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MLS MATHEMATICAL MODEL VALIDATION STUDY USING AIRBORNE MLS DATA FROM JFK AIRPORT ENGINEERING FLIGHT TESTS, OCTOBER 1989

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PURPOSE

The purpose of this validation study is to evaluate the performance of the Microwave Landing System (MLS) Mathematical Model by comparing the results of the math model's simulation of flight test profiles flown at JFK International Airport in New York City with actual airborne data collected during the test flights. Specifically, this study addresses the problem of scattering of MLS signals by the Pan American Airlines Hangar 19 on approaches to runway 13R. The approach to validation taken in this study and the philosophy of interpreting the results are discussed in detail in Concepts Analysis Division Report ACD-330-90-04, "Approach to Validation of the MLS Mathematical Model" (Linda Pasquale, Jesse D. Jones).

BACKGROUND

The MLS Mathematical Model

The MLS Mathematical Model simulates the operation of an MLS for the purpose of predicting the effects of the airport environment on the transmitted signal and the corresponding accuracy and usefulness of the signal at the receiver for providing positional information. Three categories of input data define the scenario to be modeled. One set of data describes the airport environment with emphasis on the obstacles (buildings, aircraft, terrain features) that might have reflective (multipath) or diffractive (shadowing) effects on the transmitted signal. Another set of data defines the position and signal characteristics of the MLS antenna systems, and a third set provides the coordinates of the flightpath. The model uses these data to predict (1) the characteristics of the propagated signal and (2) the receiver output angle errors caused by the scenario configuration.

Originally developed by the Lincoln Laboratory of the Massachusetts Institute of Technology, the math model has been extensively revised and baselined by personnel at the Federal Aviation Administration (FAA) Technical Center. Additional testing of the model is required to determine whether the model continues to perform satisfactorily in representing the real world and to investigate the model sensitivities to input parameters.

The Demonstration at JFK Airport

At the request of the MLS Program Office, the FAA Technical Center conducted an operational demonstration of the MLS on runway 13R at JFK International Airport during October 1989. Preparation for the demonstration included engineering flight tests, conducted on October 21, 1989, to verify and characterize system operation and to ensure the operational feasibility of the proposed demonstration flight profiles. MLS data recorded during these flight tests provide "real world" data which can be compared with math model predictions, thereby providing an opportunity to evaluate the performance of the model in simulating the JFK airport environment. Use of a Radio Telemetering Theodolite (RTT) allows independent

(non MLS) confirmation of some of the angle data.

In preparation for the demonstration, Tech Center and Bendix personnel made an on-site survey and identified the slanted corrugated roof plates (figure 1) of Pan American Hangar 19 as a possible source of signal interference for the elevation antenna. Preliminary modeling of the hangar roof plates was performed with two calculated flightpaths: the 3.0° "Canarsie" approach which would be flown for the demonstration and a 6.0° straight-in approach designed to traverse the region of maximum multipath from the hangar. The results of this preliminary modeling, presented in Concepts Analysis Division Report ACD-330-90-03, "Modeling of the Pan American Airlines Hangar at JFK Airport Runway 13R" (Linda Pasquale), predicted no out-of-tolerance signal interference for any of the simulations performed.

DATA COLLECTION AND REDUCTION METHODOLOGY

MLS Equipment and Siting

Azimuth and elevation stations from the MLS test bed system at the FAA Technical Center, and an E-System Precision Distance Measuring Equipment (DME/P), were transported to New York for the JFK demonstration. The MLS test bed is a modified Bendix FAR-171 MLS (models B-21.5-40s and BI-60s) which meets the FAA MLS accuracy tolerances FAA-STD-022b and FAA-STD-022c. The azimuth antenna used for the demonstration has a 2° beamwidth with ±40° proportional azimuth guidance. To ensure coverage of the Canarsie approach, the boresite of the azimuth antenna was rotated approximately 17° in the direction of the positive Y axis. The elevation antenna has a 1.5° beamwidth with proportional coverage from +0.9° to +15°. For centerline approaches, an RTT provided ground-based tracking elevation angle data. A map of the JFK siting and obstacle geometry is shown in figure 2.

Engineering Flight Tests

The FAA aircraft used for the flight tests, a Convair-580 (N-91), included a data collection system designed, built, installed, and tested at the Technical Center. This system records data from the MLS angle receivers, the DME/P and Mini-Ranger interrogators, and the RTT, when used. Flight profiles used for this validation study include two measured 3.0° Canarsie approaches and two 6.0° centerline approaches designed to traverse the region of maximum multipath as determined from the intersection of the specular reflection from the midpoint of the roof plate of the Pan American Hangar and the centerline of the runway. RTT tracking for the elevation antenna was available only for the centerline approaches because of nearby obstructions that blocked the line of sight off to the side.

Flightpath Creation

Flightpath data can be entered into the MLS math model in one of two ways. The coordinates of the flightpath segment endpoints can be included in the formatted input file, a method appropriate for theoretical flightpaths that are calculated mathematically. In the

alternate method, the model reads flightpath coordinates directly from a second input file. This method allows the flightpath to be defined in greater detail and is the appropriate method to use when actual flight data is available. The second method, using the measured flightpath input file, was used for this validation study.

Flightpaths were created from the MLS and DME/P data collected during the engineering flight tests. For the 6° centerline approaches, RTT angle data were used in place of the MLS elevation angle data. The angle and distance data are translated into X,Y,Z flightpath coordinates by an algorithm known as "Case 12". The Case 12 algorithm is documented in Technical Note DOT/FAA/CT-TN87/2, "Helicopter Microwave Landing System Area Navigation (MLS RNAV)" (Barry R. Billmann, James H. Remer, and Min-Ju Chang, November 1986). The software developed to reduce and analyze airborne data and create a measured flightpath is documented in Concepts Analysis Division Report ACD-330-90-02, "Data Reduction and Graphics Software for Analysis of Airborne MLS Data" (Linda Pasquale). In the absence of a completely independent (non MLS) tracking system, this method produces flightpaths that are the next best approximation to those actually flown by the aircraft.

Methods of Plot Generation

The MLS math model utilizes two stages of simulation. In the first stage, the program BMLST (and the associated plotting program BPLOTT) simulates the signal in space in the specified airport environment and produces plots which identify the multipath and shadowing effects from specific obstacles (buildings, aircraft, ground reflection surfaces). The system model programs BMLSR and BPLOTR in the second stage simulate the operation of the receiver given the transmitted signal as output from BMLST. Plots from this processing stage show the receiver error ("raw" error) which is defined as the difference between the position of the aircraft as it is in "reality" (as defined by the input flightpath) and the position as determined by simulation of the MLS system. This raw error data is further processed with a path following error (PFE) low-pass filter algorithm and a control motion noise (CMN) high-pass filter algorithm. The PFE algorithm, a low-pass filter which removes components of the error data that will not have a measurable effect on the ability of the aircraft to follow the specified flightpath, creates plots that are particularly useful for comparison with actual airborne data because they emphasize the large-scale shape of the data curve. Thus, model output for purposes of this validation study is judged primarily on the basis of the PFE error plots with support from multipath plots which identify specific sources of signal disruption.

