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COMPUTER MODELING OF TERRAIN EFFECTS ON INSTRUMENT LANDING SYSTEM (ILS) GLIDE SLOPE SYSTEMS

TECHNICAL REPORT

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1842 ELECRONICS ENGINEERING GROUP (AFCS)
SCOTT AFB, ILLINOIS 62225

15 NOVEMBER 1979

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1. REPORT NUMBER 1842 EEG/EEITN-TR-80-2	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. ~~TITLE (and Subtitle)~~ 6 Computer Modeling of Terrain Effects on Instrument Landing System (ILS) Glide Slope Systems.		5. TYPE OF REPORT & PERIOD COVERED Technical Report ~~6. PERFORMING ORG. REPORT~~ NUMBER
7. AUTHOR(s) 10 James A. Baggett		8. CONTRACT OR GRANT NUMBER(s) 12 30
~~9. PERFORMING ORGANIZATION~~ NAME AND ADDRESS 1842 EEG/EEITN Scott AFB, IL 62225		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS 1842 EEG/EEISD Scott AFB, IL 62225		~~12. REPORT DATE~~ 11 15 Nov[redacted]79 ~~13. NUMBER OF PAGES~~
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)* 12 1842 EEG/EEISD Scott AFB, IL 62225		15. SECURITY CLASS. *(of this report)* UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

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17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Glide slope, instrument landing system, computer modeling, isometric computer plot, linear approximation terrain profiles, terrain grading, capture effect.

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report describes the two major components of an instrument landing system (ILS); the localizer, which provides horizontal guidance, and the glide slope, which provides vertical guidance.

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Gerald T. Harris

GERALD T. HARRIS
Chief, Electronics and Base Systems Engineering Division (EEI)

Amos J Hardy

AMOS J. HARDY
Chief, TRACALS/Electronics Systems Branch (EEITN)

James A. Baggett

JAMES A. BAGGETT
Electronics Engineer

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

NOTE: Figures 6-14 Reproduced from Ohio University Report EER 30-2.

LIST OF TABLES

1.0 BASIC PRINCIPLES OF THE ILS GLIDE SLOPE.

1.1 The Instrument Landing System is composed of two major components. The localizer provides horizontal guidance to an approaching aircraft and a glide slope which provides vertical guidance, reference Figure 1.

1.2 The contemporary glide slope employs an imaging antenna system. This radiation technique uses the direct radiated signal in combination with ground reflected signal to develop the required lobing radiation pattern that provides the glide path used by the approaching aircraft, (refer to Figure 2).

1.3 The glide slope equipment is located to the side of the runway near the approach end. The system operates in the frequency range of 328 to 336 MHz and provides a usable signal in a sector no smaller than 8° either side of runway centerline to a distance of at least ten miles. This system will provide vertical guidance at glide path angles typically between 2.5° and 3.0°. There are three types of glide slope systems used, depending on the site conditions; null reference, sideband reference and capture-effect.

1.3.1 The most commonly used system is the null reference. This system uses two antennas installed on a 40 foot tower. The antennas are installed at a two to one height ratio. With this ratio the upper antenna will produce two signal lobes for each lobe produced by the lower antenna. The lower antenna is fed carrier with 90 and 150 Hz sideband signals (C+SB). The upper antenna is fed the 90 and 150 Hz sidebands only, (SBO). The 90 Hz sideband fed the upper antenna is out of phase with the 90 Hz sideband fed the lower antenna. This arrangement produces a composite radiation pattern shown in Figure 3. The glide path is located in the first null of the SBO pattern. In the first SBO lobe, below path, the 90 Hz sidebands of the SBO and C+SB signals are out of phase thus subtract, while the 150 Hz sidebands are in phase thus add. Therefore, an aircraft receiver in this lobe will see a predominance of the 150 Hz sideband which corresponds to a "Fly-Up" indication. On the glide path the SBO signal is nulled, or in other words, the signal reflected from the ground is out of phase with the direct signal because of the difference in path length the two signals travel. An aircraft receiver on the glide path will not see a SBO signal, only a C+SB signal which has equal amounts of 90 Hz and 150 Hz sidebands. Equal amounts of both sidebands corresponds to an "On Path" indication. In the second SBO lobe, above path, the relative phase of the sidebands are reversed from that in the first SBO lobe. In this lobe the 90 Hz sidebands of the SBO and C+SB signals add and the 150 Hz sidebands subtract. Thus, in the second SBO lobe the 90 Hz sideband is predominate, this corresponds to a "Fly Down" indication.

