technical note technical note

An Evaluation of the Accuracy of a Microwave Landing System Area Navigation System at Miami/Tamiami Florida Airport

Clifford W. Mackin

March 1990

DOT/FAA/CT-TN89/40

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

Technical Center
Atlantic City International Airport, N.J. 08405

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-TN89/40		

4. Title and Subtitle AN EVALUATION OF THE ACCURACY OF A MICROWAVE LANDING SYSTEM AREA NAVIGATION SYSTEM AT MIAMI/TAMIAMI FLORIDA AIRPORT	5. Report Date March 1990 6. Performing Organization Code ACD-330
7. Author(s) Clifford W. Mackin	8. Performing Organization Report No. DOT/FAA/CT-TN89/40
9. Performing Organization Name and Address U. S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City International Airport, N.J. 08405	10. Work Unit No. (TRAIS) 11. Contract or Grant No. T0604L
12. Sponsoring Agency Name and Address U. S. Department of Transportation Federal Aviation Administration Maintenance and Development Service Washington, D.C. 20590	13. Type of Report and Period Covered Technical Note November 1989 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A series of flight tests were performed by the Federal Aviation Administration (FAA) Technical Center at the Miami/Tamiami Florida Airport to demonstrate the operation and capabilities of a prototype Microwave Landing System (MLS) Area Navigation System (RNAV). The Technical Center's test bed MLS was transported to and collocated with the commissioned Category I Instrument Landing System (ILS) on runway 9R at Tamiami. The flight data collected indicate that the errors in aircraft position, as computed by the MLS RNAV algorithm, consistently met Category I performance criteria, and that computed centerline and glide slope operations can be conducted with Category I accuracies to runways with lateral offsets of up to 3500 feet.

17. Key Words	18. Distribution Statement
Microwave Landing System (MLS) Miami/Tamiami Airport Area Navigation (RNAV)	This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

Without the outstanding cooperation and assistance from the following organizations and personnel, it would not have been possible to conduct these tests in the time alloted:

Tamiami Airport Manager's Office, Mr. Clair Sherrick, Manager

Tamiami Sector Field Office, Mr. Carl Rubino, Manager

Miami Sector Field Office, Mr. George Priest, NAVAIDS Supervisor

Miami Sector Field Office personnel, particularly Mr. Juan Rodriquez

Air Traffic personnel from Tamiami Tower and Miami Approach Control

Dade County Airport Department

Avionics Engineering Center of Ohio University, Athens, Ohio

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

EXECUTIVE SUMMARY

A series of flight tests were performed by the Federal Aviation Administration (FAA) Technical Center at the Miami/Tamiami, Florida Airport, to demonstrate the operation and capabilities of a prototype Microwave Landing System (MLS) Area Navigation System (RNAV). The Technical Center's test bed MLS was transported to and collocated with the commissioned Category I Instrument Landing System (ILS) on runway 9R at Tamiami. The flight data collected indicate that the errors in aircraft position, as computed by the MLS RNAV algorithm, consistently met Category I performance criteria, and that computed centerline and glideslope operations can be conducted with Category I accuracies to runways with lateral offsets of up to 3500 feet.

INTRODUCTION

BACKGROUND.

During the month of March, 1989, a series of tests and demonstrations were performed at the Miami/Tamiami Florida Airport to obtain Microwave Landing System (MLS) performance data and demonstrate the capabilities and operation of a prototype MLS Area Navigation System (RNAV). The series of MLS tests which were performed at Tamiami also included an operational comparison of the course qualities of an instrument landing system (ILS) with a collocated MLS (reference 1) as well as testing to verify proposed ILS/MLS collocation standards (reference 2).

SITE DESCRIPTION.

Miami/Tamiami Airport is located approximately 5 miles southwest of Miami and is operated by the Dade County Airport Department of Florida. The airport is a general aviation airport with very high traffic volume and has extremely flat terrain. The airport has three runways: a pair of parallel 5000-foot runways (09L/27R and 09R/27L) which are separated by 3500 feet, and a 4000-foot diagonal runway (13/31) located between the parallels. The MLS was sited to serve runway 09R for conventional straight-in approaches. However, the thresholds of runways 09L and 13 were also within coverage of the MLS ground equipment. Figure 1 shows the airport layout as well as the MLS equipment positions and coverage.

EQUIPMENT DESCRIPTION

The MLS ground equipment used for these tests and demonstrations was the Bendix-built Federal Aviation Administration (FAA) Technical Center Test Bed MLS 2° beamwidth azimuth and 1.5° beamwidth elevation subsystems. Precision range information was provided by a precision distance measuring equipment (DME/P) system built by the Montek Division of E-Systems, Incorporated. The MLS azimuth subsystem provided 40° of proportional coverage on either side of the system boresight which was aligned with the centerline of runway 09R. The elevation subsystem provided proportional vertical coverage from 1° to 15° above the horizon. Range coverage provided by the DME/P system was omnidirectional to a minimum radius of 20 nautical miles (nmi) from the equipment site.

The airborne data were collected using the FAA Technical Center's fully instrumented Convair 580 (CV-580) aircraft. A Bendix ML-201A cabin class MLS receiver was used for all MLS angle data collection, and a DME/P interrogator built by SEL of the Federal Republic of Germany was used for range data. The airborne data were collected and recorded using the FAA Technical Center designed and built prototype MLS RNAV and data collection system. The system, which is based on a 68020 microprocessor, serves the dual purposes of both performing the MLS RNAV functions as well as a data collection system to evaluate various MLS equipments. Data were recorded digitally on a 9-track Kennedy 9800 tape recorder and was processed post-flight for use in this report.

The MLS RNAV and data collection system is controlled by an operator in the cabin of the aircraft. For each RNAV approach that is flown, a profile that contained the site coordinates as well as the waypoint coordinates and sequence was loaded into system memory. Once the approach began, the pilot was given guidance from the initial waypoint to the second waypoint, then from the second to the third, and so on until the approach was completed. The MLS RNAV function was performed by converting received angle (azimuth and elevation) and range information to Cartesian coordinates (x,y,z) using algorithms discussed in reference 3. This information was recorded and displayed to the pilot on a control display unit (CDU) in the flight deck which also displayed raw MLS angle, range, and waypoint information. From the computed aircraft position, the crosstrack and vertical errors were derived and presented to the pilot on a course deviation indicator (CDI).

The ground truth system used for these tests was provided and operated by personnel from the Avionics Engineering Center of Ohio University, Athens, Ohio, and consisted of a modified optical theodolite and C-band ranging element which provided resolutions of +/- 0.01° and +/- 2 meters, respectively. Data were recorded synchronously at a rate of azimuth and elevation angles and slant range from the tracker to the aircraft. Tracker time was synchronized with aircraft time using a portable IRIG-B time code generator. The tracker was positioned at a known point near the MLS elevation subsystem and tracked all runs from that location. For the approaches to runways 09L and 13, visual obstructions (trees) prevented tracking to threshold, but data were collected to within 0.3 nmi of threshold for runway 09L and 1.1 nmi of threshold for runway 13.

MLS RNAV OPERATIONAL BENEFITS

Several operational benefits can be derived from an MLS RNAV computed glide slope or computed centerline approach. The first of these benefits accrues from the capability to create a precision approach that corrects for ground siting conditions which mandate an offset azimuth subsystem location. The MLS RNAV computed centerline procedure compensates for the offset siting geometry and allows a precision straight-in approach to be flown along runway centerline. A second benefit is the capability to provide precision approach guidance to a runway, within coverage of the MLS ground subsystems, that has no operational precision approach equipment serving it. These were the types of MLS RNAV procedures that were flown at Tamiami. As shown in figure 1, the MLS ground equipment was sited to serve runway 09R. Figures 2, 3, and 4 are approach plates which show experimental MLS RNAV procedures for precision approaches that were flown to Tamiami runways 09R, 09L, and 13, respectively.