The real world data, recorded by the airborne data collection system, are processed by data reduction and graphics software that produce plots designed to facilitate comparison with the model PFE error plots previously described. The specific nature of these plots depends on the type of flightpath and the presence or absence of RTT tracking. The centerline approach flightpaths are described by "differential error" plots which show the angle error against

the distance from the azimuth antenna at which the angle is measured. The angle error is calculated by subtracting the RTT angle from the MLS receiver elevation angle and filtering the resulting value with a PFE algorithm. Similarly, the model receiver error is calculated by subtracting the angle determined from the flightpath coordinates from the angle measured by the MLS system simulation. The resulting error is PFE filtered. Thus, the model error values and the airborne error values are both PFE filtered and plotted against distance from the MLS azimuth antenna for easy comparison and analysis.

The Canarsie approaches are treated differently because RTT tracking cannot be used, and, therefore, no "error" values for airborne data can be calculated. Airborne data is represented by plots of each receiver angle (or distance) value against the elapsed time of the flight. Since model output plots receiver error against distance from azimuth antenna, the two plots cannot be compared directly. However, both will reveal significant anomalies when caused by signal interference.

DATA PRESENTATION AND ANALYSIS

Preliminary modeling using flightpath coordinates designed to simulate a 3.0° Canarsie approach predicted no multipath errors from either of the two plates representing the roof of the Pan American Hangar for either MLS receiver (azimuth and elevation) or for the DME/P. Airborne data from two Canarsie approaches, run 3 and run 6, were analyzed for this validation study. Neither showed any large-scale disruption to the received azimuth and elevation signals as illustated by figures 3 and 4, the azimuth and elevation receiver angle data for run 3. It should be noted that the azimuth angle values are "raw" receiver values relative to the azimuth boresite and are therefore rotated approximately 17° from runway centerline. When a measured flightpath was created from this data (with appropriate corrections for azimuth boresite rotation) and modeled with the Pan American Hangar roof plates, no receiver errors were predicted, as illustrated by figures 5 and 6, the model PFE error plots for azimuth and elevation, respectively. Similar results were obtained from run 6 (plots not included in this report).

Preliminary modeling of the JFK scenario with a flightpath calculated to simulate a 6.0° centerline approach did predict multipath interference on the elevation signal from the lower slanted roof plate of the Pan American Hangar, though, as reported, the separation angle in excess of 5° was large enough to prevent out-of-tolerance receiver errors. No interference was predicted for the azimuth or DME/P. The results of analyzing airborne data from two 6.0° centerline approaches, run 20 and run 21, agree with these predictions. That is, no effects are seen on the azimuth or DME/P systems. Using a measured flightpath based on airborne data from run 20, the model shows high multipath on the elevation signal from the lower roof plate at approximately 2.7 nautical miles (nmi.) from the azimuth antenna (figure 7). However, these effects

do not cause receiver errors, as is shown by figure 8. The differential error plot of the airborne data (ie: the difference between the angle as measured by the RTT and elevation systems) shows that essentially no MLS receiver errors occurred (figure 9).

Similar results are observed in the airborne and model plots of run 21 (airborne and model error plots not included in this report). However, the difference in the predicted multipath amplitude for run 21 illustrates the sensitivity of the math model to input parameters. The peak multipath interference on the elevation signal from the lower roof plate, represented by a multipath-to-direct ratio of -11.858 decibels (dB), occurred at the flightpath point 20780.912, -31.351, 1041.181 (figure 10). For run 20, the peak amplitude, -0.505 dB, occurred at 20750.111, -26.909, 990.437 (figure 7). Since the effect is observed on the elevation signal, the difference in amplitude is attributable to the difference in flightpath altitude for the two runs. This is supported by comparing these results with those of modeling a calculated 6.0° centerline approach. Here, the model predicted a multipath/direct ratio of 0.364 dB at 21225.781, 0.0, 988.720 (figure 11). Both the amplitude of the effect and the altitude of the receiver are similar to run 20. Actual multipath amplitude could not be determined for comparison with modeled data because the aircraft flew through the narrow multipath region too fast for video measurements.

CONCLUSION

Comparisons of model output with real world data collected during flight tests at JFK show the two in close agreement. With both a measured flightpath derived from airborne data and a flightpath calculated mathematically, the MLS math model correctly predicts the absence of significant signal scattering (for all systems) from the Pan American Hangar 19 roof for both a 3.0° Canarsie approach and a 6.0° centerline approach. The results of this validation study support the conclusion that the MLS mathematical model is a valuable tool for use in the evaluation of the potential sources of signal interference for an MLS system configuration in a particular airport environment.

