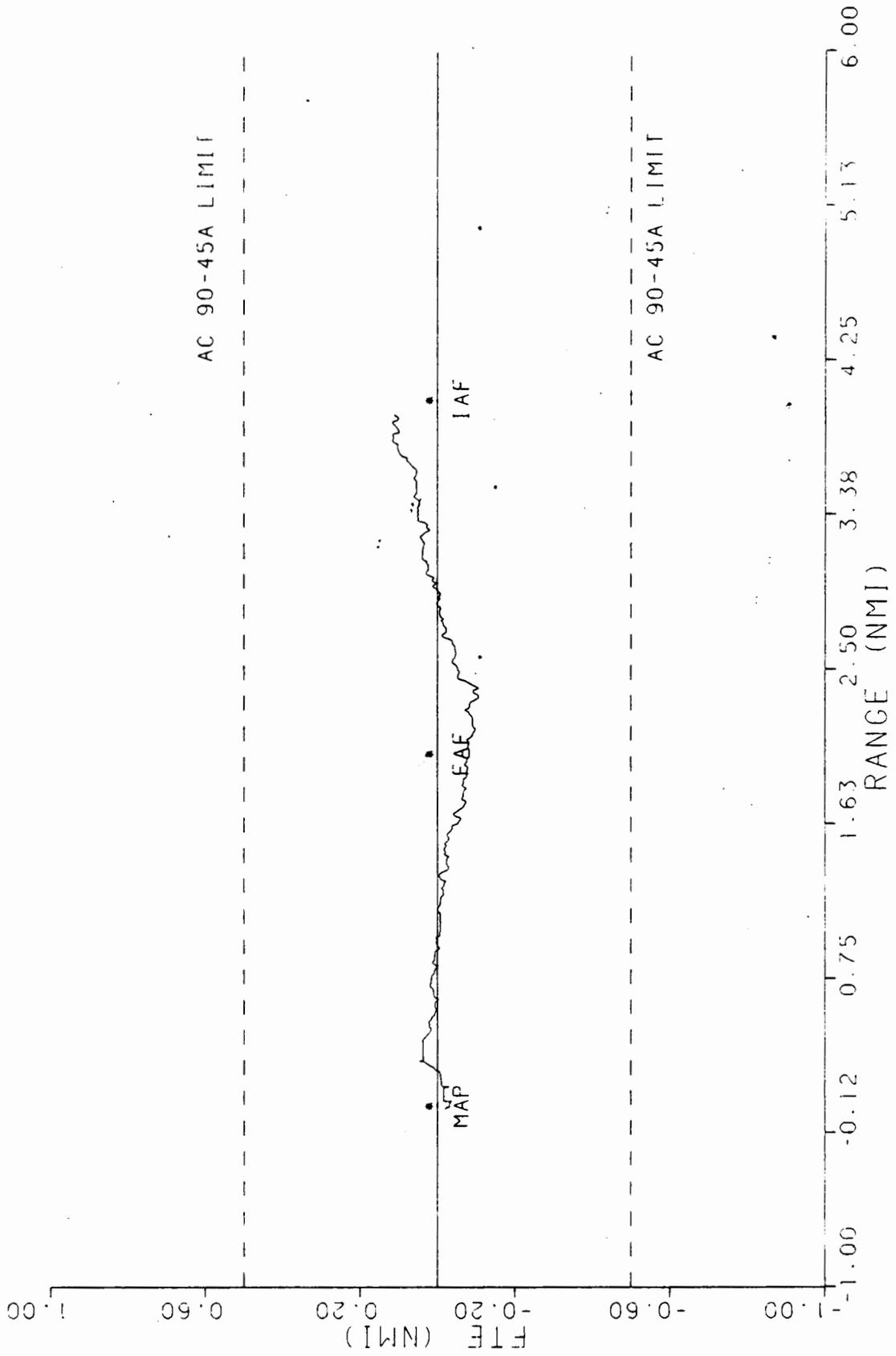
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RUN # 5

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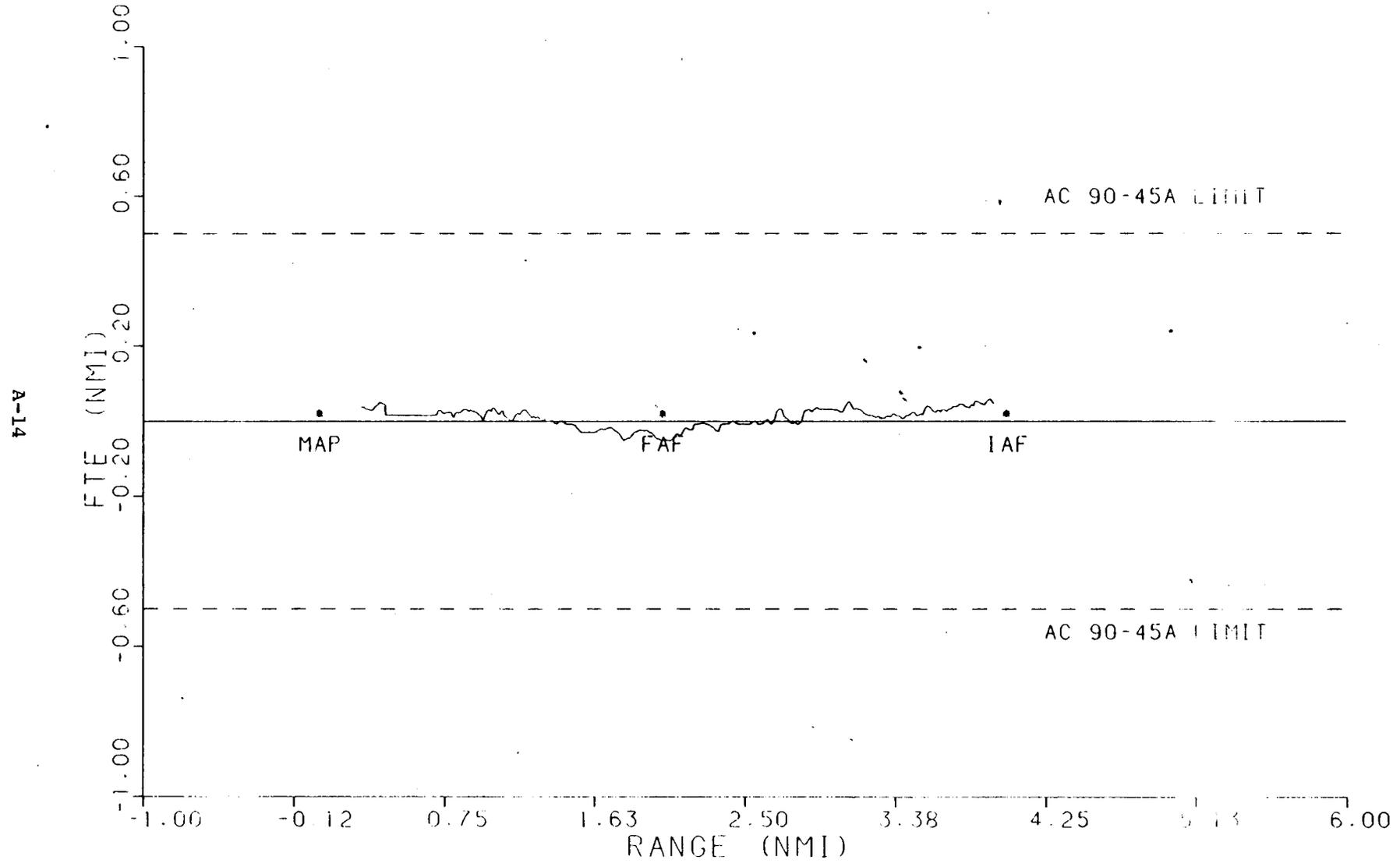
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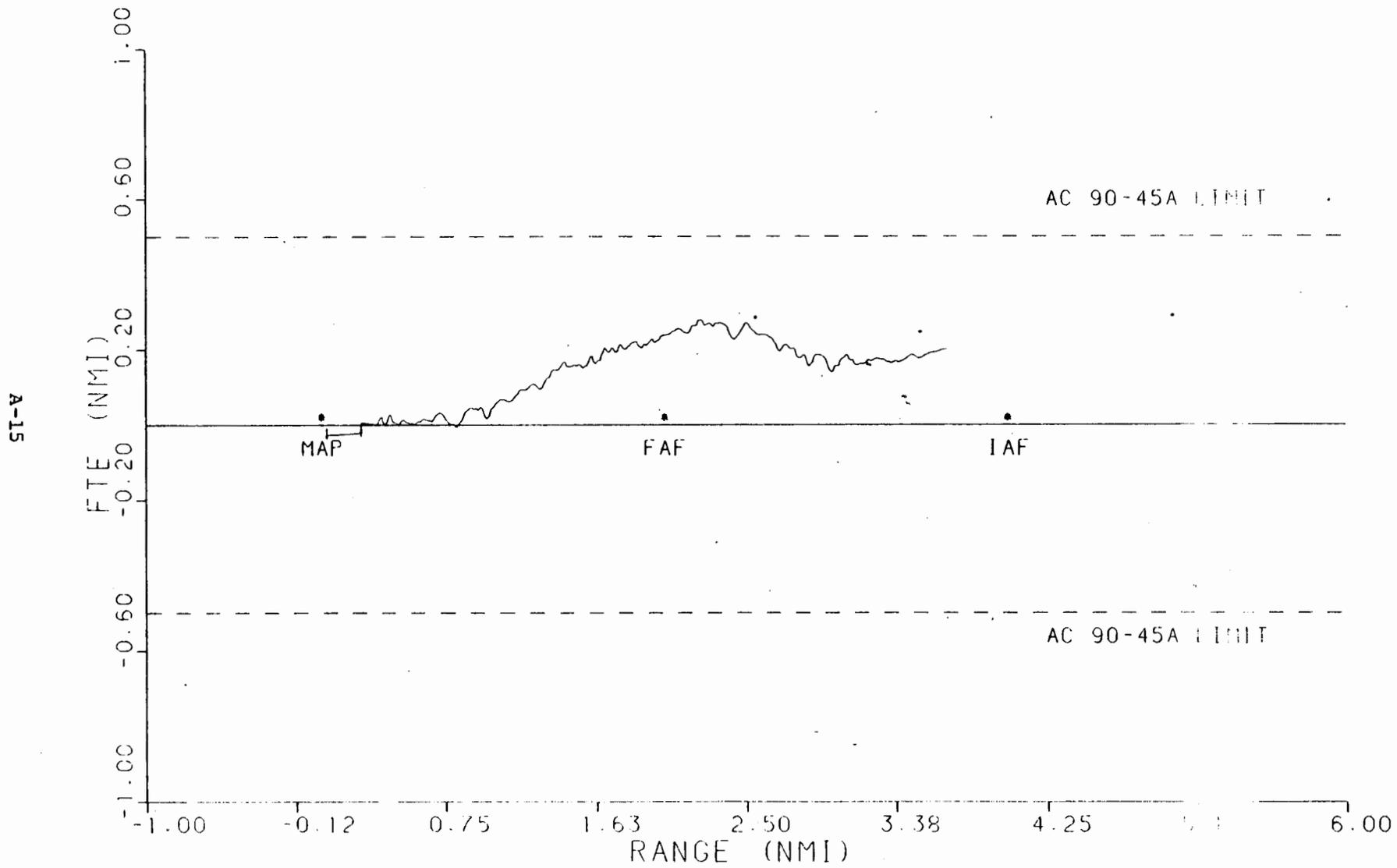
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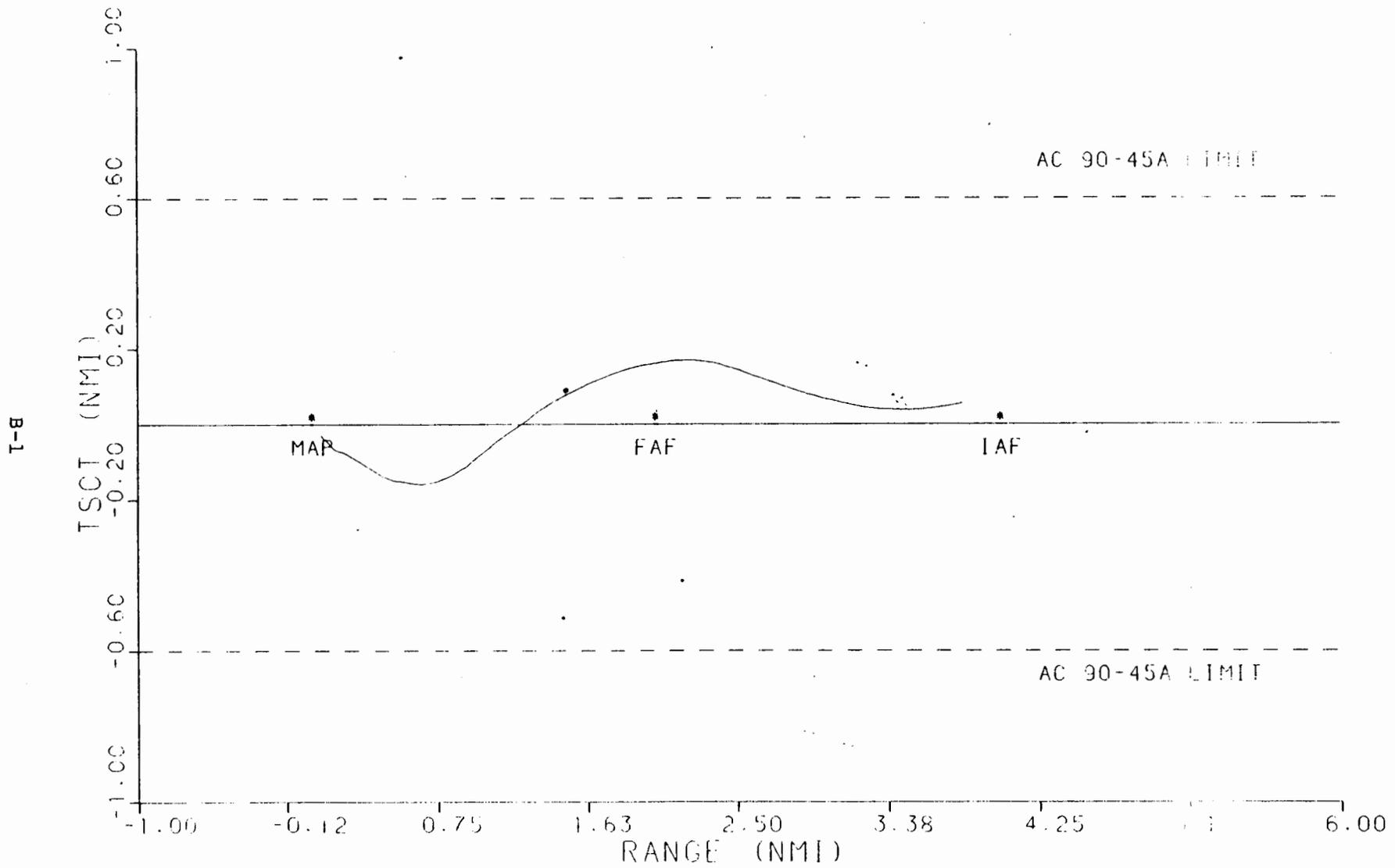
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APPENDIX B
FTE VERSUS RANGE PLOTS

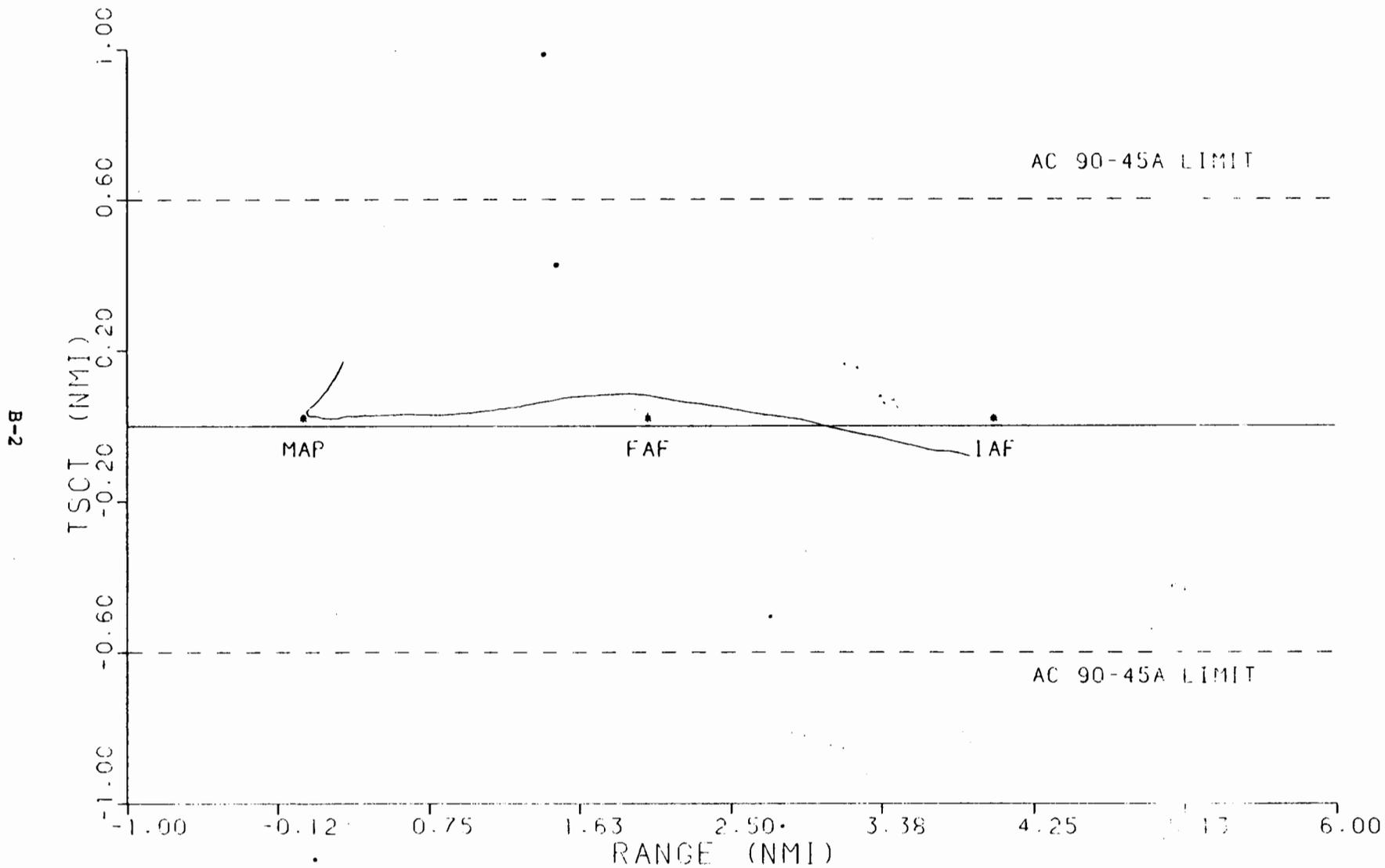
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RUN # 1

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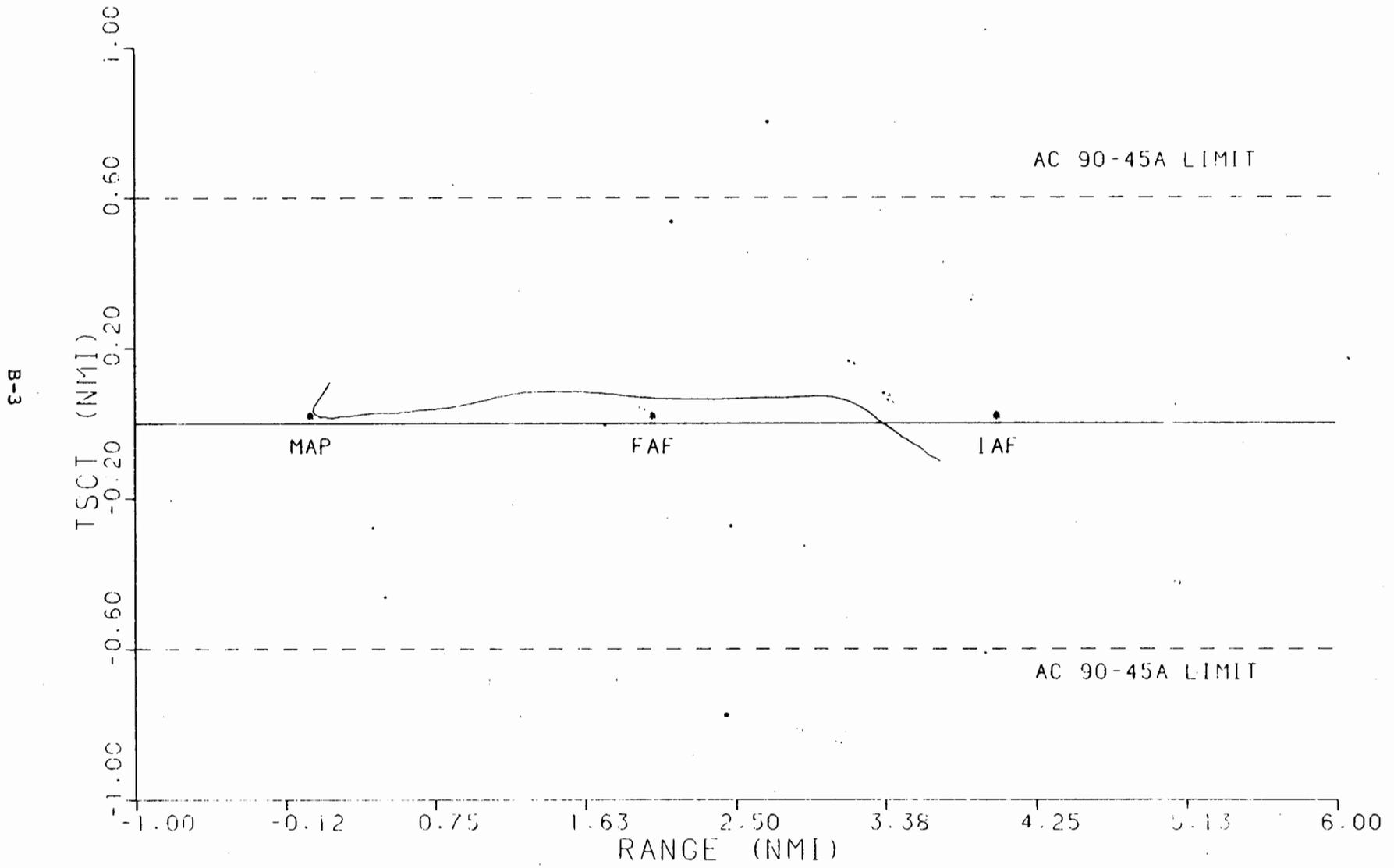
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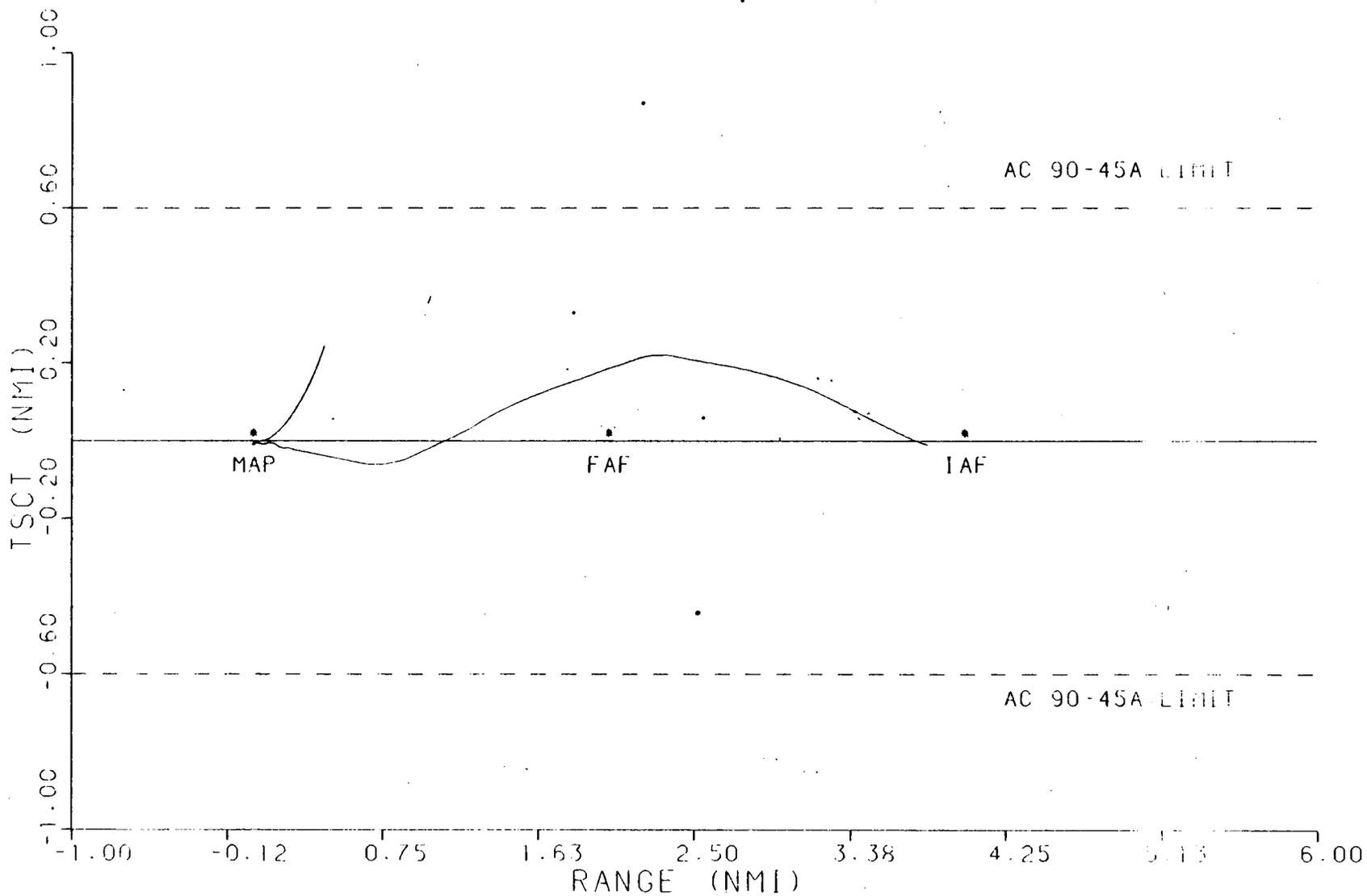
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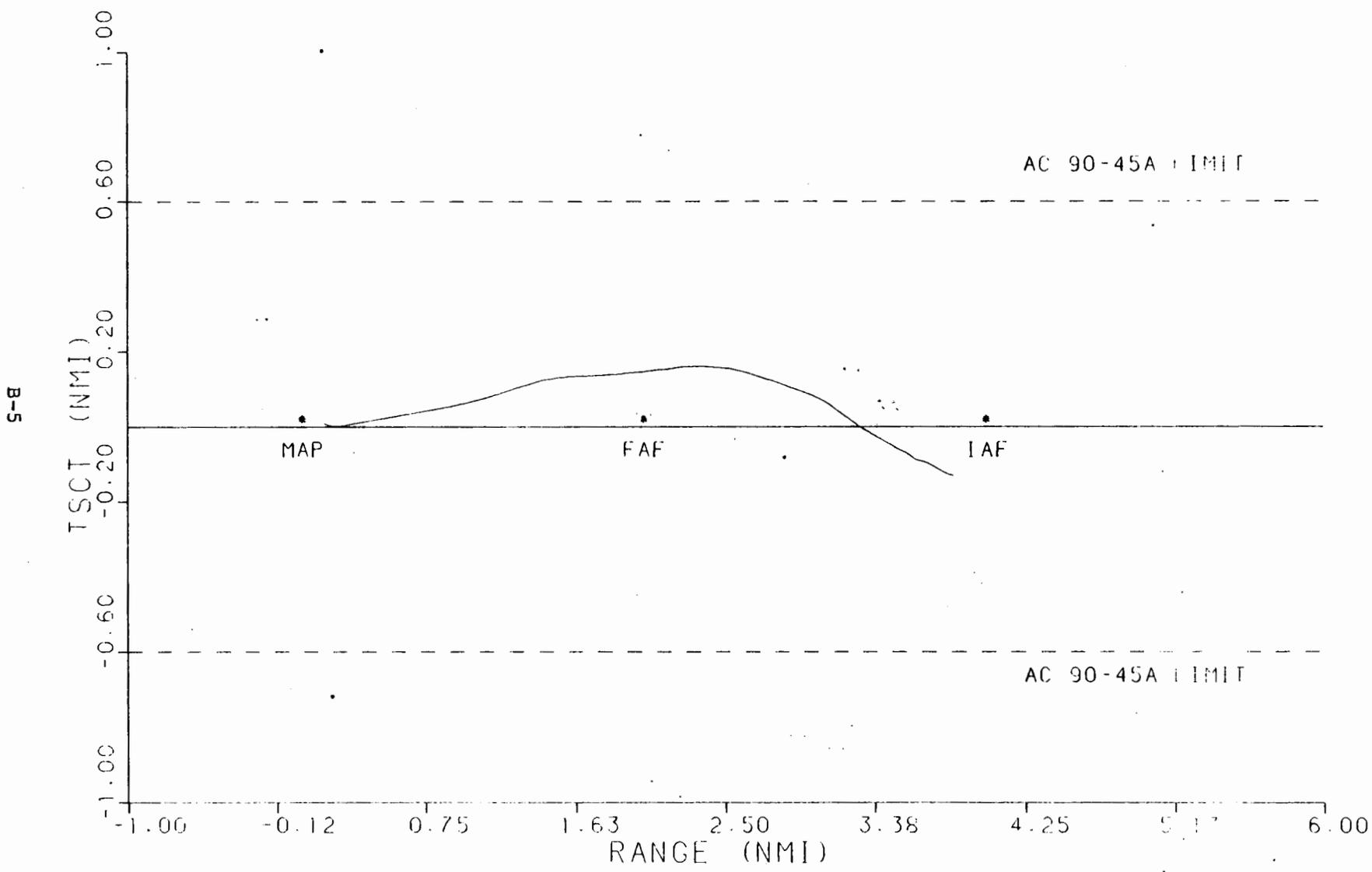
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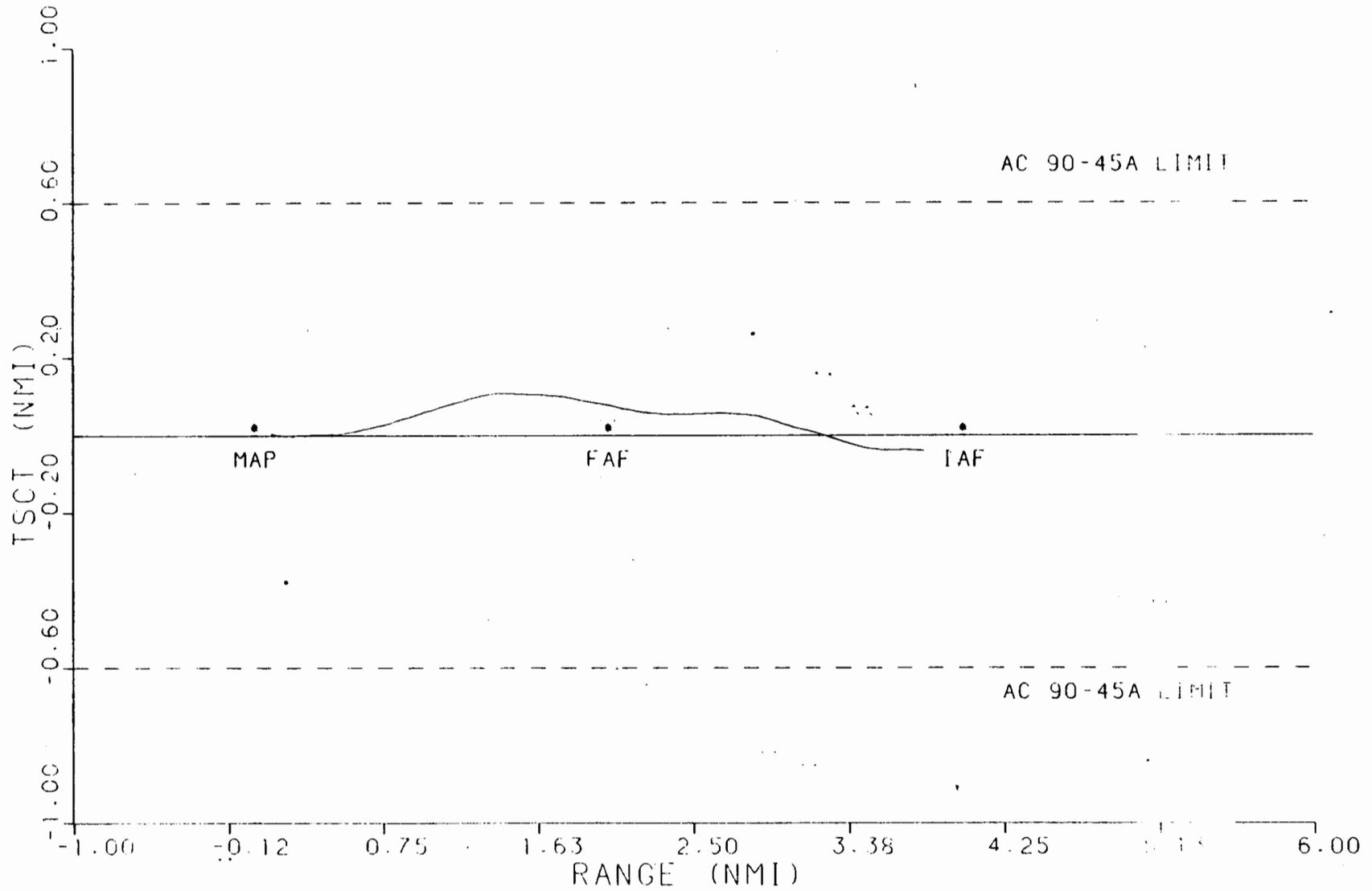
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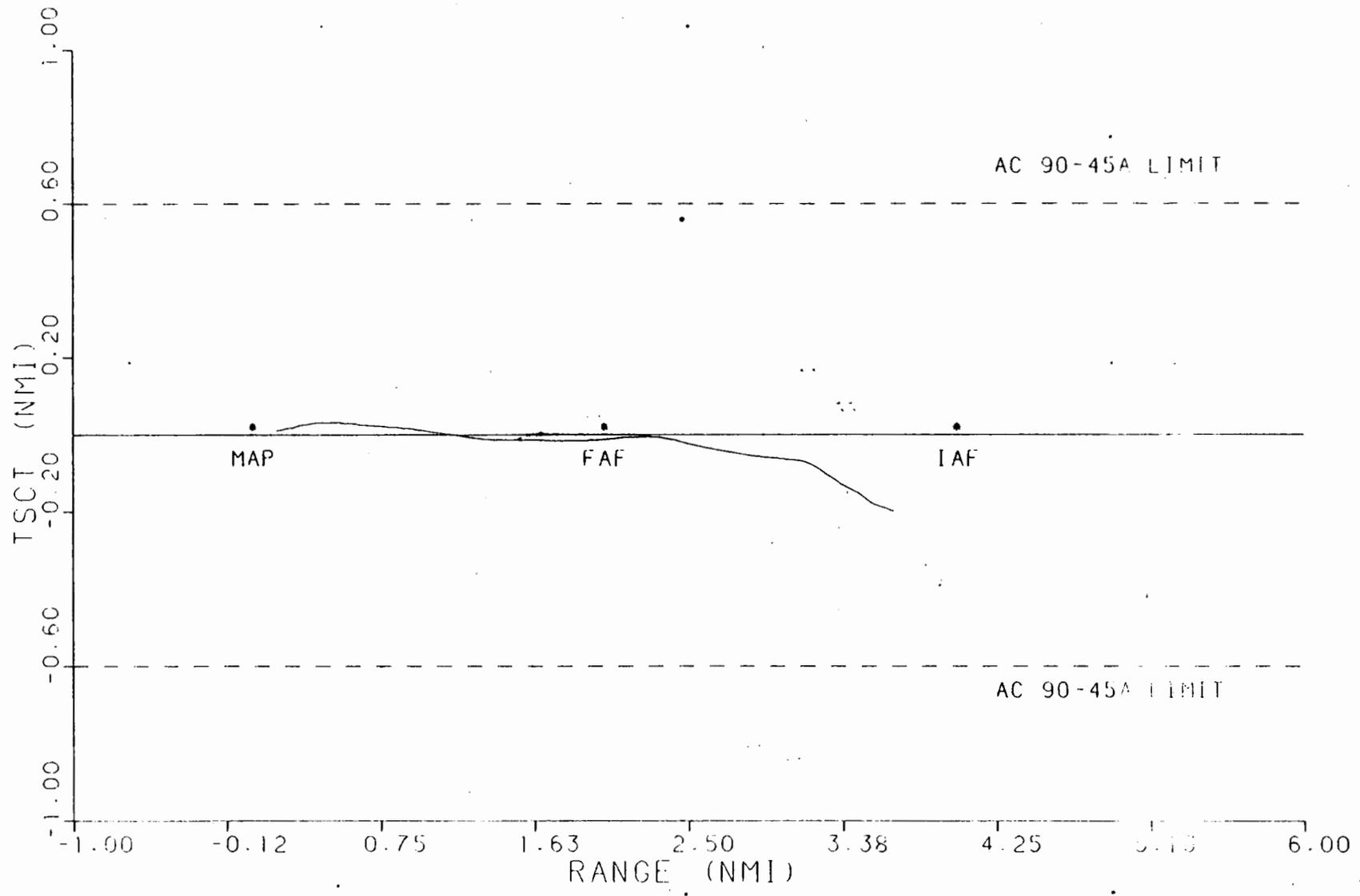
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FLIGHT #1 WITH SUBJECT PILOT #1
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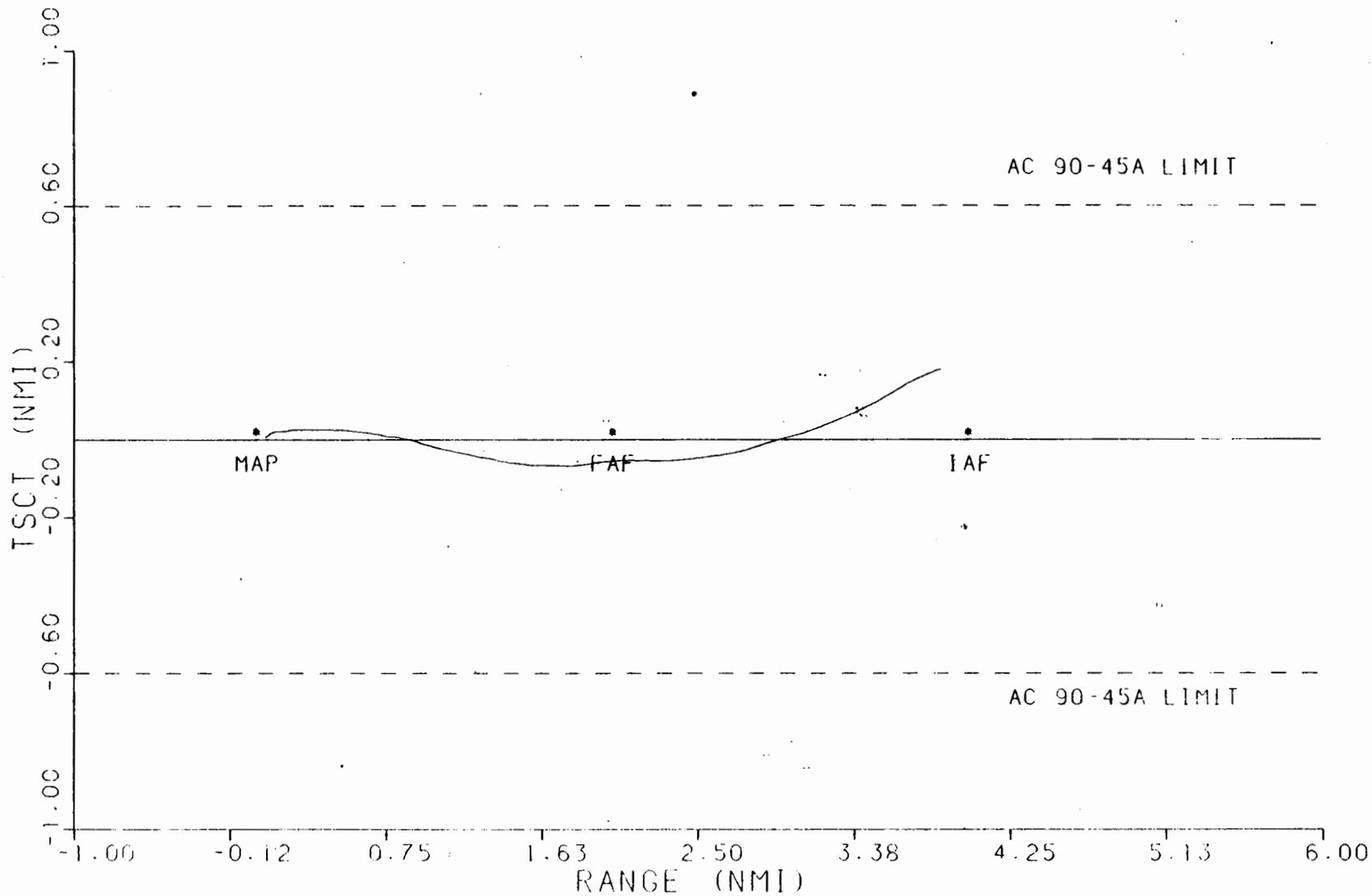
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RUN # 1

