technical note technical note

Comparison of the Performance of a Microwave Landing System Elevation Station with the Instrument Landing System End-Fire Glide Slope at Yeager Airport, Charleston, West Virginia

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March 1992

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16. Abstract

In support of Project No. 5 of the Federal Aviation Administration (FAA) Microwave Landing System (MLS) Demonstration and Evaluation Program, Comparison of MLS and Instrument Landing System (ILS) Performance, the FAA Technical Center installed an MLS elevation station collocated with the ILS basic end-fire glide slope (EFGS) serving runway 23 at Yeager Airport, Charleston, West Virginia. The EFGS is the only type of ILS glide slope antenna that will provide operationally usable performance at the site because of limited flat terrain in front of the antenna and a valley with rising hills in the approach to the runway. The FAA Technical Center's MLS test bed, consisting of a 1.5° beamwidth elevation station and a 2° beamwidth azimuth station, was transported to, and temporarily installed at Yeager Airport on runway 23. Only the MLS elevation was collocated with the commissioned ILS EFGS. The azimuth station was not collocated with the localizer for siting reasons. The MLS installation did not affect the performance of the ILS as verified by a flight check by the Atlantic City Flight Inspection Field Office (FIFO). During ground tracked partial orbits and inbound level runs and approaches, both ILS and MLS data were simultaneously recorded in the FAA Technical Center instrumented aircraft, a Convair-580, N-49. The MLS elevation data showed improved performance characteristics over the ILS basic EFGS data. Computed centerline approaches were flown to runway 23 using MLS, the field Navigation Distance Measuring Equipment (DME/N), and an FAA Technical Center in-house designed and built Level II area navigation (RNAV) computer. All of the runs showed straight courses on the extended runway centerline.

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Yeager Airport Manager's Office, Mr. Danny Huffman

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EXECUTIVE SUMMARY

In support of Project No. 5 of the Federal Aviation Administration (FAA) Microwave Landing System (MLS) Demonstration and Evaluation Program, Comparison of MLS and Instrument Landing System (ILS) Performance, the FAA Technical Center installed an MLS with the elevation station collocated with the ILS basic end-fire glide slope (EFGS) serving runway 23 at Yeager Airport, Charleston, West Virginia. The EFGS is the only ILS glide slope antenna type that will provide operationally usable performance at this site, which has limited flat terrain in front of the antenna and a valley with rising hills in the approach to the runway.

The Technical Center's MLS test bed, consisting of a 1.5° beamwidth elevation station and a 2° beamwidth azimuth station, was transported to, and temporarily installed at Yeager Airport on runway 23. The elevation station was collocated with the commissioned ILS EFGS. The azimuth station was not collocated with the localizer because a tower would have been required to place it behind the localizer and it would have been too close to the runway installed in front of the localizer.

On the same day that the MLS was installed and radiating, the ILS was flight checked by the Atlantic City Flight Inspection Field Office (FIFO). No effect on the ILS performance was found due to the MLS installation and the ILS was restored to service.

During ground tracked approaches, inbound level runs, and orbits, ILS and MLS data were simultaneously recorded in the FAA Technical Center instrumented test aircraft, a Convair-580, N-49. The resulting data showed that the MLS elevation guidance quality was clearly superior to that of the ILS EFGS.

Computed centerline approaches were flown to runway 23 using MLS, the field Navigation Distance Measuring Equipment (DME/N), and an FAA Technical Center in-house designed and built Level III area navigation (RNAV) computer. All of the runs showed straight courses along the extended runway centerline to threshold. The project pilot observed that there was an easily discernable improvement in the flyability of the MLS guidance over the ILS guidance for both the ILS "look-alike" approaches and the MLS computed centerline approaches.

INTRODUCTION

PURPOSE.

The purposes of this task were:

1. To obtain comparative performance data for an Microwave Landing System (MLS) elevation station collocated with an Instrument Landing System (ILS) end-fire glide slope (EFGS).

2. To demonstrate the guidance quality of an MLS installed at a problem ILS site.

3. To demonstrate MLS advanced procedures capability by flying computed centerline approaches at an offset MLS azimuth site.

BACKGROUND.

Yeager Airport is situated on three flattened mountaintops with the valleys between them filled in and is surrounded by valleys and mountains which make it extremely difficult to site an ILS. The airport has two runways, 05/23 and 15/33. There are two commissioned ILS facilities on either end of runway 05/23. Both ILS systems have offset localizers because of severe dropoffs at either end of the runway. A basic EFGS is commissioned for runway 23 and is restricted to 1100 feet (ft) above mean sea level (m.s.l.). The published minimum altitude for this approach is 1181 ft. m.s.l. which is 250 ft above' the landing threshold. Figure 1 shows the published ILS approach plate for runway 23.

Previously, a capture-effect glide slope was installed for runway 23, but had a threshold crossing height (TCH) of over 80 ft. To lower the TCH, the capture effect antenna would have had to be moved closer to the runway threshold; however, the resulting decrease in flat ground in front of the antenna would have caused the glidepath structure to exceed alowable tolerance limits. FAA Technical Center Letter Report 83-100-17LR, "Math Model Study of the Runway 23 Instrument Landing System Glide Slope at Charleston, West Virginia," by Jesse D. Jones, describes the math modeling study used for predicting ILS performance at the siting locations required to lower the TCH.

Although the EFGS currently installed on runway 23 meets Category I path structure tolerances, it is operationally restricted to altitudes above 1100 feet m.s.l. The possibility of improved performance at this site may be expected from the up-slope version of the basic end-fire system. The up-slope version has the front and rear antennas relocated with about double the separation of the basic system, and a middle antenna is added. The result is to scoop out the main signal below path that illuminates the high ground. Clearance (fly-up signal) below path is obtained in the up-slope version from a small clearance antenna located just behind the new middle antenna. However, the FAA does not have this glide slope antenna available yet.

The FAA MLS Program Office, under Congressional mandate, has developed a 9-project MLS Demonstration and Evaluation Program to evaluate the economic and operational benefits of MLS. Project No. 5 of this program is the Comparison of MLS to ILS Performance and addresses the direct comparison of

MLS and ILS performance through collection and analysis of operational flight test data. Of particular interest was the comparison of the performance of an MLS elevation station with the performance of an ILS EFGS installed at a difficult site. The performance criteria addressed were: (1) accuracy, (2) low altitude coverage, and (3) flyability. In accordance with these objectives, the FAA Technical Center arranged to temporarily install an MLS at an airport having this type of glide slope antenna. Yeager Airport was selected because it was the nearest airport to the FAA Technical Center having an EFGS that could accommodate a temporary MLS installation with minimum operational disruptions.

DISCUSSION

MLS EQUIPMENT AND SITING.

The back azimuth and elevation stations from the MLS test bed system installed for runway 31 service at the FAA Technical Center were selected for the Yeager Airport installation. The MLS test bed is a modified Bendix FAR-171 MLS (model B-21.5-40) which meets the FAA MLS accuracy tolerances in FAA-STD-022B and FAA-STD-022C. The back azimuth station has a 2° beamwidth antenna with +/- 40° proportional azimuth guidance, and the elevation station (figure 2) has a 1.5° beamwidth antenna with coverage from +0.9° to 15° elevation. At the FAA Technical Center, front azimuth guidance is provided by a 1° beamwidth antenna with +/- 60° proportional guidance. This station was not required for the Yeager Airport installation.

Under a maintenance support contract with Bendix, the 2° back azimuth station was electronically reconfigured to a front azimuth station (figure 3). New programmable read only memories (PROMS) were installed for the radiated basic and auxiliary data words for the Yeager Airport siting configuration. The scan rate was changed from 6.5 to 13 hertz (Hz). In lieu of concrete foundations, I-beam support frames were utilized for station support structures. An instrumented test van with an MLS receiving antenna mounted on a telescoping mast (figure 4) was driven from the Technical Center to Yeager Airport to facilitate system alignment prior to flight testing.

Site surveying was done by Technical Center personnel 1 week before the MLS was installed. The ILS EFGS and localizer antennas, the DME/N antenna, the runways 23 and 05 thresholds, the MLS elevation and azimuth antennas, and the ground tracker locations were precisely determined/staked for installation, alignment, and data analysis.

Power for the MLS sites was obtained from nearby ILS localizer and glide slope sites (arranged for by the Charleston Airway Facilities Sector Field Office). The DME/N, located 5,815 ft from runway 23 threshold and 252 ft offset from runway centerline, was utilized for cockpit range information and by the Level II MLS area navigation (RNAV) computer during the computed centerline approaches.

Synchronization via radiated C-band signal, a feature which was provided with the MLS, was used in place of a land line for synchronization between the azimuth and elevation stations.