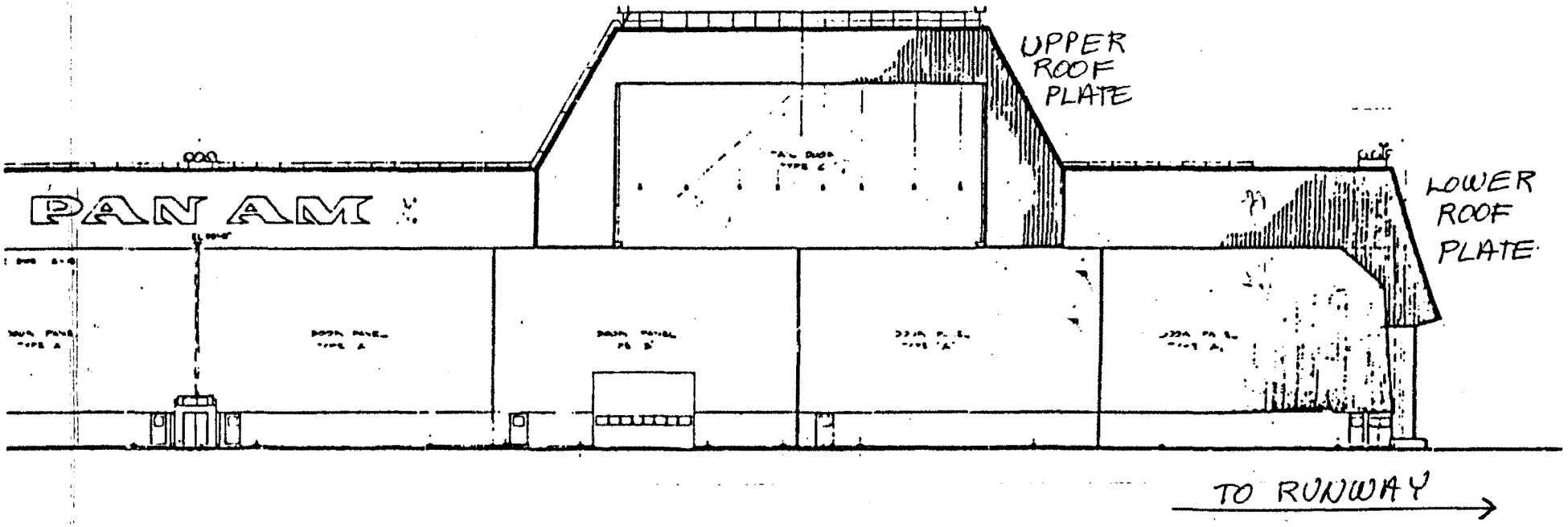

FIGURE 1. PAN AMERICAN HANGAR 19, SLANTED ROOF PLATES.

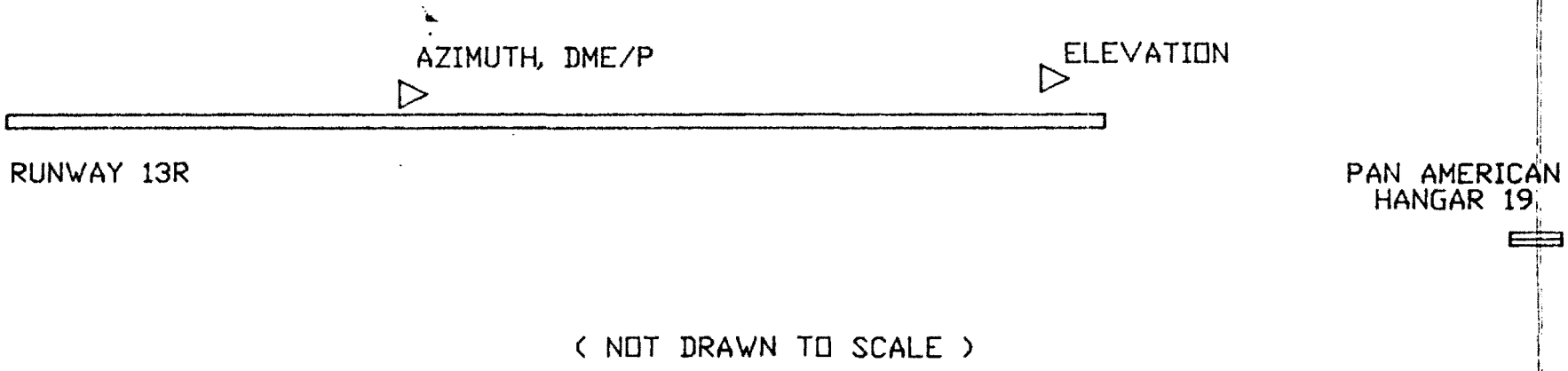

FIGURE 2. JFK INTERNATIONAL AIRPORT RUNWAY 13R SCENARIO MAP.

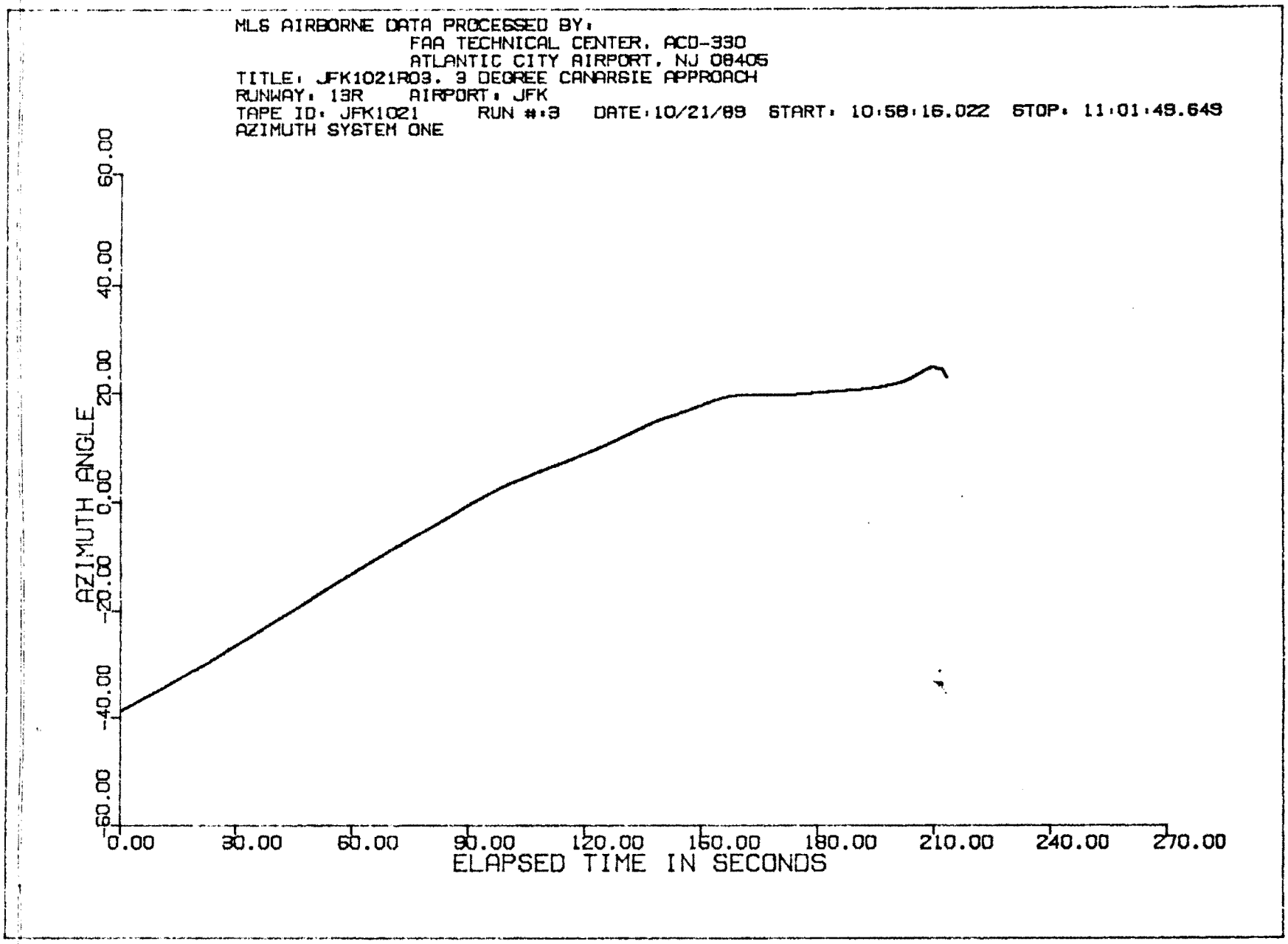

FIGURE 3. 3 DEGREE CANARSIE APPROACH, AZIMUTH SYSTEM 1, AIRBORNE ANGLE DATA.