TEST DESCRIPTION

For the purpose of this report, 3 of the 28 MLS RNAV approaches recorded during the Tamiami tests and demonstration were analyzed. The three approaches were: a two-step (4.5° to 3.0°) glide slope transition centerline approach to runway 09R (run 10), and a 3° glide slope centerline approach to runway 09L (run 11), and a 3.5° glide slope dogleg-to-centerline approach to runway 13 (run 12). Guidance for runs 10, 11, and 12 were computed at all times in both the vertical and horizontal axes. Figure 1 shows a plan view of the three approaches as obtained from the reduced tracker data. The coordinate system used in figure 1 is

Cartesian with the origin at the azimuth and the X-axis coincident with the centerline of runway 09R. Figure 5 shows profile views of the three approaches as obtained from the reduced tracker data. The coordinate systems used in figure 5 are Cartesian with the origin at the respective runway threshold and the X-axis coincident with the extended runway centerline for each of the three runways.

RESULTS AND ANALYSIS

Figures 6 through 11 are graphical representations of the error data from the three approaches. Figures 6, 7, and 8 show the MLS and DME/P accuracy data. Figures 9, 10, and 11 show the accuracy of the MLS RNAV system in Cartesian coordinate axes originating at the runway threshold for each of the approaches. The data shown in figures 6, 7, and 8 represent the accuracy of the guidance signals at the outputs of the MLS and DME/P receivers or at the input of the MLS RNAV system. The data shown in figures 9, 10, and 11 represents the accuracy of the guidance signals at the output of the MLS RNAV system.

A statistical summary of the data for all three of the approaches appears in table 1. It can be seen that while the recorded values of raw azimuth and elevation data varied considerably from run to run, the mean errors and standard deviations of the data remained relatively constant. Table 1 also shows the difference in the raw range data between the initial approach (IA) and final approach (FA) modes of the DME/P, with the mean error and standard deviation of the raw FA data being less than 20 and 15 feet, respectively, in all three of the runs. The DME/P IA/FA transition is readily apparent in the range error plots of figures 6 and 7.

The data for figure 9, which shows the tracked portion of run number 12, was within the 7 nmi IA/FA transition of the DME/P at all times so no IA values were recorded for that approach. Also, inspection of figure 8 and the run number 12 data in table 1 shows a slightly elevated noise level for both azimuth and elevation. This was possibly due to the MLS receiver's automatic selection of an omnidirectional aircraft antenna for that run in preference to the lower noise directional antenna which had been selected during the previous runs. As can be seen in figures 9, 10, and 11 the X error in each run is very similar to the range errors seen in figures 6, 7, and 8. Due to the fact that the azimuth error is virtually constant throughout each run and the Y-error is primarily a function of the azimuth error and the range, the Y error is seen to decrease with range in each of the runs. The same is true with respect to the Z errors which are primarily a function of the elevation error and the range. Because of this effect, the Y and Z errors attain their minimum values for each approach at threshold. It can also be seen that the Y and Z errors in figures 9, 10, and 11 are similar to the respective azimuth and elevation errors in figures 6, 7, and 8. These similarities are borne out by the data in table 2 which is a tabular listing of the correlation coefficients of the raw azimuth, elevation, and range errors with the X, Y, and Z errors of each of the approaches. In all three approaches the X, Y, and Z errors correlate very strongly with the range, azimuth, and elevation errors, respectively. It can also be seen in table 2 that there is no significant correlation between orthogonal parameters such as X error with azimuth error, Y error with elevation error, or Z error with range.

TABLE 1. MLS SYSTEM AND MLS RNAV ACCURACY DATA

Run No.	Sample Size	Azimuth min (deg.)	Azimuth max (deg.)	Azimuth Error mean (deg.)	Azimuth Error sd (deg.)	Elevation min (deg.)	Elevation max (deg.)	Elevation Error mean (deg.)	Elevation Error sd (deg.)	Range Error (IA) mean (ft.)	Range Error (IA) sd (ft.)	Range Error (FA) mean (ft.)	Range Error (FA) sd (ft.)	X Error (IA) mean (ft.)	X Error (IA) sd (ft.)	X Error (FA) mean (ft.)	X Error (FA) sd (ft.)	Y Error mean (ft.)	Y Error sd (ft.)	Z Error mean (ft.)	Z Error sd (ft.)
10	3186	-0.23	1.27	-0.006	0.013	2.59	3.70	0.001	0.025	83.85	23.59	16.84	11.81	81.91	26.20	16.85	11.84	2.09	6.61	1.53	10.58
11	2414	3.96	21.58	0.002	0.021	1.35	3.27	-0.007	0.023	54.32	24.53	16.61	13.28	57.14	23.08	14.90	13.39	-6.37	7.29	-2.06	9.14
12	1257	29.70	35.51	-0.004	0.025	2.67	3.55	-0.028	0.031	——	——	18.73	13.15	——	——	18.80	13.23	4.91	10.38	-9.45	11.55

TABLE 2. MLS SYSTEM AND MLS RNAV CORRELATION COEFFICIENTS

	Run Number 10			Run Number 11			Run Number 12		
	Azimuth	Elevation	Range	Azimuth	Elevation	Range	Azimuth	Elevation	Range
X	0.30	-0.11	1.00	0.00	-0.10	1.00	-0.05	0.02	0.83
Y	-0.87	0.28	-0.41	-0.82	-0.01	-0.32	-0.94	-0.05	-0.09
Z	-0.20	0.96	0.24	-0.07	0.83	-0.07	-0.07	0.94	0.51

For all approaches, the lateral and vertical guidance errors were within Category I requirements. The mean along-track error (X error) consistently consumed less than one-half of the Category I error budget of 35 feet within 2 nmi of the threshold. The mean crosstrack error (Y error) consistently consumed less than one-fifth of the Category I error budget of 35 feet. The vertical error was consistently less than the vertical error limit of 10 feet. The consistent performance along the entire approach segment of the three runs is confirmed by inspection of the error plots and the numerically small standard deviations listed in table 1.

CONCLUSIONS

1. The data from the Tamiami MLS RNAV flights show that the errors in aircraft position as computed by the algorithms described in reference 3 consistently met Category I performance criteria.

2. Results from the Tamiami MLS RNAV flights indicate that computed centerline and glide slope operations can be conducted with Category I accuracies to runways with lateral offsets of up to 3500 feet.

REFERENCES

1. Townsend, John, ILS/MLS Comparison Tests at Miami/Tamiami, Florida Airport, Federal Aviation Administration, DOT/FAA/CT-TN89/39, July 1989.

2. Townsend, John, ILS/MLS Collocation Tests at Miami/Tamiami, Florida Airport, Federal Aviation Administration, DOT/FAA/CT-TN89/38, June 1989.

3. Minimum Operational Performance Standards for Airborne MLS Area Navigation Equipment, DO-198, Radio Technical Commission for Aeronautics, Washington, DC, March 18, 1989.