1.3.2 The capture-effect system uses two frequencies and three antennas. This type glide slope system is typically used at difficult sites where terrain is a problem. Compared to the single frequency null reference or sideband reference systems, the capture-effect glide slope reduces bends and irregulariities in the glide path caused by reflections from obstacles and terrain irregularities in the far field, beyond 1200 feet from the antenna array. This is accomplished by reducing the amount of primary course forming signal, (C+SB) and (SBO), at lower approach angles near the ground and thereby reducing the interfering reflections. Another signal is then radiated, at slightly offset frequency and less amplitude, to provide

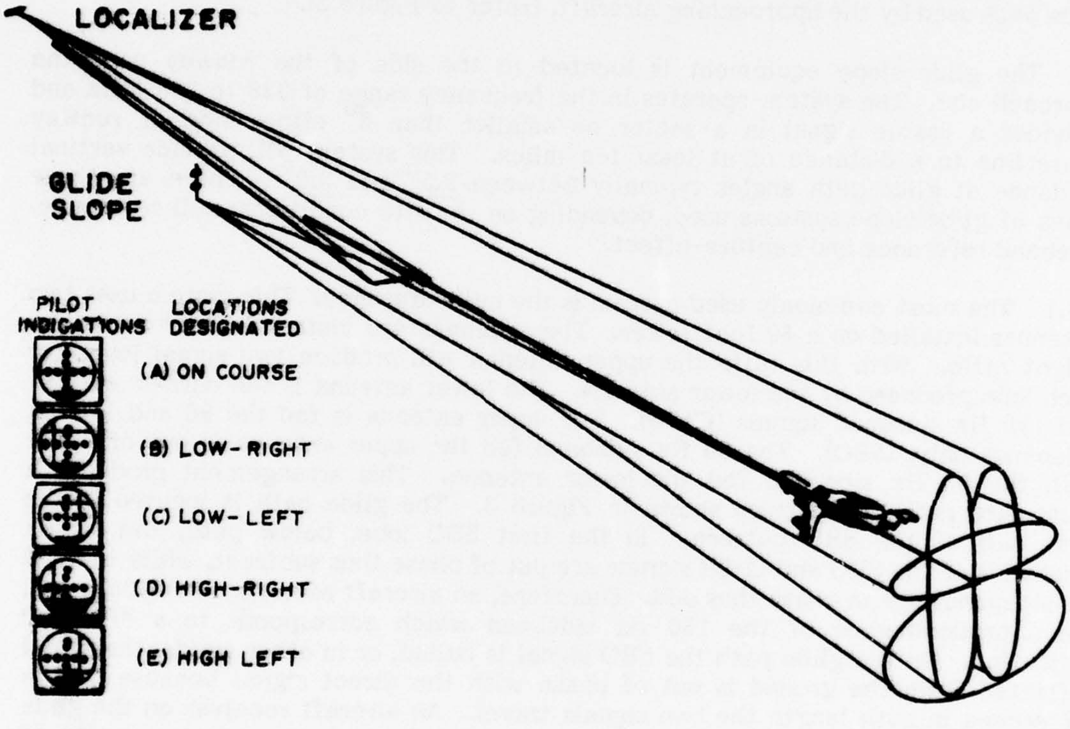


Figure 1. Major Components of ILS System

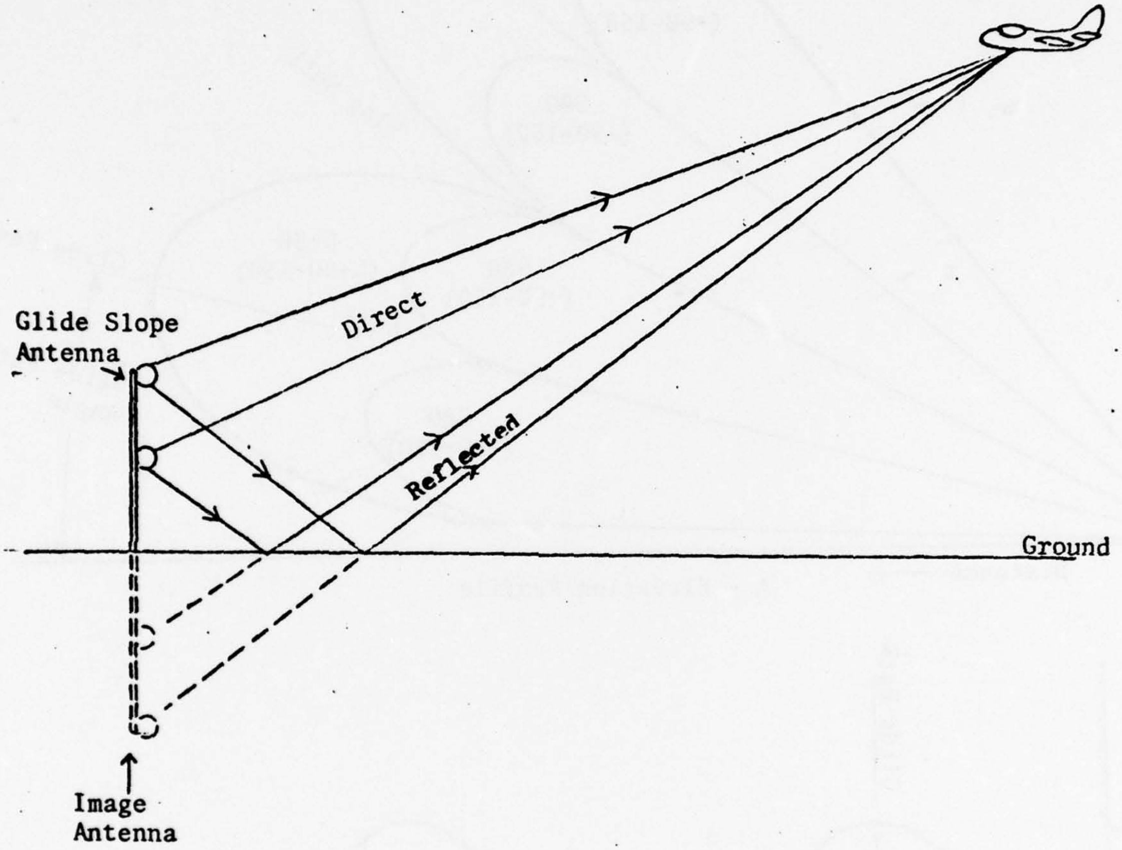
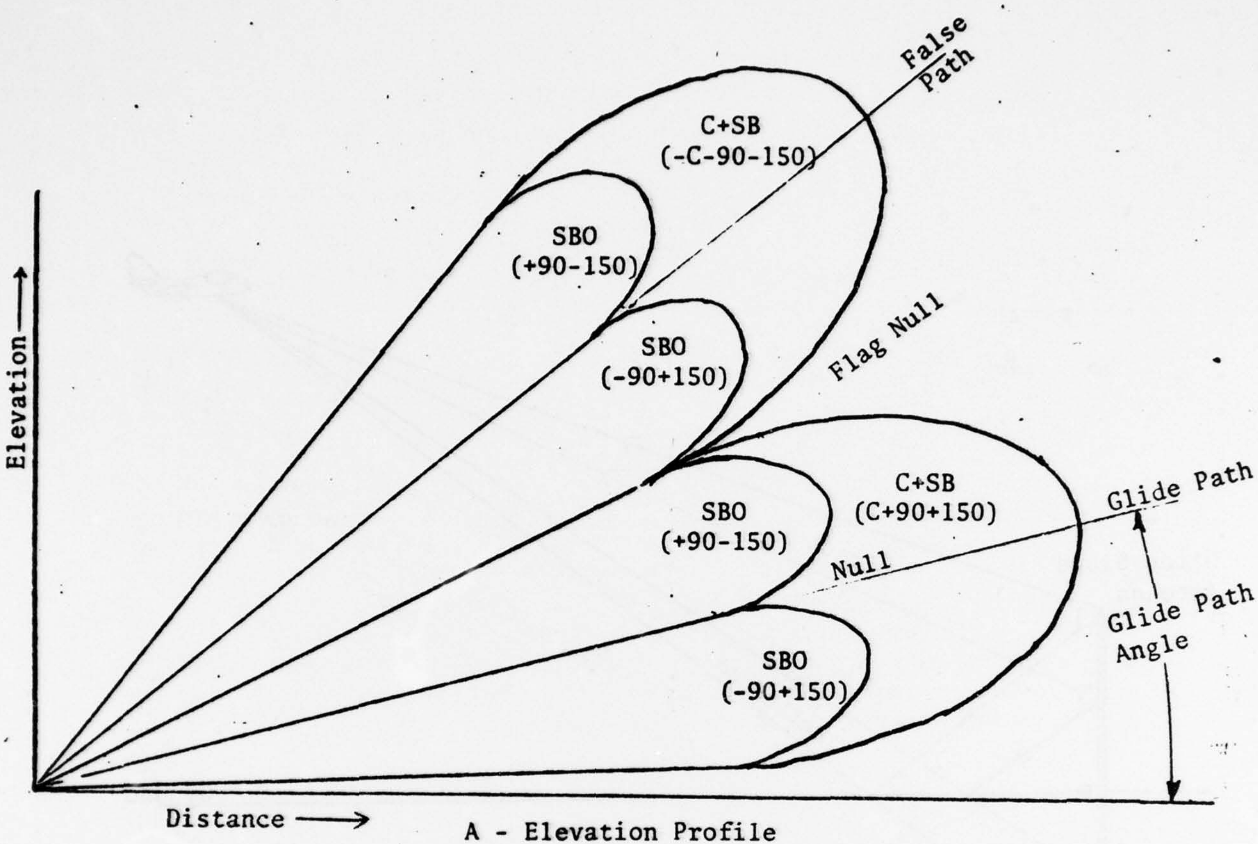