On the morning of February 26, 1991, with the ILS removed from service, the MLS was offloaded from the truck that transported it from the previous test site. The stations were leveled, mechanically aligned, and radiating by 2:00 p.m. on that same day. A flight check of the ILS on runway 23 was performed later that afternoon by the Atlantic City Flight Inspection Field Office to verify that the MLS installation did not affect the ILS guidance signals. The ILS guidance was found satisfactory and the system was restored to service after the flight check. The ILS was also flown by the FAA Technical Center's instrumented aircraft and the resulting data compared to the data from the above FAA flight check as well as the previous FAA flight check. The course width and alignment were found to be in excellent agreement.

Alignment of the MLS antennas was accomplished the next day using the FAA Technical Center instrumented test van. The MLS receiving antenna mounted on the instrumented test van's 50-ft telescoping mast was placed over surveyed points on the runway within coverage of the azimuth and elevation stations. The MLS receiver angle reading was used to set the boresight on the azimuth and elevation antennas.

ILS/MLS COLLOCATION.

The MLS elevation station was collocated with the commissioned Category I ILS EFGS serving runway 23 so that the MLS and ILS TCH's would be within 1 ft of each other. This was accomplished by siting the MLS elevation such that the antenna phase center, about 8 ft above ground, was on a 3° elevation plane having a theoretical origin at the EFGS phase center point. The resultant location for the MLS elevation antenna phase center was 134 ft in front of the ILS EFGS phase center taking into account the EFGS phase center and ground elevations. Due to soft terrain restrictions, the MLS elevation antenna phase center was sited 283 ft from the runway centerline, and between the EFGS main front and main rear antennas. The side of the station facing the runway and nearest to the EFGS antennas was 278 ft from the runway centerline. Although this location penetrated the EFGS critical area by 17 ft, the Charleston Airway Facilities Sector Field Office and Technical Center personnel were confident that it would not degrade the ILS glidepath nor affect the EFGS monitors. This was subsequently verified with the MLS installed. Figure 5 shows the collocated MLS and ILS antennas.

The MLS azimuth station was not collocated with the ILS localizer antenna. It was installed 494 ft in front of the ILS localizer and 241 ft offset from the runway centerline. It could not be offset further from the runway centerline because of a steep ravine. Collocation behind the localizer was not feasible because a tower would have been required to elevate the phase center of the MLS azimuth above the localizer array. The MLS azimuth could not be sited in front of the localizer because of proximity to the runway centerline; the localizer is installed 215 ft from centerline and, because of the offset approach angle, the MLS would have to be at least 13 ft closer to the runway to be collocated in front of the localizer. The MLS azimuth antenna was installed with a 1.47° offset to the runway centerline so the boresight would be parallel to the offset ILS localizer course. Figure 6 shows the MLS siting configuration.

FLIGHT TEST AIRCRAFT INSTRUMENTATION.

An FAA Convair 580, N-49 (figure 7), based at the FAA Technical Center was used as the flight test aircraft. The aircraft was equipped with MLS antennas and project interface switching to allow either conventional navigation (very high frequency omnidirectional radio range) and ILS deviation signals or MLS deviation signals to be displayed on the cockpit instruments in the Captain's panel. In addition, project racks in the cabin area contained a Bendix/King ML-201A MLS receiver and a Bendix/King RNA-34AF digital flight inspection navigation receiver. Both of these receivers output both analog and digital data. A prototype MLS RNAV computer, designed and fabricated by FAA Technical Center personnel, was also mounted on a project rack in the cabin. Using this computer, the MLS angle (AZ/EL) data and the DME range (R) data are sent from the MLS angle receiver and the DME interrogator to the RNAV computer. There, the MLS triple (AZ, EL, R) are converted to a cartesian triple (x, y, z) referenced to the runway datum point, a theoretical point on runway centerline directly abeam the elevation antenna phase center. Computed position is then compared to a desired position based on prestored flightpaths, and lateral and vertical deviation signals are derived.

The MLS area navigation RNAV and data collection are contained in one dual purpose unit. The RNAV unit is currently configured as a level III RNAV computer capable of segmented approaches. Digital data are displayed on a control display unit (CDU). One CDU is mounted in the cockpit (figure 8) of the aircraft, while the other CDU is mounted on a project rack in the cabin of the aircraft. Figure 9 shows the display format and legend. Analog deviations generated by the RNAV computer are also displayed on conventional flight instruments in the cockpit.

The system hardware/software consists of the following:

1. 68020 32 Bit CPU
2. Floppy Disk Controller
3. One Floppy Disk Drive
4. Hard Disk Controller
5. One Hard Disk Drive
6. PDOS Operating System
7. C Language Software
8. Interface Boards for:
    a. Analog Aircraft Parameters
    b. Operator Terminal
    c. Time Code Generator
    d. ILS Receiver
    e. Cockpit Instruments
    f. Printer
    g. Kennedy Tape Recorder

h. MLS Receiver
i. DME Interrogator

A block diagram of the system is shown in figure 10.

ILS/MLS COMPARISON FLIGHT TESTS.

Technical Center aircraft and personnel conducted an engineering flight test to baseline the performance of the Charleston EFGS prior to the installation of the MLS. After the MLS was installed, another flight test was performed. Test results further verified that there was no degrading effect on ILS performance due to the MLS installation. Before and after glidepath structure plots are shown in figure 11.

During ground tracked partial orbits and inbound level runs and approaches, both ILS and MLS data were simultaneously recorded in the instrumented aircraft. The FAA Technical Center's Single Point Optical Ranging Tracker (SPORT) was used for precise aircraft space-position determination required for system performance characterization. The SPORT is a British Aircraft Corporation of Australia Telectrascope which has undergone extensive in-house modification by Technical Center personnel. Overall system accuracy for the SPORT is +/- 36 arc seconds (+/- 0.0061°) in azimuth and elevation and +/- 1.5 meters (4.92 feet) in range. Tracker data were recorded synchronously at a rate of 10 Hz. Each data point consisted of time, azimuth angle, elevation angle, and slant range from the tracker to the aircraft. Tracker time was synchronized with aircraft time using a portable IRIG-B time code generator.

ILS and MLS course error data are usually presented differently due to different specifications for each system. All ILS EFGS data shown in this report are raw error data (receiver cross pointer minus tracker). The MLS elevation data shown in this report are also raw error data so that all comparisons are between raw error data.

Typical error plots for the MLS elevation and ILS EFGS recorded simultaneously during approaches are shown in figures 12 to 14. Comparison of the MLS plots with the ILS plots for the same run clearly shows the superior accuracy of the MLS over the ILS throughout the entire run (figure 12), and especially during the low-altitude portion of the run near the threshold (figure 13).

Figure 12 shows a composite of five approaches to runway 23 using ILS guidance. The data are displayed as error versus range from runway threshold. The approaches were made using ILS guidance to decision height and then were continued visually to runway alignment and near touch-down at which point a missed approach was initiated. Both MLS and ILS data were recorded simultaneously for all five runs. Both MLS and ILS errors are presented as unfiltered data. It can be seen that the MLS elevation data presents a much more uniform and accurate structure than does the EFGS data. The MLS elevation errors for all five approaches are bounded by +/- 0.15° from 10 miles to threshold, while the EFGS data shows excursions of +/- 0.25° from 10 miles to excursions greater than +/- 0.50° in the proximity of the runway threshold.

Figure 13 displays the data in figure 12 as error versus height above runway threshold for the final 400 ft of the approach. It can be seen that the MLS elevation guidance during this critical phase of the approach is far superior to that of the ILS EFGS in terms of uniform and accurate structure.

Typical error plots for the MLS elevation and ILS EFGS recorded simultaneously during partial orbits are shown in composite form in figure 14. Figure 14 depicts the MLS elevation and ILS EFGS errors as a function of azimuth angle from their respective phase centers. The partial orbit was flown at 2500 ft m.s.l. at a range of 5 nmi from the runway threshold. This altitude and range put the aircraft through the horizontal coverage region of both the MLS elevation and the ILS EFGS at an elevation angle of approximately 3°, the nominal glidepath angle for this system. However, in the interest of flying the aircraft at a sufficient altitude to provide a clear line of sight to the airport at all azimuth angles in the mountainous terrain, the actual elevation angle as the aircraft passed through the MLS azimuth and localizer centerline course was approximately 3.7°. The improvement in system accuracy and coverage shown by the MLS elevation over the EFGS is obvious. The severe limitation of the proportional EFGS guidance in azimuth is also evident. A characteristic of the EFGS horizontal path structure is very narrow proportional elevation guidance. The typical proportional horizontal guidance coverage is only +/-5° for this type of antenna. On either side of the proportional guidance azimuth sector, the antenna performance is controlled by the clearance array which provides a full fly-up signal. This limitation would severely restrict the attempted use of ILS procedures outside of on-course approaches. In contrast, the MLS elevation provides much more precise and broader proportional guidance in the horizontal plane. The slight increase in roughness in the MLS elevation error in the region of 25° to 40° was caused by high terrain between the elevation station and the aircraft partially blocking the elevation signal.

