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# MLS Mathematical Modeling Study of the Vertiport at the FAA Technical Center

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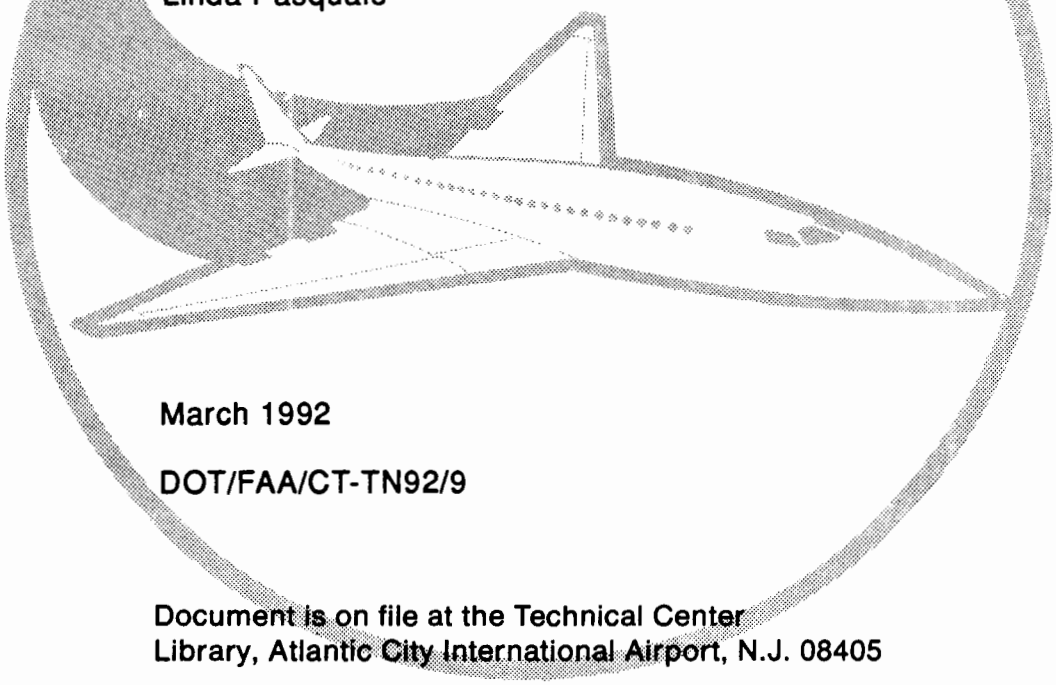
Linda Pasquale



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16. Abstract

This microwave landing system (MLS) mathematical modeling study evaluated the effects on the MLS signal of a new trailer which will be located at the Federal Aviation Administration (FAA) Technical Center Vertiport. Because the trailer will be located behind the elevation antenna, only effects on the azimuth transmitter were evaluated. The scenario was simulated with several flightpaths to determine effects throughout the coverage volume. The results of this study predicted no out-of-tolerance errors for any of the flightpaths simulated. The study concludes that the new trailer will not have significant adverse effects on the azimuth signal.

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# EXECUTIVE SUMMARY

This microwave landing system (MLS) mathematical modeling study evaluated the effects on the MLS signal of a new trailer which will be located at the Federal Aviation Administration (FAA) Technical Center Vertiport. Because the trailer will be located behind the elevation antenna, only effects on the azimuth transmitter were evaluated. The scenario was simulated with several flightpaths to determine effects throughout the coverage volume. Partial orbit flightpaths at 3° and 1° elevation angles revealed effects in the azimuth coverage volume at mid-elevation and low-elevation angles, respectively. Flightpaths following the ray reflected from the side of the trailer at several altitudes were used to investigate where these reflections would affect the azimuth signal. Finally, a published approach to the Vertiport was simulated. Both scattering and shadowing effects of the trailer were evaluated for all flightpaths.

The results of this study predicted no out-of-tolerance errors for any of the flightpaths simulated. Most of the scenarios predicted no errors at the receiver. The 1° orbit flightpath did predict errors for both shadowing and scattering effects from the trailer. However, the path following error (PFE) filtered errors for this scenario were well within the tolerance limits. The study concludes that the new trailer will not have significant adverse effects on the azimuth signal.

# INTRODUCTION

## OBJECTIVE.

This study analyzed the possible effects on the microwave landing system (MLS) signal of a trailer that will be located at the Federal Aviation Administration (FAA) Technical Center Vertiport. The study was performed using the MLS mathematical model maintained at the Technical Center. A description of the model appears in the appendix.

## BACKGROUND.

In November 1991, the technical program manager of Vertical Flight Operations requested a mathematical modeling study to determine the derogatory effects on the MLS signal, if any, of a new trailer that will be located at the FAA Technical Center Vertiport. The request also included analysis of the effects of the old trailer, currently located at the Vertiport, for purposes of comparison with the effects of the new structure. Since both the current and future structures would be located behind the elevation transmitter, only azimuth effects were investigated. The azimuth system at the Vertiport is a Hazeltine 2° beamwidth scanning from -40° to +40°.

Vertiport dimensions, transmitter coordinates, and the location and dimensions of both trailers were provided by Vertical Flight Operations personnel. The dimensions of the trailer currently located at the Vertiport are approximately 10 feet (length) by 7 feet (width) by 9 feet (height at the highest point). The dimensions of the new trailer are approximately 22 feet (length) by 7 feet (width) by 9 feet (height). The wall and slightly sloping roof on one side of each trailer were identified as possible scattering surfaces and two side walls as possible shadowing structures. All surfaces were modeled as smooth metal. The landing pad was defined as the runway with the "stop end" as the midpoint on the side closest to the azimuth transmitter. This point is the origin of the mathematical model coordinate system. A map of the scenario is provided in figure 1.

Each trailer was modeled with two partial orbit flightpaths at a radius of 10 nautical miles (nmi) from "stop end"; one at 3° elevation to investigate effects in the main coverage volume and one at 1° elevation to investigate effects near the lower coverage limit. In addition, a published approach to the Vertiport and the necessary supporting data were provided permitting the development of a model flightpath to simulate this approach. The approach waypoints are shown in figure 2. The missed approach point (MAP) is located within the perimeter of the landing pad. The first flightpath segment, from COYLE to HOWIE, is not included in the model flightpath due to its extreme length. Effects in this section of the coverage volume are investigated using the partial orbit flightpaths. Finally, the path of the reflection from the midpoint of scattering building plate 1 on the new trailer was determined, and flightpaths were defined to follow the course of this reflection at 500, 1000, 1500, and 2000 feet above the zero Z reference, respectively, to evaluate the effect of this reflection, if any.

DATA PRESENTATION AND ANALYSIS.

Partial orbit flightpaths at an elevation angle of 3° show the effects of the trailers in the main azimuth coverage volume. Scattering effects, primarily from the wall of the trailer (building 1), are seen in the area of 22° azimuth angle. Shadowing effects are observed in the region of -25° azimuth angle. These effects, using the new trailer as example, are illustrated in figures 3 and 4, respectively. The old trailer (not illustrated) showed similar effects in the same locations, but of a reduced magnitude owing to the smaller dimensions of the structure. As can be seen in figures 5 and 6, no significant errors at the receiver are predicted from these effects. Results from modeling the old trailer were almost identical.

All path following error (PFE) plots in this report show error tolerances of +/- 0.25°. This is the maximum allowable PFE tolerance for an azimuth system as defined in FAA Order 8240.50, "Flight Inspection of Micrwave Landing Systems (MLS)," Appendix 5, "MLS Flight Instpection Tolerances," paragraph 5. According to the Atlantic City Flight Inspection Field Office, this is the value used throughout the coverage volume to evaluate azimuth PFE at the FAA Technical Center Vertiport.

These two scenarios were repeated with a 1° elevation partial orbit flightpath. Again, the new trailer serves to illustrate the results. The scattering effects and shadowing effects, figures 7 and 8, respectively, occur in the same locations as with the 3° orbit but with increased magnitude due to the lower elevation angle of the flightpath. This scenario does predict errors at the receiver from shadowing effects between -15° and -30° azimuth angle, as shown in figure 9. Both shadowing building plates contribute to this effect. However, as illustrated in figure 10, these errors are well within the PFE error tolerance limits.

Simulation of the published approach shown in figure 2 also predicts no unacceptable effects on the azimuth signal. Multipath/direct amplitude ratios do not exceed -40 decibels (figure 11) nor do the trailers have any shadowing effect on the signal (figure 12). As in previous examples, the new trailer is used to illustrate this flightpath. To evaluate the shadowing effects on the approach flightpath, specular ground calculations in the model were disabled. The old trailer shows similar results in the same locations, but with reduced magnitude due to its smaller size. As expected, no errors are predicted at the receiver. The brief "error" effect at 4 nmi from threshold on the PFE error plot shown in figure 13 is a side effect of the receiver filtering algorithms. That is, this effect occurs at the point where the flightpath makes a sharp turn onto centerline (at waypoint RUDDY) and is present even when the scenario is run with no obstacles.

Finally, in an effort to verify that reflections from the wall of the new trailer, shadowing building 1, would have no serious effects on the azimuth signal, the path of a reflection from the mid-point on this building plate was determined, and flightpaths were created to follow this reflection path at altitudes of 500, 1000, 1500, and 2000 feet above the zero Z reference. The 500-foot flightpath shows the highest multipath effect, illustrated in figure 14. However, the multipath/direct amplitude ratio barely exceeds -10 decibels and causes no errors at the receiver, as seen in figure 15.

