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Program Validation of Lincoln Laboratory Microwave Landing System Math Model

Jesse D. Jones

November 1984

DOT/FAA/CT-TN84/42

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-TN84/42		

4. Title and Subtitle
PROGRAM VALIDATION OF LINCOLN LABORATORY MICROWAVE LANDING SYSTEM MATH MODEL

5. Report Date
November 1984

6. Performing Organization Code
ACT-140

7. Author(s)
Jesse D. Jones

8. Performing Organization Report No.
DOT/FAA/CT-TN84/42

9. Performing Organization Name and Address
Federal Aviation Administration
Technical Center
Atlantic City Airport, New Jersey 08405

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
T06-01G

12. Sponsoring Agency Name and Address
Federal Aviation Administration
Technical Center
Programming Engineering and Maintenance Service
Washington, D.C. 20590

13. Type of Report and Period Covered
Technical Note
September 1984

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This project was conducted to validate the Lincoln Laboratory MLS mathematical model program which was converted for implementation on the Federal Aviation Administration (FAA) Technical Center computer. The model was run with five different input scenarios to exercise all parts of the model and to provide output data for comparison with the output from the Lincoln Laboratory Amdahl computer. The comparisons show equivalent results.

17. Key Words
Microwave Landing System (MLS)
Time Reference Scanning Beam (TRSB)
Mathematical Modeling

18. Distribution Statement
Document is on file at the Technical Center Library, Atlantic City Airport, New Jersey 08405

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	85	

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EXECUTIVE SUMMARY

This project was conducted to validate the MLS mathematical model program which was converted for implementation on the Federal Aviation Administration (FAA) Technical Center Honeywell 66/60 computer. The original math model was developed and validated by Lincoln Laboratory, Massachussetts Institute of Technology. Five scenarios were selected to demonstrate: (1) terrain reflections, (2) building reflections, (3) aircraft reflections, (4) runway shadowing, (5) building shadowing, and (6) aircraft shadowing. These were input to the model for comparison with the output from the Lincoln Laboratory Amdahl computer. Comparisons show that the results from both computers are equivalent.

INTRODUCTION

PURPOSE.

The Microwave Landing System (MLS) mathematical model computer program developed by the Lincoln Laboratory of the Massachusetts Institute of Technology has been converted by Federal Aviation Administration (FAA) Technical Center personnel to operate on their Honeywell 66/60 computer. The objective of this project is to verify that analogous results are obtained from the Technical Center computer and the Lincoln Laboratory Amdahl computer for the same model input parameters.

BACKGROUND.

To aid in MLS technique selection and siting optimization, a realistic multipath mathematical model was developed by Lincoln Laboratory to simulate real-world airport environments. The term "multipath" is used to describe the reflection/shadowing phenomena because several possible paths exist for signals to travel between the transmitter and receiver, as opposed to the single (direct) path assumed in initial system design. The continuing construction of buildings in the vicinity of the approach and landing zone and the increasing use of wide body aircraft (both potentially significant multipath sources) emphasize the importance of multipath effects to the design and selection of any landing system. This model will be used to assess the degradation of a guidance path when subjected to various levels of multipath interference. The Lincoln Laboratory MLS model has been used to analyze MLS performance for various field siting configurations. Since this model has been converted for operation on the FAA Technical Center's Honeywell 66/60 computer, a validated model program was required to provide the Technical Center with the assurance that the capability to evaluate the performance of an MLS in a real-world environment has not been compromised by the conversion process.

DISCUSSION

MLS MATHEMATICAL MODEL DESCRIPTION.

The MLS mathematical model simulation program is written in the FORTRAN IV computer language and has successfully been used on computers in the United States, United Kingdom, and the Federal Republic of Germany. An MLS simulation may be considered as consisting of three elements.

1. The first element is the airport and flightpath model. This model consists of the input data which specifies the locations and composition of reflecting and shadowing obstacles, terrain features, antenna locations, and the path flown by the aircraft.

2. The second element is known as the propagation model. This element determines the signals at the receiver for each point along the flightpath, taking into account the various multipath reflections.

3. The third element is the Time Reference Scanning Beam (TRSB) system and receiver model. This part of the simulation computes the receiver error caused by multipath for the specified ground equipment antenna patterns, aircraft antenna pattern, scan format, and receiver processing algorithm.

Figure 1 shows the interrelationship of these elements to the total MLS simulation. (See Bibliography for detailed theory and description.)

AIRPORT/FLIGHTPATH MODEL.

The airport and flightpath model (used as a block data subprogram) consists of data specified for the particular airport environment being considered. At the FAA Technical Center, this information is currently entered in an interactive session which creates the block data file for input to the propagation model. The degree of approximation to an actual airport environment will depend heavily upon the simulation and the scatterer geometry. For example, in a case where the multipath is out of beam and of short duration, hangars might be represented by a single plate; however, to closely predict actual system performance in a critical multipath situation, it would be necessary to input the same hangar with many plates representing the various electrical properties of the different parts of the hangar.

PROPAGATION MODEL.

Propagation modeling consists of executing the propagation program with the airport/flightpath model input (block data). This model determines the multipath characteristics of the specified airport environment. The numerical results from the propagation model define the direct signal; signals reflected from or diffracted by terrain, buildings, and aircraft; and the changes in the direct signal characteristics due to shadowing by runway humps, buildings, and aircraft. The type of multipath considered in a simulation is dependent upon and determined by the input parameters defined in the block data. Numerical results are saved in three different files: one file for further processing by the system model (data set 8), and the other two for plotting of the multipath data (data sets 14 and 16). The propagation model can accommodate the multipath types specified below.

TERRAIN REFLECTION MODELING. The terrain is typically represented by a collection of rectangular and triangular plates, each with prescribed orientation, roughness, and dielectric constant. By varying these parameters, one can assess the sensitivity of performance to terrain type (e.g., dry ground versus snow). The multipath levels are computed either by a numerical Kirchoff-Fresnel integral or a simplified approximation.

BUILDING REFLECTION MODELING. Buildings are represented by one or more rectangular plates of prescribed orientation and surface material. The various plates represent salient features of a building such as the doors of a hangar. By allowing each plate to have a different surface material characterization, inhomogeneous surfaces (e.g., concrete walls with metal doors) can be modeled. Consideration is also made for secondary ground reflection paths. The levels are computed assuming Fresnel diffraction and using closed form Fresnel integral expressions.

AIRCRAFT REFLECTION MODELING. For aircraft, it is essential to consider the curvature of the surfaces as this tends to spread the reflections over a much greater region than would be the case with flat plates. The fuselages and tail fins are both modeled as cylinders or a section thereof. The resulting multipath levels are computed by a combination of Fresnel diffraction (integrals) and geometric optics.

SHADOWING. Shadowing by buildings or aircraft causes both an attenuation and distortion of the transmitted wavefront. Both of these factors are considered in the models for shadowing. The shadowing obstacles are represented by one or more rectangular plates which approximate the object silhouette. Similar techniques have been successfully used in studying the effects of widebody aircraft on the Instrument Landing System (ILS). The shadowing of the azimuth signal by runway humps requires explicit consideration of the surface curvature, and is computed by mathematical algorithms similar to those of aircraft reflection modeling.

The graphical routines used to display the propagation model results at the FAA Technical Center are from the TEKTRONIX Plot 10 Terminal Control System. These routines provide easy access to the graphic capabilities of the Tektronix 4010 type Direct View Storage Tube (DVST) terminals. Information displayed on the storage tube may be copied as desired (via a hard copy unit) to provide a permanent record of the results. Graphical output from the multipath model consists of a listing of the input parameters used in the simulation, the flightpath of the receiver, an airport map showing the location of the transmitters and obstacles, and multipath diagnostics. These diagnostics display relative azimuth (AZ), distance measuring equipment (DME), and elevation (EL) multipath/direct (M/D) amplitude ratios (for the maximum component of the several multipath components from a given obstacle) and separation angles (time delay for DME) along the flightpath for the obstacles generating significant multipath components, and the variation in the direct signal AZ, DME, or EL level where shadowing is involved. Input parameters and airport maps are included in this report for all scenarios discussed. Multipath and diagnostic plots are included as applicable.

SYSTEM MODEL.

The TRSB system and the MLS receiver algorithms are simulated in the system model. This model considers the received signal as a superposition of the received direct path signal and a number of replicas (multipath) of it, each having its own amplitude, delay, angle, and Doppler shift. The system model then determines the receiver error by taking into account the nature of the transmitted signals and the antenna patterns. The functional form of the beam waveform is determined from measured or theoretical patterns and is included in the model as a function subprogram. By superimposing the beam patterns corresponding to the various signal paths, the net received envelope is determined.

The remainder of the system model parallels the processing by the receiver microprocessor. A tracking gate is centered on the largest consistent envelope peak with the beam arrival angle derived by finding the times at which the leading and trailing edges of the received envelope cross a threshold. Various checks and tracking algorithms are applied to each measurement before it is presented as angle data. DME is not a part of the system model at this time.

The output of the system model is displayed on a Tektronix DVST using the TEKTRONIX Plot 10 graphics subroutines. A specific transmitter (AZ or EL) is selected for plotting and the errors generated by the model are plotted versus the distance along the flightpath. The applicable error plot (AZ or EL) is included for most of the scenarios discussed in this report.

PROGRAM VALIDATION SCENARIOS.

The scenarios listed below were recommended by the MLS model's author, Dr. James Evans, to validate the FAA version of the program. Input and output data required for program validation were provided by Dr. Evans.

1. Scenario 1 is derived from the J. F. Kennedy Airport geometry as an example of elevation reflection multipath from buildings.

2. Scenario 2 is designed to show shadowing by buildings.

3. Scenario 3 is derived from the Los Angeles Airport to show azimuth reflection multipath from buildings and aircraft, along with shadowing by a humped runway.

4. Scenario 4, based on actual flight tests, is designed to demonstrate azimuth shadowing by a taxiing aircraft.

5. Scenario 5 involves the demonstration of ground reflections from tilted terrain, and is based upon field tests made by Lincoln Laboratory at Ft. Devens, Massachusetts.

DATA PRESENTATION AND ANALYSIS

Two sets of graphical output were generated by Lincoln Laboratory. One set was generated using the original Lincoln Laboratory model and the other set was generated using the FAA version of the model as it existed on the Lincoln Laboratory computer. Due to better readability (larger size), the latter set of plots is the one to which the FAA Technical Center output was compared. With one exception, both sets of plots from Lincoln Laboratory were identical and indicate that there were no coding problems with the FAA model program. The exception occurred when the AZ separation angle and DME time delay plots for scenario 3 did not agree on the duration of the affect from building 1 when the M/D ratio went below the lower plot limit. Since the M/D ratio was below -40 decibels (dB), the differences are considered insignificant.

The propagation model was run at the FAA Technical Center using the same block data inputs as were used at Lincoln Laboratory. Some additional parameters were added to the block data to define a few variables, which normally were input from the keyboard while the model was running at Lincoln Laboratory.

The system model at the FAA Technical Center was run with two sets of input data. One input to the system model was the output (data set 8) from the Lincoln Laboratory propagation model, which was used to verify that both system models provided the same output when using identical input data. The output from the FAA propagation model was also used as an input to the FAA system model to show the cumulative effect of computational differences between the two computers and programs

The axes on all plots are determined by automatic scaling routines which are different between the two computers. However, this scaling does not affect the actual data values.

The airport maps included are from the FAA propagation model graphical output. These plots depict the building, aircraft, and runway hump locations with respect to the MLS transmitter locations indicated by a star. Each transmitter location is labeled by use of symbols specified at the upper right corner of the plot. The origin of the coordinate system used is typically located at the stop end of the runway. Buildings, aircraft, and terrain plates are normally identified on these plots by a number corresponding to a number on the input parameter listing. However, for clarity, additional labeling has been added manually. Two plots are required to depict the flightpath. The first plot shows the flightpath on the standard x-z coordinate system. The runway is labeled if the flightpath crosses threshold. The flightpath is indicated by the dashed line with the numbered waypoints.

The other flightpath plot shows the elevation (z-axis) versus the "distance along the flightpath." These two plots may be correlated by referring to the table on the latter plot. The distance along the flightpath is the x-axis used on all multipath and shadowing plots.

M/D signal ratio, separation angle (time delay for DME), and shadowing (if applicable) plots are generated by the propagation model for each transmitter. After ranking the multipath components from all scatterers according to relative amplitude, only the largest component from each scatterer is used for plotting (limited to six scatterers for each plot). AZ and EL error plots are the only plots currently available from the system model. Only those plots appropriate to the scenario are included in this report, although all available plots were compared.

SCENARIO 1.

Figures 2, 3 and 4 show the airport layout and flightpath simulated in this scenario. Table 1 summarizes the input parameters (see appendix A for an explanation of the symbols). Since this example was designed to show elevation multipath, only the elevation M/D ratio, elevation separation angles, and elevation error plots are shown. Figures 5 through 7 are the respective output plots from the FAA Technical Center model. These figures may be compared to figures 8 through 10 which are the Lincoln Laboratory model output. To aid in comparison, the FAA output was plotted over the Lincoln Laboratories plots as shown in figures 11 through 13. The + symbol used for plotting the FAA output on the Lincoln Laboratory plots is centered on the FAA data location.

Figure 14 shows the comparison between the original Lincoln Laboratory elevation error and the elevation error from the FAA system model using the propagation model output data as the input. With the exception of a few points that are slightly offset from the original, the FAA output is identical to the Lincoln Laboratory output.

All of the other plots from the propagation and system models were compared and showed no discernible differences.

SCENARIO 2.

Shadowing of the MLS system is demonstrated by the airport geometry shown in figure 15 depicting the input parameters of table 2. Flightpath plots are shown in figures 16 and 17. Shadowing of the azimuth antenna is shown by the

FAA output plot of figure 18. The FAA output shown in figure 19 indicates correctly that there is no shadowing of the elevation signal. The FAA model has been corrected to eliminate the erroneous indication (in the Lincoln Laboratory plot which is not shown) of elevation shadowing where none existed. The azimuth system error generated by the FAA model is displayed in figure 20. Figures 21 and 22 are the Lincoln Laboratory plots corresponding to figures 18 and 20. Figures 23 and 24 are plots of the FAA model output plotted over the original Lincoln Laboratory data. Figure 25 is the result of plotting the FAA system error with the Lincoln Laboratory data set 8 input over the original Lincoln Laboratory output. All other output data were compared and are essentially identical between the FAA and Lincoln Laboratory computers.

SCENARIO 3.

This scenario provides a demonstration of azimuth multipath and runway hump shadowing. The airport layout is specified by table 3 and shown in figure 26. Figures 27 and 28 show the flightpath. The output from the FAA model for the azimuth M/D ratio, separation angle, and azimuth shadowing are provided in figures 29 through 31, respectively. Figure 32 is the system error generated by the FAA model. Due to a rerun of the propagation model for this scenario to correct an erroneous Lincoln Laboratory input procedure, no corresponding Lincoln Laboratory output from the system model is available. Figures 33 through 35 are the Lincoln Laboratory propagation model outputs corresponding to figures 29 through 31. Plotting the FAA outputs over these plots creates figures 36 through 38. These comparisons, along with those not shown, indicate essentially identical output data.

SCENARIO 4.

The geometry for this scenario, specified in table 4 and shown in figure 39, was based on actual flight tests to show the shadowing effects of taxiing aircraft. The flightpath of the approaching aircraft is shown in figures 40 and 41. The aircraft taxiing on the runway is indicated by the two "T's" marking both ends of its trajectory on the runway. The azimuth shadowing plot generated by the FAA model is presented in figure 42 with the system error plot presented in figure 43. The corresponding original Lincoln Laboratory plots are shown in figures 44 and 45. Figures 46 and 47 are generatd by plotting the FAA output over the Lincoln Laboratory plots. All plots from the FAA model were found to be essentially identical to the original Lincoln Laboratory plots. The output of the FAA system model using the Lincoln Laboratory data set 8 inputs (figure 48) shows some differences of about 0.01°. We cannot explain this anomaly since all other FAA system model outputs using the Lincoln Laboratory data set 8 as input resulted in identical plots. However, this difference is considered minimal and can be ignored for practical applications.

SCENARIO 5.

This scenario simulates ground reflections from rectangular plates tilted to simulate terrain slopes. These plates were configured as shown in figure 49 and specified in table 5. A vertical flightpath is simulated as shown by figures 50 and 51. Propagation model output plots are not included because multipath levels were very low (below -40 dB). The FAA system model output is shown in figure 52; the comparable Lincoln Laboratory output is shown in figure 53. A comparison of these two outputs, figure 54, shows many small differences between the two plots. These differences, however, only appear to affect the peak amplitude and can be attributed to the greater precision capability (36-bit versus 32-bit) of the FAA computer, since no changes were made to the focusing ground subroutines which are used for this simulation. When the system model is run with the Lincoln Laboratory data set 8 as input, the plots are essentially identical as indicated by figure 55.

NUMERICAL COMPARISONS.

The propagation model output (data set 8) from both computers was compared numerically. The parameters compared and acceptable differences were:

1. Amplitude: +/-0.05 dB.

2. Phase: +/-0.09 radians (about 5°). An excess number of errors were encountered with this comparison due to angles being equivalent, but some multiple of 2 pi radians.

3. Azimuth angle: +/- 0.004 radians (about 0.25°).

4. Elevation angle: +/-0.004 radians.

5. Scalloping Frequency: +/- 0.3 hertz (Hz).

6. Azimuth incidence angle (with respect to the velocity vector of the aircraft): +/- 0.02 radians (about 1.0°).

7. Elevation incidence angle (with respect to the velocity vector of the aircraft): +/- 0.02 radians.

The results of the numerical comparisons are shown in table 6. This table shows the number of samples, the number of times the samples exceeded the limits, and the arithmetic average difference for each scenario.

In scenario 4 none of the elevation incidence angle samples compared were within limits. The model author studied the problem and indicated that a minor coding change will correct this. However, this parameter is only involved when a directional aircraft antenna is simulated which is not currently performed. Therefore, this problem should have no affect on our current modeling efforts, and the coding change will be implemented in the near future.

The amplitude and phase values compared in scenario 5 exceeded the tolerance about 50 percent of the time. Again, we attribute these differences to computer precision differences. However, it should be noted that large phase differences associated with small amplitudes may be neglected since a small shift in the zero crossing location will yield a phase error in that region. As shown by the comparison plot (figure 55), the differences have a minimal effect on the final output.

CONCLUSIONS

The Federal Aviation Administration (FAA) Microwave Landing System (MLS) propagation model and system model provide results comparable to the original Lincoln Laboratory program when provided with the same input data. The greater precision available in the FAA Honeywell 66/60 computer results in minor differences in actual numerical and graphical data. However, these differences should not affect interpretation or analysis of the final results. It is concluded that the FAA MLS mathematical model program is validated.

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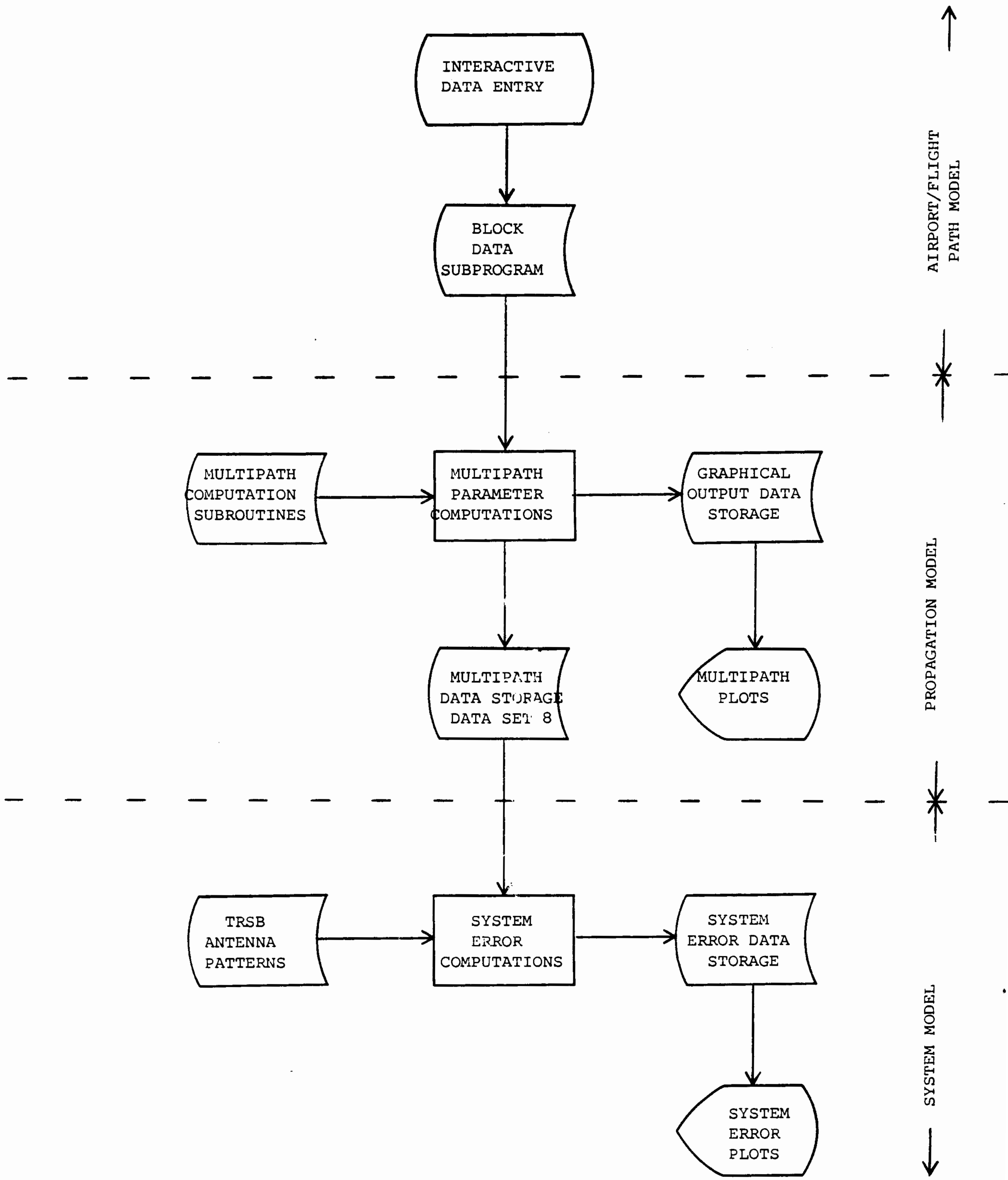