MLS/RNAV FLIGHT TESTS.

Advanced procedures MLS approaches to runway 23 using the MLS/RNAV for centerline computation were made on two flights. Figure 15 shows a composite of the aircraft position in x and y for 12 typical runs using MLS computed centerline guidance. For comparison purposes, six typical ILS approaches are also shown. The coordinate origin for this figure is at the datum point with the x-axis along runway centerline. Also depicted in the same figure are the runway threshold area and, in the case of the ILS approaches, the localizer course. It can be seen that the MLS computed centerline procedure allows execution of a straight-in approach down the runway centerline even when the ground stations are configured for an offset ILS "look-alike" approach. Additionally, it can be seen from figure 15 that the MLS computed centerline approaches allowed the pilot to accomplish a much tighter cross-track dispersion near the runway threshold than when ILS guidance was used.

The project pilot who flew the MLS/ILS comparison test flights and computed centerline approaches provided the following comments: "There was a sizable and easily discernible improvement in flyability of the MLS over the ILS. While the offset of the ILS localizer and MLS azimuth was small, the increase in confidence and control obtained with the MLS/RNAV computed centerline was impressive. The physical siting of this airport, on a mountaintop surrounded by cliffs, subjects the approaching pilot to a number of visual illusions. The use of MLS/RNAV to compute a centerline approach markedly reduces the illusion effects and the approach workload by providing an aligned view of the runway throughout the approach and by removing the last minute 'jog' manuever required with the raw data and offset installation."

CONCLUSIONS

1. The flight test data showed: (a) that Microwave Landing System (MLS) elevation guidance quality is clearly superior to the Instrument Landing System (ILS) basic end-fire glide slope (EFGS) in accuracy, low altitude coverage, and flyability; and (b) the MLS elevation has much broader horizontal proportional guidance coverage than the ILS basic EFGS.

2. The temporary installation of the MLS on runway 23 at Yeager Airport and the subsequent test flights demonstrated the superior guidance quality of MLS at a problem ILS glide slope site.

3. Computed centerline approaches using MLS/area navigation (RNAV) with an offset MLS azimuth installation demonstrated the advanced operational capability of MLS over ILS. These procedures markedly reduced pilot workload and disorientation during approaches to the instrument runway at Yeager Airport. It should be noted that there is a commercially available MLS receiver, completely certified with a Technical Service Order (TSO), that can perform the computations necessary to allow MLS computed centerline approaches similar to the ones performed in this flight test.

4. The test flights satisfactorily demonstrated that an MLS elevation and an ILS basic EFGS may be collocated without degrading the performance of either system.