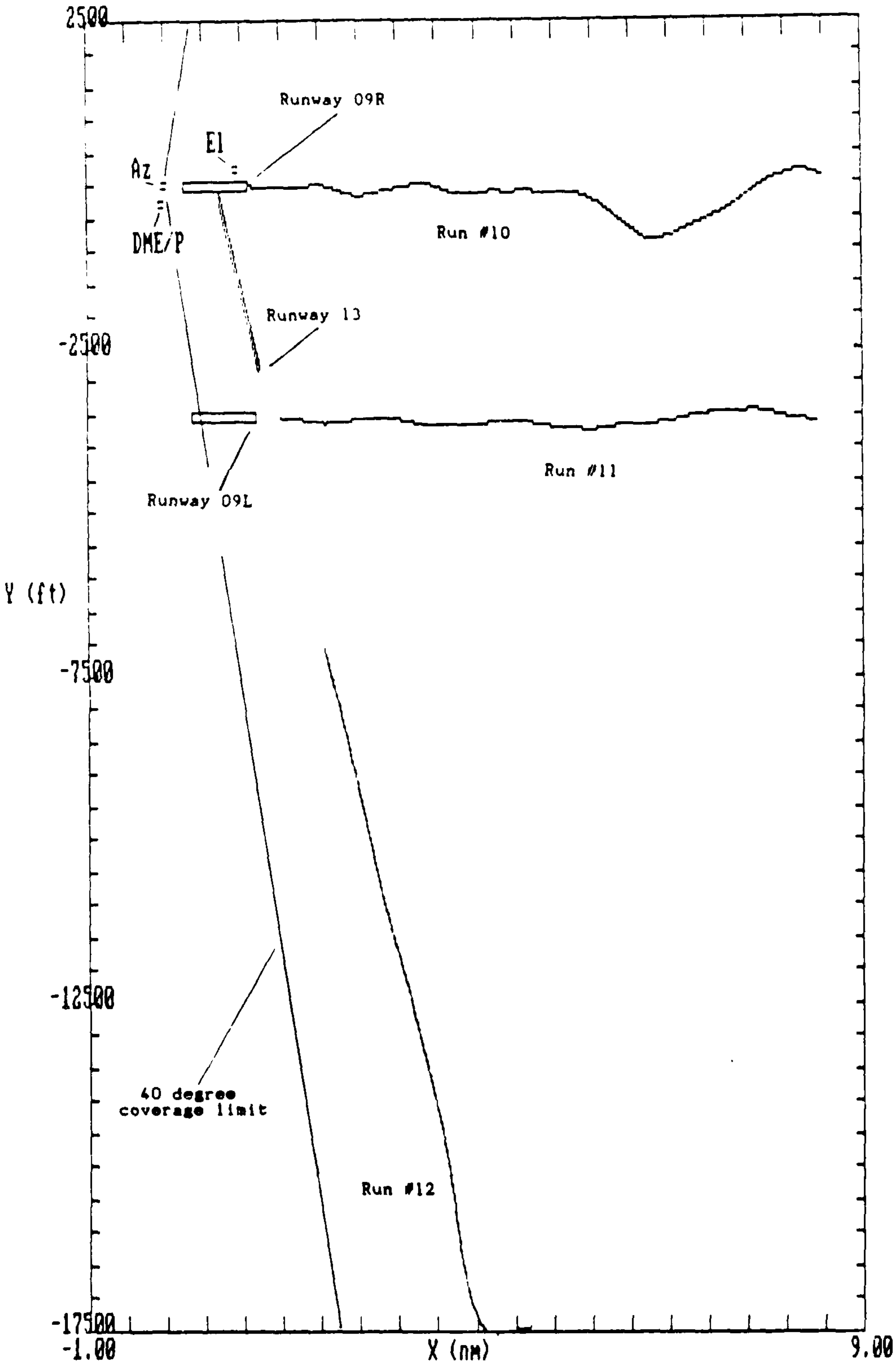
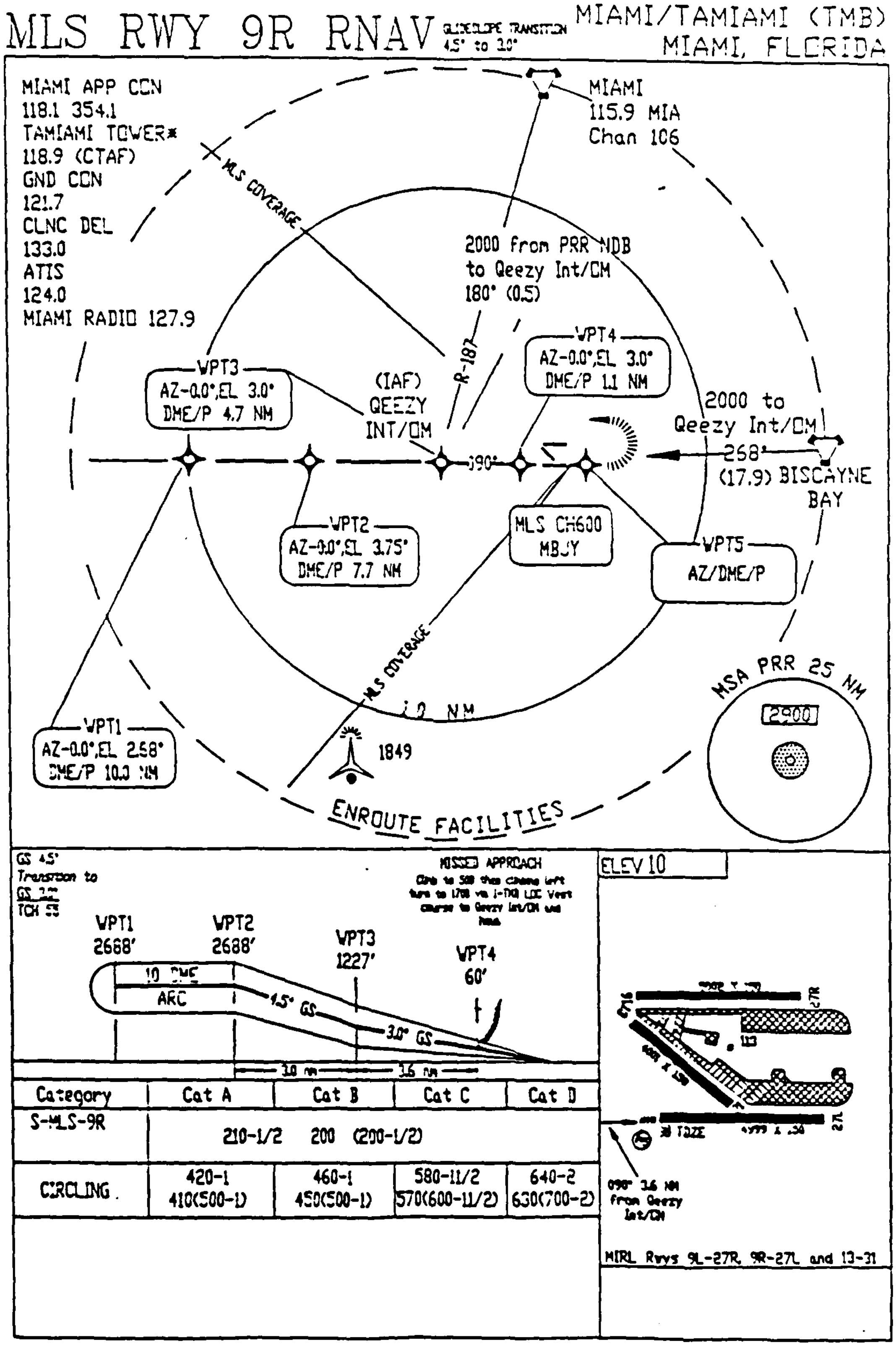