FIGURE 1. MLS MATHEMATICAL MODEL SIMULATION FLOW DIAGRAM

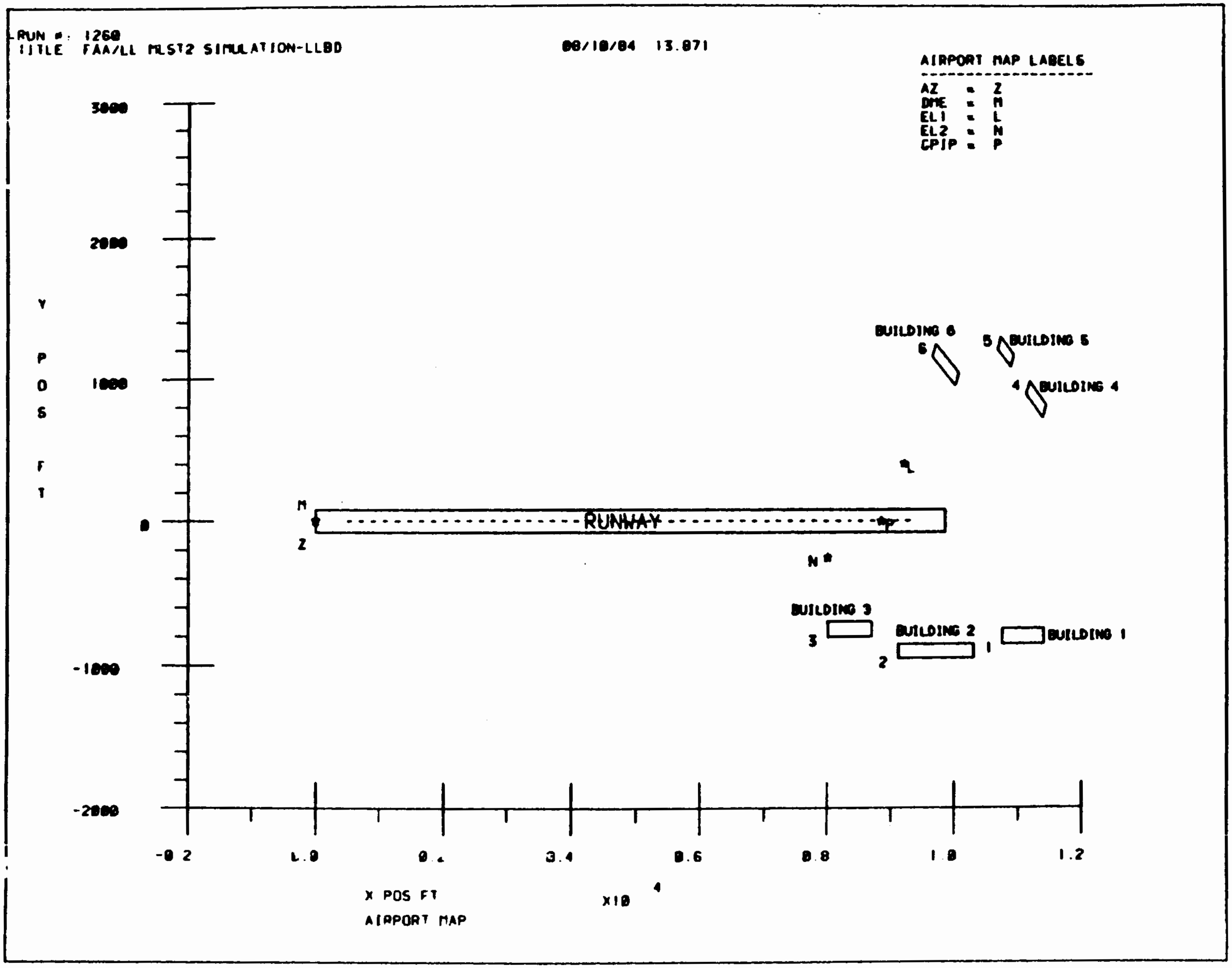

FIGURE 2. SCENARIO 1, AIRPORT MAP SHOWING BUILDING LOCATIONS

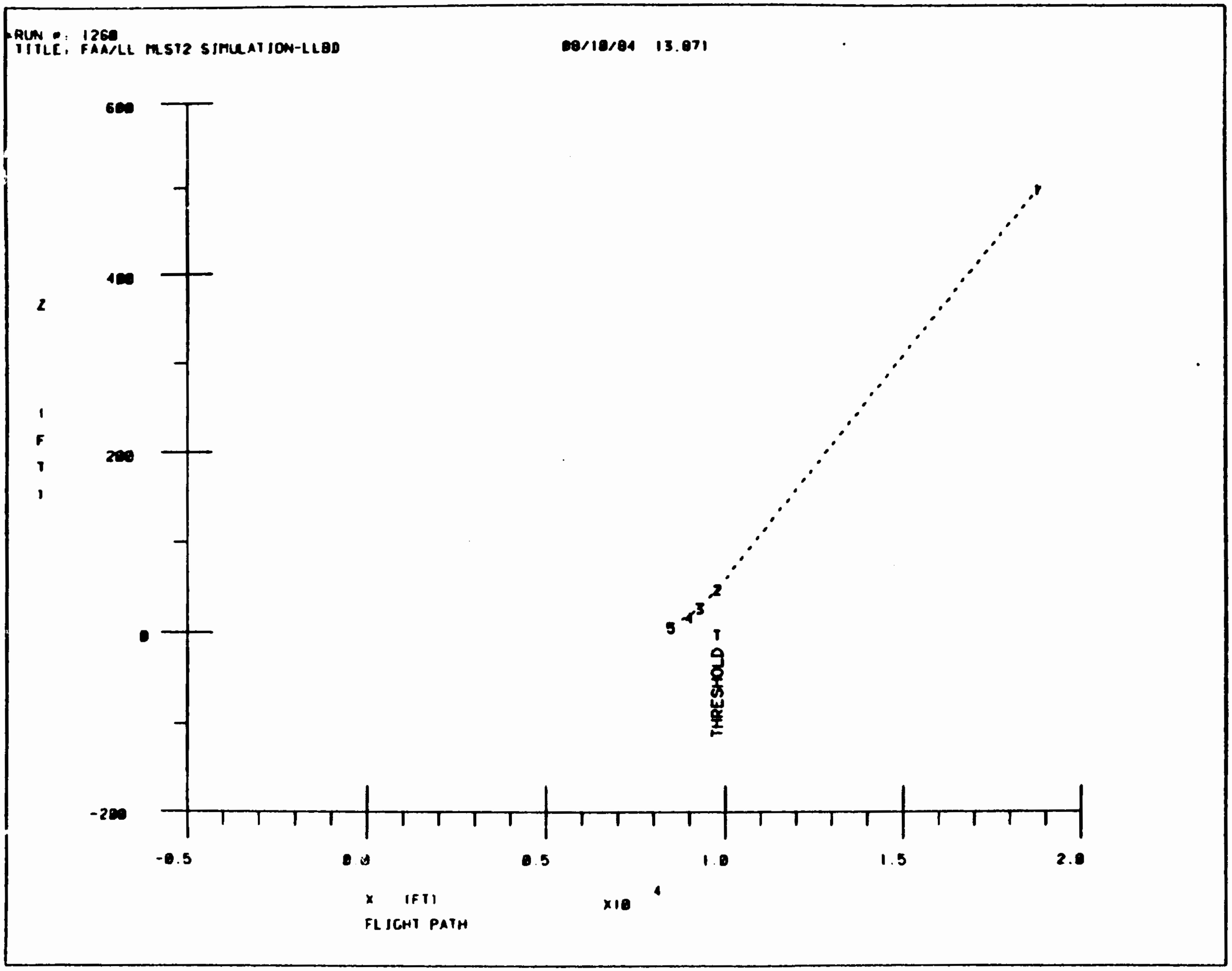

FIGURE 3. SCENARIO 1, APPROACH FLIGHT PATH IN X-Z COORDINATE PLANE

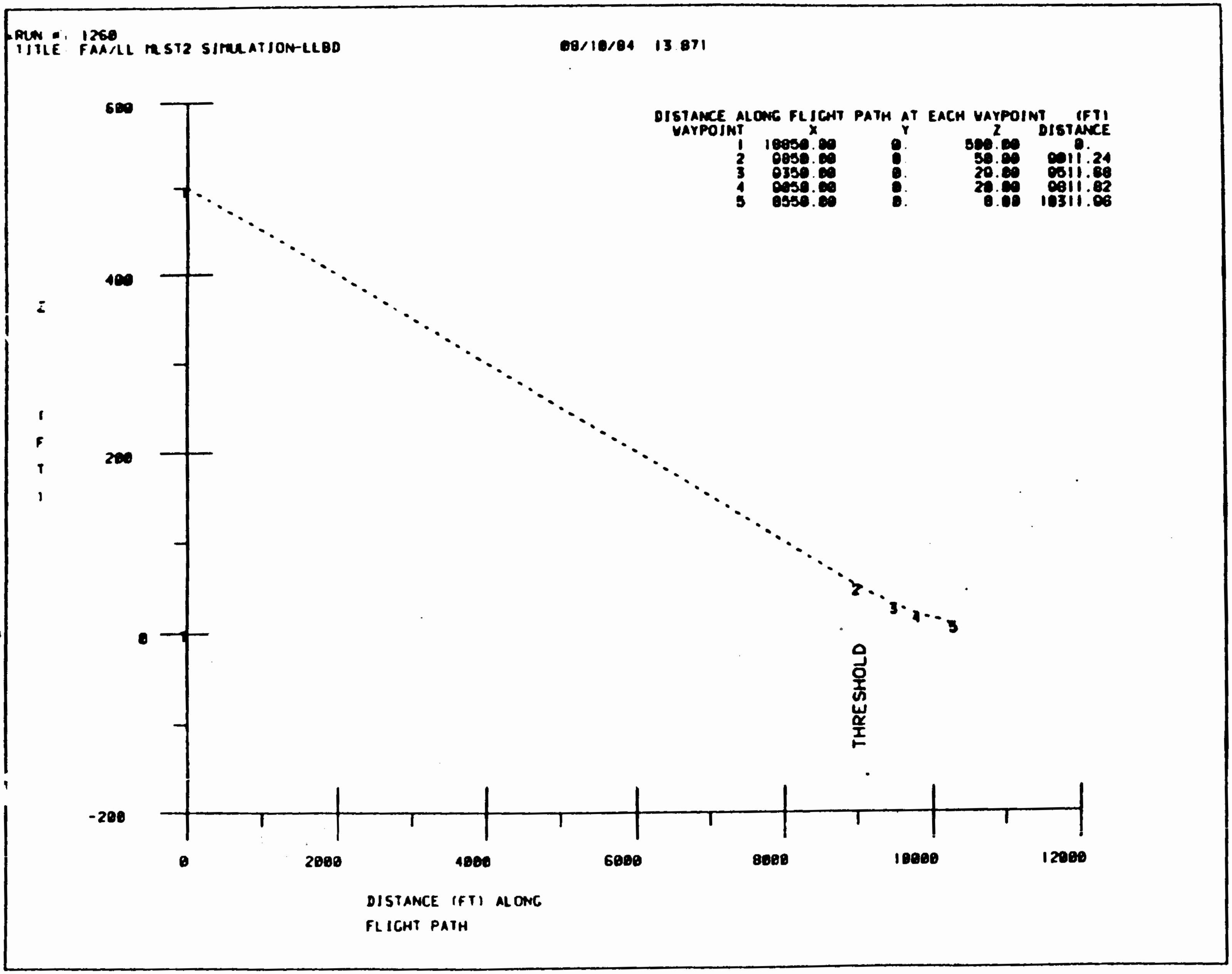

FIGURE 4. SCENARIO 1, APPROACH FLIGHTPATH IN DISTANCE-Z COORDINATE PLANE

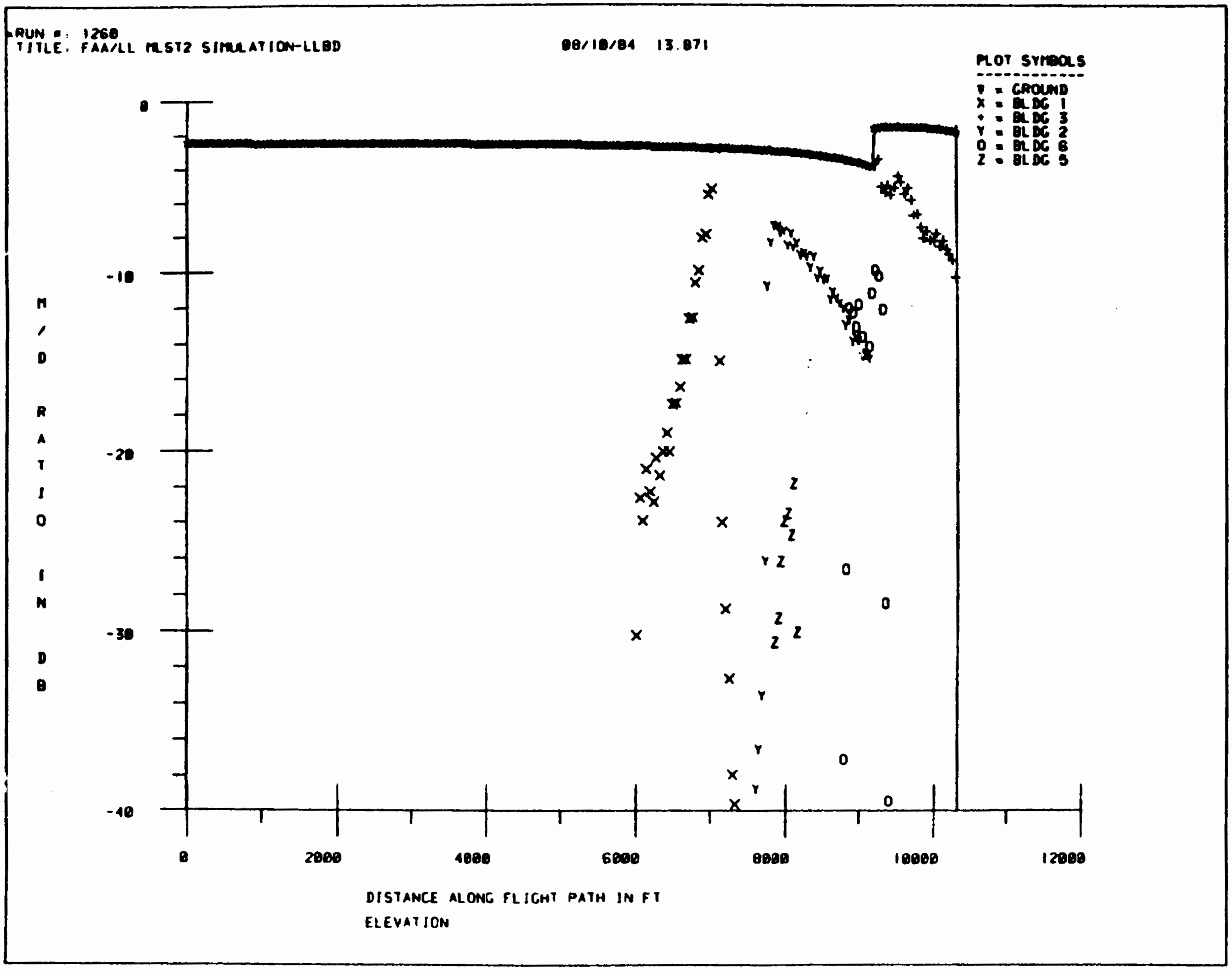

FIGURE 5. SCENARIO 1, FAA OUTPUT, ELEVATION ANTENNA, MULTIPATH/DIRECT SIGNAL PLOT

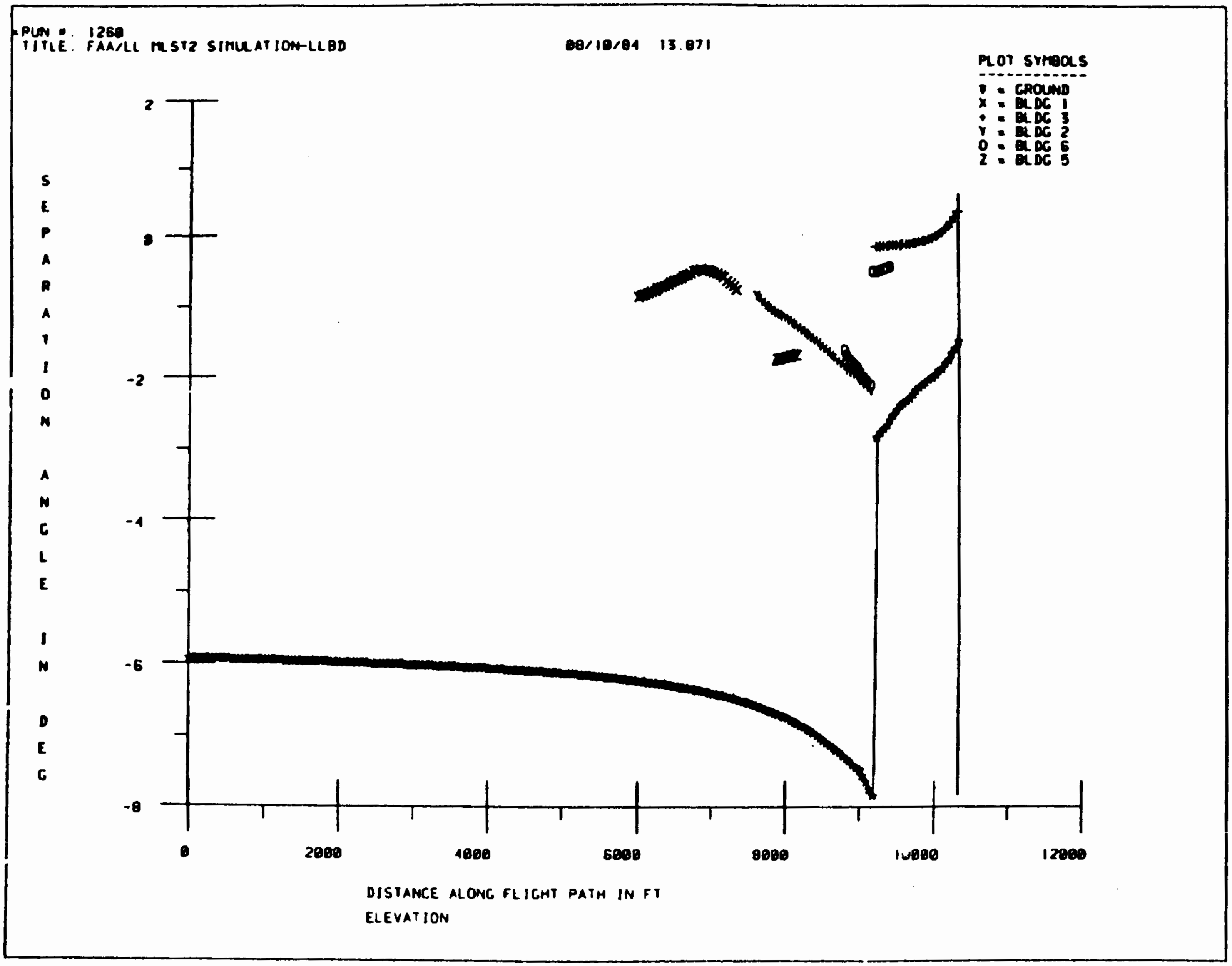

FIGURE 6. SCENARIO 1, FAA OUTPUT, ELEVATION ANTENNA, SEPARATION ANGLE PLOT

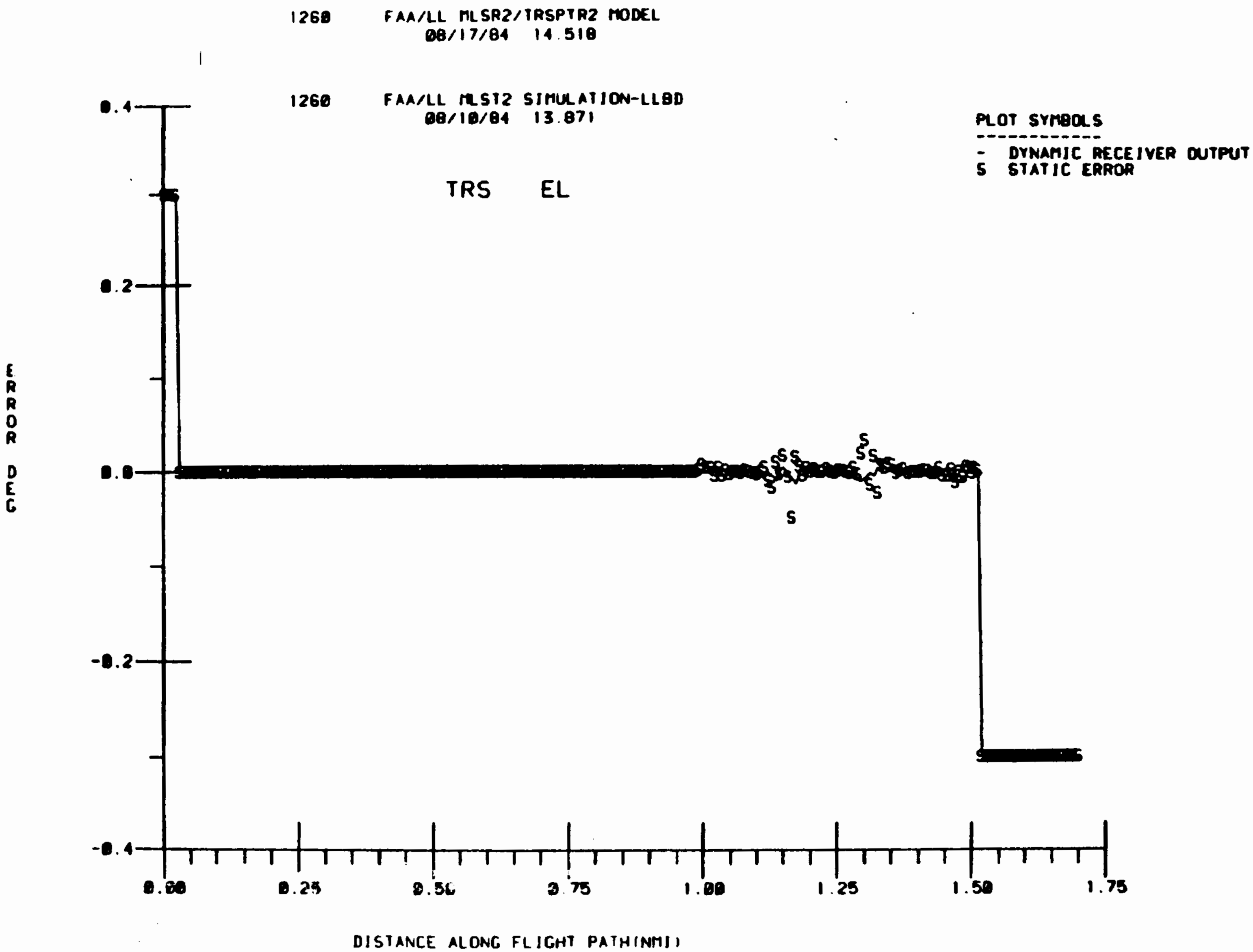

FIGURE 7. SCENARIO 1, FAA OUTPUT, ELEVATION ANTENNA, ERROR PLOT

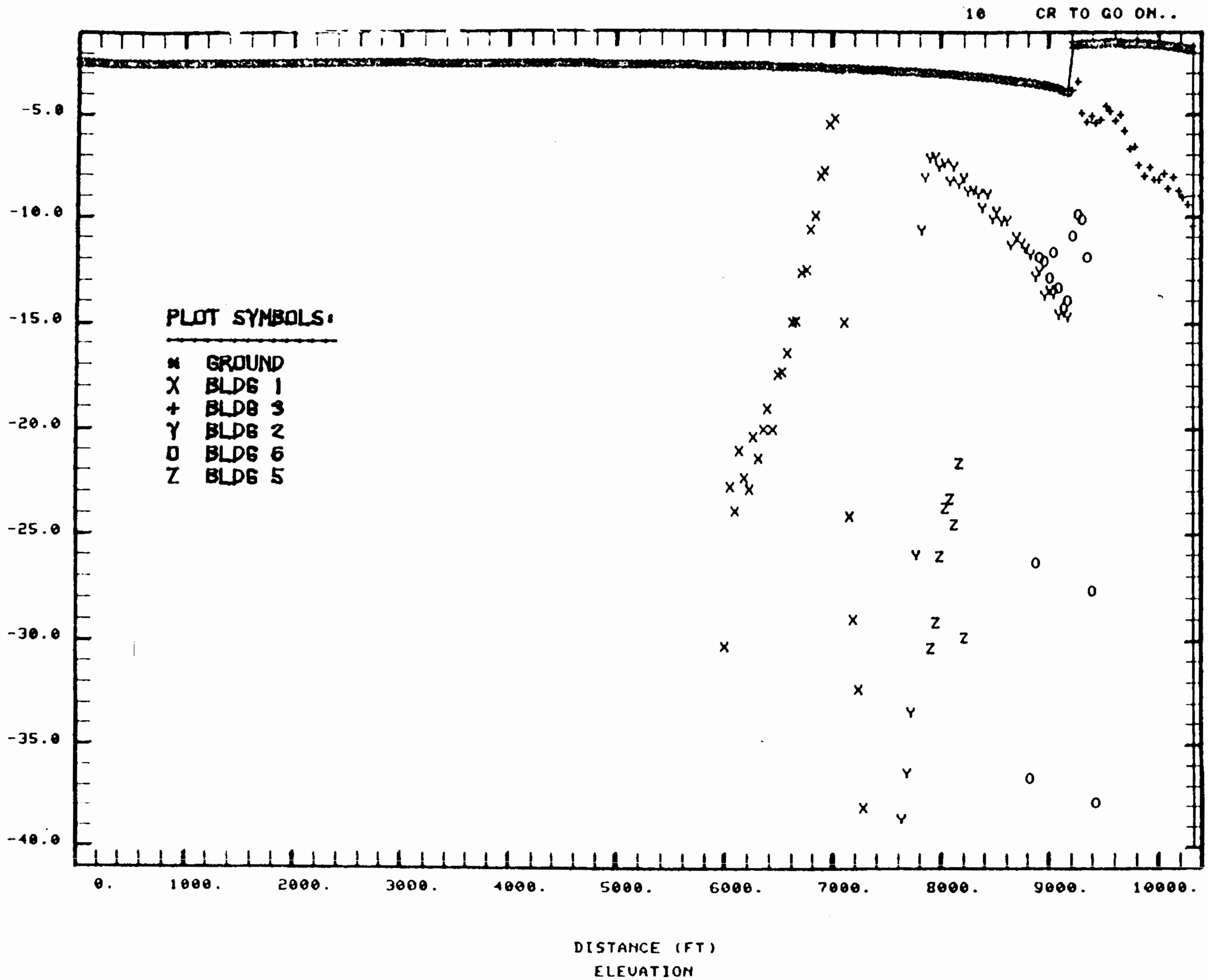

FIGURE 8. SCENARIO 1, LINCOLN LABORATORY OUTPUT, ELEVATION ANTENNA, MULTIPATH/DIRECT SIGNAL PLOT

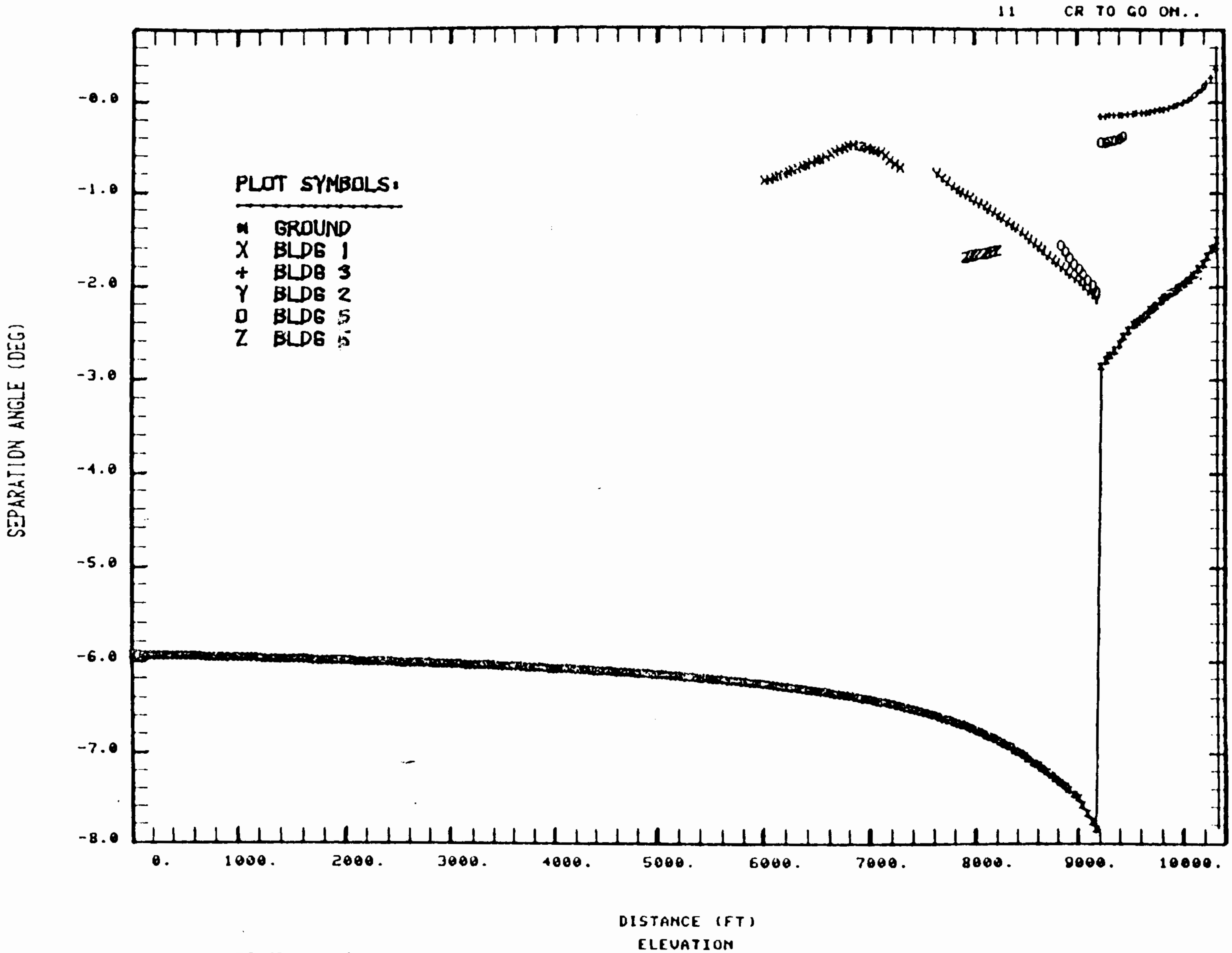

FIGURE 9. SCENARIO 1, LINCOLN LABORATORY OUTPUT, ELEVATION ANTENNA, SEPARATION ANGLE PLOT

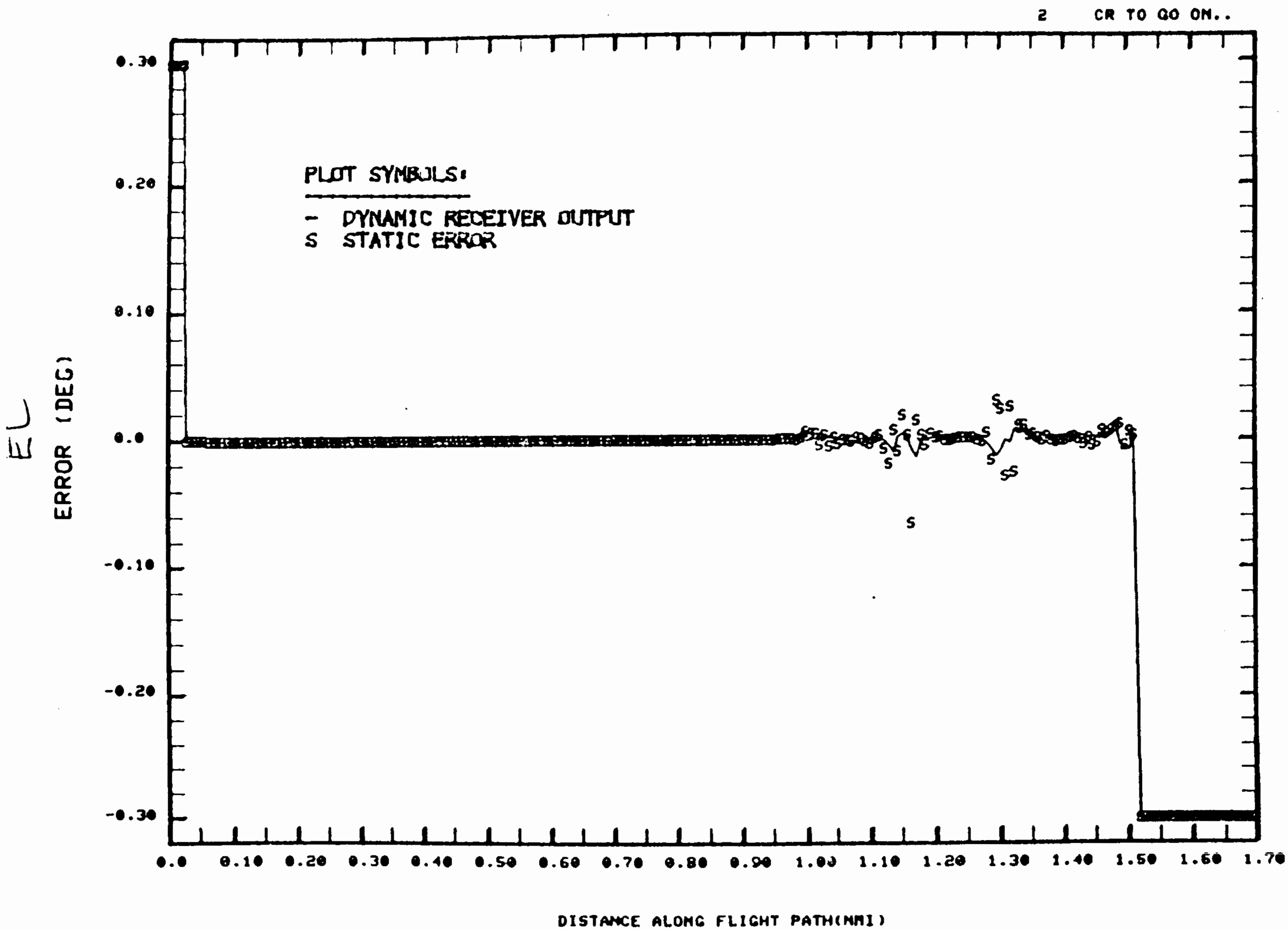

FIGURE 10. SCENARIO 1, LINCOLN LABORATORY OUTPUT, ELEVATION ANTENNA, SIMULATED RECEIVER ERROR PLOT

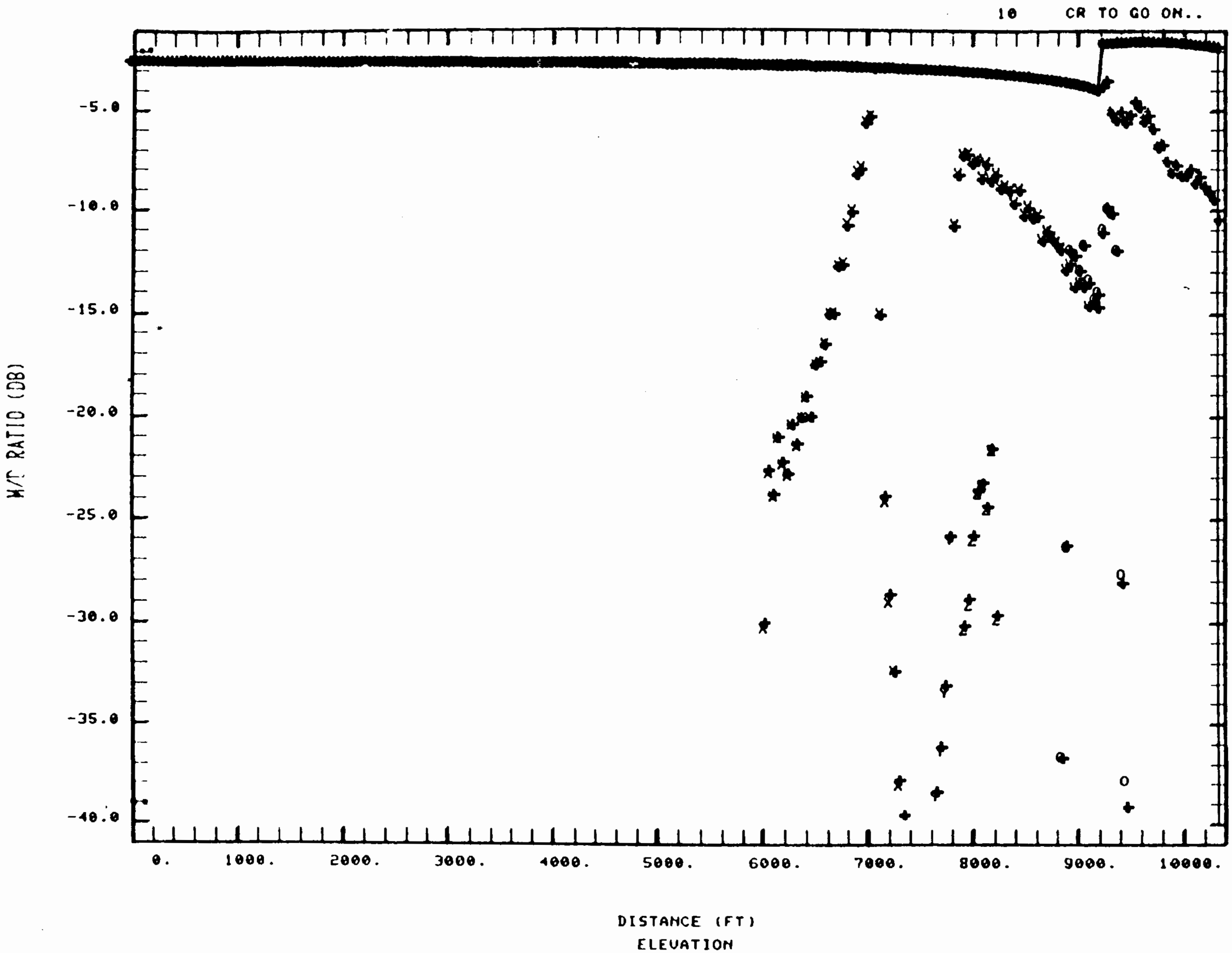

FIGURE 11. SCENARIO 1, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, ELEVATION ANTENNA, MULTIPATH/DIRECT SIGNAL PLOT

