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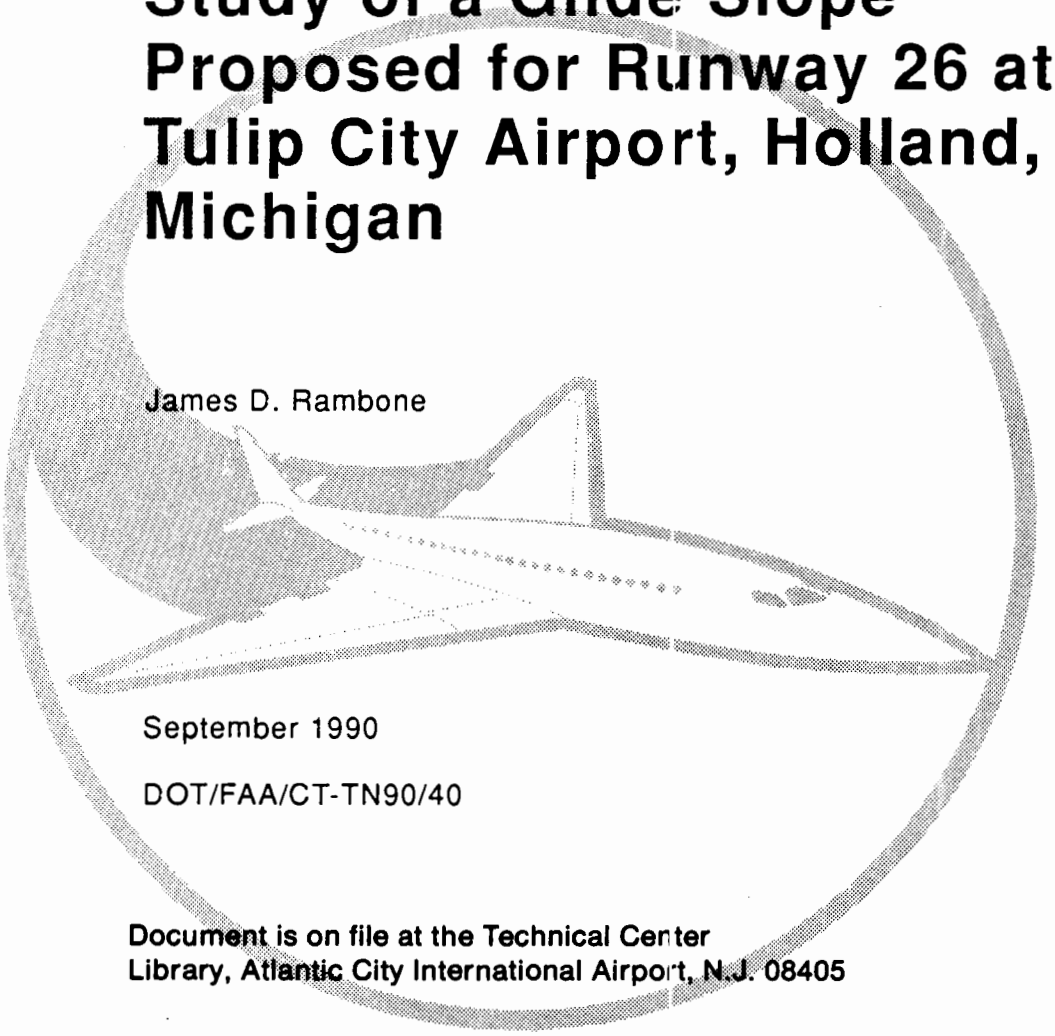
ILS Mathematical Modeling Study of a Glide Slope Proposed for Runway 26 at Tulip City Airport, Holland, Michigan

James D. Rambone



September 1990

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16. Abstract

This Technical Note describes the instrument landing system (ILS) math modeling performed by the Federal Aviation Administration (FAA) Technical Center at the request of the Michigan Airway Facilities Sector. Data are presented showing the computed performance of a proposed glide slope for runway 26 at Tulip City Airport, Holland, Michigan. As requested, null reference and capture effect systems are modeled at the proposed glide slope site. The glide slope systems were modeled with existing and modified terrain grading. Modeled path structure and level run plots are provided for each of the glide slope systems installed at the proposed location. Modeled results indicate that the null reference system installed at the proposed site should meet Category I path structure tolerances with either existing or modified terrain grading. Modeled path structure results for the capture effect system installed at the same location with existing terrain grading exceed Category I path structure tolerances in Zone 3. Modeled results indicate that the capture effect system with the modified terrain grading should meet Category I tolerances. Level run performance for each of the systems modeled meets Category I linearity and symmetry tolerances with existing and modified terrain grading.

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EXECUTIVE SUMMARY

This instrument landing system (ILS) math modeling study, performed at the request of the Michigan Airways Facilities Sector, provides data showing the computed performance of a proposed glide slope for runway 26 at the Tulip City Airport, Holland, Michigan. Modeled path structure and level run plots are provided for null reference and capture effect glide slope systems installed at the proposed glide slope site. The proposed glide slope site will be located 728 feet back from runway threshold and 400 feet left offset of centerline.

The glide slope systems were modeled with existing and modified terrain grading. Modified terrain grading consisted of smoothing the terrain between the glide slope site and runway centerline from the site to just beyond threshold. The terrain was modified to have a constant positive slope from the site to threshold centerline to improve glide slope performance. Modeled results indicate that the null reference system installed at the proposed site should meet Category I path structure tolerances with either existing or modified terrain grading. Modeled path structure results for the capture effect system installed at the same location with existing terrain grading exceed Category I path structure tolerances in Zone 3. Modeled results indicate that the capture effect system with modified terrain grading should meet Category I tolerances. Level run performance for each of the systems modeled meets Category I linearity and symmetry tolerances with existing and modified terrain grading.

INTRODUCTION

PURPOSE.

The purpose of this math modeling study was to provide computer modeled performance data for an instrument landing system (ILS) glide slope proposed for runway 26 at the Tulip City Airport.

BACKGROUND.

The Michigan Airway Facilities Sector (MI-AFS) will be installing an ILS glide slope to serve runway 26 at the Tulip City Airport, Holland, Michigan. In support of this project, the Michigan Airway Facilities Sector has requested a math modeling study through the Navigation and Landing Division, ANN-100, which, in turn, was forwarded to the Federal Aviation Administration (FAA) Technical Center for accomplishment. The MI-AFS requested math modeling of a glide slope proposed for runway 26. Null reference and capture effect glide slope systems were requested to be modeled at the glide slope site with derogating effects from existing and modified terrain grading. The proposed glide slope site is located 728 feet backset from threshold, 400 feet left offset of centerline, and at a ground elevation of 667.65 feet mean sea level (m.s.l.). The ground elevation is 687.95 feet m.s.l. at runway 26 threshold and 682.04 feet m.s.l at the runway point intercept (RPI). Category I glide slope performance is required. A desired threshold crossing height (TCH) of 35 feet is based on a height group 1 (general aviation, small commuters, corporate turbojets). Glide slope modeling was limited to the derogating effects from ground terrain. This modeling effort was performed under project T0603S. The Technical Program Manager is Mr. Edmund A. Zyzys. Additional information regarding this study may be obtained by contacting Mr. James D. Rambone at FTS 482-5373 or (609) 484-5373.

DISCUSSION

ILS MATH MODELS.

The FAA Technical Center conducts ILS mathematical computer model studies through application of physical optics or geometric theory of diffraction techniques to compute anticipated ILS performance. The mathematical model used for this simulation was the Ohio University Geometrical Theory of Diffraction (OUGTD) model which was obtained from Ohio University under an FAA Technical Center contract. This program was written for Ohio University by Mr. Vichate Ungvichian to account for the interactions of electromagnetic waves when reflected and/or diffracted from the terrain between an ILS antenna and an aircraft (reference 1). The OUGTD program utilizes the Geometrical Theory of Diffraction (GTD) and the Uniform Theory of Diffraction (UTD) as the basic theories when computing the diffraction of the electromagnetic waves. The GTD and UTD theories both treat electromagnetic waves as rays. This is acceptable due to the localized nature of wave interactions at very high frequencies (above 100 megahertz (MHz)). This treatment allows one to include the multiple interaction (i.e., doubly diffracted, etc.) between neighboring ground plates with little computational effort, which is a very difficult task

when using the Physical Optics theory. The UTD theory is used to calculate the fields in the transition areas; the GTD theory is used in all other areas.