## CONCLUSIONS.

The results of this mathematical modeling study predict that the new trailer, to be located at the Technical Center Vertiport in the position illustrated in figure 1, will have no significant effects on the azimuth signal. Experiments show that the greatest scattering effects will occur in the region of 22° azimuth angle and the greatest shadowing effects around -25° azimuth for an aircraft flying at 1° elevation. However, even with this scenario, the math model does not predict out-of-tolerance errors at the receiver.

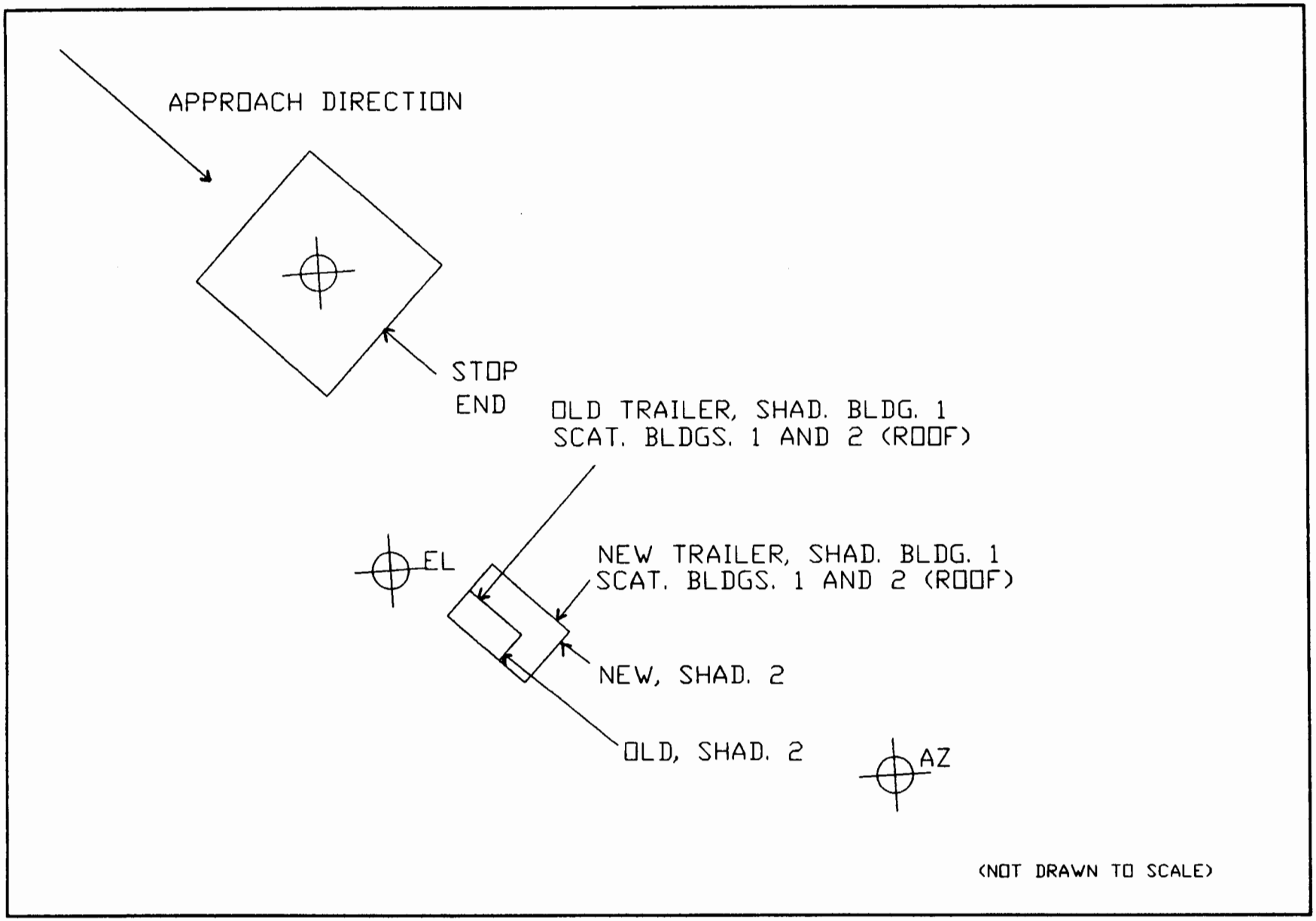


**FIGURE 1. SCENARIO MAP**

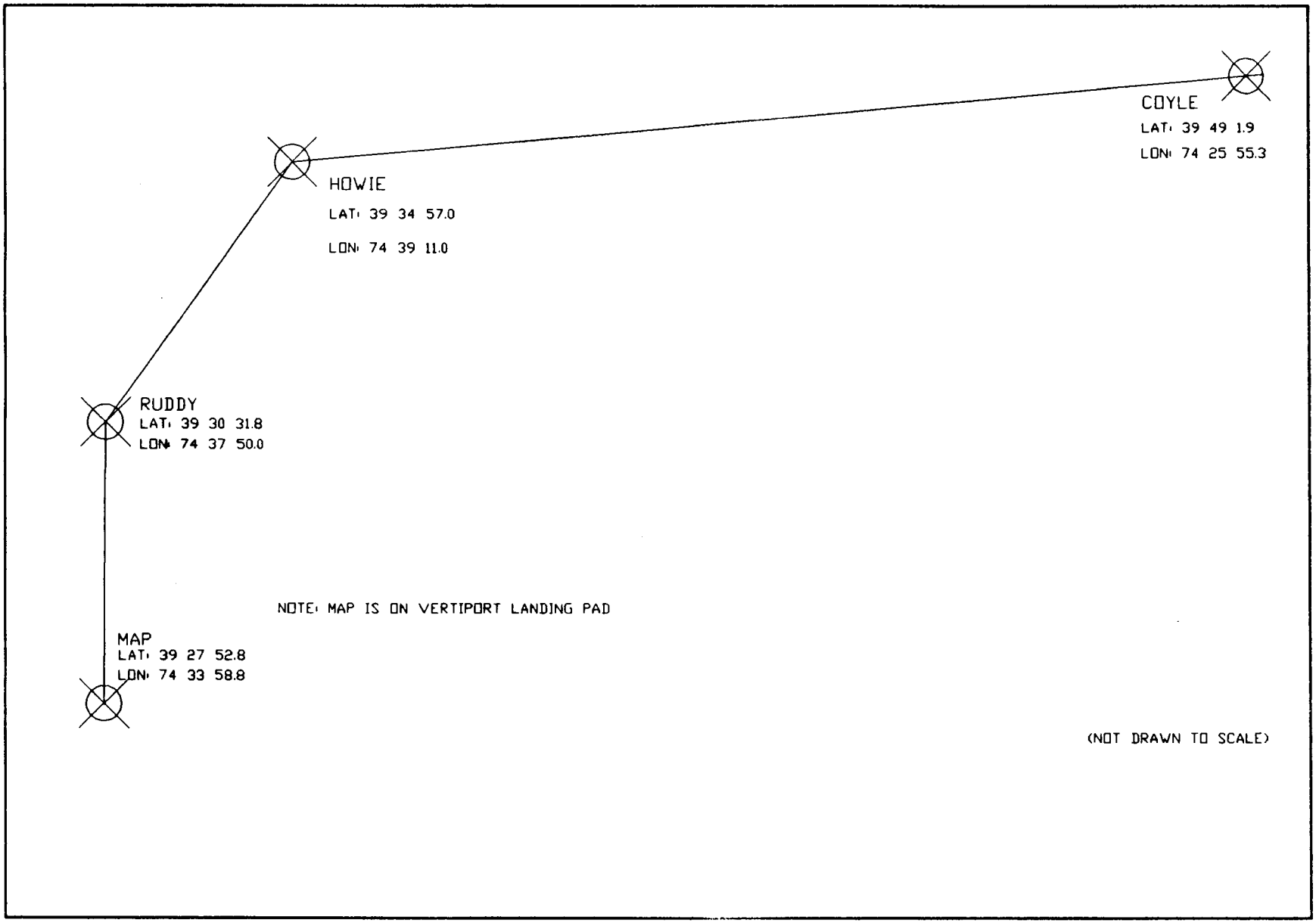


**FIGURE 2. WAYPOINTS OF PUBLISHED APPROACH TO FAA TECHNICAL CENTER VERTIPORT**

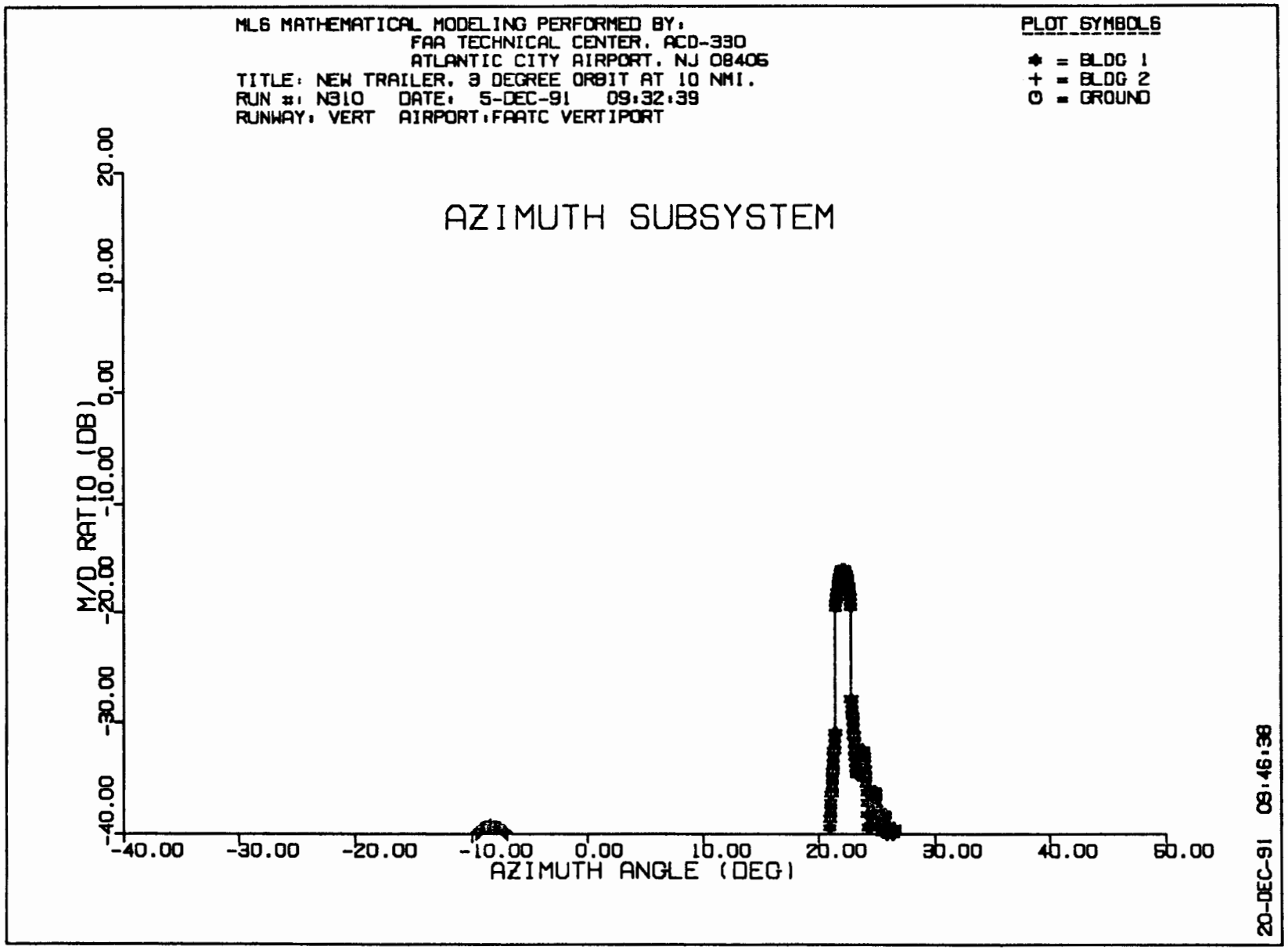


**FIGURE 3. 3 DEGREE PARTIAL ORBIT FLIGHTPATH, MULTIPATH/DIRECT SIGNAL RATIO PLOT**

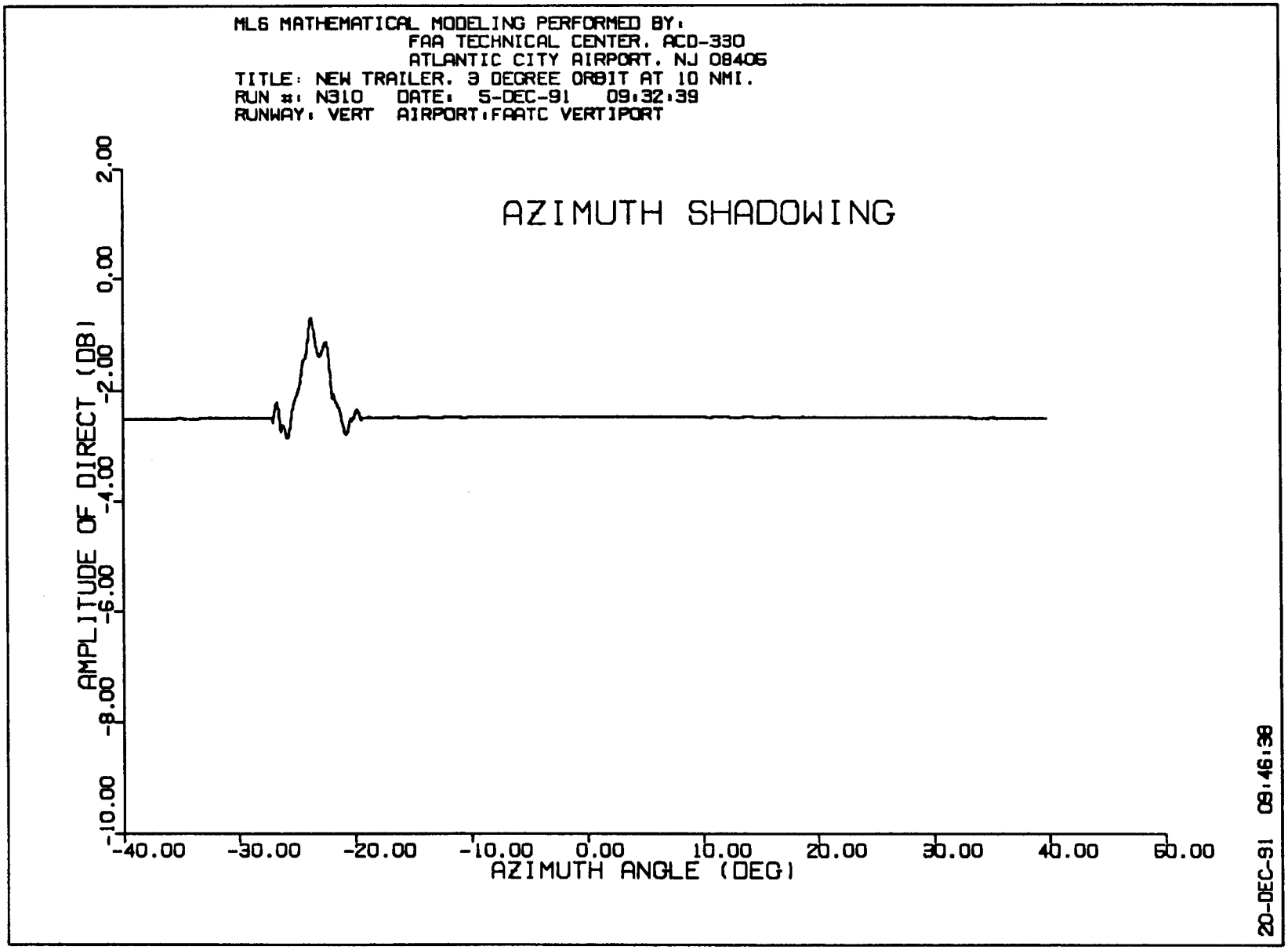


**FIGURE 4. 3 DEGREE PARTIAL ORBIT FLIGHTPATH, SHADOWING PLOT**

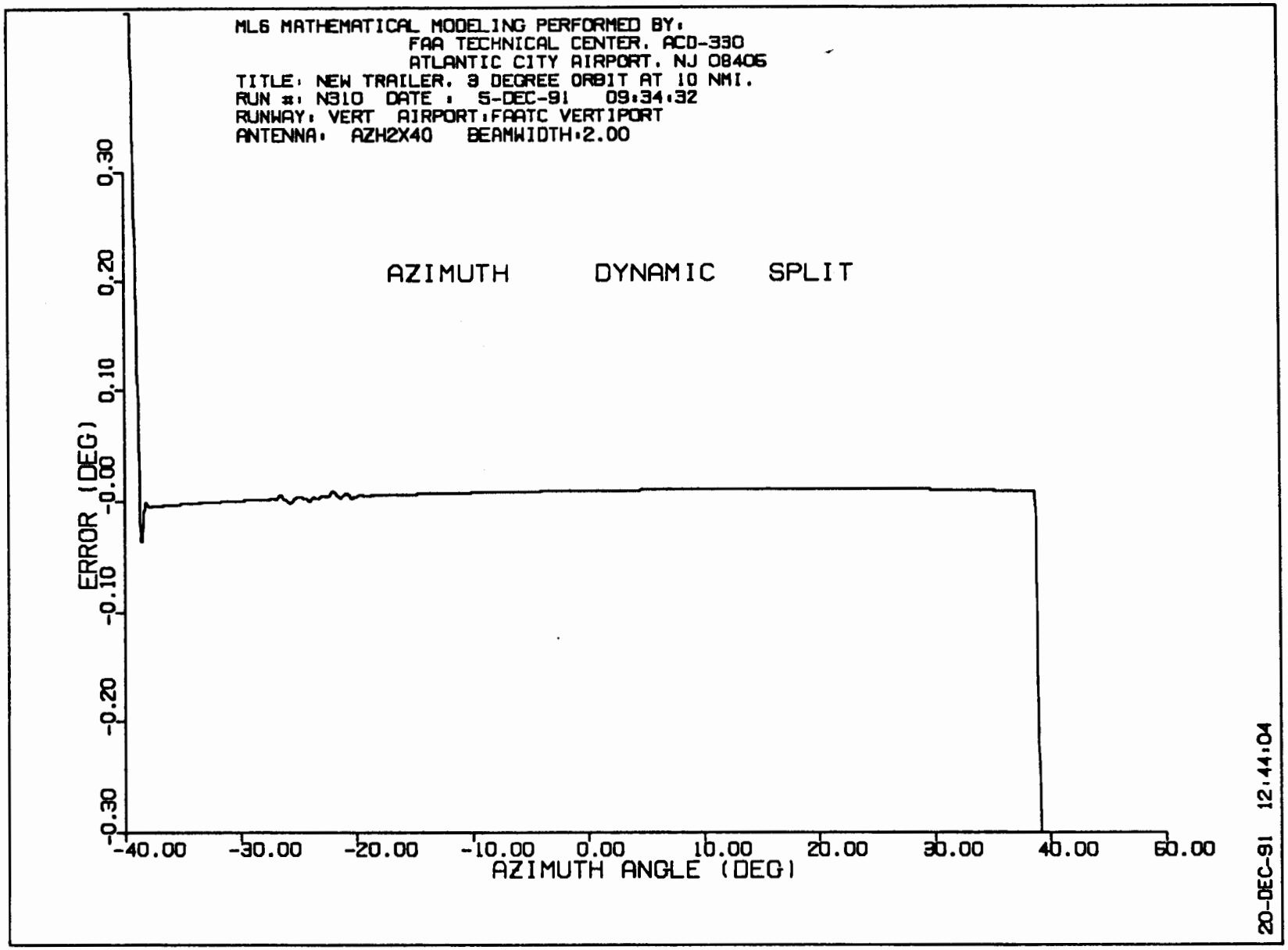


**FIGURE 5. 3 DEGREE PARTIAL ORBIT FLIGHTPATH, RAW ERROR PLOT**

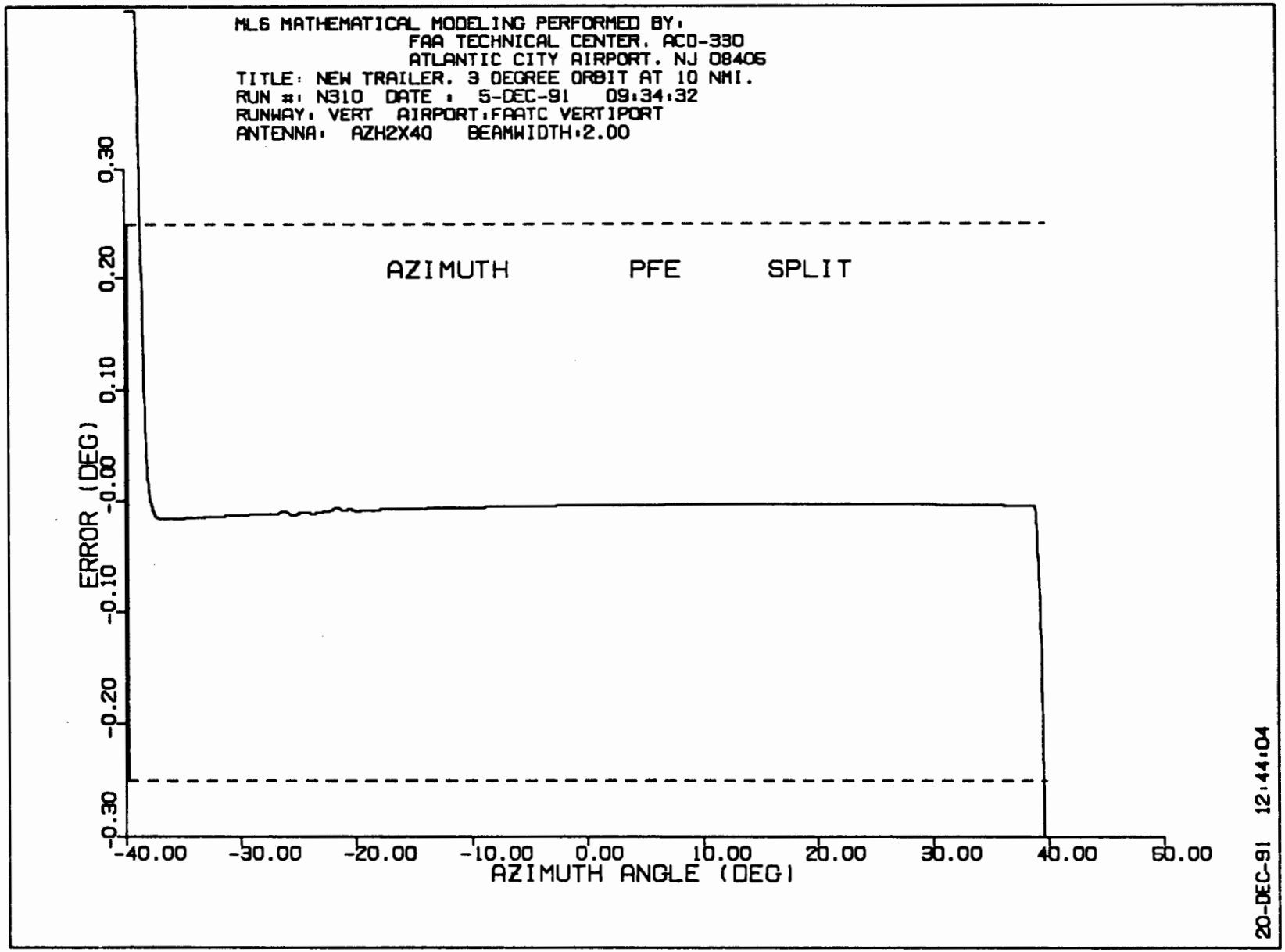


**FIGURE 6. 3 DEGREE PARTIAL ORBIT FLIGHTPATH, PFE ERROR PLOT**

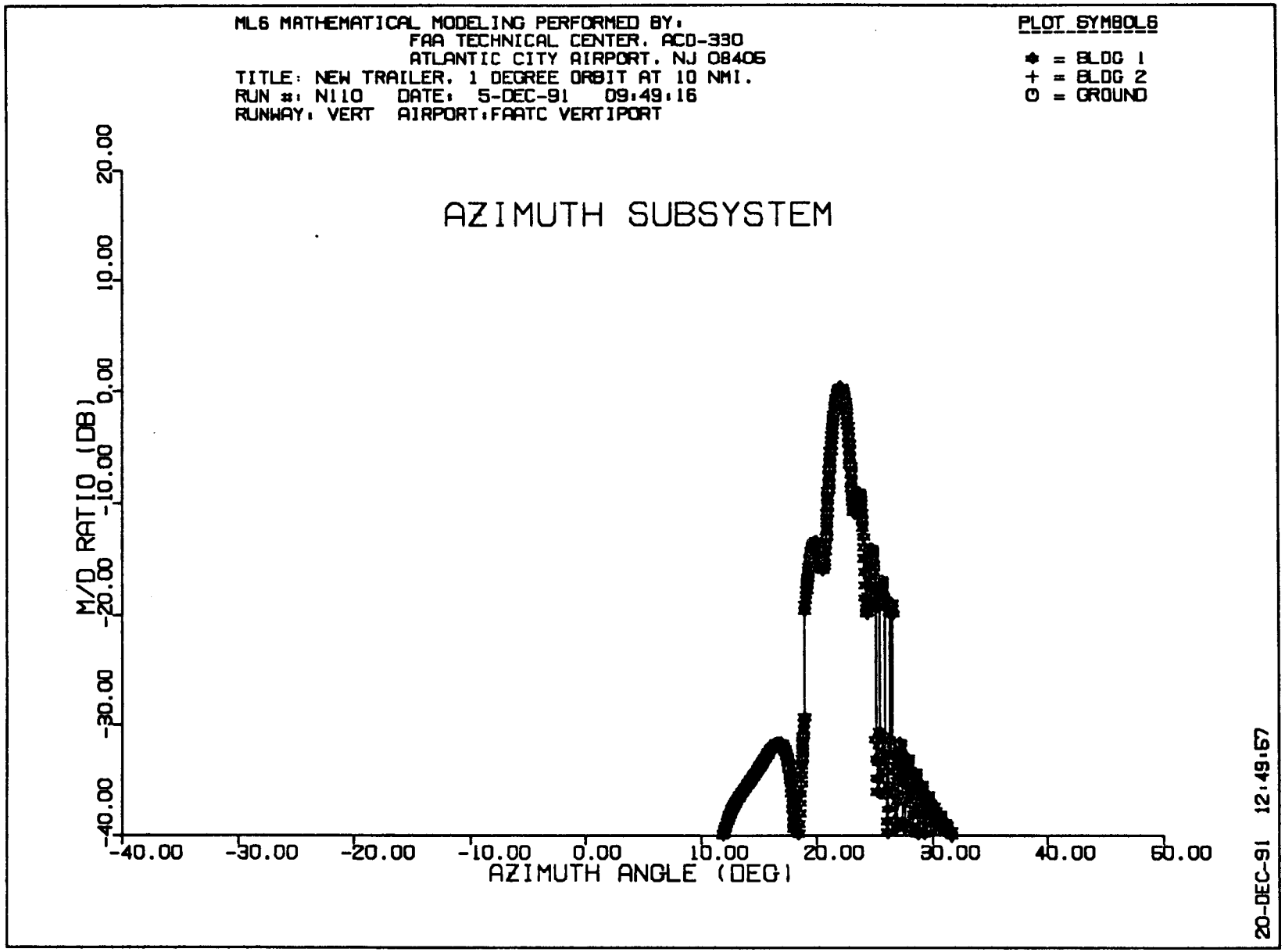