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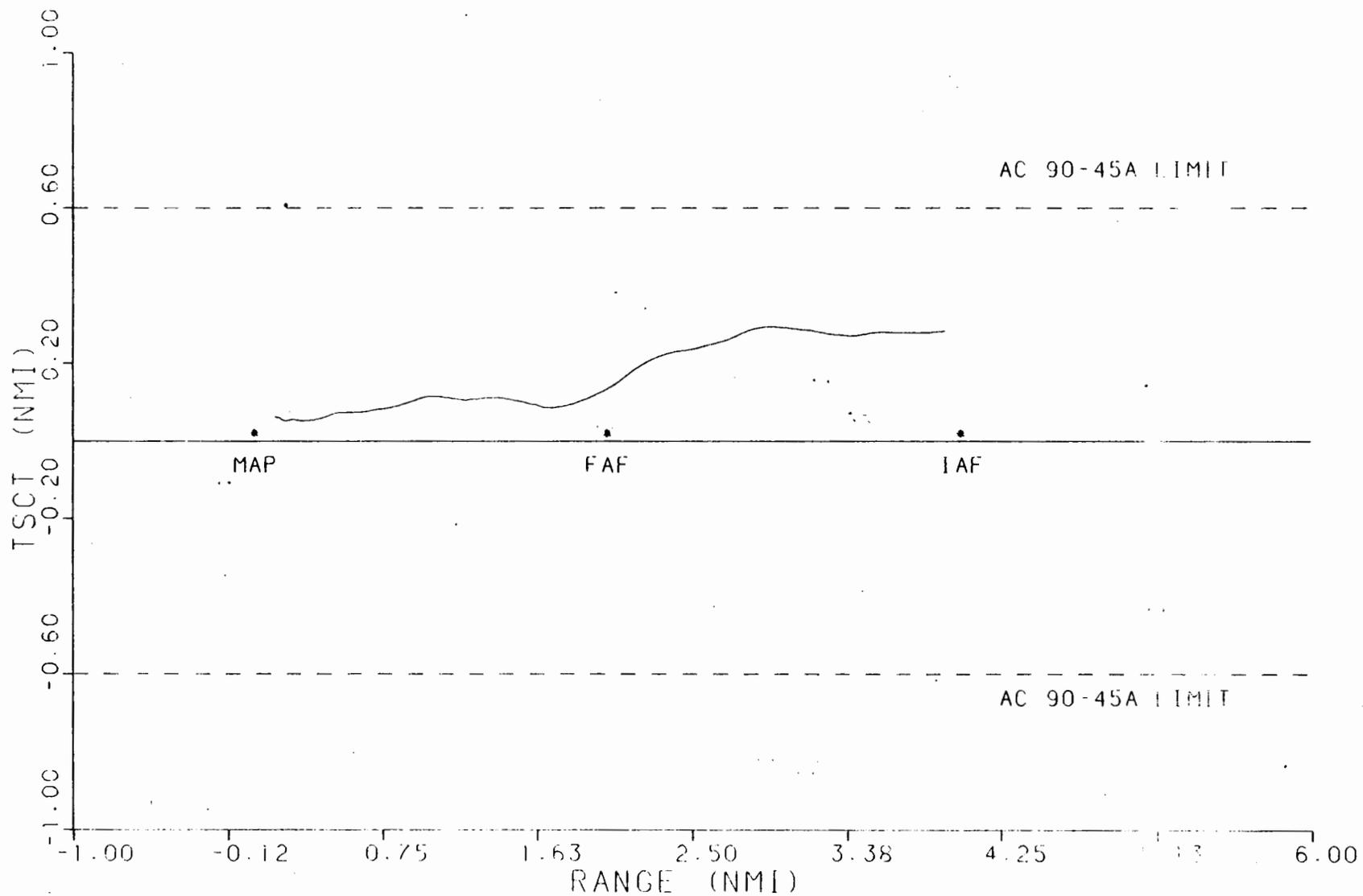
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RUN # 2

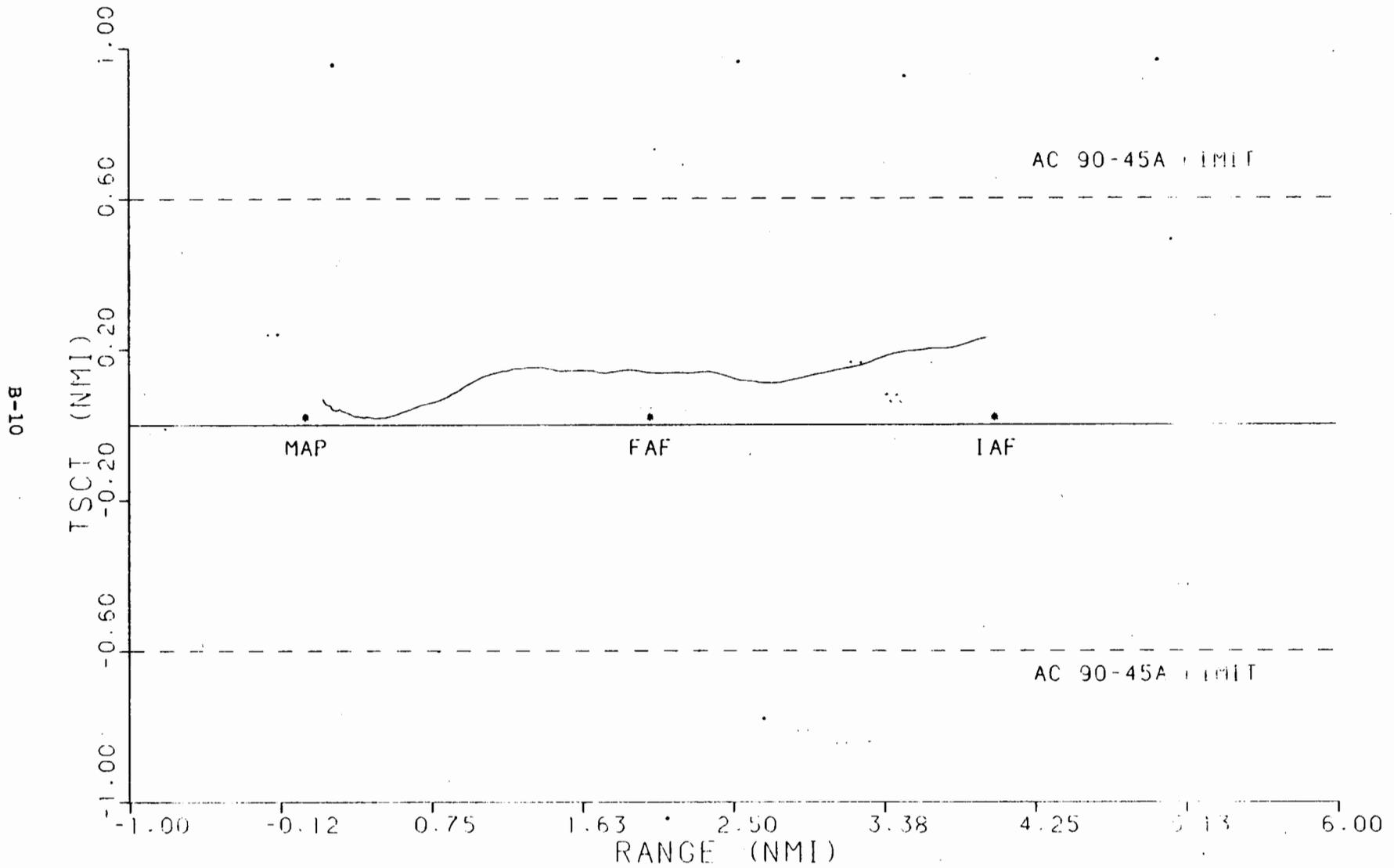
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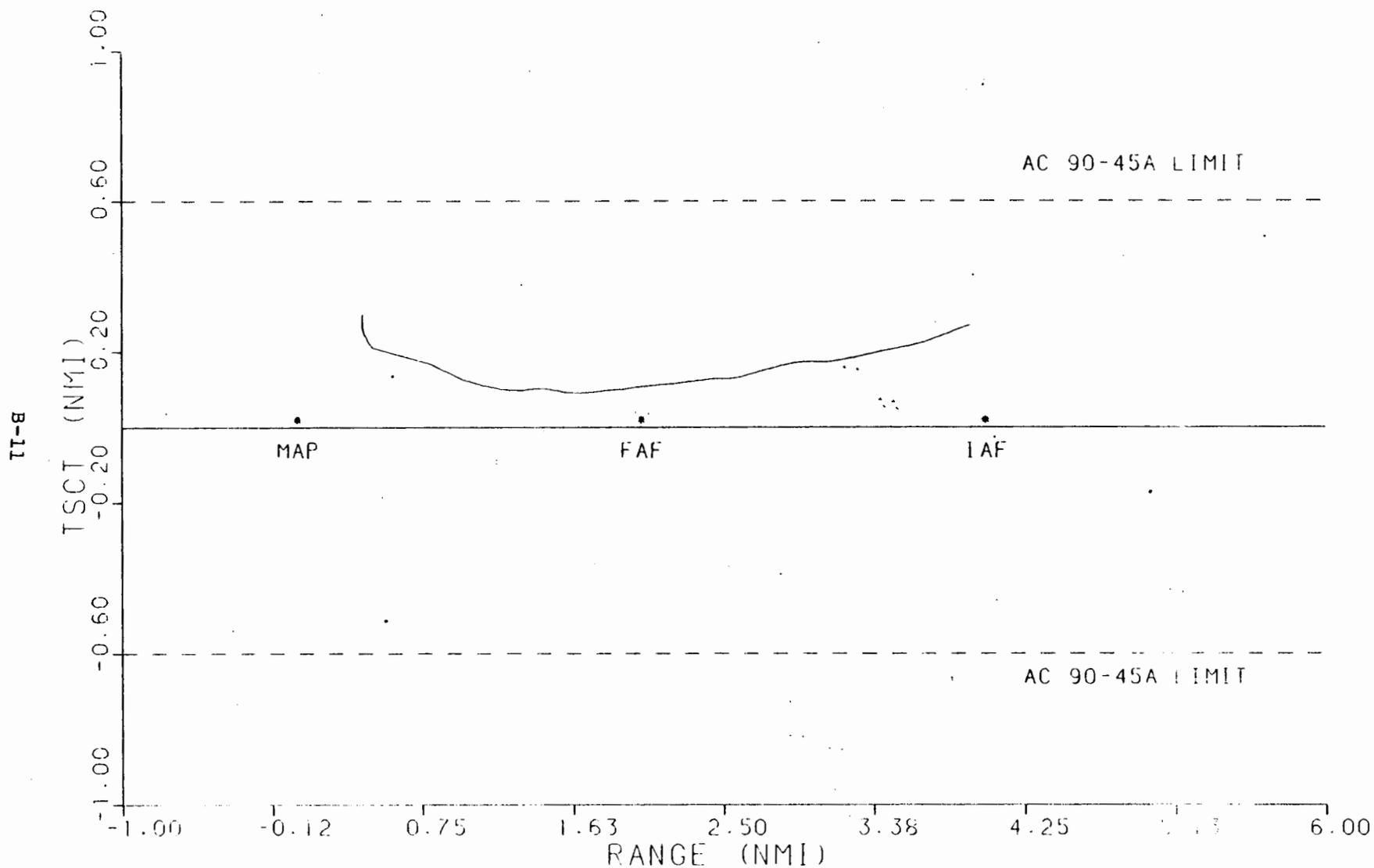
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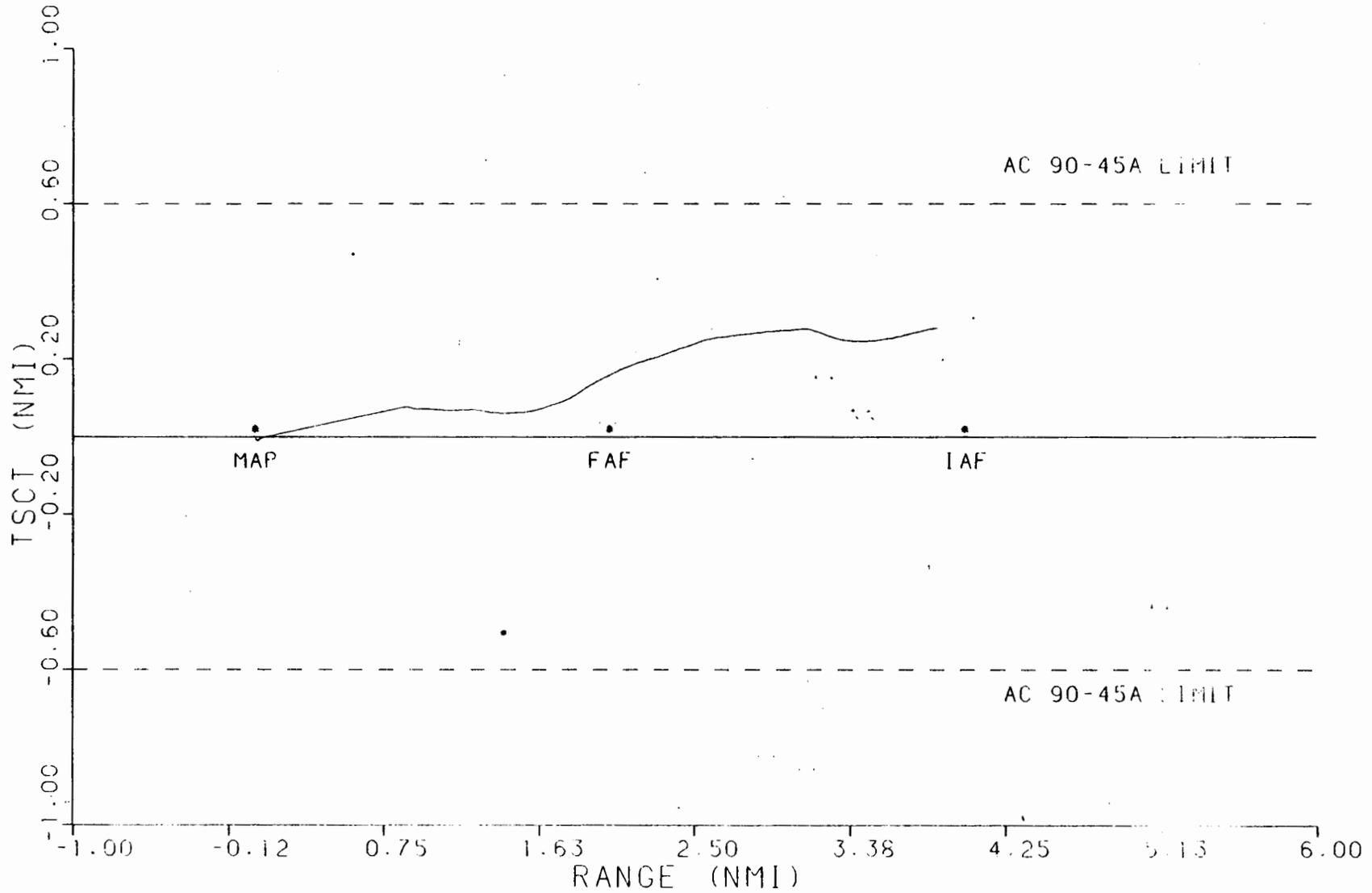
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ATLANTIC CITY AIRPORT, N. J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 5

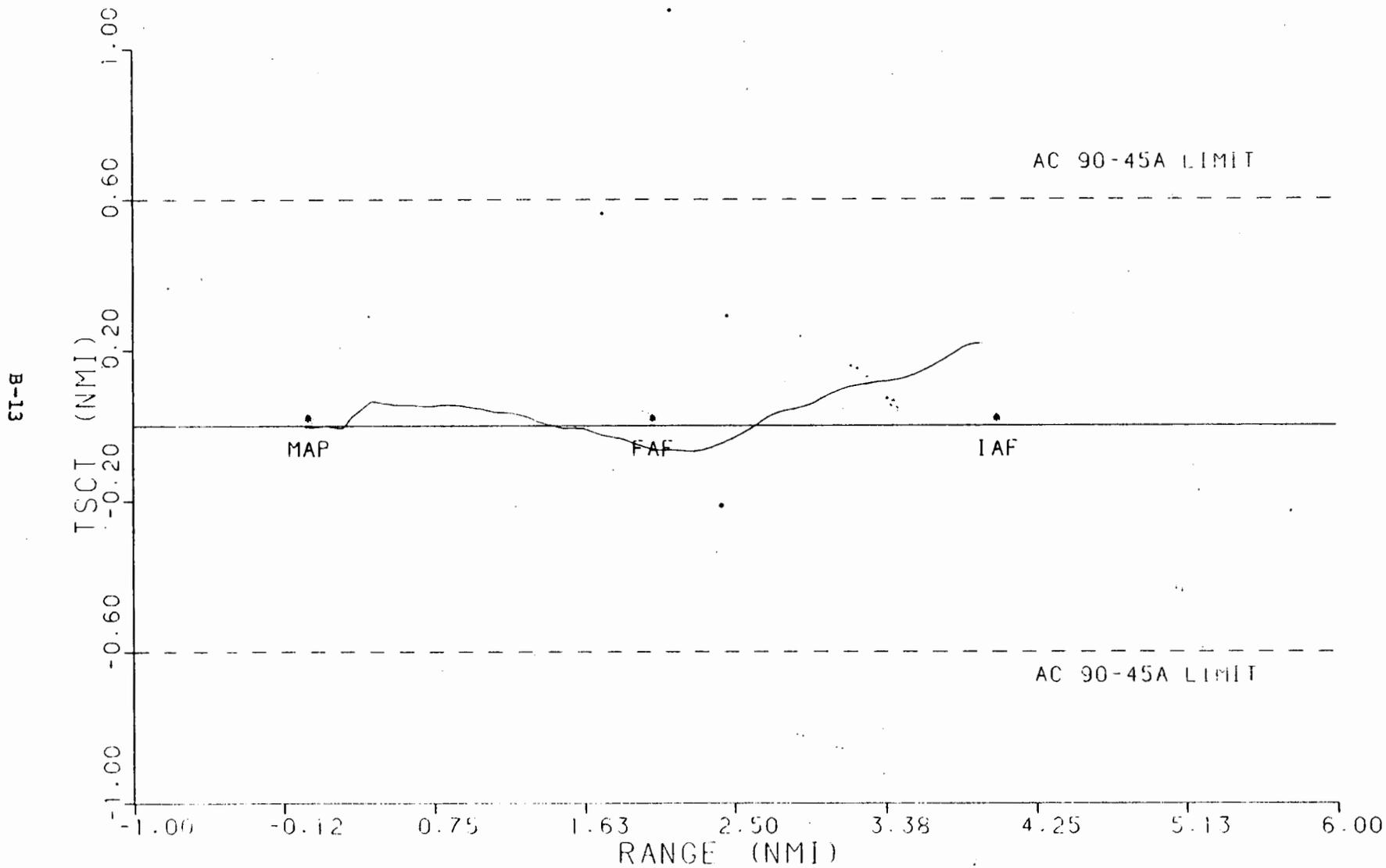
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTA CITY AIRPORT, N.J. 07425

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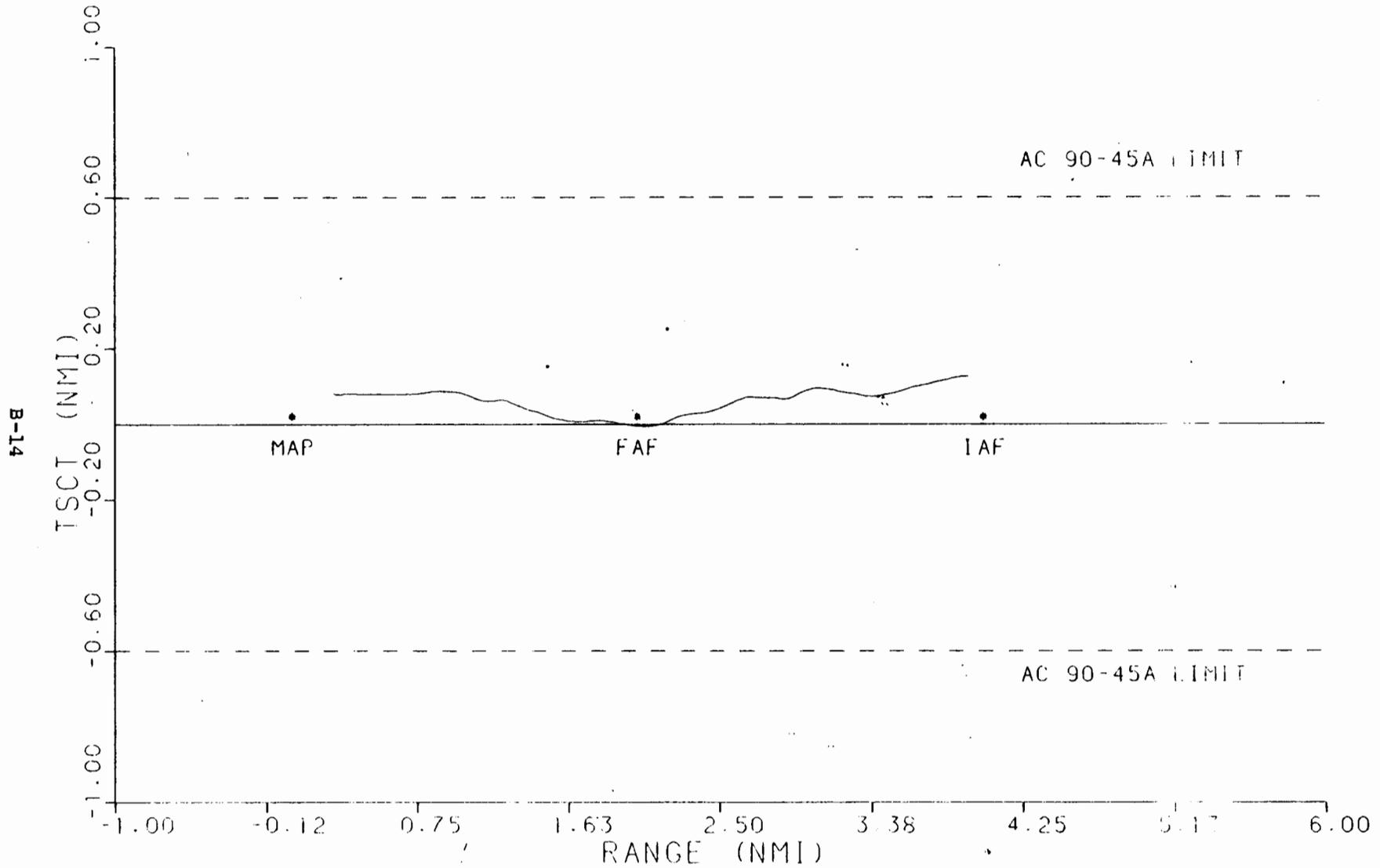
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 6

DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTA CITY AIRPORT, N.J. 08405



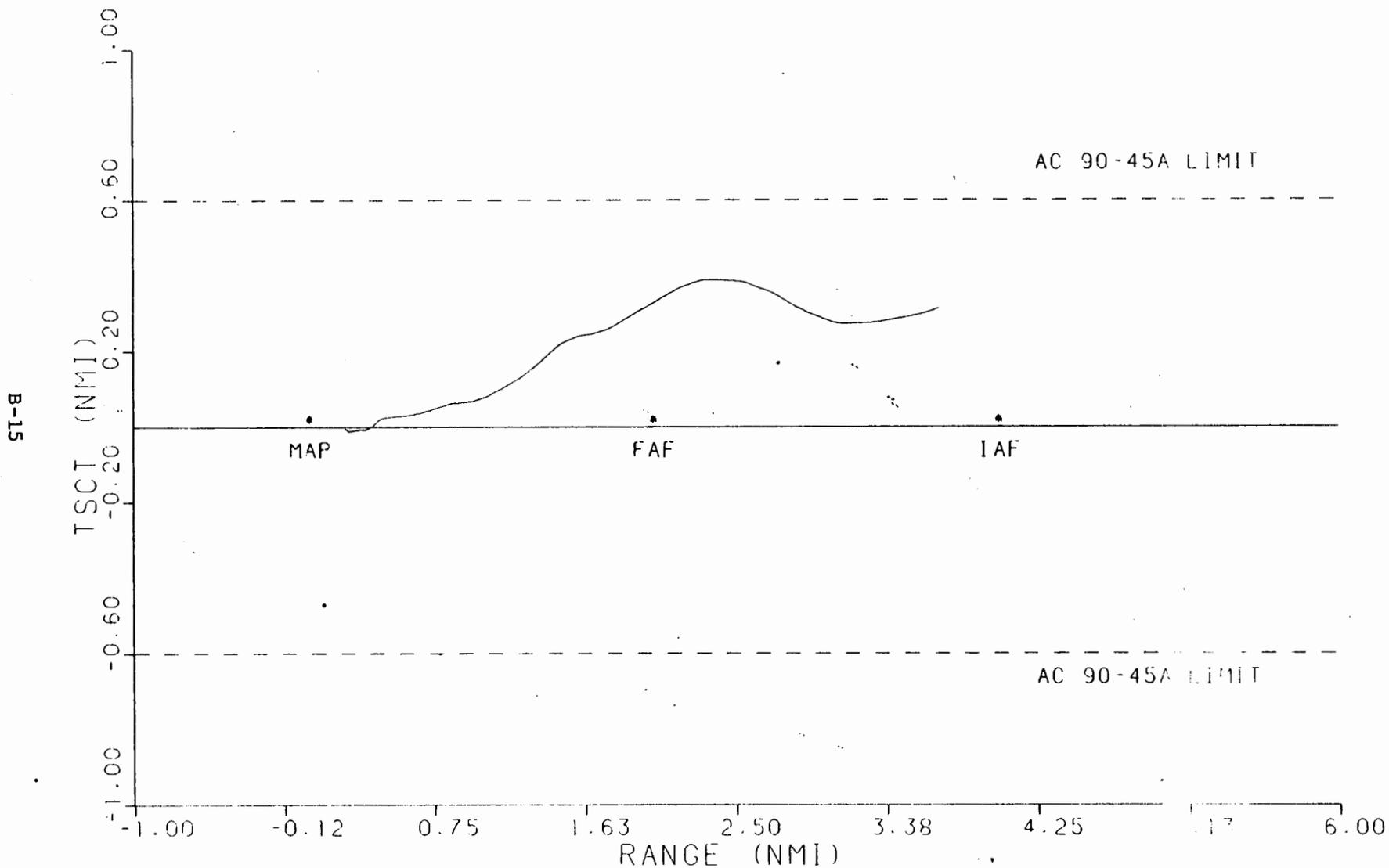
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 7

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTA FITE AIRPORT, N. J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 8

DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405

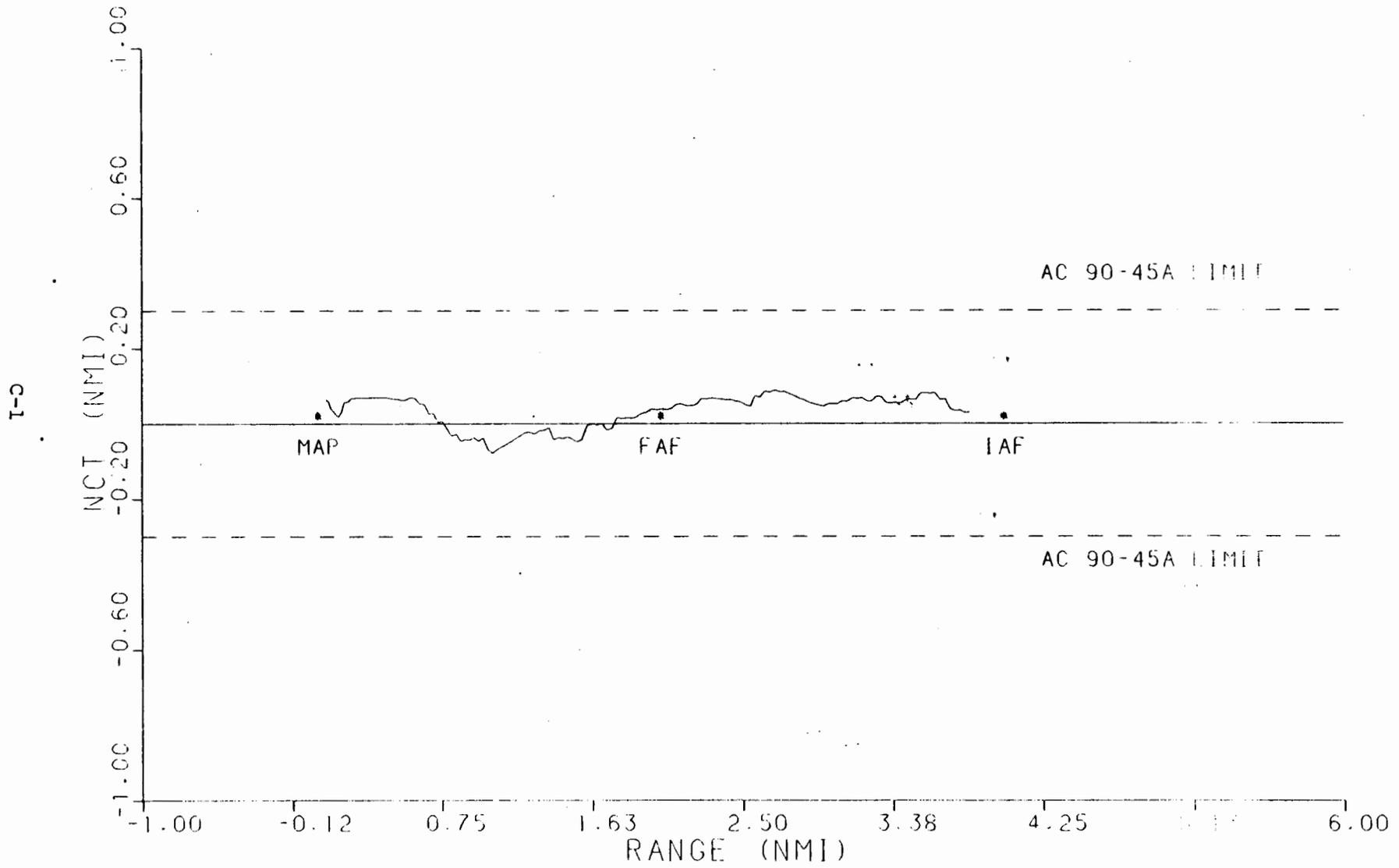


APPENDIX C

NCT VERSUS RANGE PLOTS

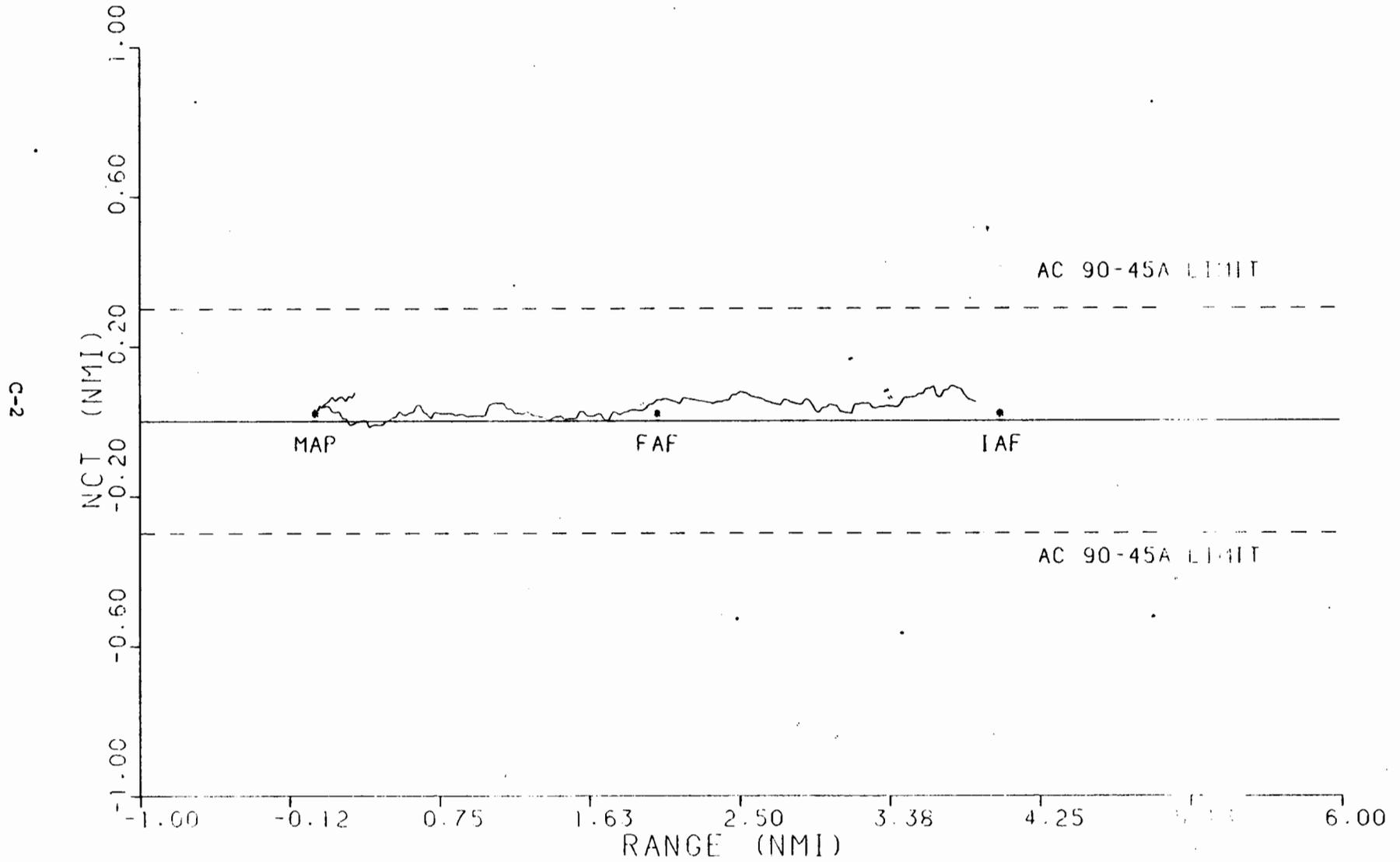
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 1

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405



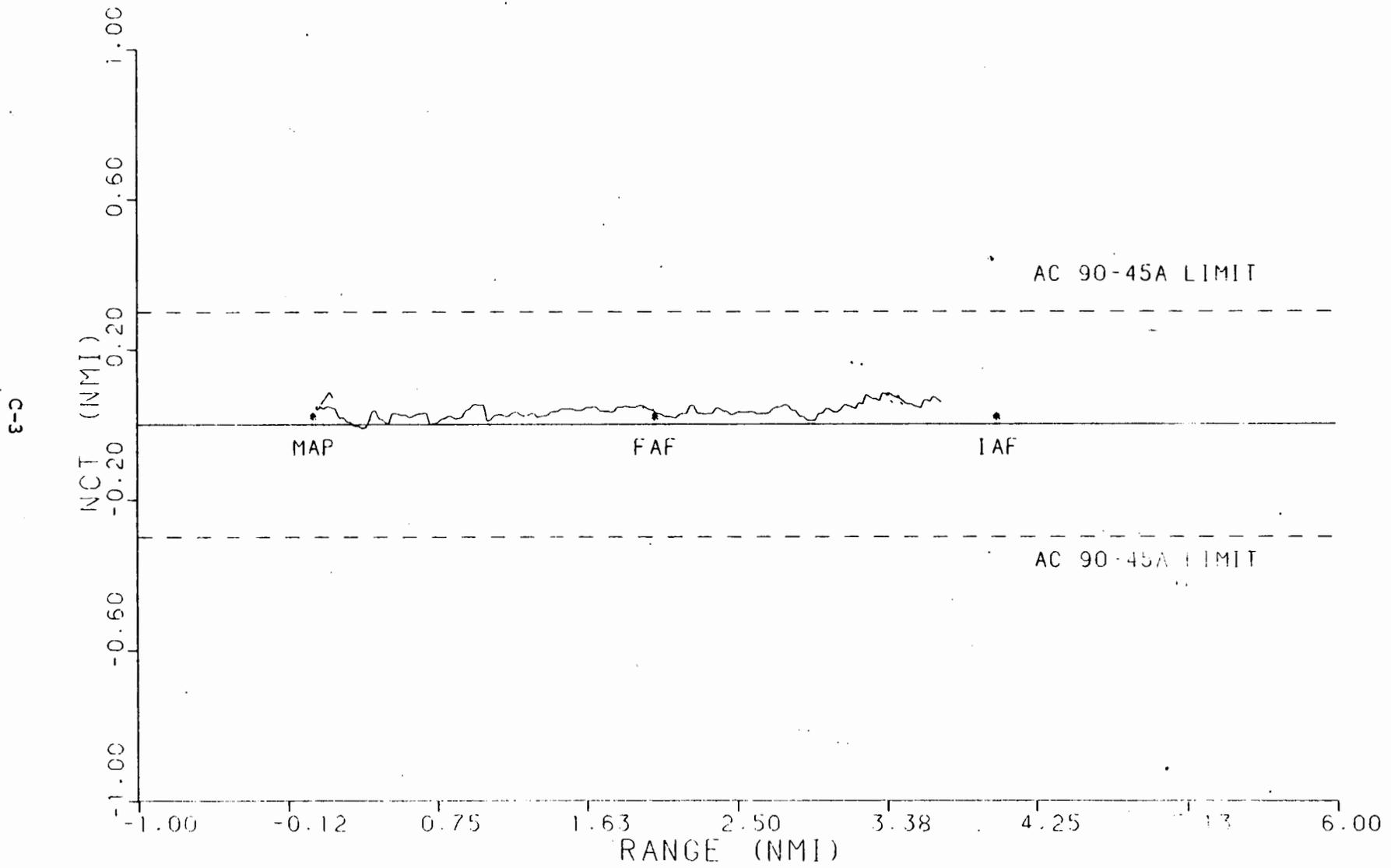
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 2

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



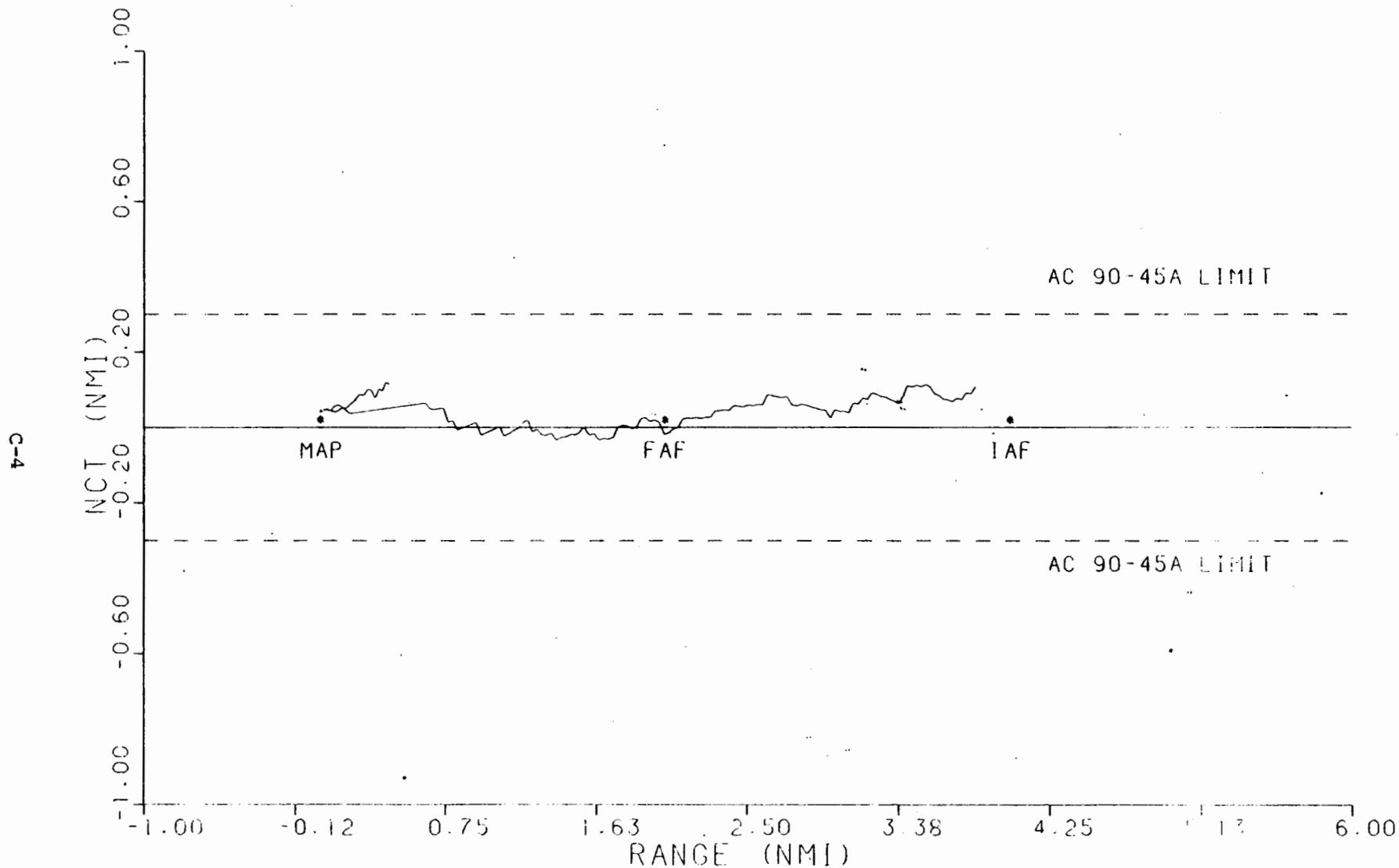
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 3

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405



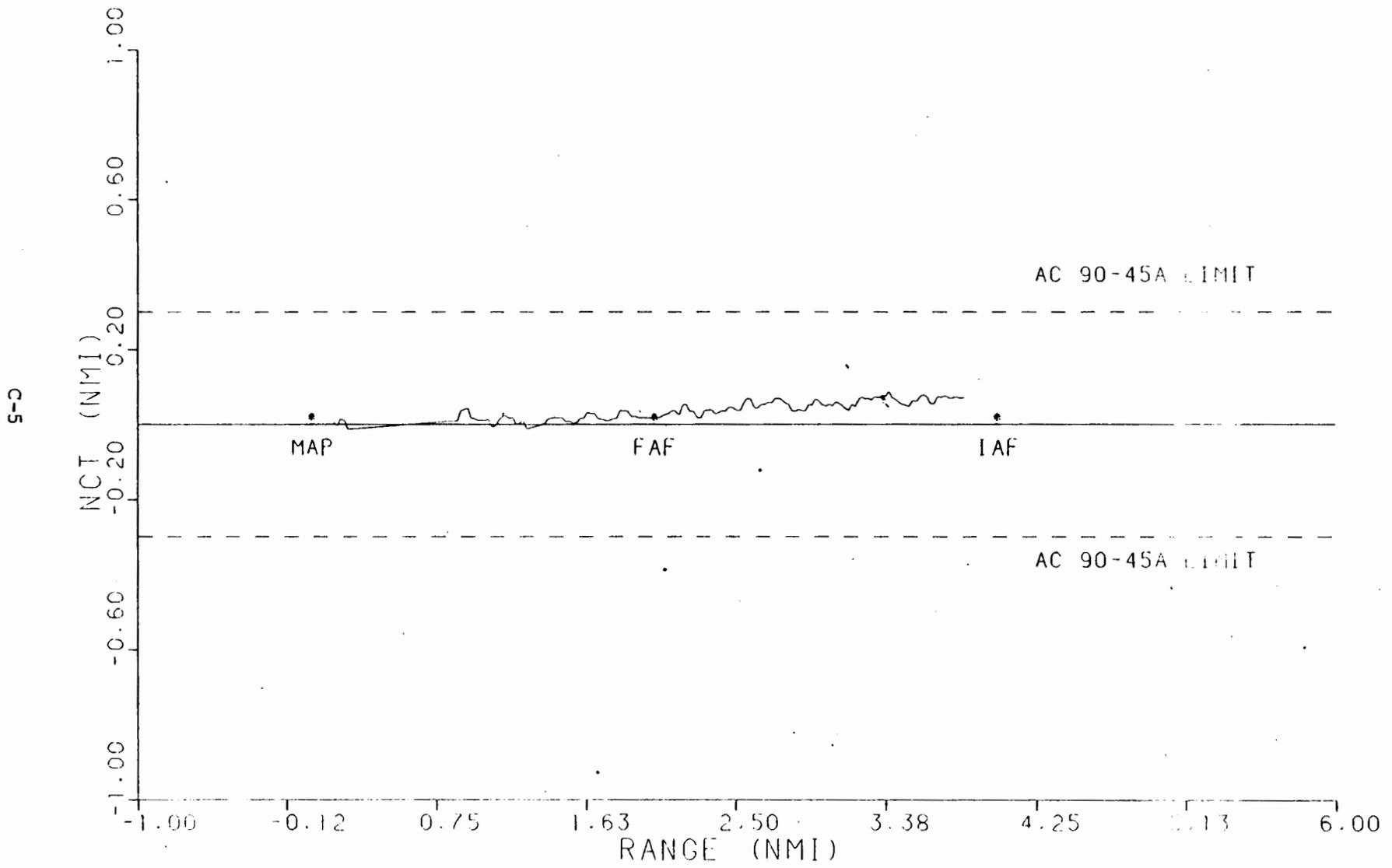
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 4