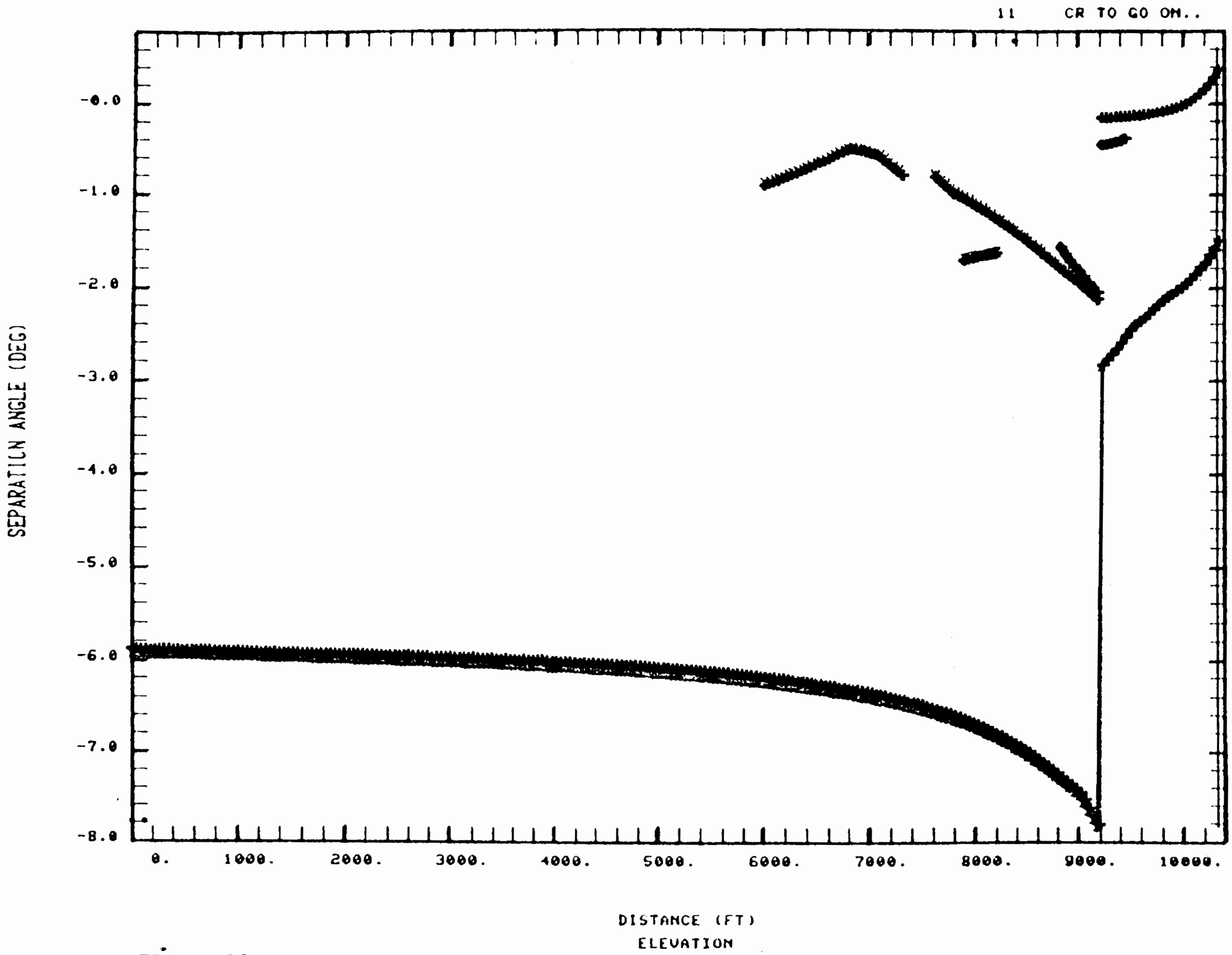

FIGURE 12. SCENARIO 1, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, ELEVATION ANTENNA, SEPARATION ANGLE PLOT

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EL

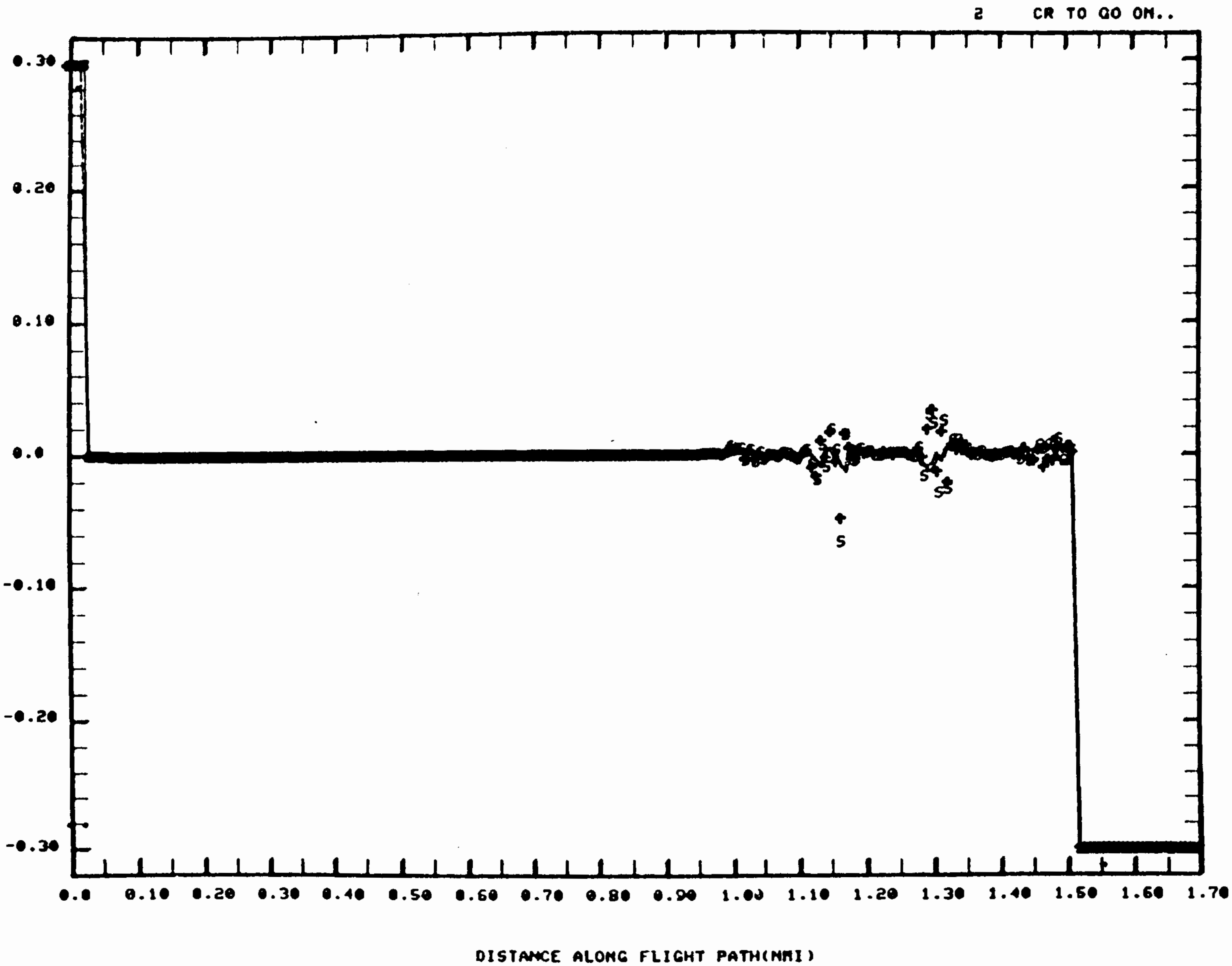

FIGURE 13. SCENARIO 1, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, ELEVATION ANTENNA, SIMULATED RECEIVER ERROR PLOT

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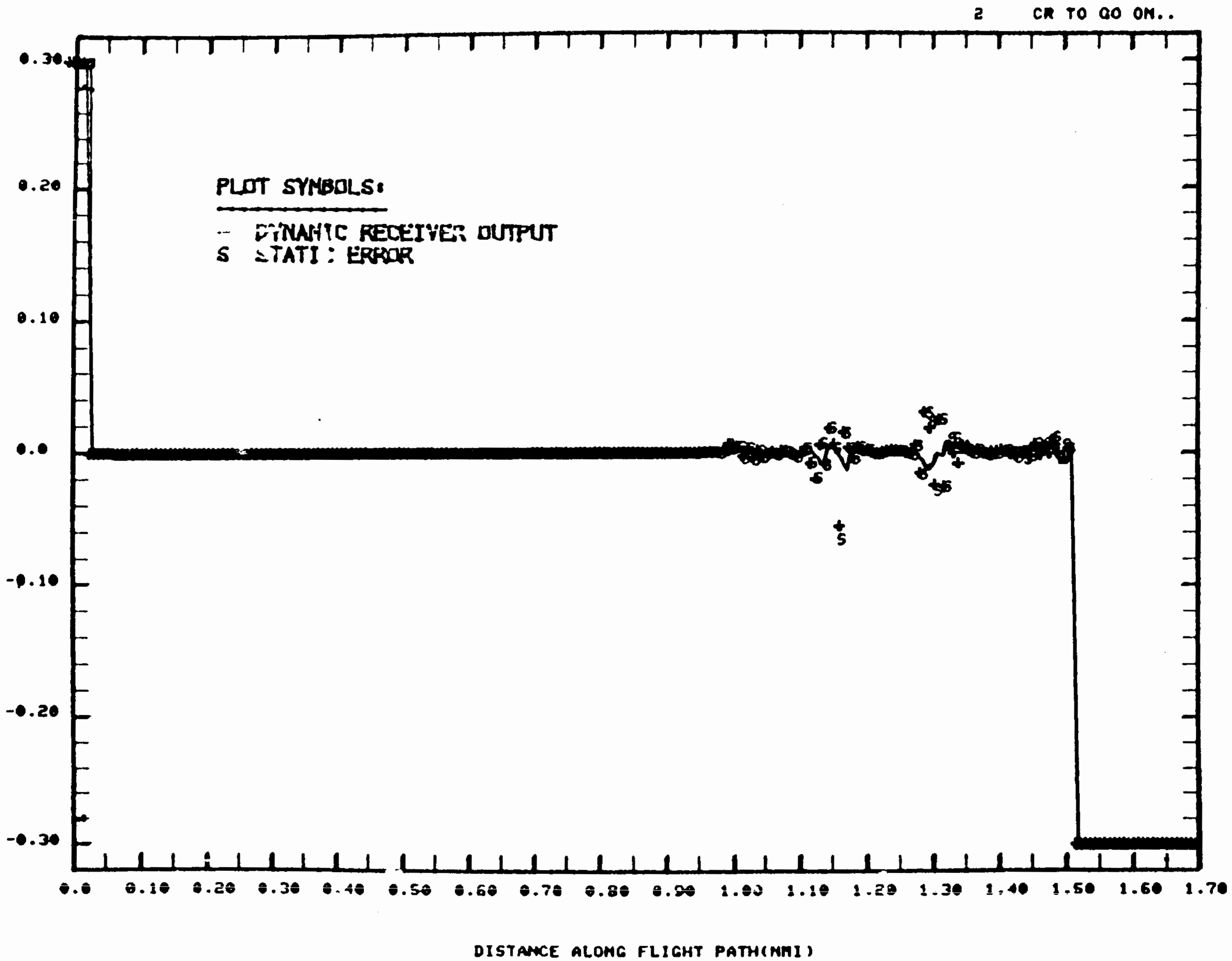

FIGURE 14. SCENARIO 1, FAA SYSTEM MODEL OUTPUT WITH LINCOLN LABORATORY DATA SET 8 INPUT COMPARED TO ORIGINAL LINCOLN LABORATORY OUTPUT

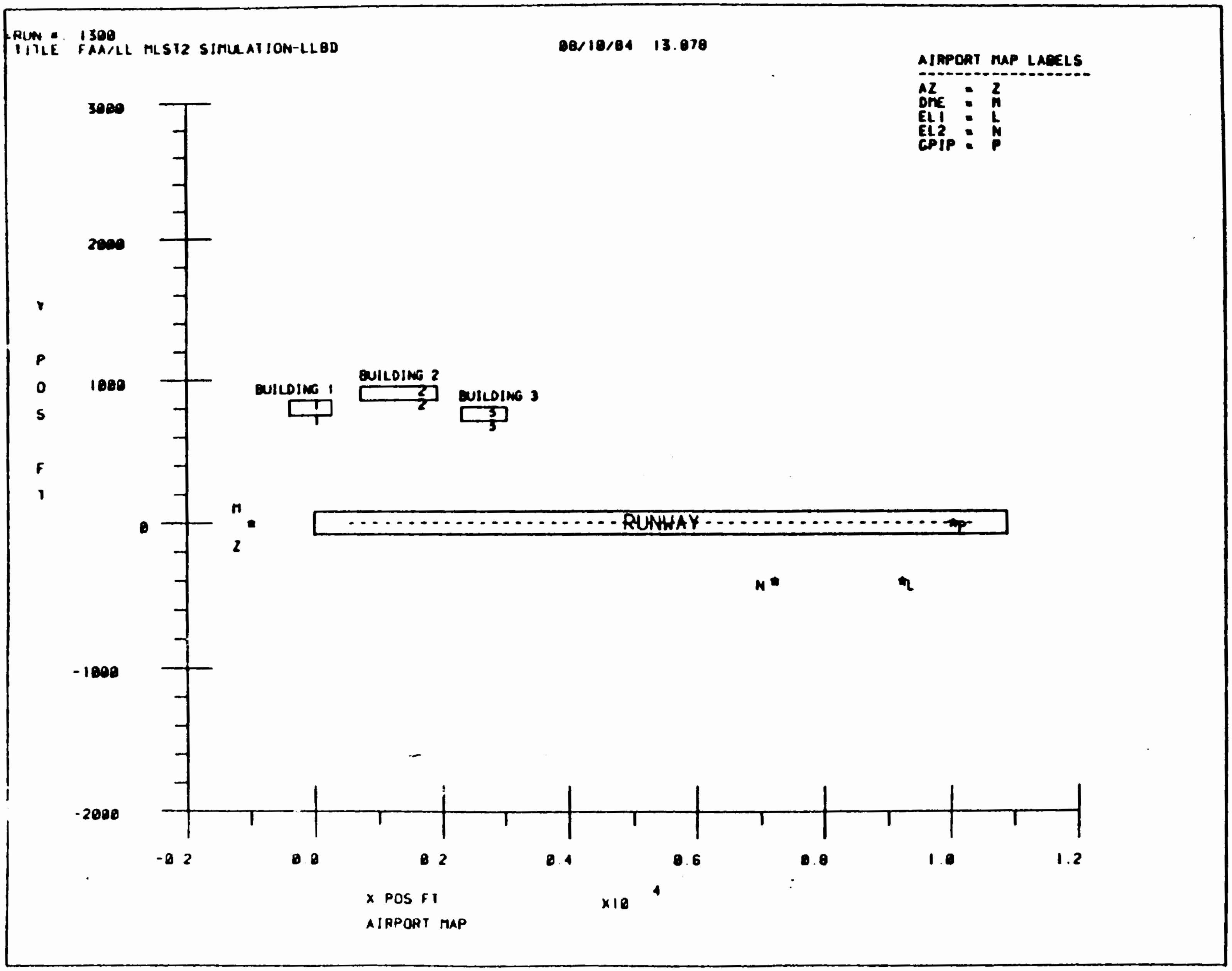

FIGURE 15. SCENARIO 2, AIRPORT MAP SHOWING SHADOWING BUILDING LOCATIONS

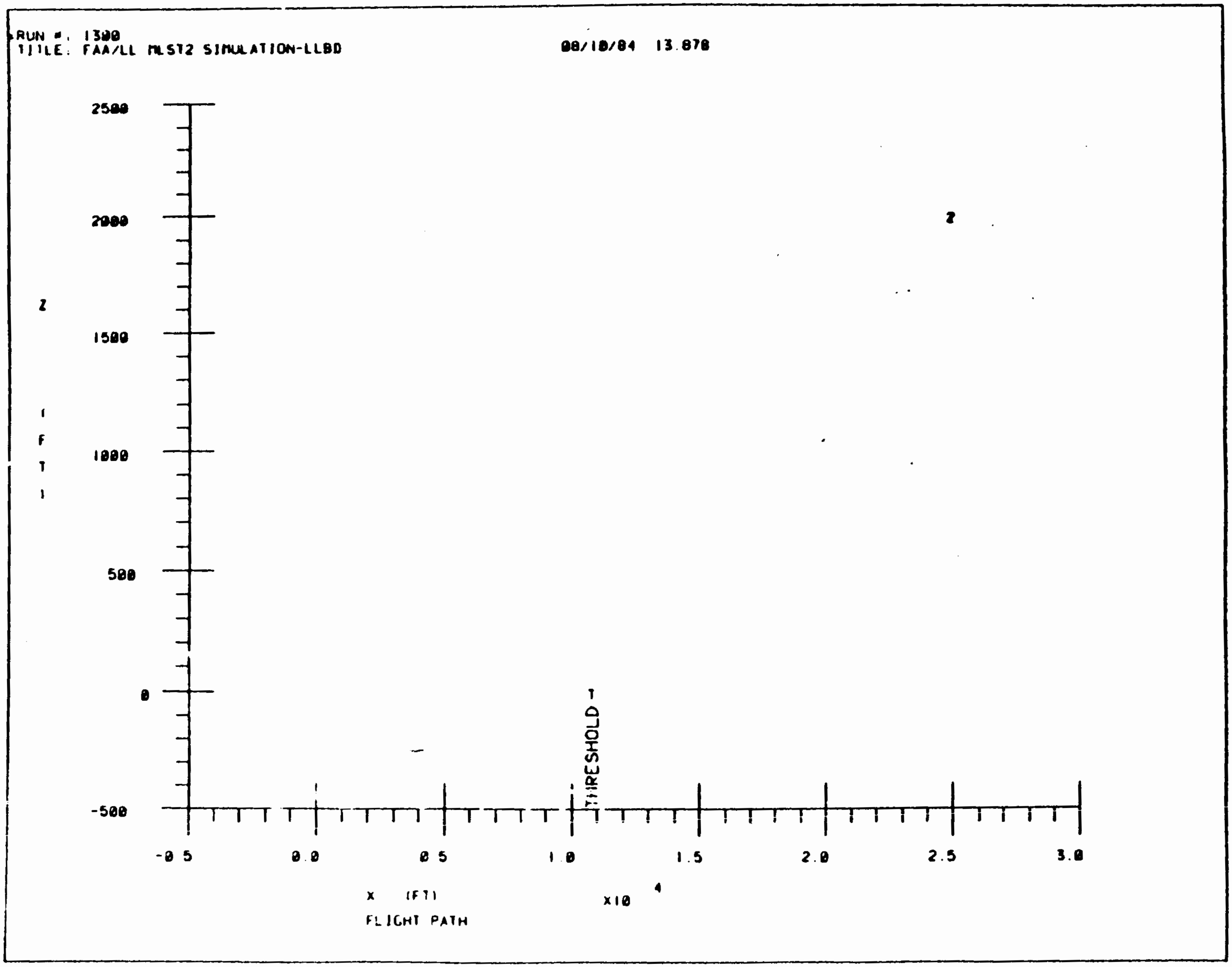

FIGURE 16. SCENARIO 2, APPROACH FLIGHTPATH IN X-Z COORDINATE PLANE

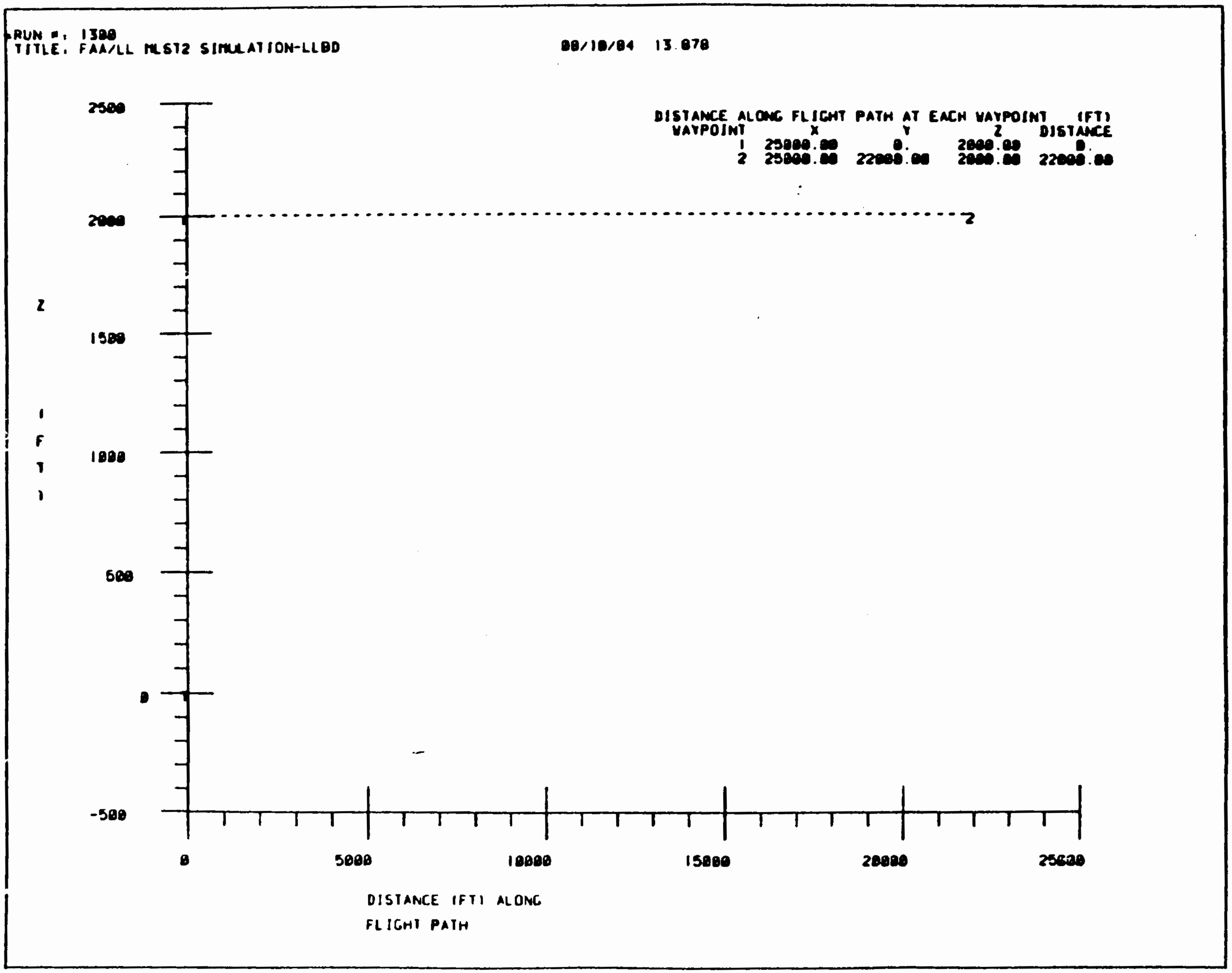

FIGURE 17. SCENARIO 2, APPROACH FLIGHTPATH IN DISTANCE-Z COORDINATE PLANE

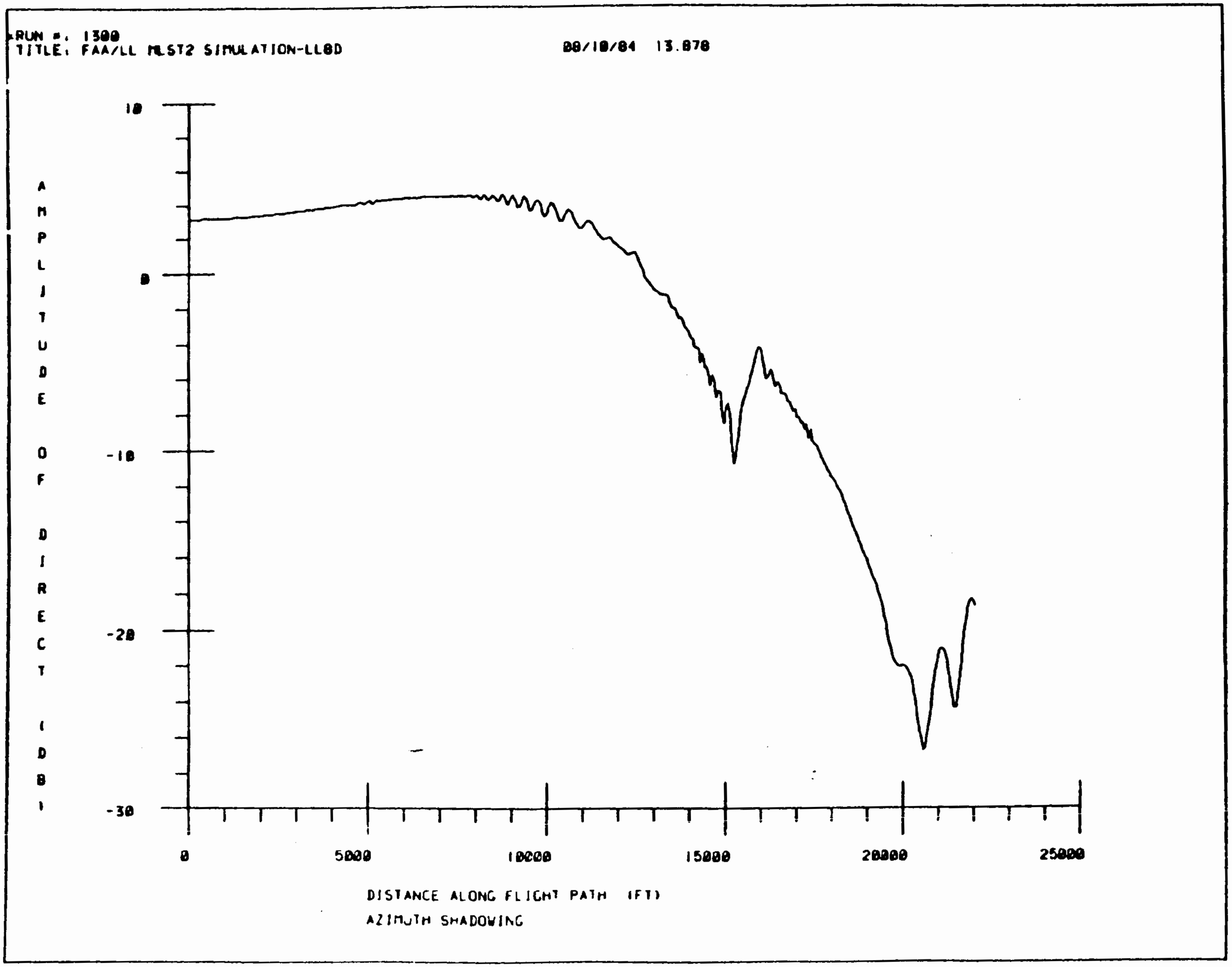

FIGURE 18. SCENARIO 2, TAA OUTPUT, AZIMUTH ANTENNA SHADOWING PLOT

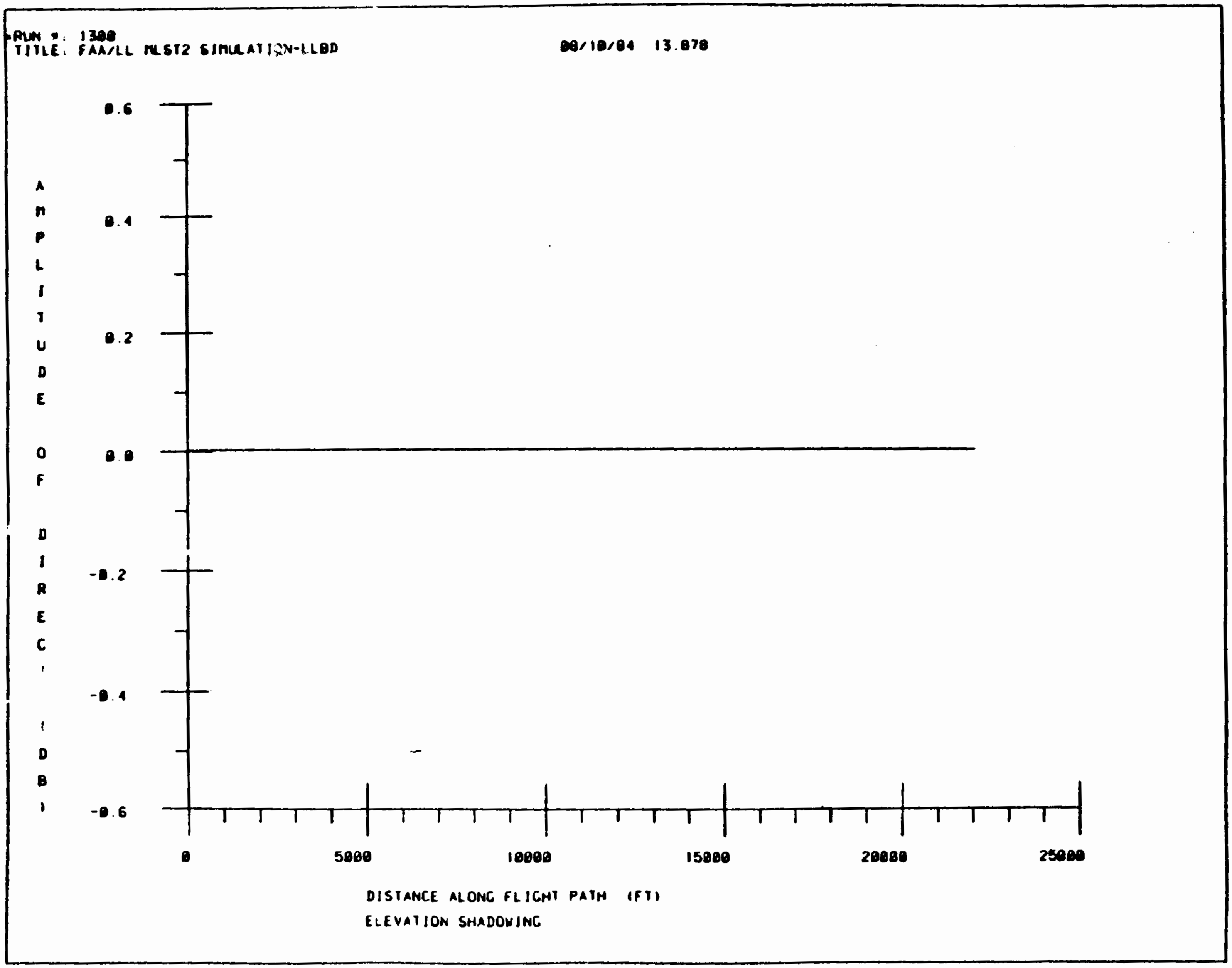

FIGURE 19. SCENARIO 2, FAA OUTPUT, ELEVATION ANTENNA SHADOWING PLOT

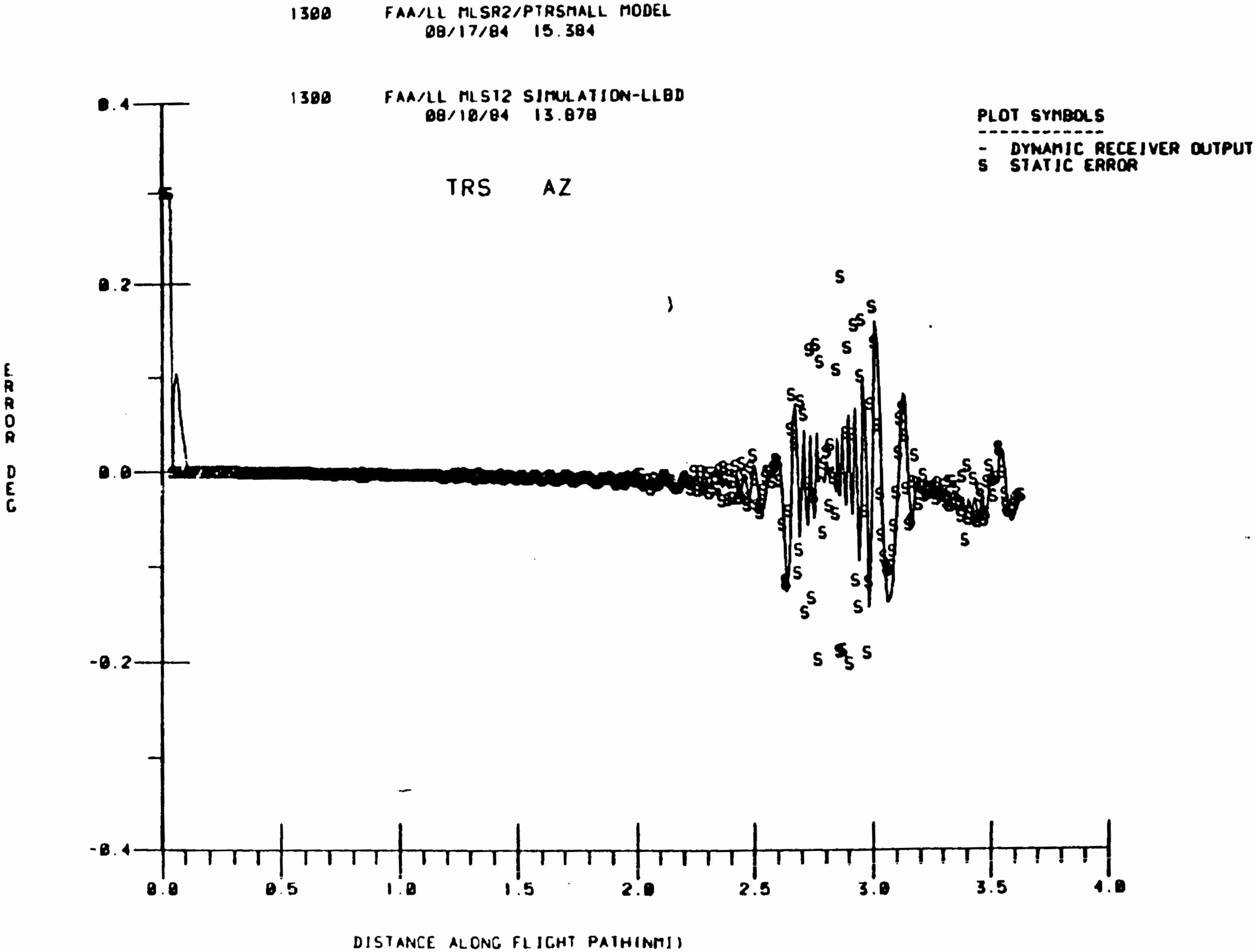

FIGURE 20. SCENARIO 2, FAA OUTPUT, AZIMUTH ANTENNA, SIMULATED RECEIVER ERROR PLOT

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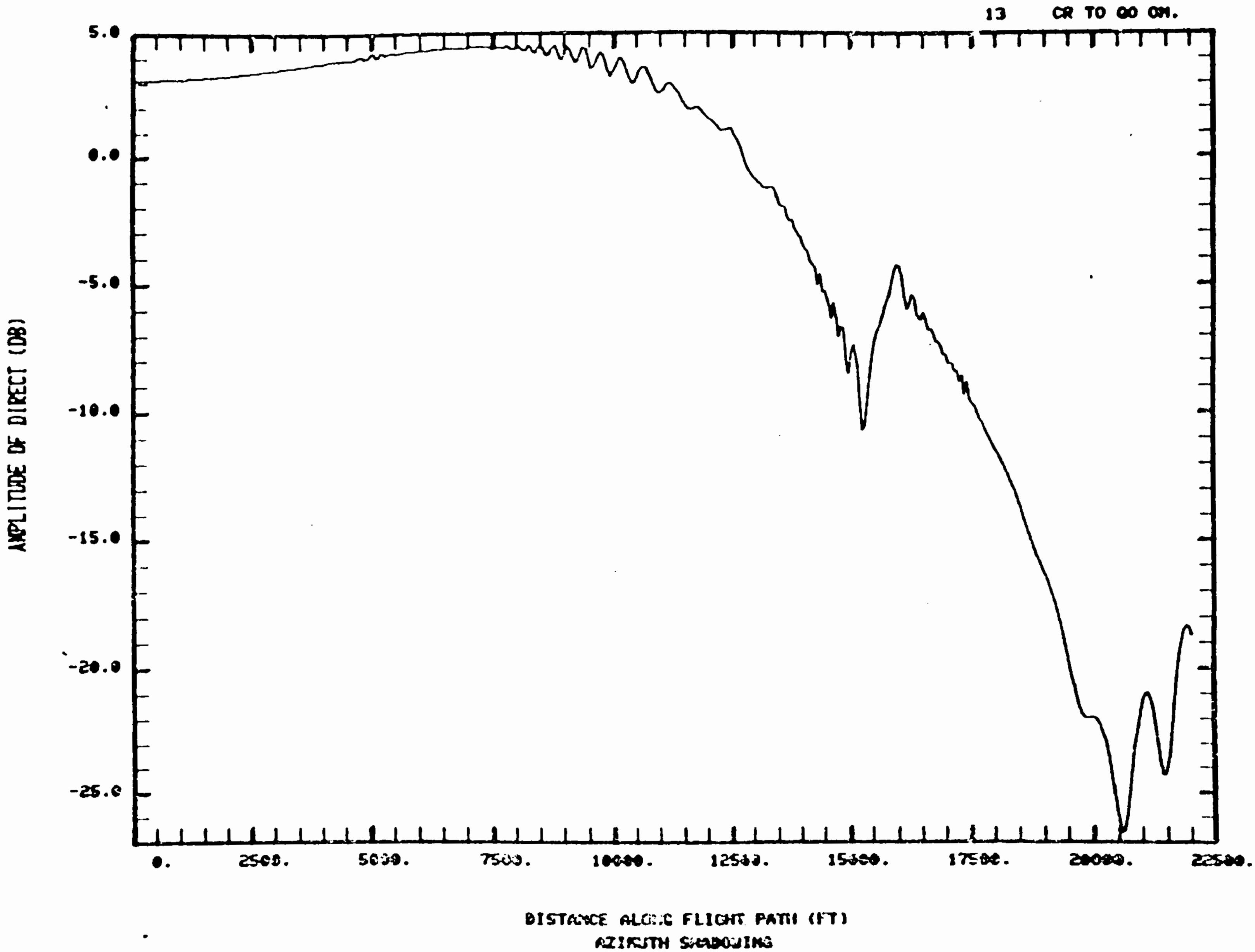