**FIGURE 7. 1 DEGREE PARTIAL ORBIT FLIGHTPATH, MULTIPATH/DIRECT SIGNAL RATIO PLOT**

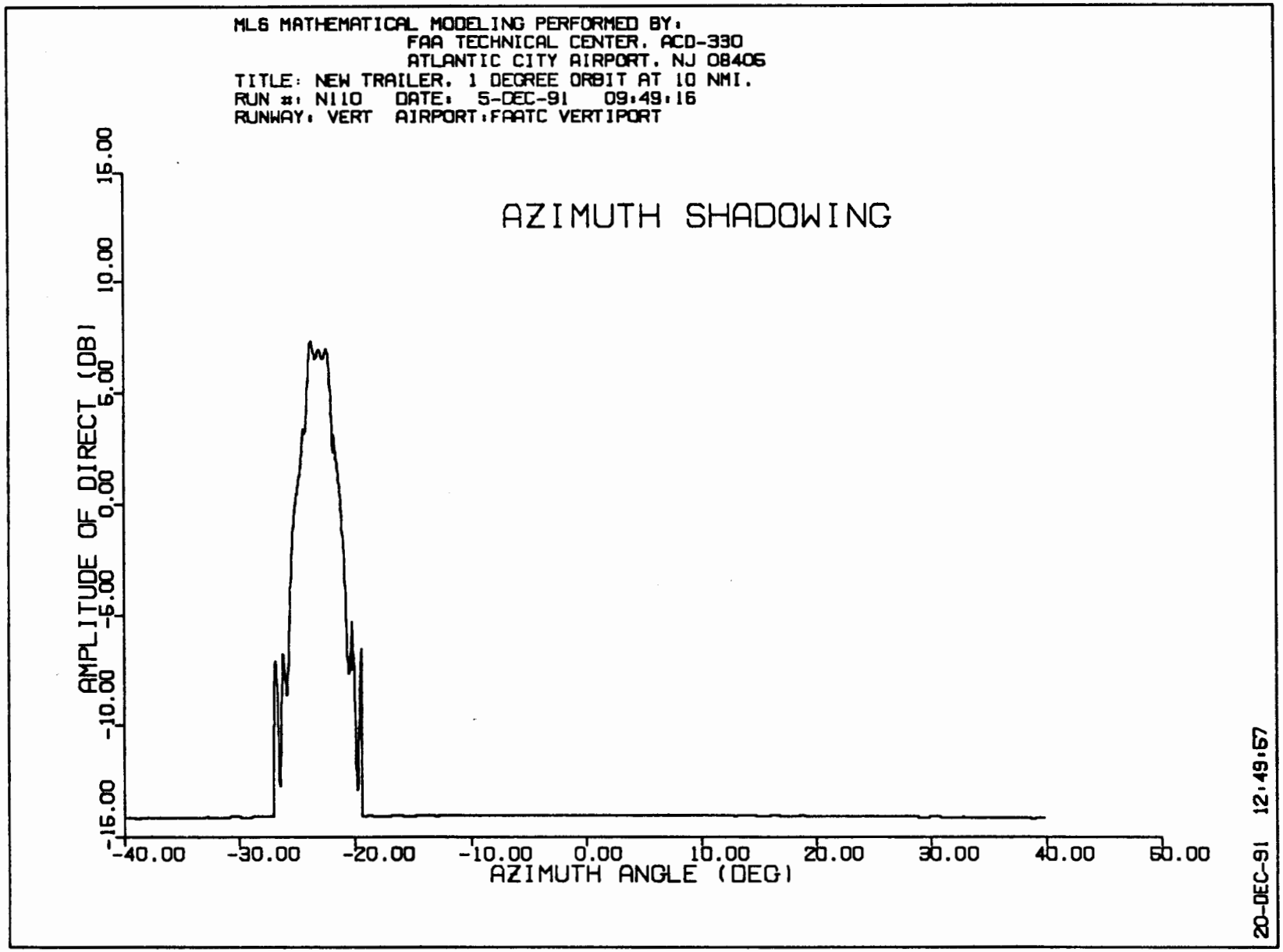


**FIGURE 8. 1 DEGREE PARTIAL ORBIT FLIGHTPATH, SHADOWING PLOT**

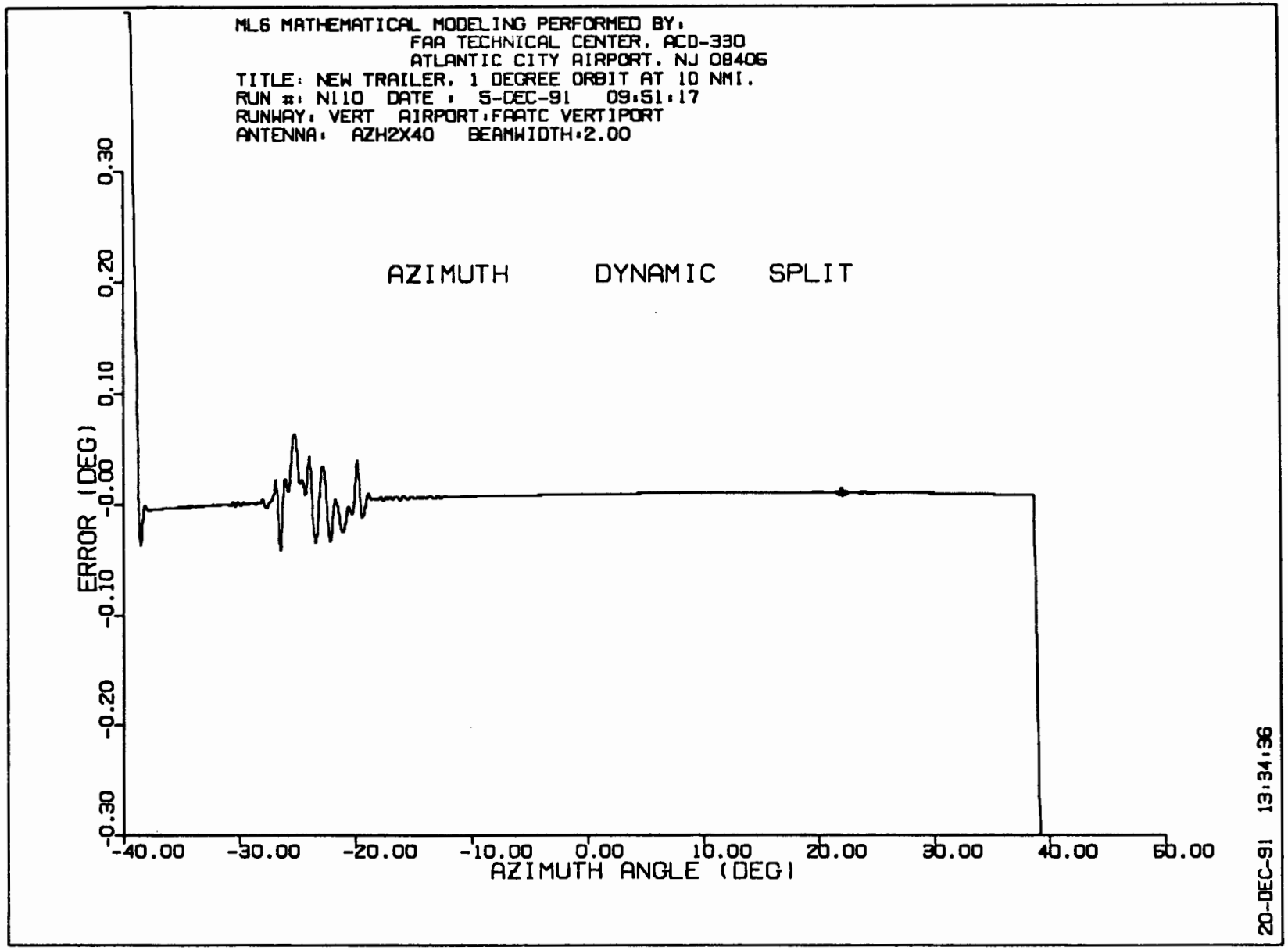


**FIGURE 9. 1 DEGREE PARTIAL ORBIT FLIGHTPATH, RAW ERROR PLOT**

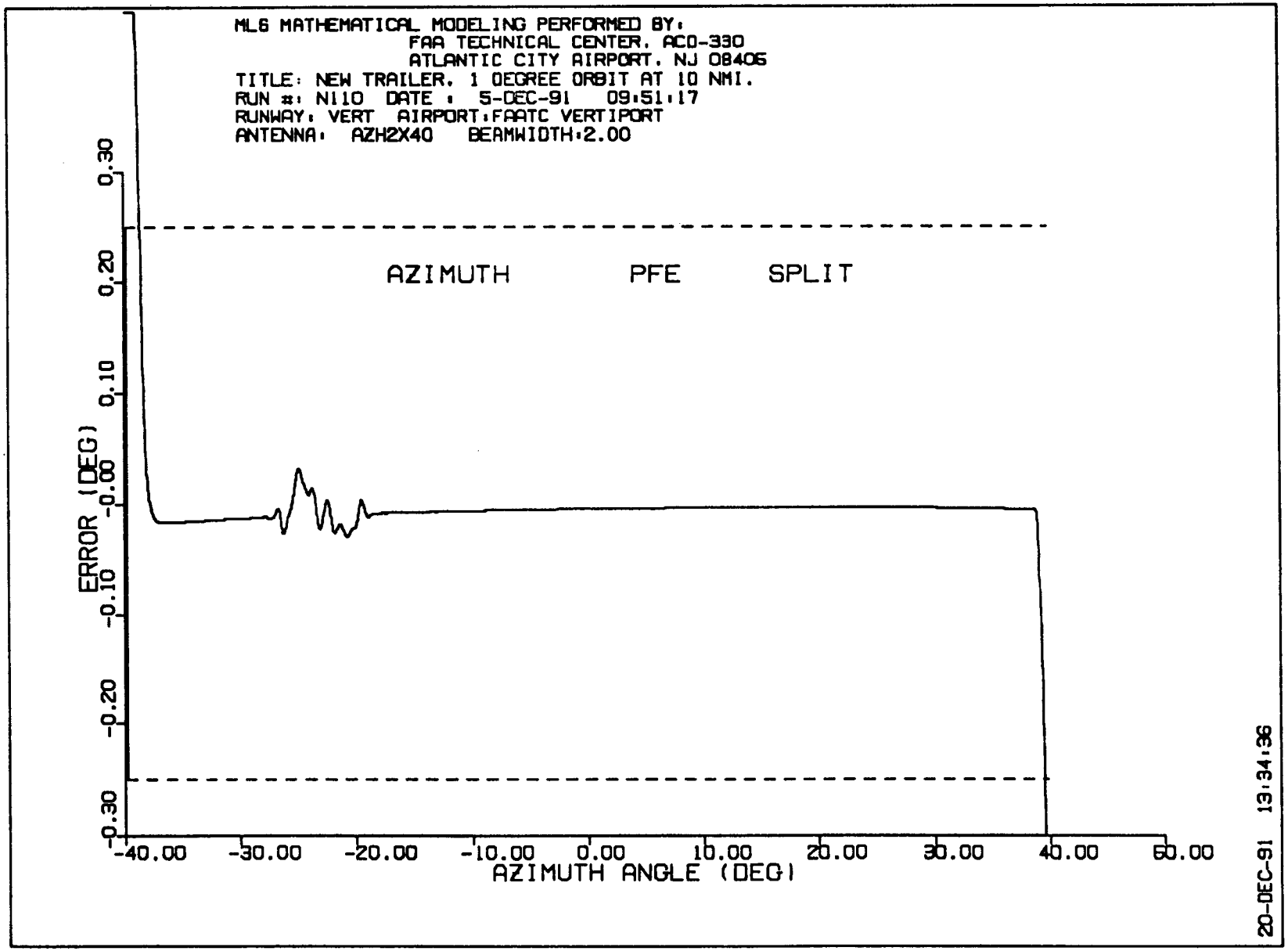


**FIGURE 10. 1 DEGREE PARTIAL ORBIT FLIGHTPATH, PFE ERROR PLOT**

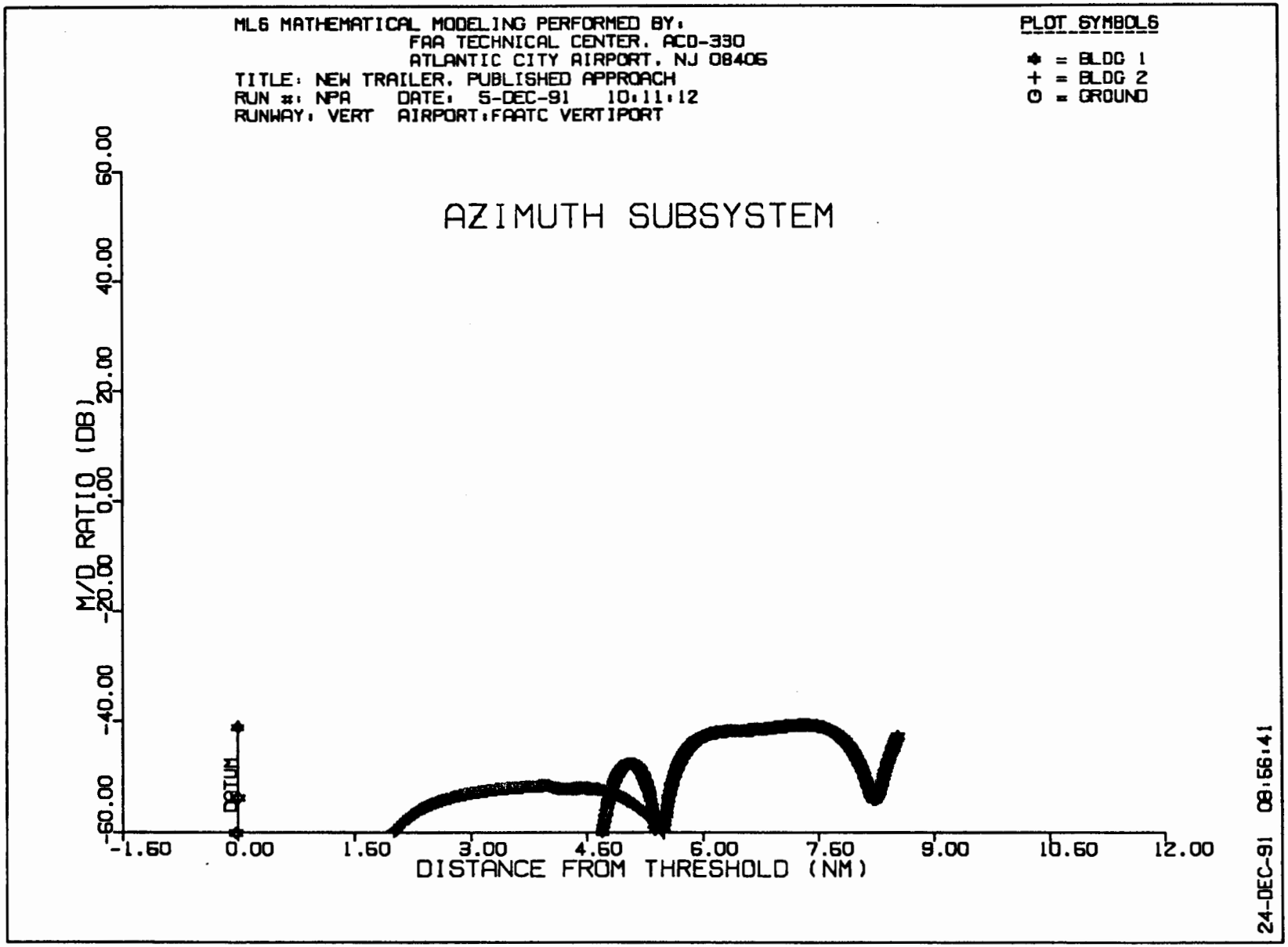


**FIGURE 11. PUBLISHED APPROACH FLIGHTPATH, MULTIPATH/DIRECT SIGNAL RATIO PLOT**

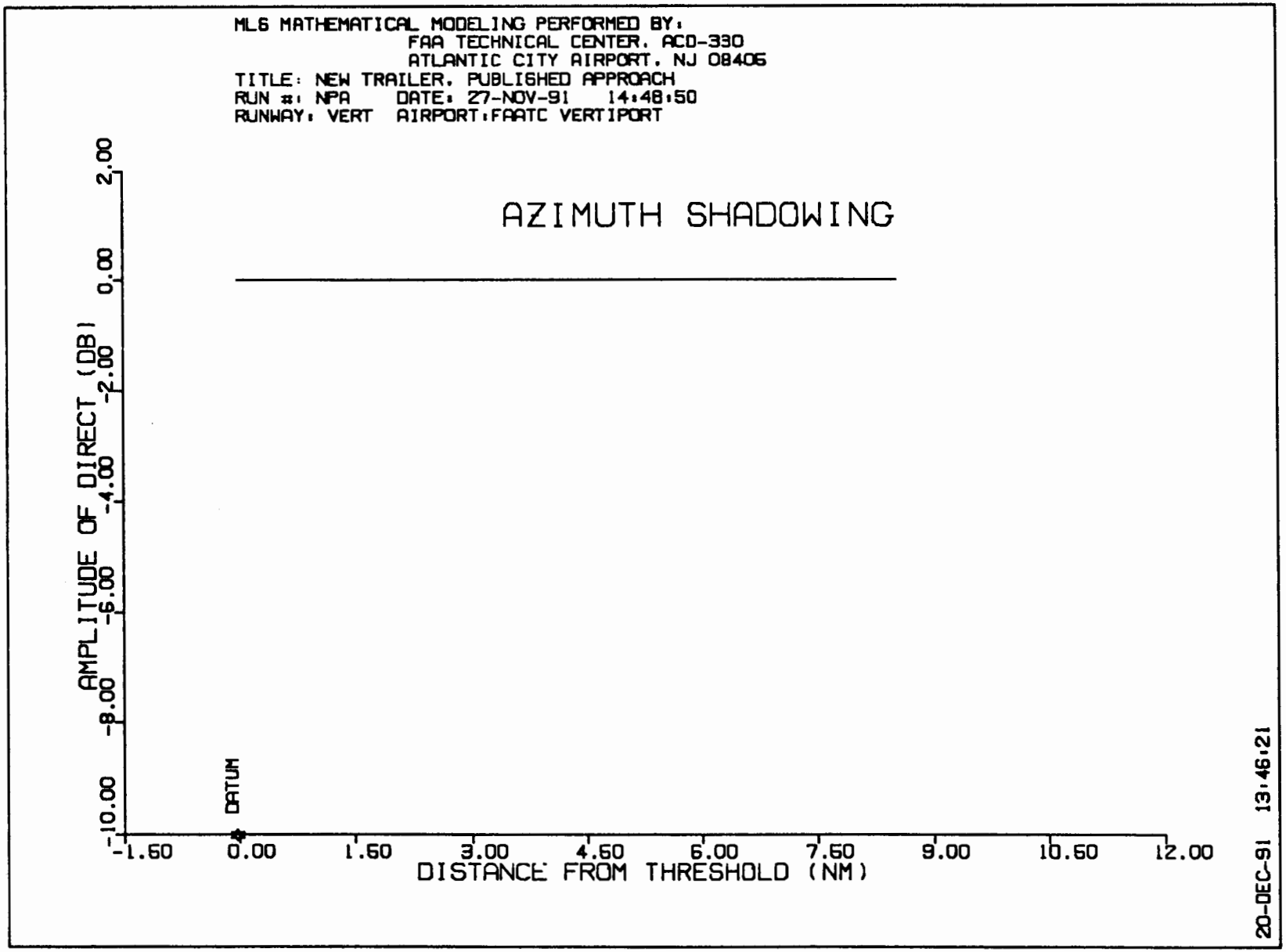


**FIGURE 12. PUBLISHED APPROACH FLIGHTPATH, SHADOWING PLOT**

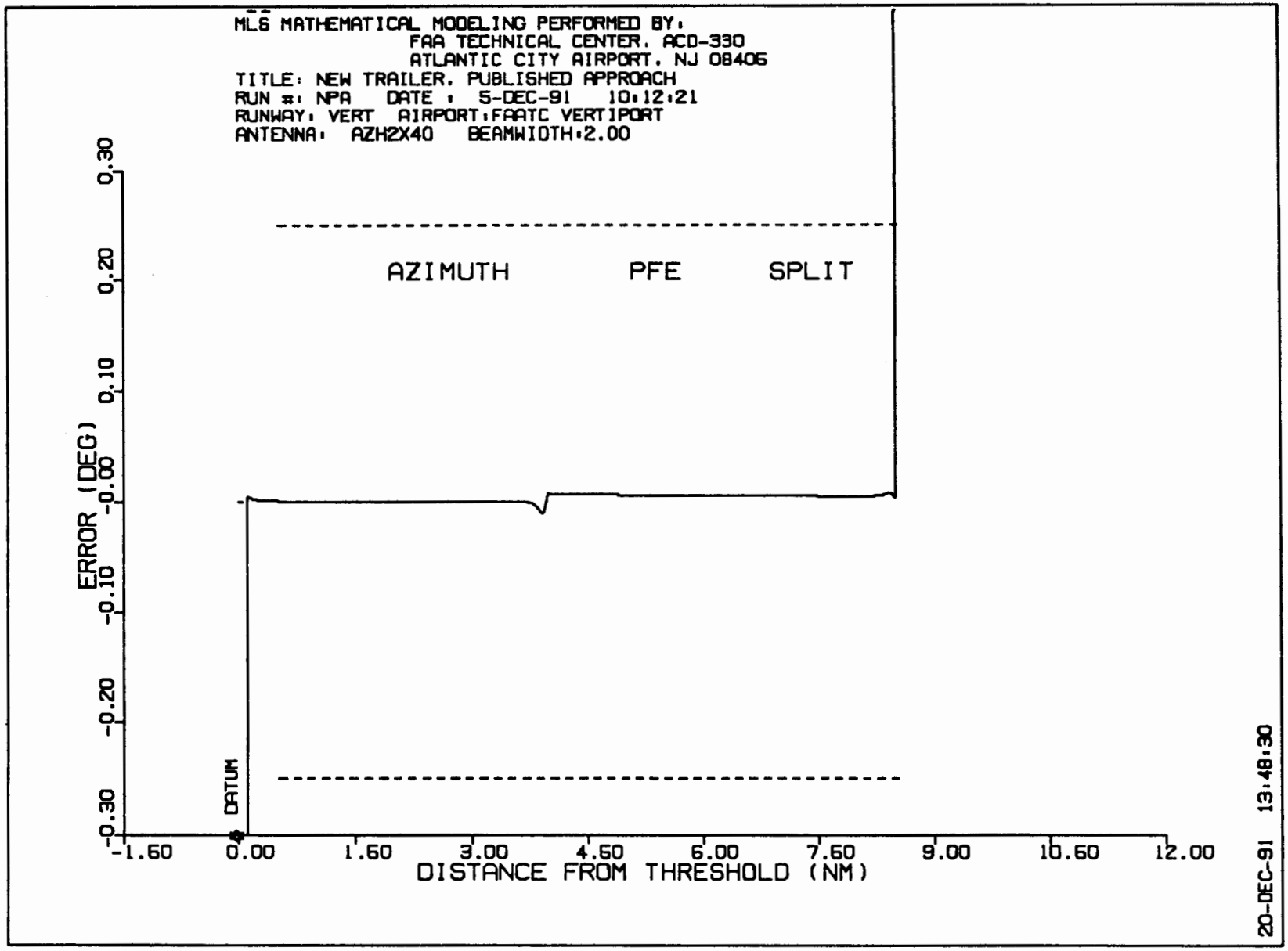


**FIGURE 13. PUBLISHED APPROACH FLIGHTPATH, PFE ERROR PLOT**

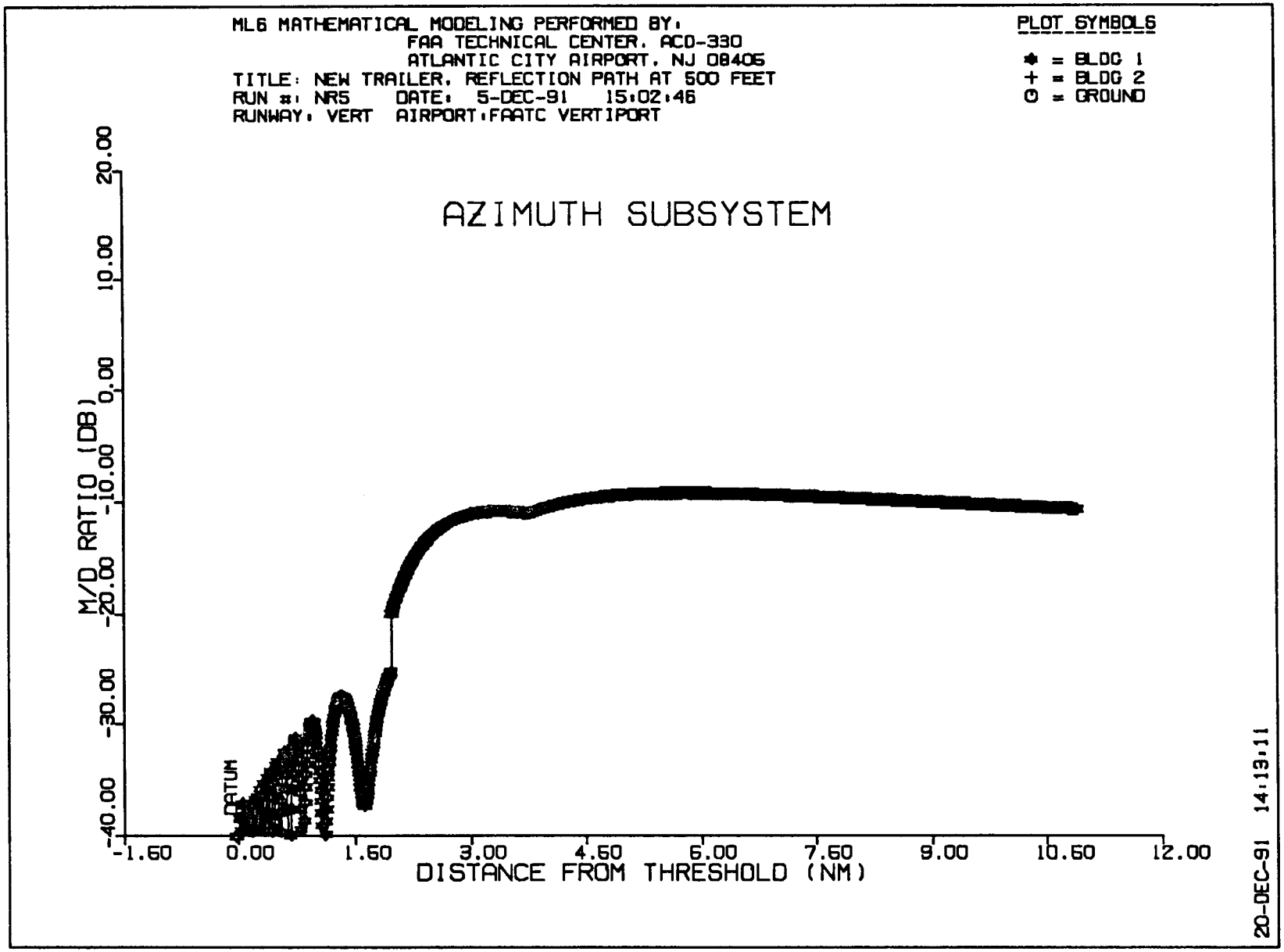


**FIGURE 14. REFLECTION FLIGHTPATH AT 500 FEET, MULTIPATH/DIRECT SIGNAL RATIO PLOT**

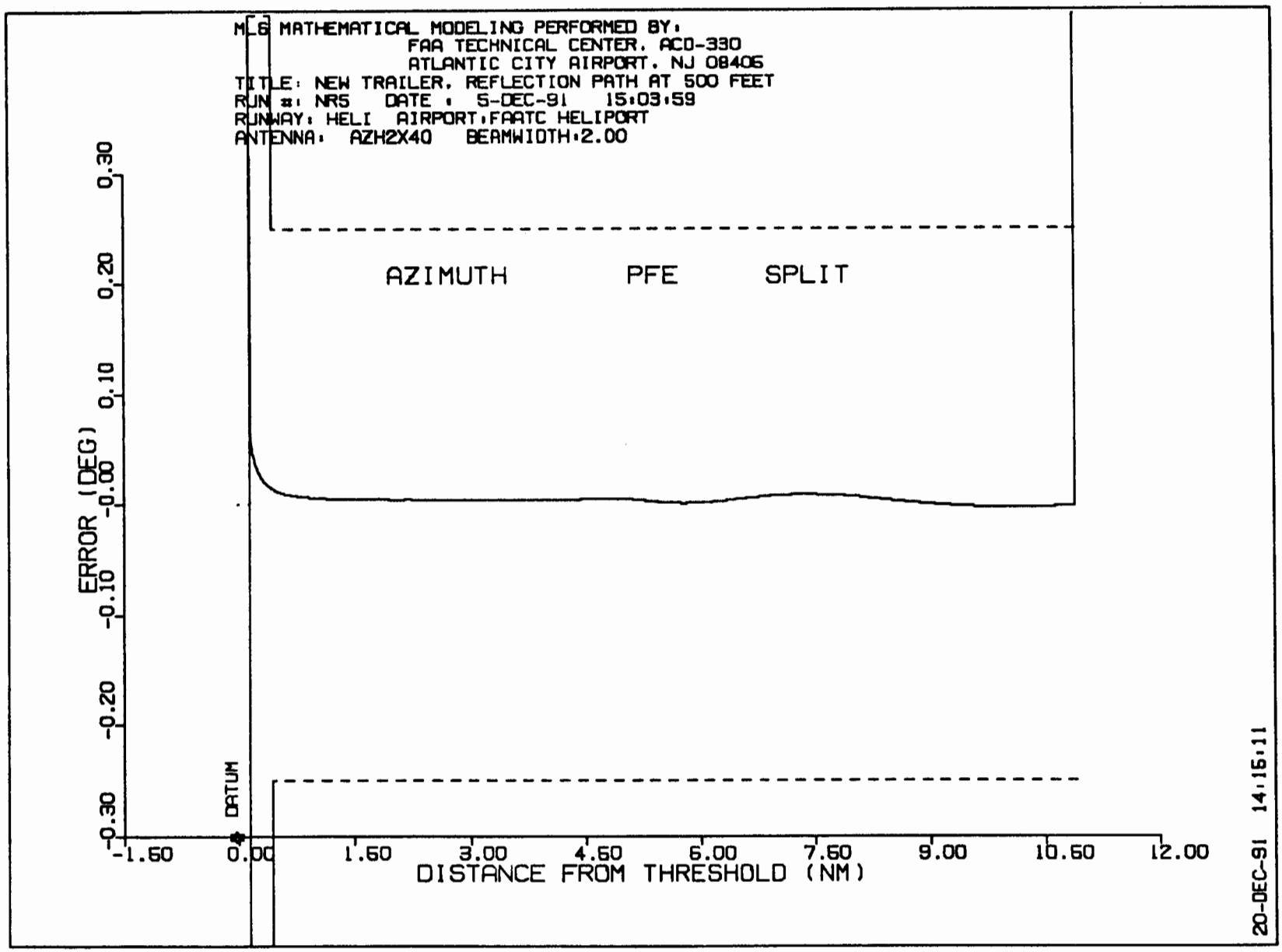


**FIGURE 15. REFLECTION FLIGHTPATH AT 500 FEET, PFE ERROR PLOT**

# APPENDIX - DESCRIPTION OF THE MLS MATHEMATICAL MODEL

The MLS Mathematical Model is a computer simulation of the effects of an airport environment on the MLS signal. It is used to provide guidance in the selection of MLS and siting configuration for a specific airport environment by predicting the errors due to multipath in that environment.