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 5

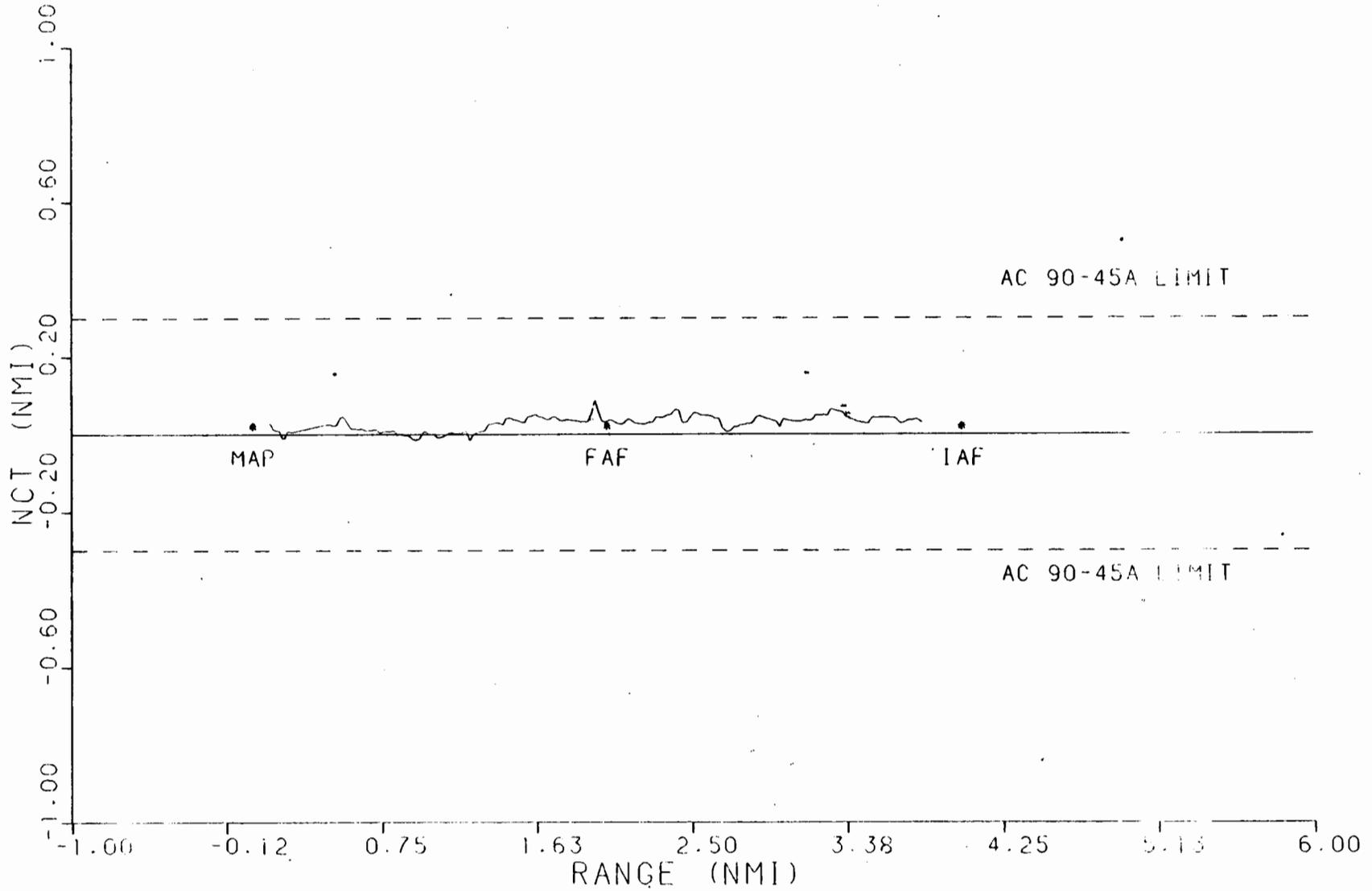
DATA PROVIDED BY THE FAA TECHNICAL CENTER
ALBANY CITY AIRPORT, N. J. 08407



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 6

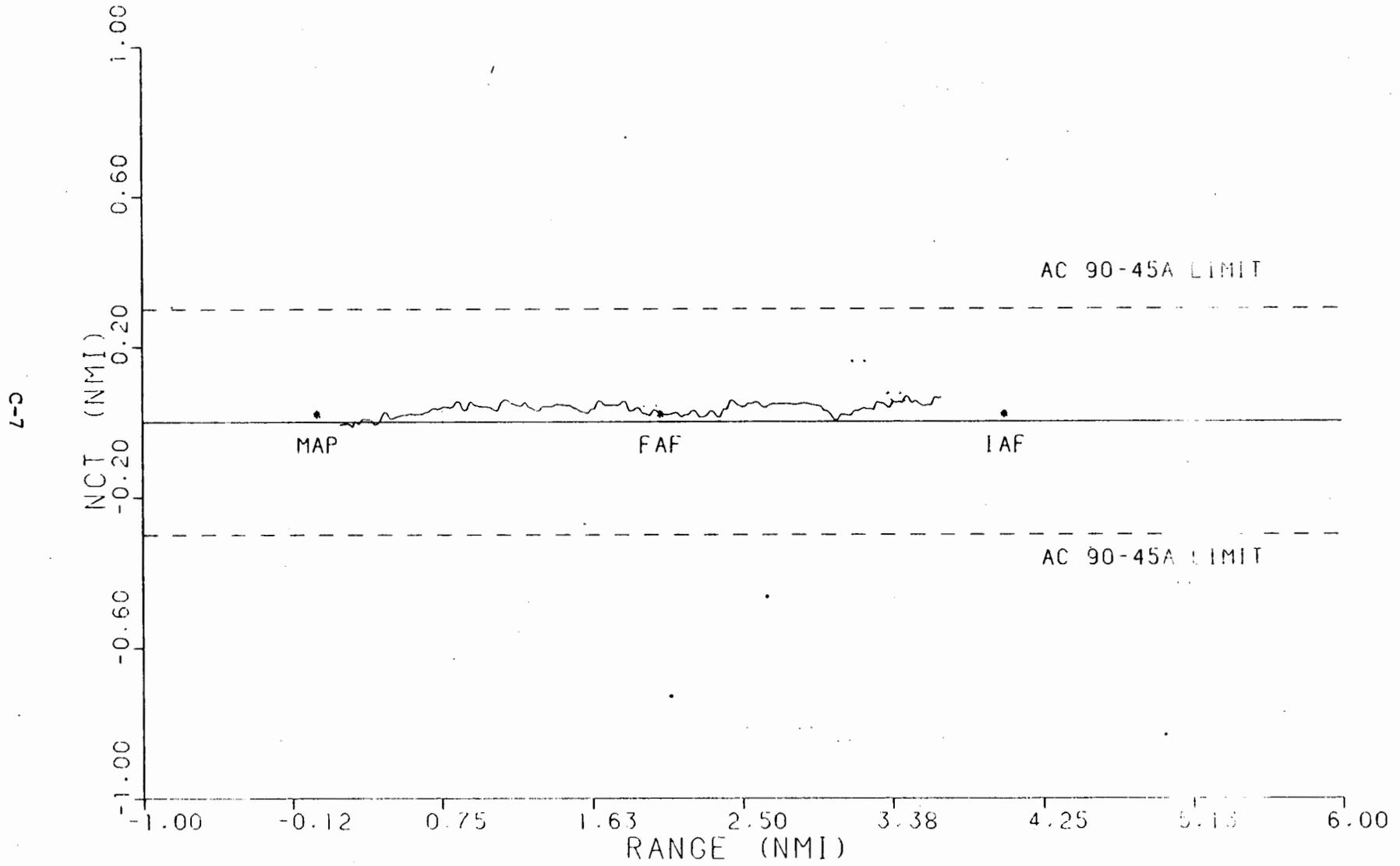
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405

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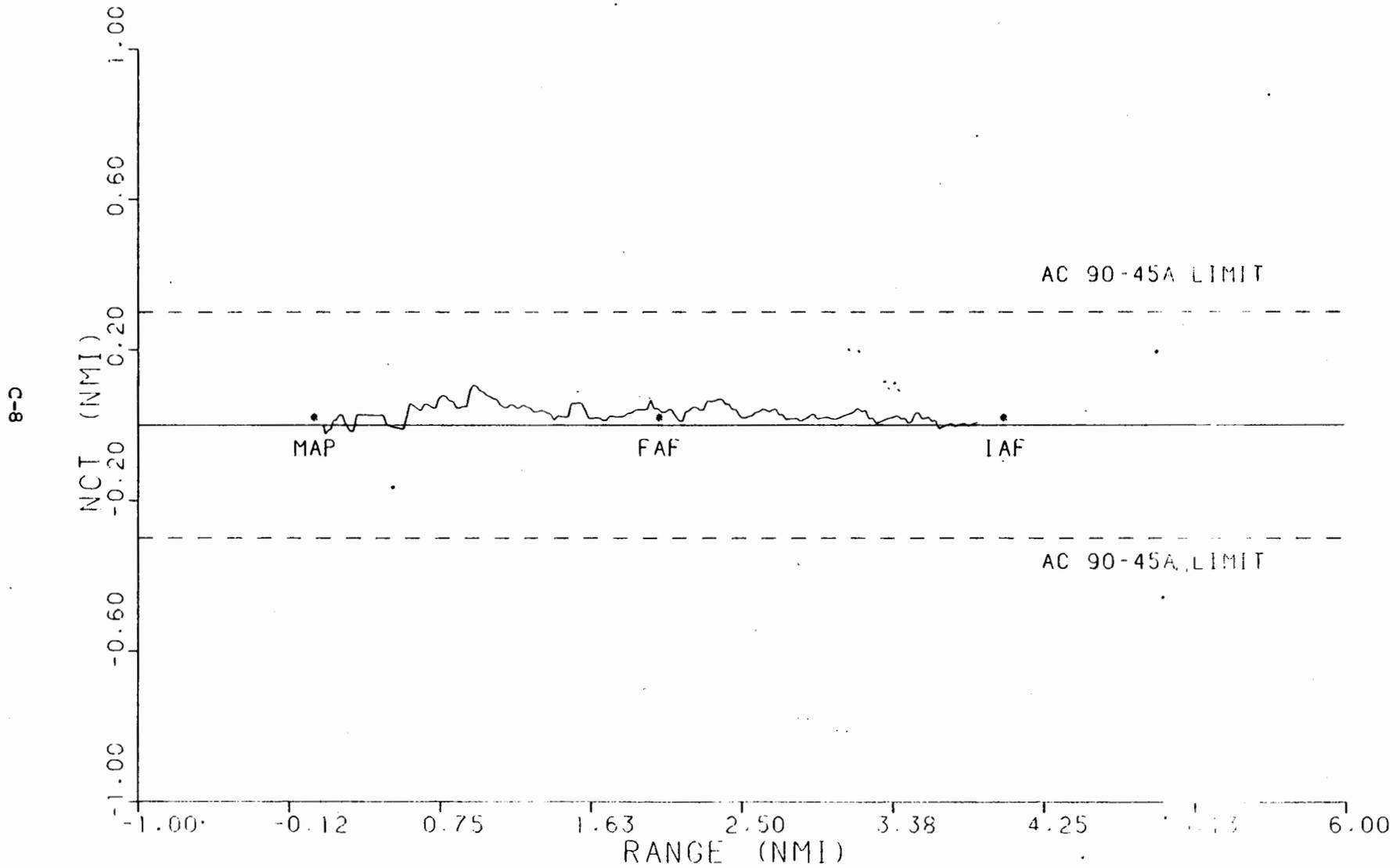
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 8

DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 1

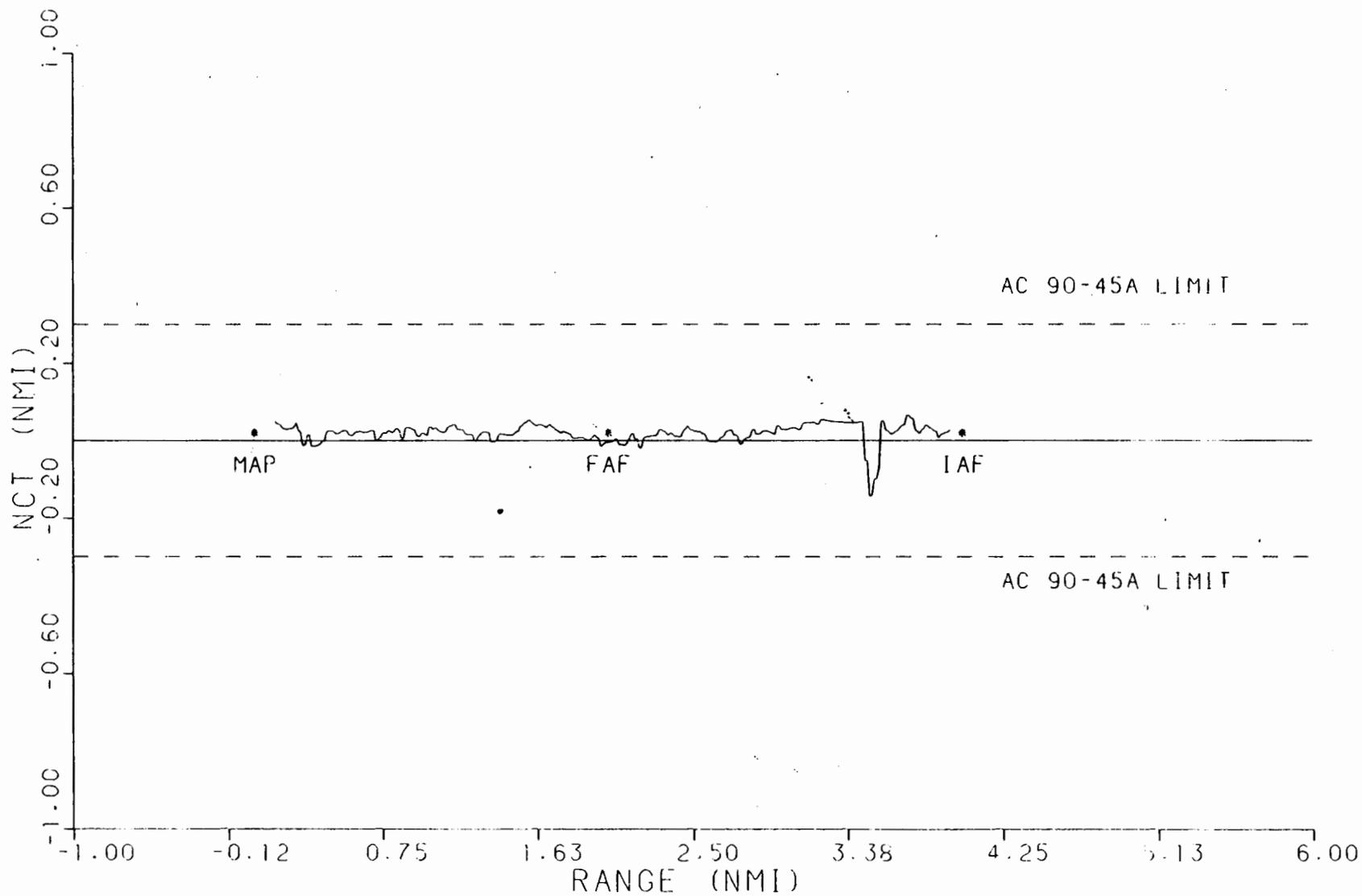
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 2

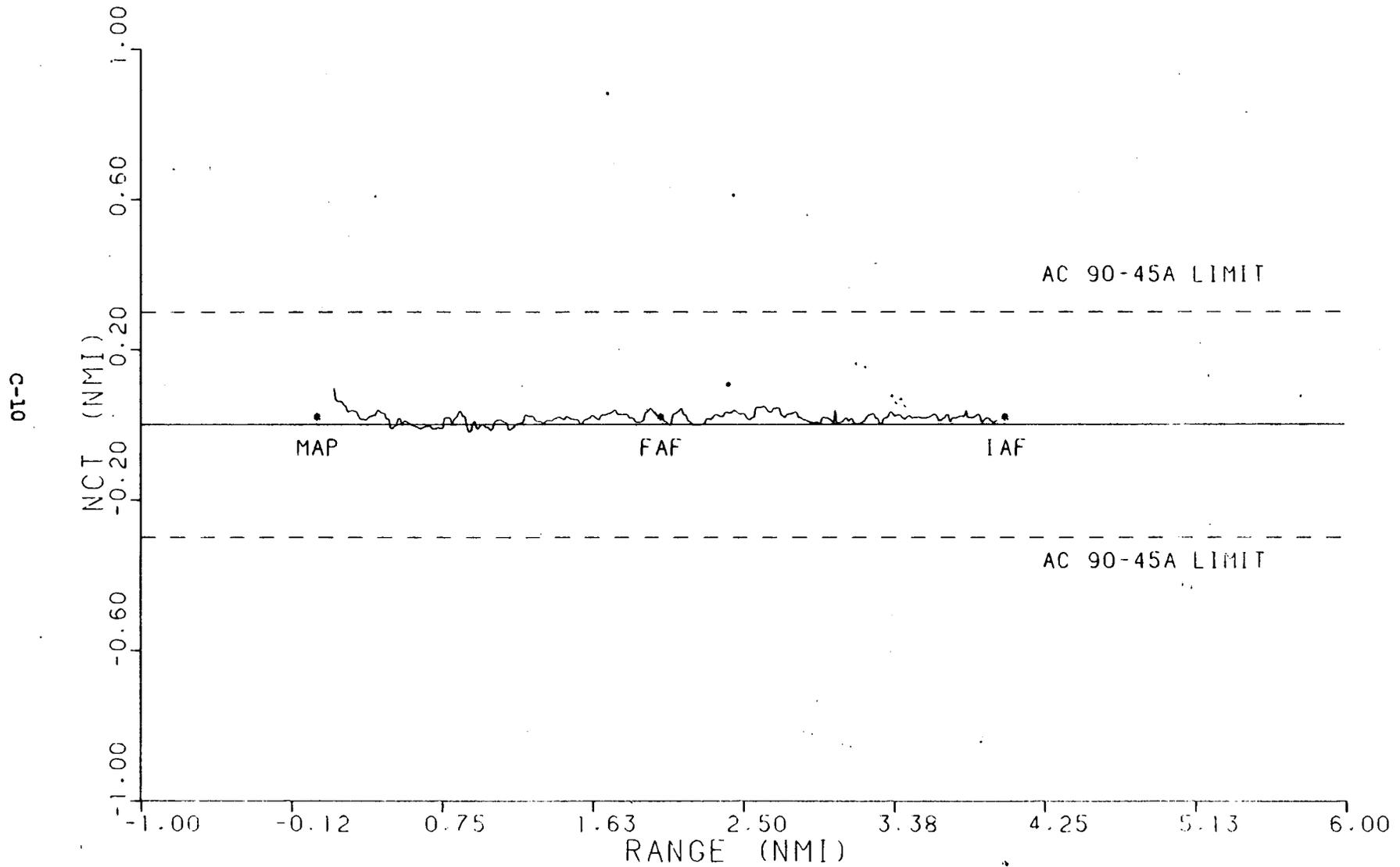
DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

6-C



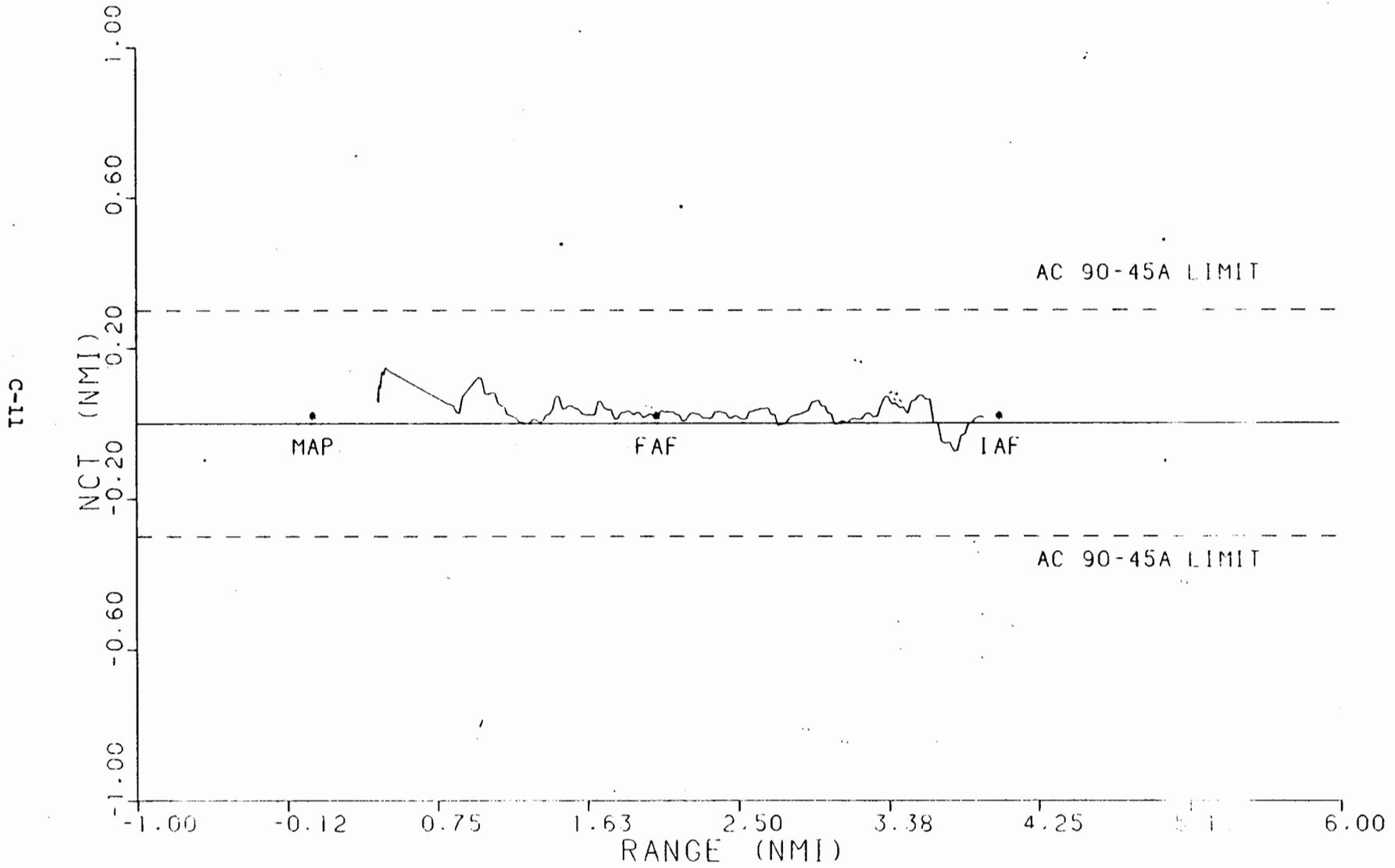
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 3

DATA OBTAINED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08402



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 4

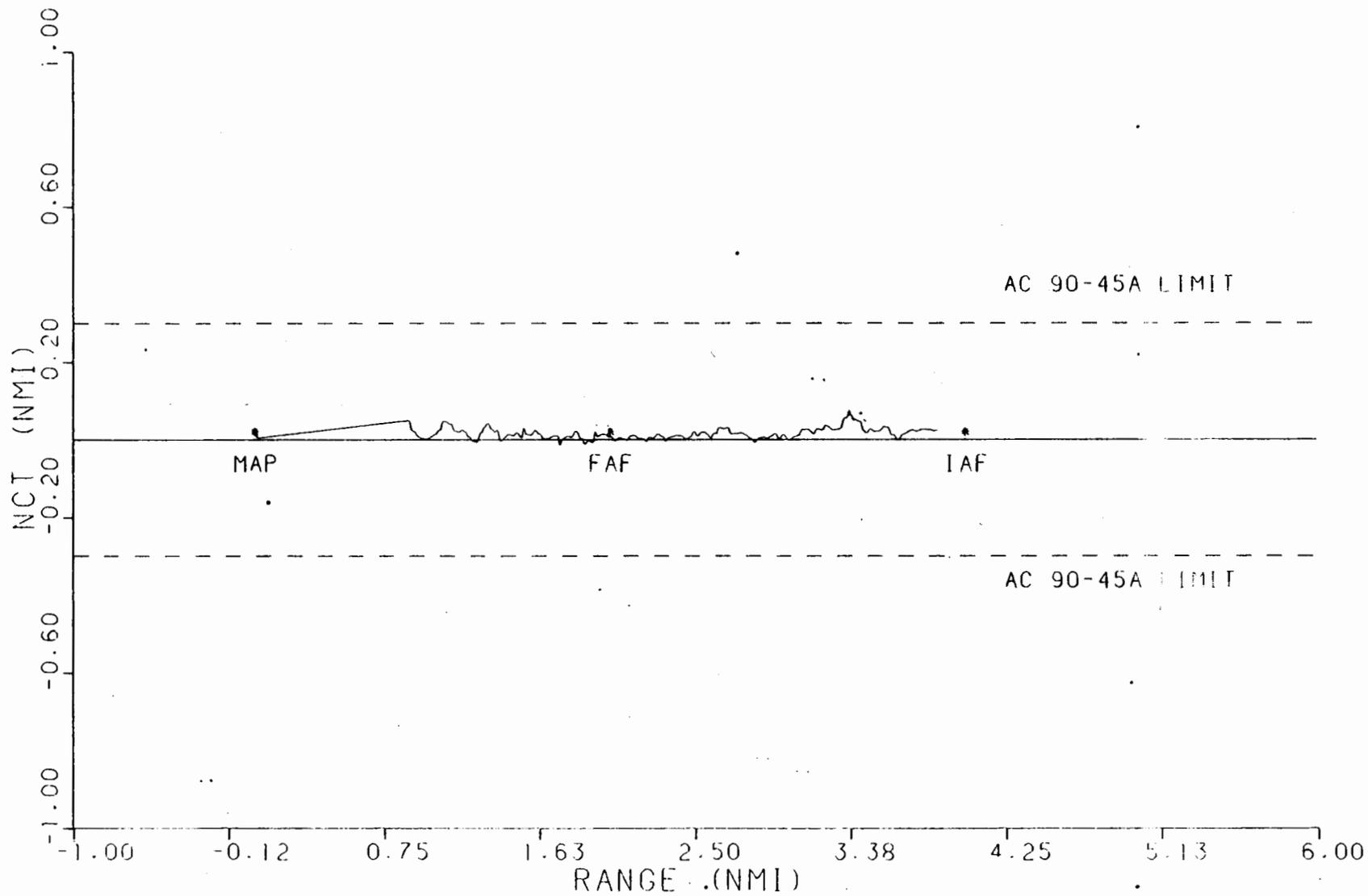
DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 5

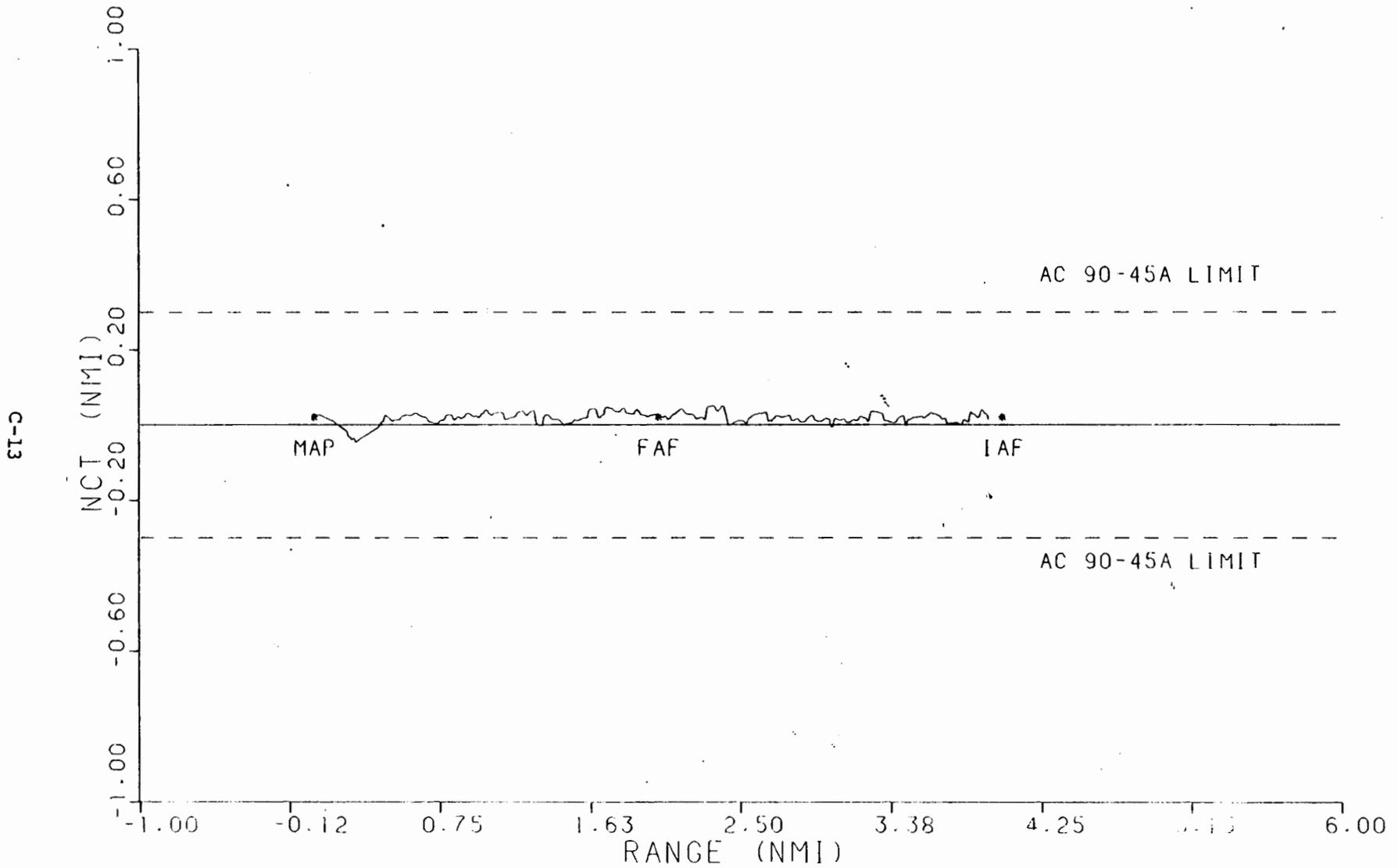
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405

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FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 6

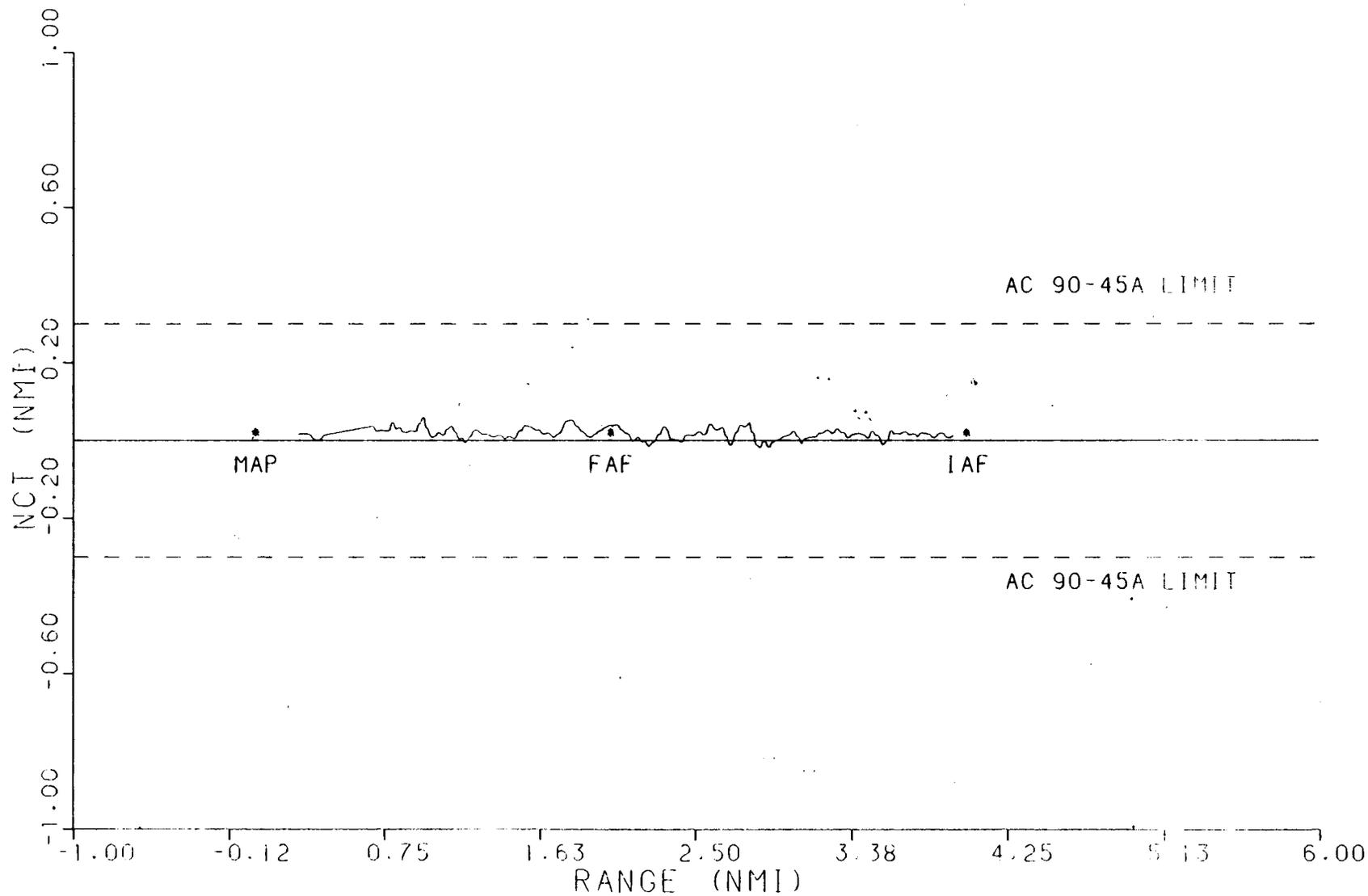
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 7

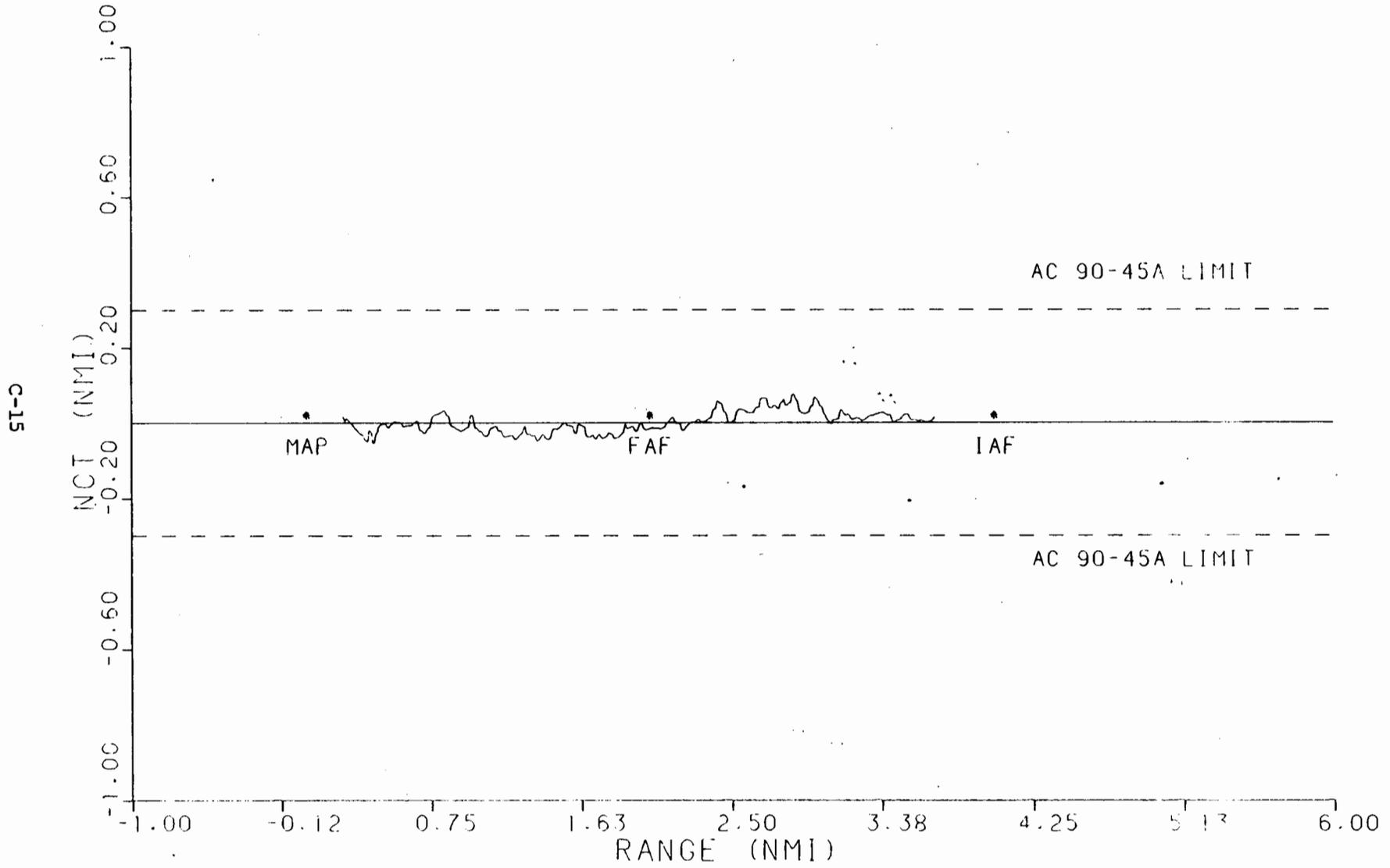
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

C-14



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 8

DATA PROVIDED BY THE FAA TECHNICAL CENTER
AT WASHINGTON AIRPORT, WJ 08405

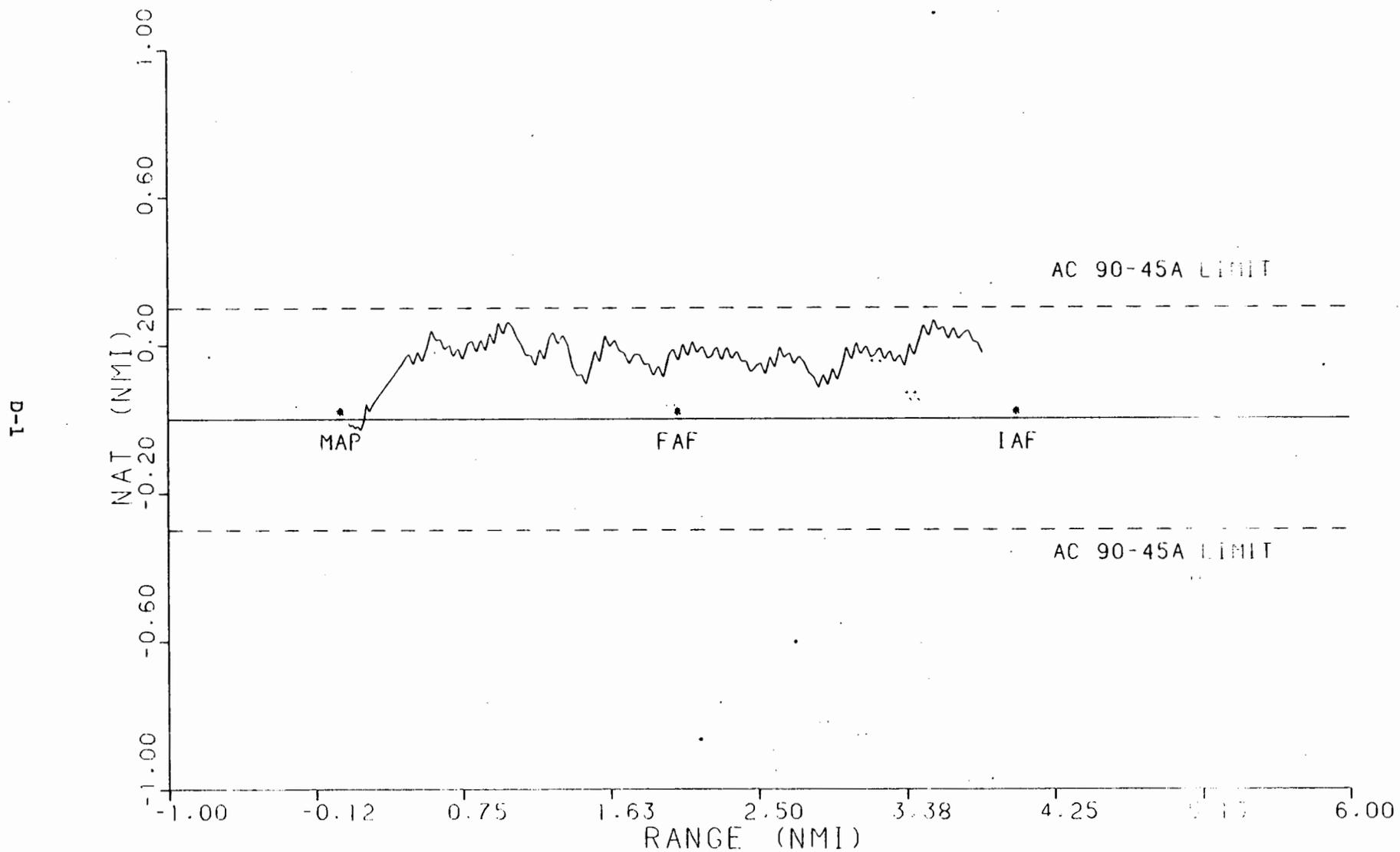


APPENDIX D

NAT VERSUS RANGE PLOTS

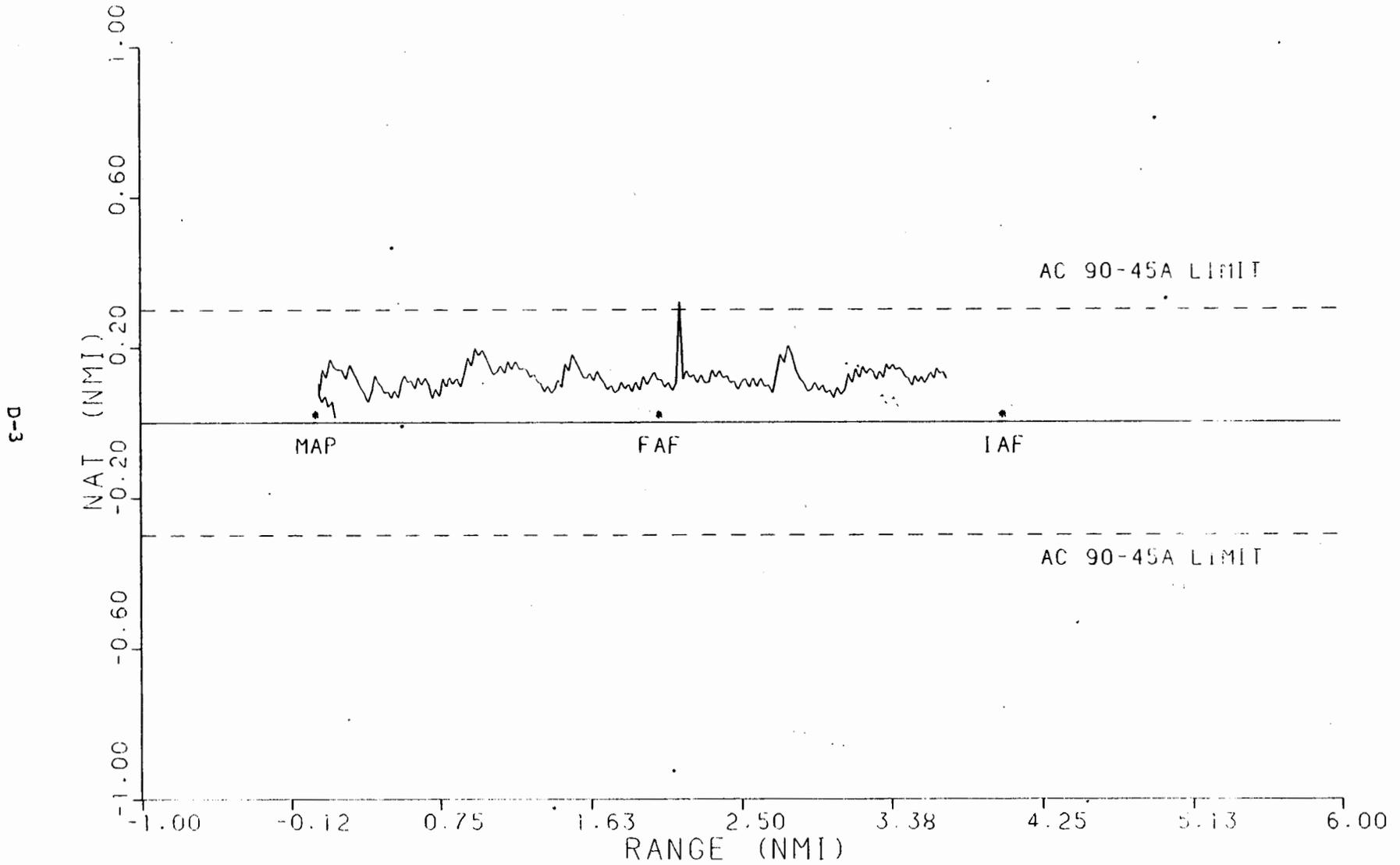
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 1

DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTA-FTY AIRPORT, N.J. 28402



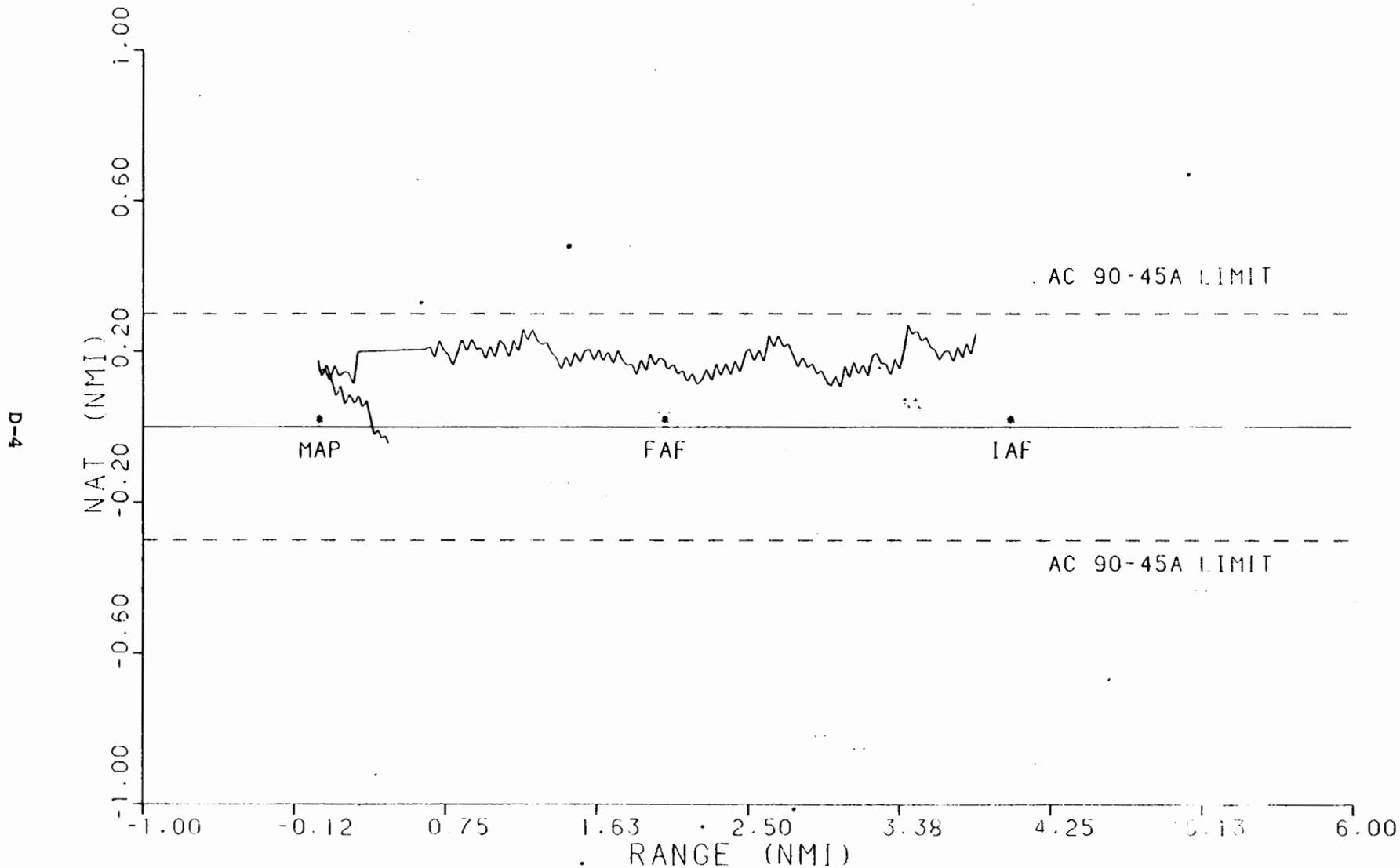
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 3

DATA PROCESSED BY THE FAA TECHNICAL CENTER
AT WASHINGTON FIELD AIRPORT, W. J. 20422



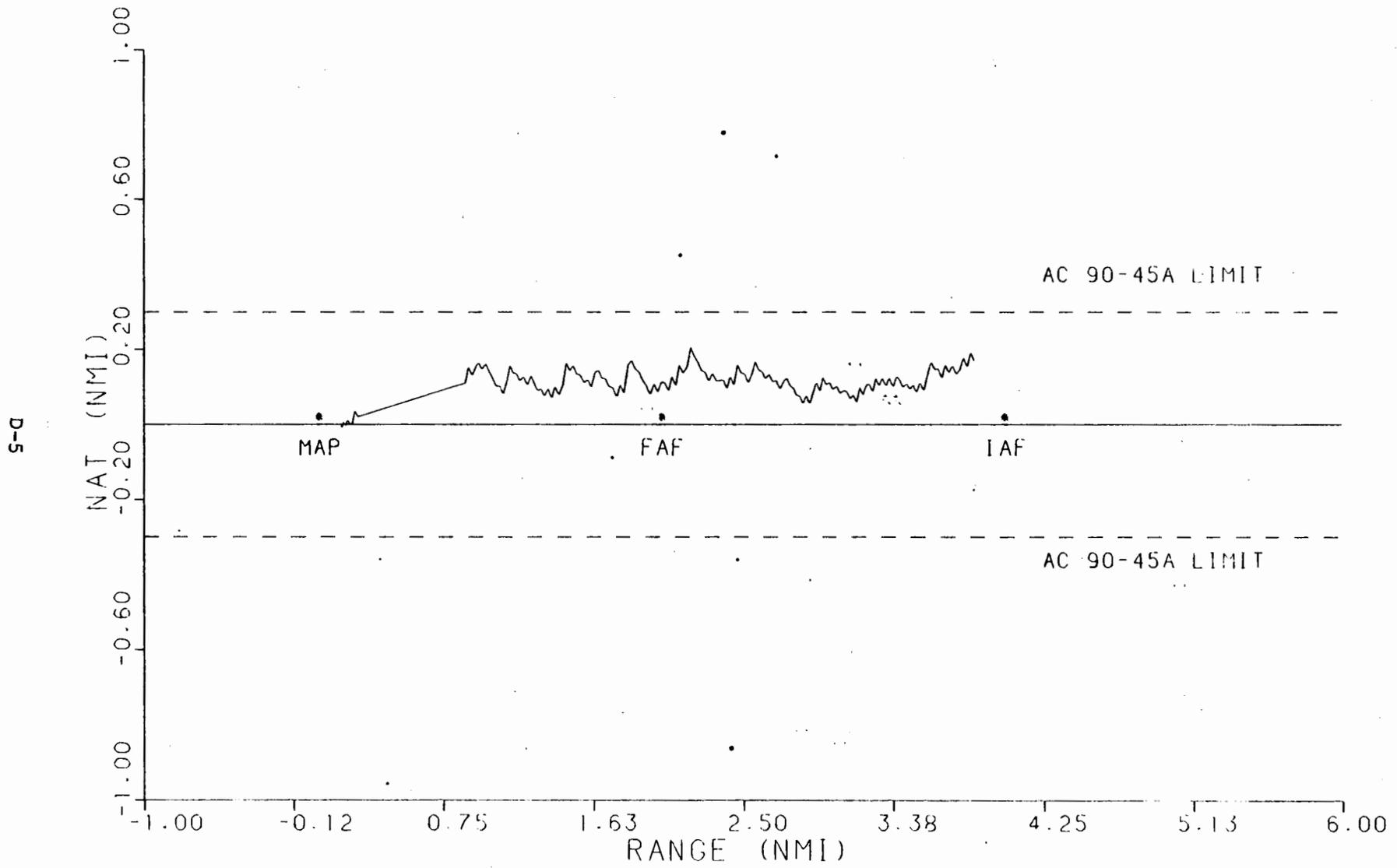
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 4

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 5

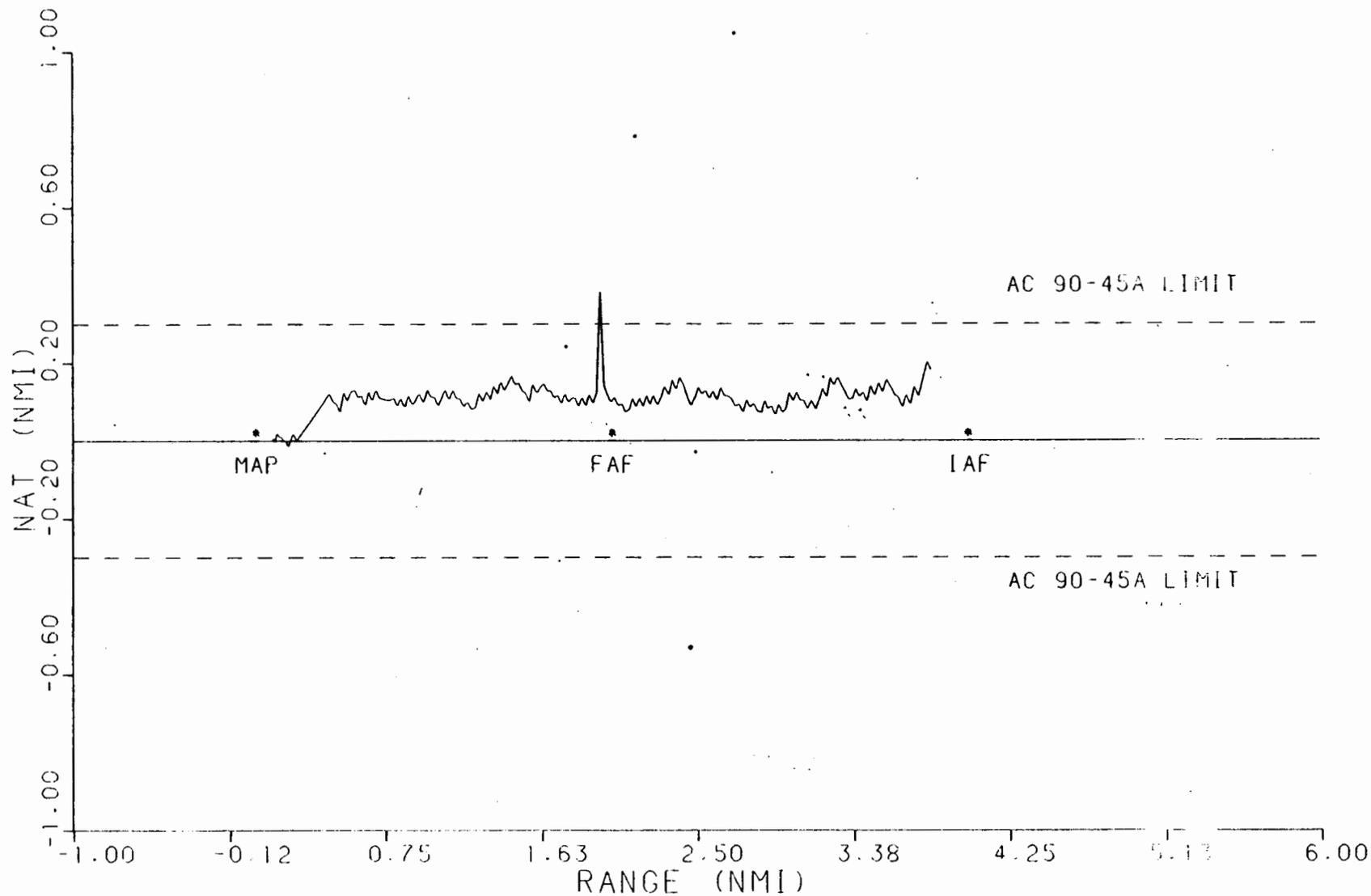
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 6

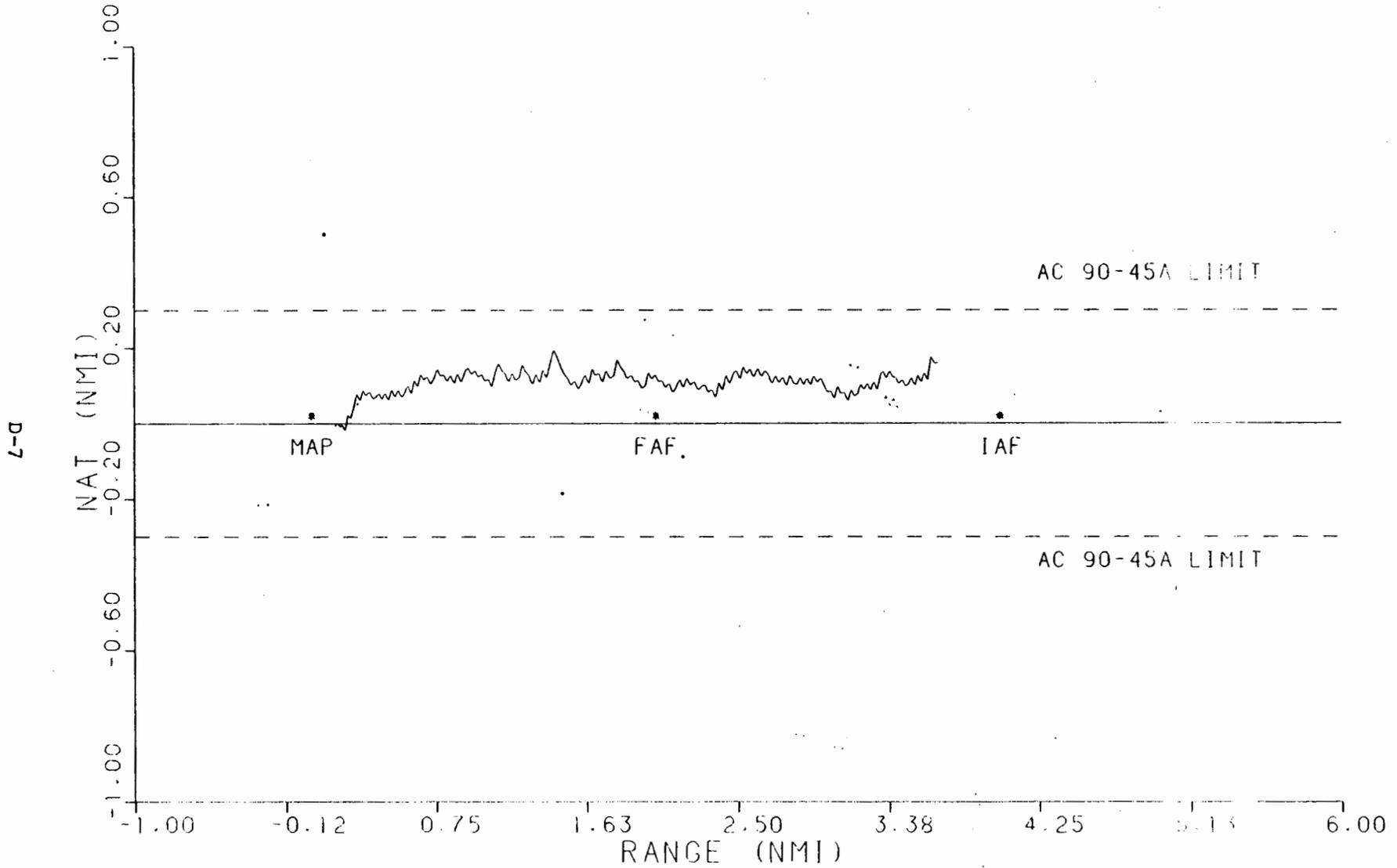
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

9-D



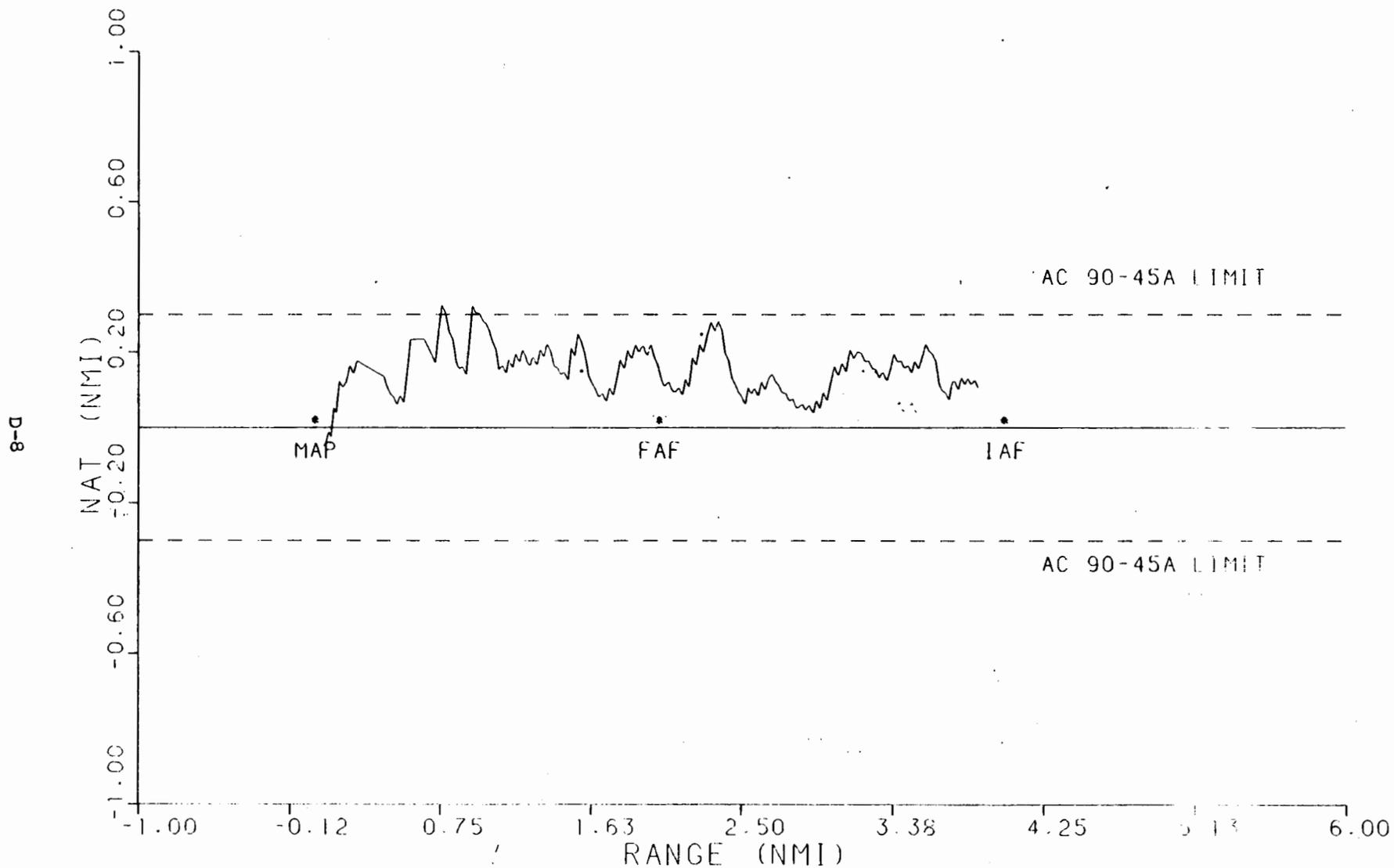
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 8

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTA, GEORGIA AIRPORT, N.J. 08495



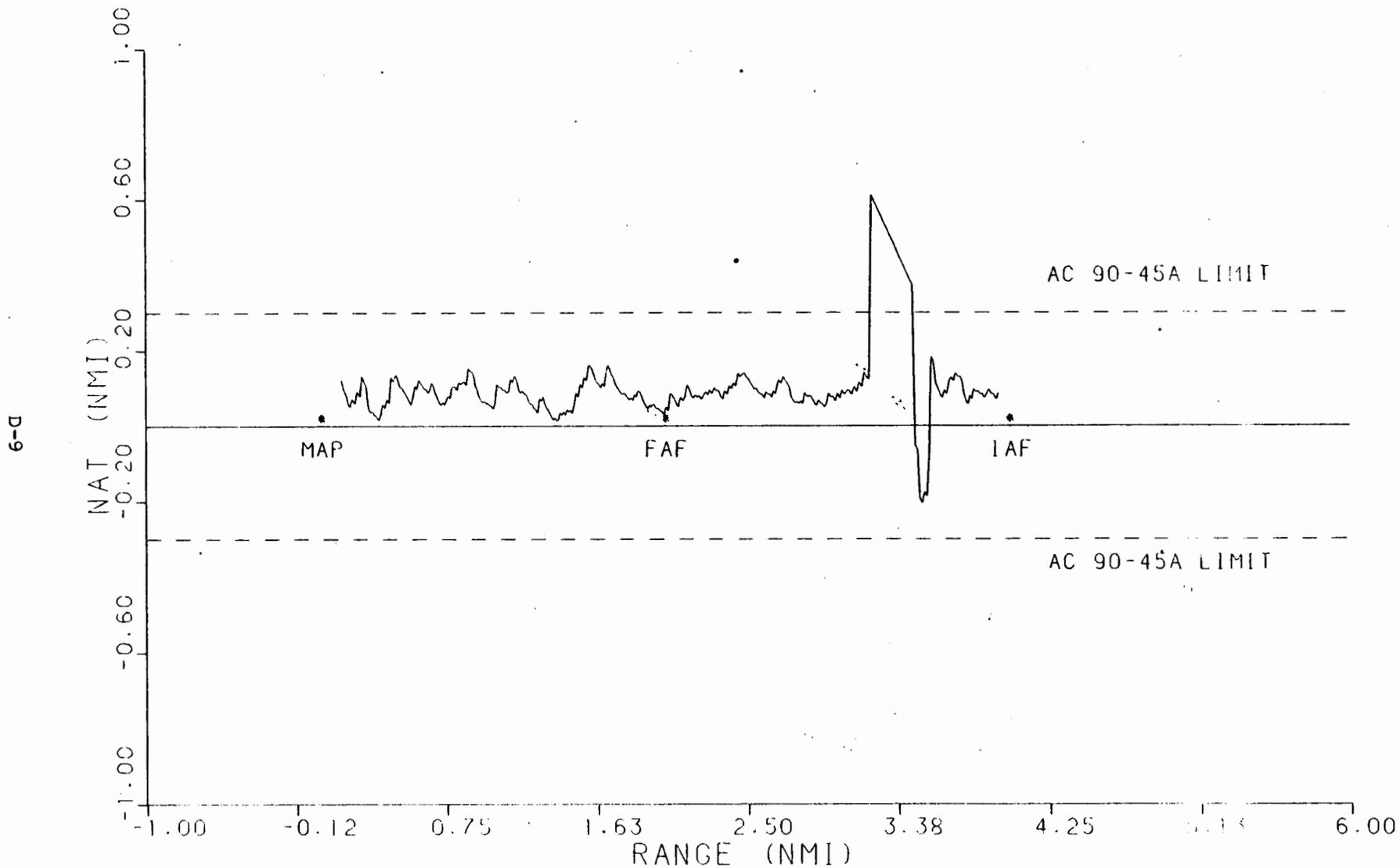
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 1

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



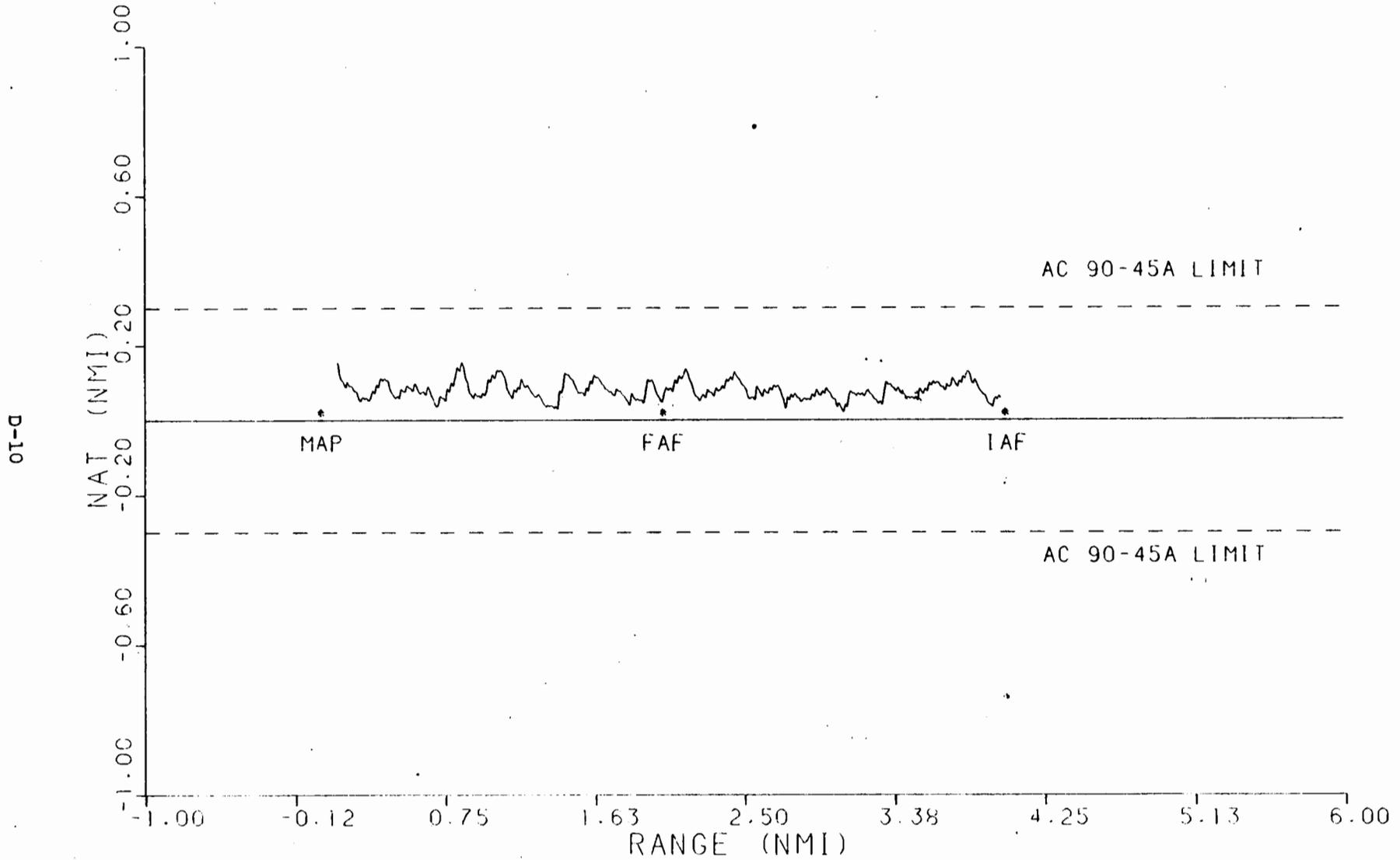
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 2

DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTA CITY AIRPORT, N J 08405



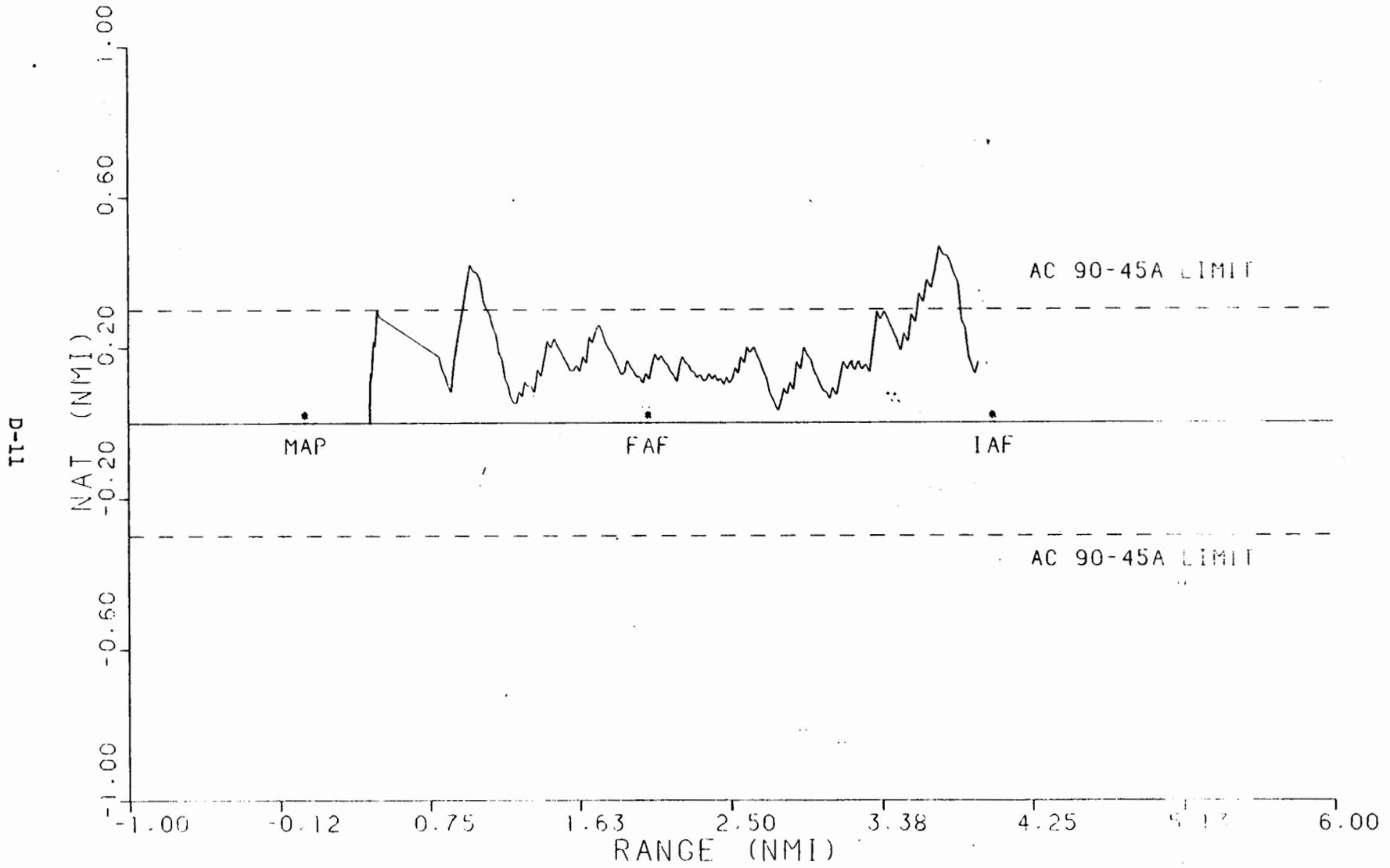
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 3

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTA, GEORGIA AIRPORT, W. J. 09405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 4

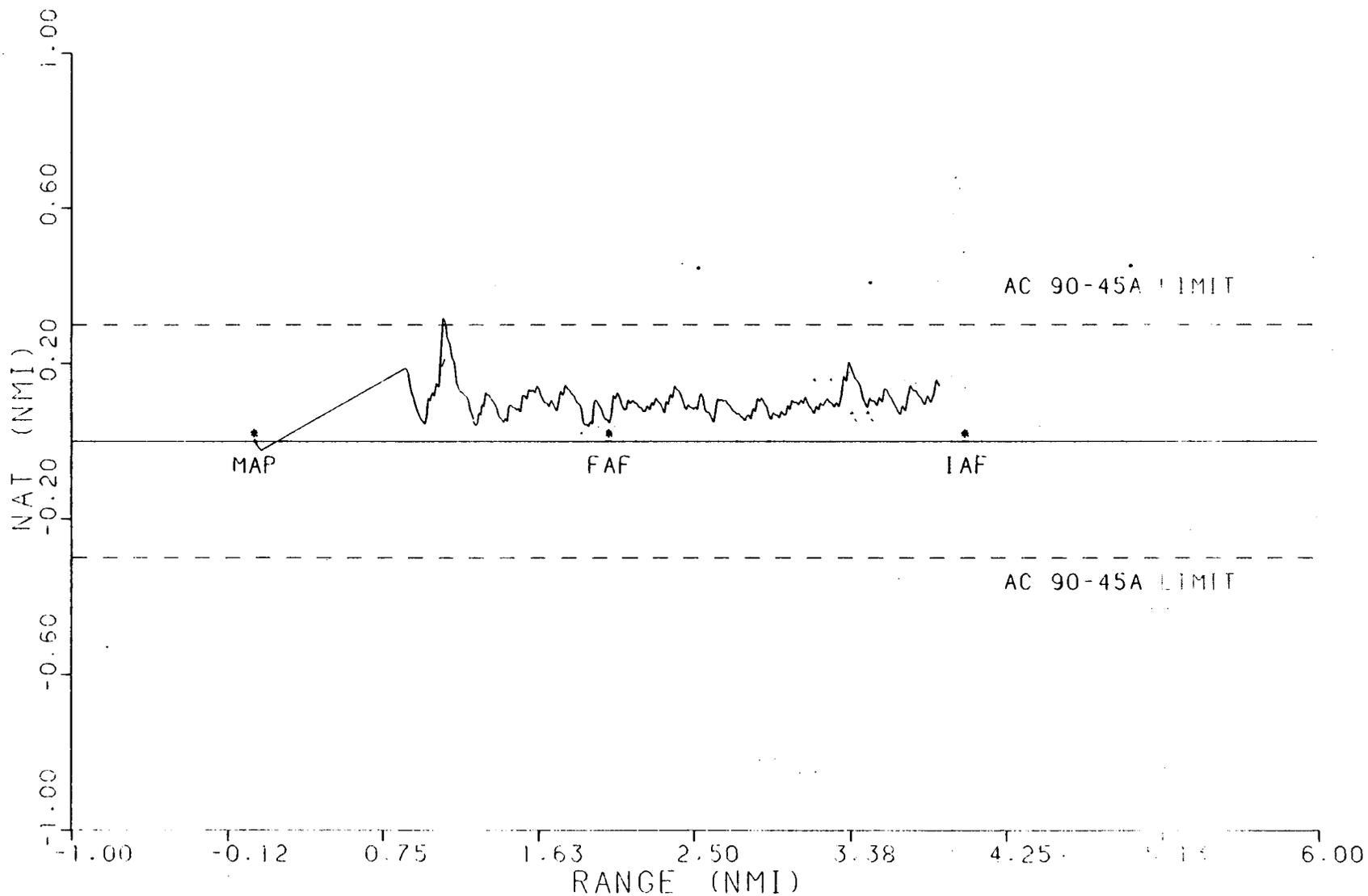
DATA PROCESSED BY THE FAA TECHNICAL CENTER
AT WASHINGTON AIRPORT, N.J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 5

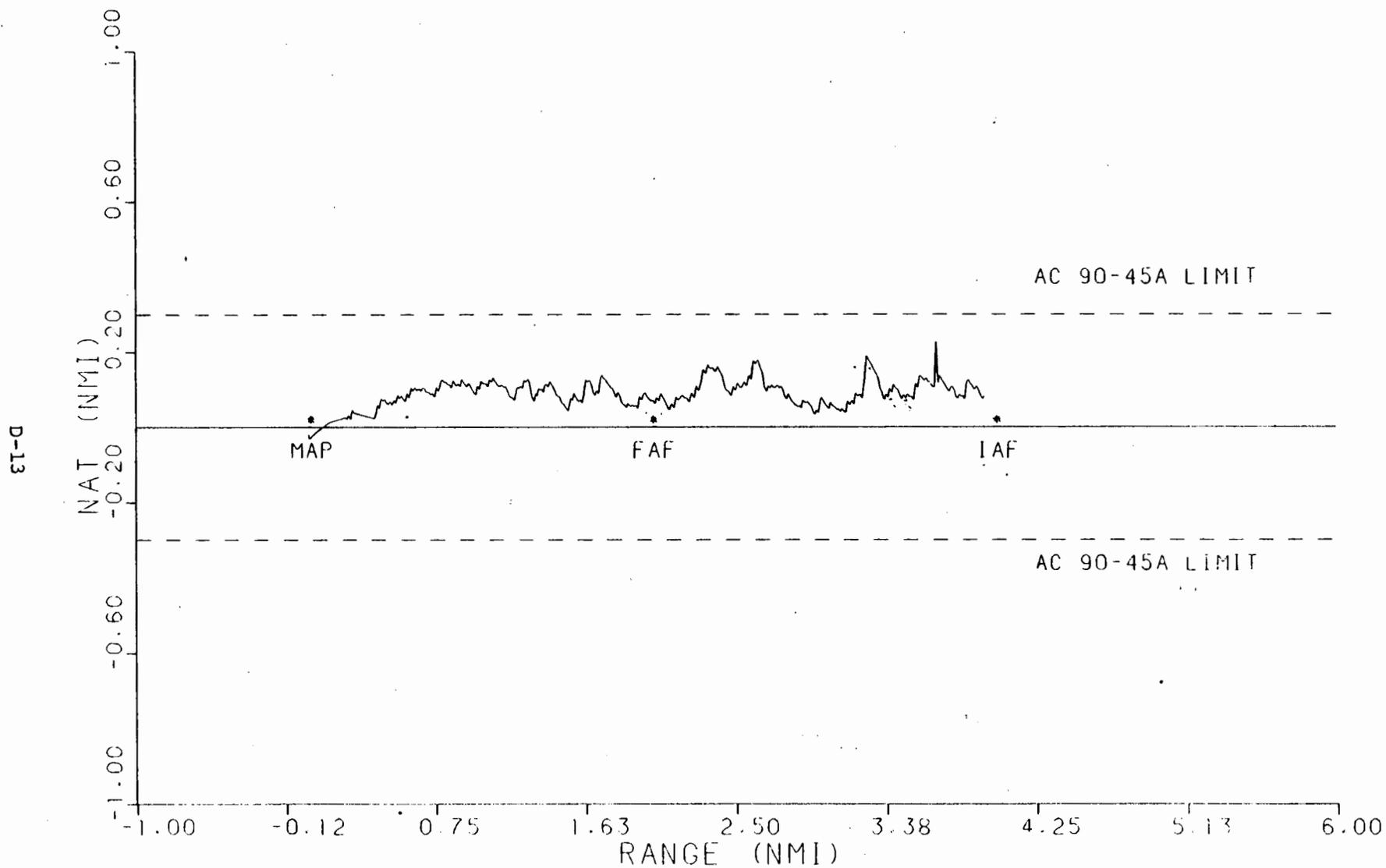
DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTA, GEORGIA AIRPORT, N.J. 08405

D-12



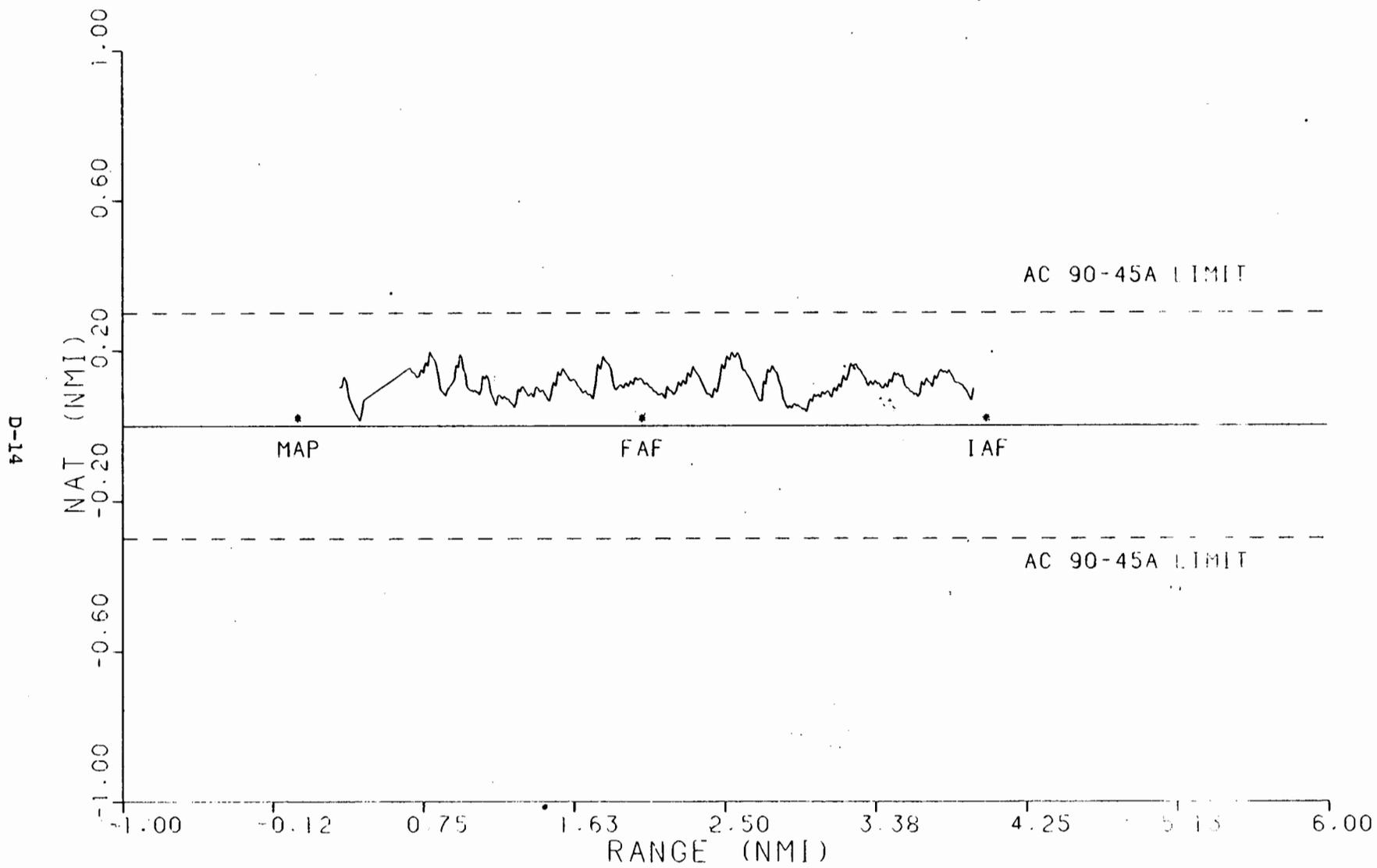
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 6