FIGURE 21 SCENARIO 2, LINCOLN LABORATORY OUTPUT, AZIMUTH ANTENNA SHADOWING PLOT

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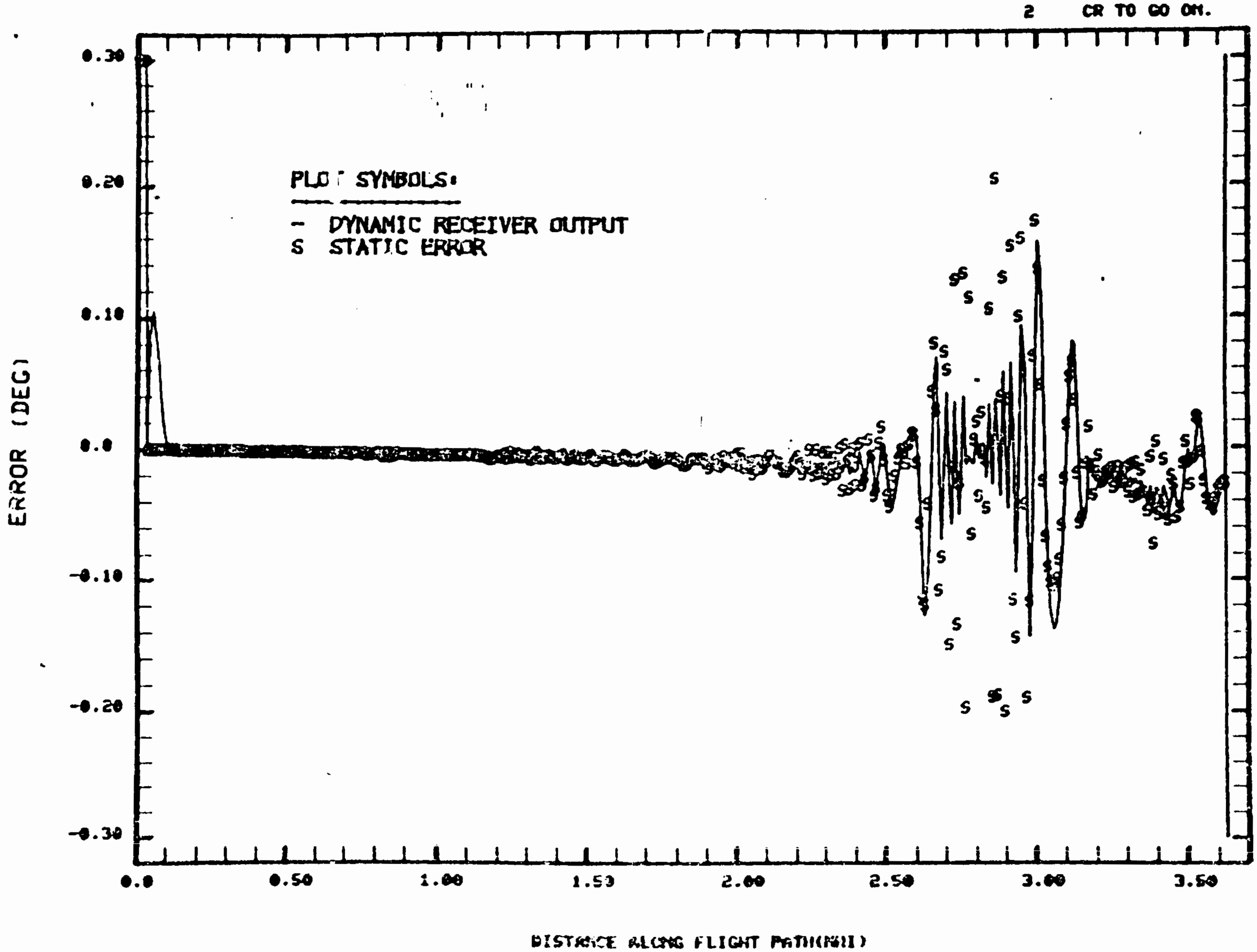

FIGURE 22. SCENARIO 2, LINCOLN LABORATORY OUTPUT, AZIMUTH ANTENNA, SIMULATED RECEIVER ERROR PLOT

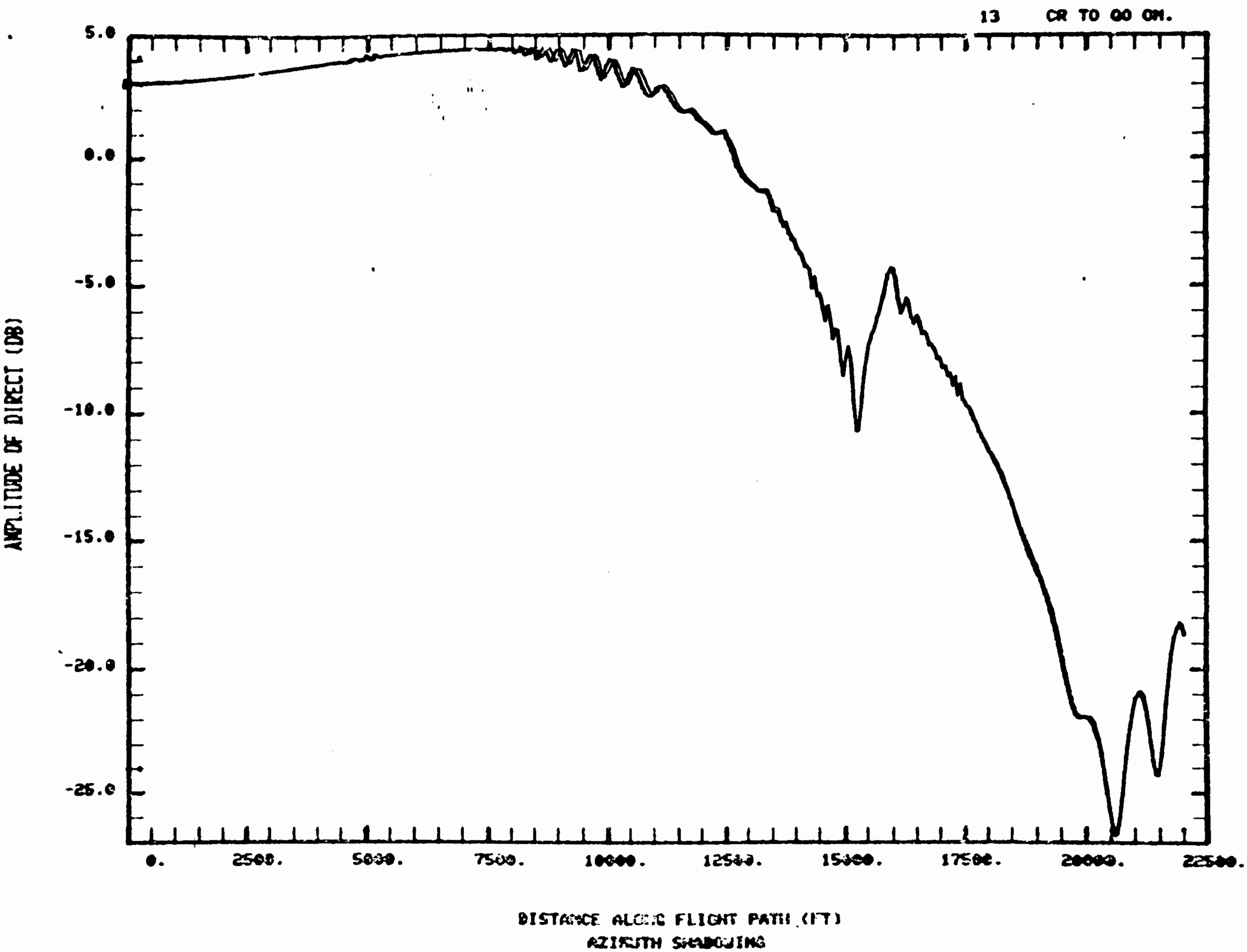

FIGURE 23. SCENARIO 2, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, AZIMUTH ANTENNA SHADOWING PLOT

F-6

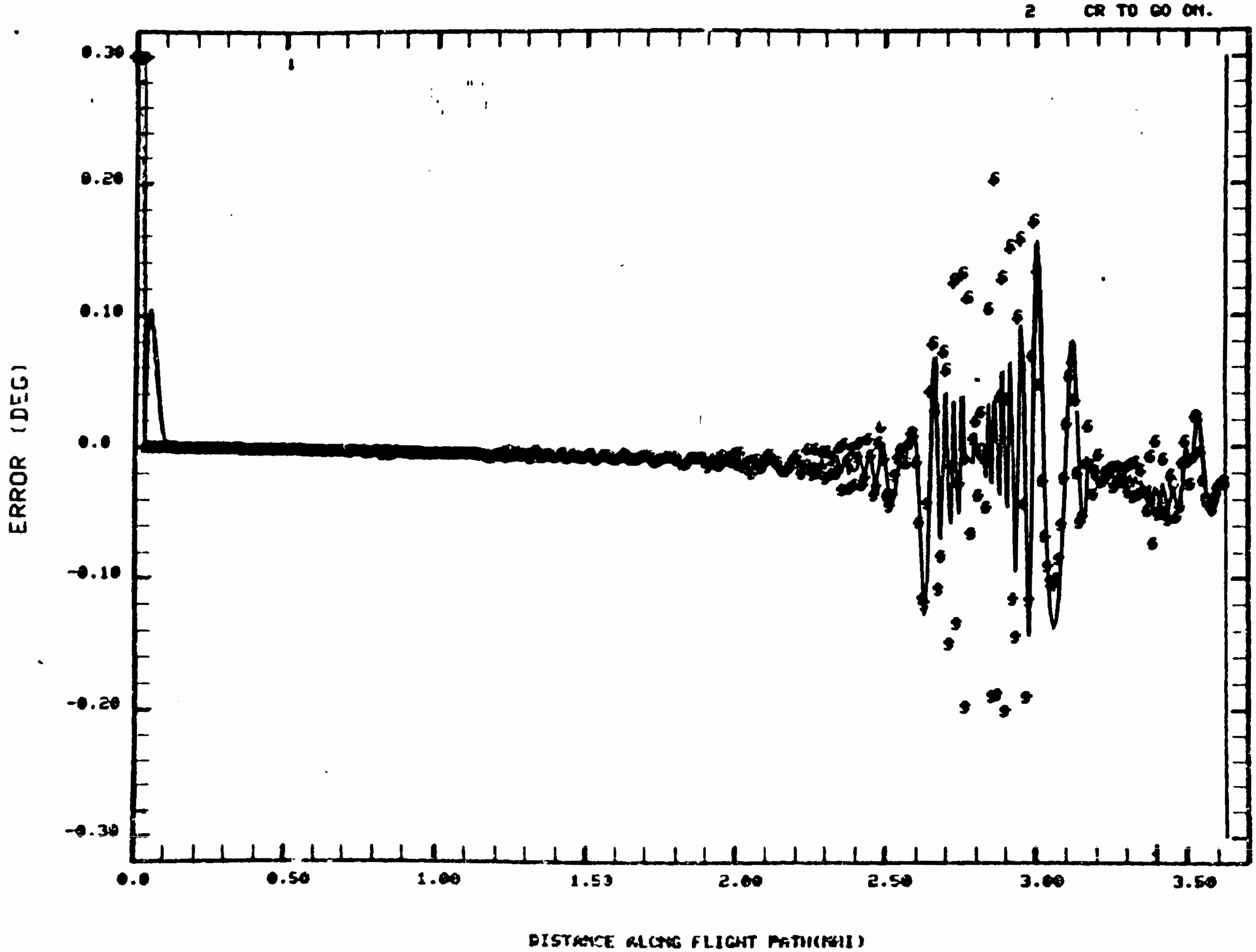

FIGURE 24. SCENARIO 2, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, AZIMUTH ANTENNA SIMULATED RECEIVER ERROR PLOT

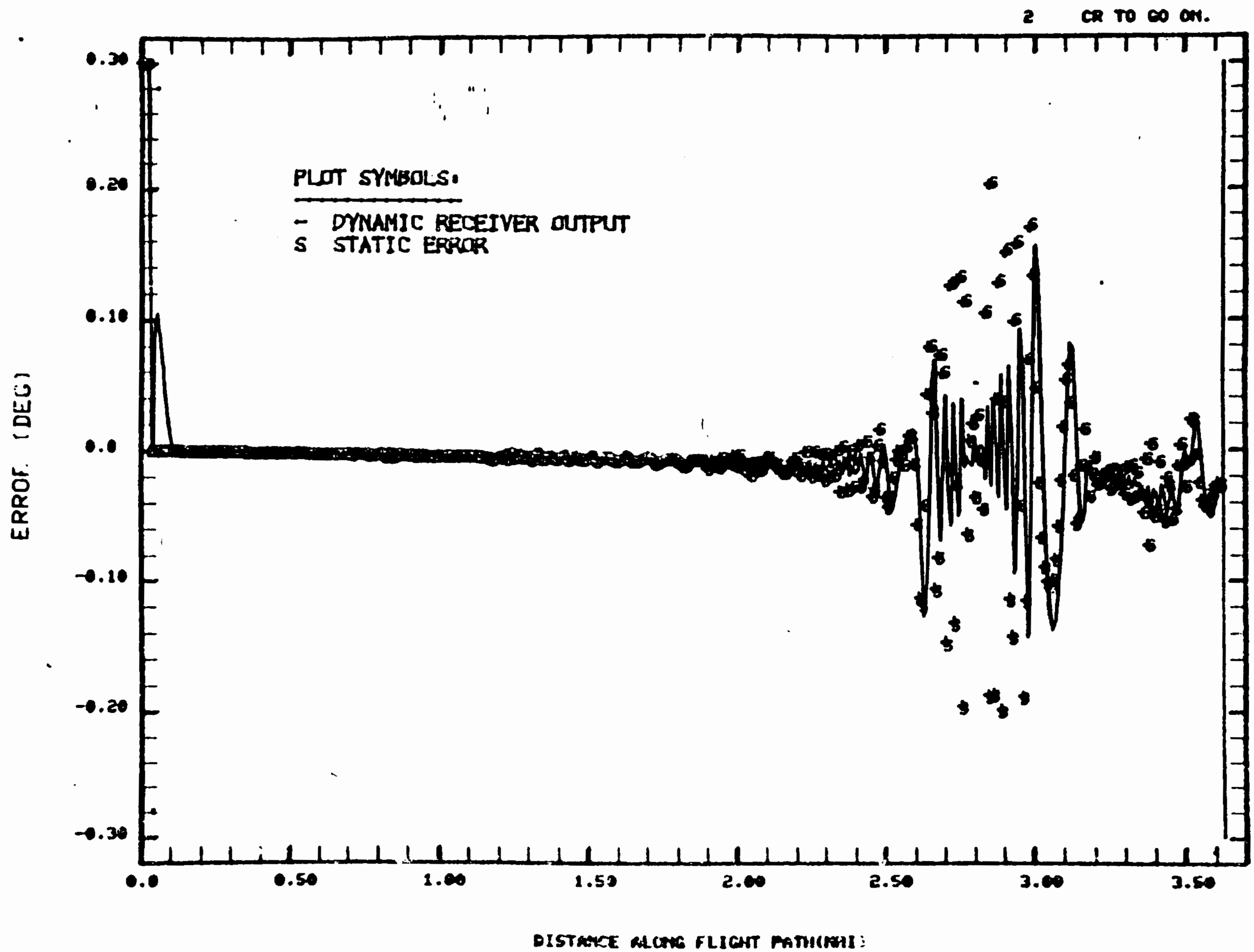

FIGURE 25. SCENARIO 2, FAA SYSTEM MODEL OUTPUT WITH LINCOLN LABORATORY DATA SET 8 INPUT COMPARED TO ORIGINAL LINCOLN LABORATORY OUTPUT