FIGURE 1. TAMIAMI AIRPORT LAYOUT AND MLS SITES

FOR EXPERIMENTAL USE ONLY



Category	Cat A	Cat B	Cat C	Cat D
S-MLS-9R	210-1/2 200 (200-1/2)			
CIRCLING	420-1 410(500-1)	460-1 450(500-1)	580-11/2 570(600-11/2)	640-2 630(700-2)

FIGURE 2. EXPERIMENTAL APPROACH PLATE - RUN #10

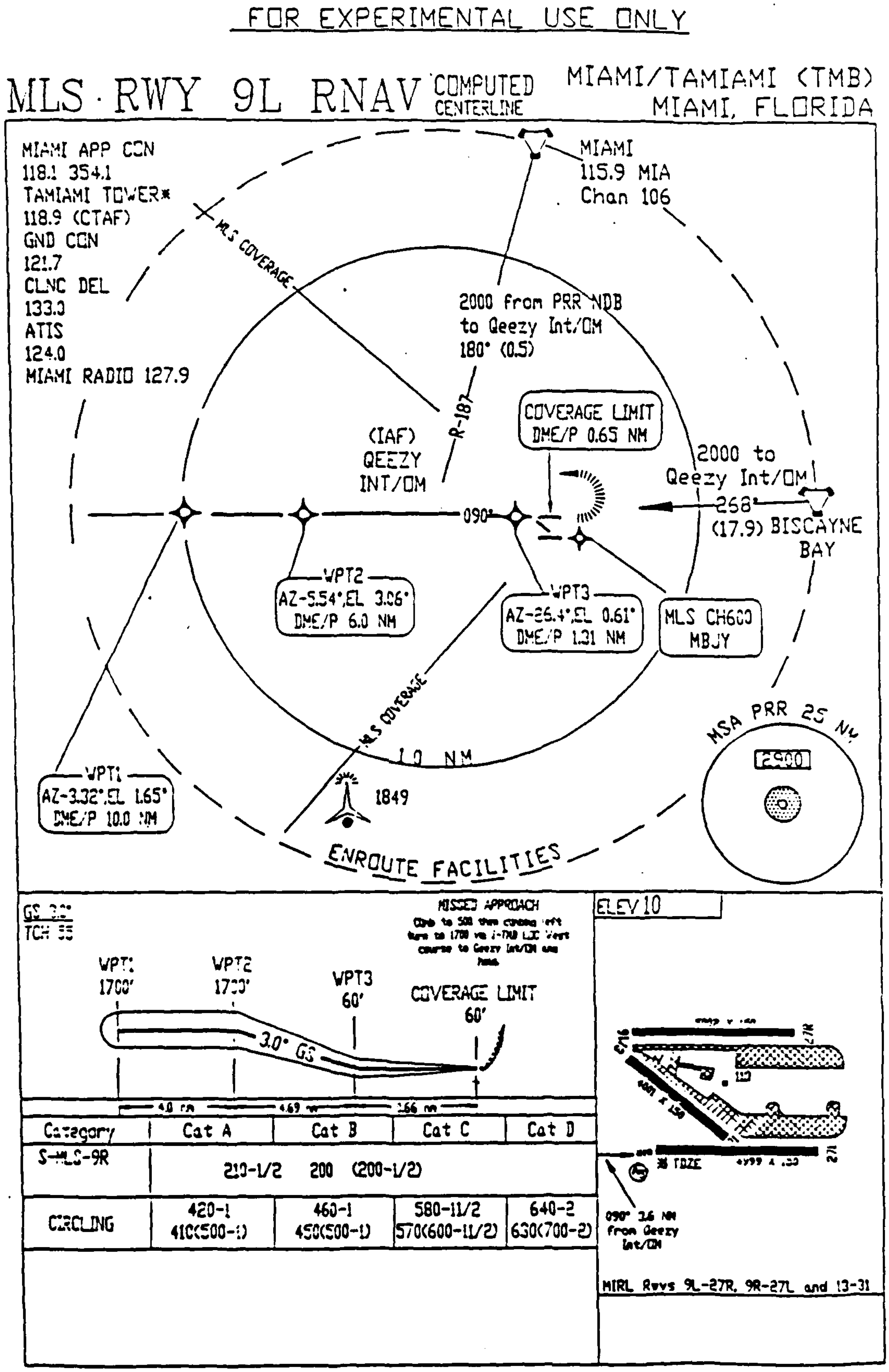
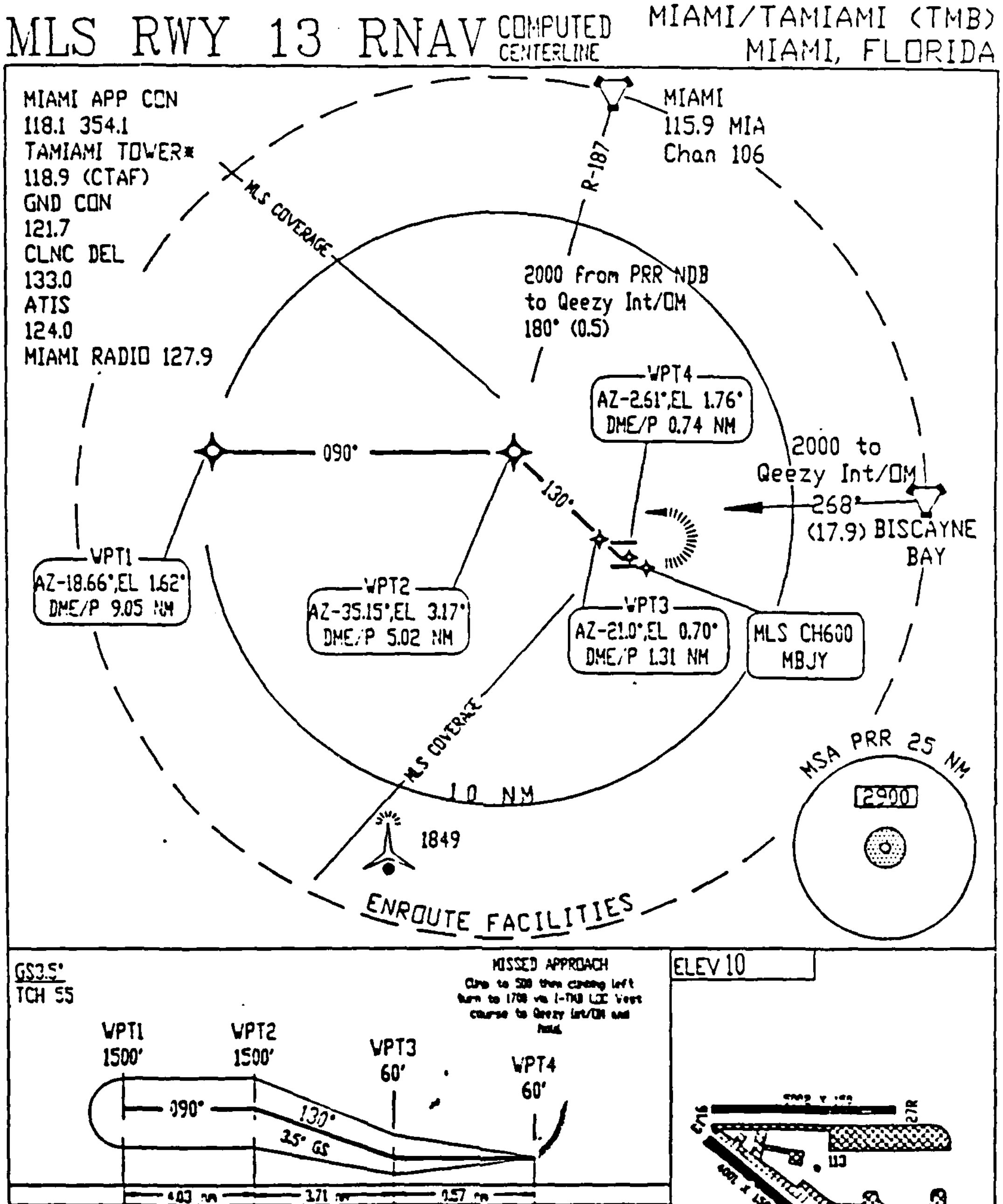