The model considers the direct ray plus 13 additional rays. Each ray is determined by the various terrain irregularities encountered in front of the ILS antenna system. These rays are:

1.	Direct	8.	Reflected-reflected-diffracted
2.	Reflected	9.	Reflected-reflected-reflected
3.	Diffracted	10.	Reflected-diffracted-reflected
4.	Reflected-reflected	11.	Diffracted-diffracted-reflected
5.	Reflected-diffracted	12.	Reflected-diffracted-diffracted
6.	Diffracted-reflected	13.	Diffracted-reflected-reflected
7.	Diffracted-diffracted	14.	Diffracted-reflected-diffracted

The pseudo-3D version of the model was used for this modeling effort. This version uses a matrix of X, Y, and Z coordinates for the terrain to compute a new terrain profile for each observation point (simulated aircraft position). The term "pseudo-3D" is used to emphasize the fact that the model is not truly 3-dimensional, but rather an enhancement of the 2D version which uses a single terrain profile for all observation points.

The subroutine that determines the profile was modified by FAA Technical Center engineers to eliminate some restrictions on establishing the origin and selection of coordinates. For each observation point and its associated terrain profile, the simulated Course Deviation Indicator (CDI) deflection is computed from the various combinations of rays.

Input data required by the model consists of two data files: the terrain matrix file and the input/control file. The terrain matrix file consists of X (distance perpendicular to the runway), Y (distance along the runway centerline extended), and Z (elevation values referenced to the base of the antenna mast). The computer model applies an interpolation process to the terrain matrix file to determine a new terrain profile for each observation point (simulated aircraft position) along the flightpath. The new profile is that of the terrain directly below a line drawn from the ILS antenna to the observation point. This profile is the surface used in the computation of the glide slope radio frequency (RF) energy at the observation point. The input/control file consists of data describing the antenna system (location, amplitude, and phase of each antenna element), along with other pertinent site and flightpath data. Antenna heights were computed to produce actual path angles of approximately 3.0 degrees. Antenna current phasing for all simulations were computed using a simulation of the airborne phasing techniques detailed in the Flight Inspection Manual, OAP 8200.1 (reference 2).

In the simulation, samples of antenna current phase are recorded while flying the simulated aircraft along an approach angle of 1.5 degrees from 8 to 4 nautical miles (nmi) with respect to the site. Ten samples of antenna current phase are recorded for each antenna. Using average phase values, the phase of the upper antenna is adjusted for zero phase difference with respect to the lower antenna for sideband reference or null reference systems. For the capture effect system, the phases of the lower and upper antennas are adjusted to result in zero phase difference with respect to the middle antenna. This

technique is similar to the method originated by the Ohio University Avionics Center for their modeling applications.

ILS MODELING PERFORMED.

Figure 1 shows the location of the proposed glide slope site with respect to runway 26. The GTD-3D glide slope model was used to model the effects of existing and modified terrain on glide slope performance. Figure 2 shows a composite of terrain profiles for simulated aircraft positions in the distance interval from 35,000 to 1,000 feet from runway point of intercept (RPI) in increments of 1,000 feet for the existing terrain. A composite terrain plot is also provided for modified terrain grading (figure 3). Modified terrain grading, shown in figure 4, consisted of smoothing the terrain between the glide slope site and runway centerline from the site to just beyond threshold. The terrain was modified to have a constant positive slope from the site to runway centerline at threshold to improve glide slope performance. As requested, null reference and capture effect systems were modeled at the proposed glide slope site with existing and modified terrain grading. A summary of the model input data describing the glide slope antenna systems at the proposed site is provided in table 1. Glide slope level and path structure computer runs were made with this data.

DATA PRESENTATION.

Glide slope modeling results are presented in the form of course structure and level run plots. The reference flightpath for a structure plot is the hyperbolic path formed by the intersection of a cone originating at the base of the antenna and a vertical plane located along runway centerline. In the model, this path is determined by the location of the eyepiece of the theodolite. For the data presented, the theodolite eyepiece is positioned at the X and Y coordinates of the glide slope antenna mast, but at the elevation (Z coordinate) of the RPI. Modeled results are given in figures 5 through 12. Path structure run results are given in figures 5 through 8. Null reference system performance with existing terrain grading is shown in figure 5 and with modified terrain grading in figure 6. Figure 7 shows capture effect system performance with existing terrain grading. Capture effect system performance with modified terrain grading is shown in figure 8. Level run results are given in figures 9 through 12. Figures 9 and 10 are the modeled level run results for the null reference system with existing and modified terrain grading, respectively. Modeled level run performance for the capture effect system with existing terrain grading is shown in figure 11. Figure 12 shows capture effect system performance with modified terrain grading.

DATA ANALYSIS.

Glide slope modeled path structure results for the null reference system with existing terrain grading (figure 5) and with modified terrain grading (figure 6) provides a path structure within Category I tolerance limits. Modeled capture effect path structure results with existing terrain grading (figure 7) provides a path structure which meets Category I tolerances in Zone 2, but exceeds tolerance limits in Zone 3. Modeled path structures results for the capture effect system with modified terrain grading (figure 8) shows an appreciable improvement in performance providing a path structure well within Category I tolerances. The level run results for the null reference system

TABLE 1. GLIDE SLOPE DATA SUMMARY

Antenna	Existing Terrain Grading CE Ant. Height/Offset (ft/ft)	Existing Terrain Grading NR Ant. Height/Offset (ft/ft)	Modified Terrain Grading CE Ant. Height/Offset (ft/ft)	Modified Terrain Grading NR Ant. Height/Offset (ft/ft)
Lower	14.83/0.8240	14.83/0.000	14.93/0.8360	14.93/0.0000
Middle	29.65/0.0000	--	29.86/0.0000	--
Upper	44.48/-1.374	29.66/-0.842	44.79/-1.393	29.87/-0.836
Average Path Angle (deg)	3.0	3.0	3.0	3.0
Path Width (deg)	0.70	0.70	0.70	0.70
Path Symmetry (percent)	50/50	47/53	50/50	48/52
A-Ratio*	0.288	0.278	0.287	0.276
Phase (deg)	8.977/-12.693	9.022	9.113/-12.766	-9.142
Backset from threshold (ft)	728.0	728.0	728.0	728.0
Offset from centerline (ft)	400.0	400.0	400.0	400.0
Elevation (ft m.s.l.)	667.95	667.95	667.95	667.95
Frequency (MHz)	332.9	332.9	332.9	332.9

* Ratio of separate sideband signal amplitude to carrier sideband signal amplitude.

(figures 9 and 10) show a linear crossover and near symmetrical glidepath which meets Category I tolerances. Level run results for the capture effect system (figures 11 and 12) show a linear crossover and symmetrical glidepath which meets Category I tolerances.

CONCLUSIONS

Modeled results indicate that satisfactory Category I path structure performance should be obtained with the null reference system installed at the proposed site with either existing or modified terrain grading. Modeled path structure results for the capture effect system installed at the same location with existing terrain grading shows CDI deflections which exceed Category I path structure tolerances in Zone 3. Modeled results indicate that the capture effect system with modified terrain grading should meet Category I tolerances. Level run performance meets Category I linearity and symmetry tolerances for both glide slope systems modeled with existing and modified terrain grading.

REFERENCES

1. User's Manual for the Ohio University Geometric Theory of Diffraction Glide Slope Model, Ohio University, Technical Report Number OU/AEC/ERR 47-7, February 1982.