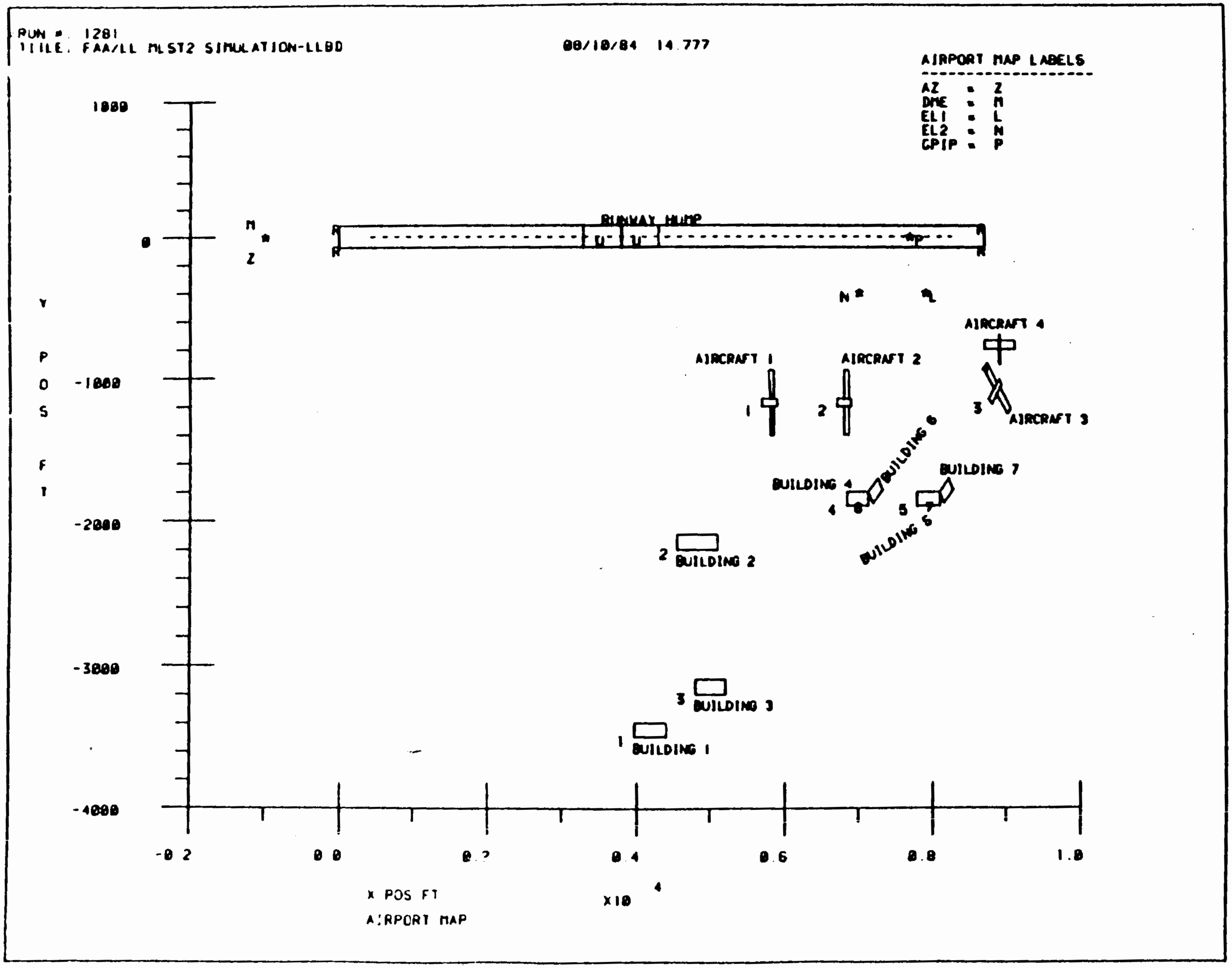

FIGURE 26. SCENARIO 3, AIRPORT MAP SHOWING BUILDING AND AIRCRAFT LOCATIONS

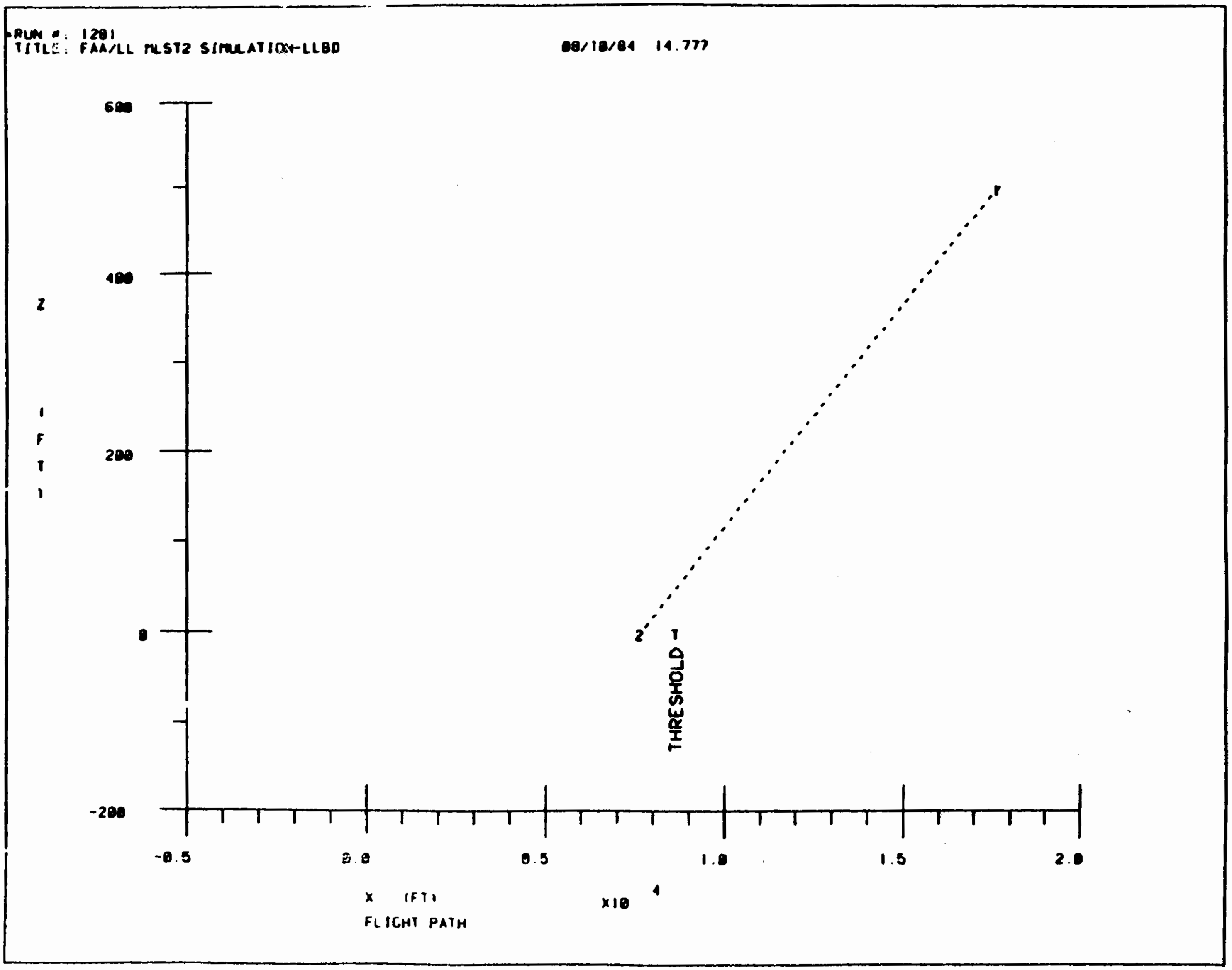

FIGURE 27. SCENARIO 3, APPROACH FLIGHTPATH IN X-Z COORDINATE PLANE

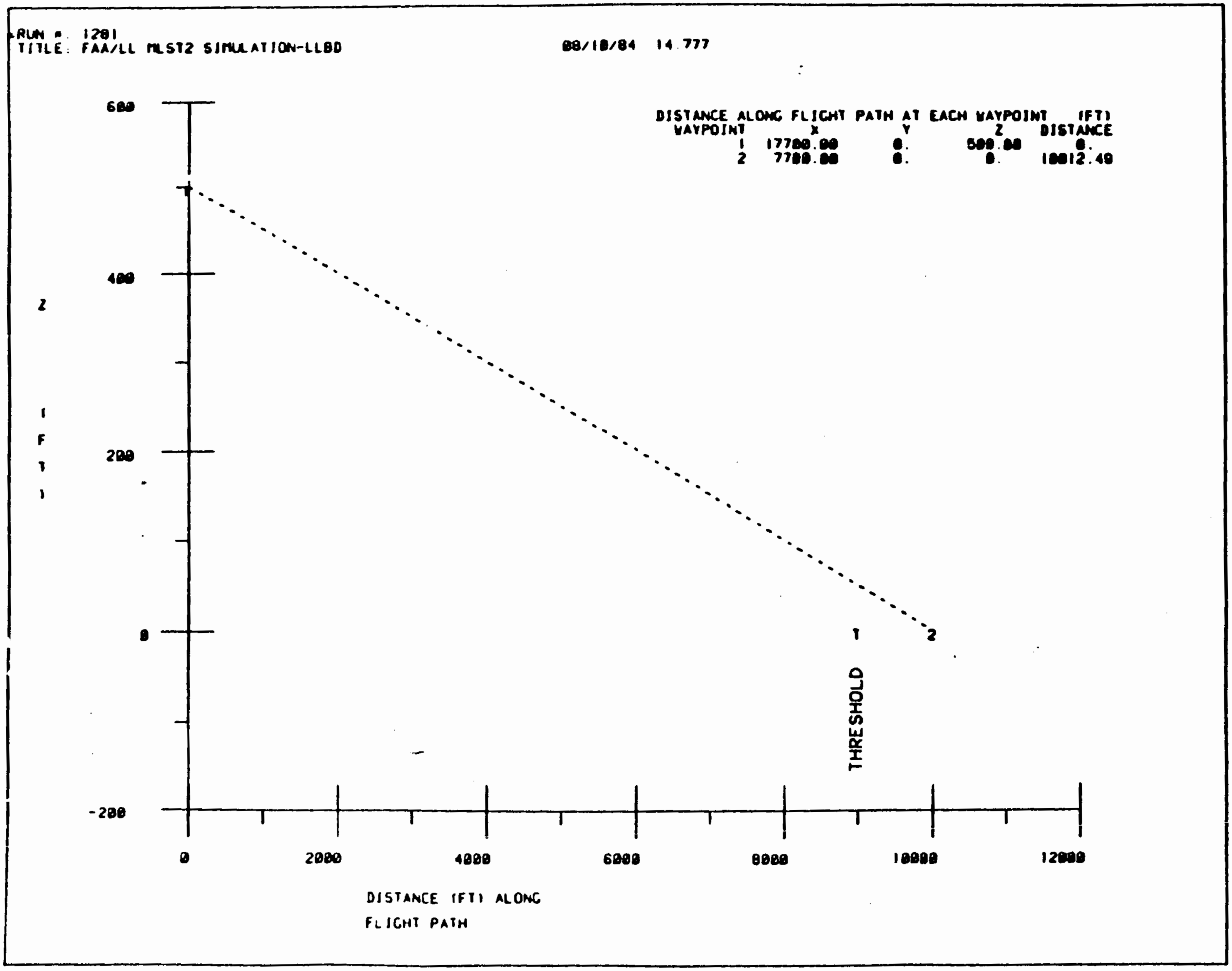

FIGURE 28. SCENARIO 3, APPROACH FLIGHTPATH IN DISTANCE-Z COORDINATE PLANE

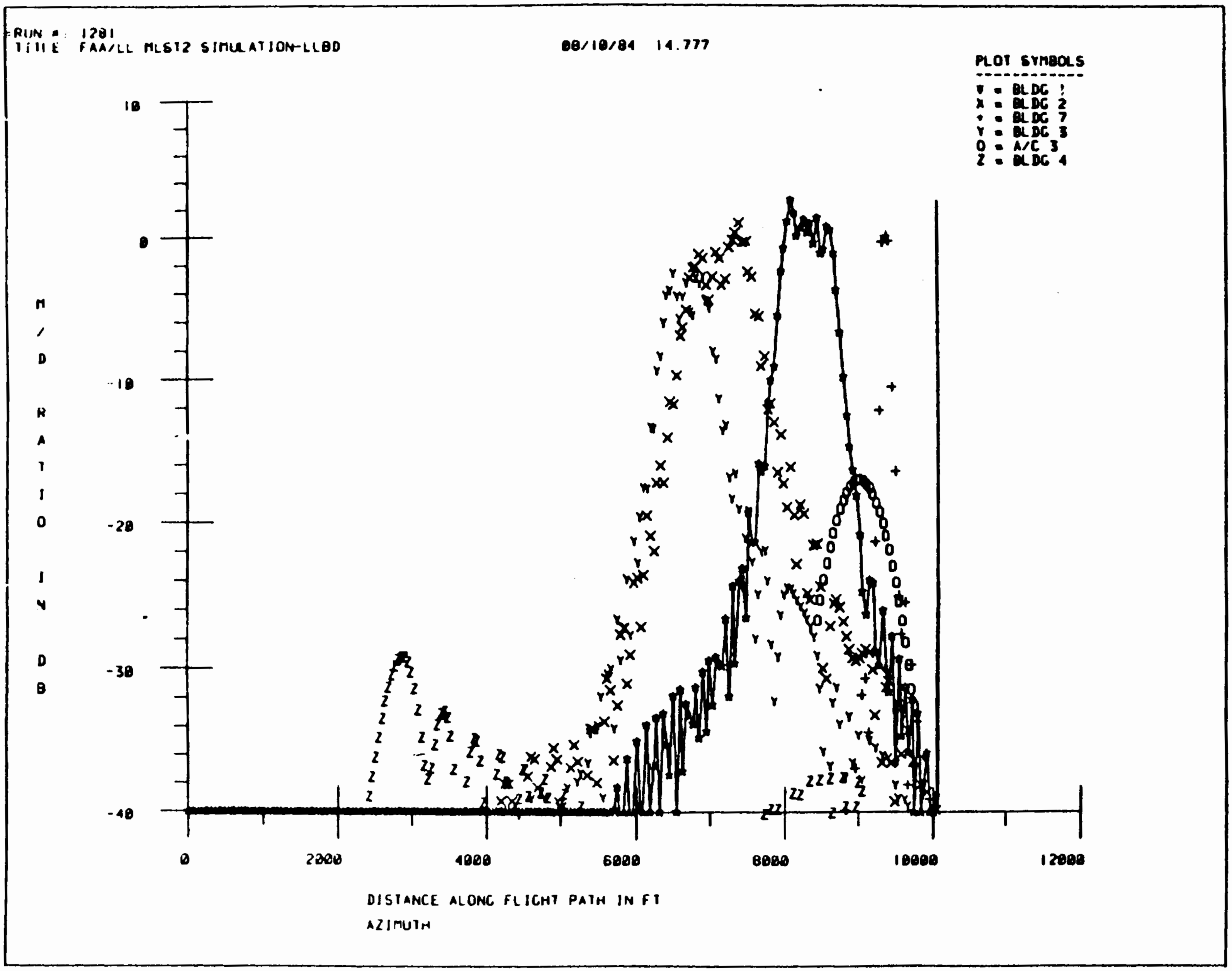

FIGURE 29. SCENARIO 3, FAA OUTPUT, AZIMUTH ANTENNA, MULTIPATH/DIRECT SIGNAL PLOT

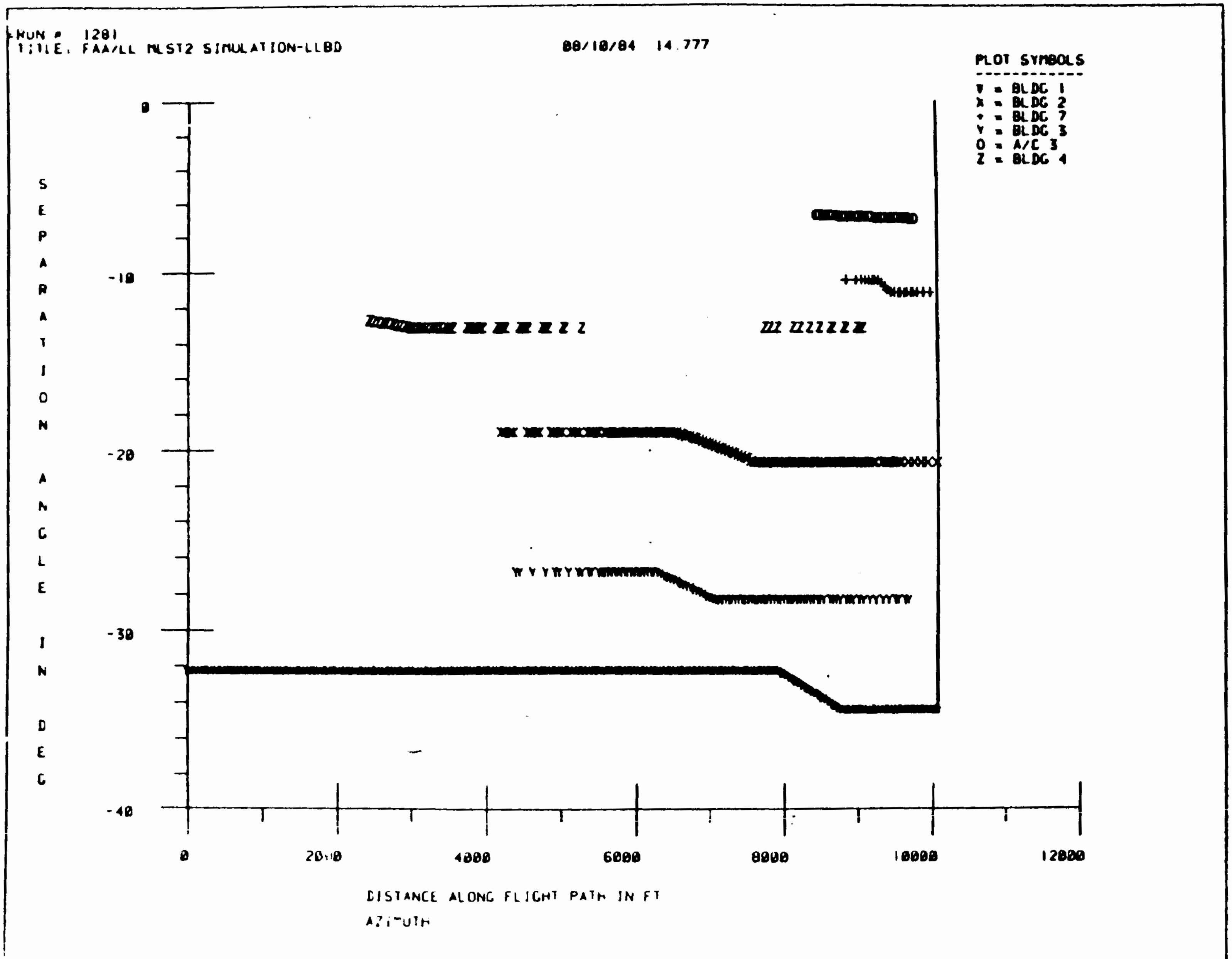

FIGURE 30. SCENARIO 3, FAA OUTPUT, AZIMUTH ANTENNA, SEPARATION ANGLE PLOT

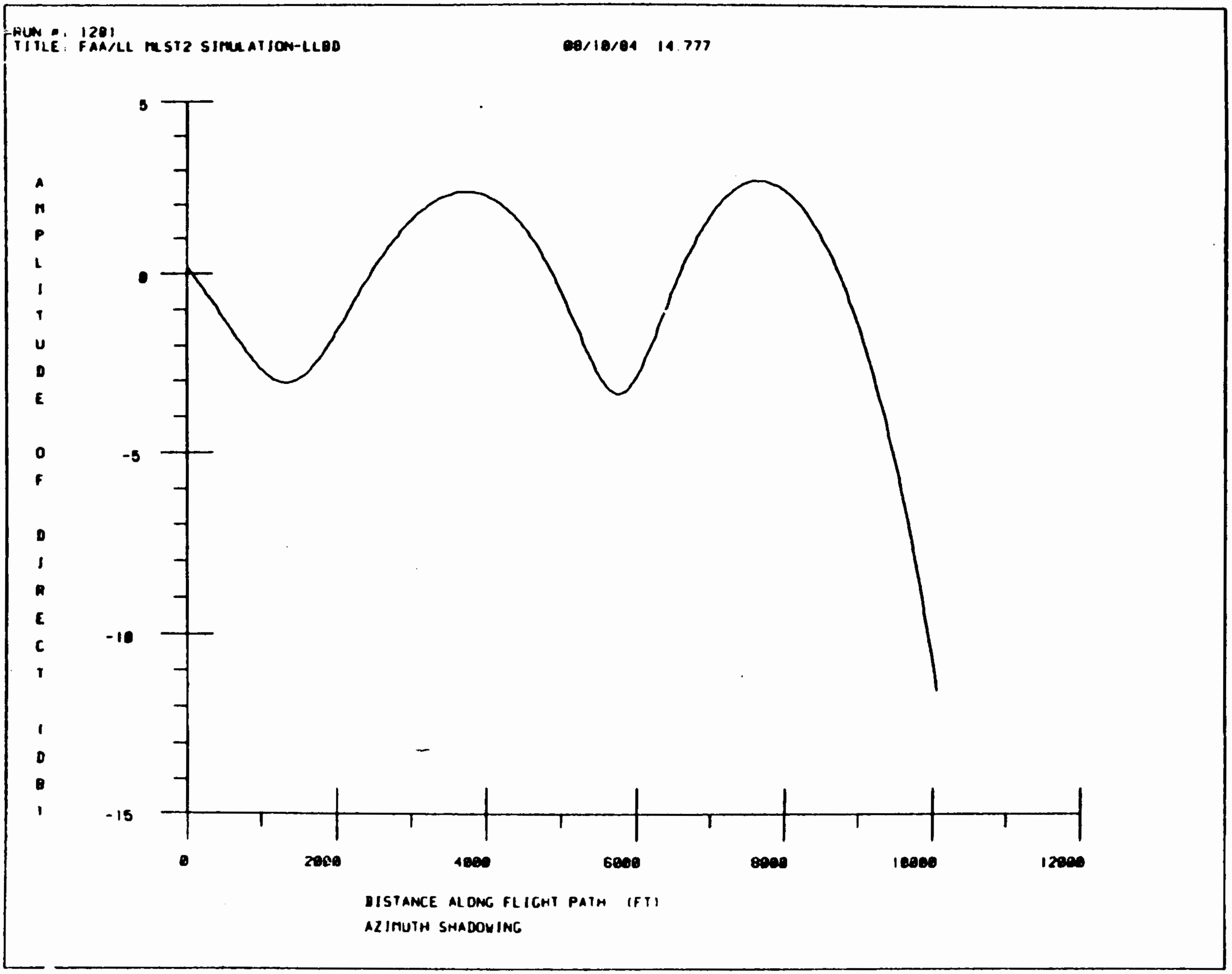

FIGURE 31. SCENARIO 3, FAA OUTPUT, AZIMUTH ANTENNA SHADOWING PLOT

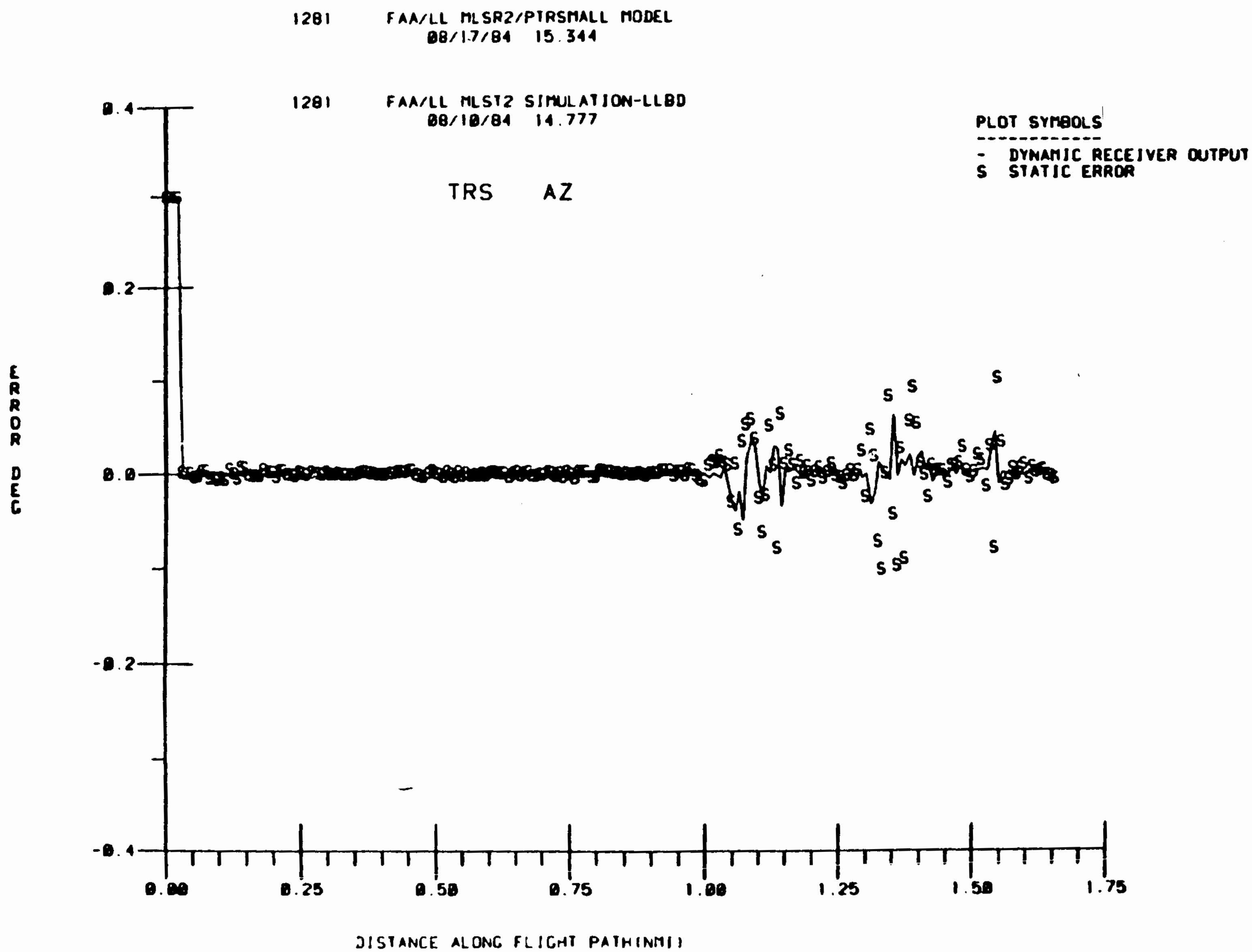

FIGURE 32. SCENARIO 3, FAA OUTPUT, AZIMUTH ANTENNA, SIMULATED RECEIVER ERROR PLOT

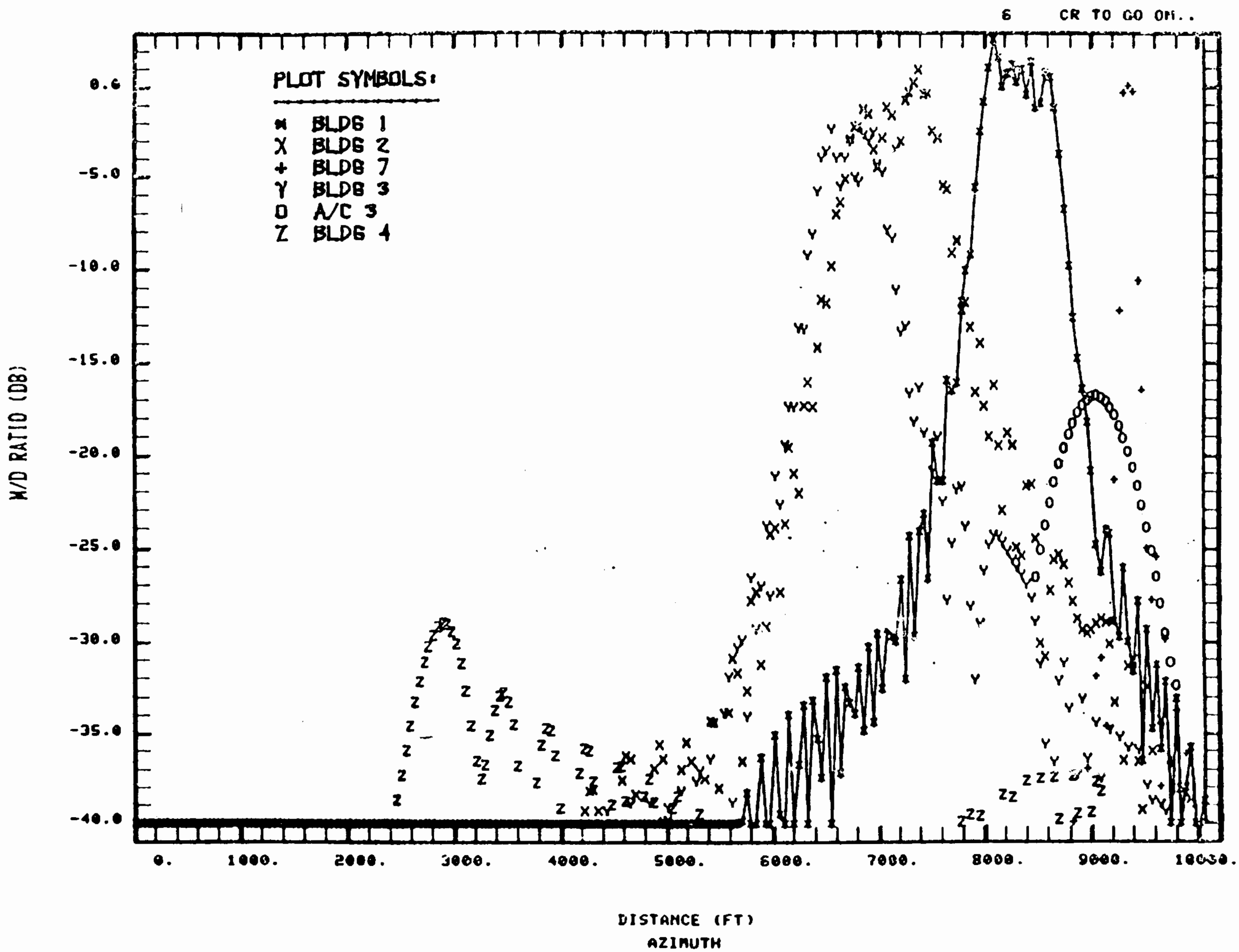

FIGURE 33. SCENARIO 3, LINCOLN LABORATORY OUTPUT, AZIMUTH ANTENNA, MULTIPATH/ DIRECT SIGNAL PLOT

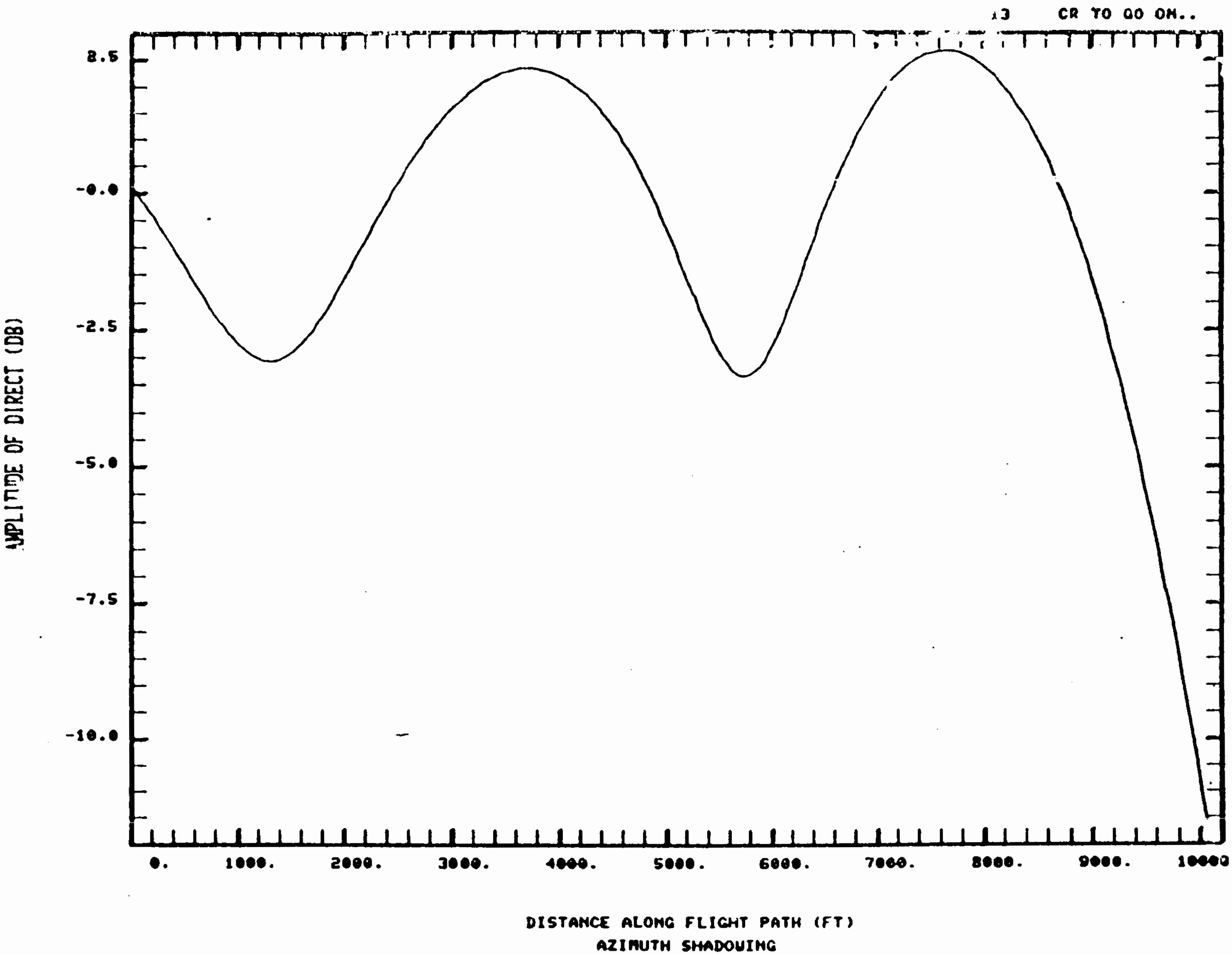

FIGURE 35. SCENARIO 3, LINCOLN LABORATORY OUTPUT, AZIMUTH ANTENNA SHADOWING PLOT

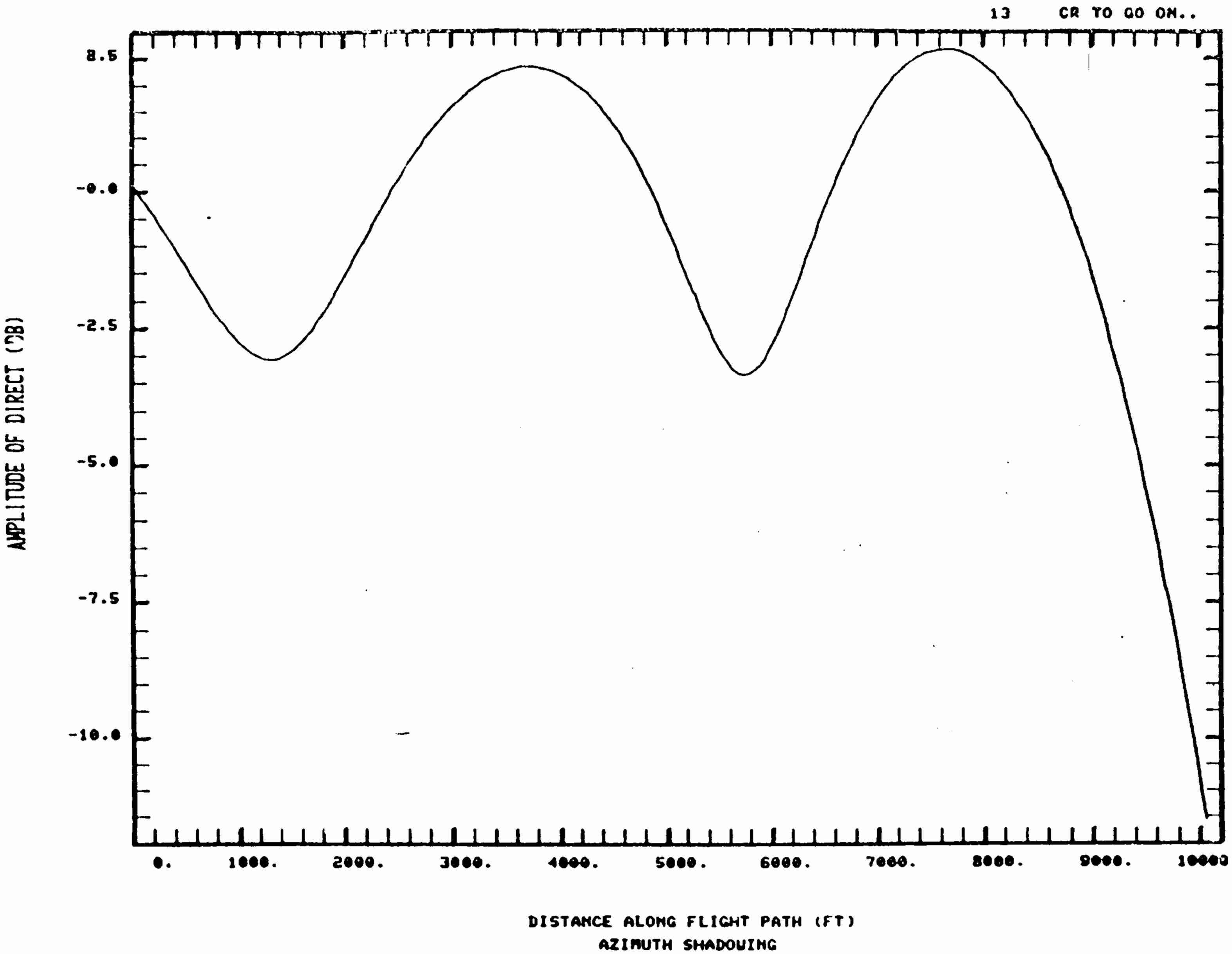

FIGURE 35. SCENARIO 3, LINCOLN LABORATORY OUTPUT, AZIMUTH ANTENNA SHADOWING PLOT

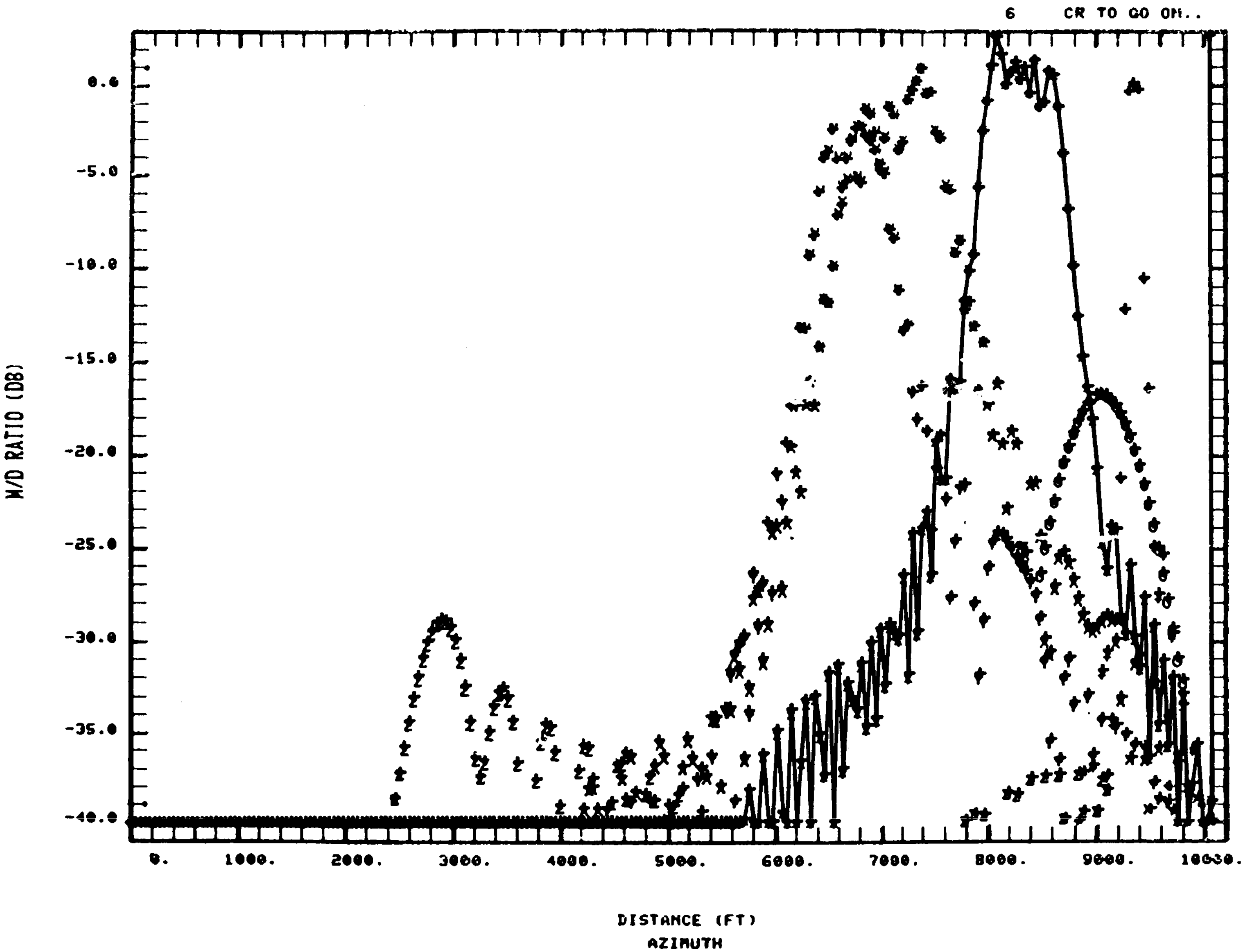

FIGURE 36. SCENARIO 3, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, AZIMUTH ANTENNA, MULTIPATH/DIRECT SIGNAL PLOT

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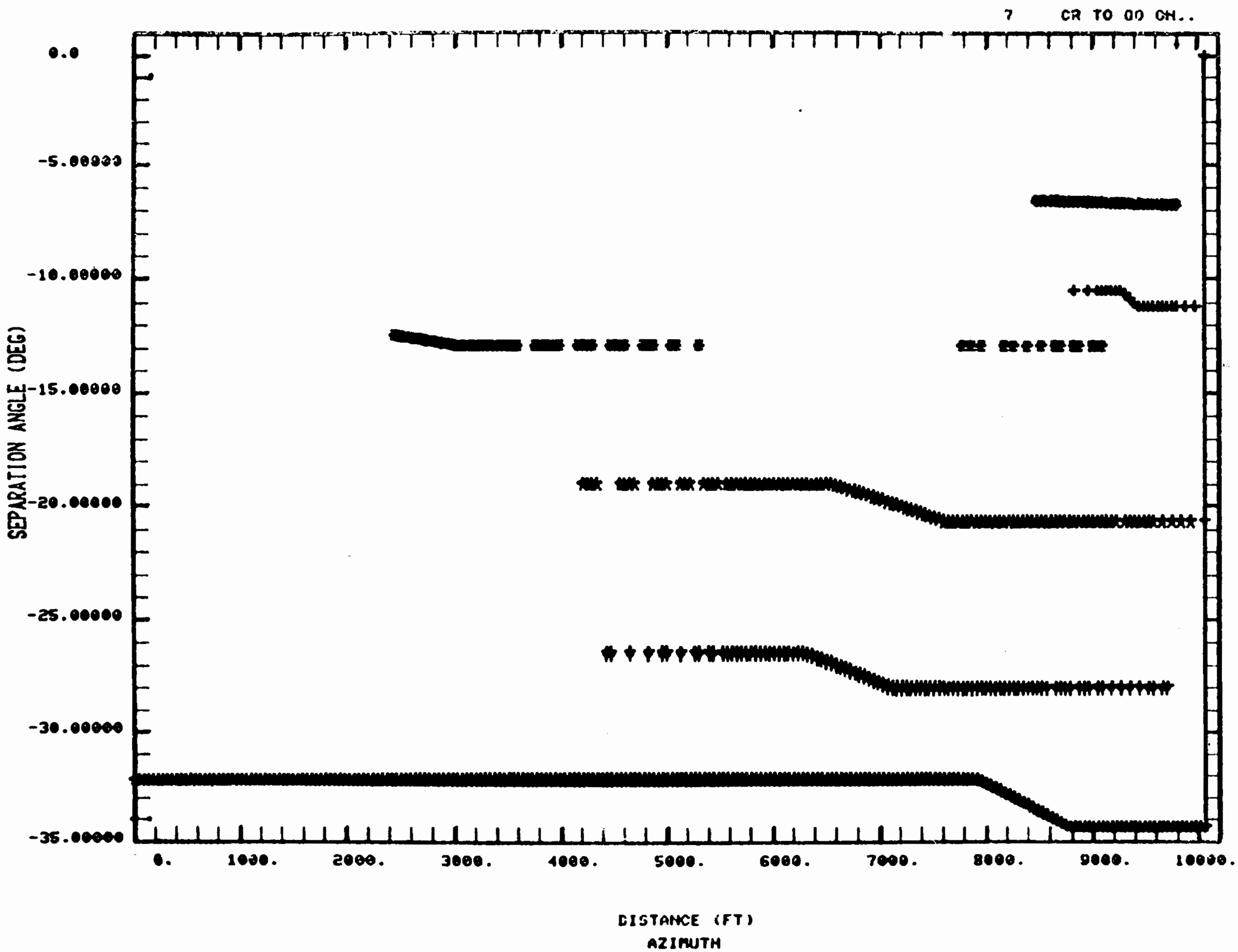