## THE MODEL SOURCE CODE.

The complete model consists of four computer programs. The source code, about 40,000 lines, is written in ANSI standard FORTRAN-77 and has been successfully implemented on a variety of mainframe and personal computers.

A complete site simulation is performed in two stages. The first stage is the execution of program BMLST. This is the propagation (or transmitter) model, a simulation of the signal in space as it interacts with objects in the airport environment. Output from BMLST is written to two files. One file provides plotting information to BPLOTT, a program that plots the multipath and shadowing effects on the signal from each of the ground stations--azimuth (AZ), elevation (EL), precision distance measuring equipment (DME/P). The second file is the input file to the second stage of simulation.

In this second stage, program BMLSR simulates the behavior of an MLS receiver. At each point along the flightpath, the system (or receiver) model evaluates the signal it is receiving in order to distinguish the direct beam from any caused by multipath. Once the receiver is confident that it has acquired the direct signal, it compares this MLS angle with the true position of the aircraft (as defined by the flightpath coordinates, discussed in the section on input parameters). The angular difference between these positions is the error at that flightpath point for that system (AZ or EL). This error is written to an output file which is used by program BPLOTR to plot the error data. BPLOTR also filters the error data with both path following error (PFE) and control motion noise (CMN) algorithms and plots the filtered data with appropriate error tolerances (discussed in the section on output). These plots allow the user to evaluate the receiver errors and determine whether or not they fall within acceptable tolerance limits.

## INPUT PARAMETERS.

The model accepts input from an ASCII text input file consisting of 13 sections of input data. The input data fall roughly into three categories: (1) a description of the airport environment, (2) the configuration of the MLS and DME/P systems, and (3) a specification of the flightpath of the receiver.