FIGURE 3. EXPERIMENTAL APPROACH PLATE - RUN #11

FOR EXPERIMENTAL USE ONLY



Category	Cat A	Cat B	Cat C	Cat D
S-MLS-9R	210-1/2 200 (200-1/2)			
CIRCLING	420-1 410(500-1)	460-1 450(500-1)	580-11/2 570(600-11/2)	640-2 630(700-2)

FIGURE 4. EXPERIMENTAL APPROACH PLATE - RUN #12

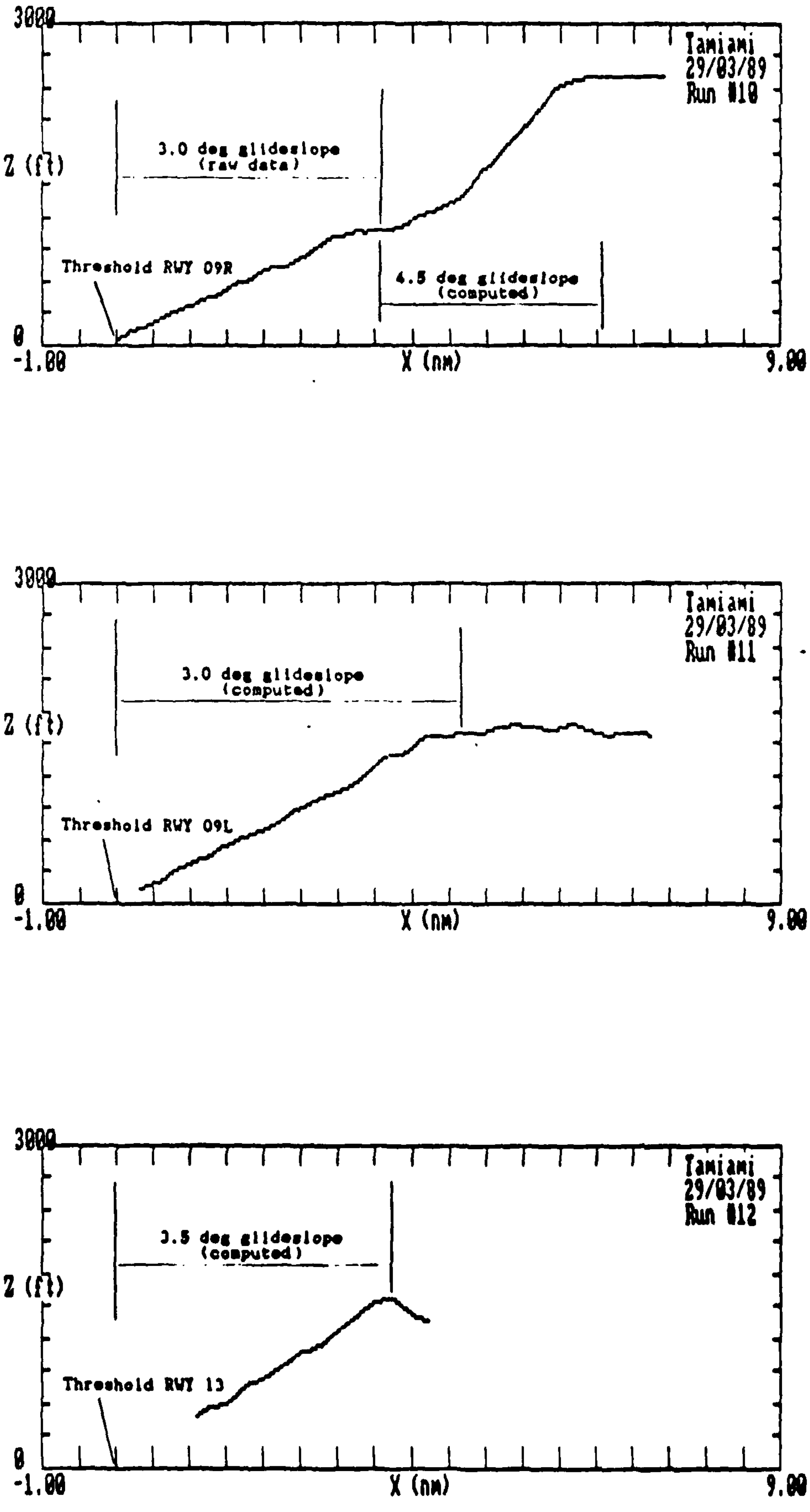
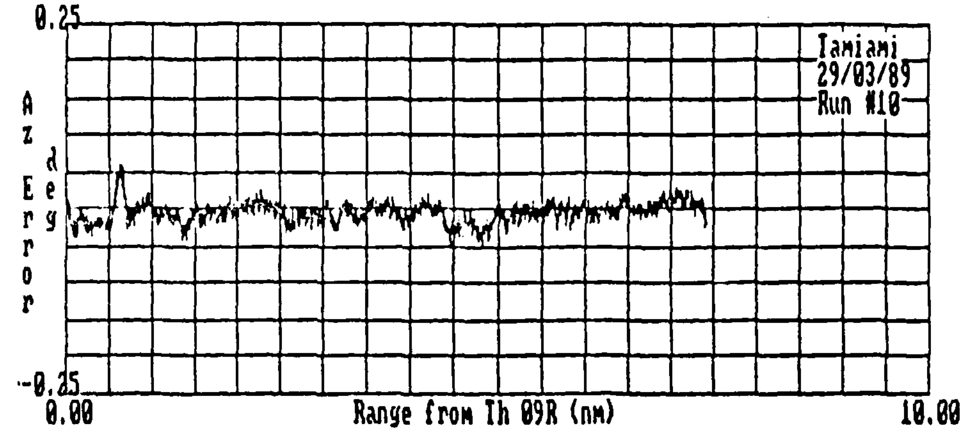
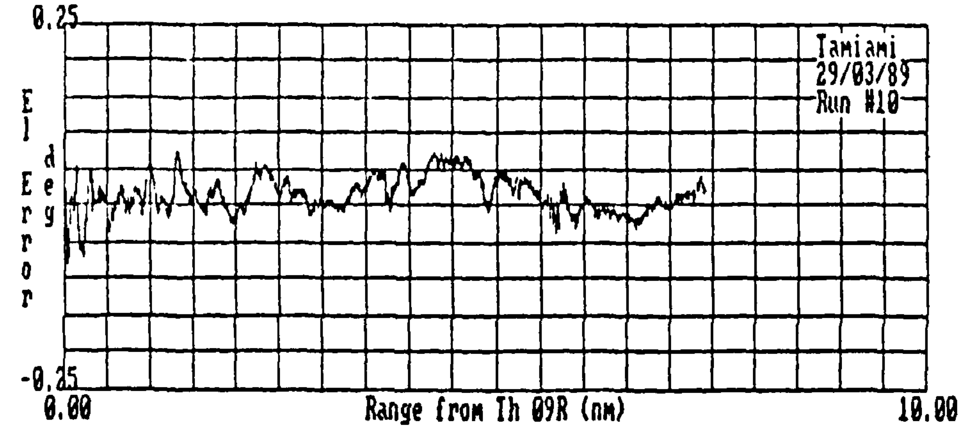