2. United States Flight Inspection Manual, FAA Handbook, OAP 8200.1, Change 32, Section 217.

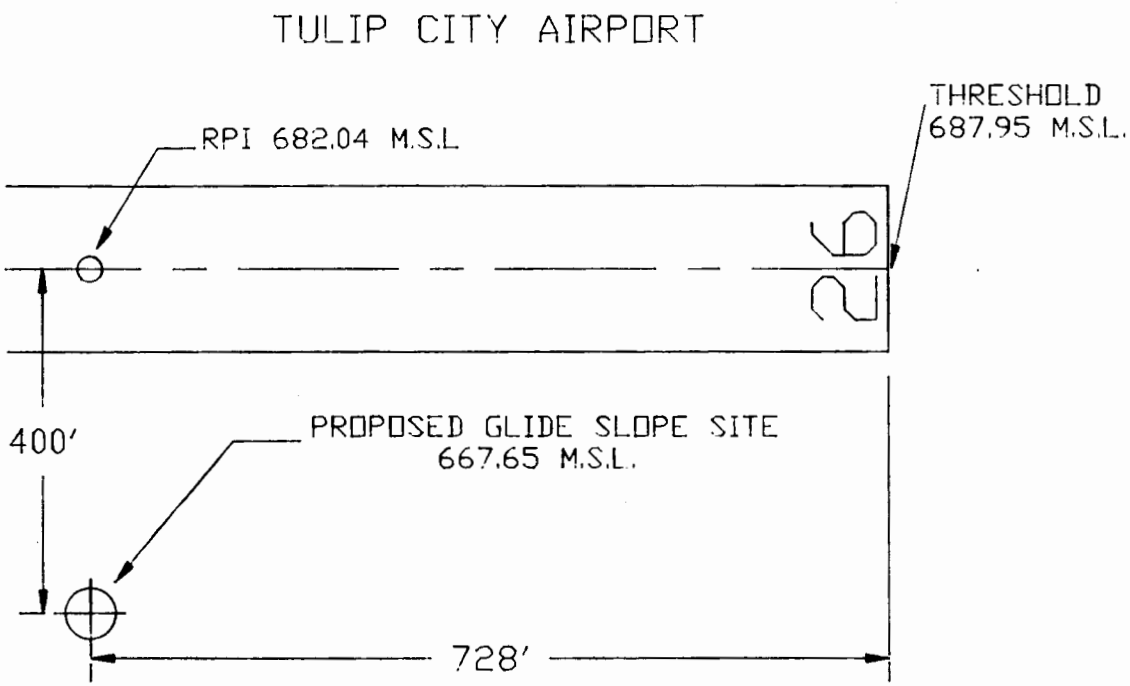


FIGURE 1. TULIP CITY RUNWAY 26, ILS MATH MODELING LAYOUT