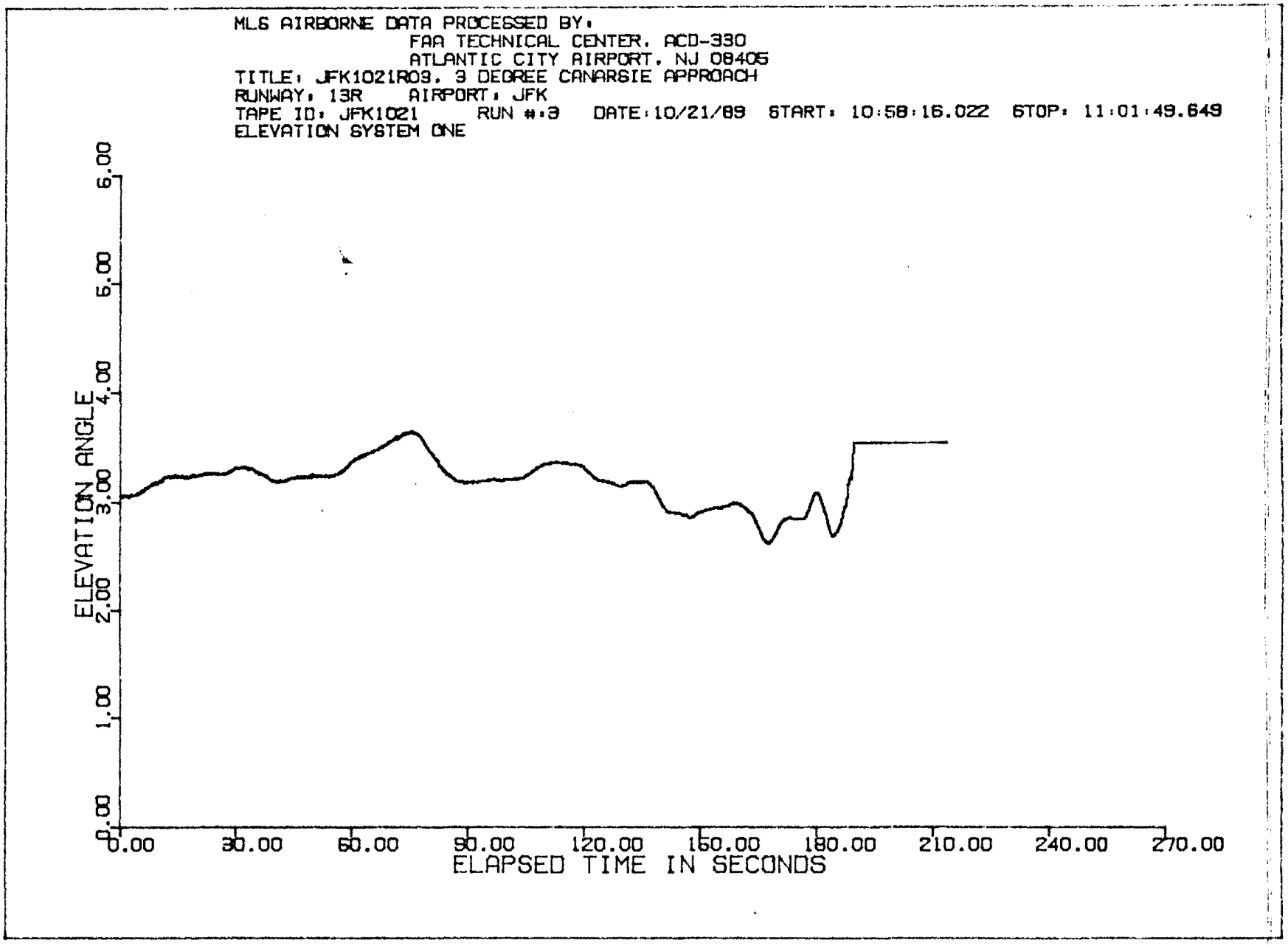

FIGURE 4. 3 DEGREE CANARSIE APPROACH, ELEVATION SYSTEM 1, AIRBORNE ANGLE DATA.