FIGURE 5. HEIGHT (Z) vs Range (X) - Runs #10, #11, #12





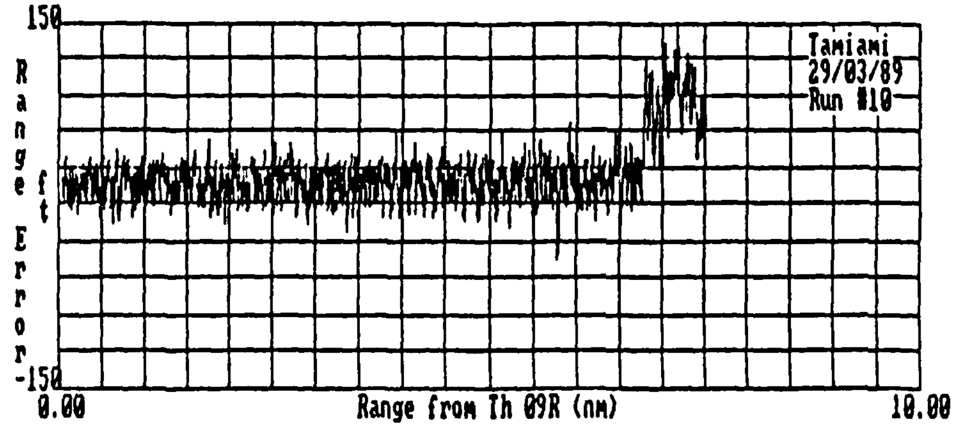
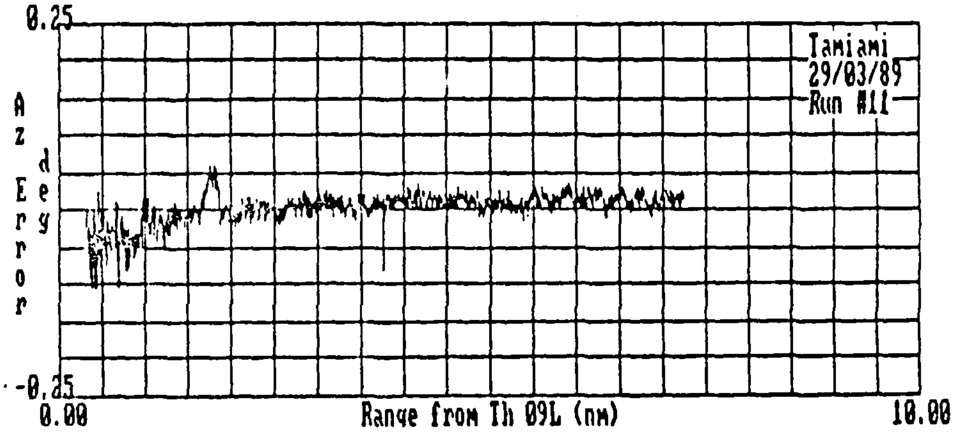
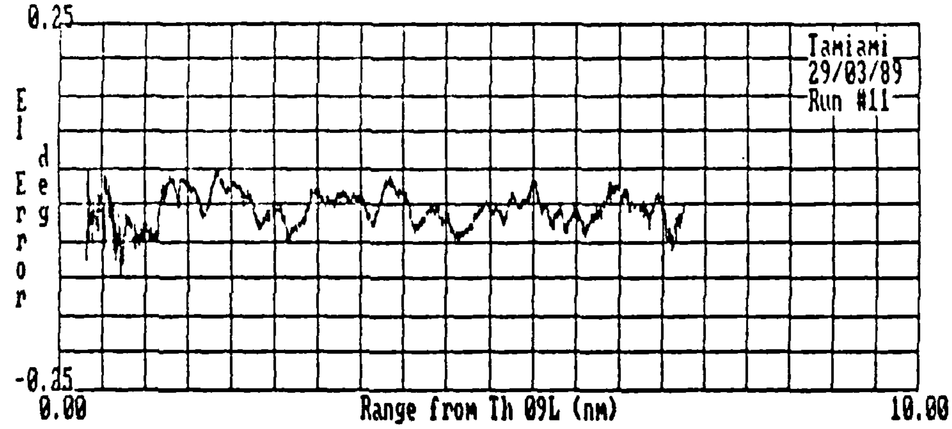