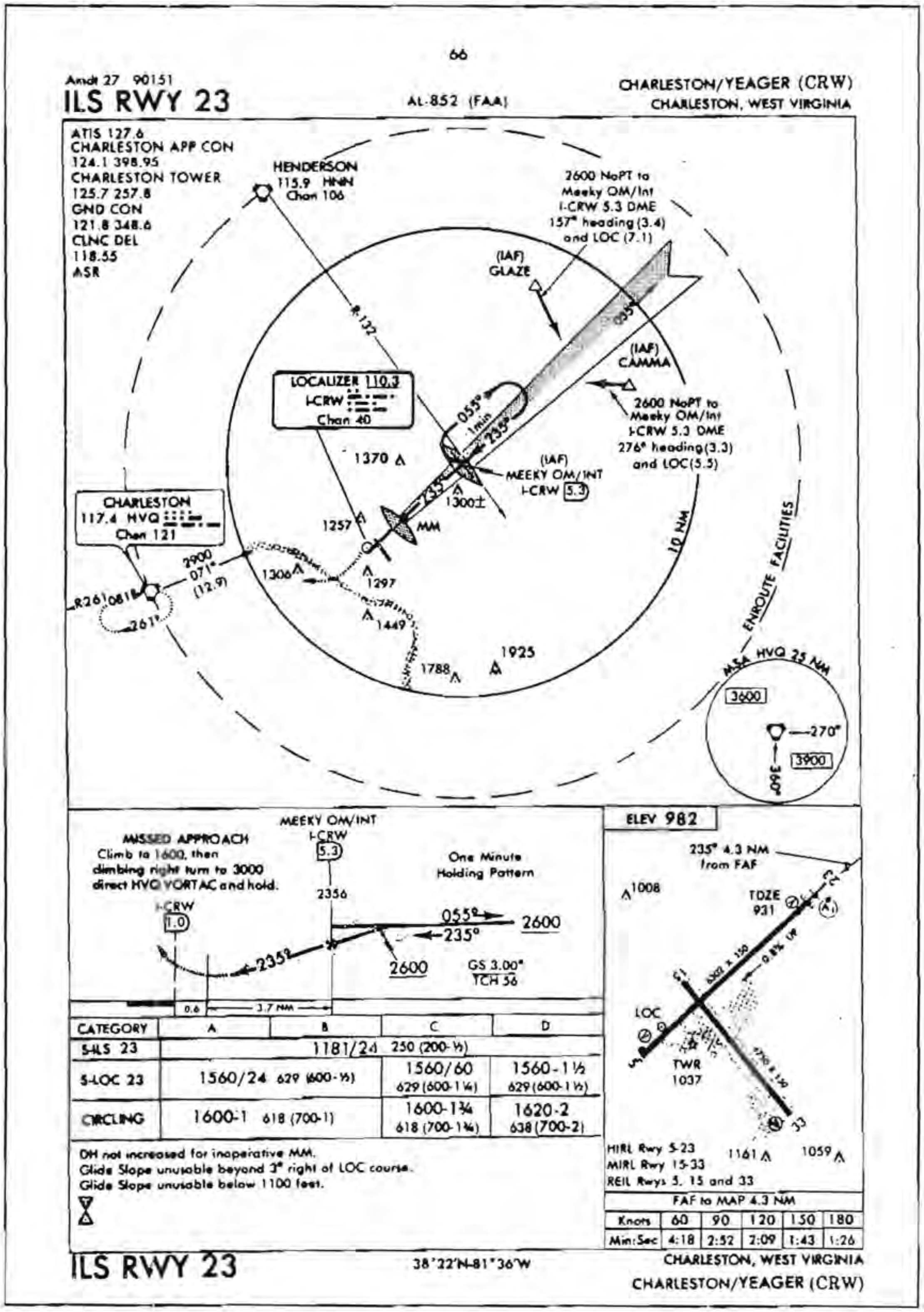


FIGURE 1. CHARLESTON, WV, RUNWAY 23 ILS APPROACH PLATE

FIGURE 2. MLS ELEVATION STATION

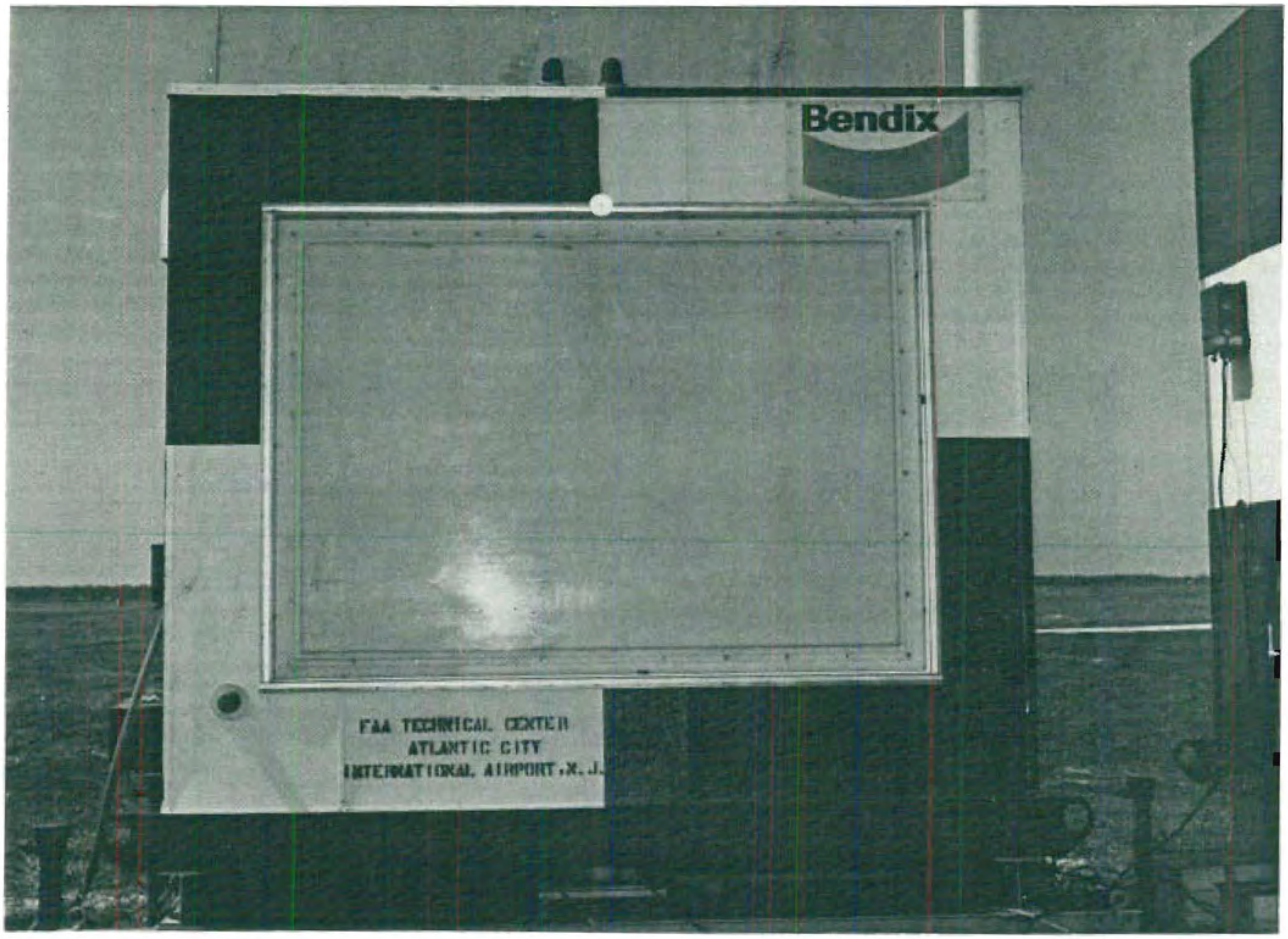


FIGURE 3. MLS AZIMUTH STATION

FIGURE 4. INSTRUMENTED TEST VAN

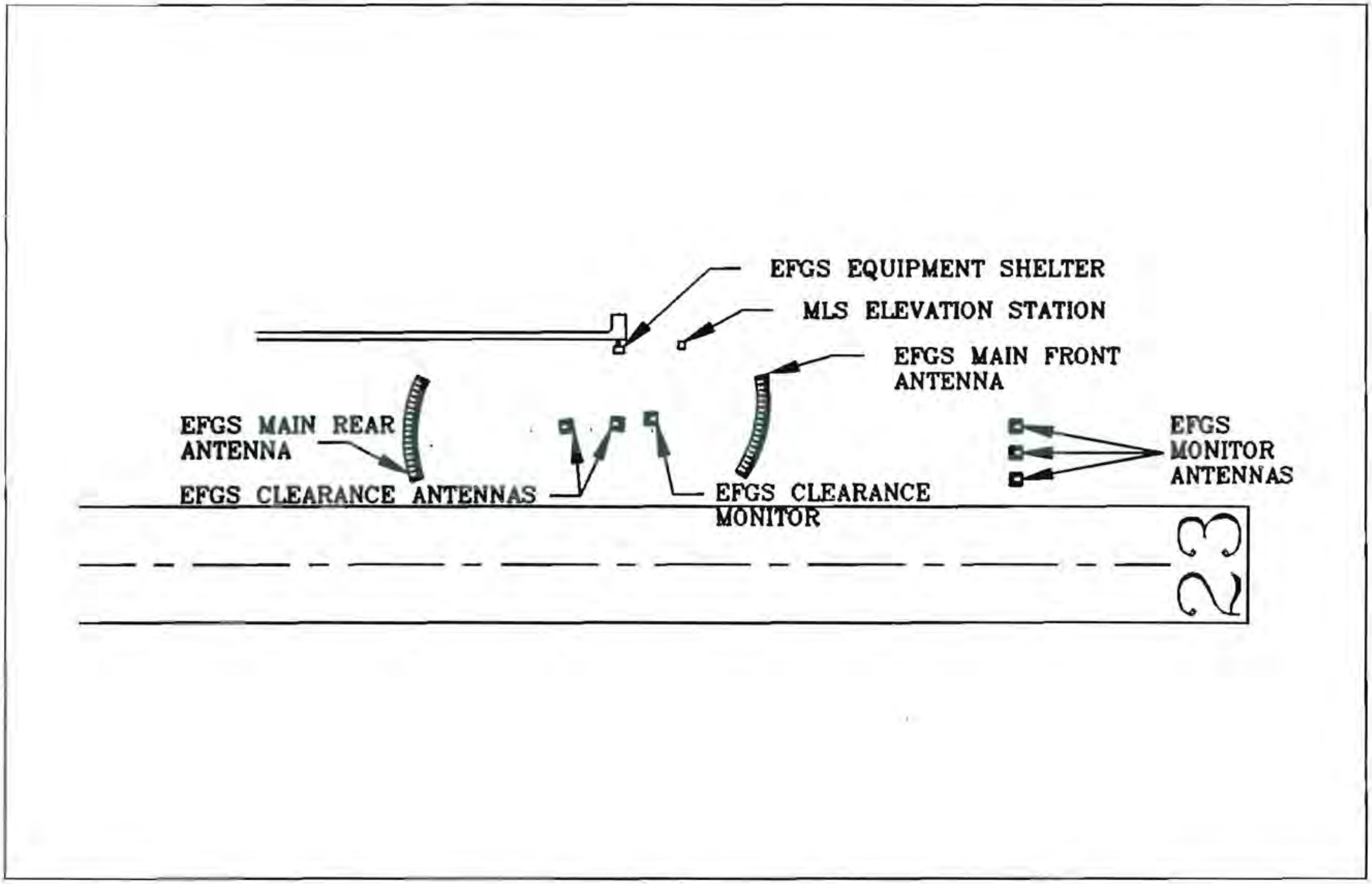


FIGURE 5. ILS END-FIRE GLIDE SLOPE/MLS ELEVATION COLLOCATION

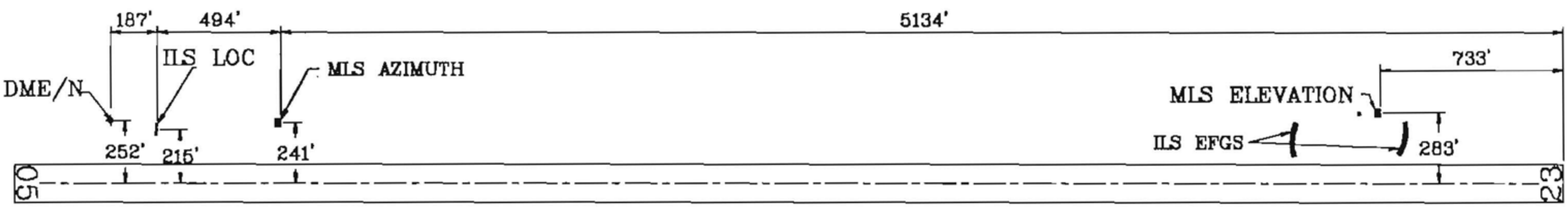


FIGURE 6. YEAGER AIRPORT MLS SITING

FIGURE 7. FAA CONVAIR 580, N-49

FIGURE 8. MLS RNAV CONTROL DISPLAY UNIT IN COCKPIT

MLS RNAV CDU

```
3D        HH:MM:SS        DAT

AZ  ____________          °
EL  ____________          °
PDME ___________          NMI
X   ____________          FT
Y   ____________          FT
Z   ____________          FT
FR  ____________    TO  ______

DTW ____________          NMI
CTE ____________          FT
HTE ____________          FT
```

```
NAV STATE -       -> NONE    
             3D   -> CASE 12 
             2D   -> CASE 9B    As Taken From RTCA DO-198
                       OR    
                     CASE 3  
```

RECORDER STATE - DAT -> RECORDING

AZ - RAW ANGLE IN DEGREES
EL - RAW ANGLE IN DEGREES
PDME - RAW DME IN NMI

X,Y,Z - RELATIVE TO DATUM POINT(0,0,0)
ON R/W CL ACROSS FROM EL SITE

FR,TO - WAYPOINT NUMBERS

DTW - DISTANCE TO "TO WAYPOINT" IN NMI(3D), FT(2D)