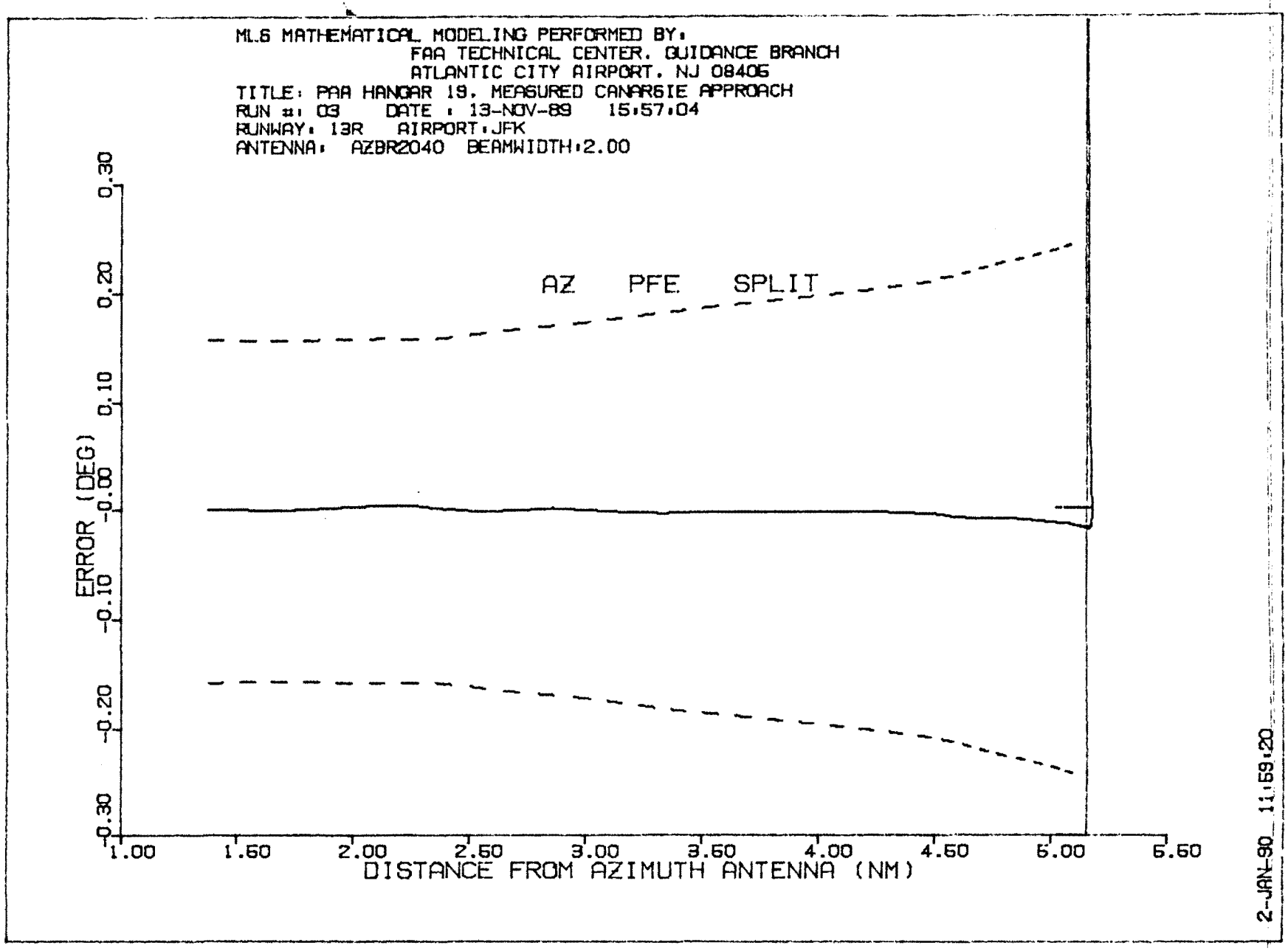

FIGURE 5. 3 DEGREE MEASURED CANARSIE APPROACH, AZIMUTH SYSTEM, MODEL PFE FILTERED ERROR PLOT.

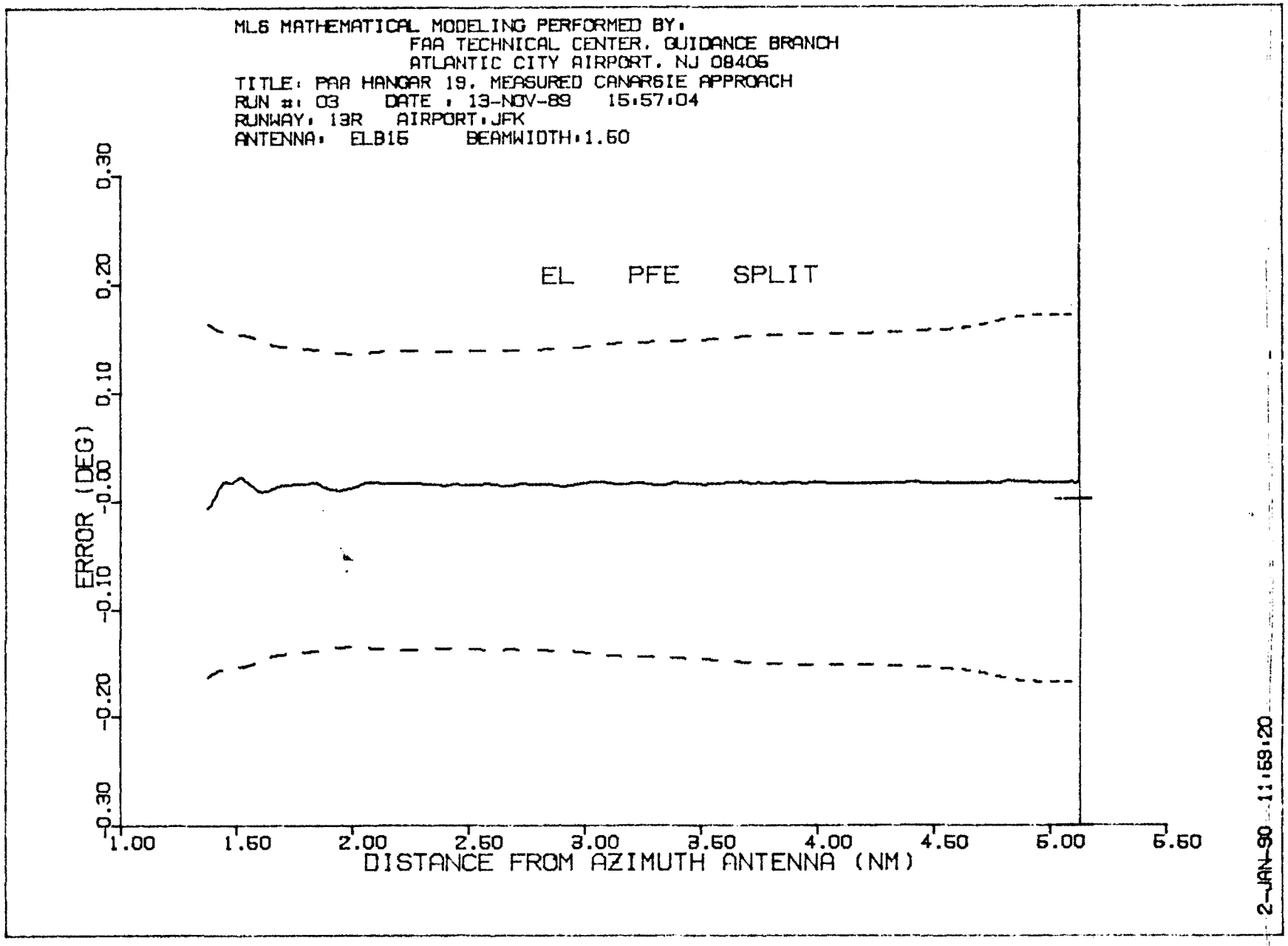

FIGURE 6. 3 DEGREE MEASURED CANARSIE APPROACH, ELEVATION SYSTEM, MODEL PFE FILTERED ERROR PLOT.