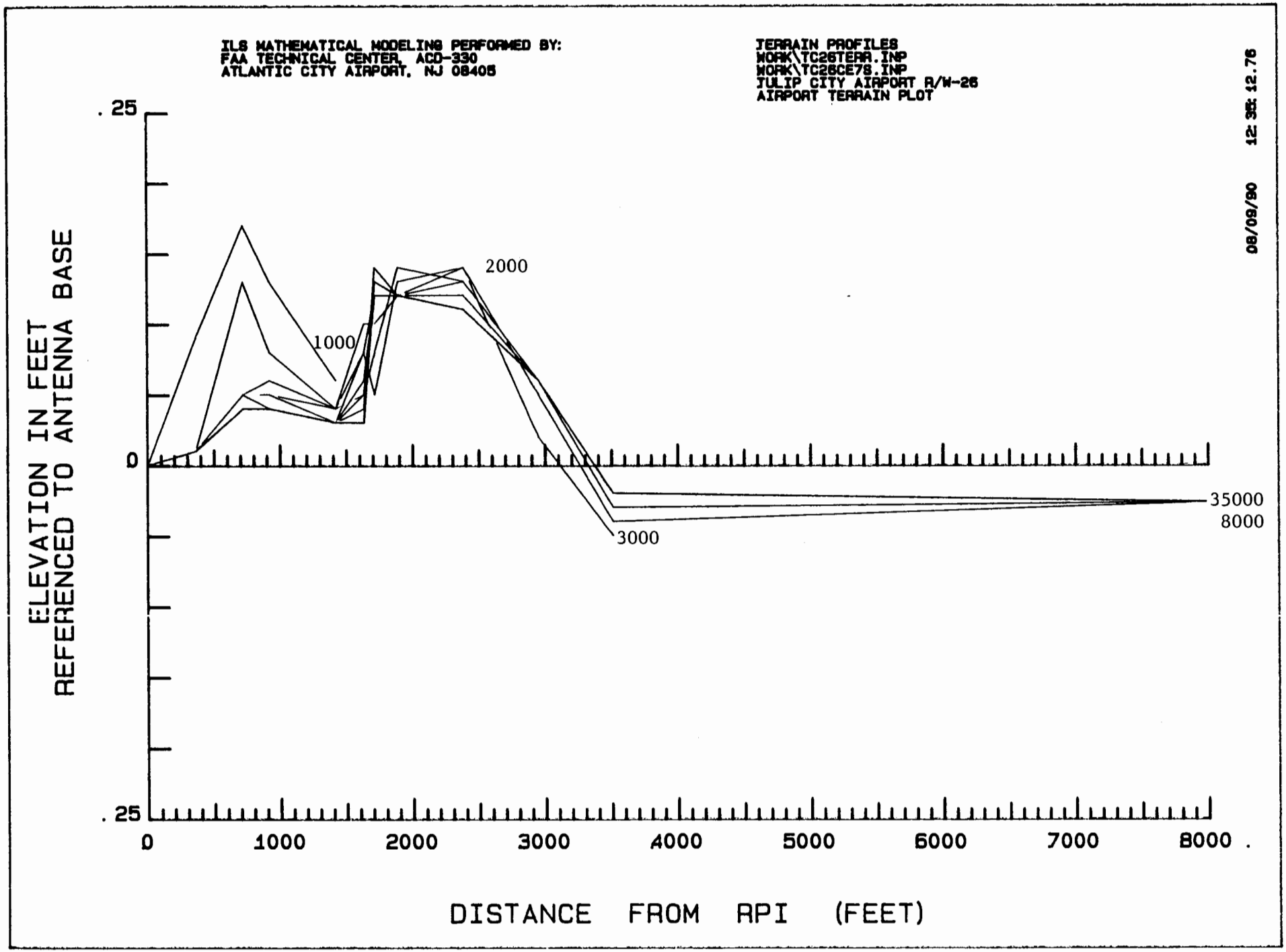


FIGURE 2. TULIP CITY RUNWAY 26, EXISTING TERRAIN PROFILE

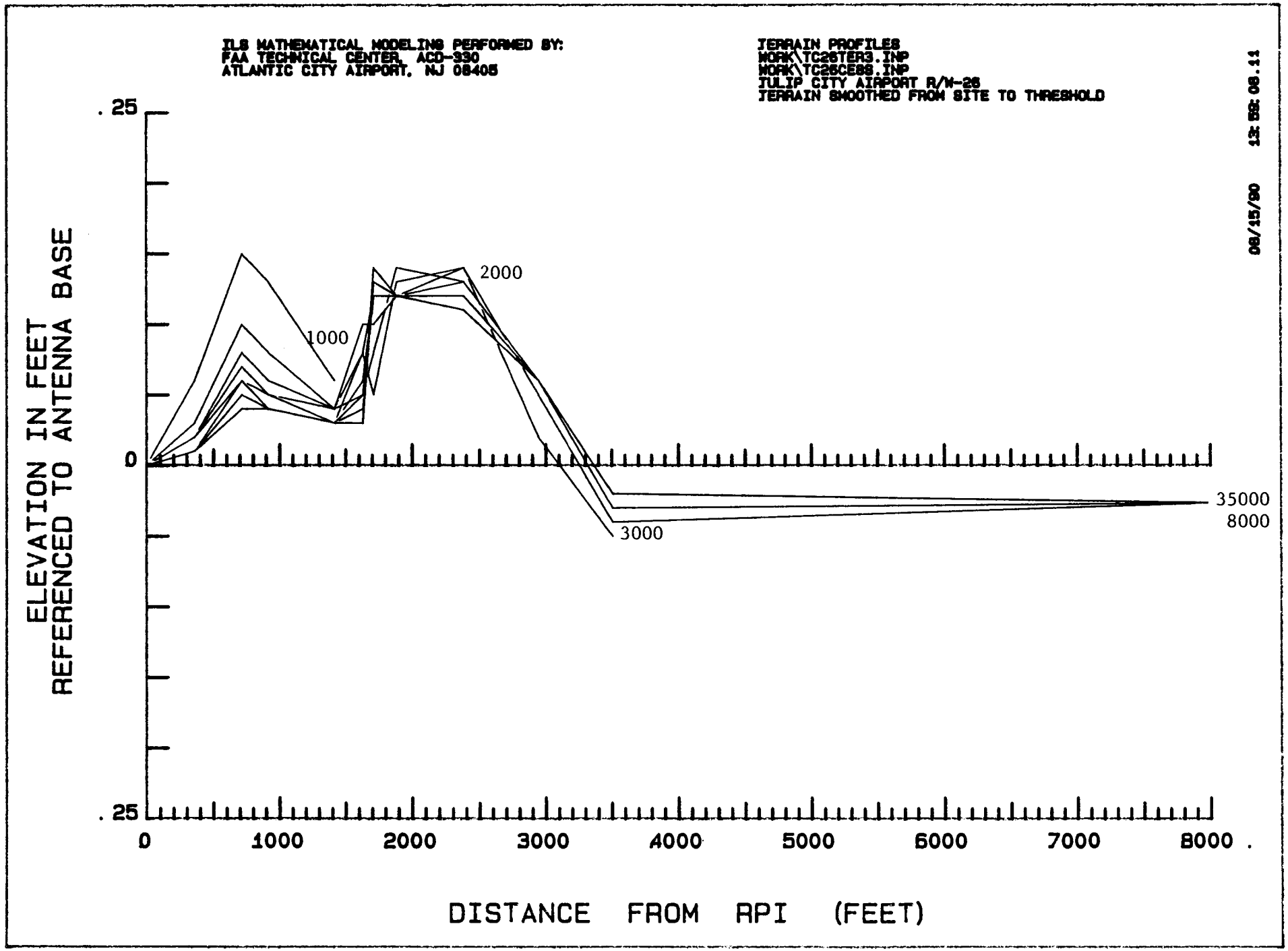
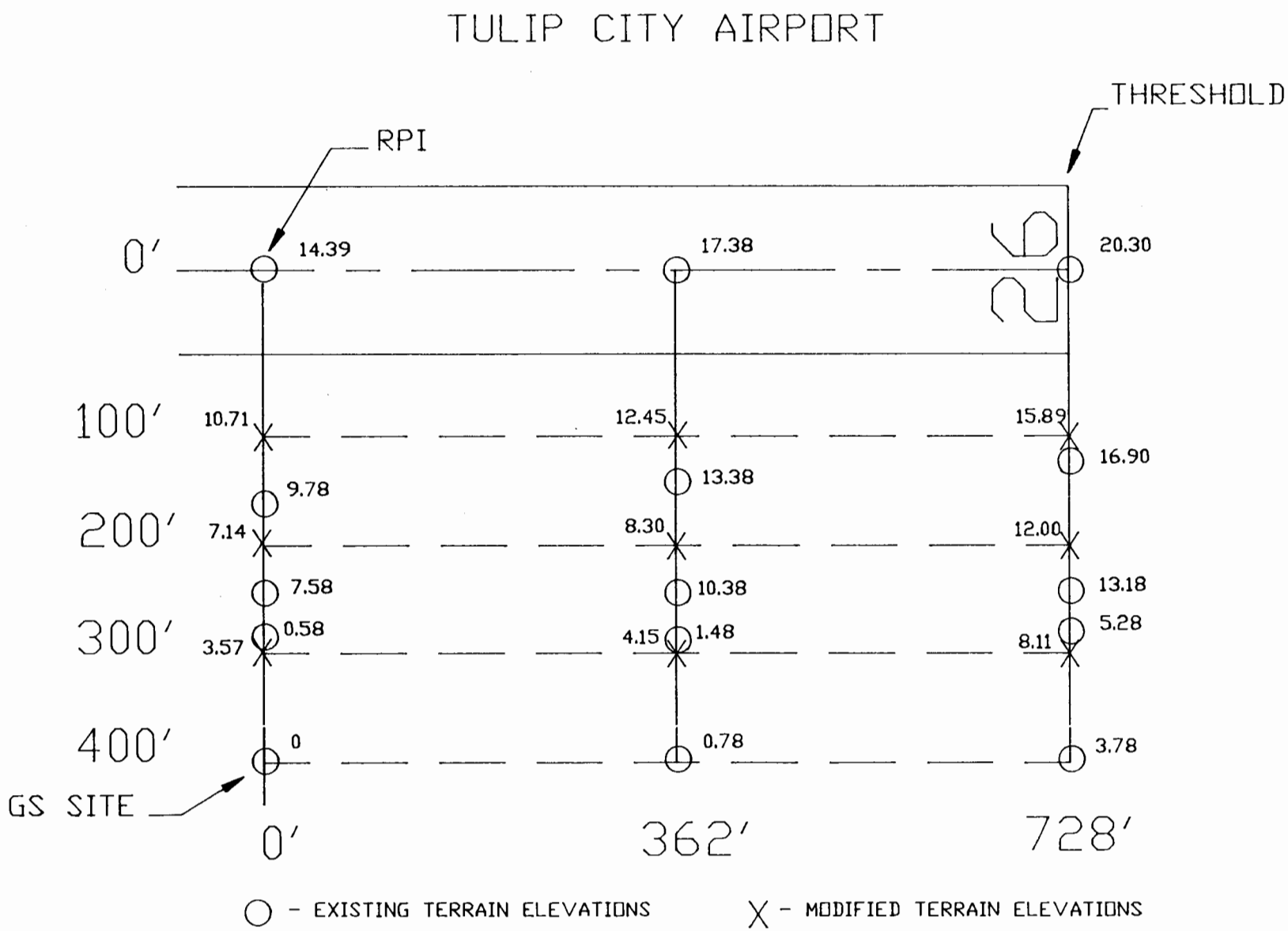