CTE - CROSS TRACK ERROR IN FT

HTE - HEIGHT ERROR IN FT

FIGURE 9. CONTROL DISPLAY UNIT FORMAT AND LEGEND

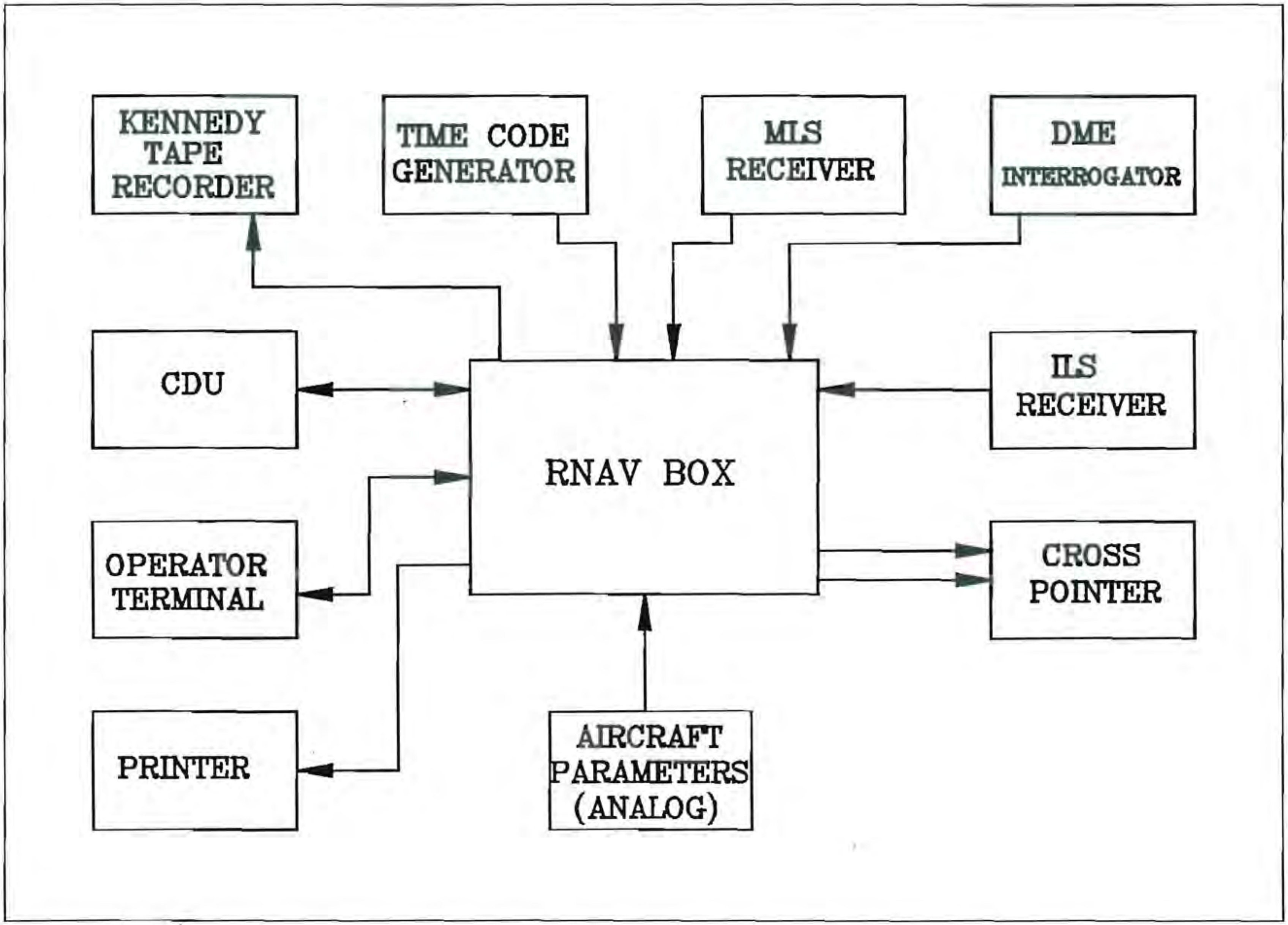
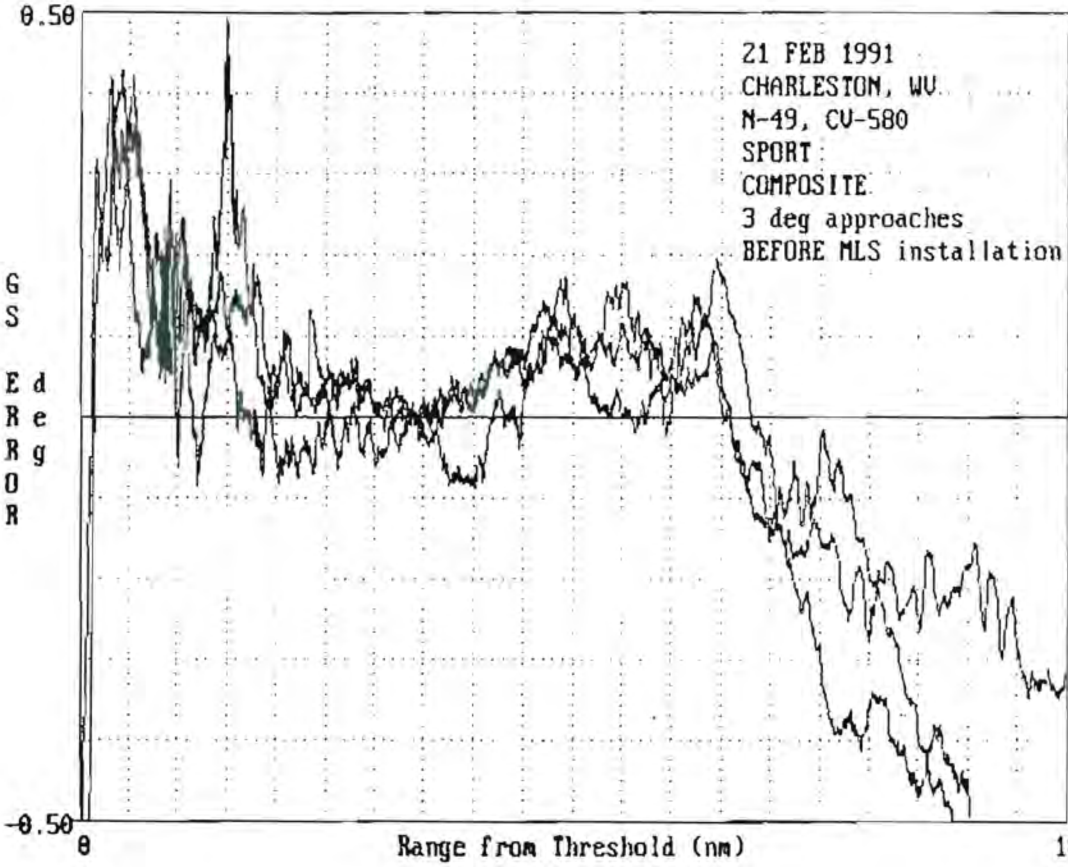