FIGURE 37. SCENARIO 3, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, AZIMUTH ANTENNA, SEPARATION ANGLE PLOT

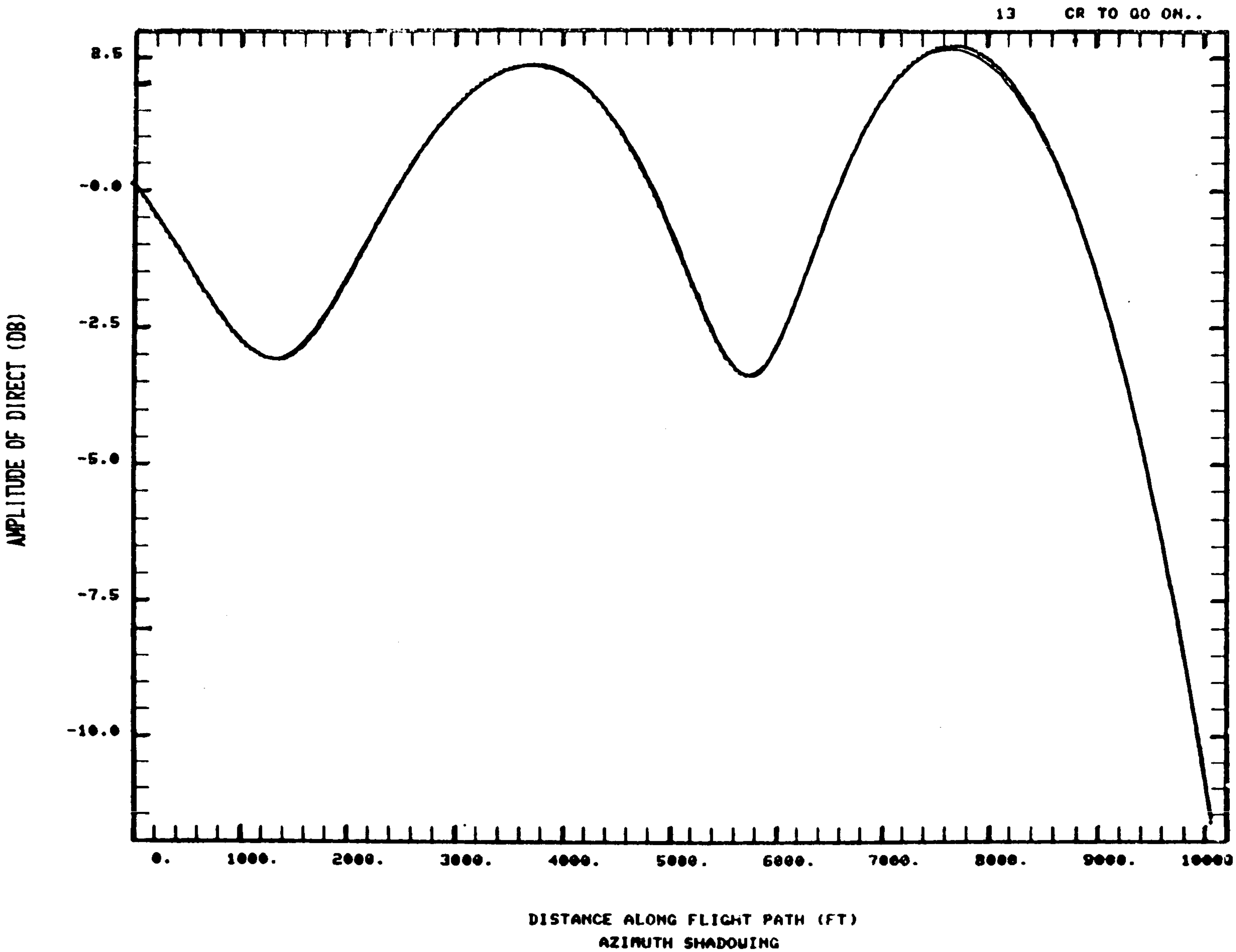

FIGURE 38. SCENARIO 3, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, AZIMUTH ANTENNA SHADOWING PLOT

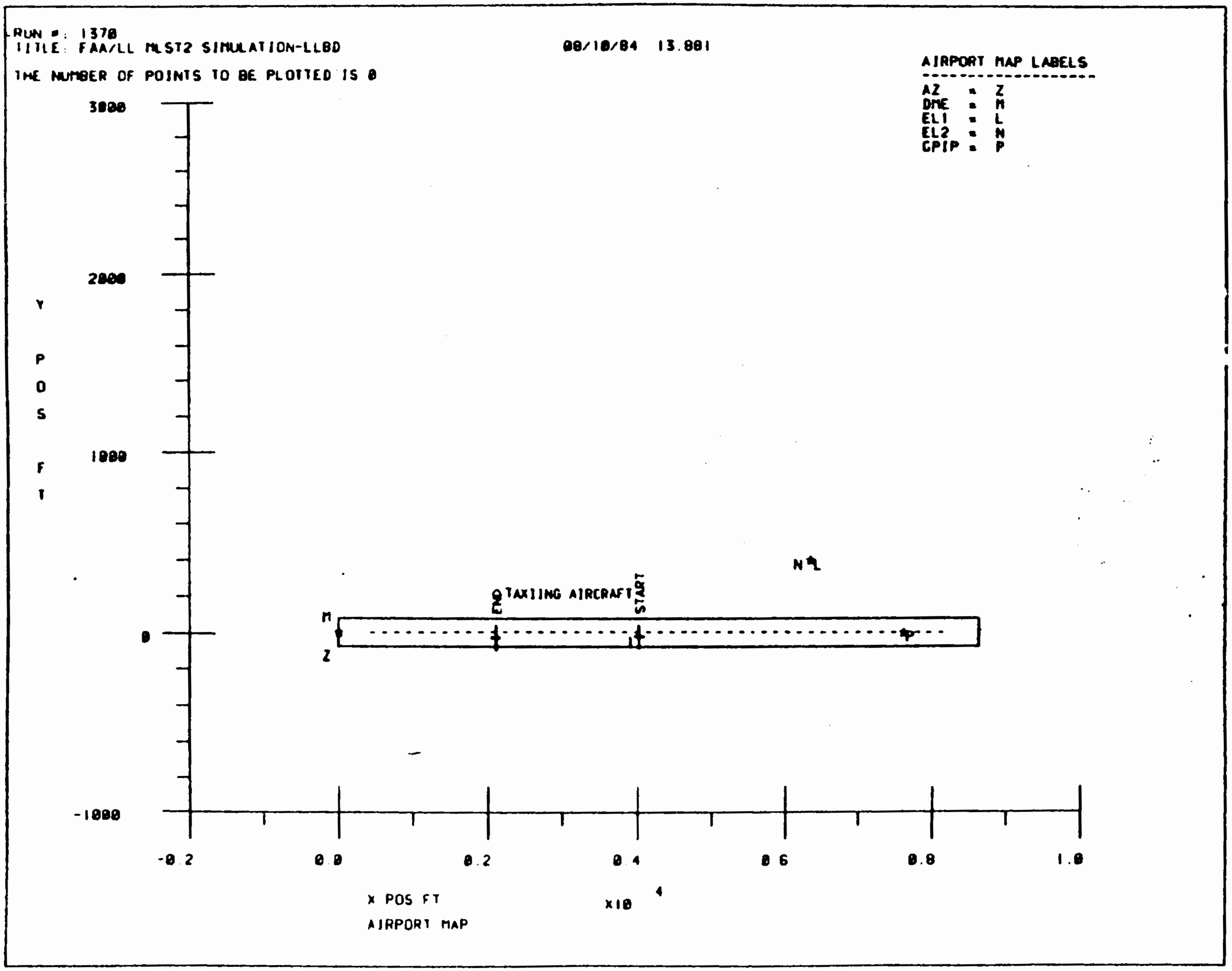

FIGURE 39. SCENARIO 4, AIRPORT MAP SHOWING TAXIING AIRCRAFT

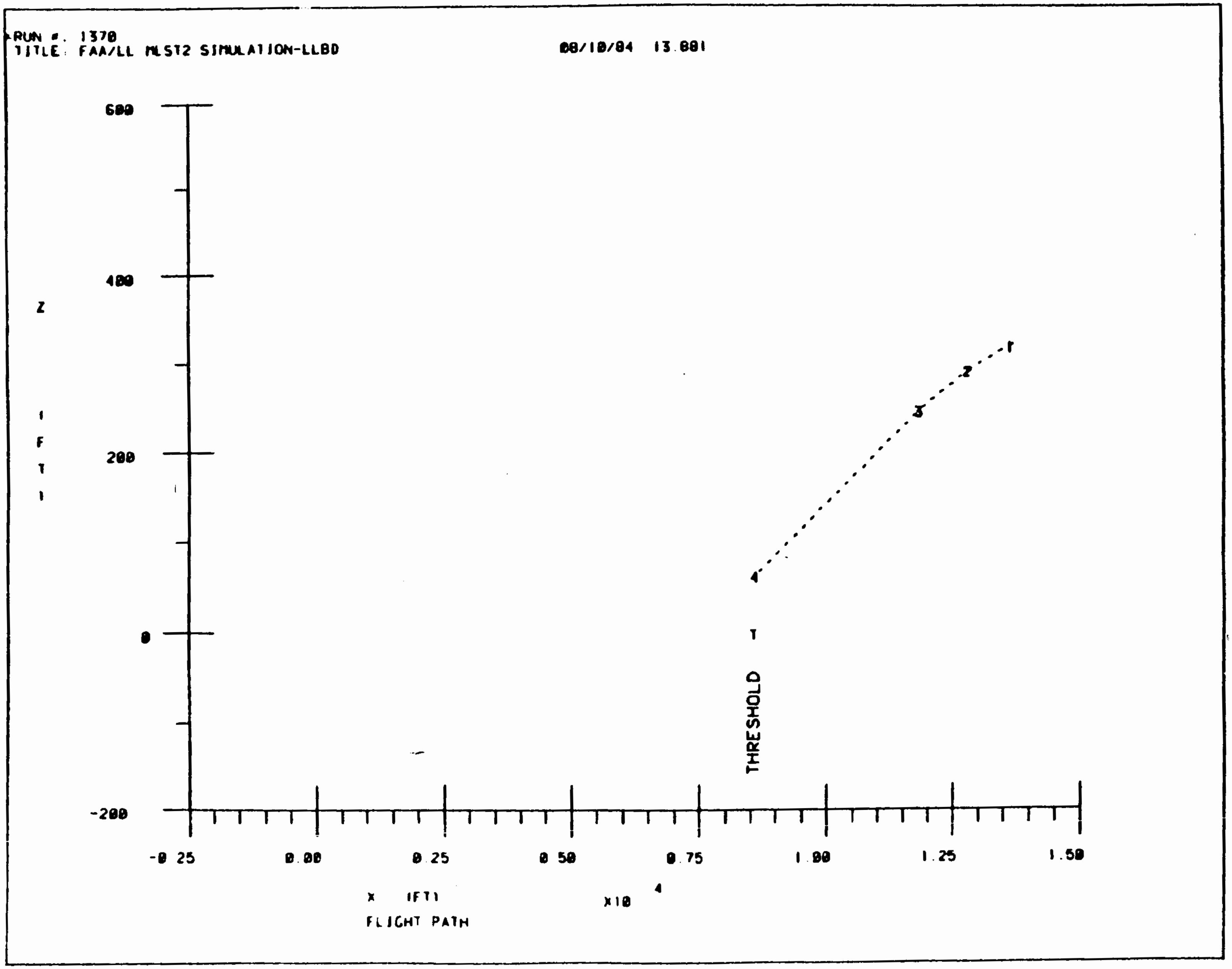

FIGURE 40. SCENARIO 4, APPROACH FLIGHTPATH IN X-Z COORDINATE PLANE

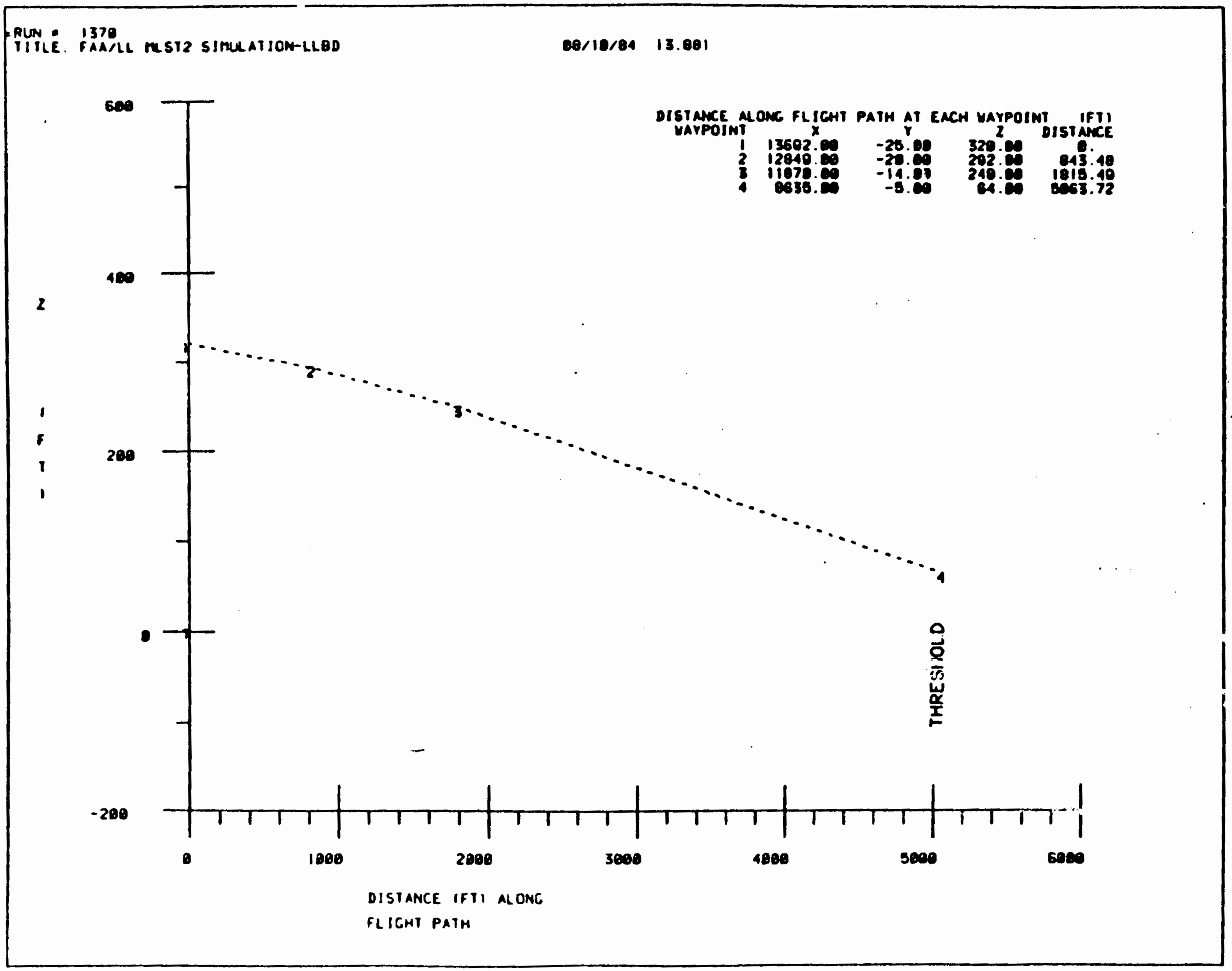

FIGURE 41. SCENARIO 4, APPROACH FLIGHTPATH IN DISTANCE-Z COORDINATE PLANE

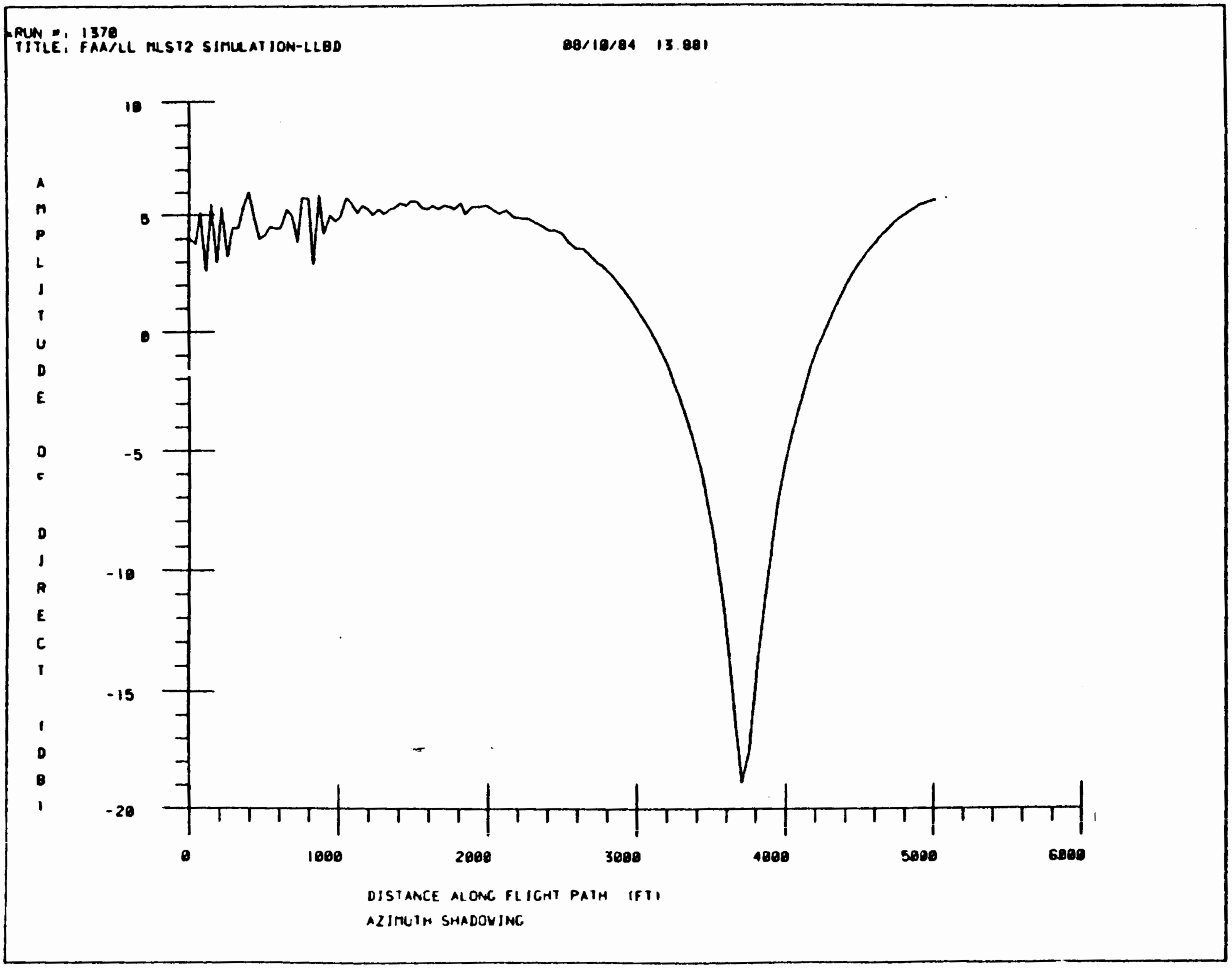

FIGURE 42. SCENARIO 4, FAA OUTPUT, AZIMUTH ANTENNA SHADOWING PLOT

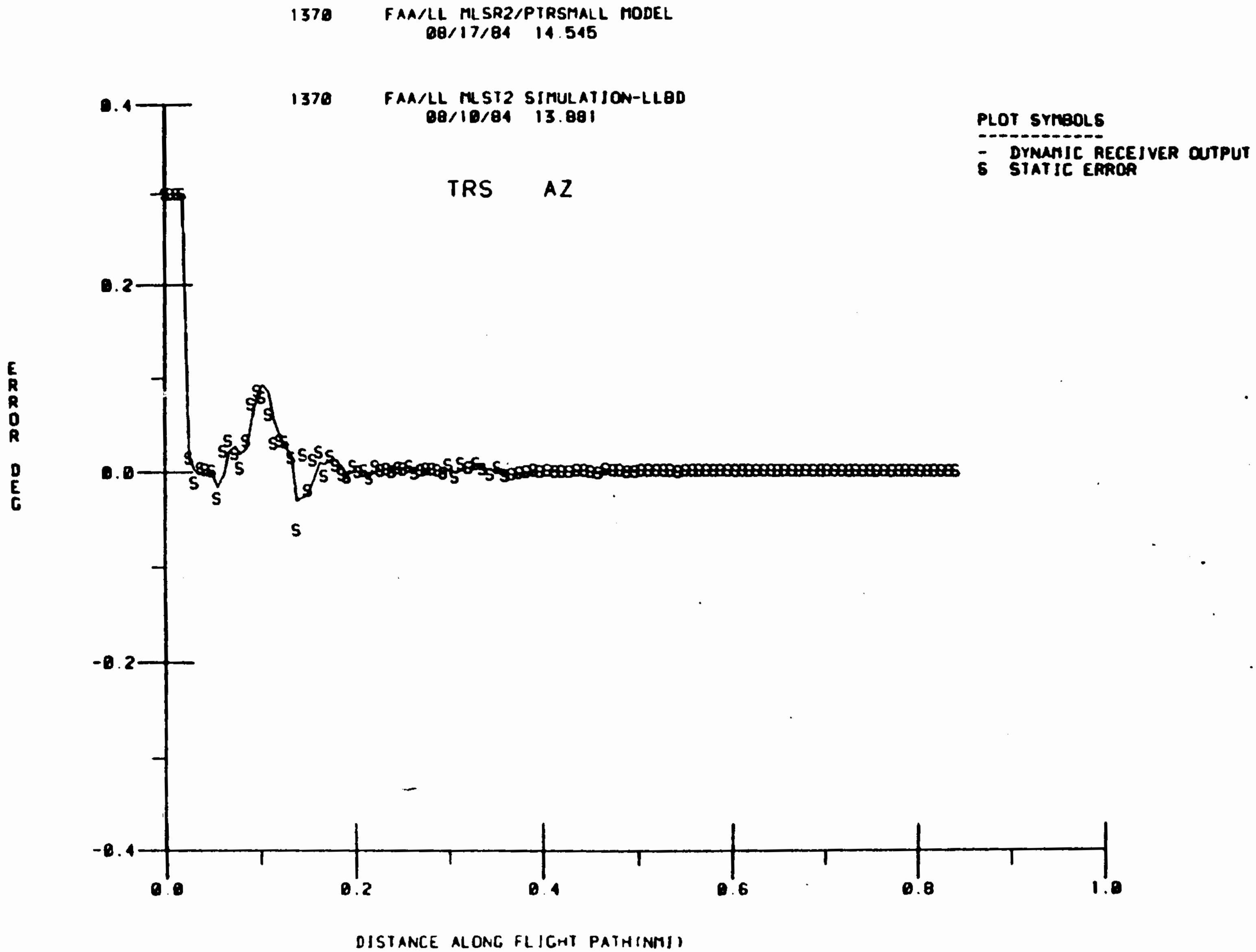

FIGURE 43. SCENARIO 4, FAA OUTPUT, AZIMUTH ANTENNA, SIMULATED RECEIVER ERROR PLOT

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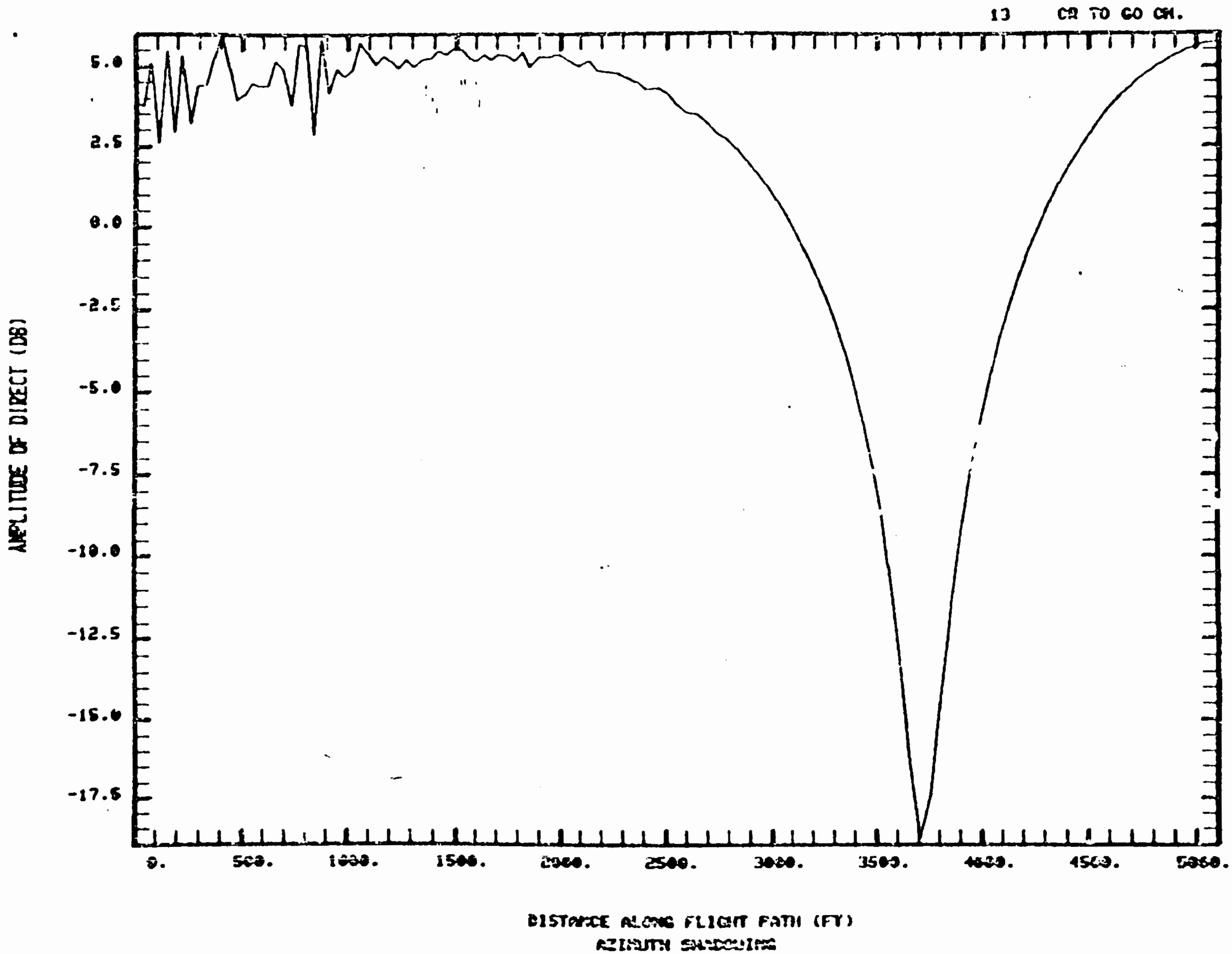