FIGURE 3. TULIP CITY RUNWAY 26, MODIFIED TERRAIN PROFILE



NOTE: ELEVATIONS ARE REFERENCED TO GS SITE ELEVATION.
DRAWING NOT TO SCALE

FIGURE 4. TULIP CITY RUNWAY 26, EXISTING/MODIFIED GRADING

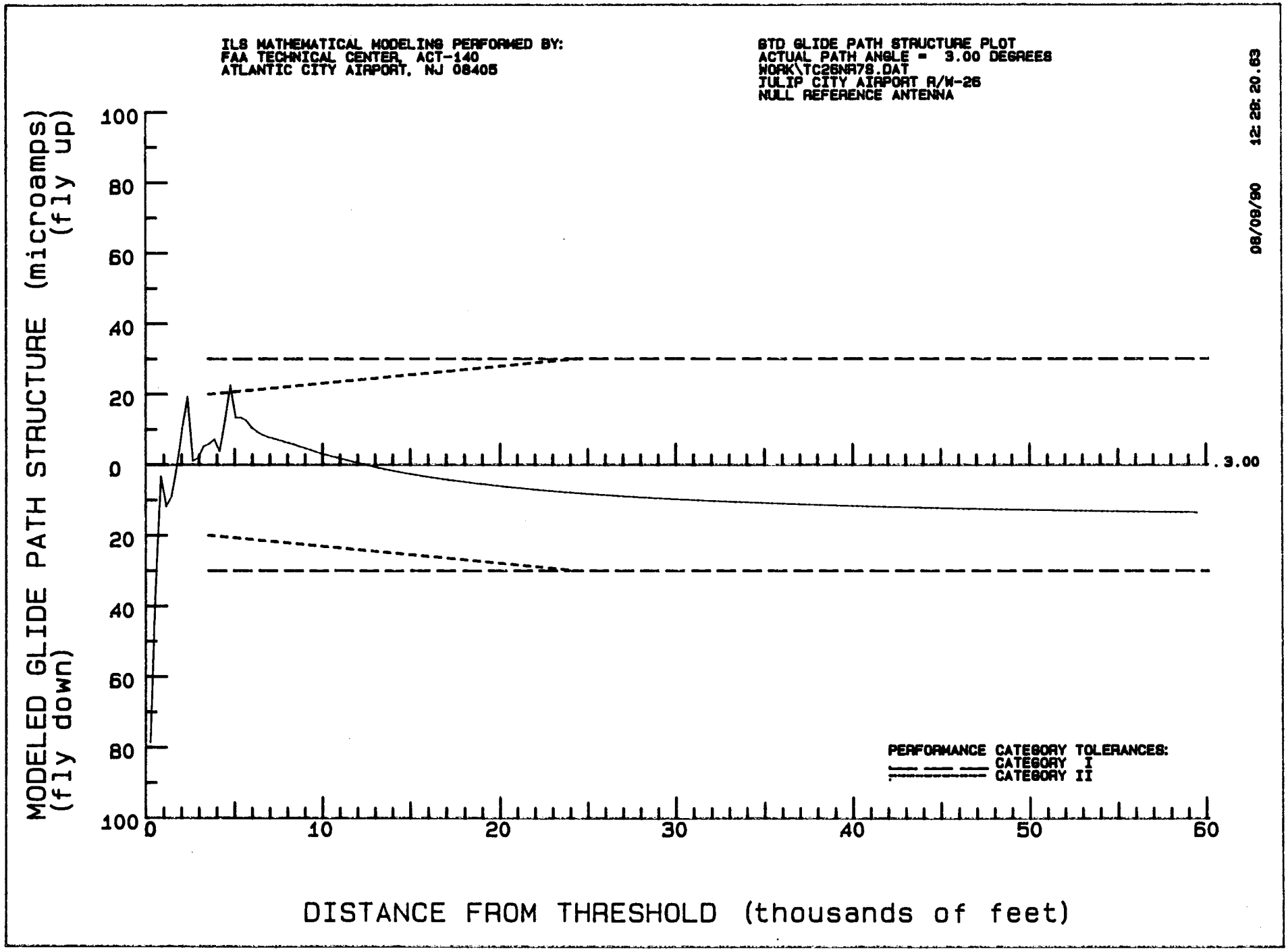


FIGURE 5. MODELED PATH STRUCTURE, TULIP CITY RUNWAY 26, NULL REFERENCE SYSTEM, EXISTING TERRAIN