FIGURE 6. MLS AND DME/P ACCURACY DATA - RUN #10





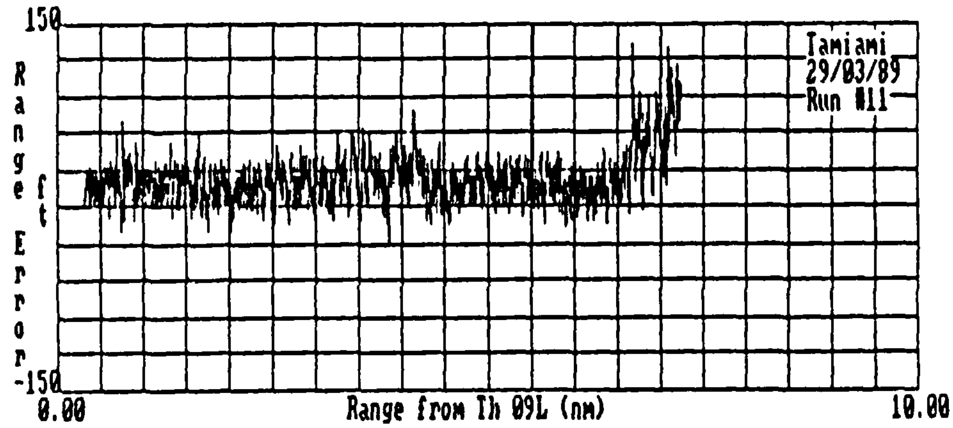


FIGURE 7. MLS AND DME/P ACCURACY DATA - RUN #11

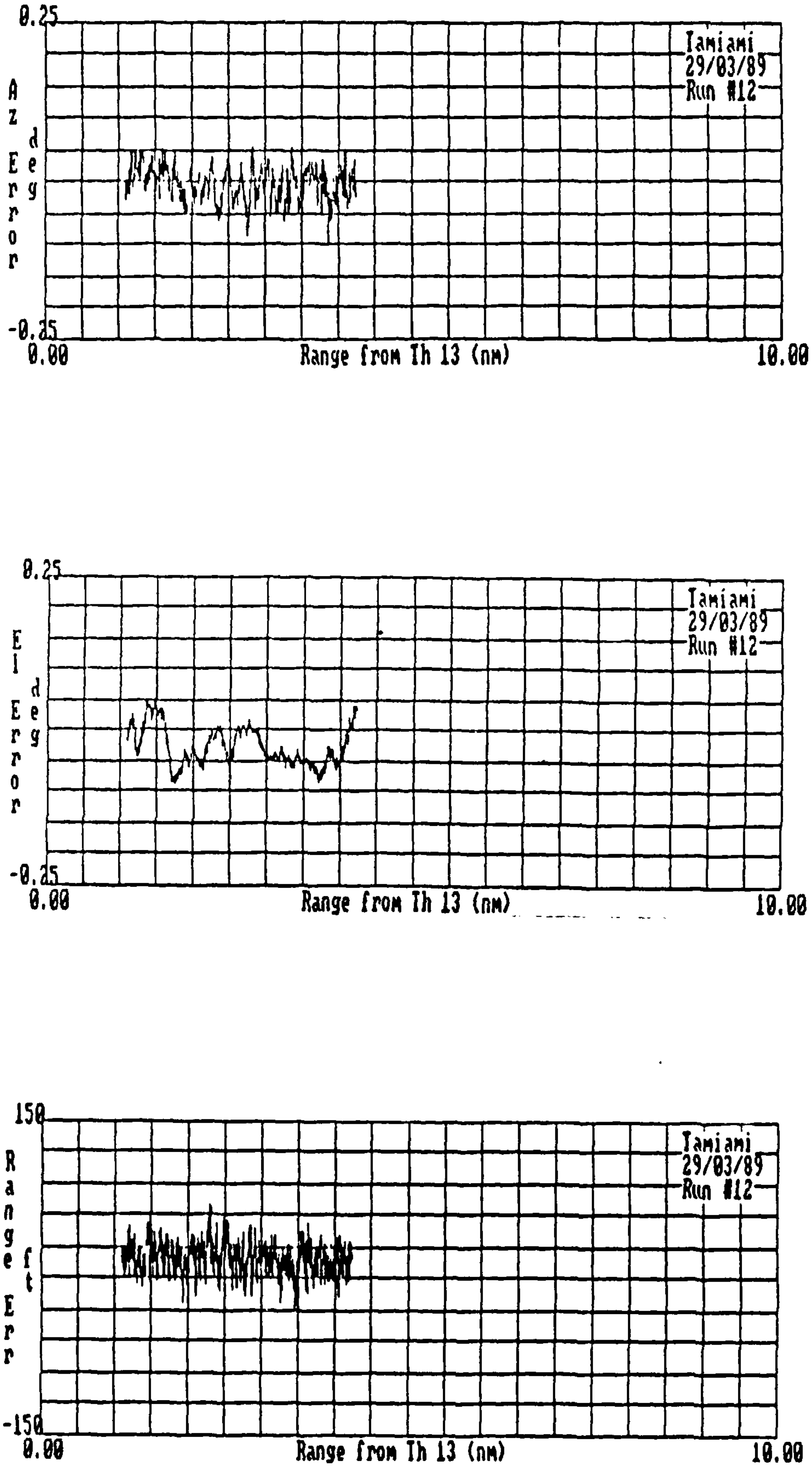
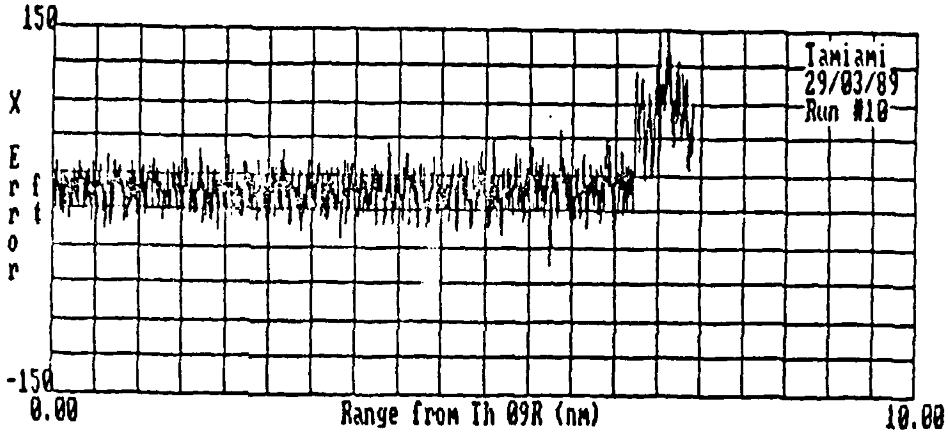
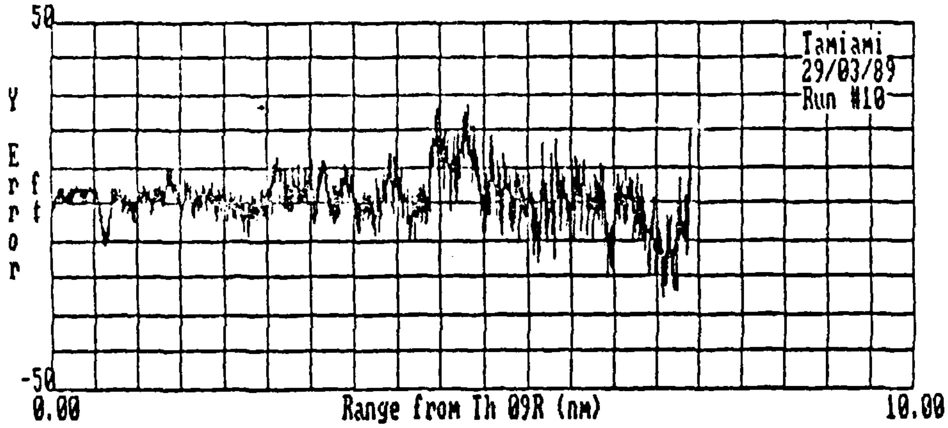