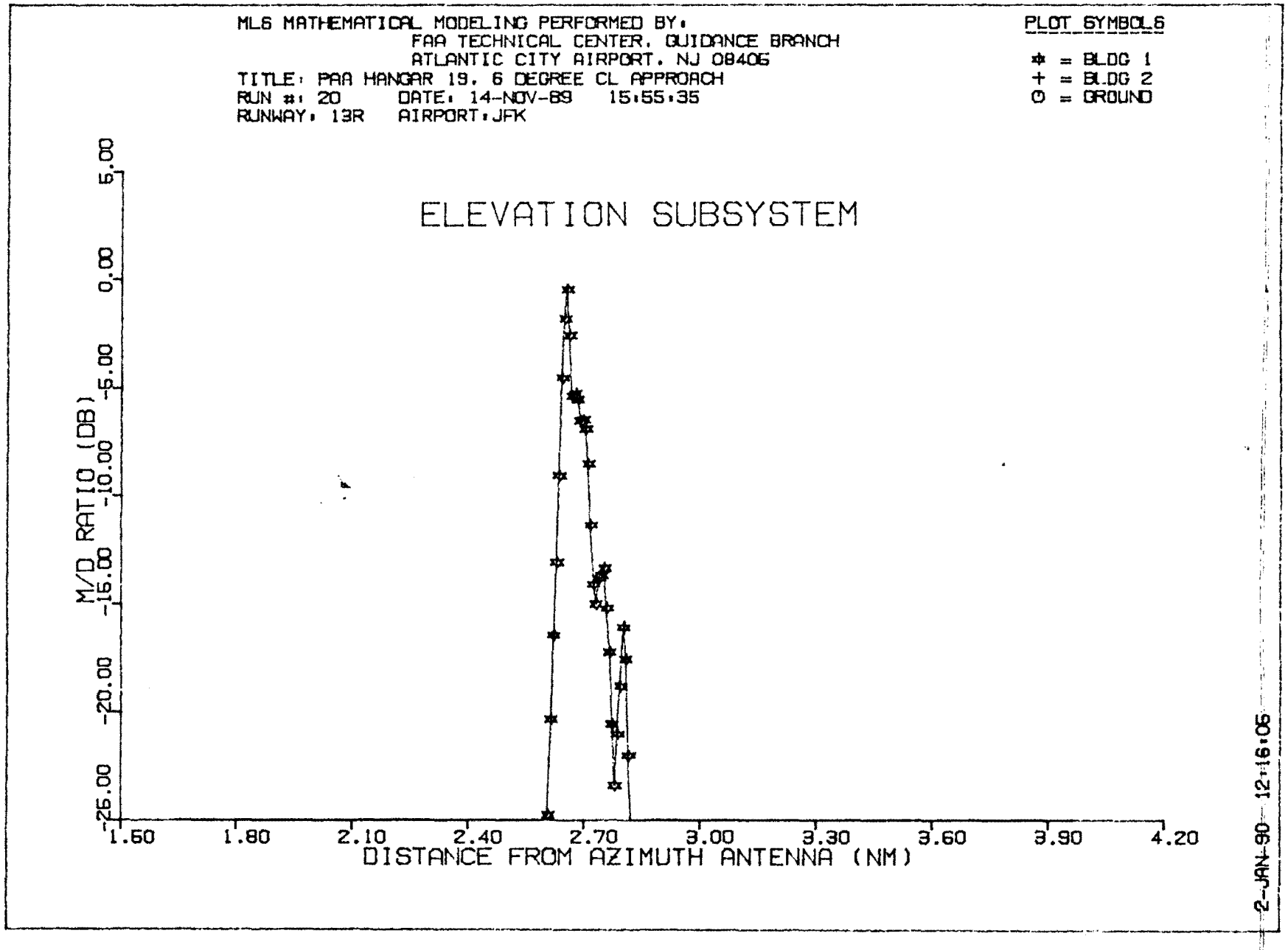

FIGURE 7. **6 DEGREE MEASURED CENTERLINE APPROACH, ELEVATION SYSTEM, MODEL MULTIPATH/DIRECT RATIO PLOT.**

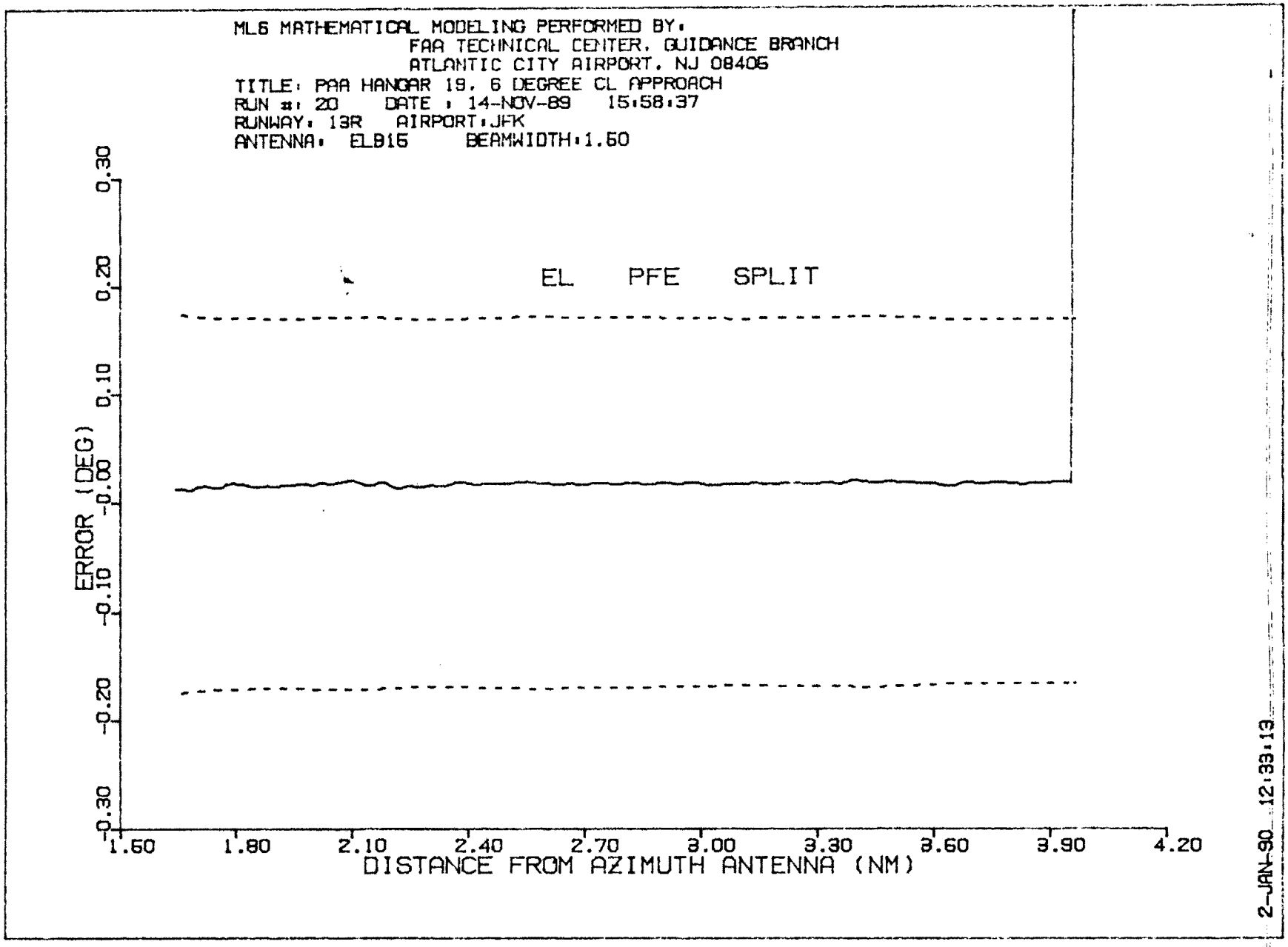