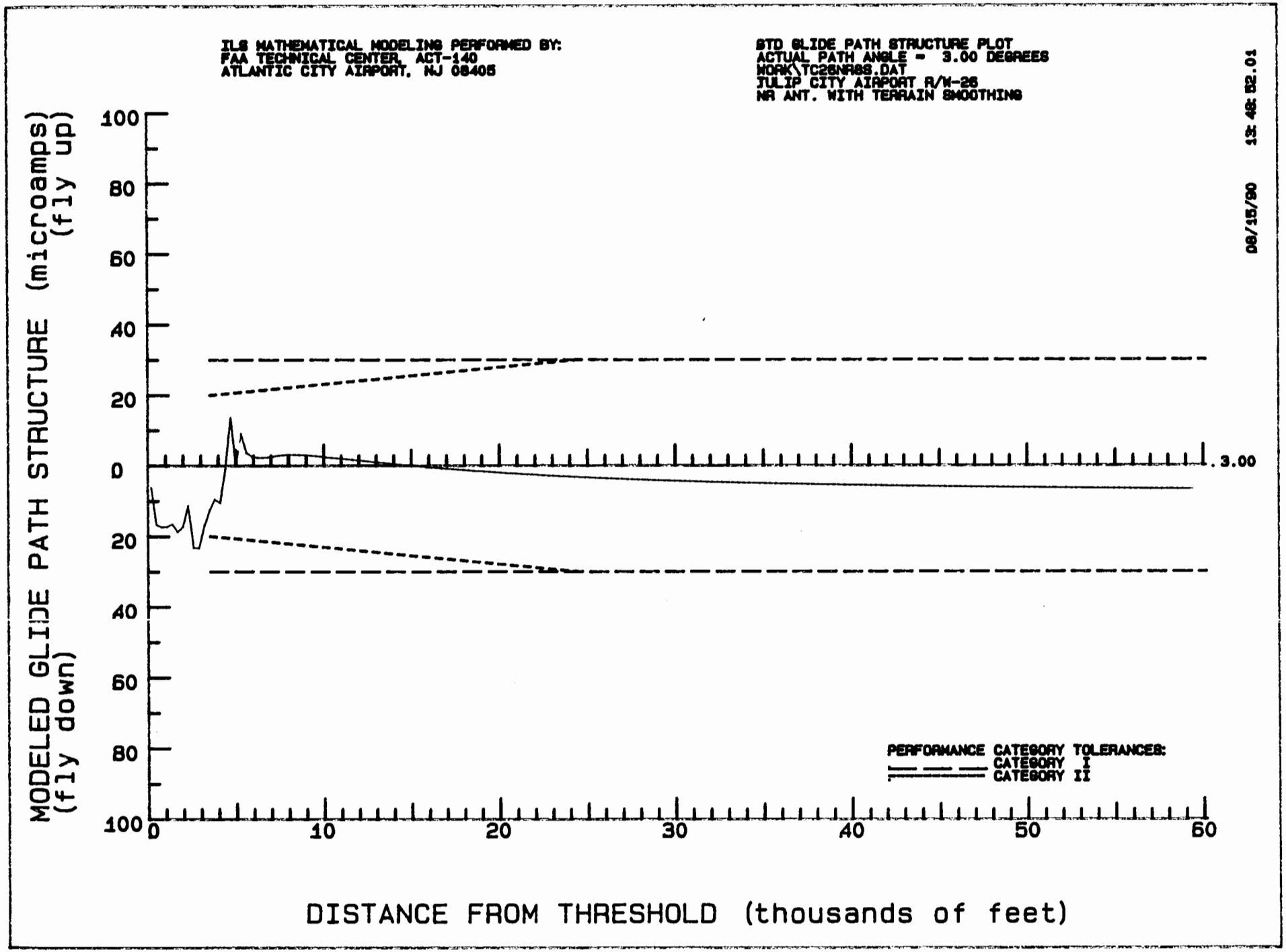


FIGURE 6. MODELED PATH STRUCTURE, TULIP CITY RUNWAY 26, NULL REFERENCE SYSTEM, MODIFIED TERRAIN

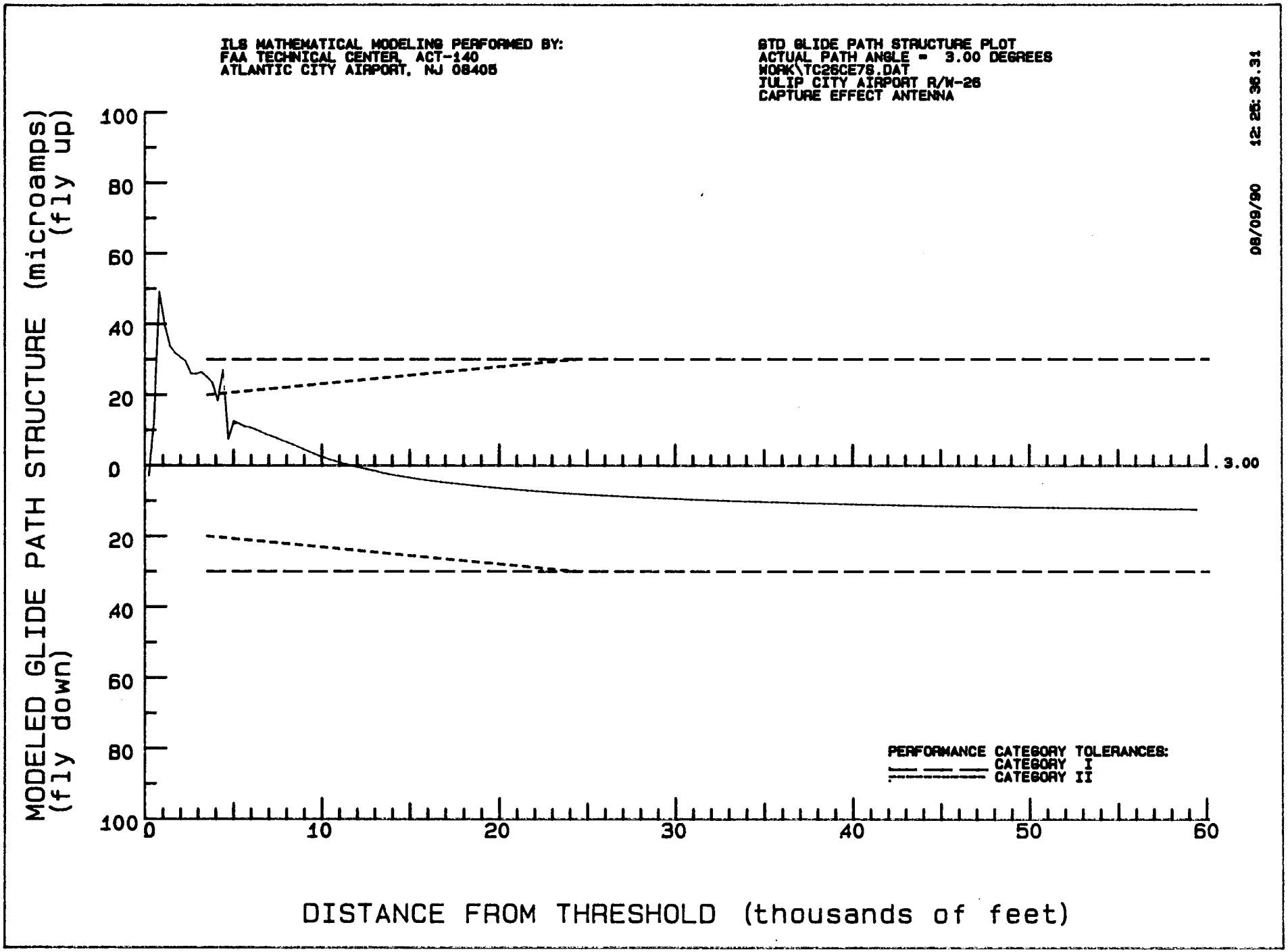


FIGURE 7. MODELED PATH STRUCTURE, TULIP CITY RUNWAY 26, CAPTURE EFFECT SYSTEM, EXISTING TERRAIN

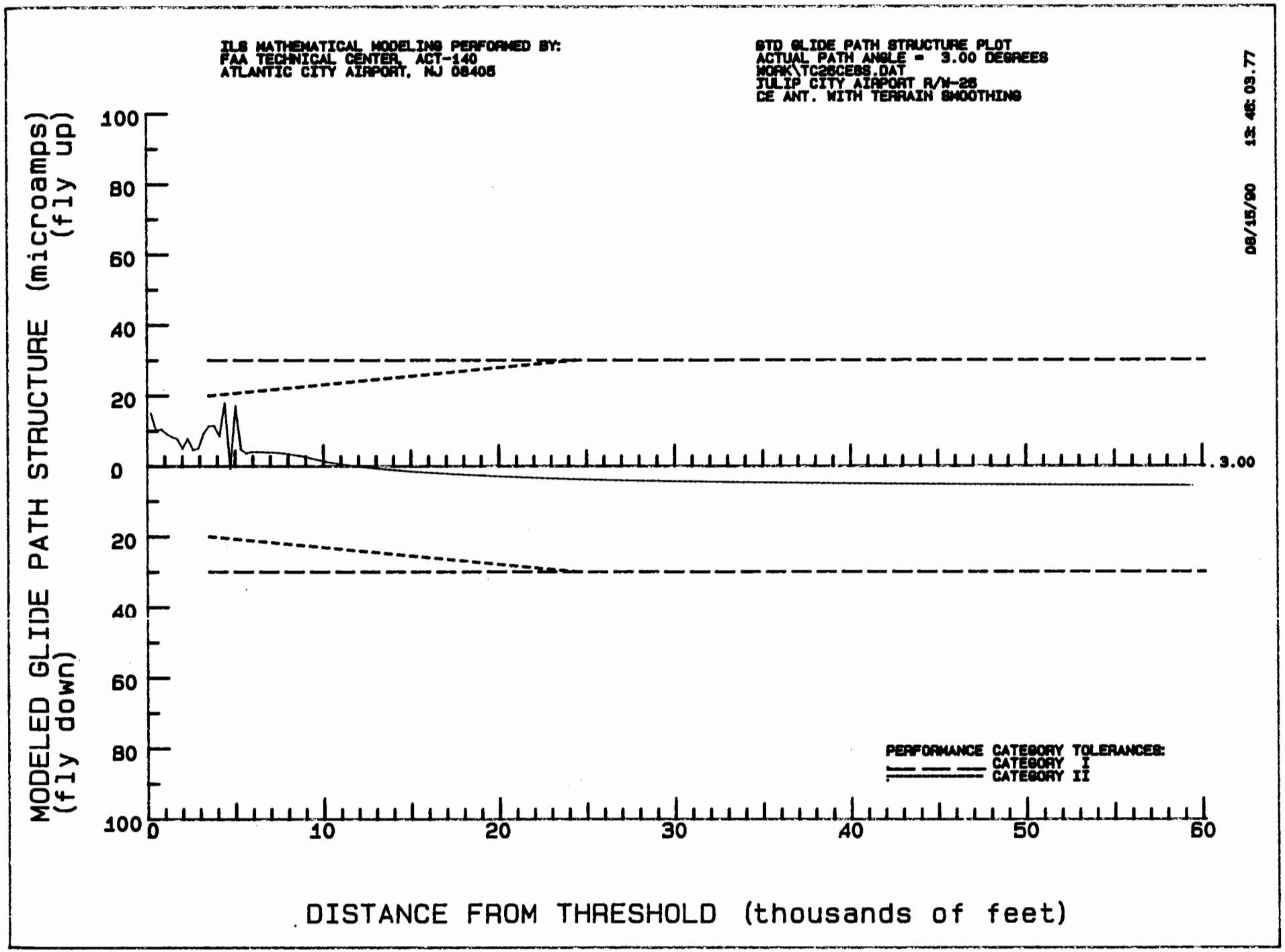