FIGURE 10. MLS RNAV AND DATA COLLECTION SYSTEM BLOCK DIAGRAM



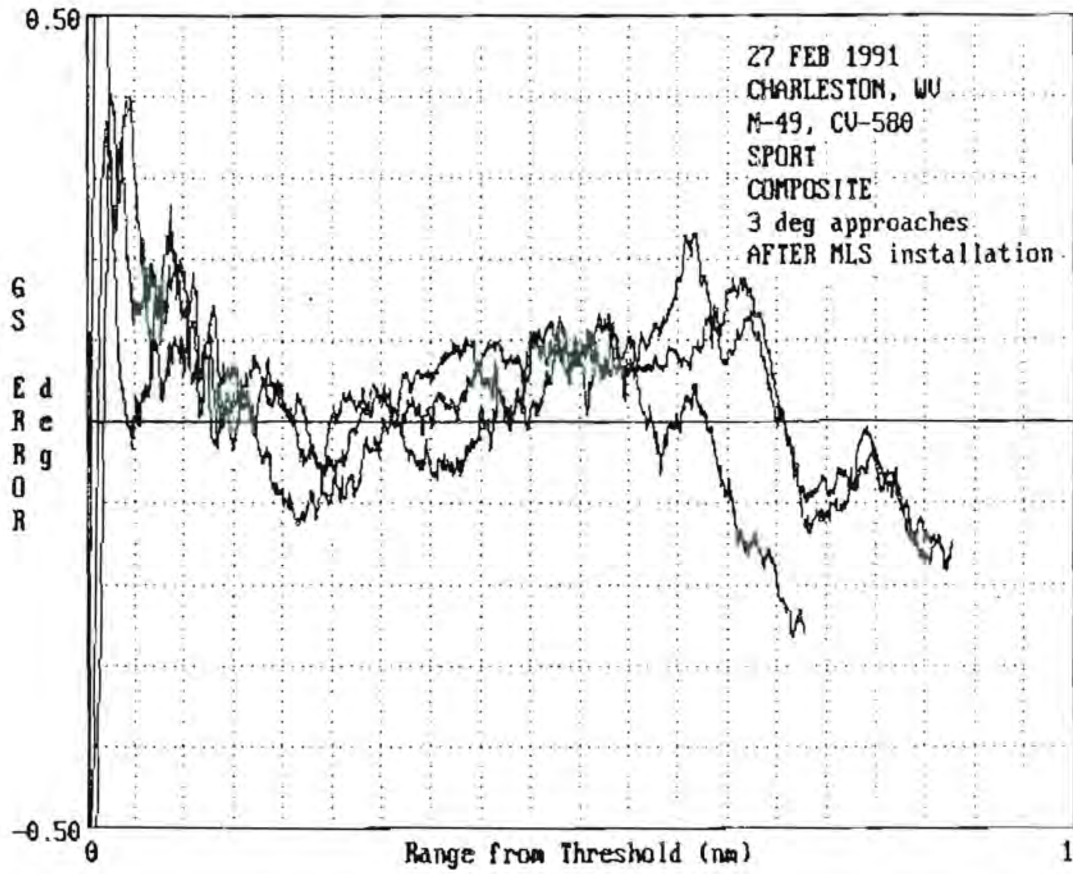
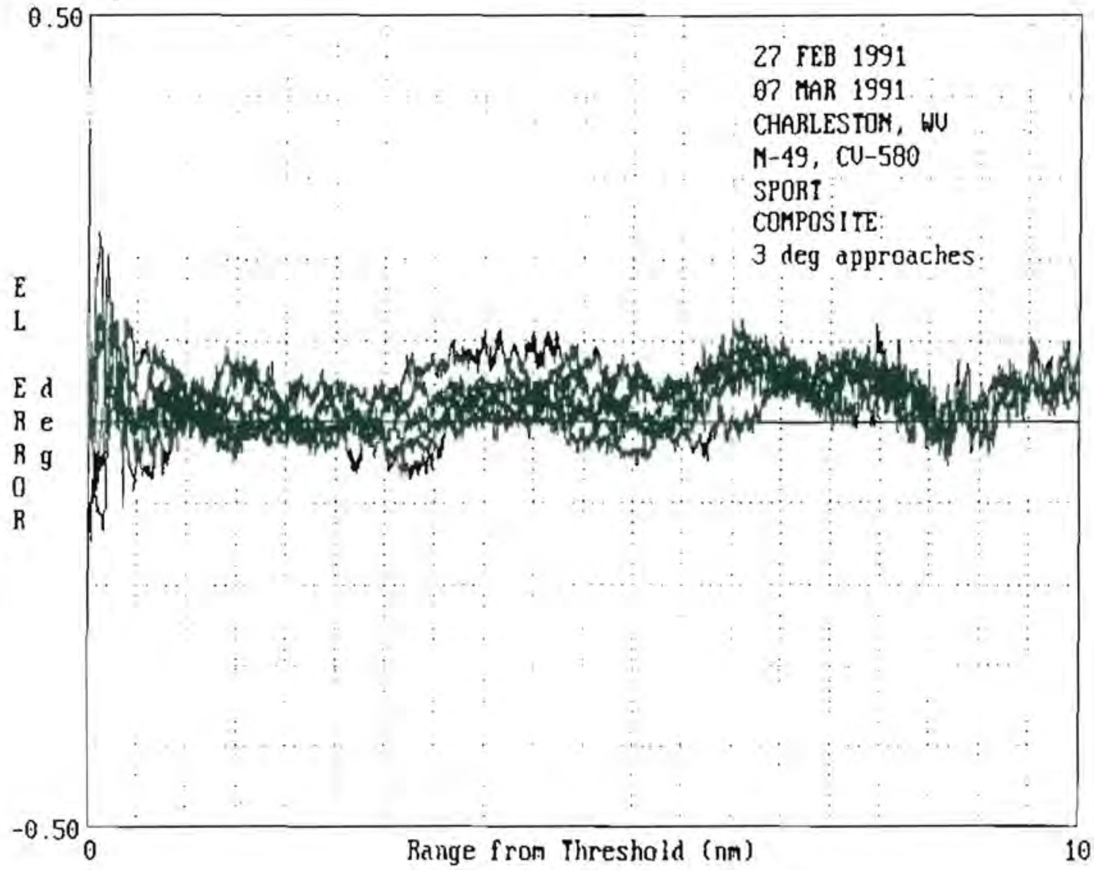


FIGURE 11. EFGS GLIDEPATH STRUCTURE BEFORE AND AFTER MLS INSTALLATION



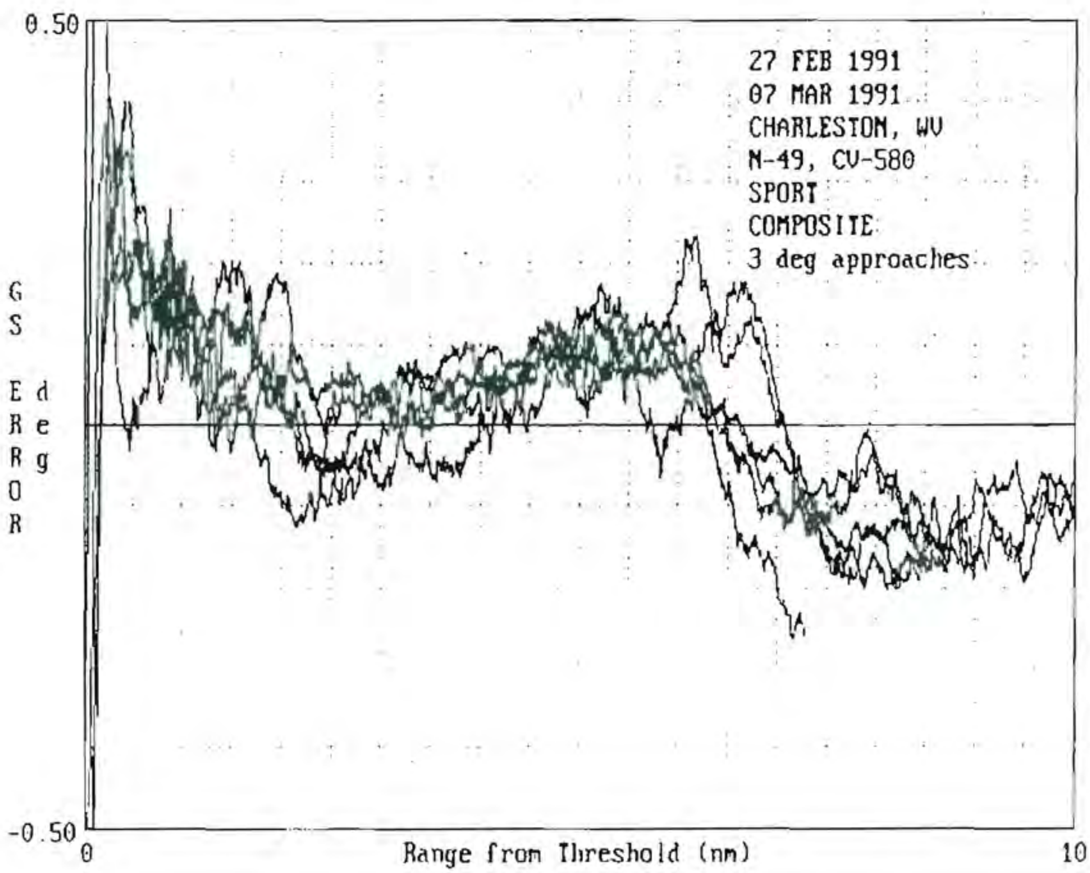
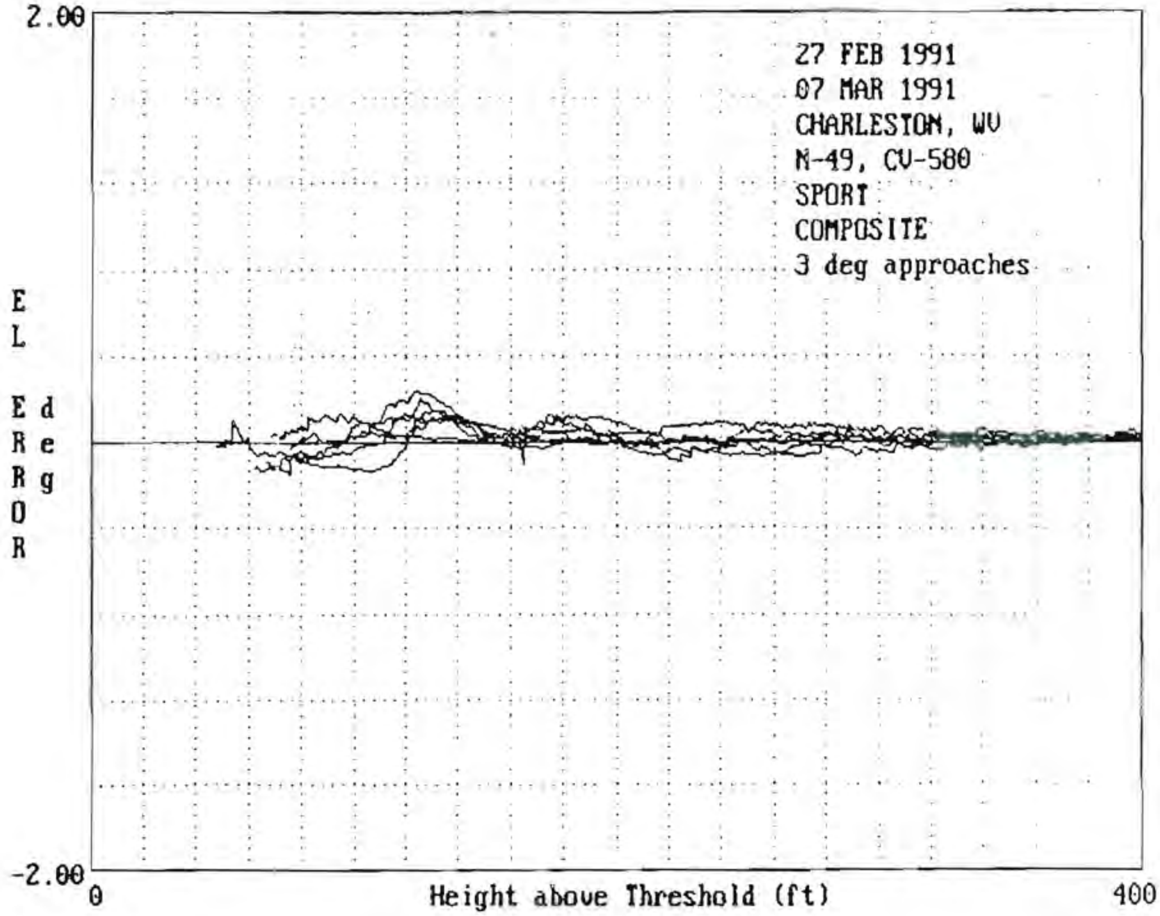