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



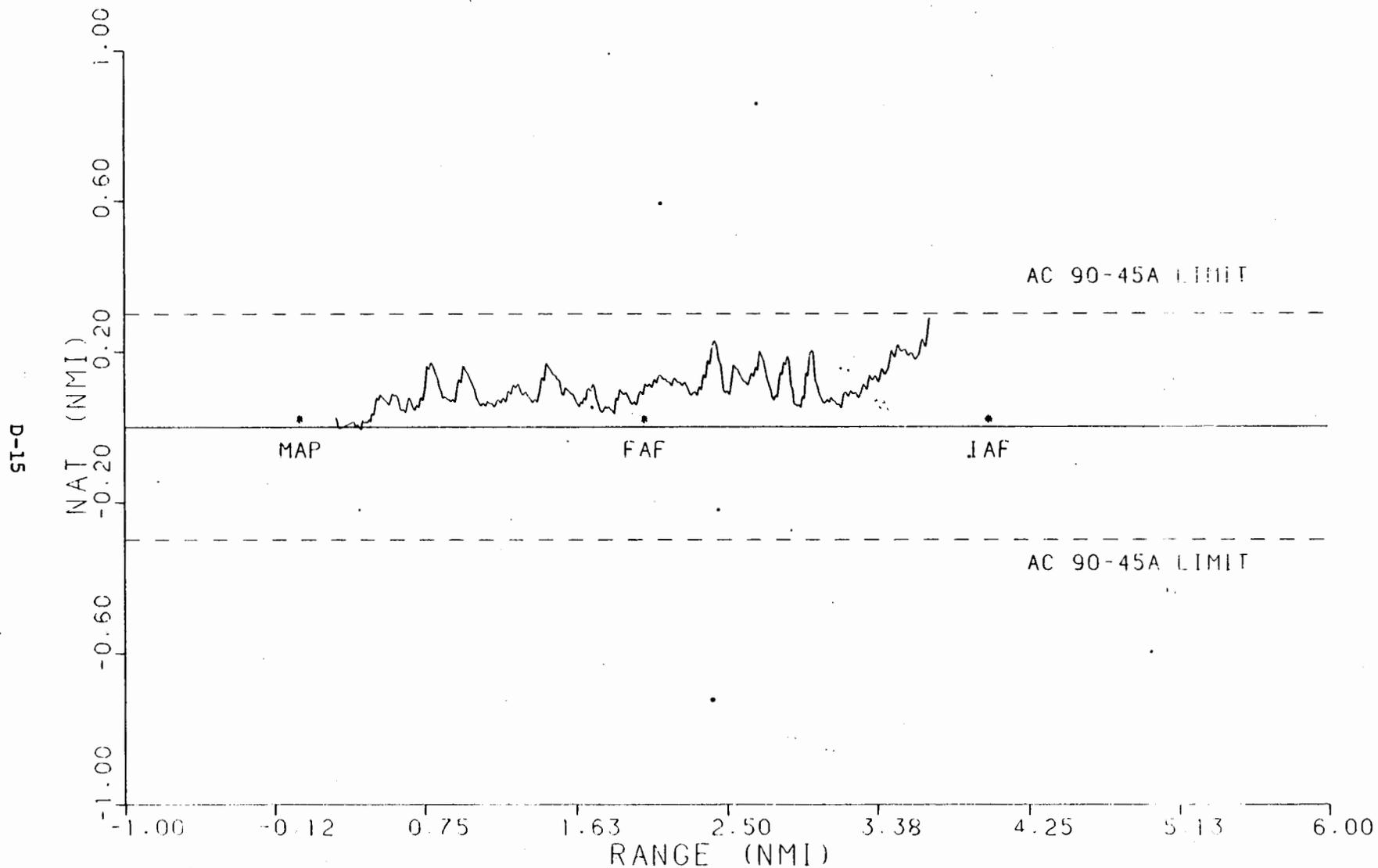
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 7

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 8

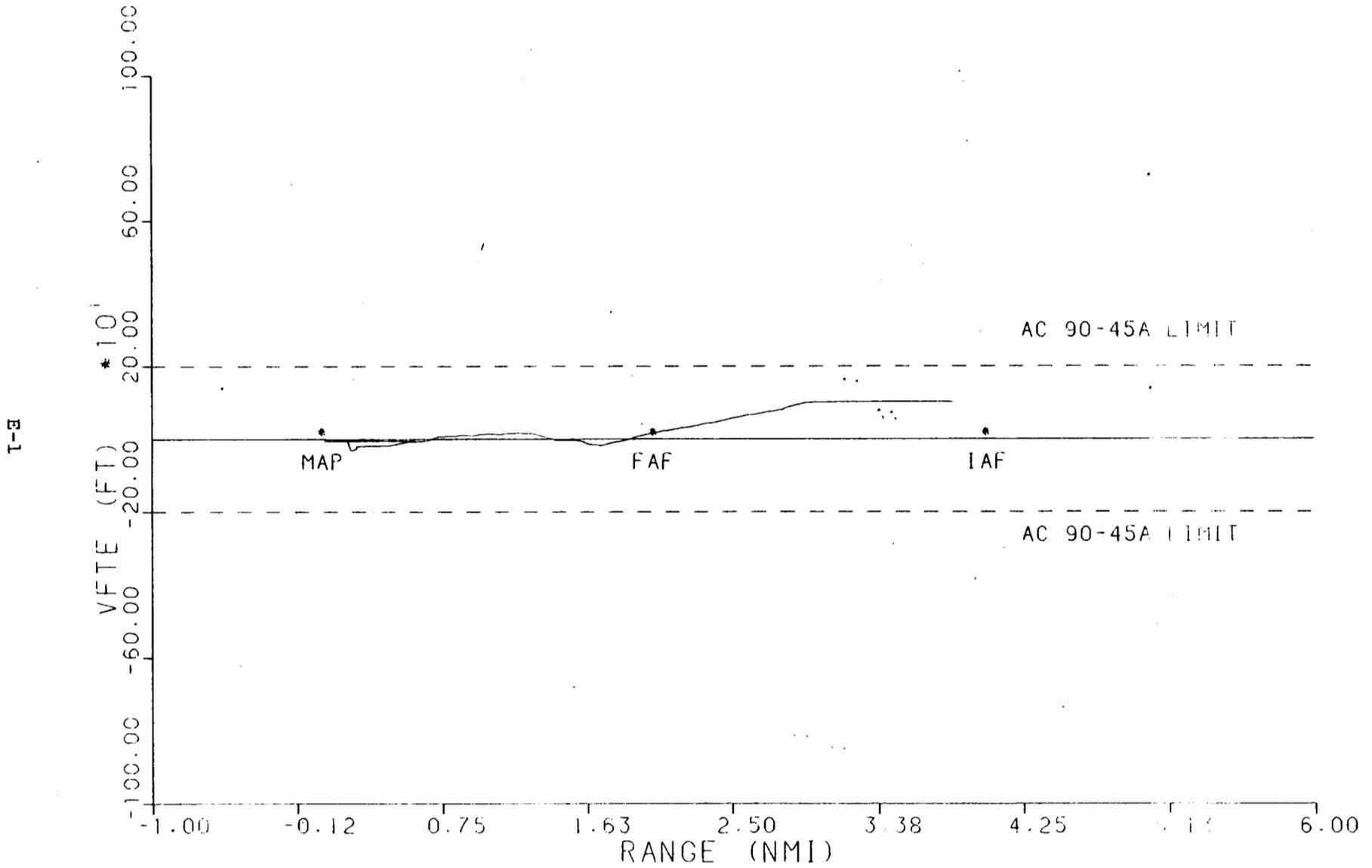
DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTA CITY AIRPORT, N J 02422



APPENDIX E
VFTE VERSUS RANGE PLOTS

FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 1

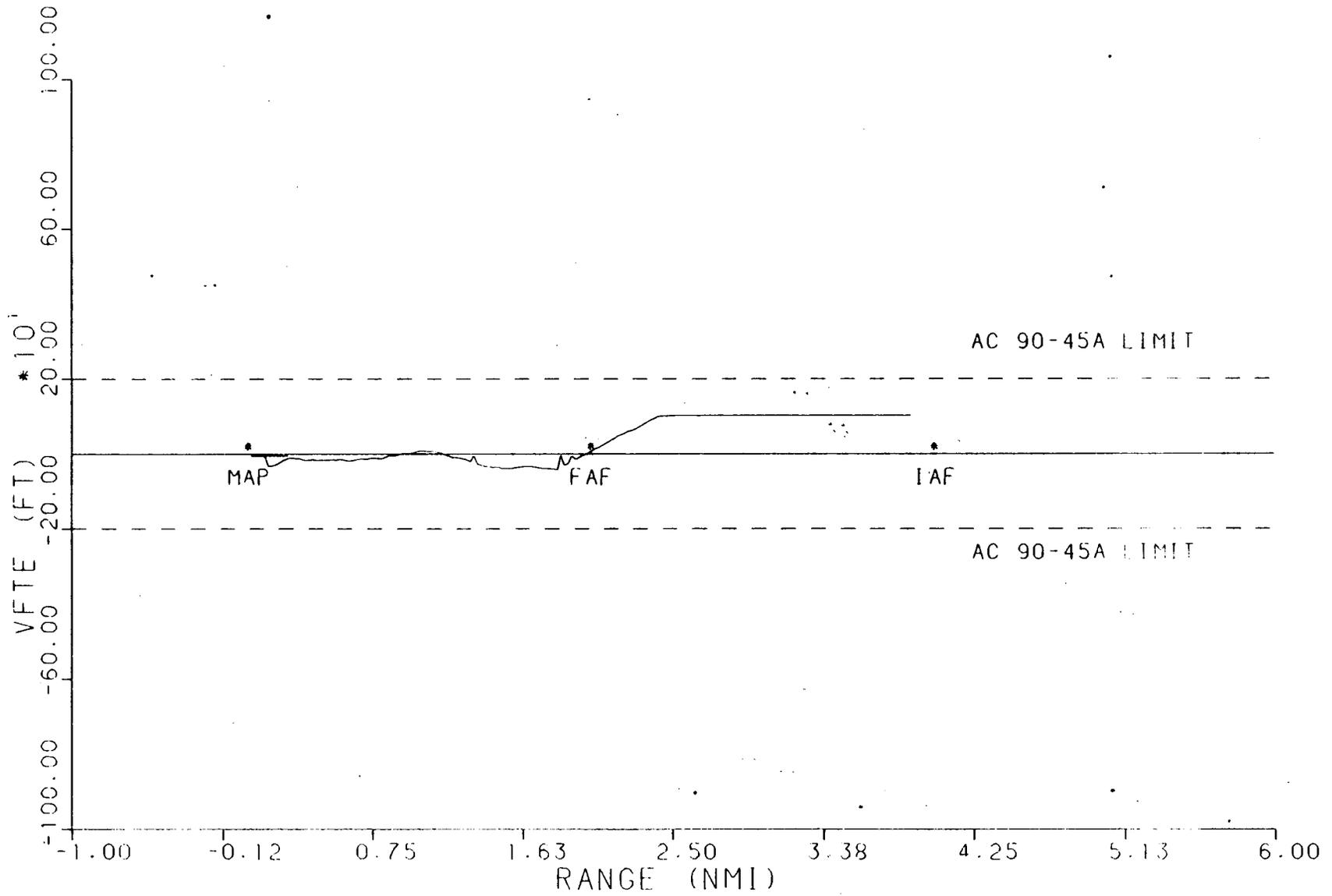
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATWENTON, NJ AIRPORT, N.J. 08402



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 2

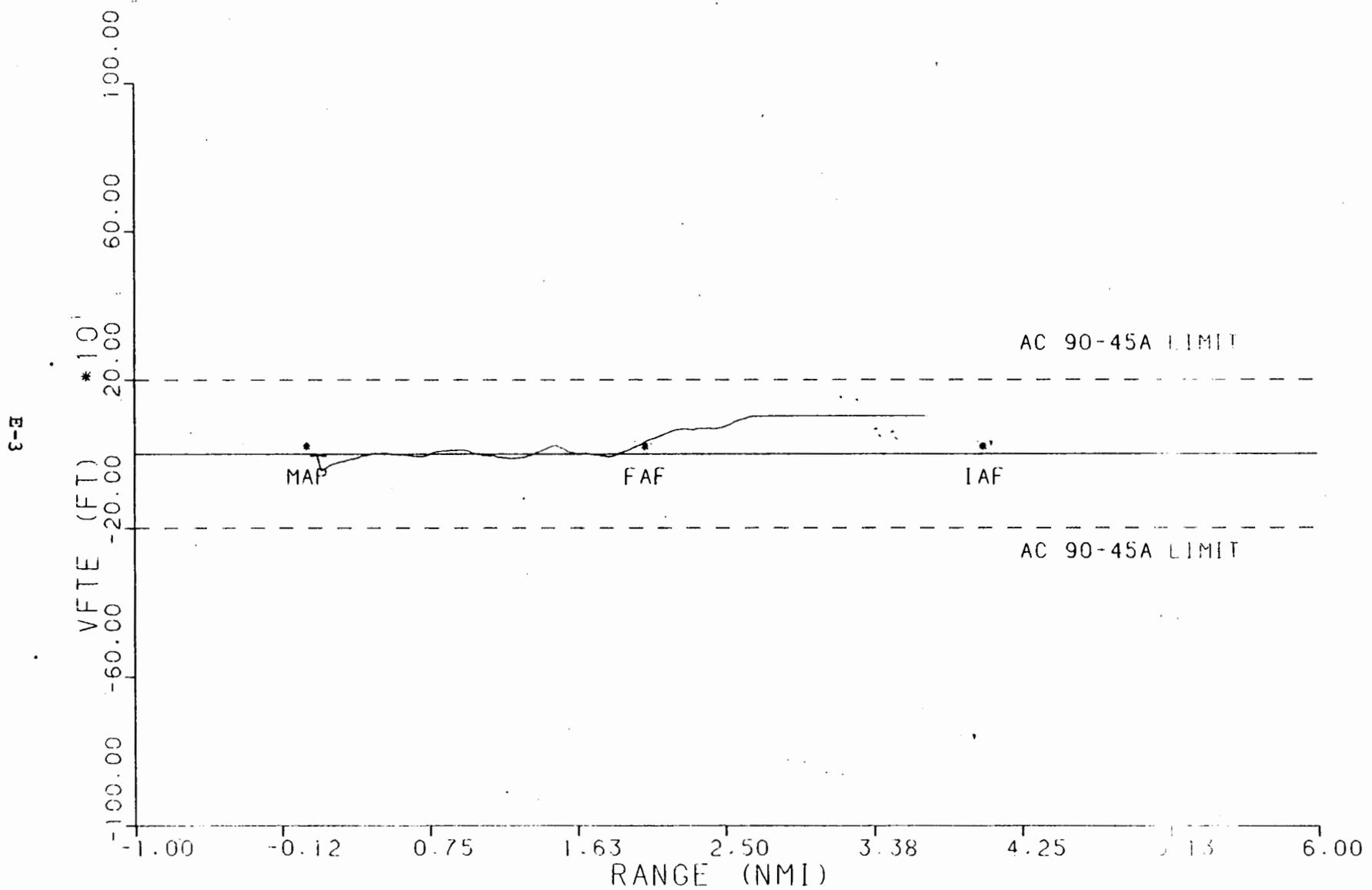
DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

E-2



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 3

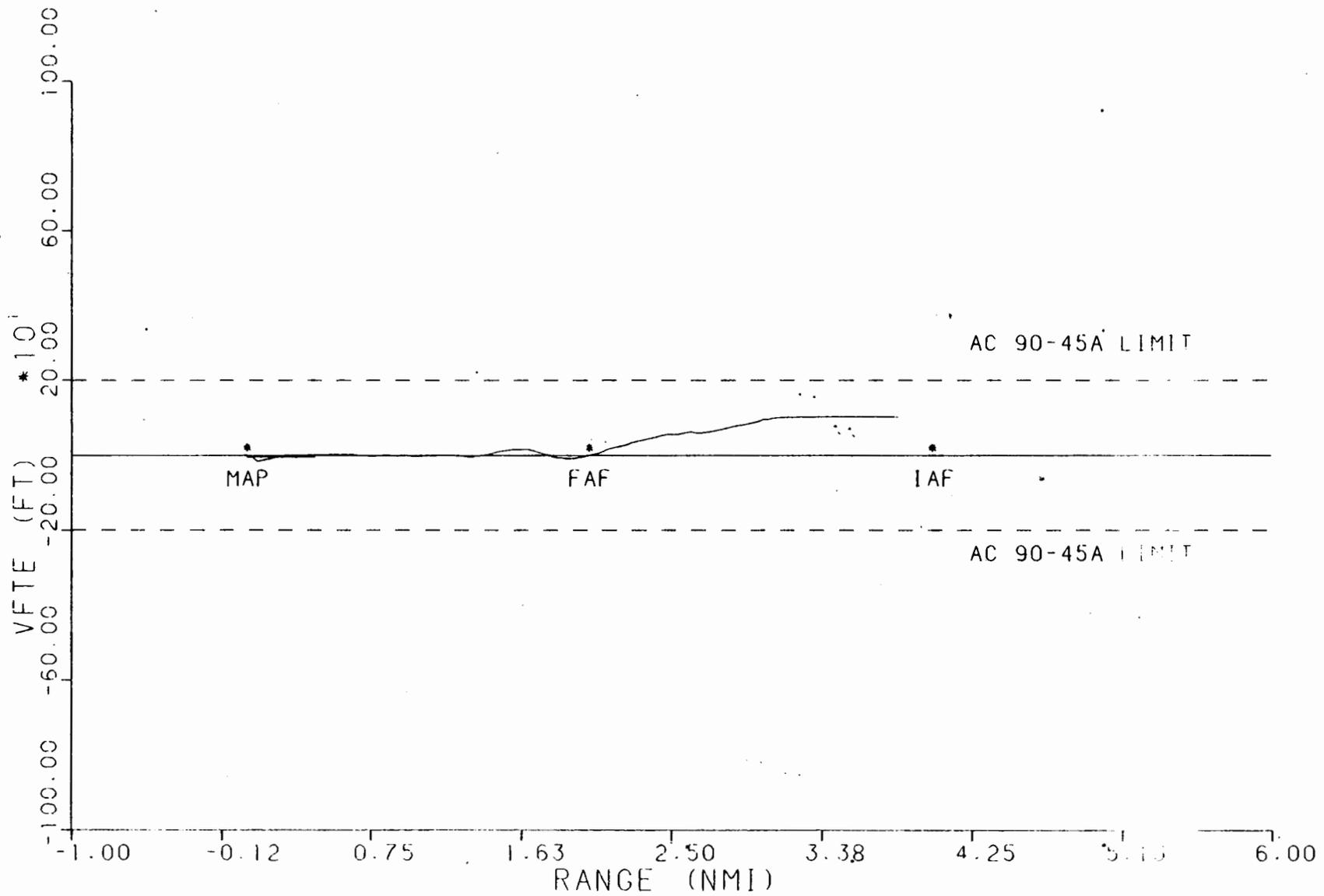
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 4

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405

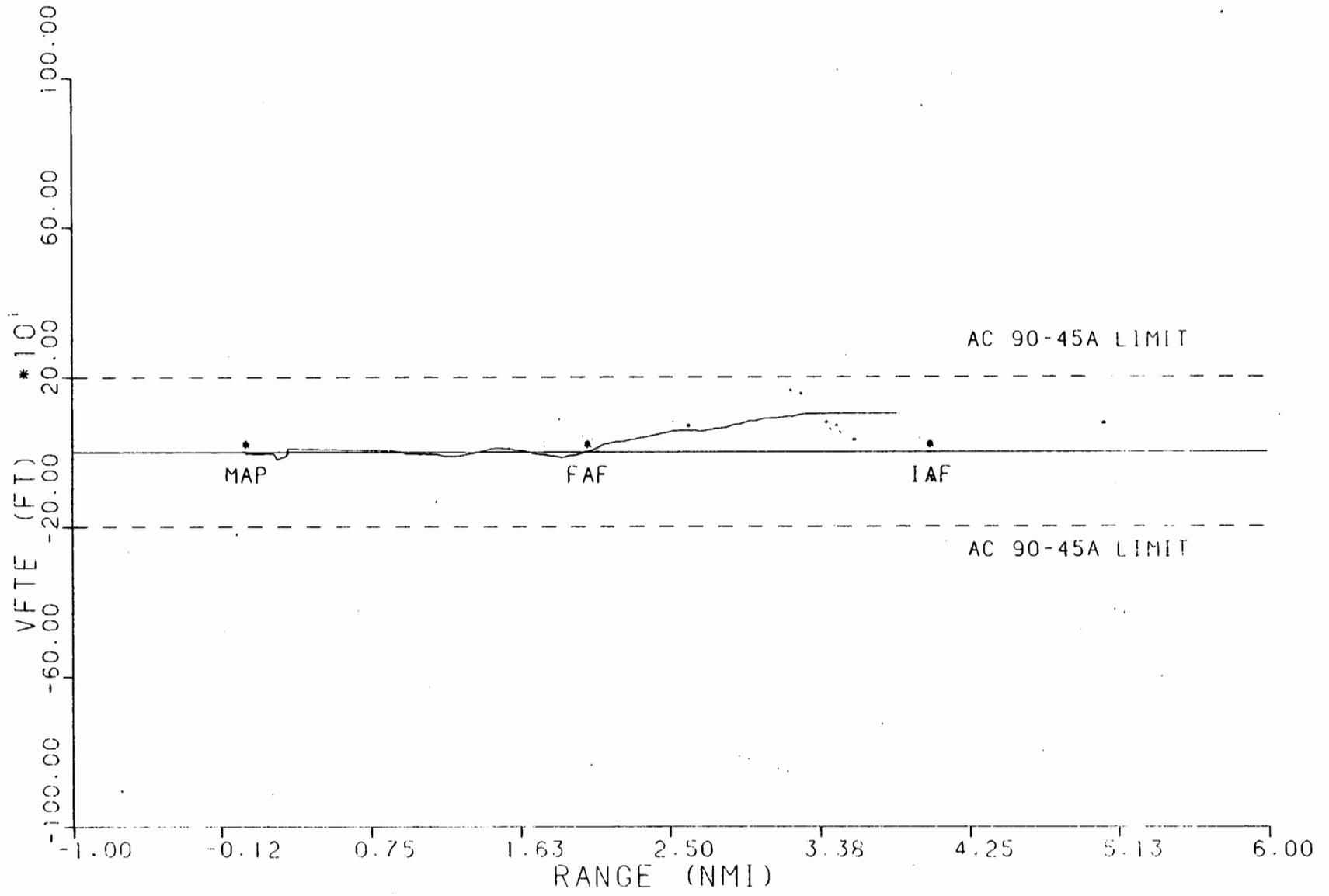
E-4



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 5

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405

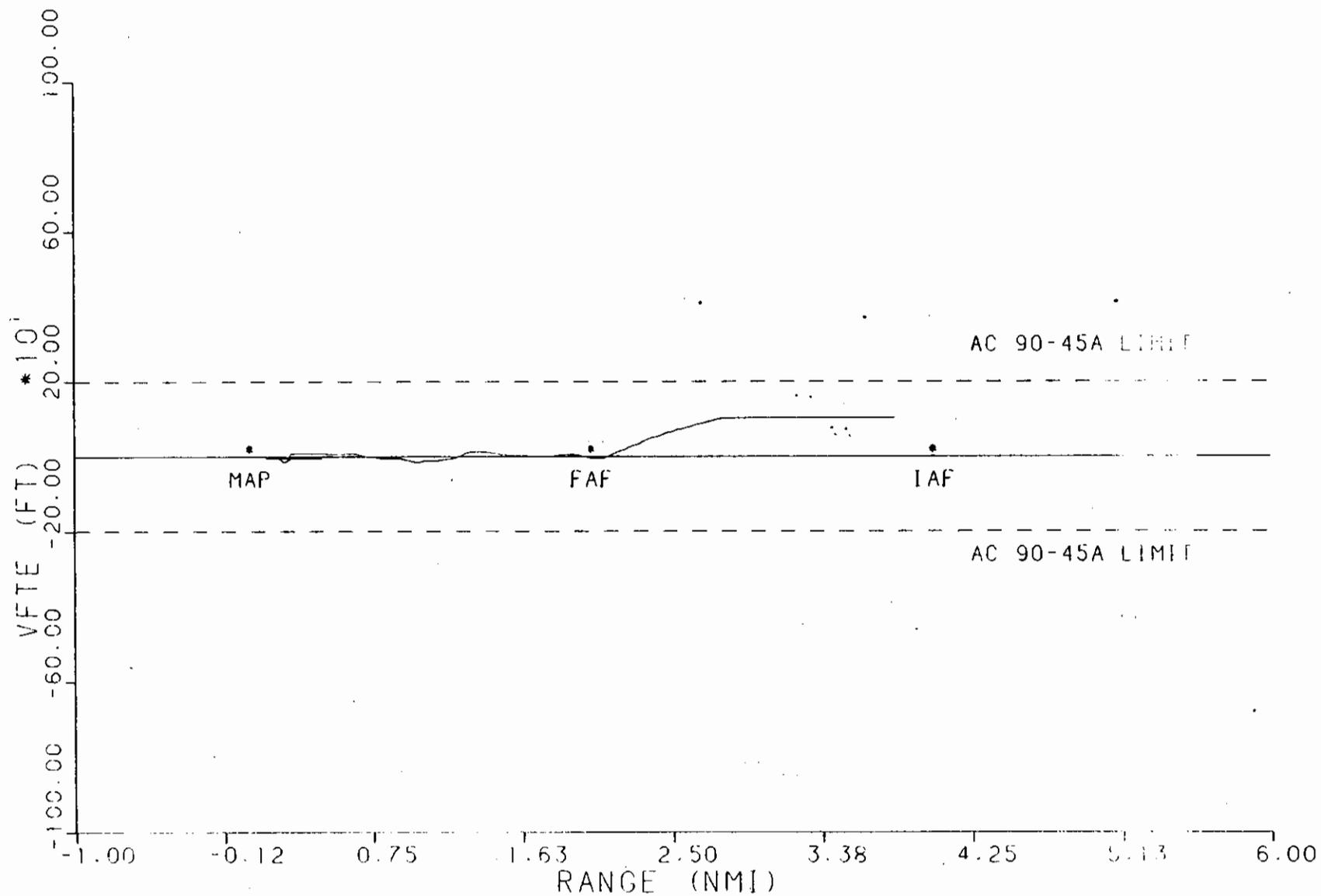
E-5



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 6

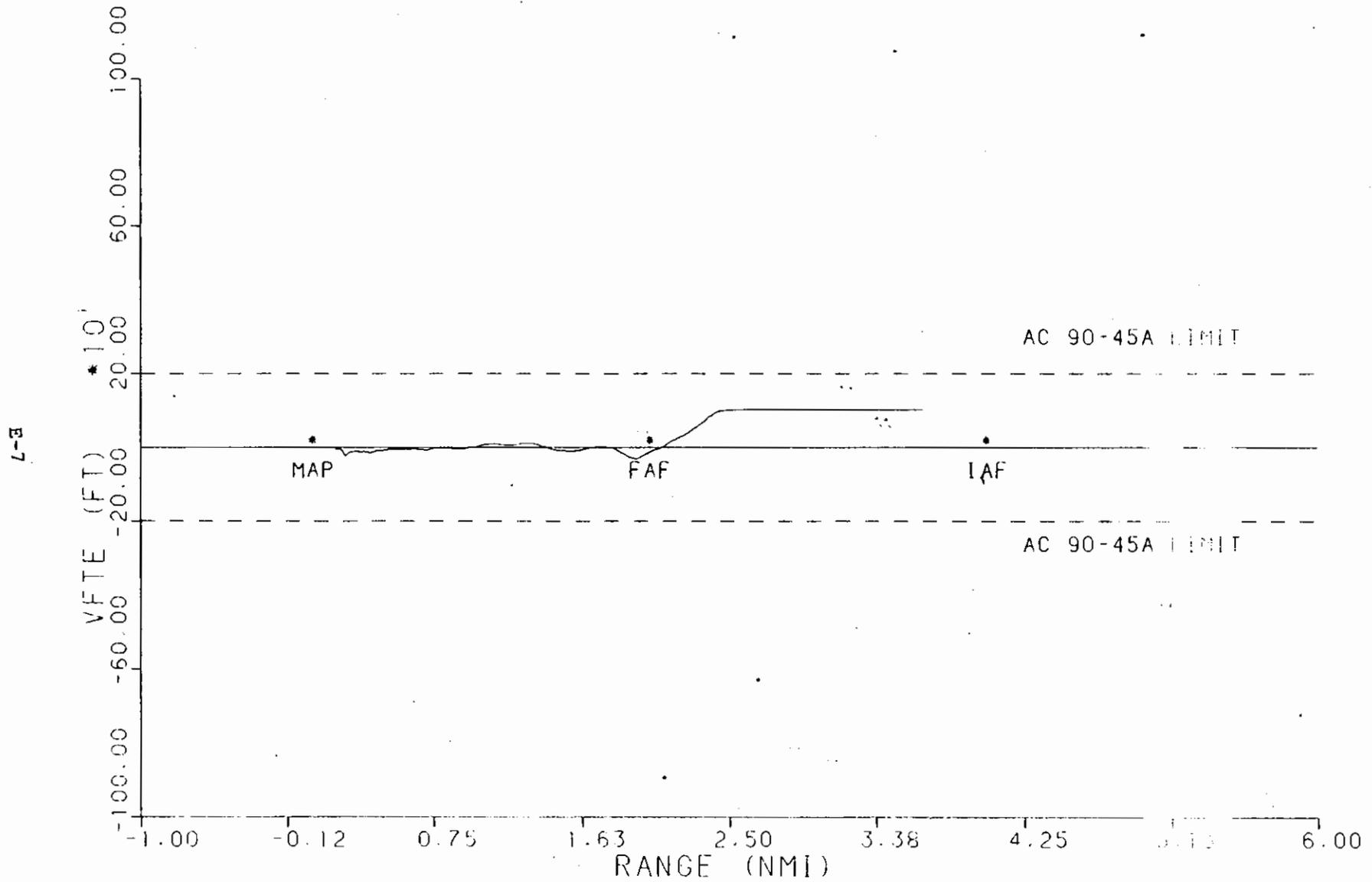
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08402

B-3



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 8

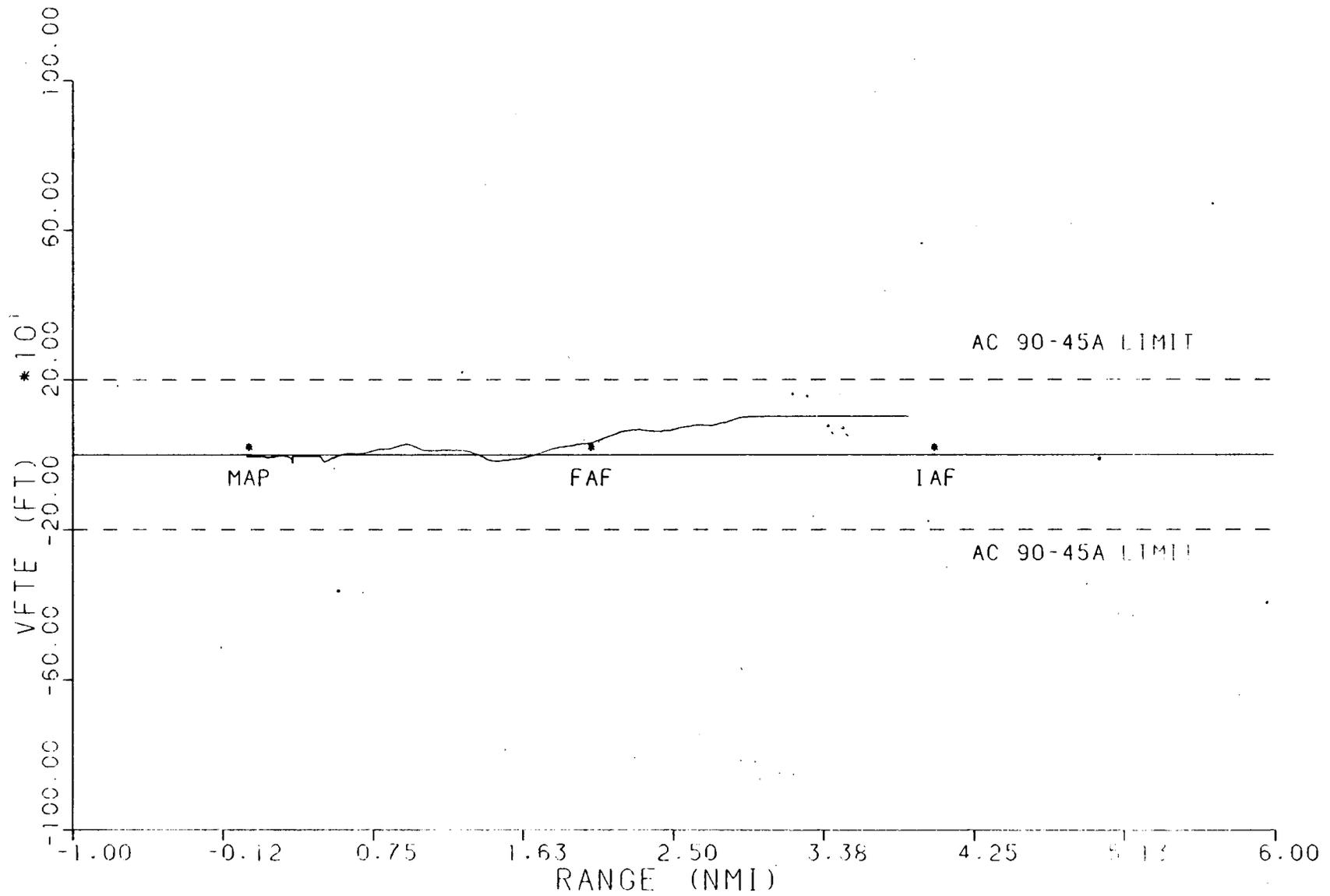
DATA PROVIDED BY THE FAA TECHNICAL CENTER
AT WASHINGTON AIRPORT, N. J. 08425



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 1

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405

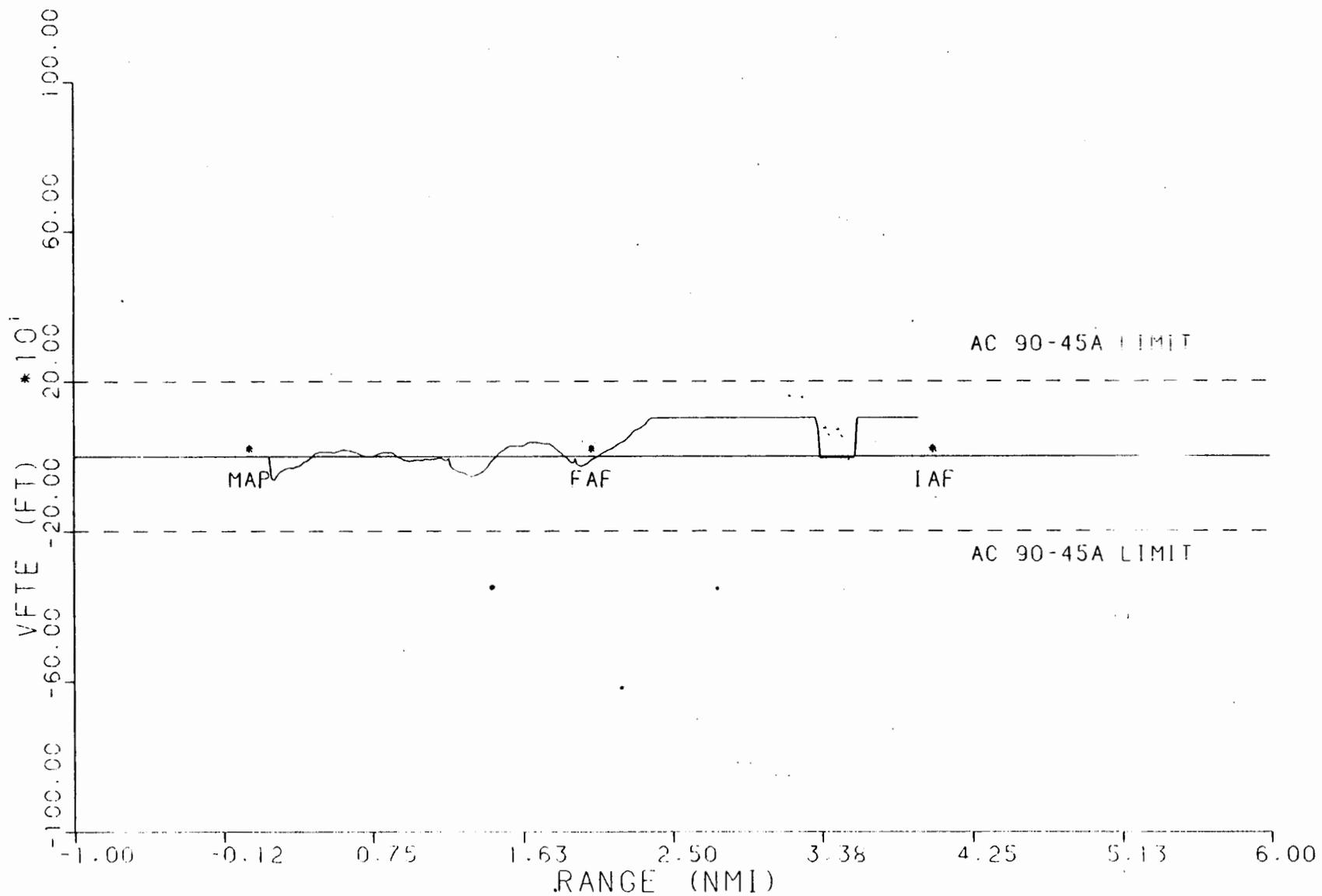
E-8



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 2

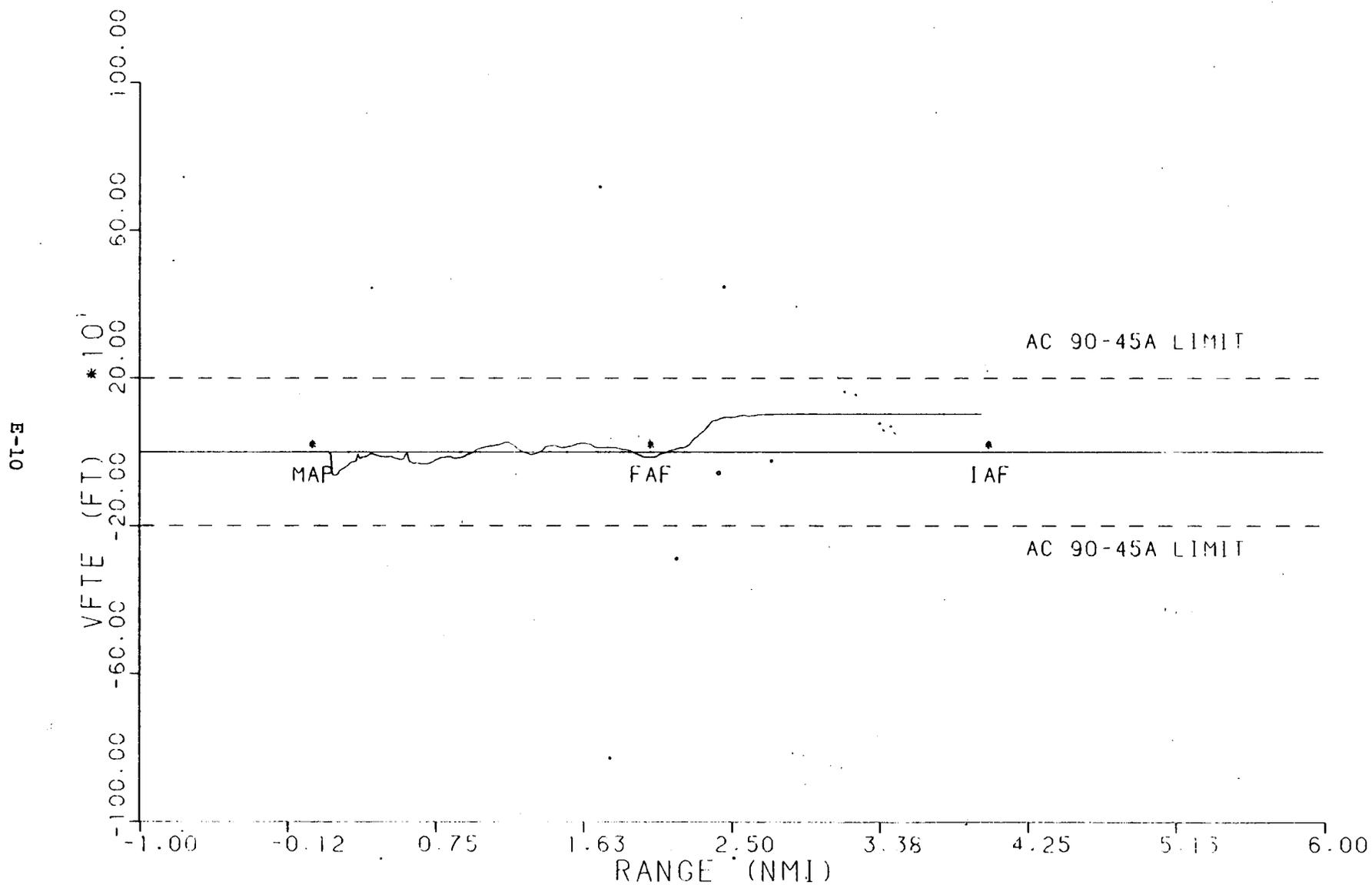
DATA PROVIDED BY THE FAA TECHNICAL CENTER
AIRMILITARY AIRPORT, N. J. 08402

E-9



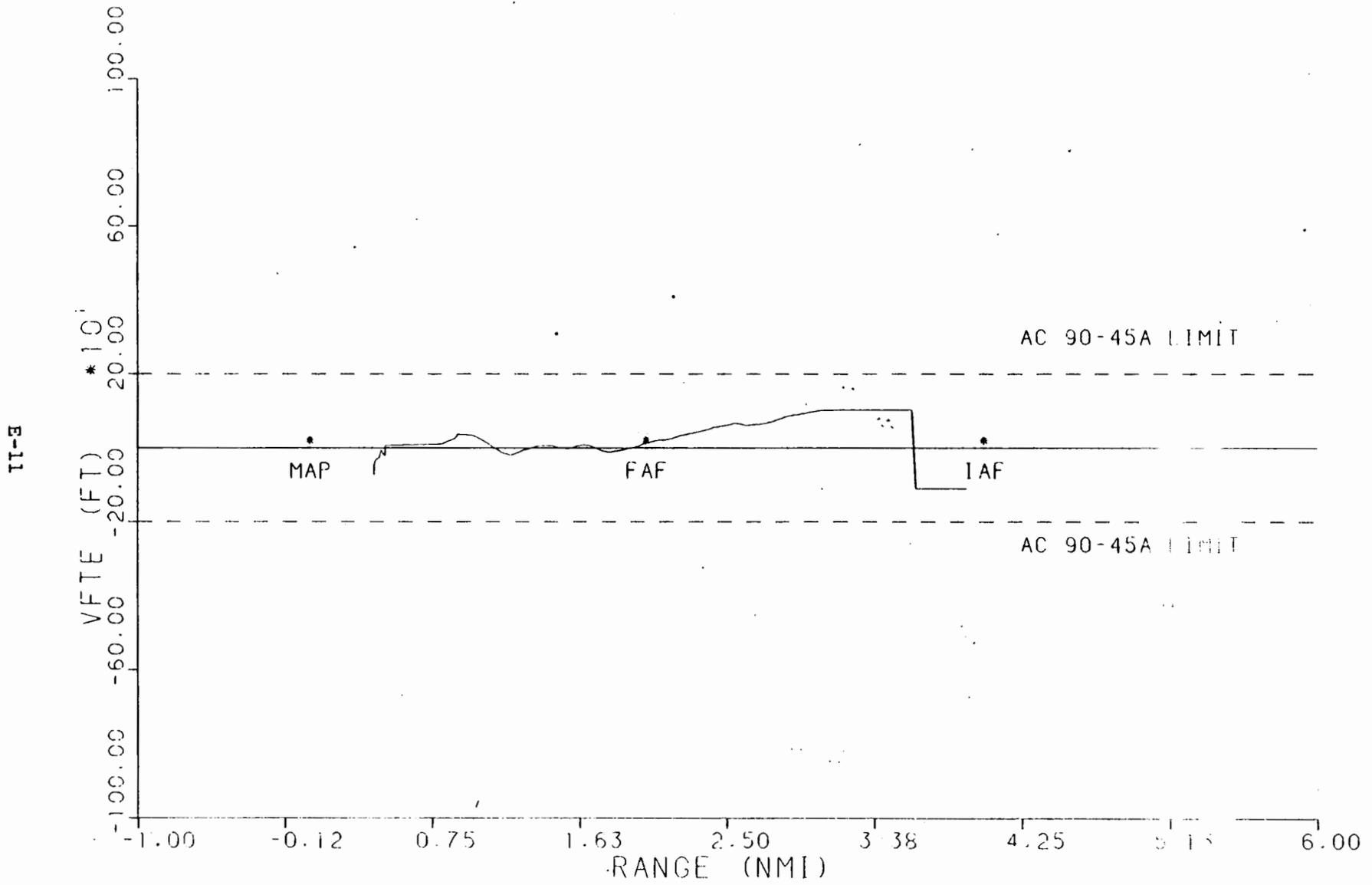
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 3