FIGURE 8. MODELED PATH STRUCTURE, TULIP CITY RUNWAY 26, CAPTURE EFFECT SYSTEM, MODIFIED TERRAIN

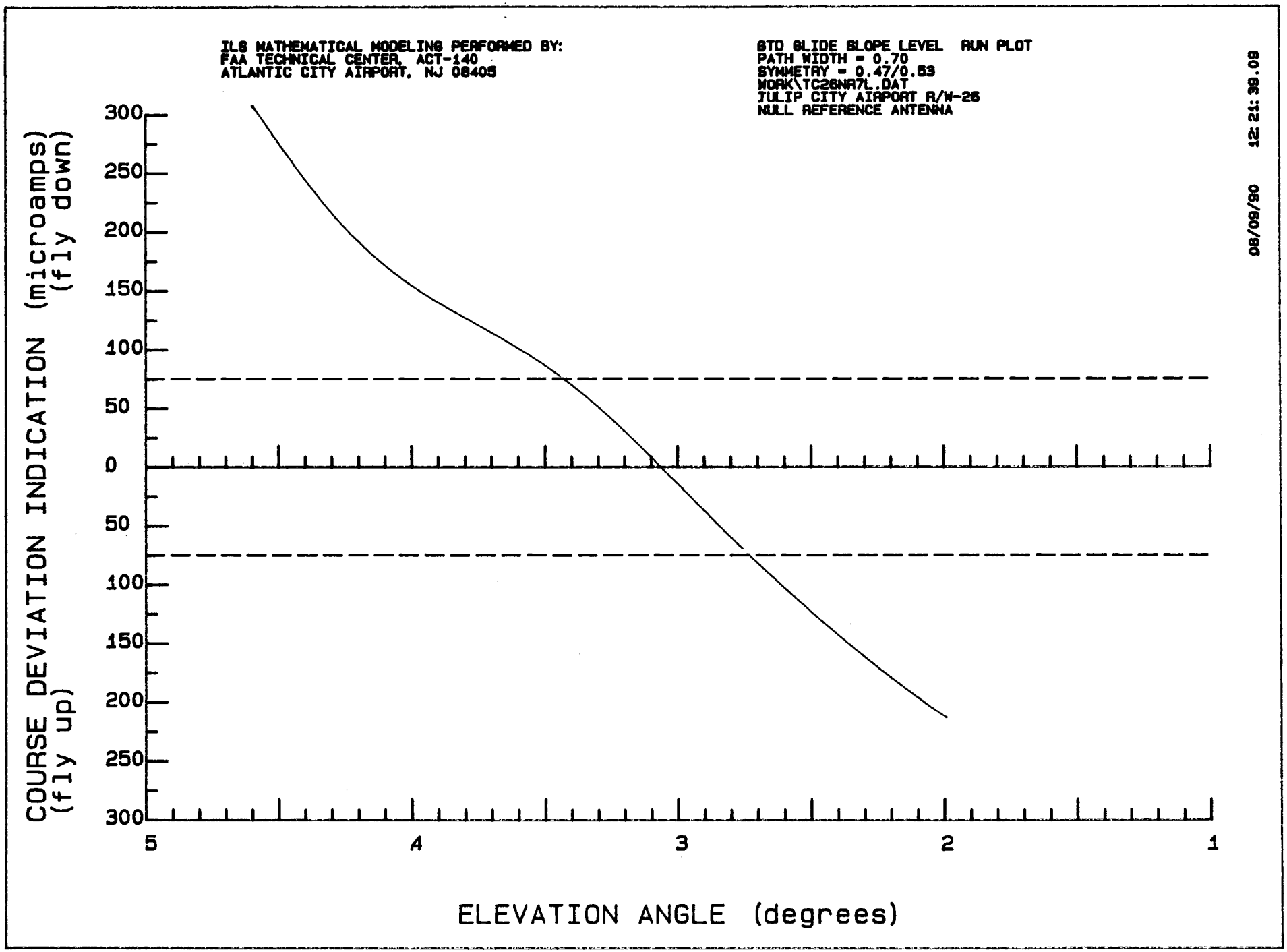


FIGURE 9. MODELED LEVEL RUN, TULIP CITY RUNWAY 26, NULL REFERENCE SYSTEM, EXISTING TERRAIN

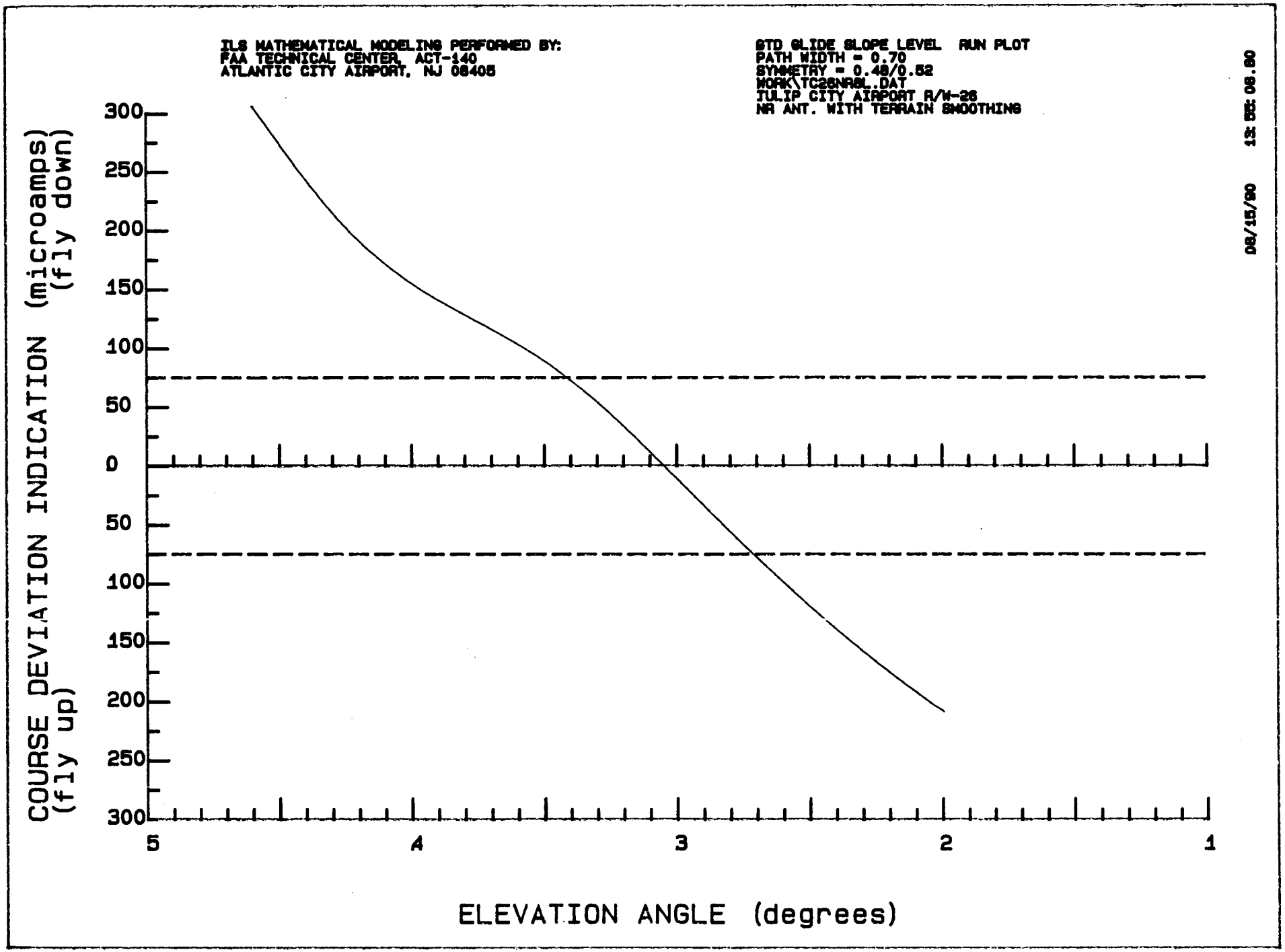