FIGURE 12. ILS/MLS ERROR PLOTS FROM APPROACHES - ERROR VS RANGE



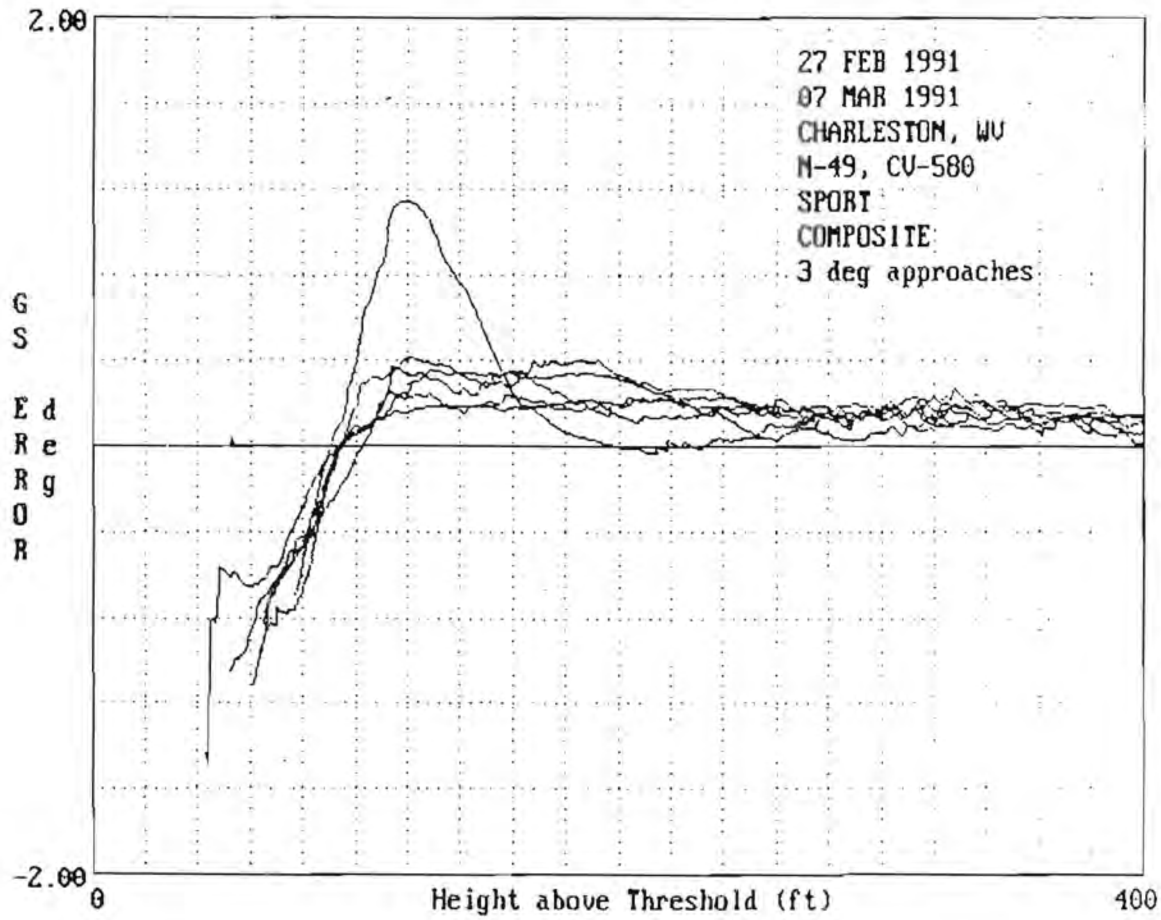


FIGURE 13. ILS/MLS ERROR PLOTS FROM APPROACHES - ERROR VS HEIGHT ABOVE THRESHOLD

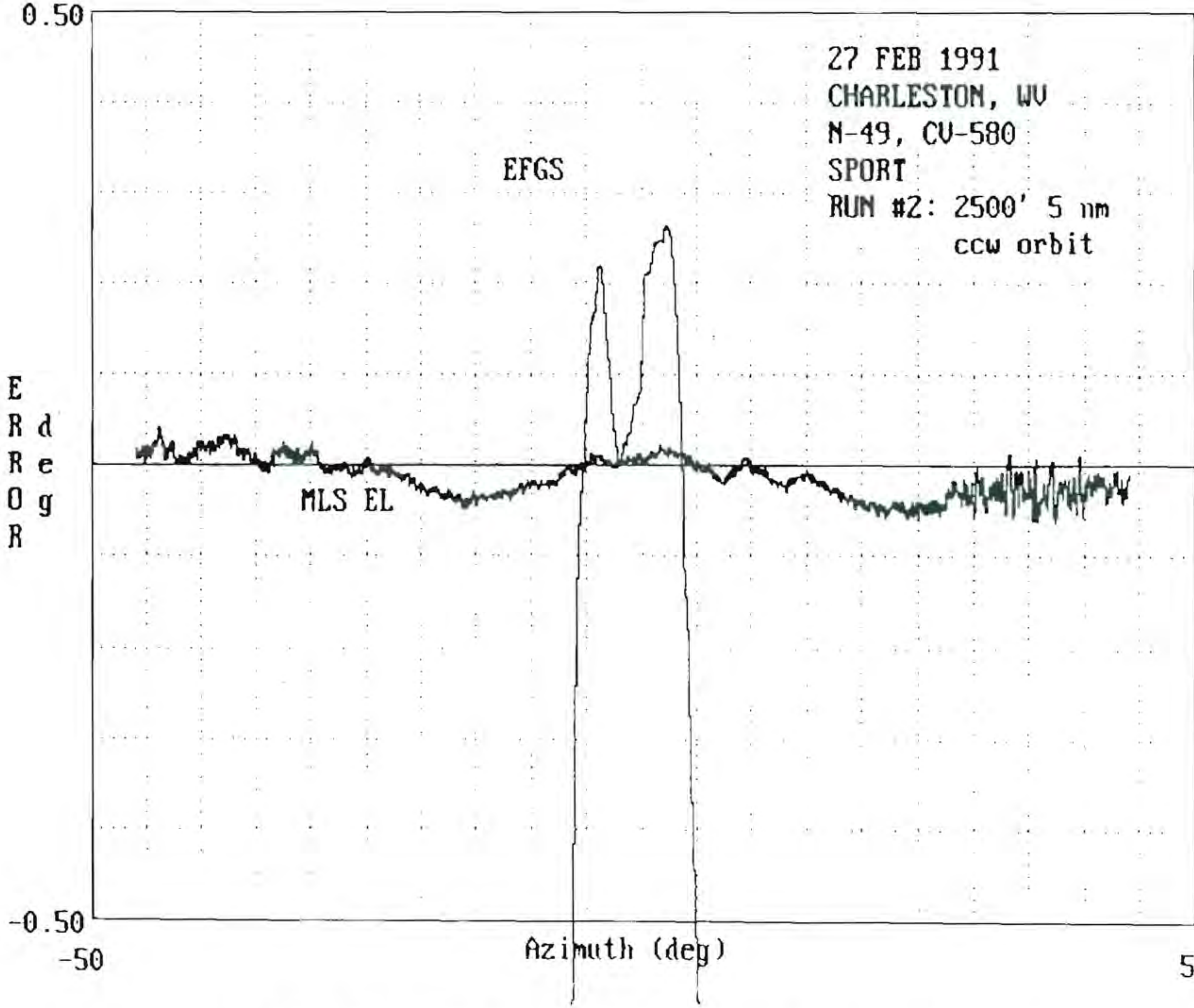