DATA PROVIDED BY THE FAA TECHNICAL CENTER
ALBANY COUNTY AIRPORT, N. J. 06405



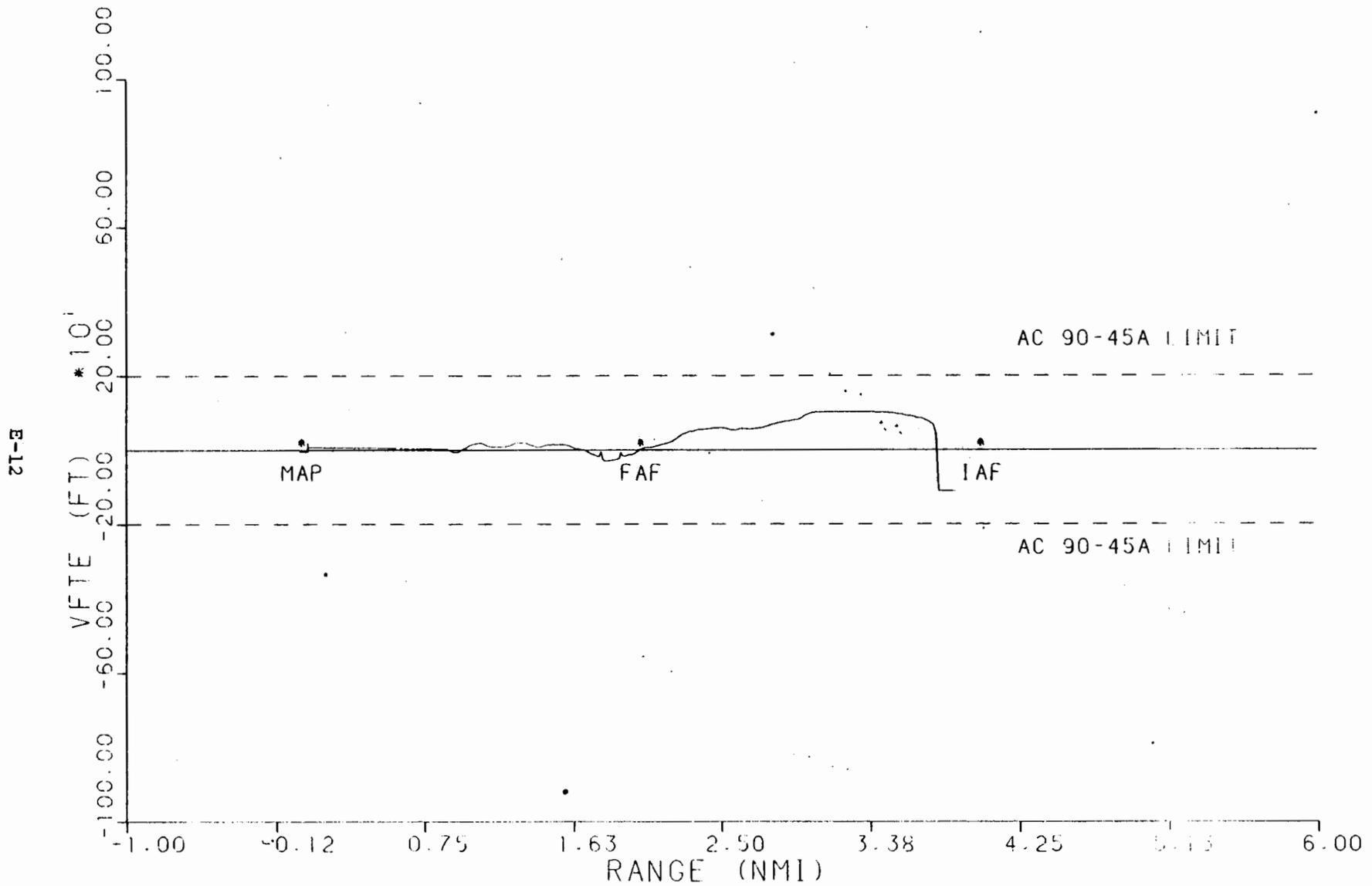
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 4

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTA, GEORGIA AIRPORT, W J 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 5

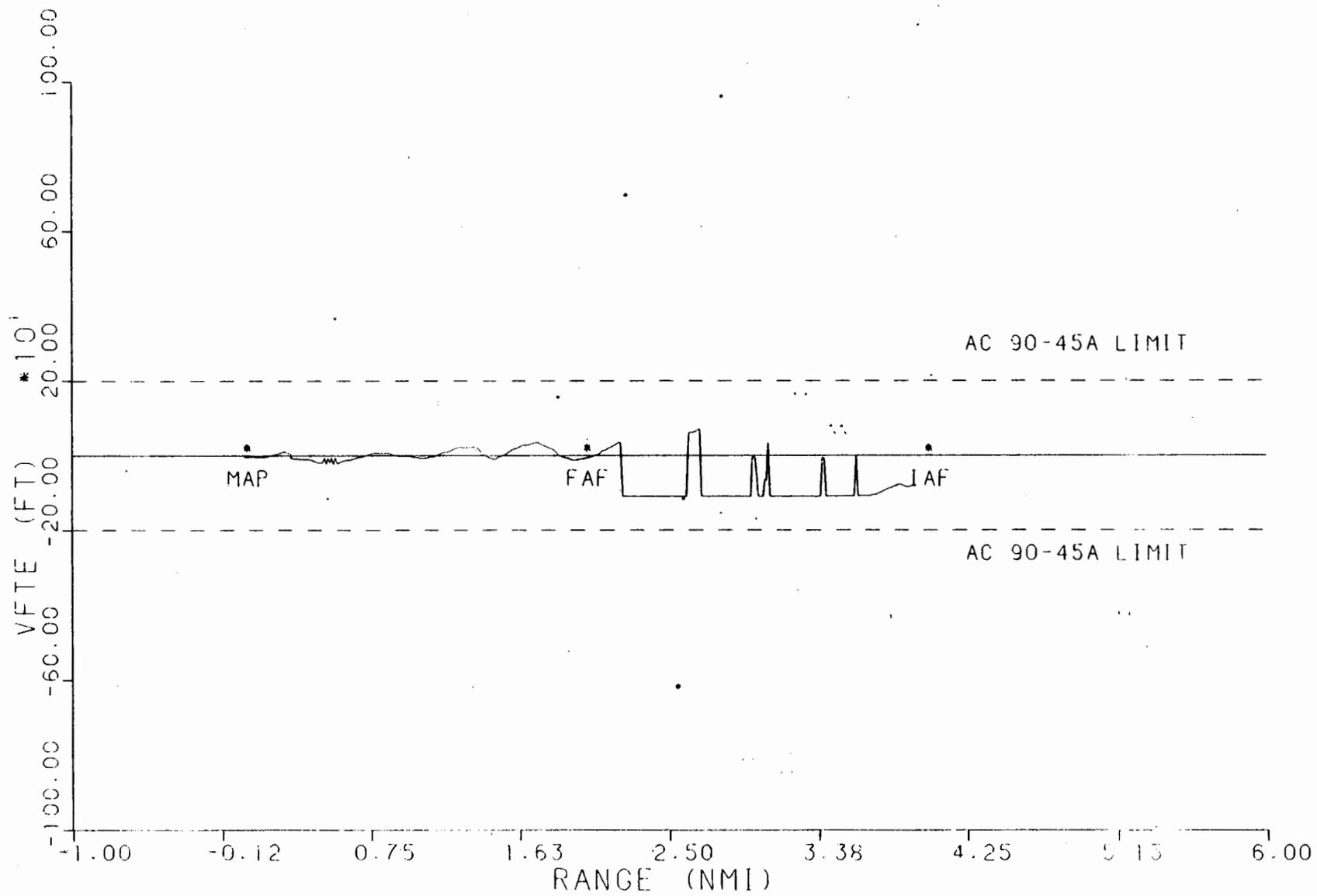
DATA PRODUCED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 6

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405

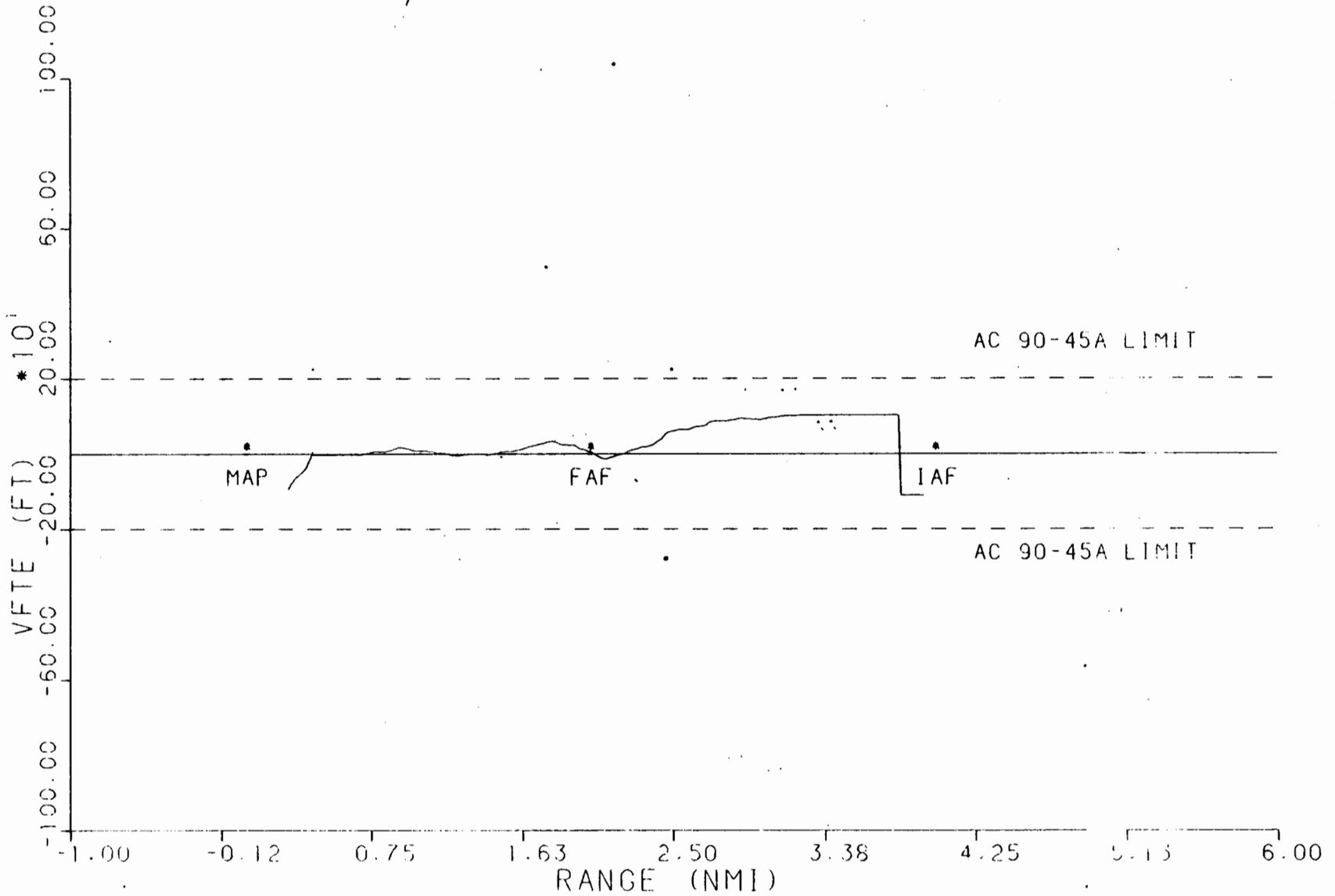
E-13



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 7

DATA PROCESSED BY THE FAA TECHNICAL CENTER
AT WASHINGTON AIRPORT, N.J. 08405

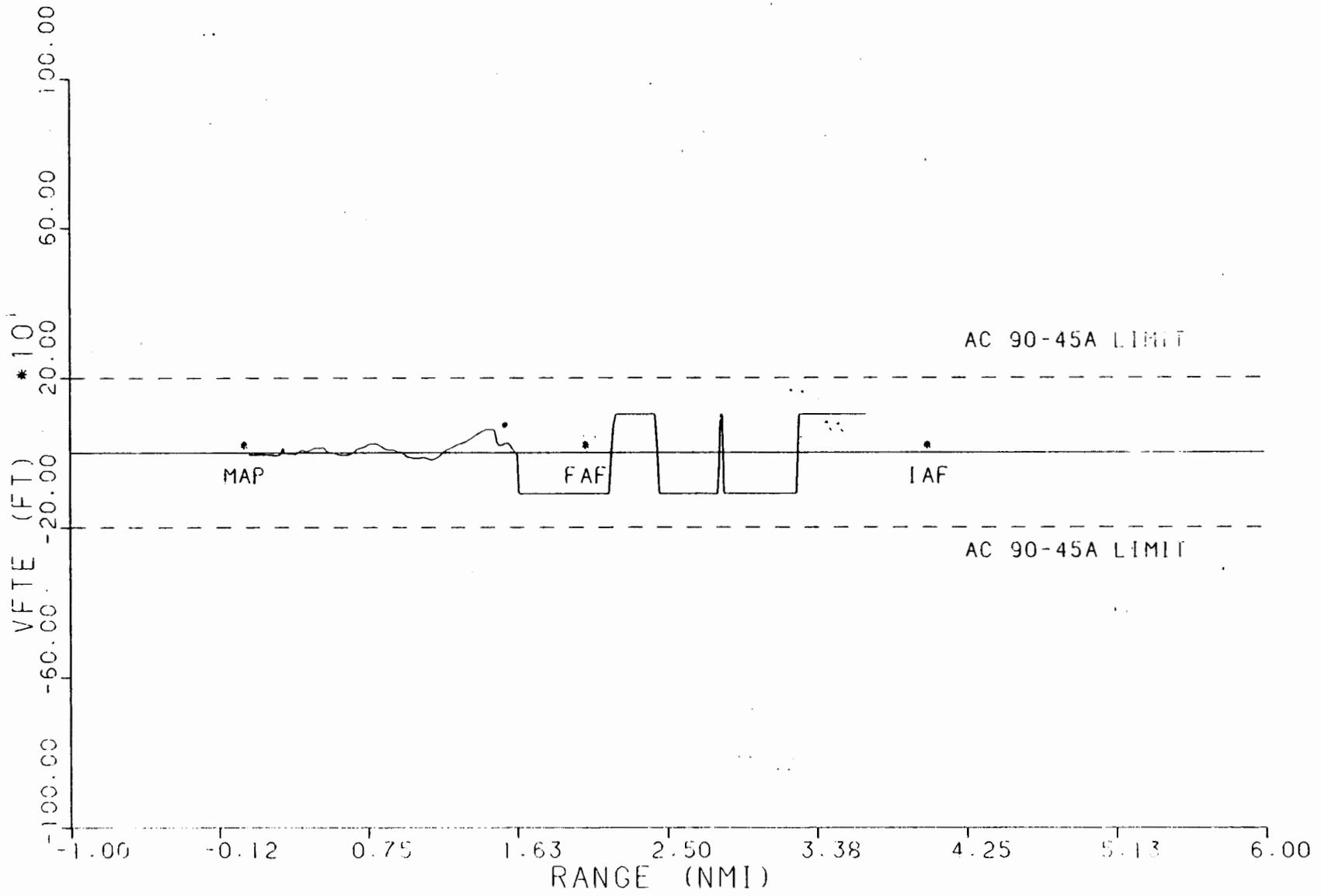
E-14



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 8

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTA, GEORGIA AIRPORT, N J 08405

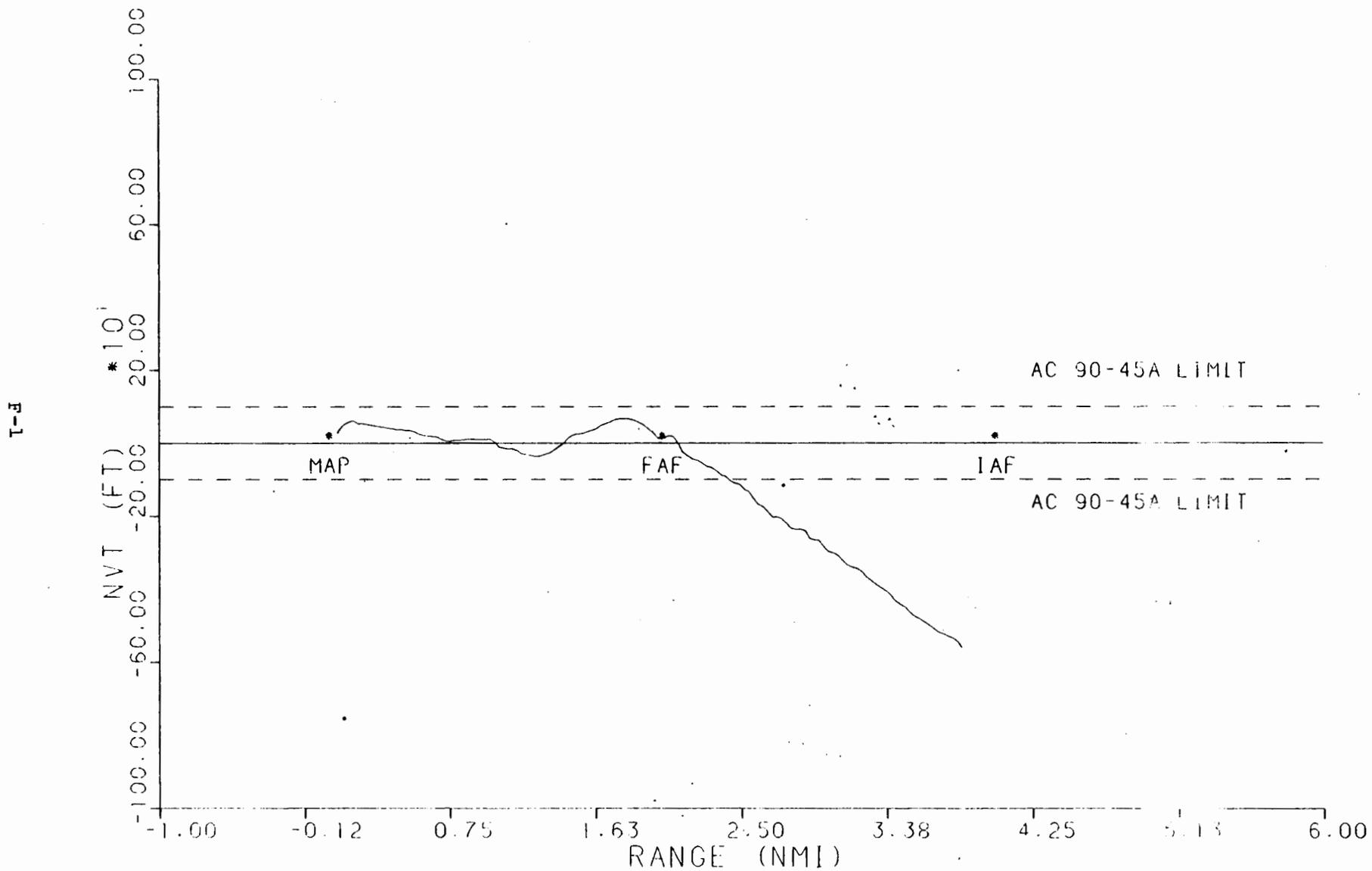
B-15



APPENDIX F
NVT VERSUS RANGE PLOTS

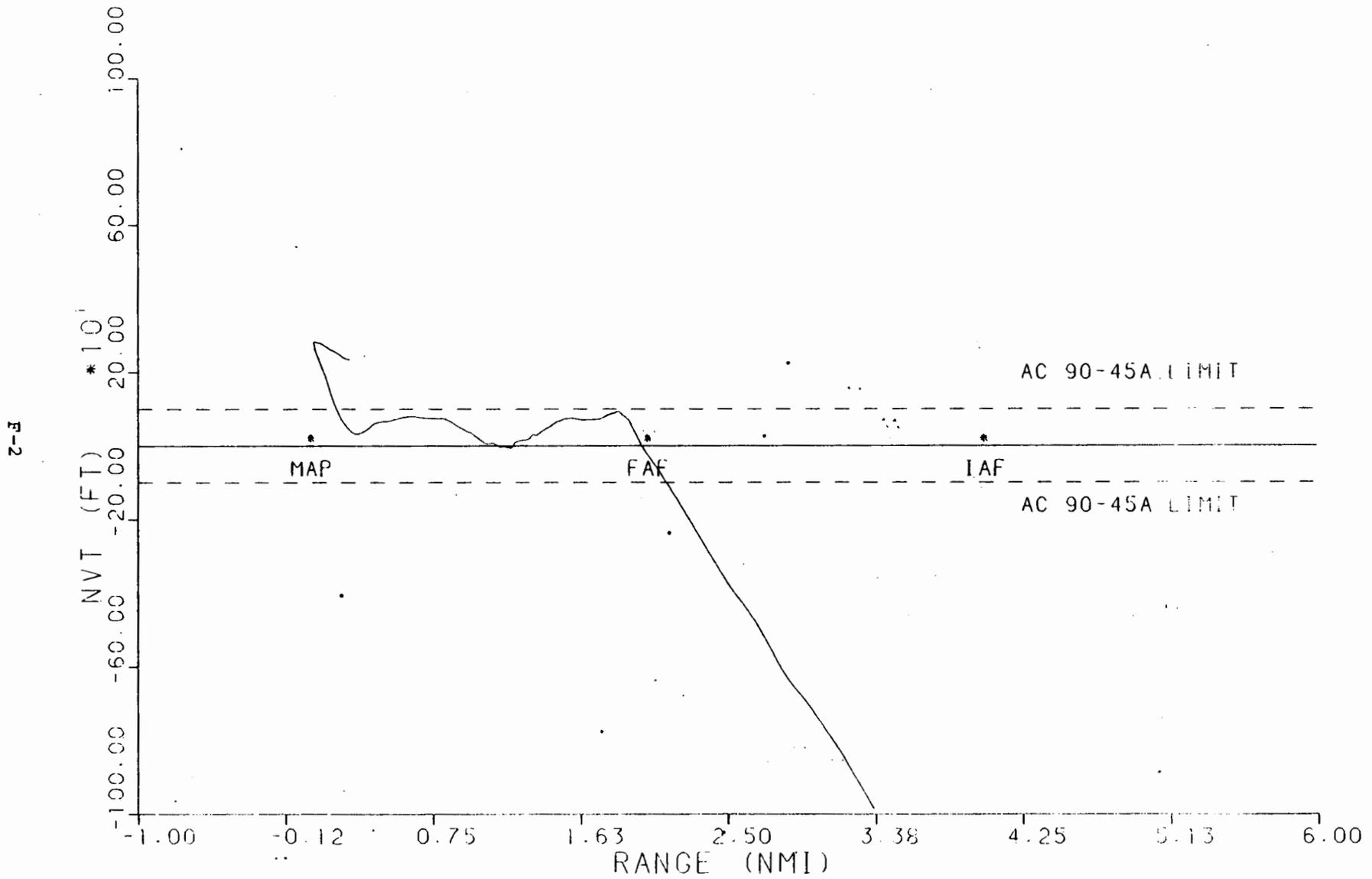
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 1

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTA, GEORGIA AIRPORT, N.J. 08400



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 2

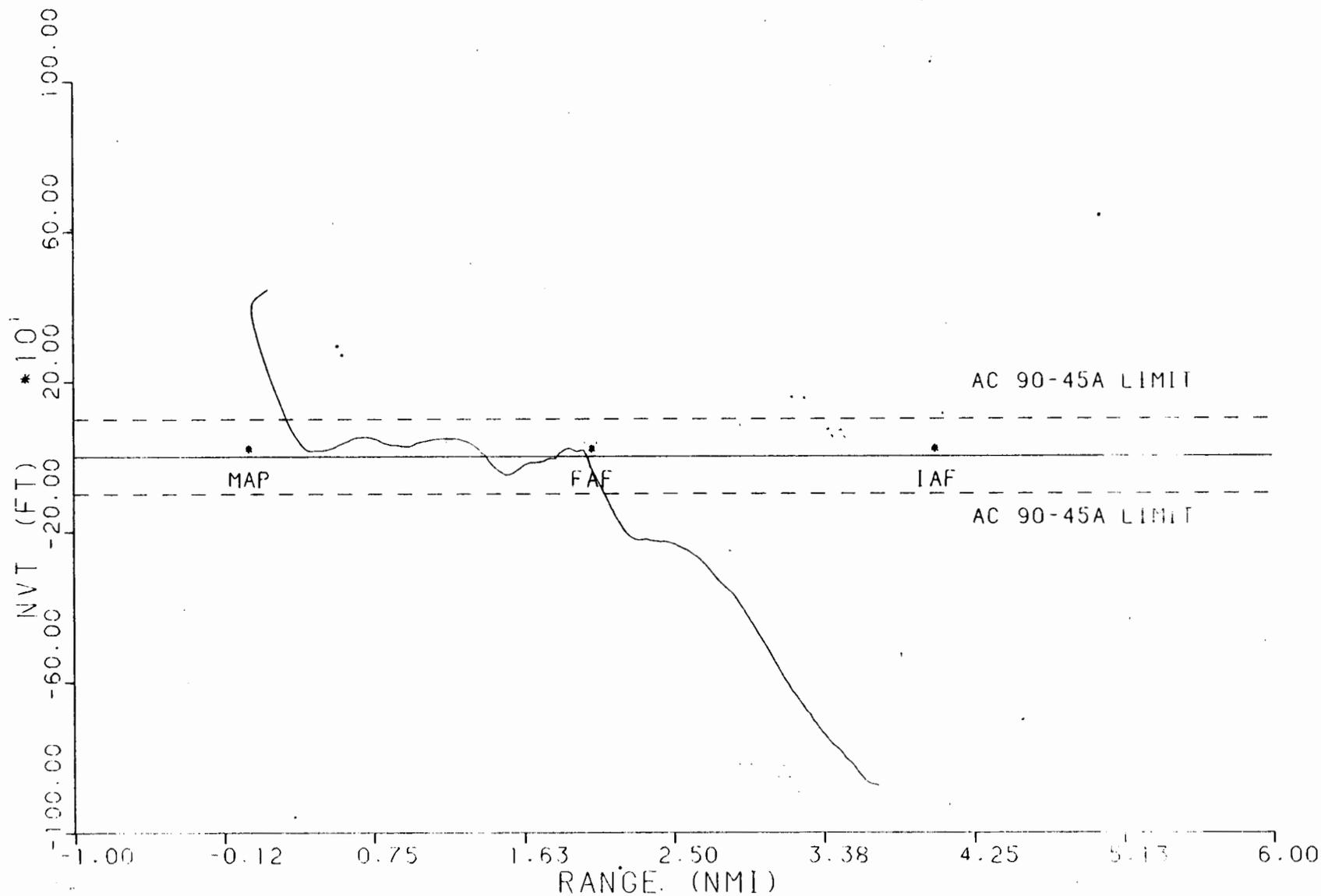
DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 3

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08402

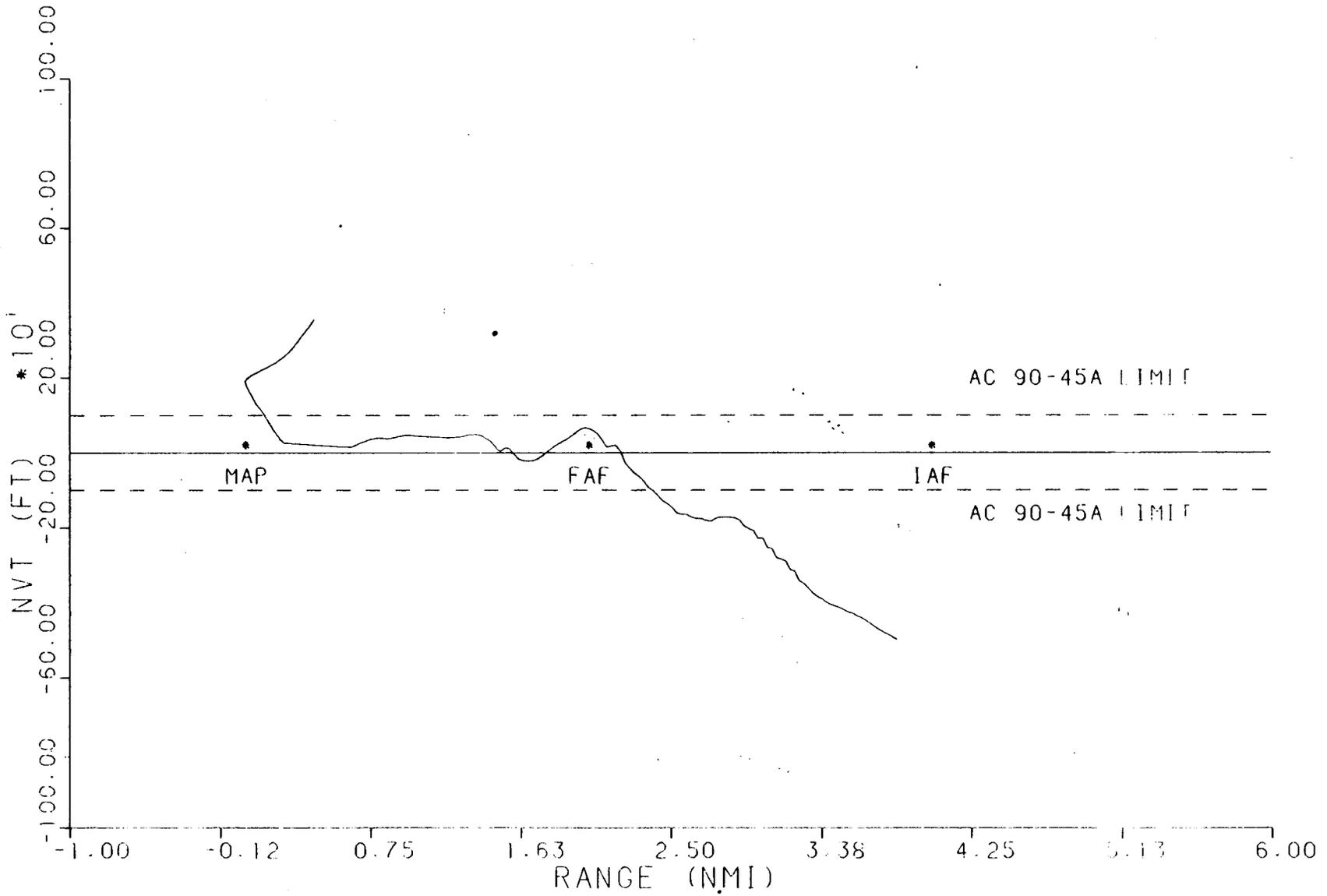
E-3



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 4

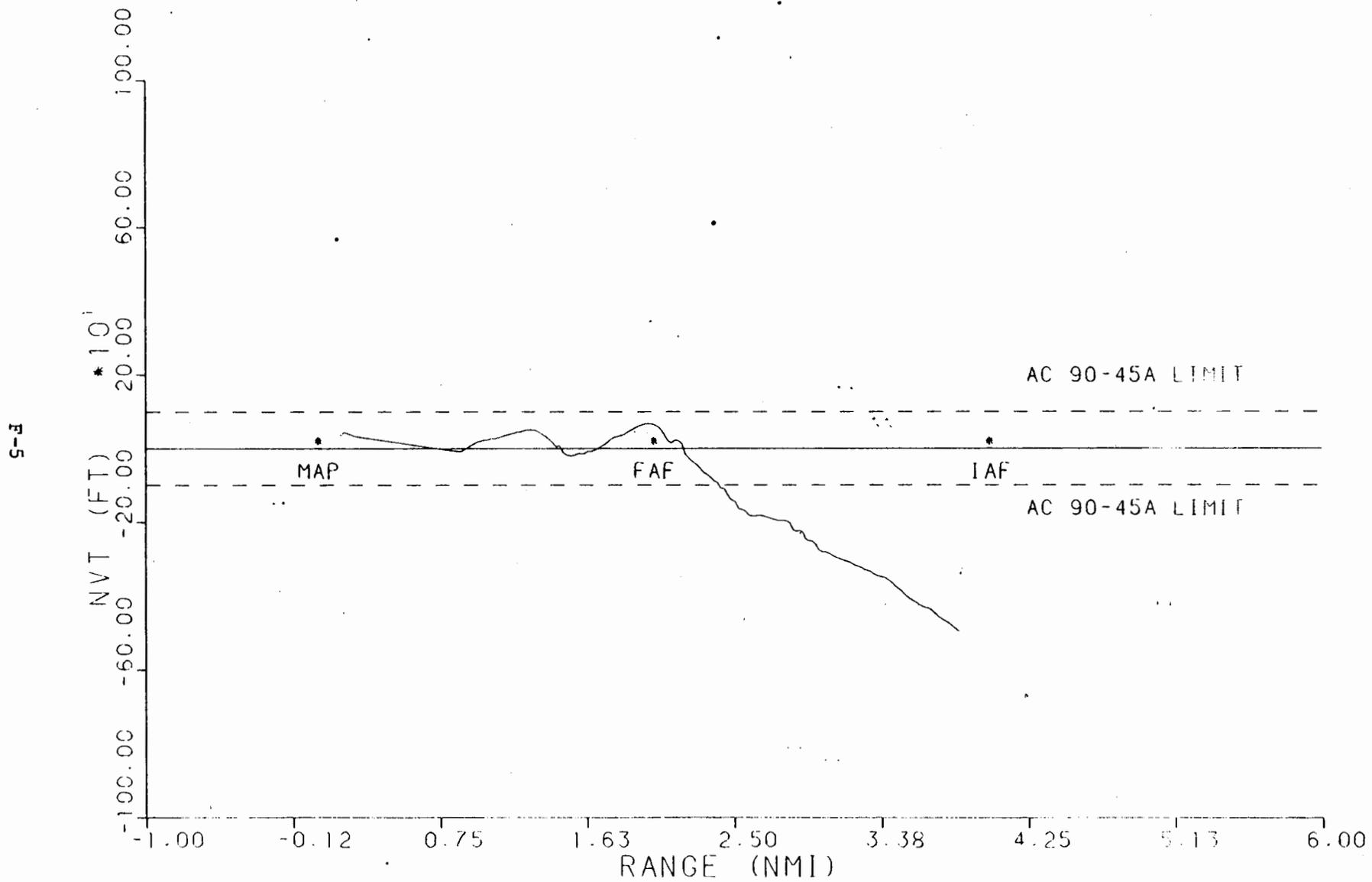
DATA PROVIDED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08403

E-4



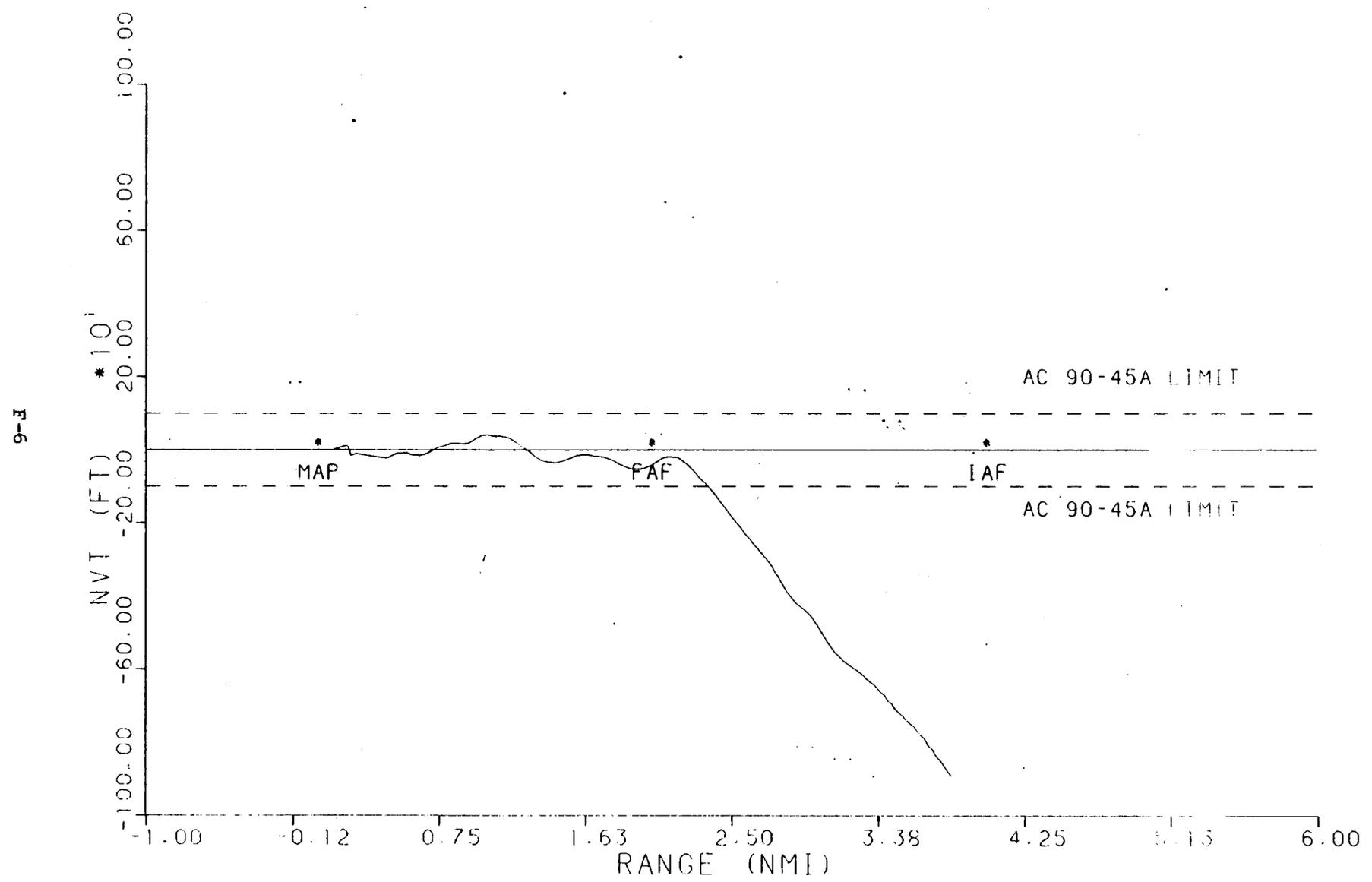
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 5