FIGURE 44. SCENARIO 4, LINCOLN LABORATORY OUTPUT, AZIMUTH ANTENNA SHADOWING PLOT

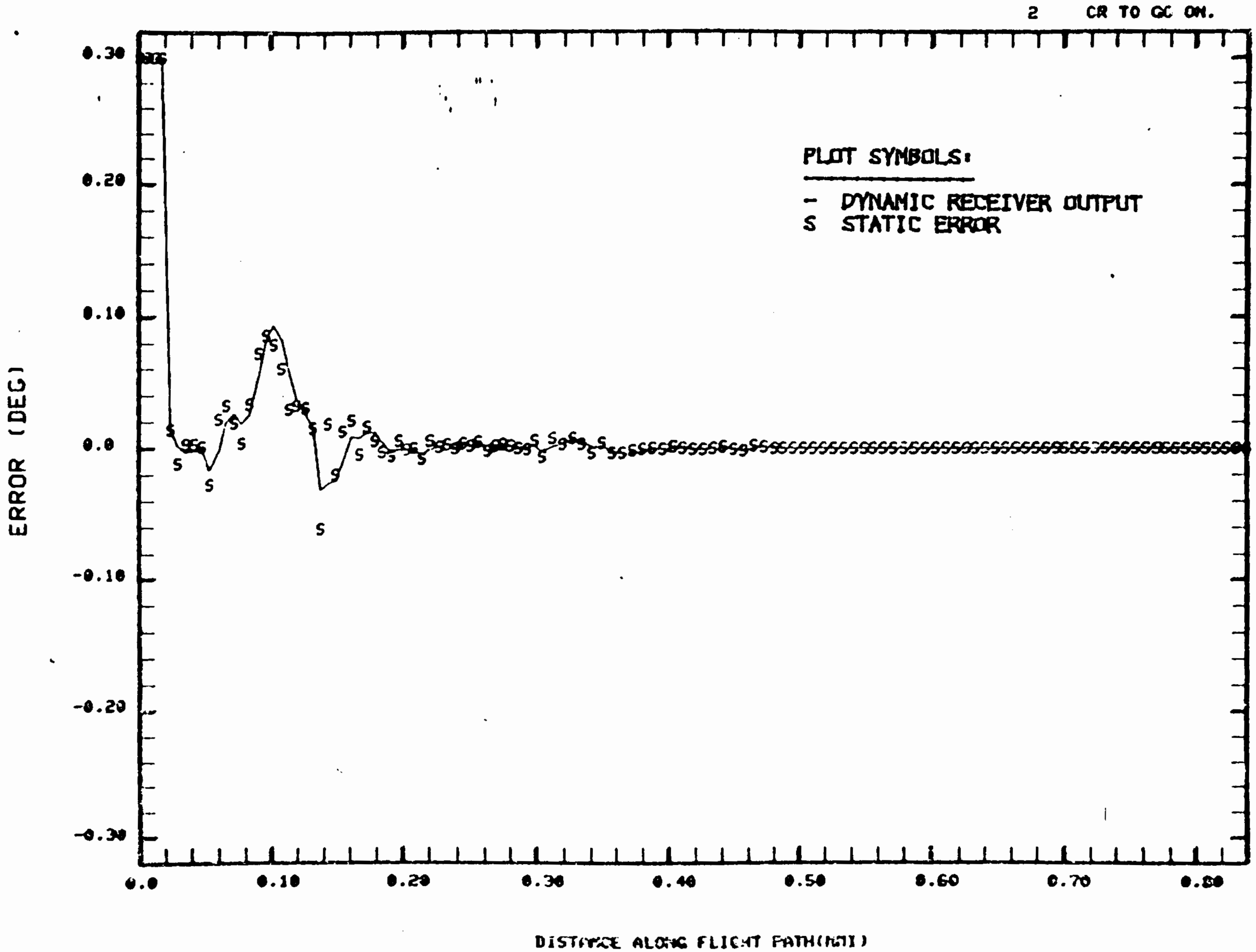

FIGURE 45. SCENARIO 4, LINCOLN LABORATORY OUTPUT, AZIMUTH ANTENNA, SIMULATED RECEIVER ERROR PLOT

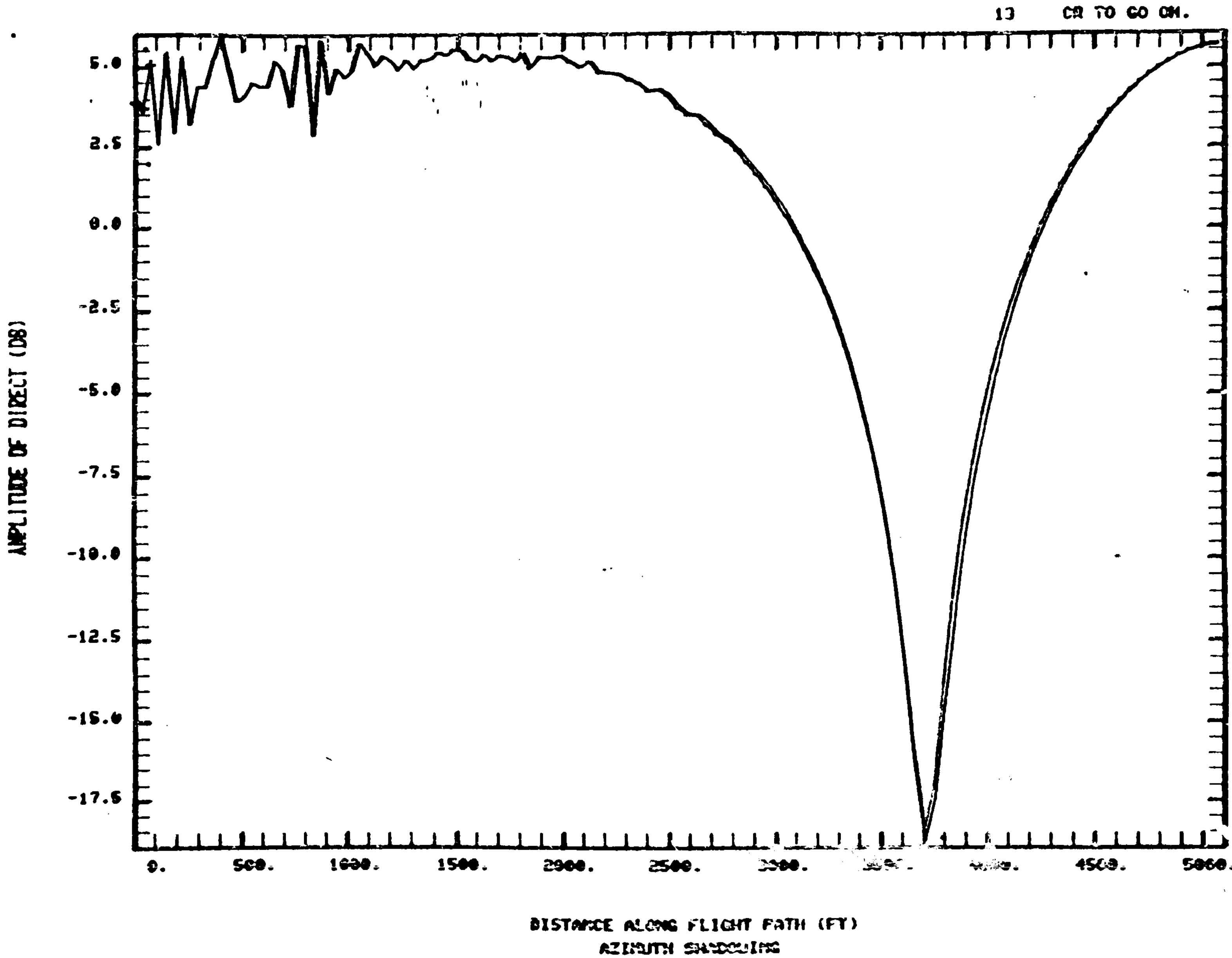

FIGURE 46. SCENARIO 4, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, AZIMUTH ANTENNA SHADOWING PLOT

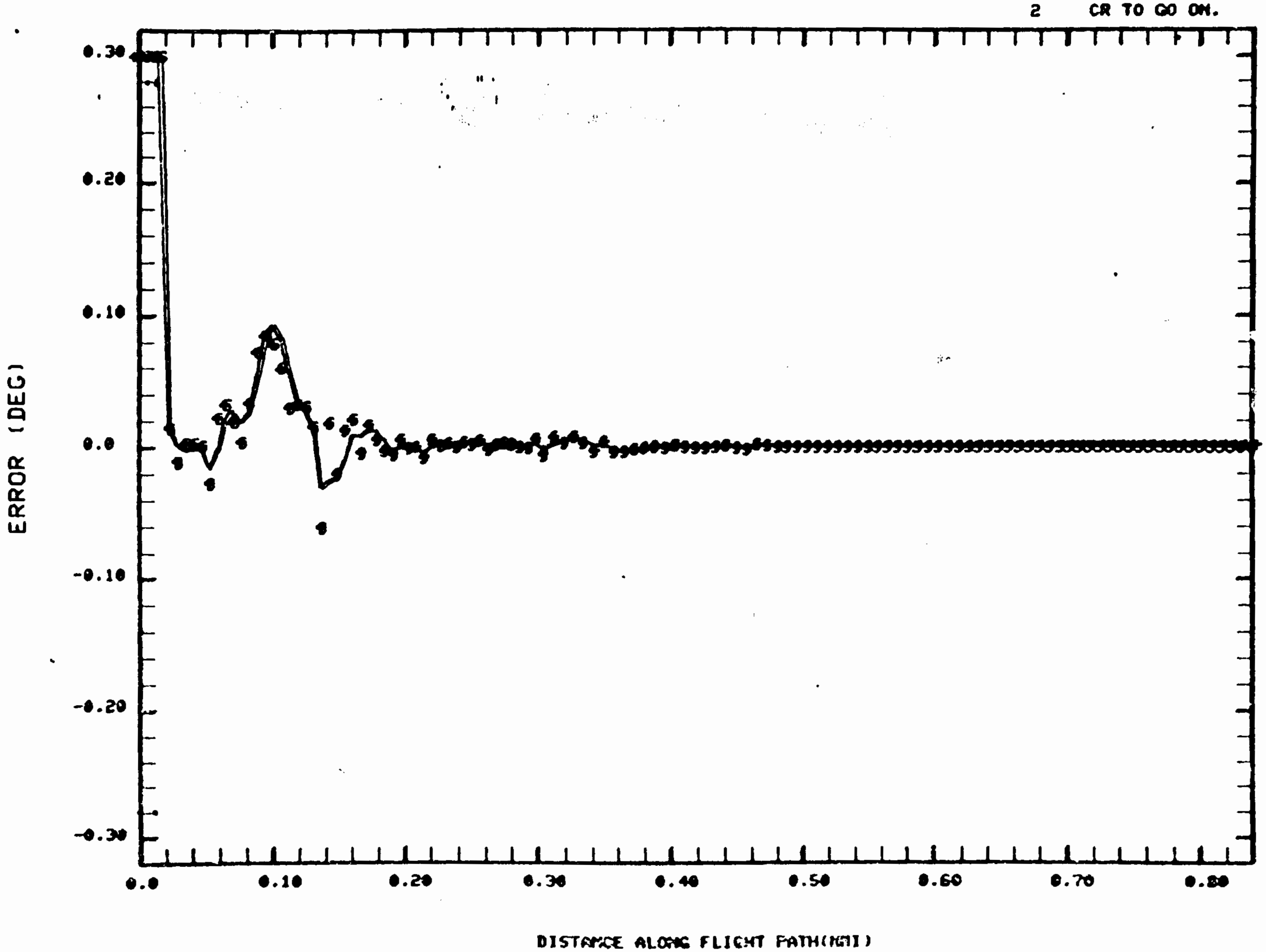

FIGURE 47. SCENARIO 4, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, AZIMUTH ANTENNA, SIMULATED RECEIVER ERROR PLOT

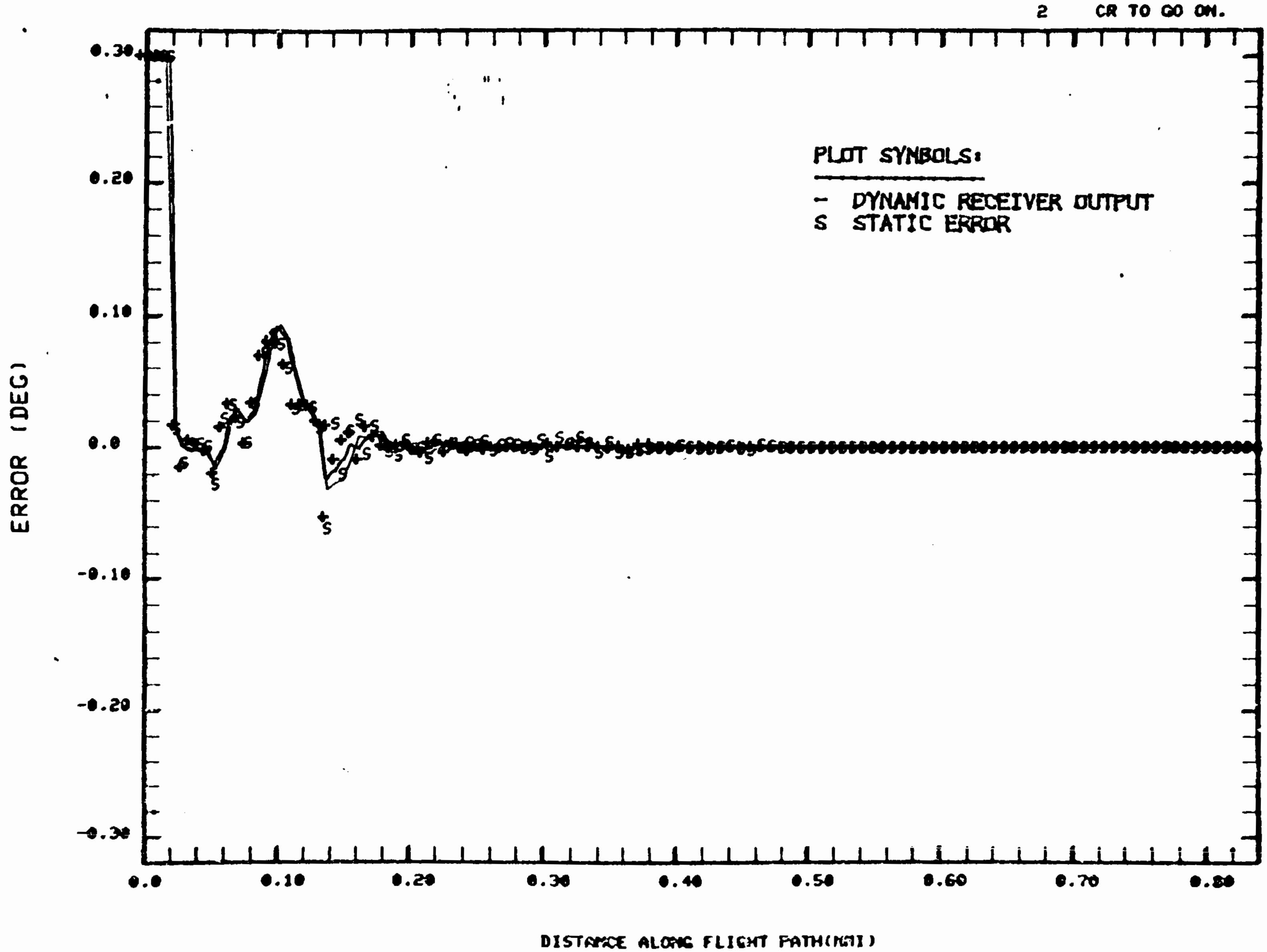

FIGURE 48. SCENARIO 4, FAA SYSTEM MODEL OUTPUT WITH LINCOLN LABORATORY DATA SET 8 INPUT COMPARED TO ORIGINAL LINCOLN LABORATORY OUTPUT