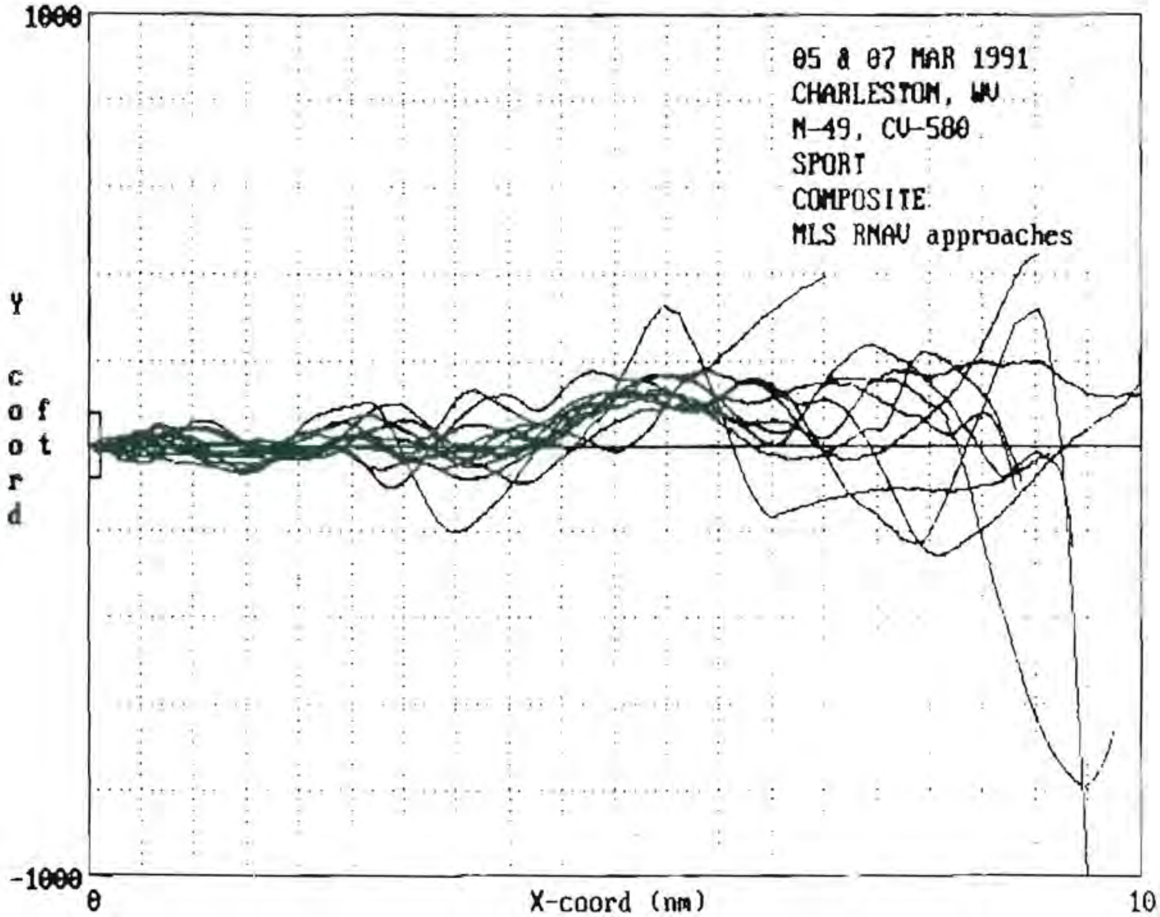


FIGURE 14. ILS/MLS ERROR PLOTS FOR PARTIAL ORBITS - ERROR VS AZIMUTH



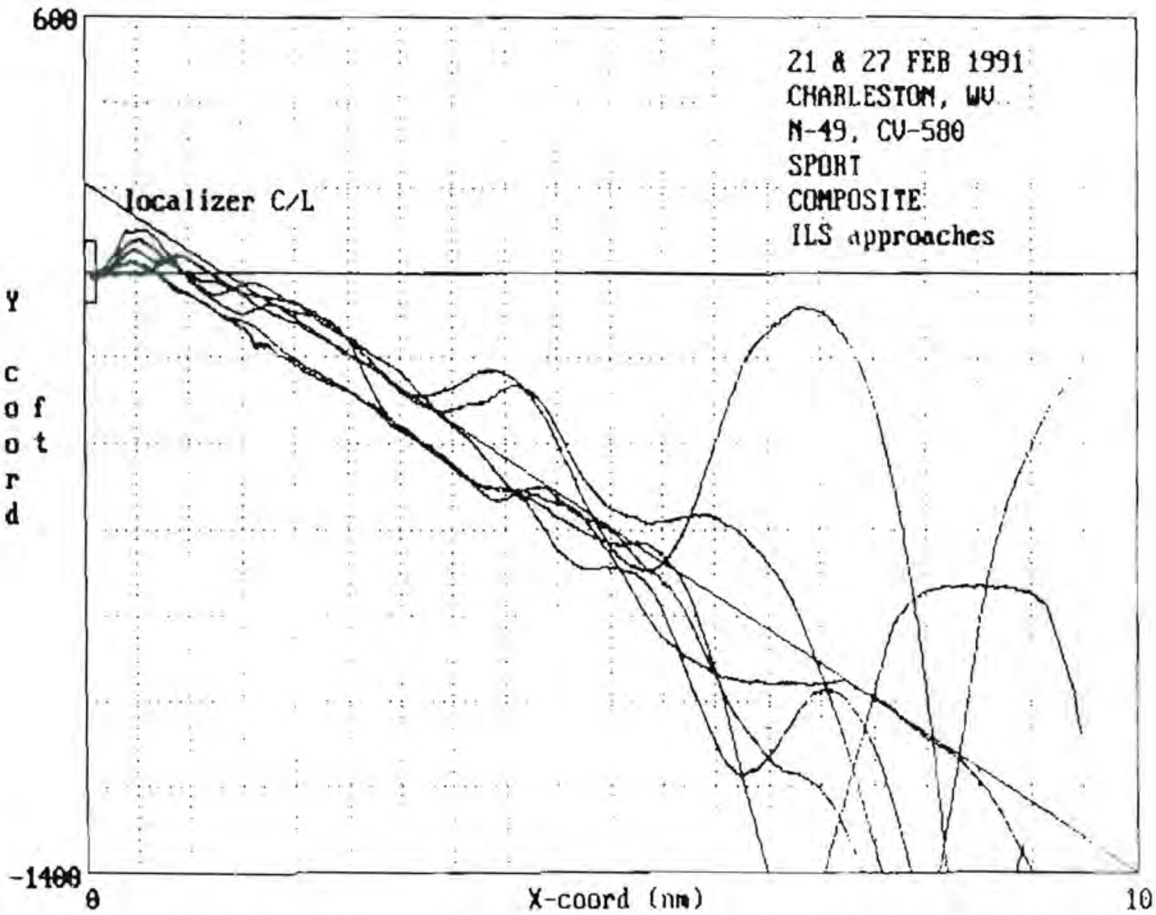


FIGURE 15. MLS COMPUTED CENTERLINE AND ILS APPROACHES - X VS Y COMPOSITE PLOT