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405



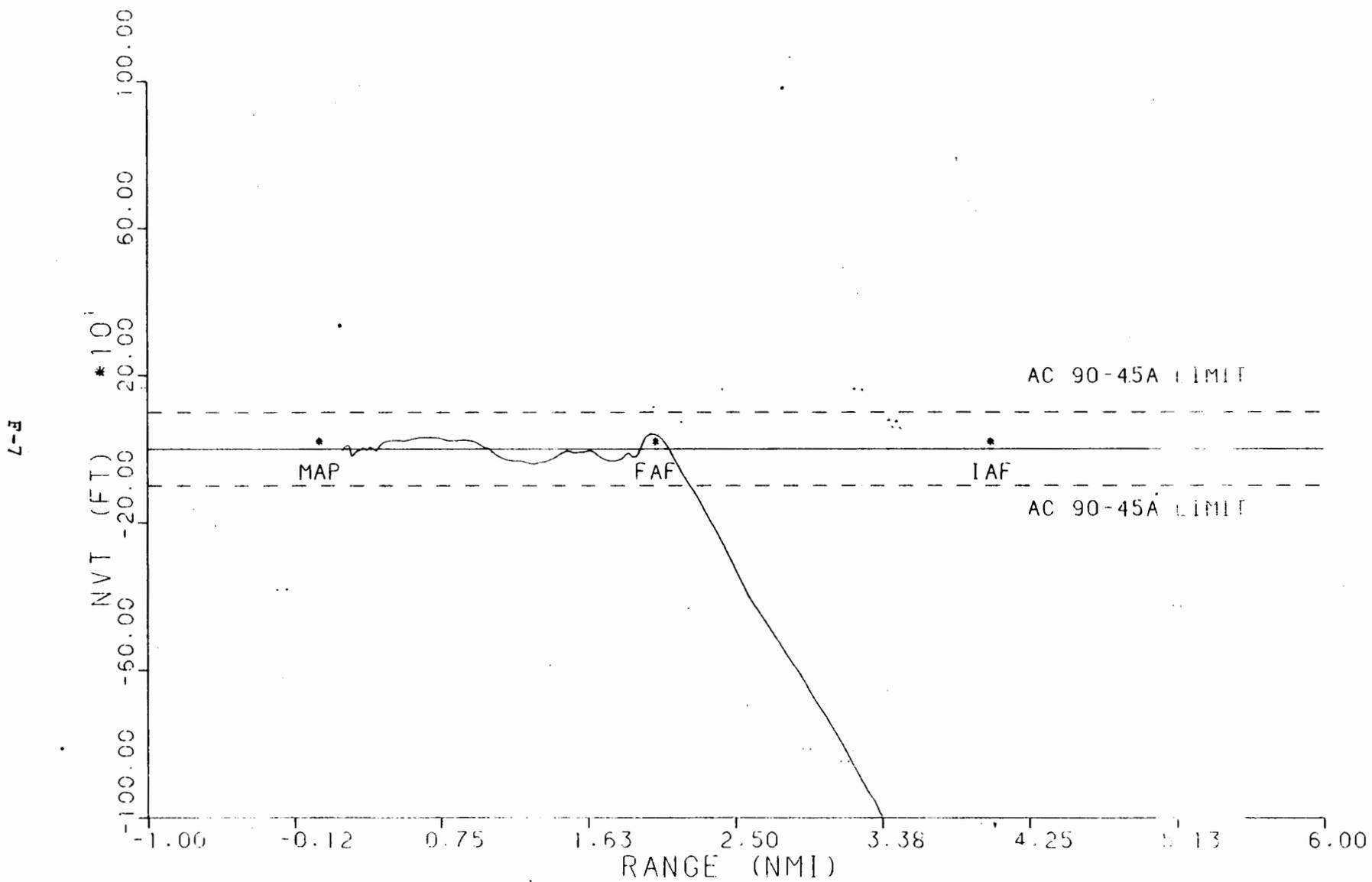
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 6

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



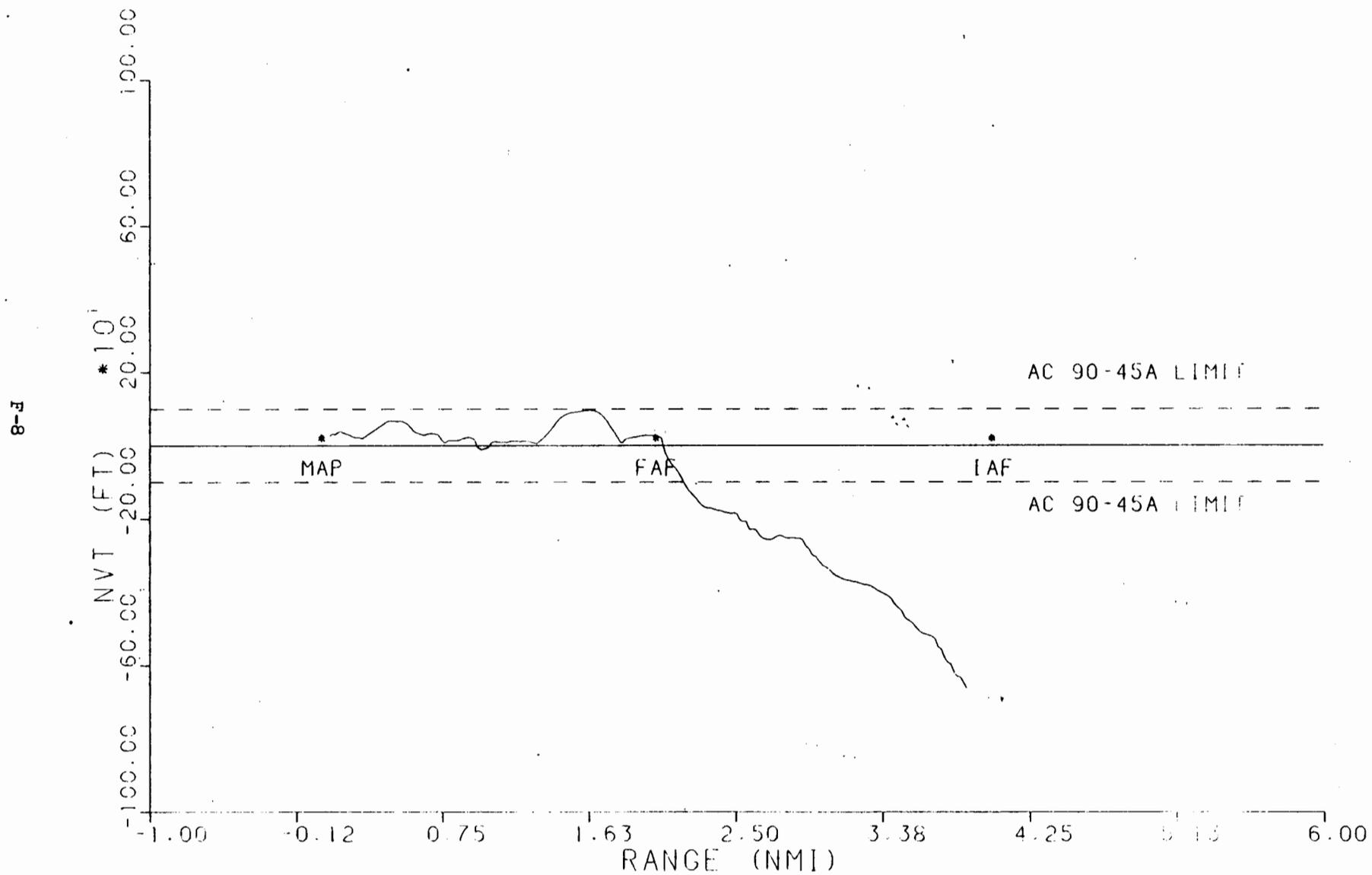
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 8

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



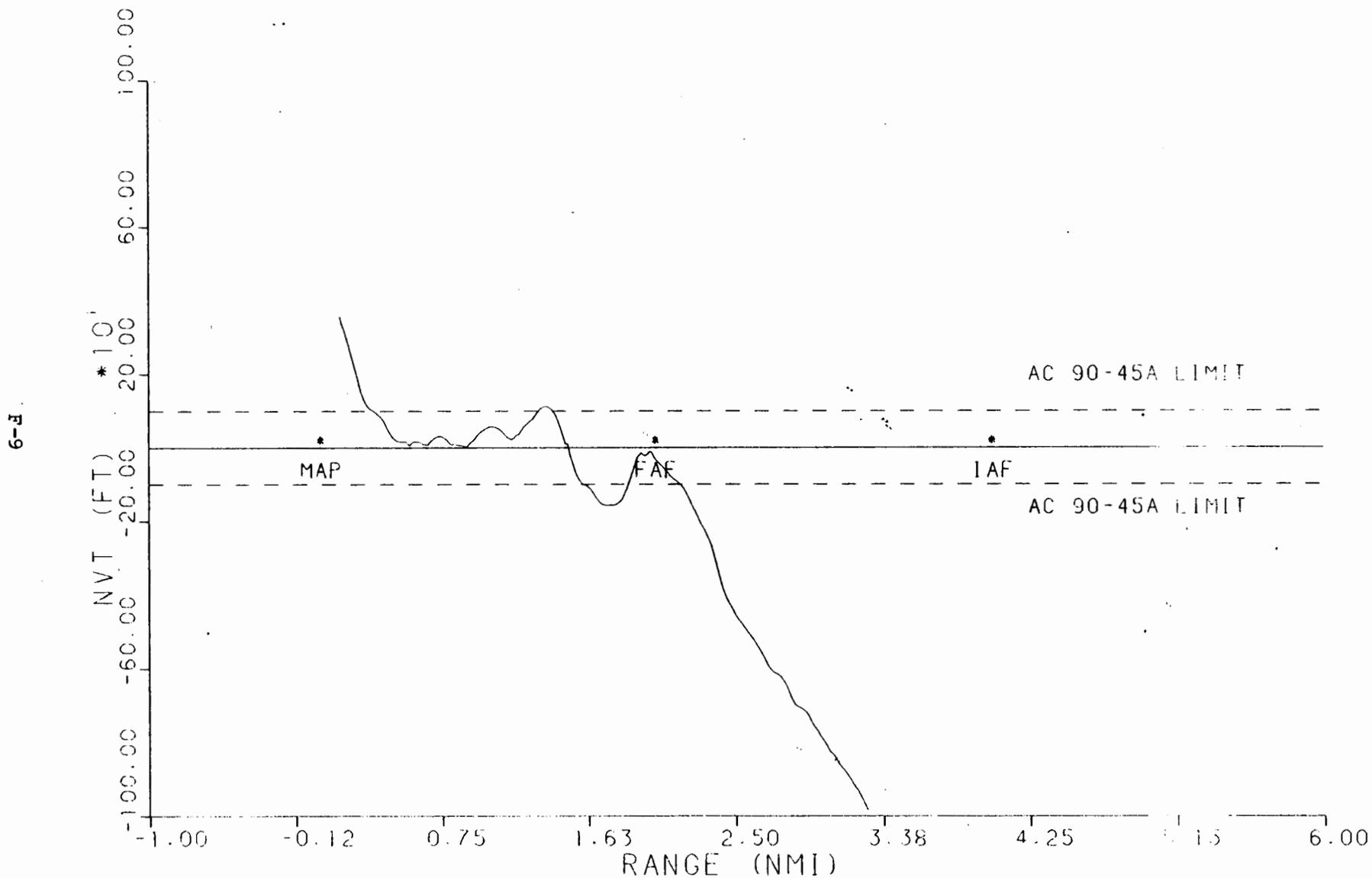
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 1

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08402



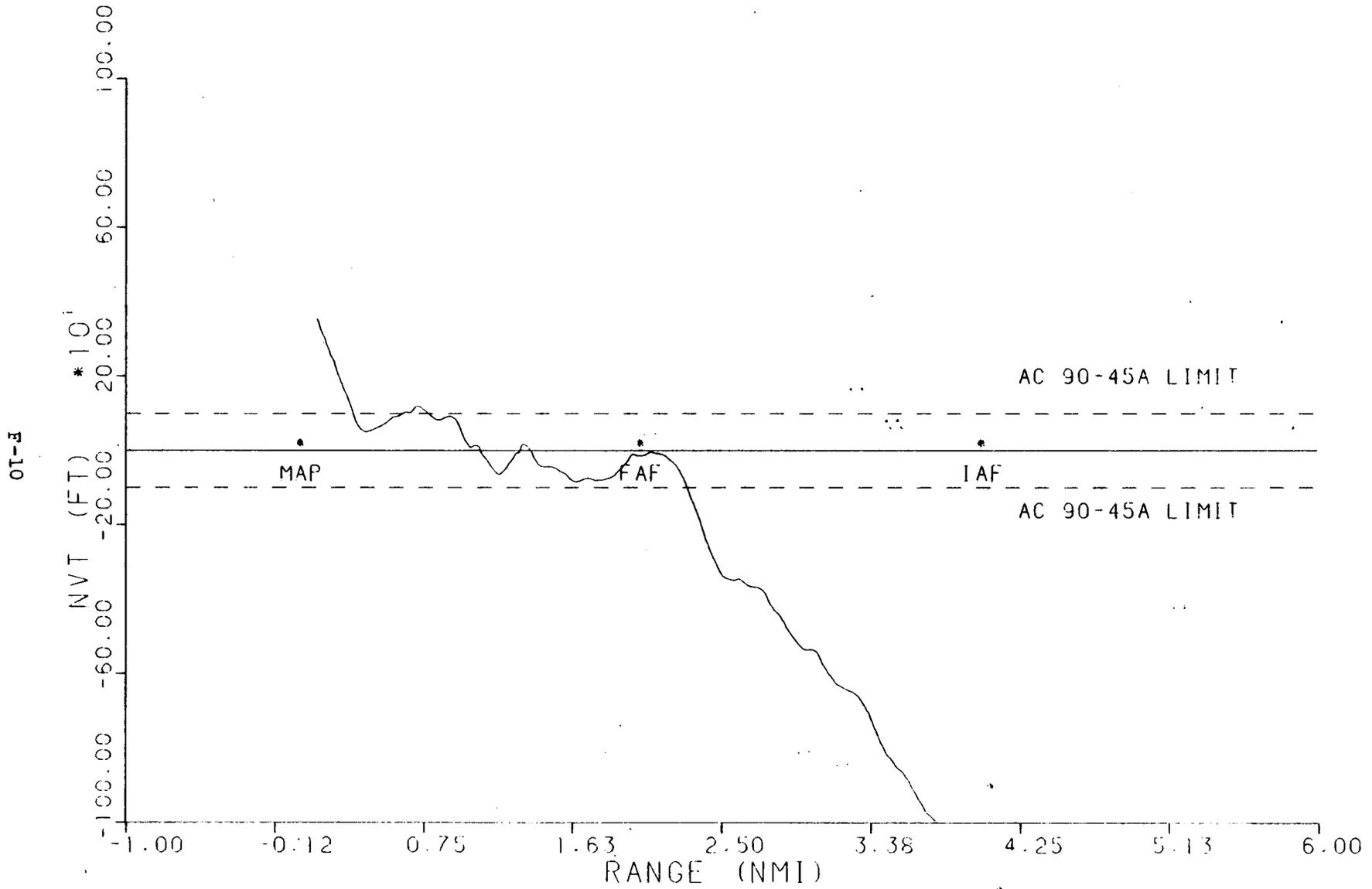
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 2

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



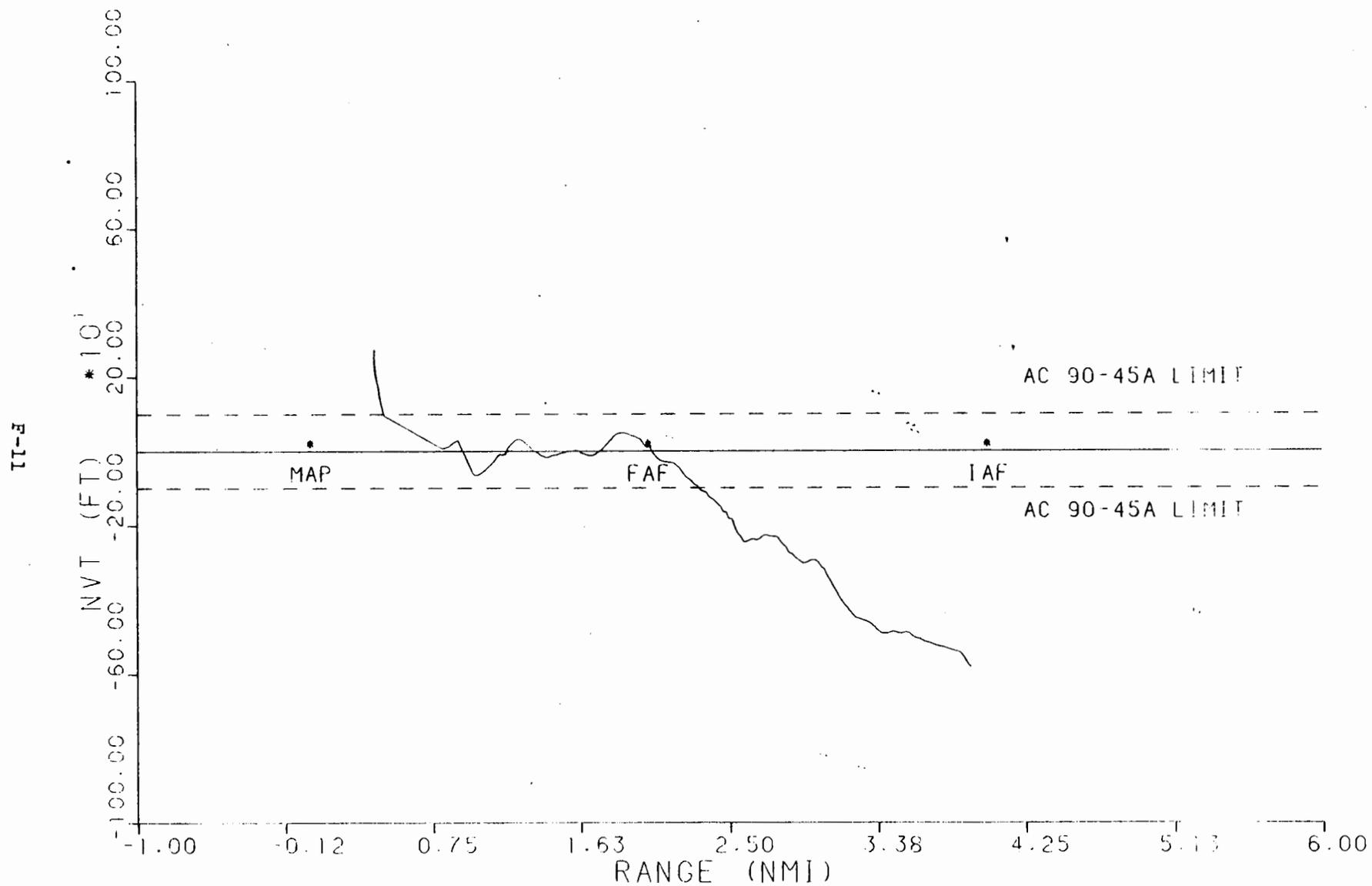
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 3

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405



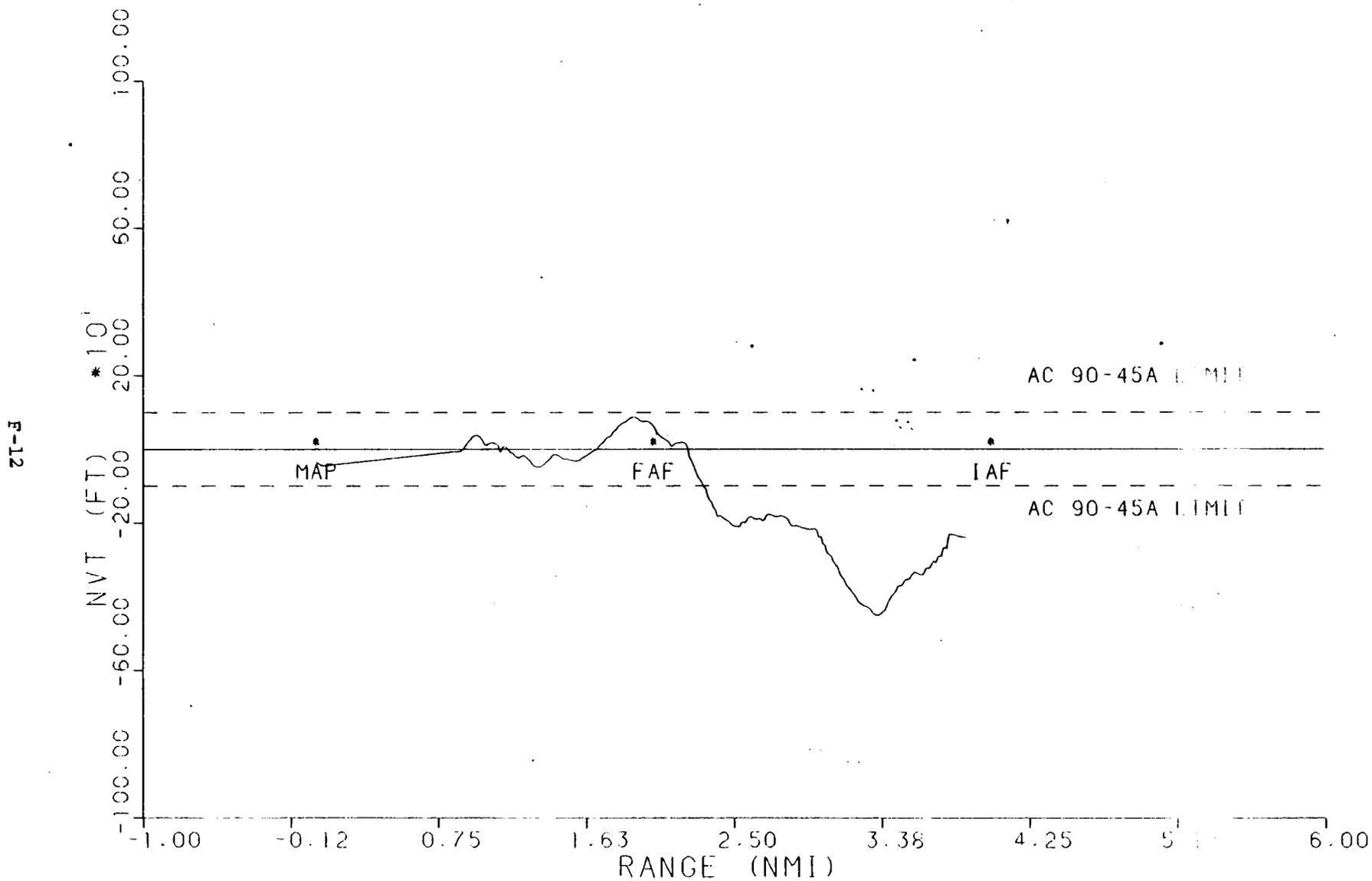
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 4

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTA, GEORGIA, N.J. 08405



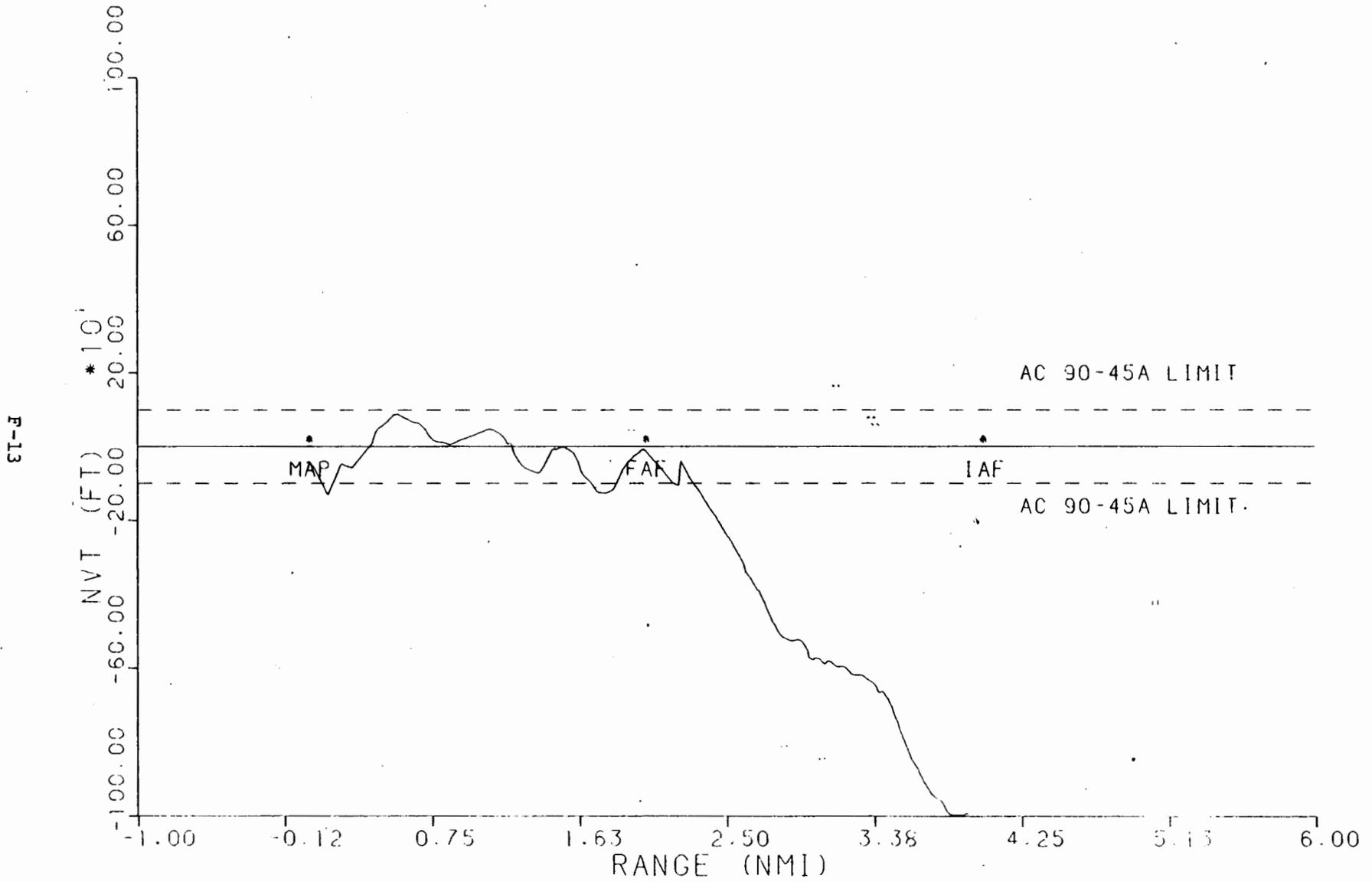
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 5

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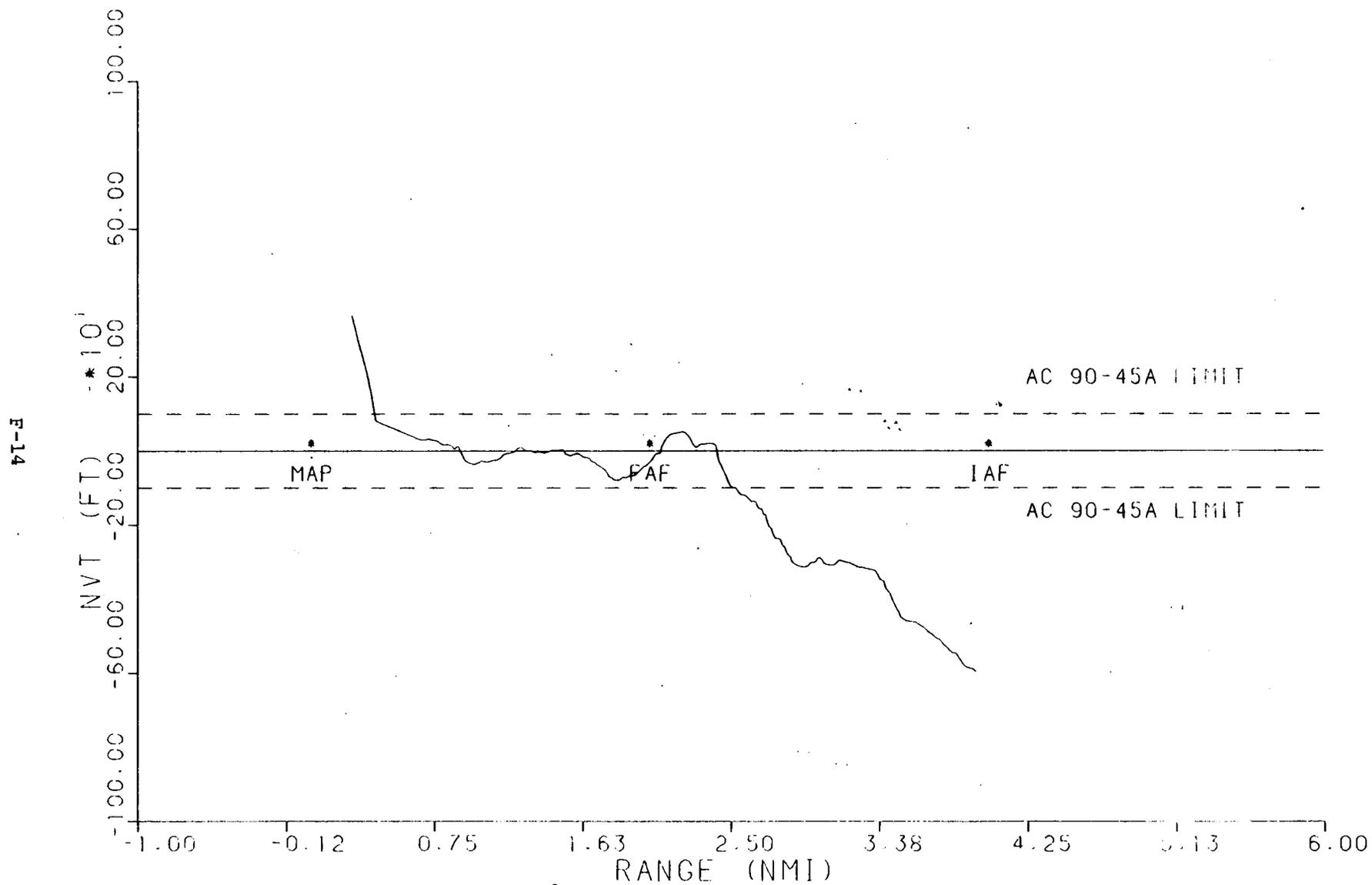
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 6

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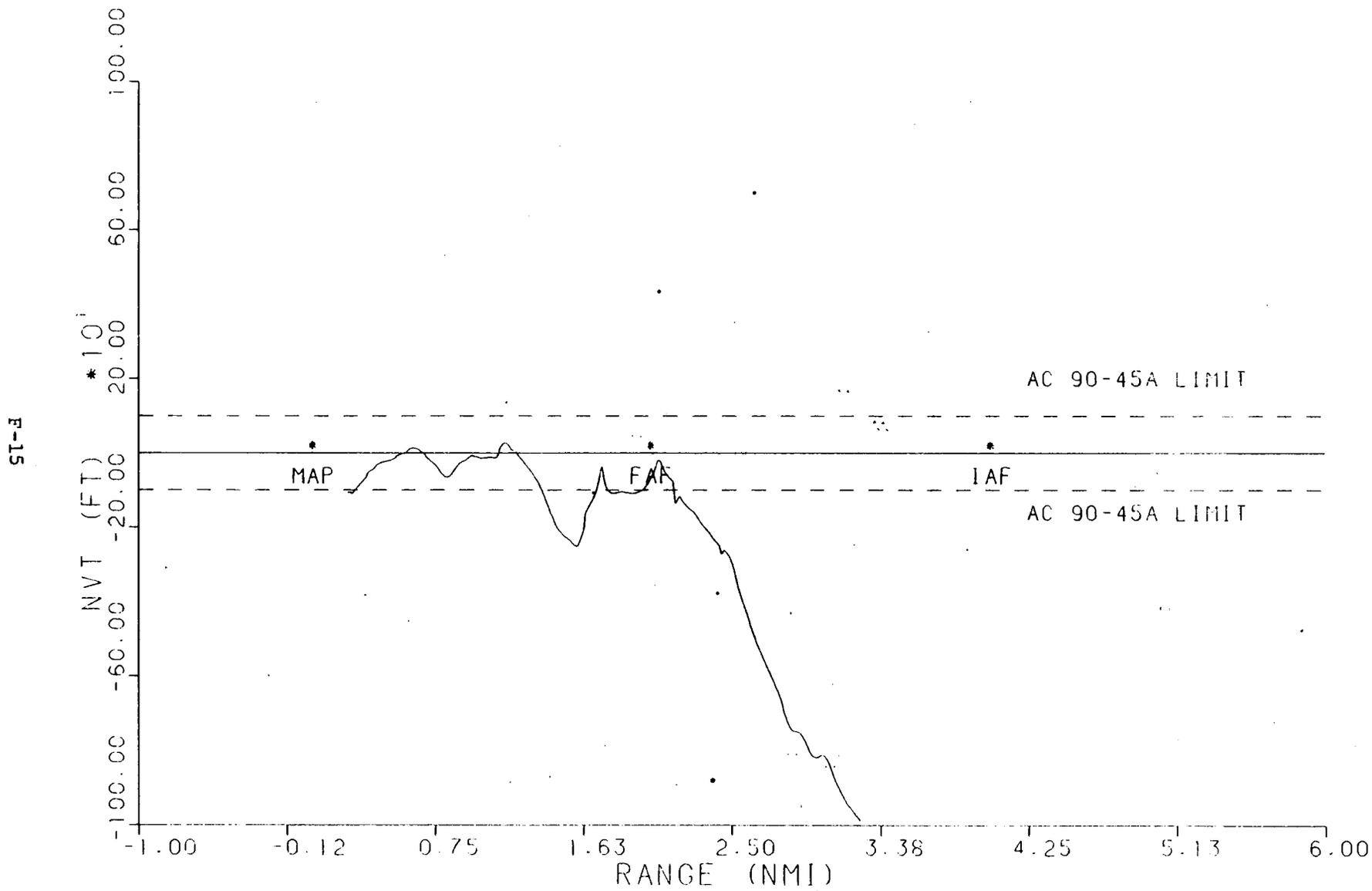
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 7

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FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 8

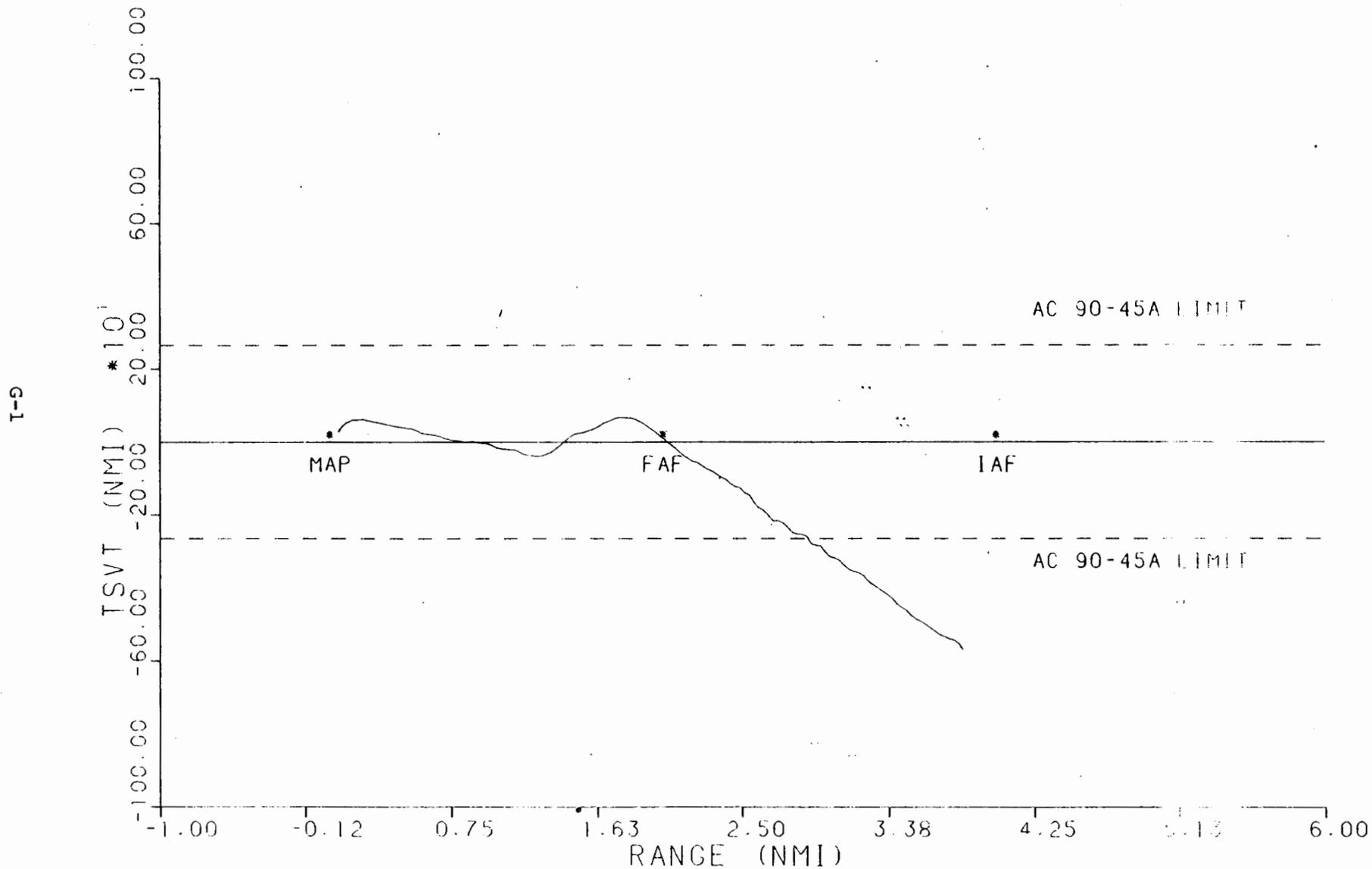
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APPENDIX G
TSVT VERSUS RANGE PLOTS

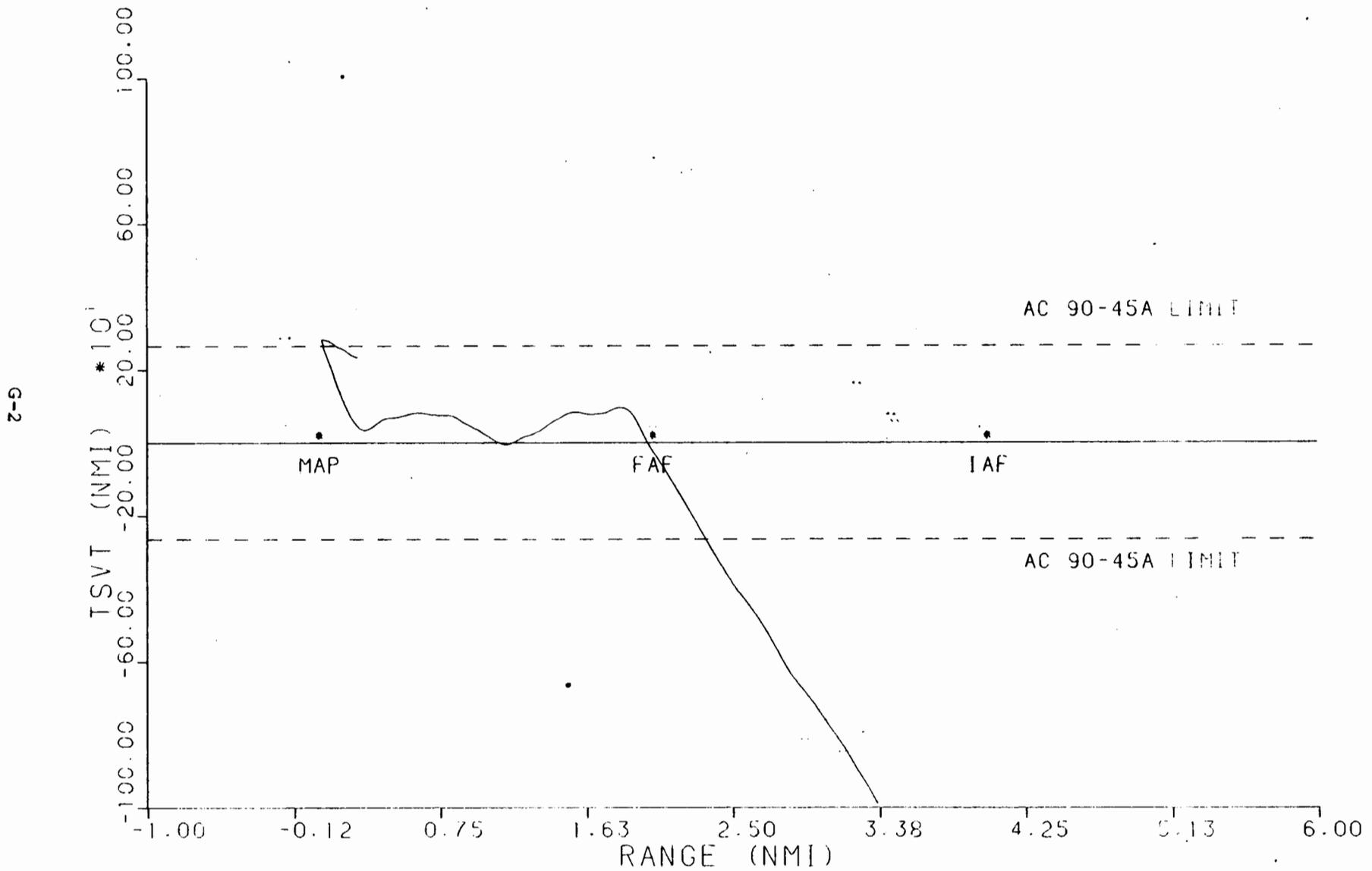
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 1

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ATLANTA, GA AIRPORT, N J 08405



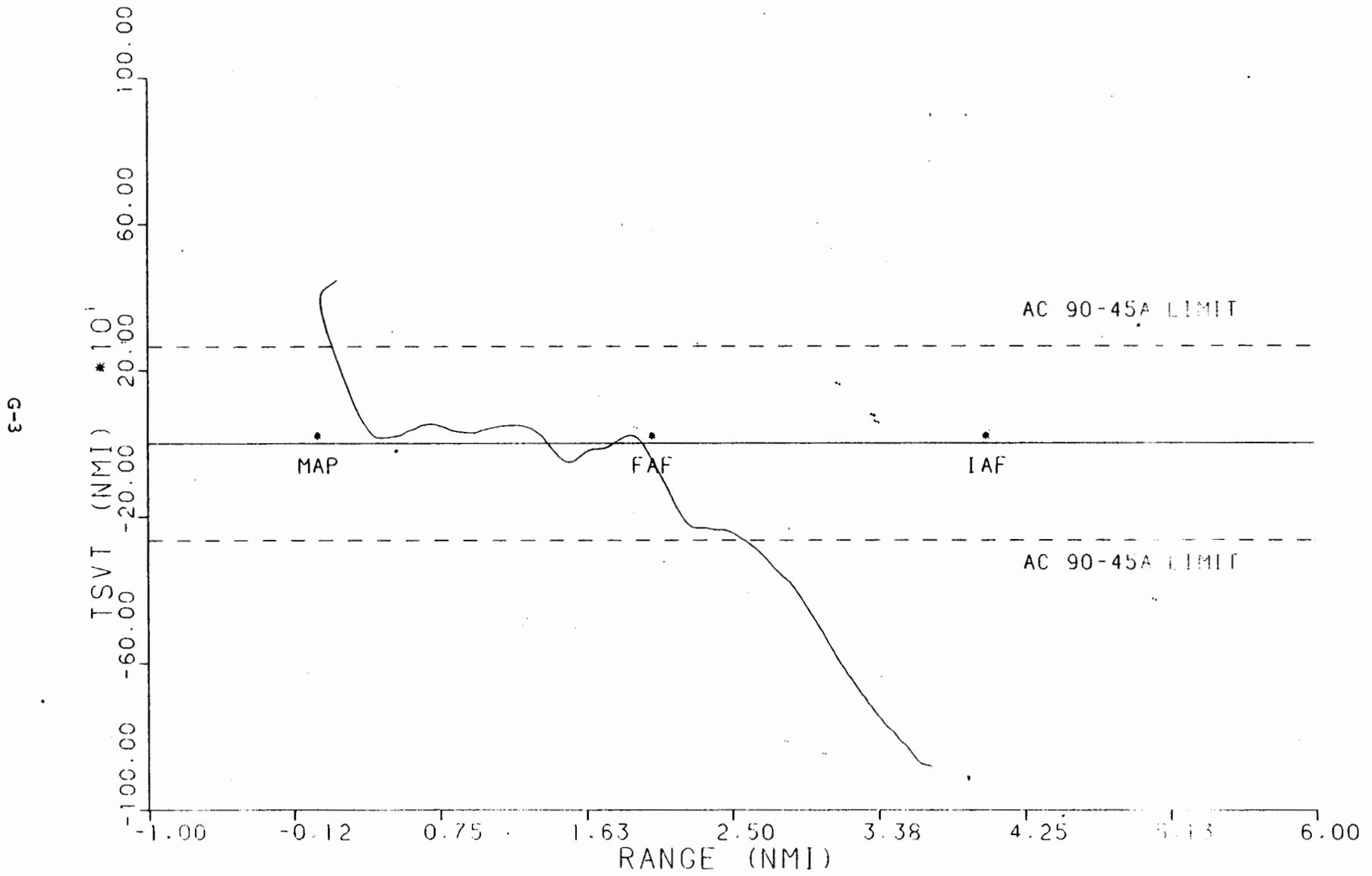
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RUN # 2