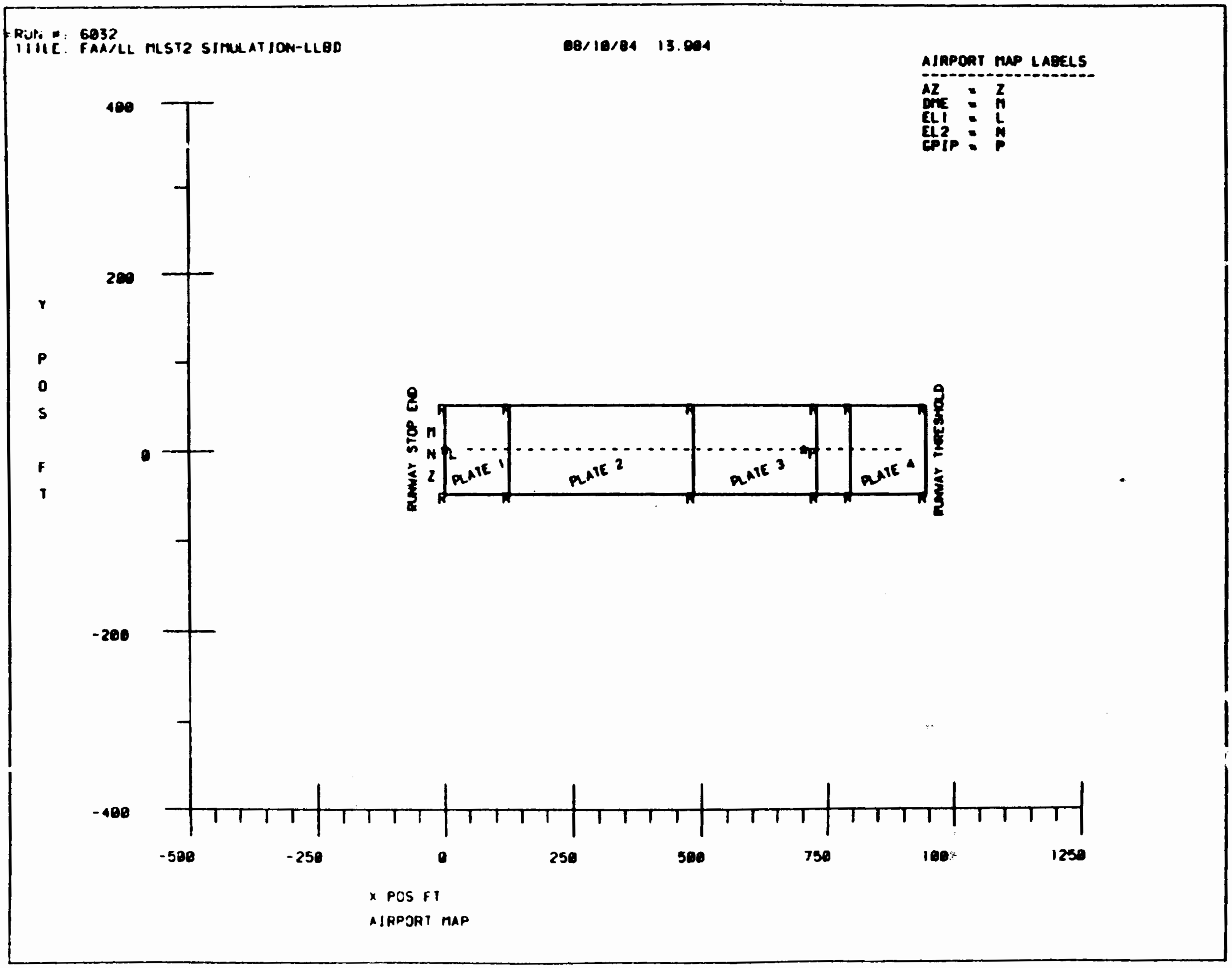

FIGURE 49. SCENARIO 5, AIRPORT MAP SHOWING SLOPED TERRAIN PLATES

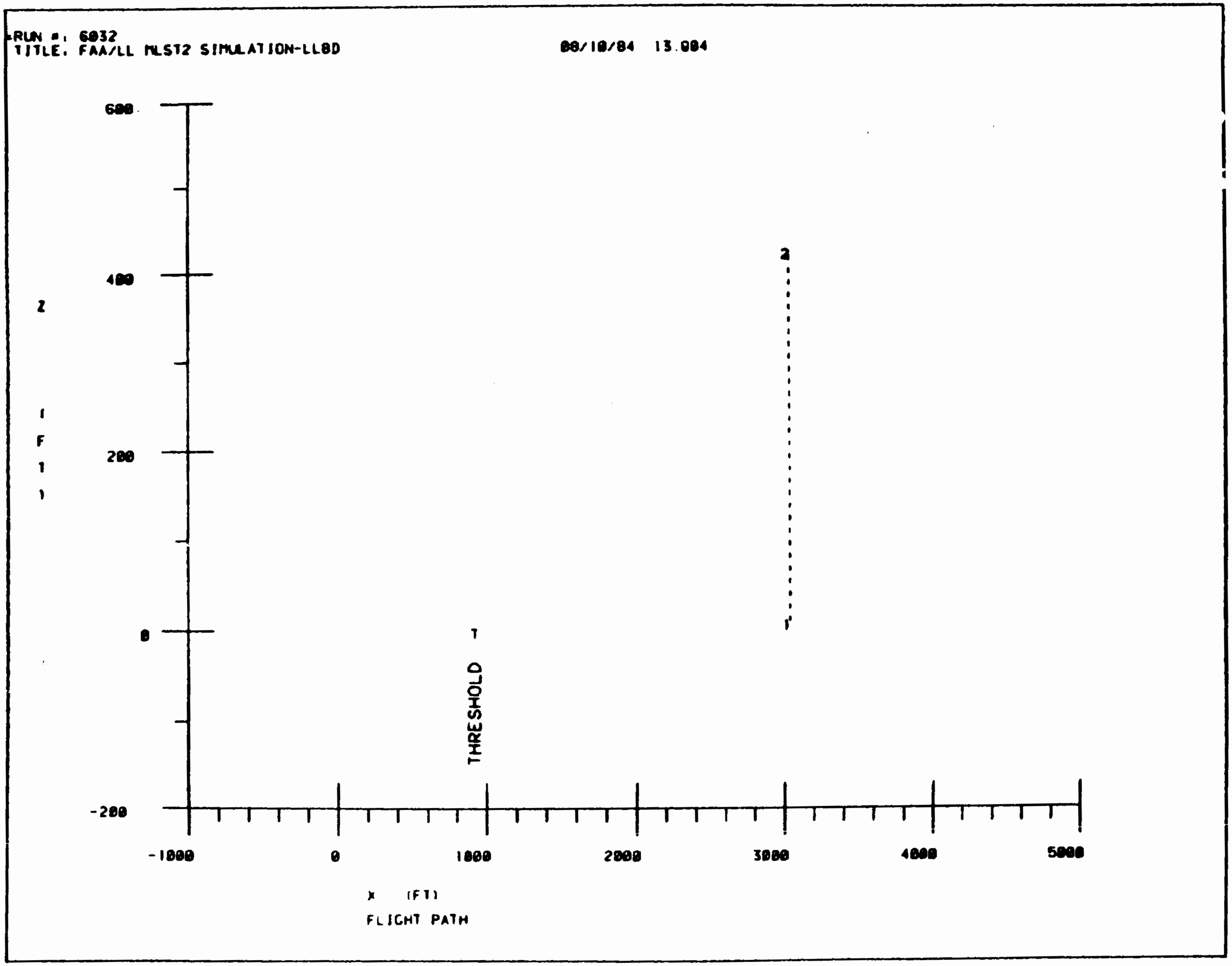

FIGURE 50. SCENARIO 5, APPROACH FLIGHTPATH IN X-Z COORDINATE PLANE

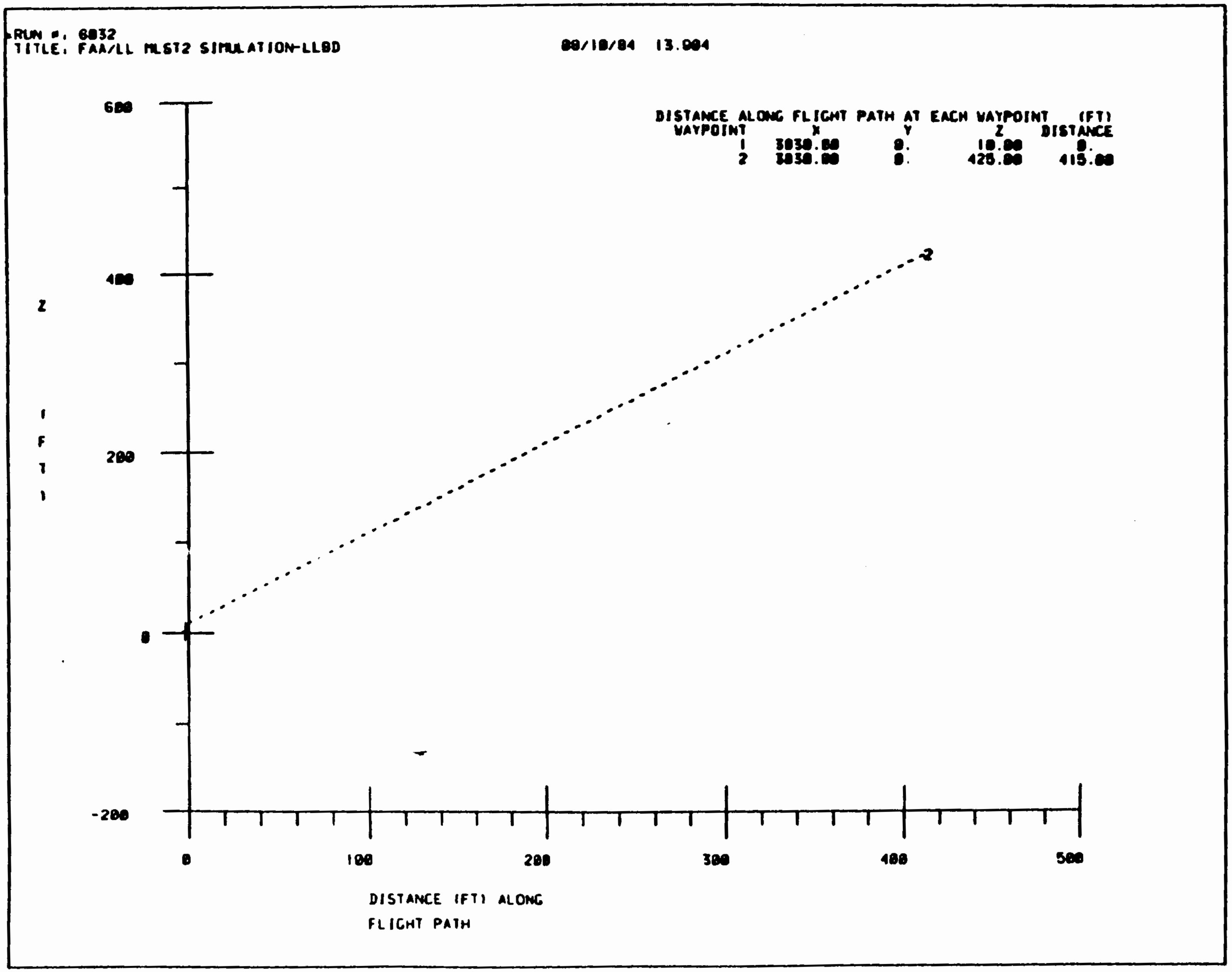

FIGURE 51. SCENARIO 5, APPROACH FLIGHTPATH IN DISTANCE-Z COORDINATE PLANE

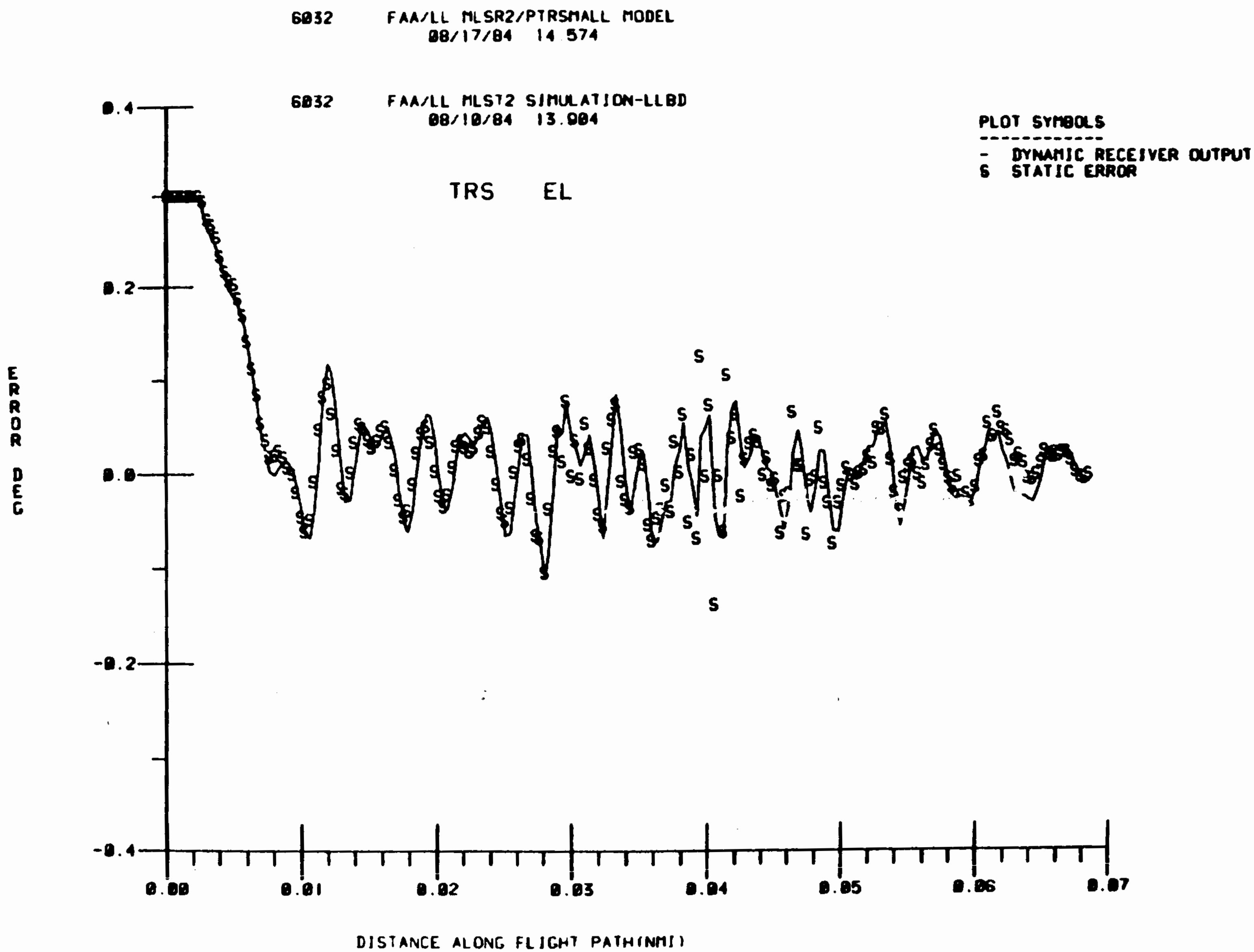

FIGURE 52. SCENARIO 5, FAA OUTPUT, ELEVATION ANTENNA, SIMULATED RECEIVER ERROR PLOT

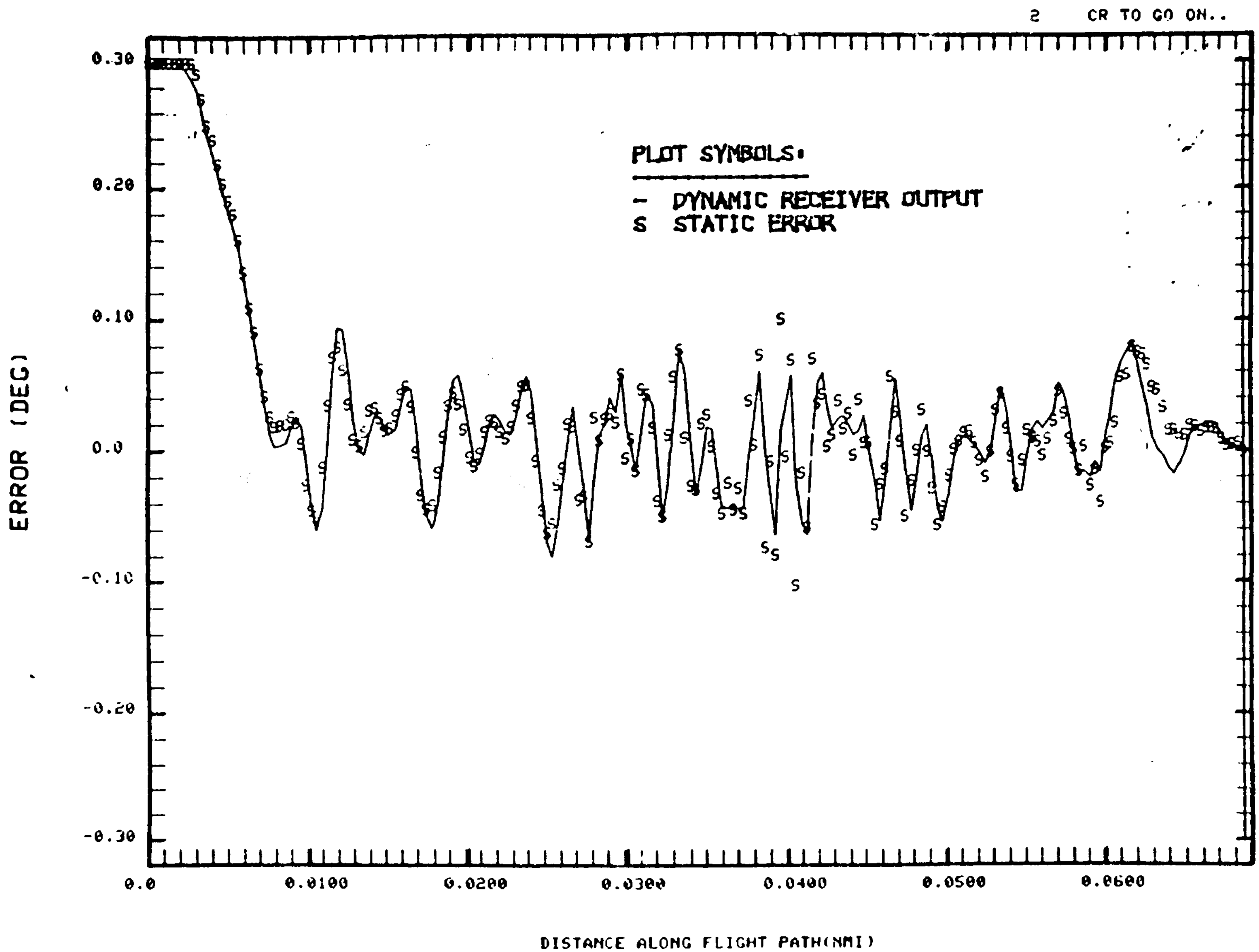

FIGURE 53. SCENARIO 5, LINCOLN LABORATORY OUTPUT, ELEVATION ANTENNA, SIMULATED RECEIVER ERROR PLOT

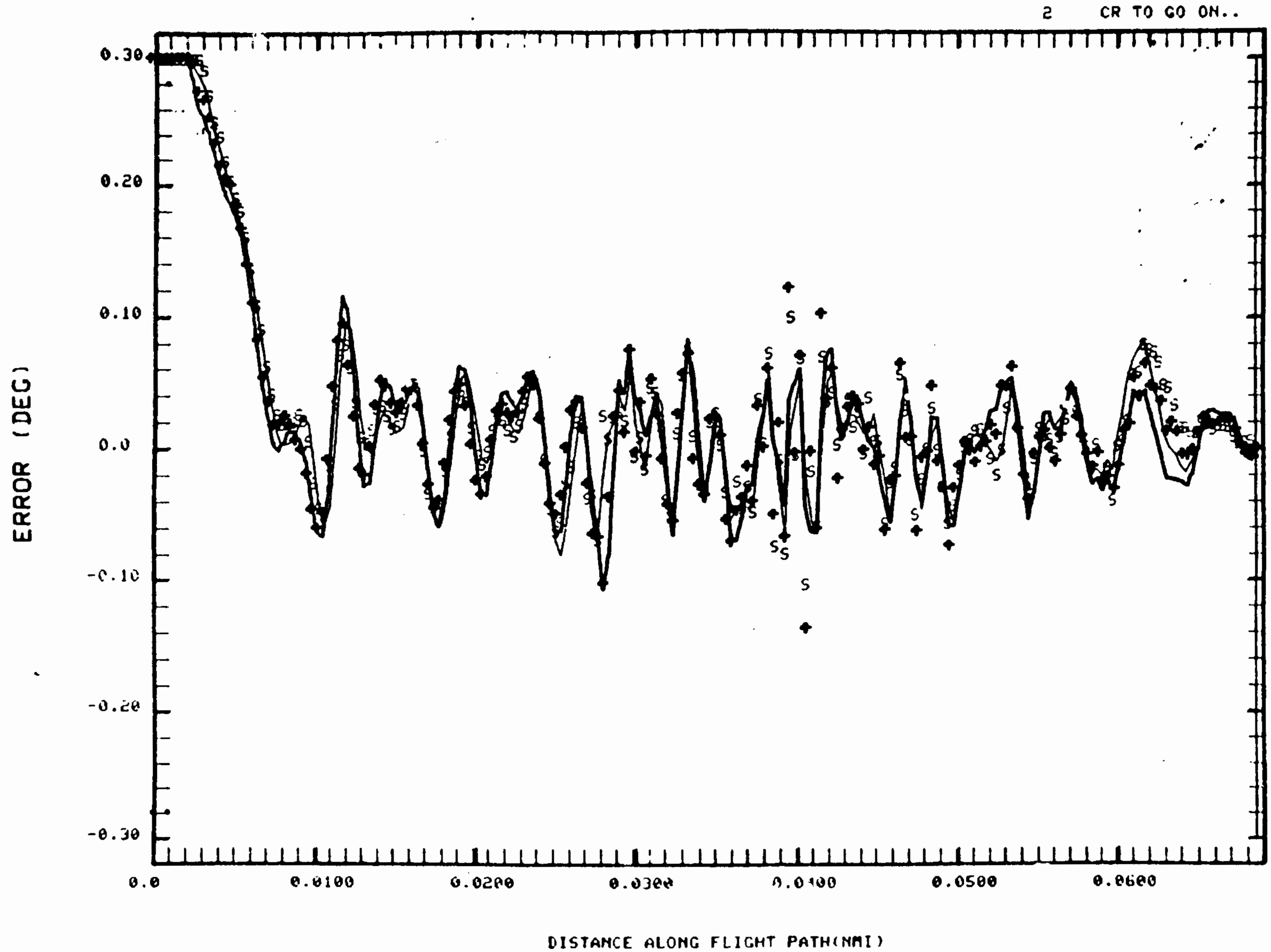

FIGURE 54. SCENARIO 5, FAA OUTPUT PLOTTED ON LINCOLN LABORATORY PLOT, ELEVATION ANTENNA, SIMULATED RECEIVER ERROR PLOT

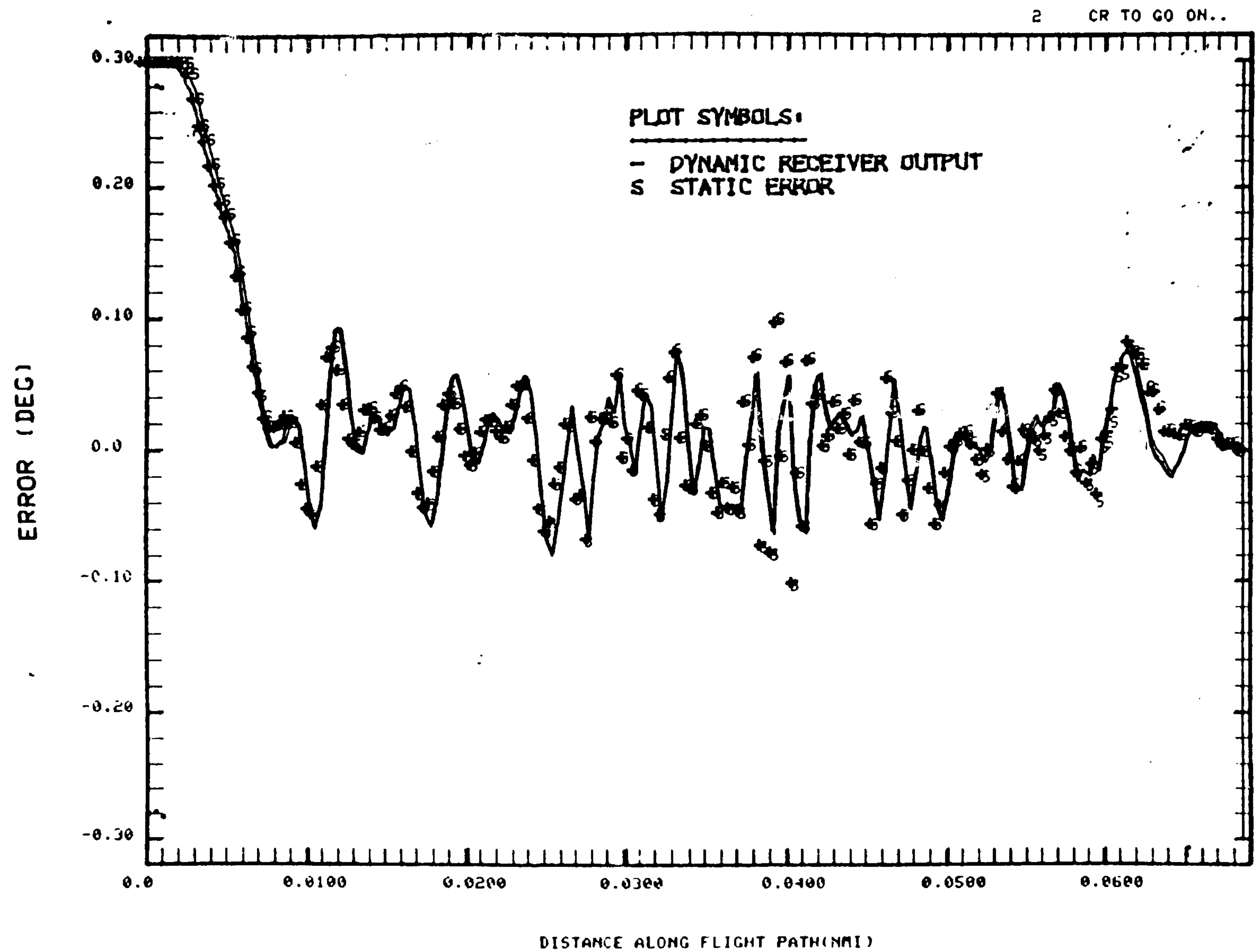

FIGURE 55. SCENARIO 5, FAA SYSTEM MODEL OUTPUT WITH LINCOLN LABORATORY DATA SET 8 INPUT COMPARED TO ORIGINAL LINCOLN LABORATORY OUTPUT

TABLE 1. SCENARIO 1, MLS TRANSMITTER DATA AND INPUT PARAMETERS

```
PROGRAM TO DO MULTIPATH MODELING AND SIMULATION OF MLS
1260     FAA/LL MLST2 SIMULATION-LLBD                                08/10/84   13.071

PARAMETERS FOR  AZ    SYSTEM ARE:
PARAMETER              VALUE            UNITS
XMTRAZX              0.                 FT
XMTRAZY              0.                 FT
XMTRAZZ              0.500E 01          FT
WLAZ                 0.107E 00          FT
PLZAZ                  T
DIMAZ                0.121E 02          FT
ITYPAZ                 1

PARAMETERS FOR  DME   SYSTEM ARE:
PARAMETER              VALUE            UNITS
XMTRDMX              0.                 FT
XMTRDMY              0.120E 02          FT
XMTRDMZ              0.500E 01          FT
WLD                  0.107E 00          FT
PLZD                   T
DIMDME               0.400E 01          FT
ITYPD                  2

PARAMETERS FOR  EL1   SYSTEM ARE:
PARAMETER              VALUE            UNITS
XMTRE1X              0.020E 04          FT
XMTRE1Y              0.400E 03          FT
XMTRE1Z              0.100E 02          FT
WLE1                 0.107E 00          FT
PLZE1                  T
DIMEL1               0.110E 02          FT
ITYPE1                 3

PARAMETERS FOR  EL2   SYSTEM ARE:
PARAMETER              VALUE            UNITS
XMTRE2X              0.800E 04          FT
XMTRE2Y             -0.250E 03          FT
XMTRE2Z              0.150E 02          FT
WLE2                 0.107E 00          FT
PLZE2                  T
DIMEL2               0.787E 01          FT
ITYPE2                 4

MULTIPATH EDITING PARAMETERS
 THRESHOLDS FOR EACH PASS =   0.10E-04  0.10E-01  0.30E-01
 OUT OF BEAMNESS: AZ=  3.00 DEG  EL=  3.00 DEG    DME=   0.50E-05 SEC
```

TRANSMITTER DATA

TABLE 1. SCENARIO 1, MLS TRANSMITTER DATA AND INPUT PARAMETERS (CONTINUED)

PARAMETERS USED IN COMPUTATION OF SPECULAR GROUND REFLECTION
ISPGRD= 1
ERB= 1.2000+J 0. SH20= 0. NFZ= 2.00 NA=25 NB=11

PARAMETERS USED IN COMPUTATION OF MULTIPATH REFLECTIONS

BUILDING PARAMETERS ARE,

NO	XL	YL	XR	YR	HB	HBOT	SH2B	ERBR	ERBI	TILT	GRNDBD
1	10750.	-750.	11400.	-750.	100.	0.	0.	0.15E 02	0.	0.	0.
2	9100.	-850.	10300.	-850.	100.	0.	0	0.15E 02	0.	0.	0.
3	8000.	-700.	8700.	-700.	50.	0.	0.	0.15E 02	0.	0.	0.
4	11150.	800.	11400.	725.	52.	0.	0.	0.15E 02	0.	0.	0.
5	10700.	1200.	10000.	1075.	52.	0.	0.	0.15E 02	0.	0.	0.
6	9675.	1150.	10025.	950.	50.	0.	0.	0.15E 02	0.	0.	0.

ERG= 1.2000 0. SH2G= 0.

PARAMETERS USED IN COMPUTATION OF SHADOWING

RUNWAY DIMENSIONS
RUNLEN= 9850.00FT RUNWID= 150.00FT DRATE= 0.20SEC

APPROACH FLIGHT PATH DATA & WAYPOINT COORDINATES

PT	X	Y	Z	VEL	DINC
1	18850.00	0.	500.00	219.56	43.91
2	9850.00	0.	50.00	219.56	43.91
3	9350.00	0.	20.00	219.56	43.91
4	9050.00	0.	20.00	219.56	43.91
5	8550.00	0.	0.00	219.56	43.91

ZCUT IS 42.70

INPUT PARAMETERS

TABLE 2. SCENARIO 2, MLS TRANSMITTER DATA AND INPUT PARAMETERS

```
PROGRAM TO DO MULTIPATH MODELING AND SIMULATION OF MLS
1300     FAA/LL MLST2 SIMULATION-LLBD                                08/10/84   13.070

PARAMETERS FOR  AZ    SYSTEM ARE:
PARAMETER              VALUE            UNITS
XMTRAZX             -0.100E 04          FT
XMTRAZY              0.                 FT
XMTRAZZ              0.600E 01          FT
WLAZ                 0.107E 00          FT
PLZAZ                  T
DIMAZ                0.121E 02          FT
JTYPAZ                1

PARAMETERS FOR  DME   SYSTEM ARE:
PARAMETER              VALUE            UNITS
XMTRDMX             -0.100E 04          FT
XMTRDMY              0.                 FT
XMTRDMZ              0.600E 01          FT
WLD                  0.107E 00          FT
PLZD                   T
DIMDME               0.400E 01          FT
JTYPD                 2

PARAMETERS FOR  EL1   SYSTEM ARE:
PARAMETER              VALUE            UNITS
XMTRE1X              0.920E 04          FT
XMTRE1Y             -0.400E 03          FT
XMTRE1Z              0.130E 02          FT
WLE1                 0.107E 00          FT
PLZE1                  T
DIMEL1               0.1[illegible]9E 02          FT
JTYPE1                3

PARAMETERS FOR  EL2   SYSTEM ARE:
PARAMETER              VALUE            UNITS
XMTRE2X              0.720E 04          FT
XMTRE2Y             -0.400E 03          FT
XMTRE2Z              0.130E 02          FT
WLE2                 0.107E 00          FT
PLZE2                  T
DIMEL2               0.787E 01          FT
JTYPE2                4

MULTIPATH EDITING PARAMETERS
 THRESHOLDS FOR EACH PASS =    0.10E-04  0.10E-01  0.30E-01
 OUT OF BEAMNESS: AZ=  3.00 DEG  EL=  3.00 DEG    DME=   0.50E-05 SEC
```

TRANSMITTER DATA

TABLE 2. SCENARIO 2, MLS TRANSMITTER DATA AND INPUT PARAMETERS (CONTINUED)

PARAMETERS USED IN COMPUTATION OF SPECULAR GROUND REFLECTION
ISPGRD= 1
ER0= 1.2000+J 0. SH20= 0. NFZ= 2.00 NA=25 NB=11

PARAMETERS USED IN COMPUTATION OF MULTIPATH REFLECTIONS

BUILDING PARAMETERS ARE,

NO	XL	YL	XR	YR	HB	HBOT	SH2B	ERBR	ERBI	TILT	GRNDBD
1	250.	750.	-400.	750.	100.	0.	0.	0.15E 02	0.	0.	0.
2	1000.	850.	700.	850.	100.	0.	0.	0.15E 02	0.	0.	0.
3	3000.	700.	2300.	700.	50.	0.	0.	0.15E 02	0.	0.	0.

ERG= 1.2000 0. SH2G= 0.

PARAMETERS USED IN COMPUTATION OF SHADOWING
PARAMETERS FOR SHADOWING DUE TO BUILDINGS ARE

NO	SHBLD,	XL	YL	XR	YR	HBS	HBT
1		250.0	750.0	-400.0	750.0	100.0	0.
2		1000.0	850.0	700.0	850.0	100.0	0.
3		3000.0	700.0	2300.0	700.0	50.0	0.

RUNWAY DIMENSIONS
RUNLEN= 10850.00FT RUNWID= 150.00FT DRATE= 0.20SEC

APPROACH FLIGHT PATH DATA & WAYPOINT COORDINATES

PT	X	Y	Z	VEL	DINC
1	25000.00	0.	2000.00	270.00	54.00
2	25000.00	22000.00	2000.00	0.	0.

ZCUT IS 0.

INPUT PARAMETERS

TABLE 3. SCENARIO 3, MLS TRANSMITTER DATA AND INPUT PARAMETERS

```
PROGRAM TO DO MULTIPATH MODELING AND SIMULATION OF MLS
1281     FAA/LL MLST2 SIMULATION-LLBD                          08/10/84   14.777

PARAMETERS FOR  AZ    SYSTEM ARE:
PARAMETER             VALUE            UNITS
XMTRAZX             -0.100E 04         FT
XMTRAZY              0.                FT
XMTRAZZ              0.500E 01         FT
WLAZ                 0.100E 01         FT
PLZAZ                  T
DIMAZ                0.121E 02         FT
ITYPAZ                1

PARAMETERS FOR  DME   SYSTEM ARE:
PARAMETER             VALUE            UNITS
XMTRDMX             -0.100E 04         FT
XMTRDMY              0.                FT
XMTRDMZ              0.500E 01         FT
WLD                  0.100E 01         FT
PLZD                   T
DIMDME               0.400E 01         FT
ITYPD                 2

PARAMETERS FOR  EL1   SYSTEM ARE:
PARAMETER             VALUE            UNITS
XMTRE1X              0.700E 04         FT
XMTRE1Y             -0.400E 03         FT
XMTRE1Z              0.130E 02         FT
WLE1                 0.100E 01         FT
PLZE1                  T
DIMEL1               0.118E 02         FT
ITYPE1                3

PARAMETERS FOR  EL2   SYSTEM ARE:
PARAMETER             VALUE            UNITS
XMTRE2X              0.700E 04         FT
XMTRE2Y             -0.400E 03         FT
XMTRE2Z              0.130E 02         FT
WLE2                 0.100E 01         FT
PLZE2                  T
DIMEL2               0.787E 01         FT
ITYPE2                4

MULTIPATH EDITING PARAMETERS
 THRESHOLDS FOR EACH PASS =   0.10E-04  0.10E-01  0.30E-01
 OUT OF BEAMNESS: AZ=  3.00 DEC  EL=  3.00 DEC    DME=   0.50E-05 SEC
```

TRANSMITTER DATA

TABLE 3. SCENARIO 3, MLS TRANSMITTER DATA AND INPUT PARAMETERS (CONTINUED)

PARAMETERS USED IN COMPUTATION OF SPECULAR GROUND REFLECTION

RECTANGULAR SURFACE ELEMENTS ARE,

NO	X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3
1	0.	-75.	0.	0.	75.	0.	8700.	75.	0.

NO	ERSR	ERSI	SH2S
1	5.0000	0.	0.0066

NRSPEC= 0
ISPGRD= 1
ER0= 1.2000+J 0. SH20= 0. NFZ= 2.00 NA=25 NB=11

PARAMETERS USED IN COMPUTATION OF MULTIPATH REFLECTIONS

BUILDING PARAMETERS ARE,

NO	XL	YL	XR	YR	HB	HBOT	SH2B	ERBR	ERBI	TILT	GRNDBD
1	3975.	-3400.	4400.	-3400.	100.	0.	0.0130	0.10E 01	-0.10E 00	0.	0.
2	4550.	-2100.	5080.	-2100.	100.	0.	0.0130	0.10E 01	-0.10E 00	0.	0.
3	4800.	-3100.	5200.	-3100.	100.	0.	0.0130	0.10E 01	-0.10E 00	0.	0.
4	6825.	-1800.	7125.	-1800.	50.	0.	0.0130	0.10E 01	-0.10E 00	0.	0.
5	7780.	-1800.	8080.	-1800.	50.	0.	0.0130	0.10E 01	-0.10E 00	0.	0.
6	7125.	-1800.	7254.	-1706.	50.	0.	0.0130	0.10E 01	-0.10E 00	0.	0.
7	8080.	-1800.	8200.	-1706.	50.	0.	0.0130	0.10E 01	-0.10E 00	0.	0.

ERG= 1.2000 0. SH2G= 0.

AIRCRAFT PARAMETERS ARE:

NO	XT	YT	XC	YC	NACTYP	ALT	GRNDAC
1	5700.0	-1150.0	5000.0	-1150.0	1	0.	0.
2	6700.0	-1150.0	6000.0	-1150.0	1	0.	0.
3	8758.6	-1150.0	8000.0	-1000.6	1	0.	0.
4	8000.0	-900.0	8900.0	-700.0	1	0.	0.

PARAMETERS USED IN COMPUTATION OF SHADOWING

RUNWAY HUMP SHADOWING PARAMETERS ARE

	X	Y	Z
HMPST	3300.0	0.	0.
HMPTOP	3800.0	0.	5.0
HMPEND	4300.0	0.	0.

RUNWAY DIMENSIONS
RUNLEN= 8700.00FT RUNWID= 150.00FT DRATE= 0.20SEC

APPROACH FLIGHT PATH DATA & WAYPOINT COORDINATES

PT	X	Y	Z	VEL	DINC
1	17700.00	0.	500.00	219.56	43.01
2	7700.00	0	0.	0	0

ZCUT IS 50.00

INPUT PARAMETERS

TABLE 4. SCENARIO 4, MLS TRANSMITTER DATA AND INPUT PARAMETERS

```
PROGRAM TO DO MULTIPATH MODELING AND SIMULATION OF MLS
1370     FAA/LL MLST2 SIMULATION-LLBD                              08/10/84  13.001

PARAMETERS FOR  AZ    SYSTEM ARE,
PARAMETER             VALUE             UNITS
XMTRAZX             0.                  FT
XMTRAZY             0.                  FT
XMTRAZZ             0.700E 01           FT
WLAZ                0.107E 00           FT
PLZAZ                 T
DIMAZ               0.121E 02           FT
JTYPAZ               1

PARAMETERS FOR  DME   SYSTEM ARE.
PARAMETER             VALUE             UNITS
XMTRDMX             0.                  FT
XMTRDMY             0.                  FT
XMTRDMZ             0.100E 02           FT
WLD                 0.100E 01           FT
PLZD                  T
DIMDME              0.400E 01           FT
JTYPD                2

PARAMETERS FOR  EL1   SYSTEM ARE,
PARAMETER             VALUE             UNITS
XMTRE1X             0.634E 04           FT
XMTRE1Y             0.400E 03           FT
XMTRE1Z             0.000E 01           FT
WLE1                0.107E 00           FT
PLZE1                 T
DIMEL1              0.118E 02           FT
JTYPE1               3

PARAMETERS FOR  EL2   SYSTEM ARE,
PARAMETER             VALUE             UNITS
XMTRE2X             0.634E 04           FT
XMTRE2Y             0.400E 03           FT
XMTRE2Z             0.000E 01           FT
WLE2                0.107E 00           FT
PLZE2                 T
DIMEL2              0.787E 01           FT
JTYPE2               4

MULTIPATH EDITING PARAMETERS
 THRESHOLDS FOR EACH PASS =   0.10E-04  0.10E-01  0.30E-01
 OUT OF BEAMNESS: AZ=  3.00 DEG   EL=  3.00 DEG    DME=   0.50E-05 SEC
```

TRANSMITTER DATA

TABLE 4. SCENARIO 4, MLS TRANSMITTER DATA AND INPUT PARAMETERS (CONTINUED)

PARAMETERS USED IN COMPUTATION OF SPECULAR GROUND REFLECTION
ISPGRD= 1
ER0= 1.2000+J 0. SH20= 0.066 NFZ= 2.80 NA=25 NB=11

PARAMETERS USED IN COMPUTATION OF MULTIPATH REFLECTIONS

PARAMETERS USED IN COMPUTATION OF SHADOWING
PARAMETERS FOR SHADOWING DUE TO AIRCRAFT ARE

	SHPOS1			SHPOS2		
NO	X	Y	Z	X	Y	Z
1	4076.0	-25.0	0.	2167.0	-20.0	127.0

NO	SHACTP	SHVEL	SHANG
1	6	275.0	14.0

RUNWAY DIMENSIONS
RUNLEN= 8600.00FT RUNWID= 150.00FT DRATE= 0.20SEC

APPROACH FLIGHT PATH DATA & WAYPOINT COORDINATES

PT	X	Y	Z	VEL	DINC
1	13692.00	-25.00	320.00	181.70	36.30
2	12849.00	-20.00	292.00	181.70	36.30
3	11878.00	-14.00	248.00	232.00	46.40
4	8635.00	-5.00	64.00	0.	0.

ZCUT IS 0.

INPUT PARAMETERS

TABLE 5. SCENARIO 5, MLS TRANSMITTER DATA AND INPUT PARAMETERS

PROGRAM TO DO MULTIPATH MODELING AND SIMULATION OF MLS
6032 FAA/LL MLST2 SIMULATION-LLBD 08/10/84 13.904

PARAMETERS FOR AZ SYSTEM ARE:

PARAMETER	VALUE	UNITS
XMTRAZX	0.	FT
XMTRAZY	0.	FT
XMTRAZZ	0.400E 01	FT
WLAZ	0.902E 00	FT
PLZAZ	T	
DIMAZ	0.125E 02	FT
ITYPAZ	1	

PARAMETERS FOR DME SYSTEM ARE:

PARAMETER	VALUE	UNITS
XMTRDMX	0.	FT
XMTRDMY	0.	FT
XMTRDMZ	0.150E 02	FT
WLD	0.902E 00	FT
PLZD	T	
DIMDME	0.234E 02	FT
ITYPD	2	

PARAMETERS FOR EL1 SYSTEM ARE:

PARAMETER	VALUE	UNITS
XMTRE1X	0.	FT
XMTRE1Y	0.	FT
XMTRE1Z	0.760E 01	FT
WLE1	0.191E 00	FT
PLZE1	T	
DIMEL1	0.120E 02	FT
ITYPE1	3	

PARAMETERS FOR EL2 SYSTEM ARE:

PARAMETER	VALUE	UNITS
XMTRE2X	0.	FT
XMTRE2Y	0.	FT
XMTRE2Z	0.760E 01	FT
WLE2	0.191E 00	FT
PLZE2	T	
DIMEL2	0.120E 02	FT
ITYPE2	4	

MULTIPATH EDITING PARAMETERS
THRESHOLDS FOR EACH PASS = 0.10E-04 0.10E-01 0.30E-01
OUT OF BEAMNESS: AZ= 3.00 DEG EL= 3.00 DEG DME= 0.50E-05 SEC

TRANSMITTER DATA

TABLE 5. SCENARIO 5, MLS TRANSMITTER DATA AND INPUT PARAMETERS (CONTINUED)

PARAMETERS USED IN COMPUTATION OF SPECULAR GROUND REFLECTION

RECTANGULAR SURFACE ELEMENTS ARE.

NO	X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3
1	0	-50.	0.	0	50.	0	126.	-50.	-10.
2	126	-50.	-10	126.	50.	-10.	482.	-50.	-13.
3	482	-50	-13.	482.	50.	-13.	724.	-50.	-3.
4	702.	-50.	-4.	702.	50.	1.	940.	-50.	0.

NO	ERSR	ERSI	SH2S
1	6.0000	-0.0033	0.
2	6 0000	-0.0033	0.
3	6 0000	-0.0033	0.
4	6.0000	-0.0033	0.

NRSPEC= 1 1 1 1

ISPGRD= 0

ER0= 15.0000+J 0. SH20=****** NFZ= 2.00 NA=25 NB=11

PARAMETERS USED IN COMPUTATION OF MULTIPATH REFLECTIONS

PARAMETERS USED IN COMPUTATION OF SHADOWING

RUNWAY DIMENSIONS

RUNLEN= 940.00FT RUNWID= 100.00FT DRATE= 0.20SEC

APPROACH FLIGHT PATH DATA & WAYPOINT COORDINATES

PT	X	Y	Z	VEL	DINC
1	3030 00	0.	10.00	6.00	2.00
2	3030 00	0.	425 00	0.	0.

ZCUT IS 10.00

INPUT PARAMETERS

TABLE 6. SUMMARY OF DIFFERENCES BETWEEN FAA AND LINCOLN LABORATORY DATA SET 8

	AMPLITUDE (DB)	PHASE (RADIANS)	AZIMUTH PROPAGATION ANGLE (RAD)	ELEV. PROPAGATION ANGLE (RAD)	SCALLOPING FREQ. (HZ)	AZIMUTH INCIDENCE ANGLE (RAD)	ELEV. INCIDENCE ANGLE (RAD)
SCENARIO 1							
NUMBER OF SAMPLES	641	641	641	641	641	641	641
SAMPLES EXCEEDING LIMIT	0	6	0	0	1	0	0
AVERAGE DIFFERENCE	0.0001	0.0045	0.0000	0.0000	0.0189	0.0000	0.0000
SCENARIO 2							
NUMBER OF SAMPLES	2280	2280	2280	2280	2280	2280	2280
SAMPLES EXCEEDING LIMIT	0	0	0	0	0	0	0
AVERAGE DIFFERENCE	0.0000	0.0002	0.0000	0.0000	0.0089	0.0000	0.0000
SCENARIO 3							
NUMBER OF SAMPLES	2676	2676	2676	2676	2676	2676	2676
SAMPLES EXCEEDING LIMIT	0	17	0	2	0	0	0
AVERAGE DIFFERENCE	0.0001	0.0310	0.0000	0.0000	0.0179	0.0000	0.0000
SCENARIO 4							
NUMBER OF SAMPLES	62	62	62	62	62	62	62
SAMPLES EXCEEDING LIMIT	0	12	0	0	0	0	62
AVERAGE DIFFERENCE	0.0007	0.1365	0.0000	0.0002	0.0178	0.0020	0.0456
SCENARIO 5							
NUMBER OF SAMPLES	824	824	824	824	824	824	824
SAMPLES EXCEEDING LIMIT	414	486	8	10	0	8	0
AVERAGE DIFFERENCE	0.0445	0.4059	0.0002	0.0016	0.0056	0.0561	0.0002

APPENDIX

SPECIFICATION OF INPUT PARAMETERS DISPLAYED

PARAMETERS REQUIRED FOR MULTIPATH COMPUTATIONS.

The following parameters are required to specify the airport model which is employed in the multipath computation section of the program. A standard rectangular coordinate system is used, where the XY-plane is in the plane of the runway, the X-axis is coincident with the runway centerline and the Z-axis passes through the stop end of the runway. All lengths, frequencies, and times are given in feet, hertz (Hz), and seconds, respectively.

TRANSMITTER PARAMETERS (AZIMUTH, DISTANCE MEASURING EQUIPMENT, AND ELEVATION).

1. XMTRAZ - (X,Y,Z), XMTRDM - (X,Y,Z), XMTRE1 - (X,Y,Z), XMTRE2 - (X,Y,Z): X,Y,Z-coordinates of location of transmitter.

2. WLAZ, WLD, WLE1, WLE2: Wavelength (nominally 0.2 feet for C-band).

3. PLZAZ, PLZD, PLE1, PLE2: Polarization (vertical or horizontal).

4. DIMAZ, DIMDME, DIMEL1, DIMEL2: Dimension of transmitter antenna.

SPECULAR GROUND REFLECTION.

1. NR: Number of rectangular surface elements.

2. (X1, Y1, Z1), (X2, Y2, Z2), (X3, Y3, Z3): X,Y,Z-coordinate of two corners, plus X,Z coordinates of third corner, in increasing order of magnitude for the X-coordinate, for each rectangular surface element.

3. ERSR, ERSI, SH2S: The real and imaginary relative dielectric constants, and the root-mean-square roughness height, respectively, for each rectangular surface element.

4. NT: Number of triangular surface elements.

5. (X1, Y1, Z1), (X2, Y2, Z2), (X3, Y3, Z3): X,Y,Z-coordinates of the three corners of each triangular surface element, in increasing order of magnitude of the X-coordinate.

6. ERSR, ERSI, SH2S: (see 3 above) for each triangular surface element.

7. ERO, SH20: Default values of dielectric constant and roughness height which are used in those regions not specified by previously defined rectangular and triangular areas.

SCATTERING FROM BUILDINGS.

1. NBLD: Number of buildings.

2. HBOT: Height of bottom edge of front face of buildings above ground for each building.

3. HB: Height of building, relative to bottom edge, for each building.

4. (XL, YL), (XR, YR): X, Y-coordinates of left-hand and right-hand, edge of front face of building, for each building.

5. ERBR, ERBI, SH2B: Real and imaginary relative dielectric constants and the RMS roughness height.

6. ERG, SH2G: Dielectric constant and RMS roughness height for ground reflection. These parameters are specified only once, since they are assumed to be the same for the ground surrounding each building.

SCATTERING FROM AIRCRAFT.

1. NAC: Number of aircraft.

2. NACTYP: Aircraft type, for each aircraft, e.g., 1(= 747), 2(= 707-320B), 3(= 727), 4(= DC10), 5(= C-124). A subroutine ACTYPE is called, using the appropriate aircraft type, to load the following aircraft parameters, which are already stored in computer memory, into a suitable storage area:

1 Area of wings
2 Radius of fuselage
3 Length of fuselage
4 Radius of curvature of tail fin
5 Width of tail fin
6 Height of tail fin
7 Height of center of fuselage above the ground

3. (XT, YT), (XC, YC): X, Y-coordinates of cockpit and tail fin edge of fuselage centerline, for each aircraft.

4. ALT: Altitude of each aircraft defined as the height of fuselage centerline above the ground. If aircraft is parked on the ground, then ALT should be set to zero so the program can recognize that a default value should be used in computations.

The parameters ERG and SH2G specified in item 6 under "Scattering From Buildings" are also used to obtain ground reflections for scattering from the fuselage and tail fin.

SHADOWING DUE TO BUILDINGS.

1. (XL, YL), (XR, YR): X, Y-coordinates of left-hand and right-hand, edge of each shadowing surface.

2. HBS: Height of shadowing surface relative to bottom edge.

3. HBT: Height of bottom edge of surface relative to Z-axis reference.

SHADOWING DUE TO RUNWAY HUMP.

1. HMPST, HMPTOP, HMPEND: X, Y, Z-coordinates for the location of the hump along the runway.

The runway hump is assumed to extend from the lower, to the upper, edge of the runway.

SHADOWING DUE TO AIRCRAFT.

Only one shadowing aircraft is considered by the program, for which the following should be specified:

1. SHACTYP: Aircraft type (see item 2 under "Scattering From Aircraft").

2. SHPOS1: X, Y, Z-coordinates of center of fuselage of shadowing aircraft at the starting frame number

3. SHPOS2: X, Y, Z-coordinates of center of fuselage of shadowing aircraft at the ending frame number (assumes linear path).

4. SHANG: Pitch angle, angle between fuselage centerline and the X-axis measured in the X-Z plane.

5. SHVEL: Velocity of shadowing aircraft between SHPOS1 and SHPOS2.

APPROACH FLIGHTPATH AND WAYPOINT COORDINATES.

1. VEL: Aircraft receiver velocity, in ft/sec, for each segment. This velocity is considered as being along the flightpath.

2. X,Y,Z: X, Y, Z-coordinates for each segment of each flightpath.

3. DINC: Distance along flightpath between evaluation points, nominally 40 feet.

4. ZCUT: Altitude at which transition from EL-1 to EL-2 system occurs, nominally 100 feet.

In addition to the preceding data concerning the airport model, the following information should also be specified:

RUNLEN: Length of runway

RUNWID: Width of runway

GPIP: X, Y, Z-coordinates of glide path intercept point (GPIP)