FIGURE 8. MLS AND DME/P ACCURACY DATA - RUN #12





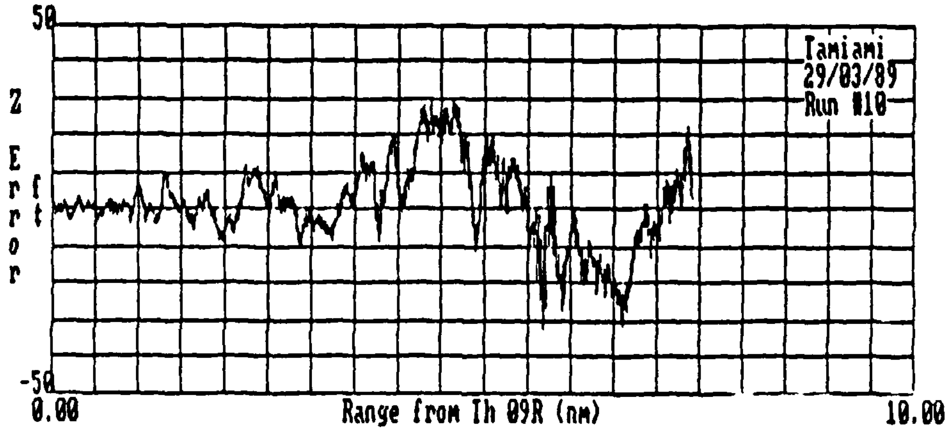
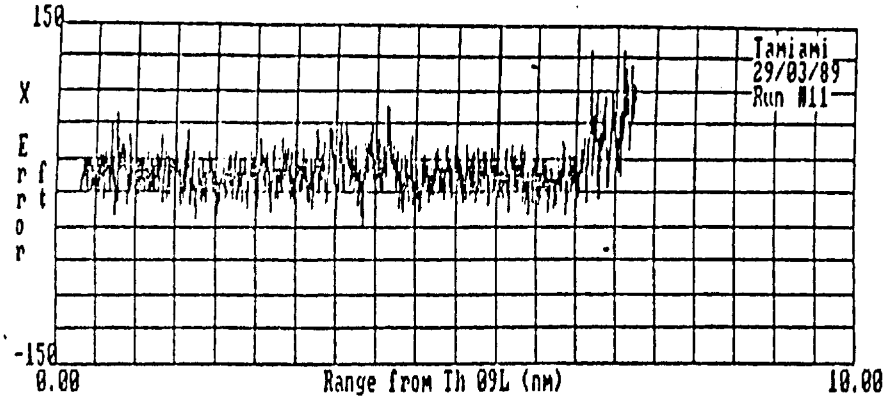
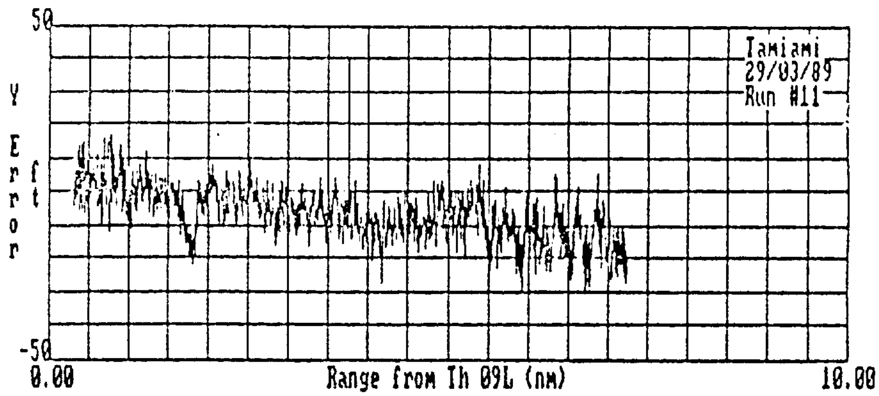


FIGURE 9. MLS RNAV ACCURACY DATA - RUN #10





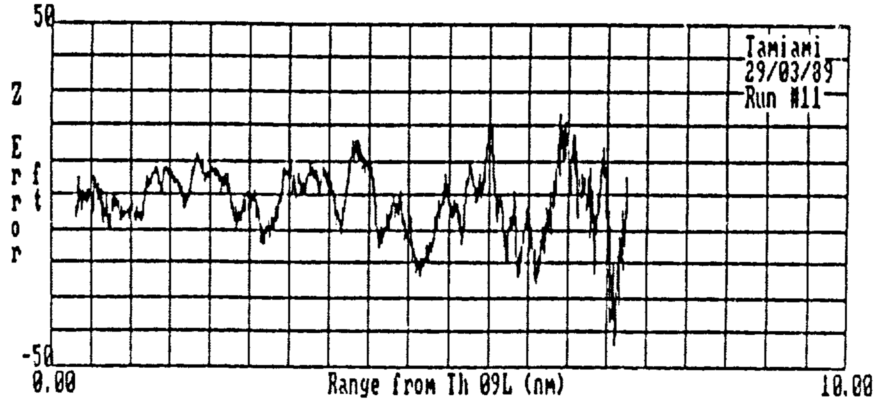
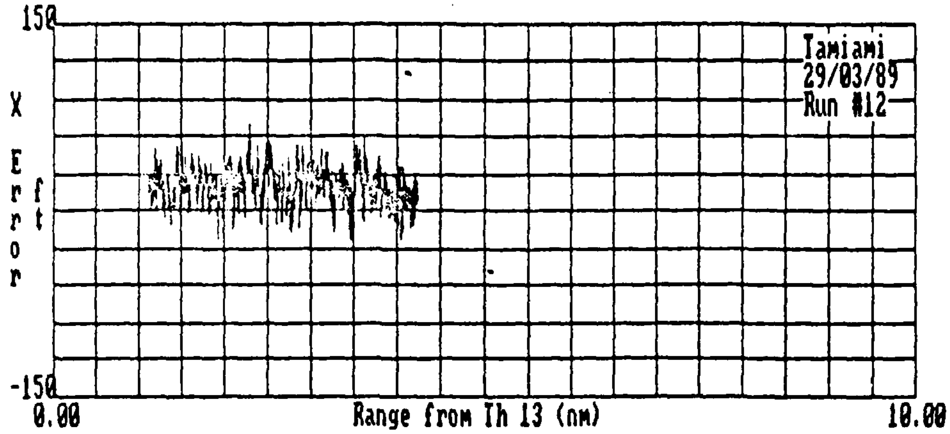
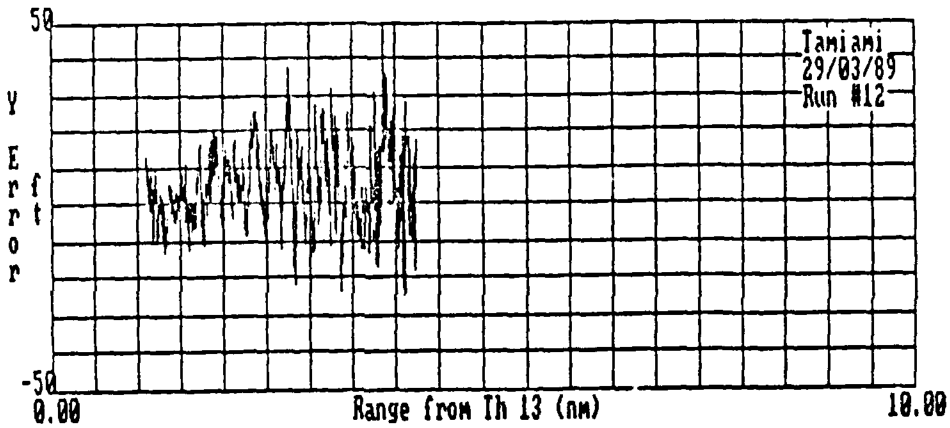


FIGURE 10. MLS RNAV ACCURACY DATA - RUN #11





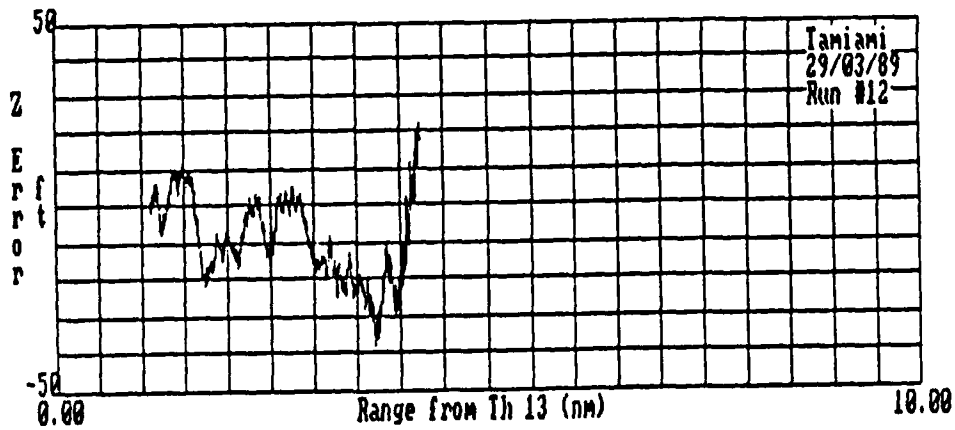


FIGURE 11. MLS RNAV ACCURACY DATA - RUN #12