FIGURE 10. MODELED LEVEL RUN, TULIP CITY RUNWAY 26, NULL REFERENCE SYSTEM, MODIFIED TERRAIN

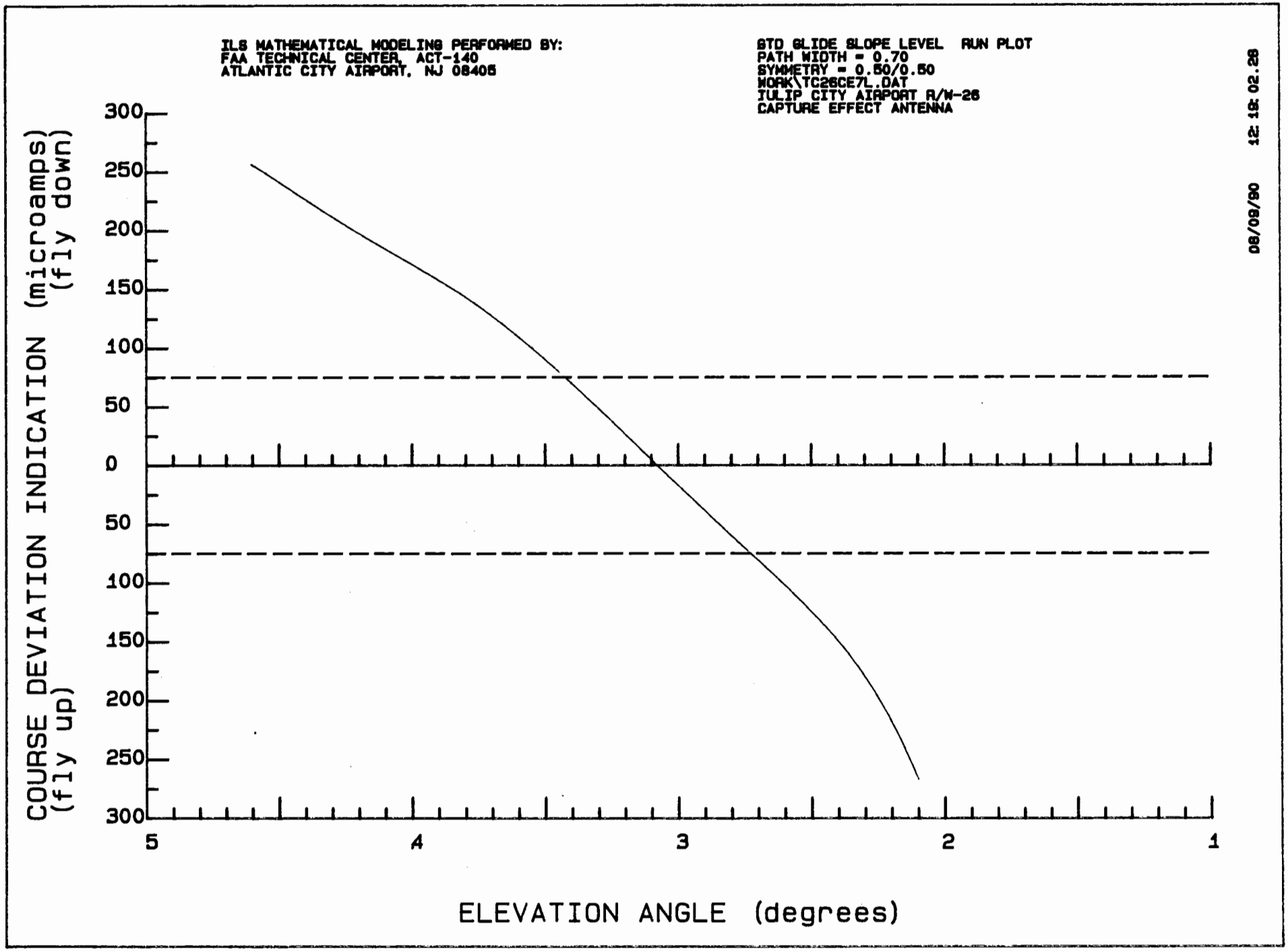


FIGURE 11. MODELED LEVEL RUN, TULIP CITY RUNWAY 26, CAPTURE EFFECT SYSTEM, EXISTING TERRAIN

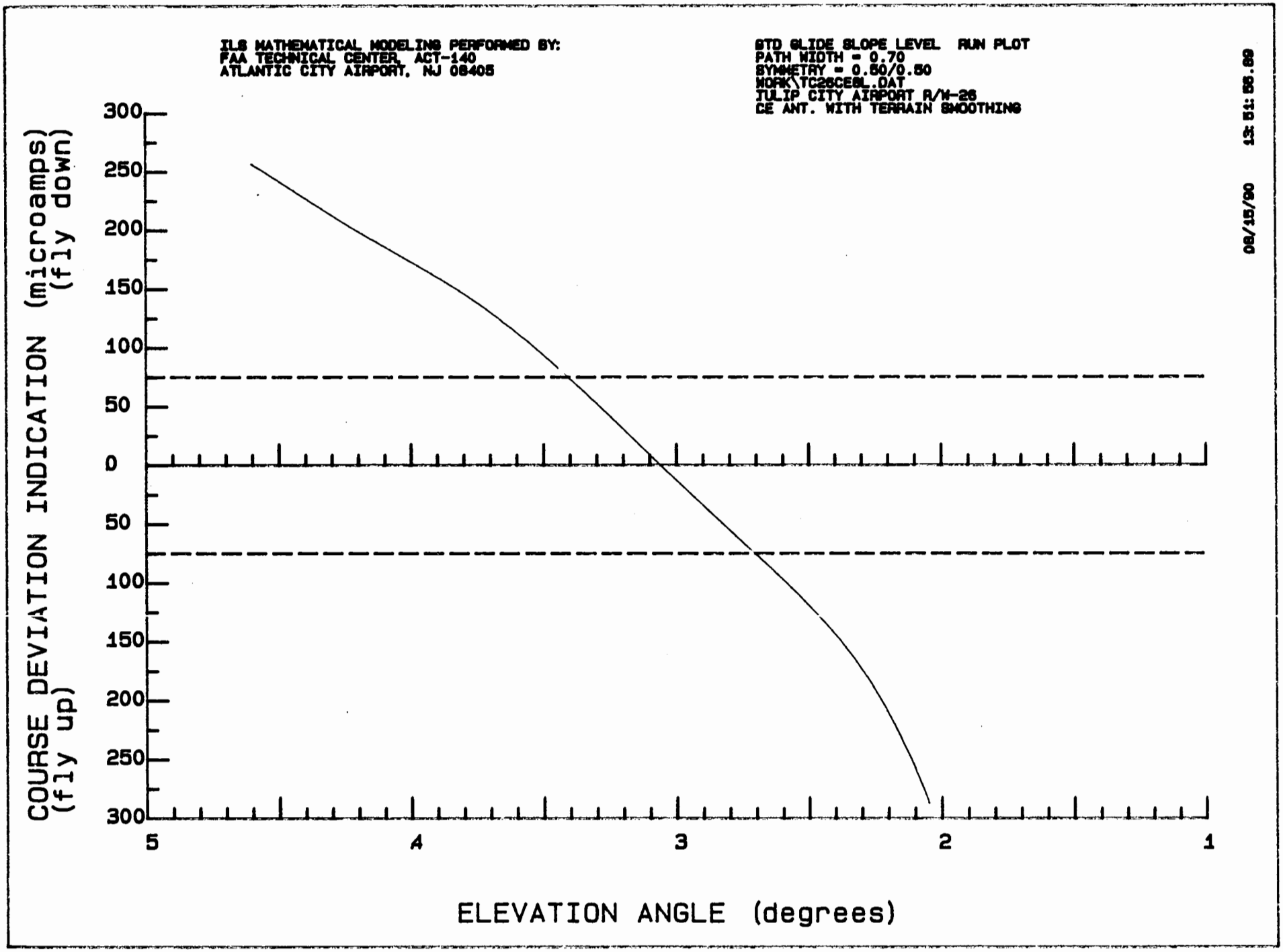


FIGURE 12. MODELED LEVEL RUN, TULIP CITY RUNWAY 26, CAPTURE EFFECT SYSTEM, MODIFIED TERRAIN