FIGURE 8. 6 DEGREE MEASURED CENTERLINE APPROACH, ELEVATION SYSTEM, MODEL PFE FILTERED ERROR PLOT.

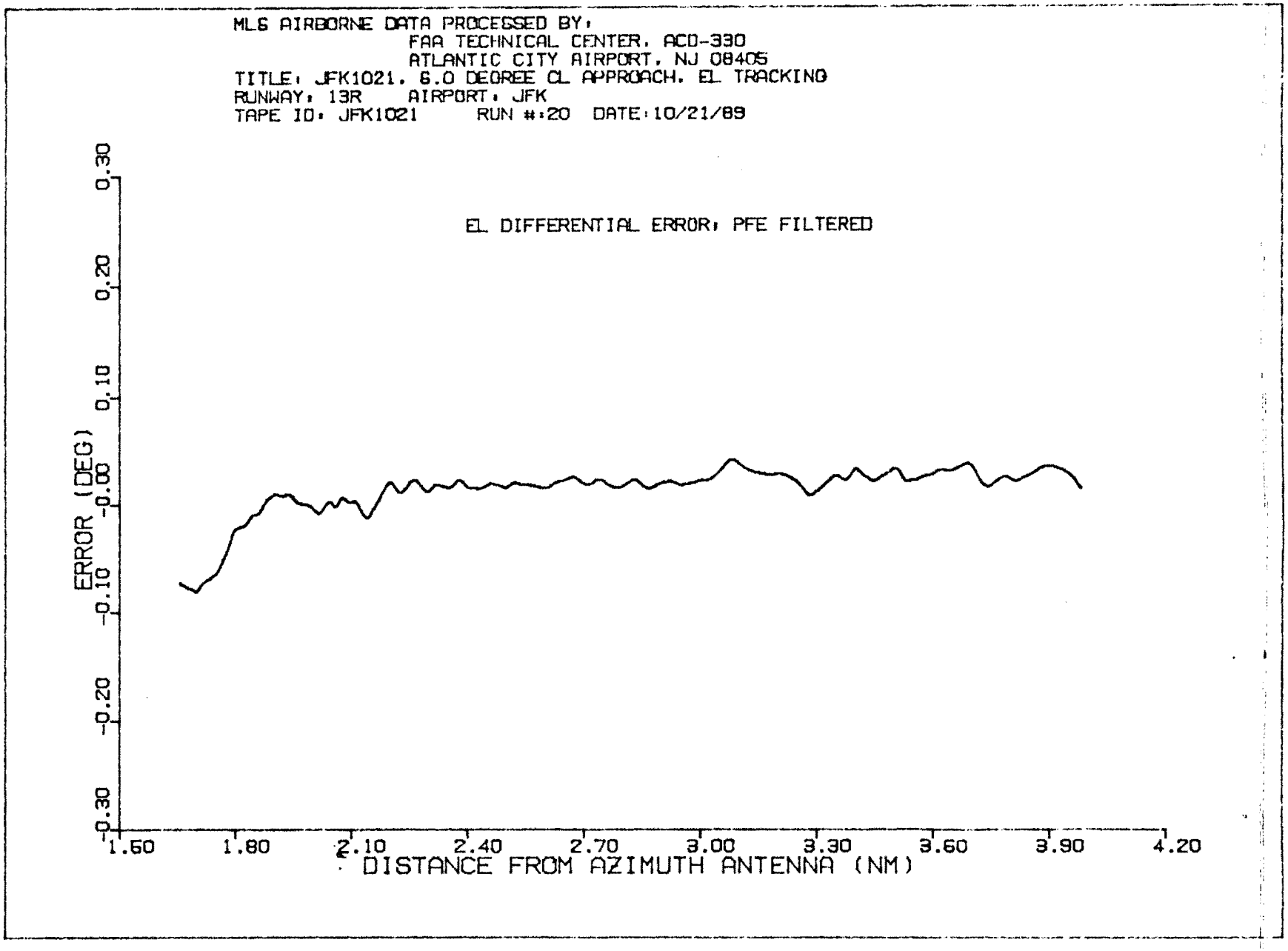

FIGURE 9. 6 DEGREE CENTERLINE APPROACH, ELEVATION SYSTEM, AIRBORNE DIFFERENTIAL ERROR PLOT.