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 3

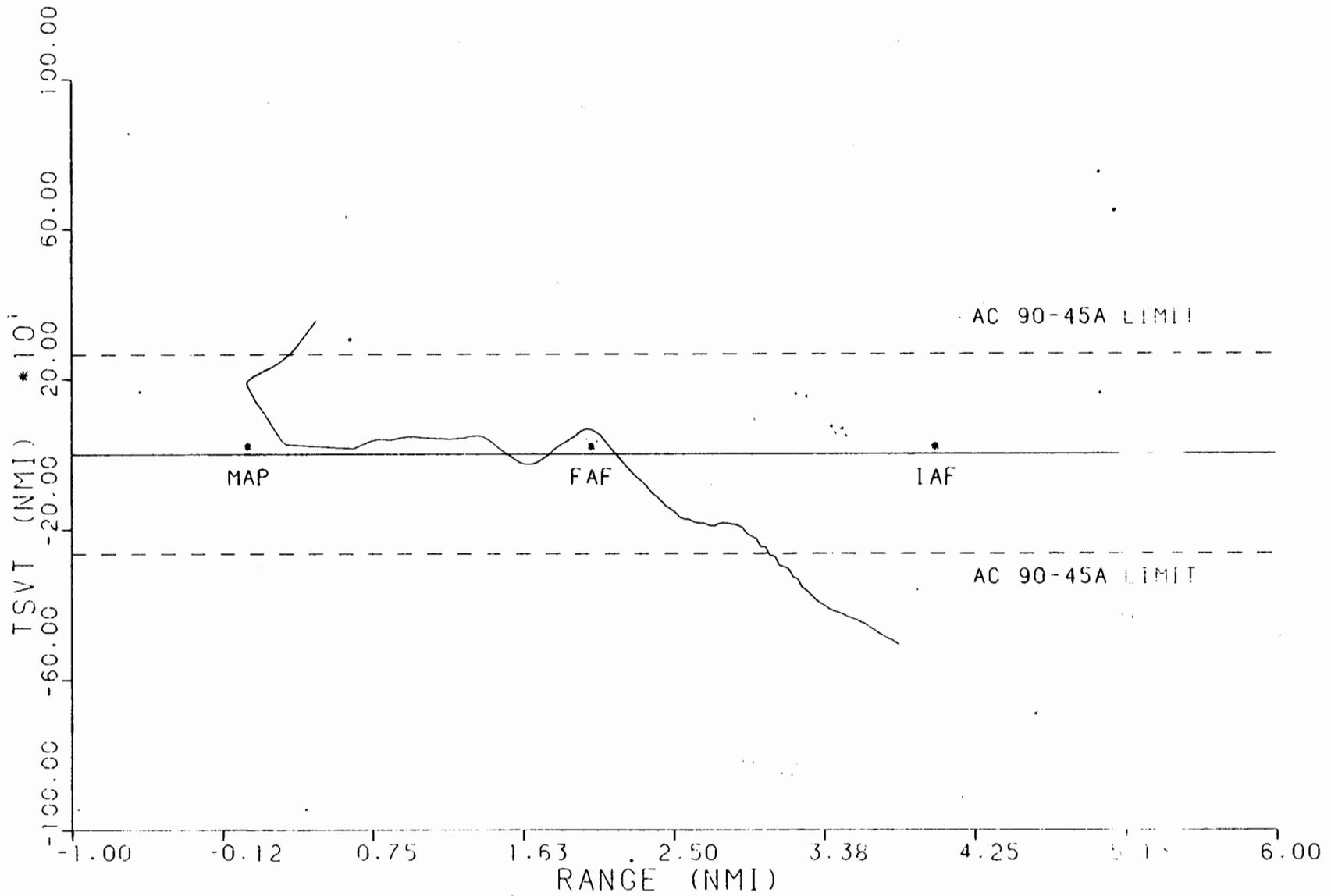
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ATLANTIC CITY AIRPORT, N. J. 08405



FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 4

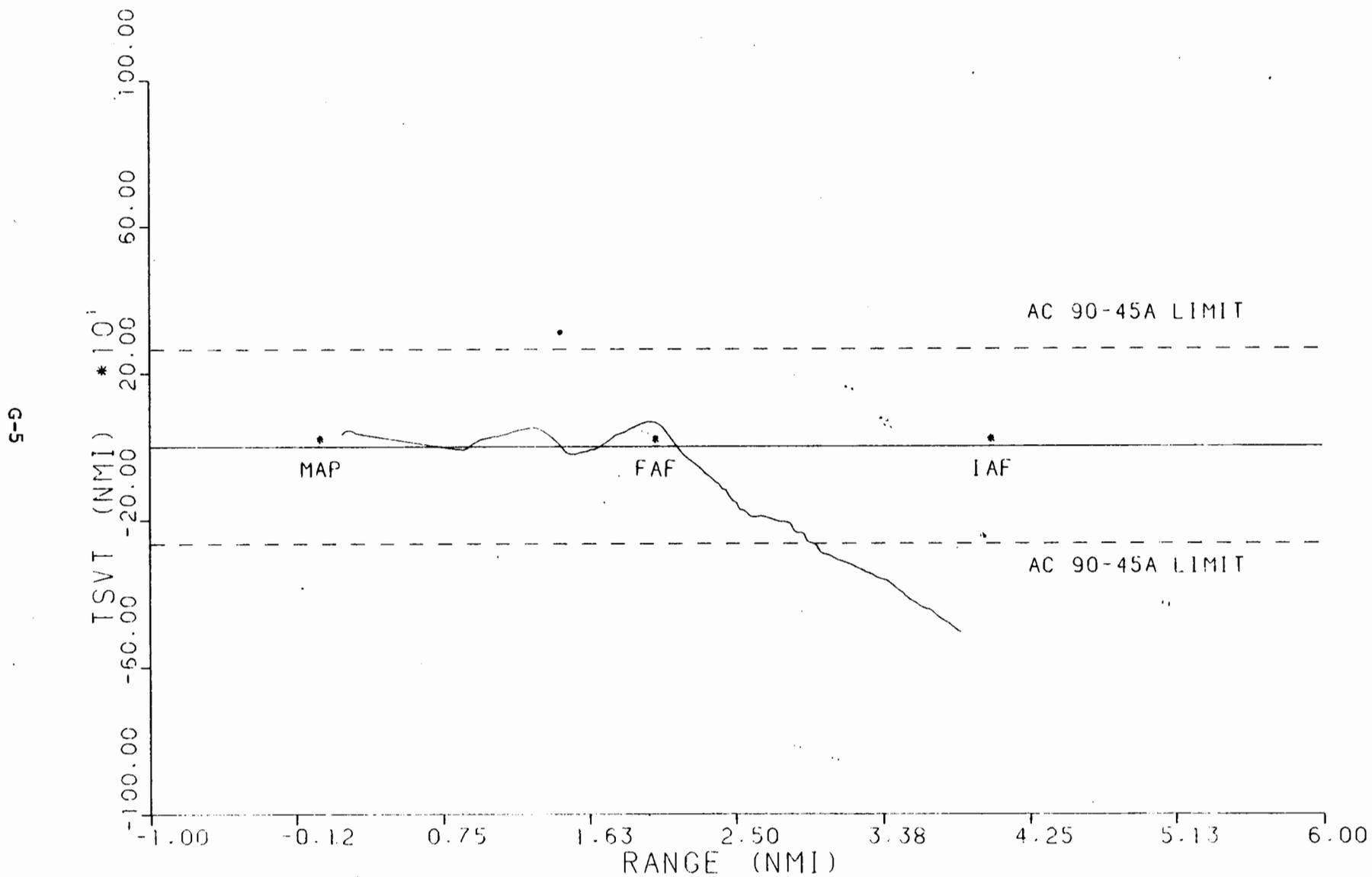
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ATLANTIC CITY AIRPORT, N. J. 08405

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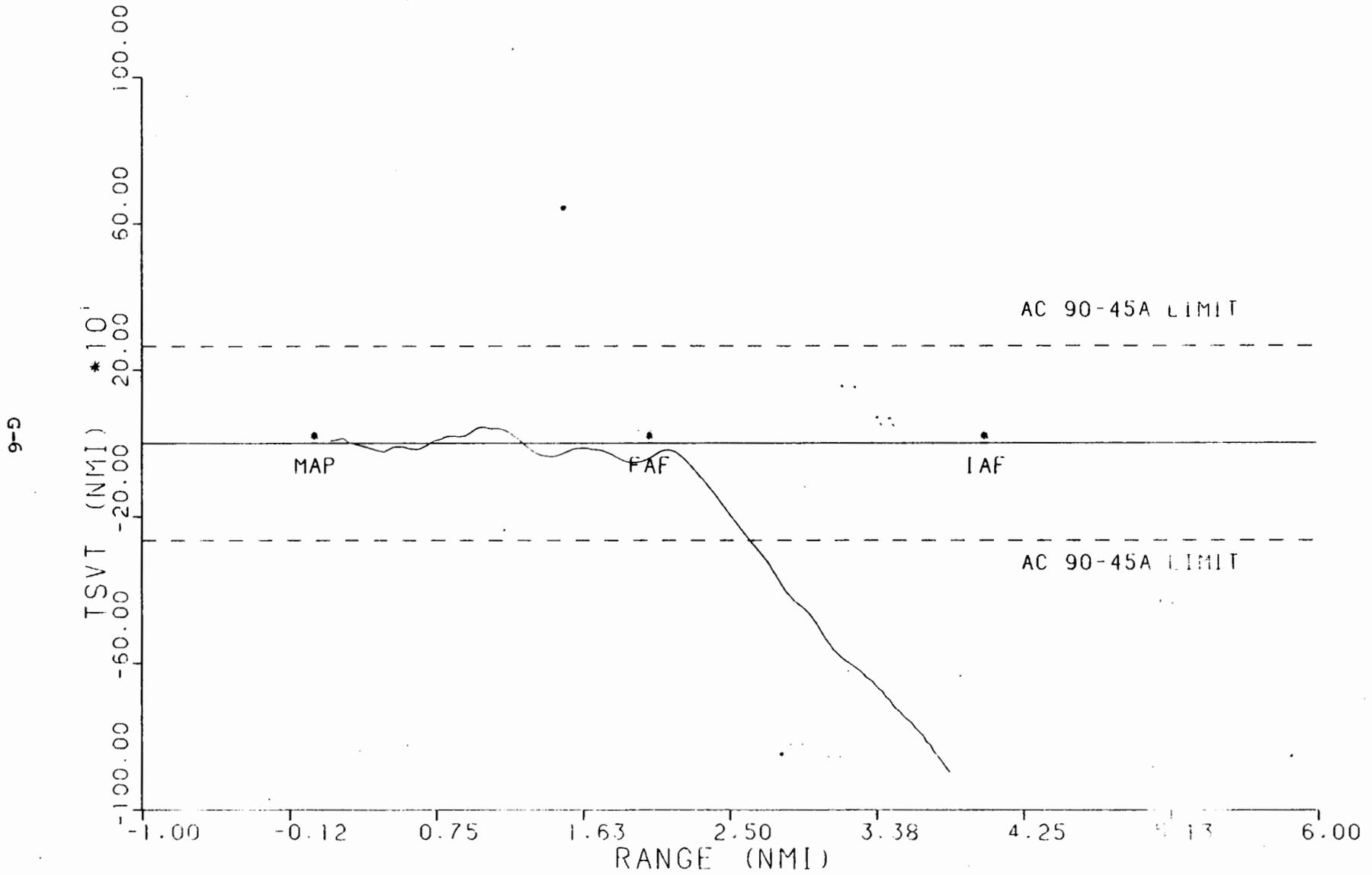
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 5

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ATLANTIC CITY AIRPORT, N.J. 08402



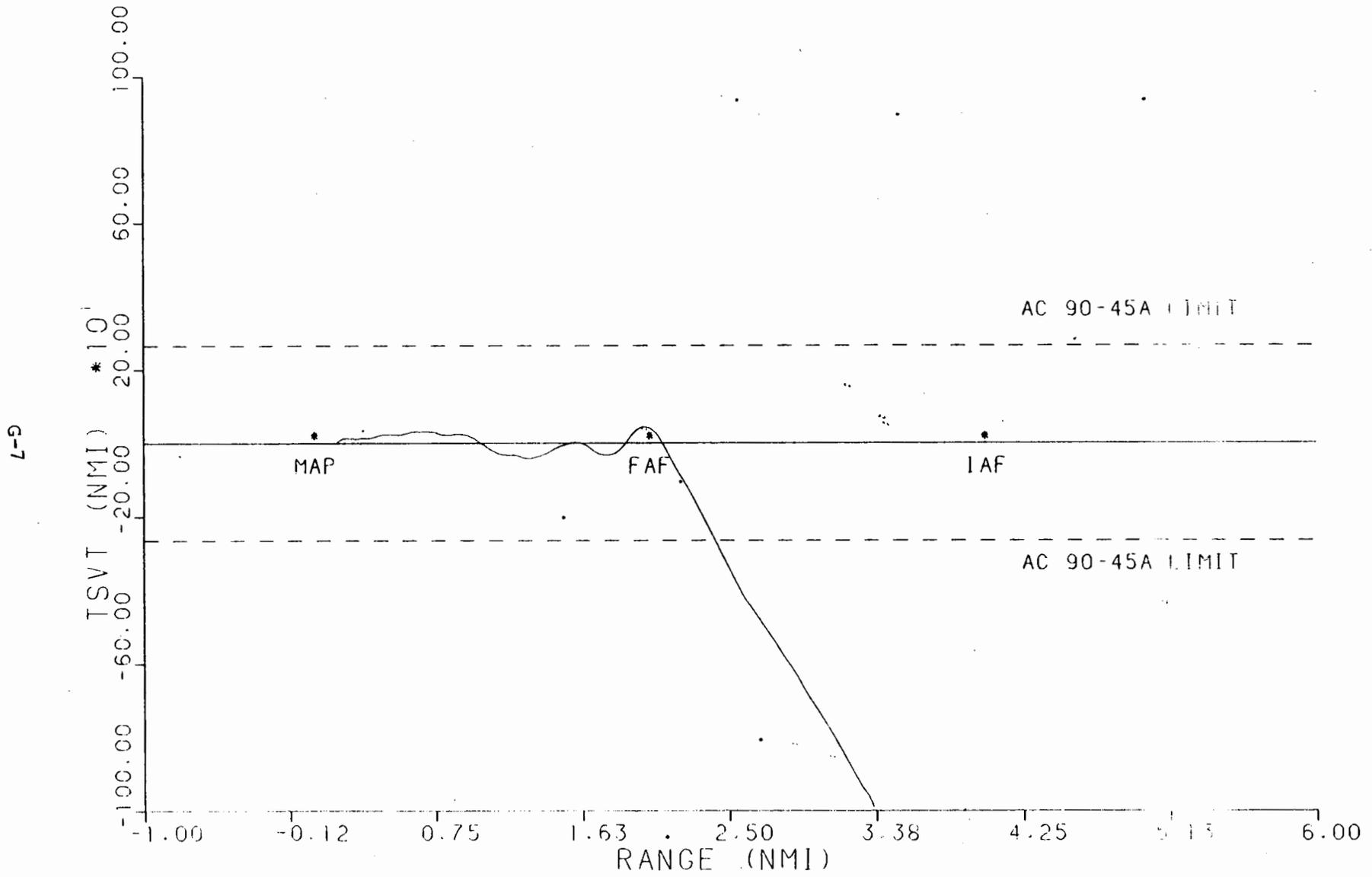
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 6

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



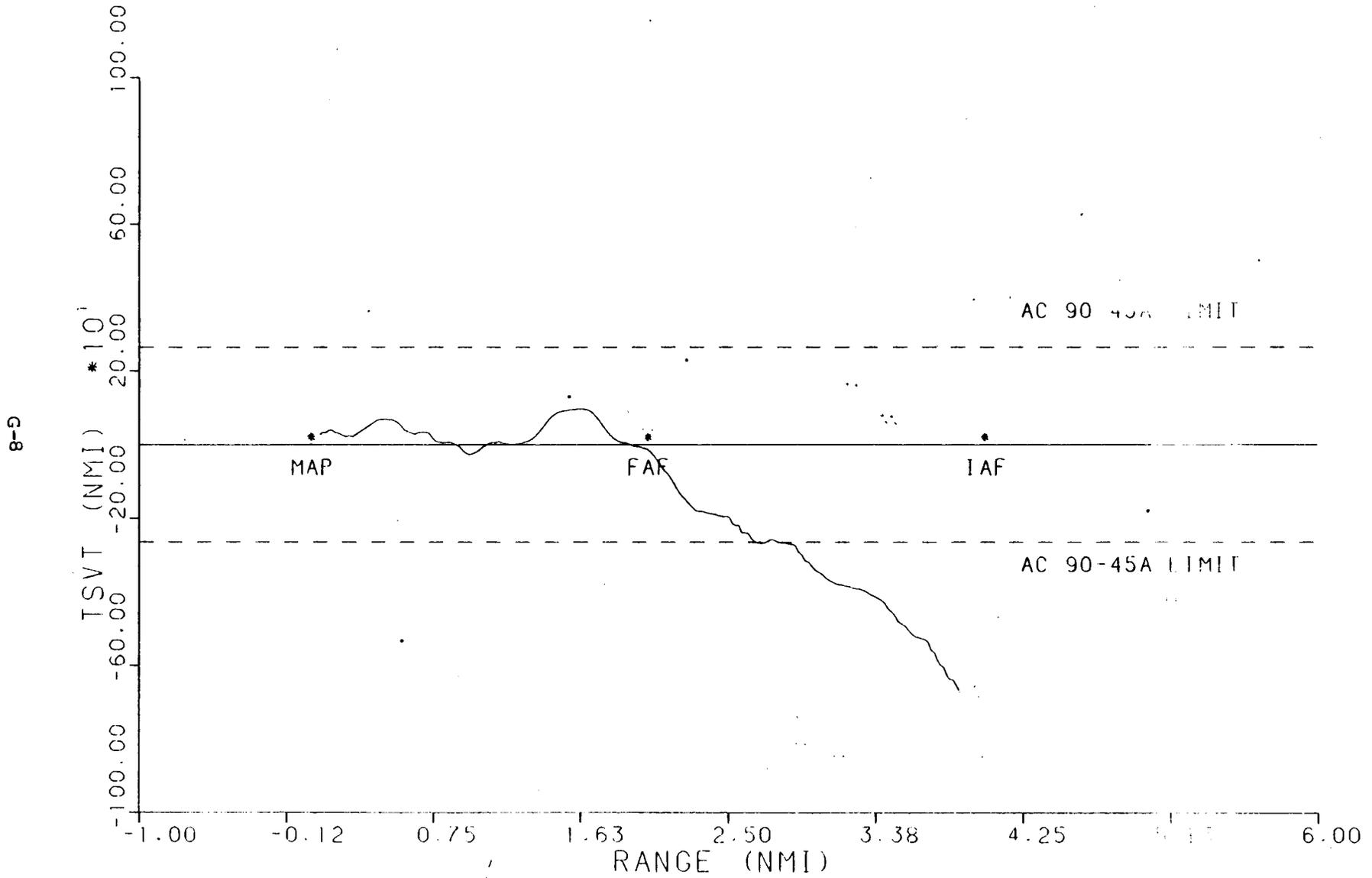
FLIGHT #1 WITH SUBJECT PILOT #1
RUN # 8

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



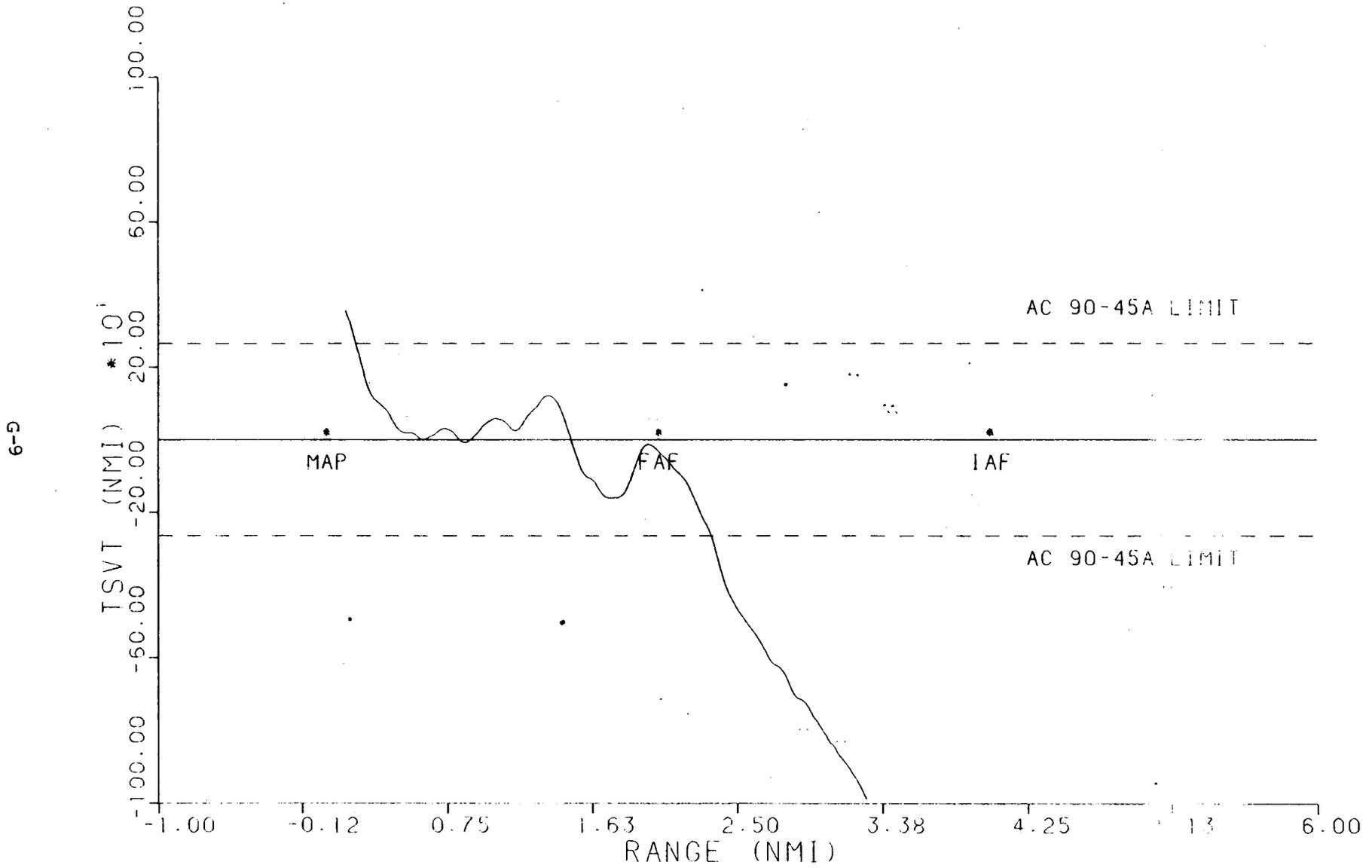
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 1

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405



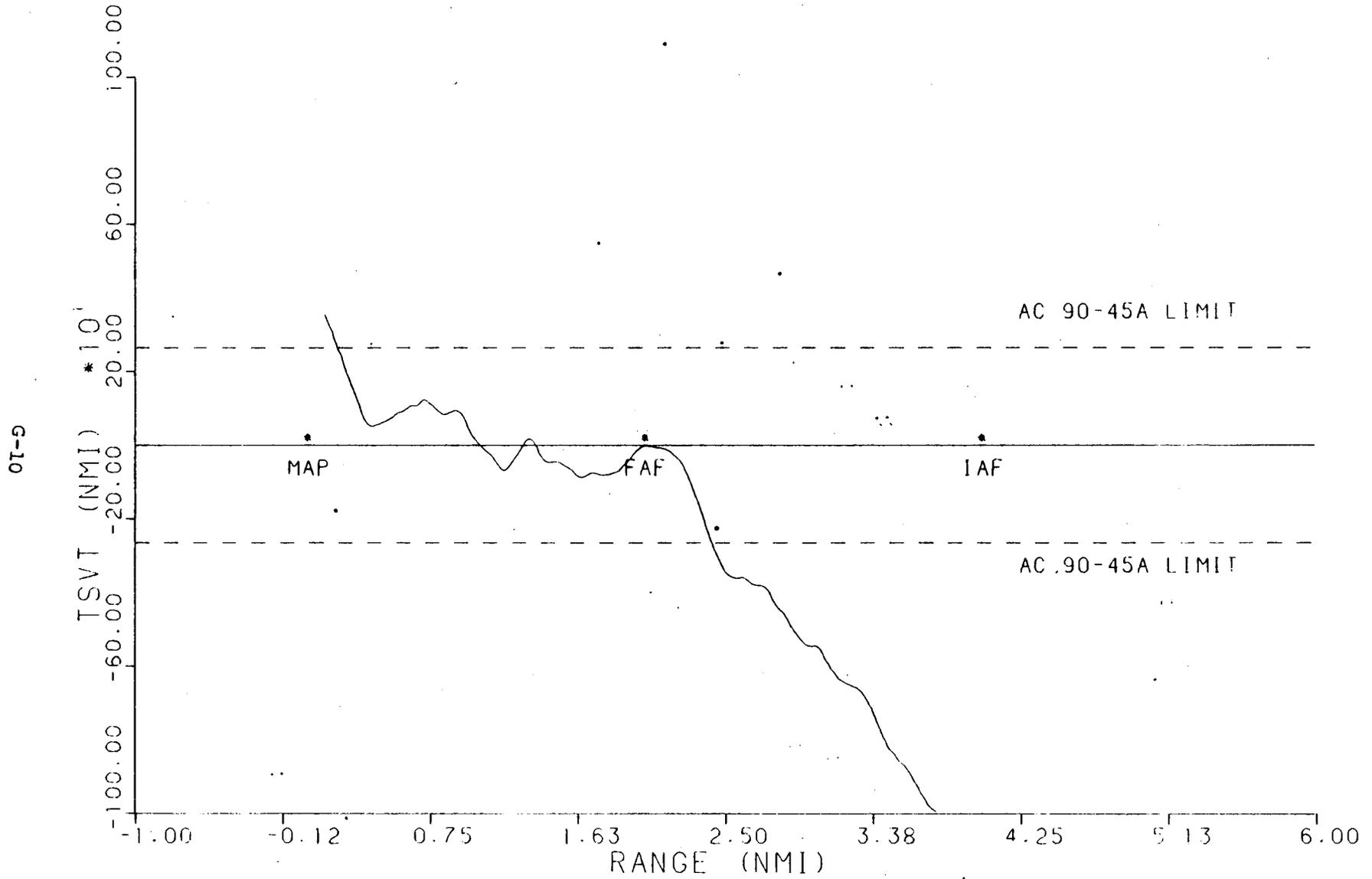
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RUN # 2

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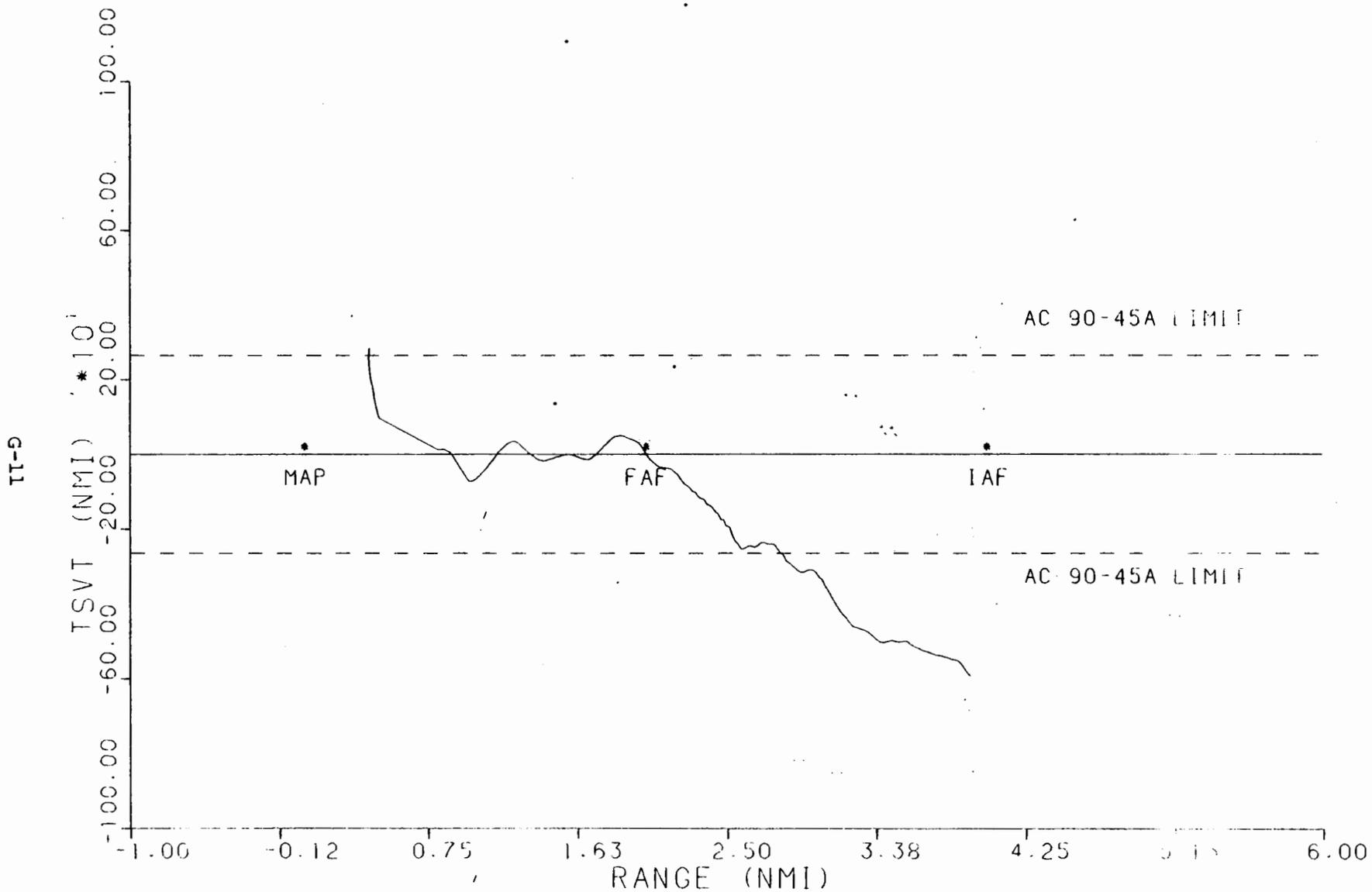
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 3

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405



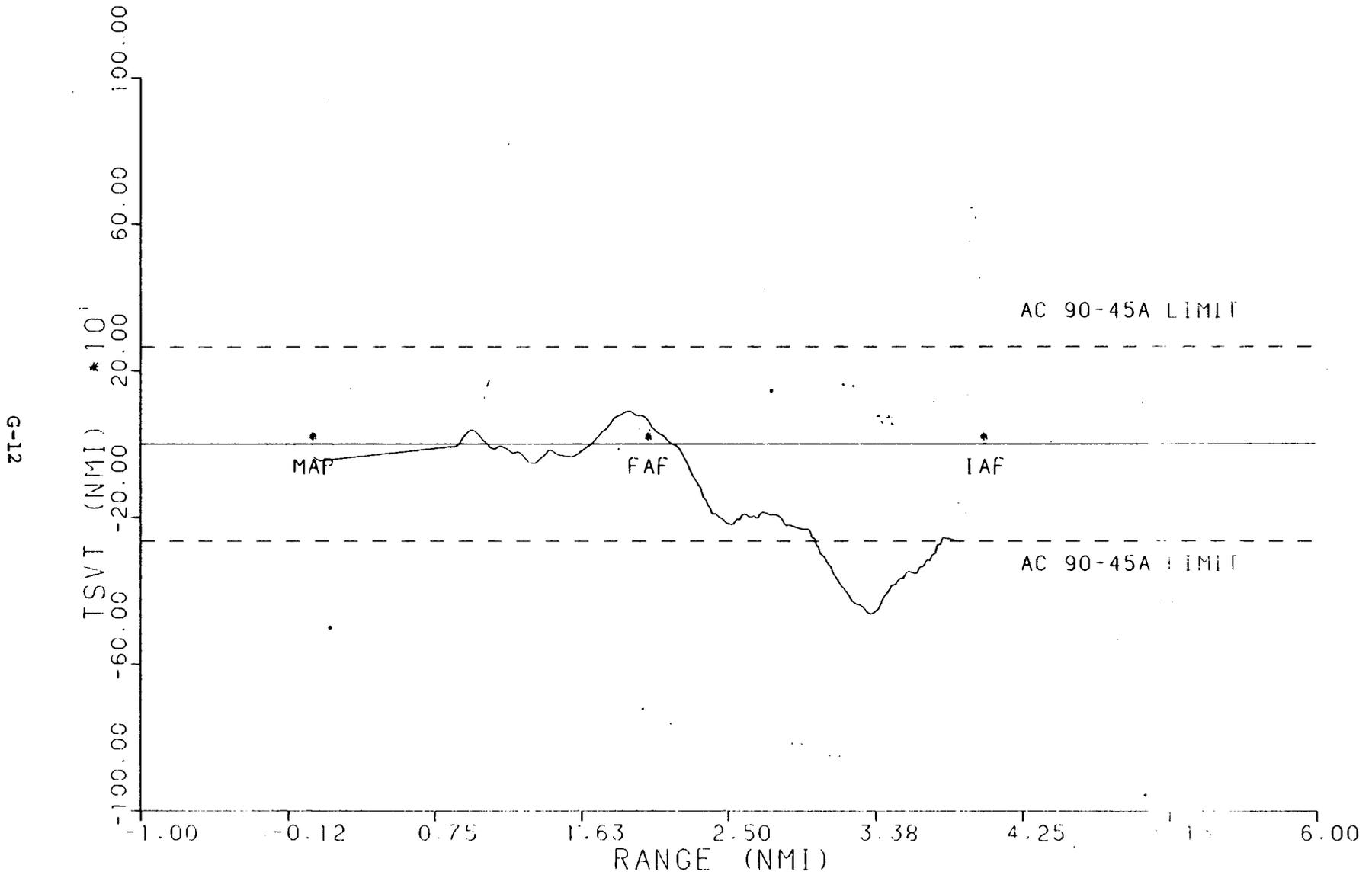
FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 4

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ATLANTA, GEORGIA AIRPORT, N.J. 08105



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 5

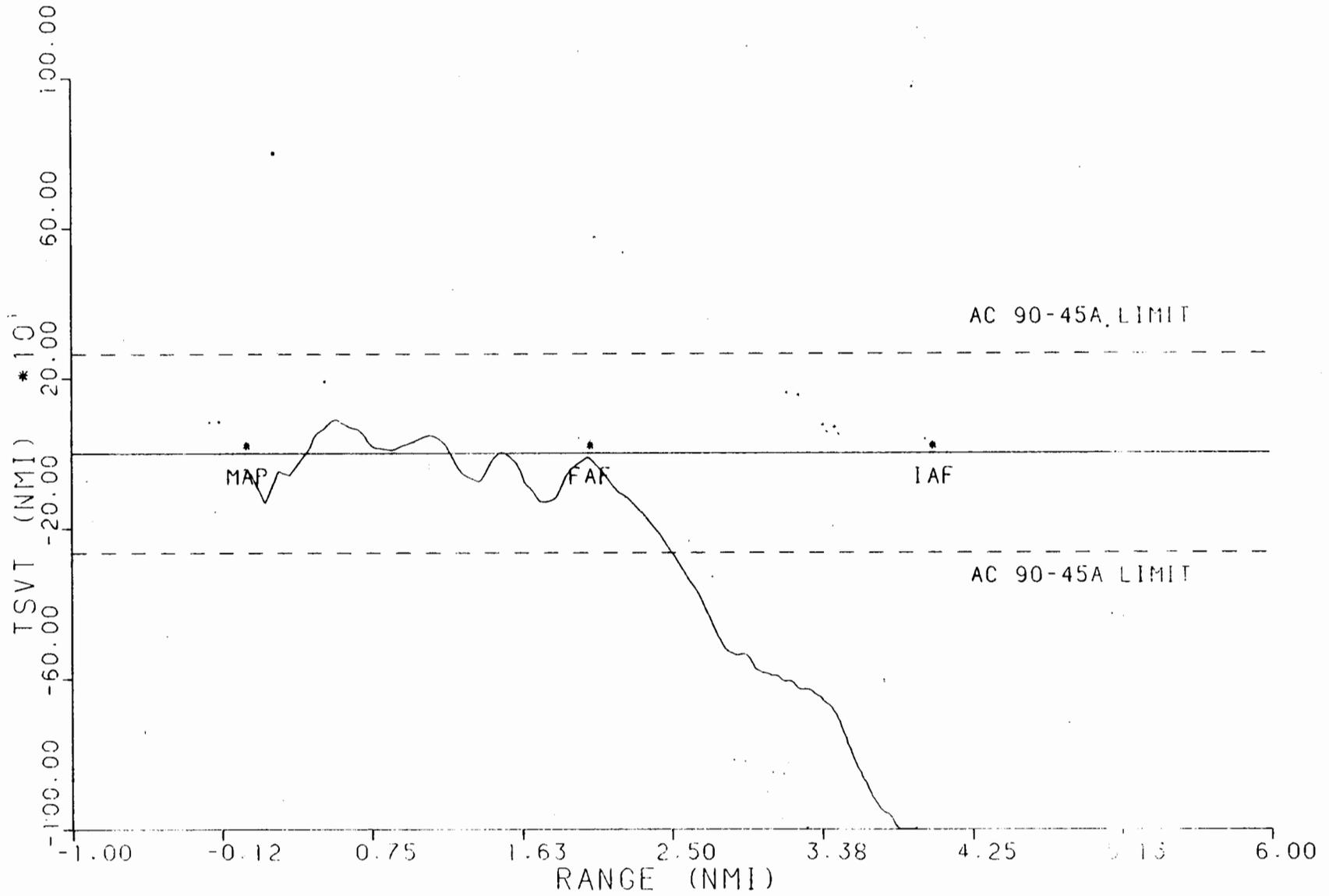
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ATLANTIC CITY AIRPORT, N. J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 6

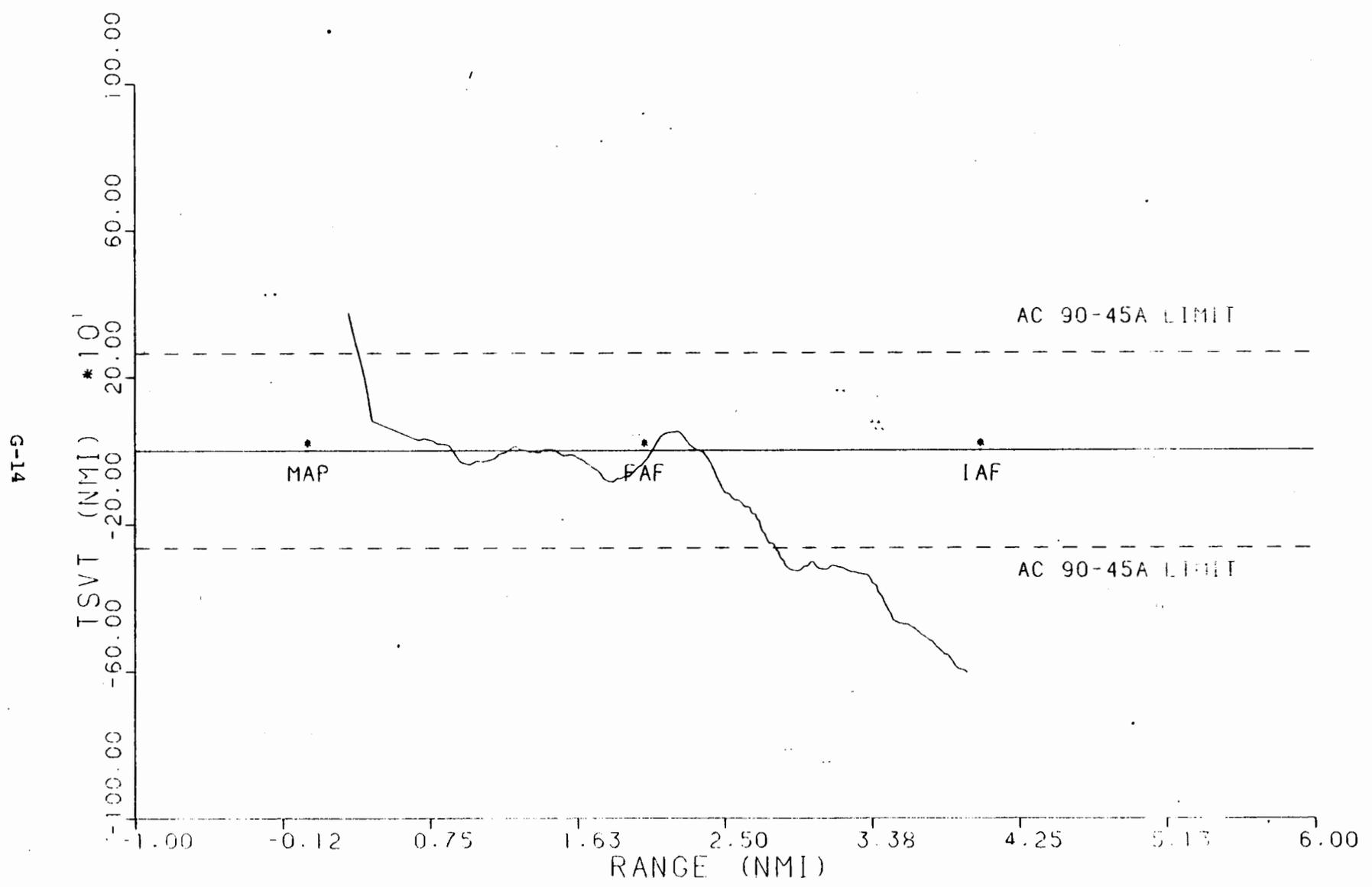
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ATLANTIC CITY AIRPORT, N J 08425

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FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 7

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N. J. 08405



FLIGHT #2 WITH SUBJECT PILOT #2
RUN # 8

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTA CITY AIRPORT, N.J. 08425