The airport environment is described by coordinate information relative to the runway. The coordinate system assumes an origin at the centerline of the stop end of the runway and is a right-handed coordinate system with the positive X axis along centerline pointing toward the threshold and the positive Z axis pointing up. Each obstacle must be identified in separate sections of the input file as to its potential effect on the MLS signal, i.e., reflective (scattering) or diffractive (shadowing). Obstacles that can be defined include buildings, aircraft (shadowing aircraft can be moving), terrain features, and a runway hump. Obstacles are represented by simple geometric shapes such as rectangles, triangles, and cylinders. User input defines the location of the object and whatever additional information is required (vertical orientation, surface

For the configuration of the ground systems, the user specifies the location of each transmitter and the type. The user can also indicate a frequency and scan angle limits for each transmitter. The appropriate data for representing the specified transmitter type are loaded into memory by program BMLSR and are used in the evaluation of the signal at the receiver. The receiving antenna is assumed omnidirectional. The propagation portion of the model (BMLST) assumes an omnidirectional transmitter pattern in its operation and does not consider the characteristics of the receiver other than its location in space.

Currently, the path of the receiver is represented as a set of 2 to 36 coordinate triplets (X, Y, Z) which define the locations of the flightpath waypoints. Multipath calculations are made for points between the waypoints depending on the velocity (in feet/second) and distance increment (in feet) defined by the user. These latter values are constrained by the model's assumption of a data rate of 5 Hertz for the PFE and CMN filter algorithms.

OUTPUT.

Output from the math model is provided in graphic form by the two plotting programs (BPLOTT for the propagation model, BPLOTR for the system model). Output from BPLOTT includes tables of data and plots (flightpath plots and airport map) that allow the user to verify the input data. In addition, a multipath plot shows the multipath/direct ratio in decibels for each point along the flightpath for each of the six highest multipath sources in the environment. This is accompanied by a plot of the separation angle in degrees (for AZ and EL) or the time delay in nanoseconds (for DME/P). If the user has specified shadowing obstacles, a shadowing plot shows the effect of the simulated shadowing obstacles on the magnitude of the direct signal. For both scattering and shadowing, each transmitter is plotted separately, as requested by the user.

The output from BPLOTR is a plot of the angle error in degrees for each system. The DME/P interrogator is not implemented by the system model at this time. Error plots are provided in four formats. The static error shows the raw error at each receiver point. The dynamic error also shows the raw error with account taken of the movement of the receiver. PFE and CMN plots show the error as filtered by these algorithms, respectively. In addition, tolerance and coverage limits are calculated based on Federal Aviation Administration (FAA) specifications and are displayed on the filtered error plots. The user can then see at a glance whether or not the MLS signal goes out of tolerance at any point along the flightpath. If it does not, it is reasonable to conclude that the airport environment, as defined, will not adversely affect the MLS signal.