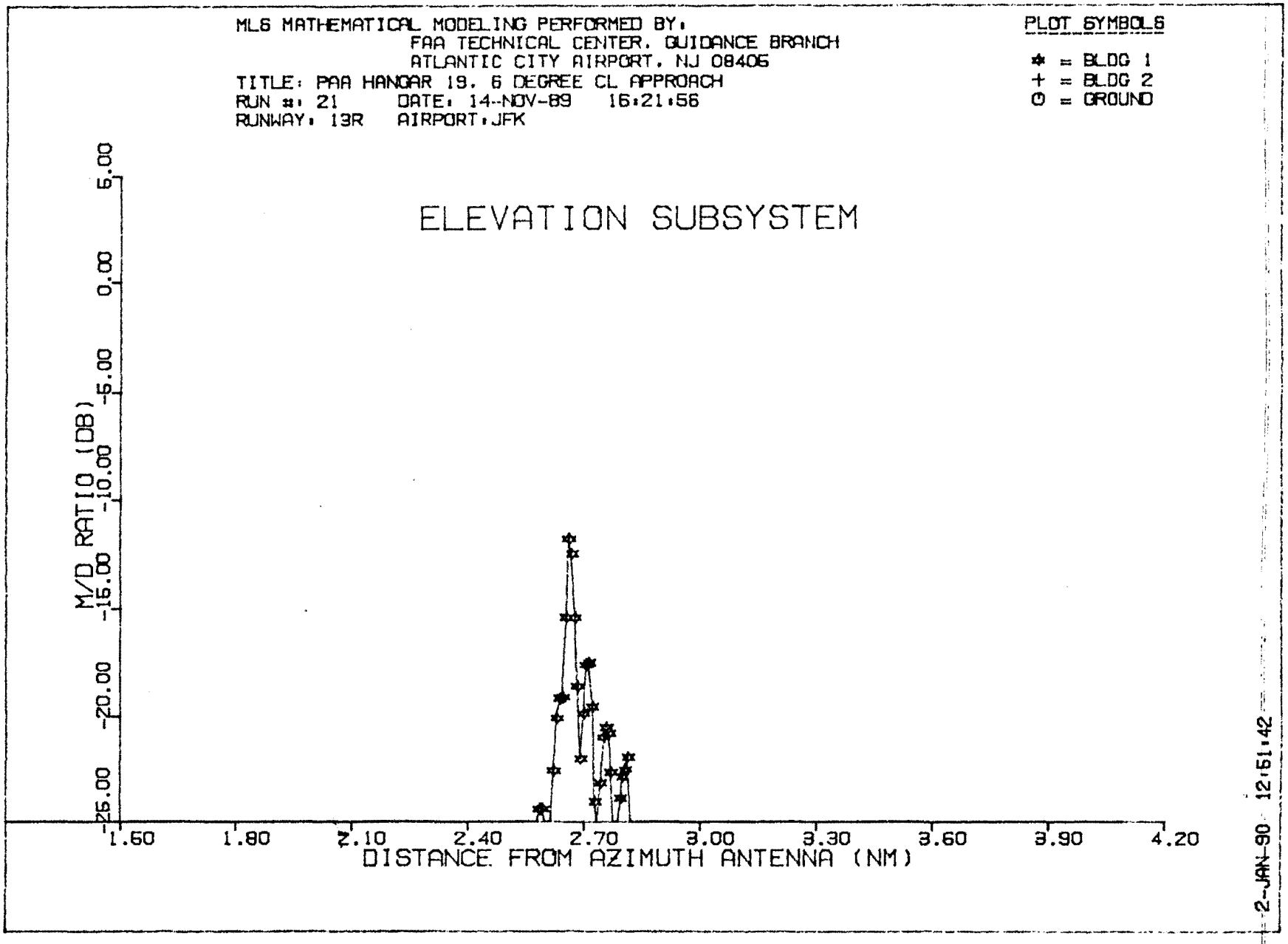

FIGURE 10. **6 DEGREE MEASURED CENTERLINE APPROACH, ELEVATION SYSTEM, MODEL MULTIPATH/DIRECT RATIO PLOT.**

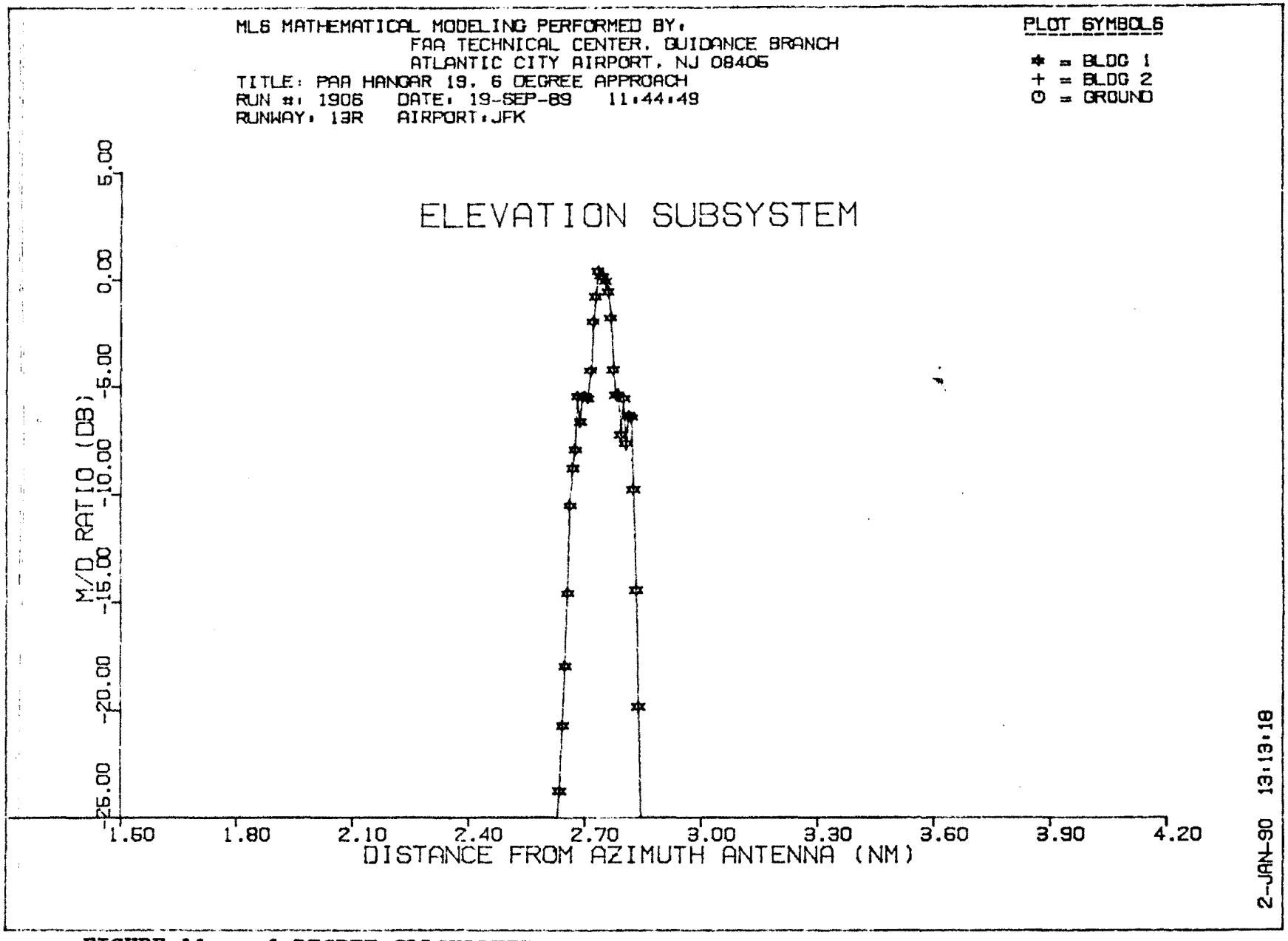

FIGURE 11. 6 DEGREE CALCULATED CENTERLINE APPROACH, ELEVATION SYSTEM, MODEL MULTIPATH/DIRECT RATIO PLOT.