Figure 2. Principle of Image Antenna



A - Elevation Profile

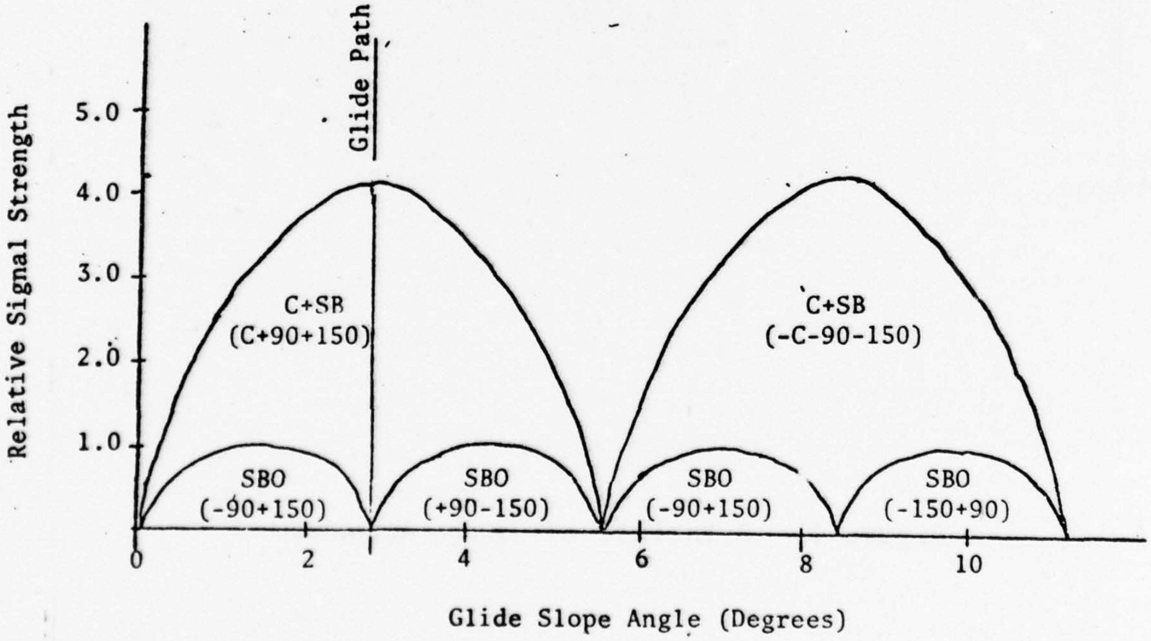


Figure 3. Null Reference Radiation Patterns

coverage at these lower approach angles. This signal is called the clearance signal, (CL), and contains only a 150 Hz sideband (refer to Figure 4). Interference from the clearance signal being reflected back on to the glide path is effectively elliminated because of the characteristics of the linear detector within the aircraft receiver. When two signals of slightly different frequencies, but both within the band pass frequency of the receiver, are processed by the linear detector, the detector will amplify the stronger of the two signals and reduce the weaker signal. The ILS receiver will "capture" the stronger signal.

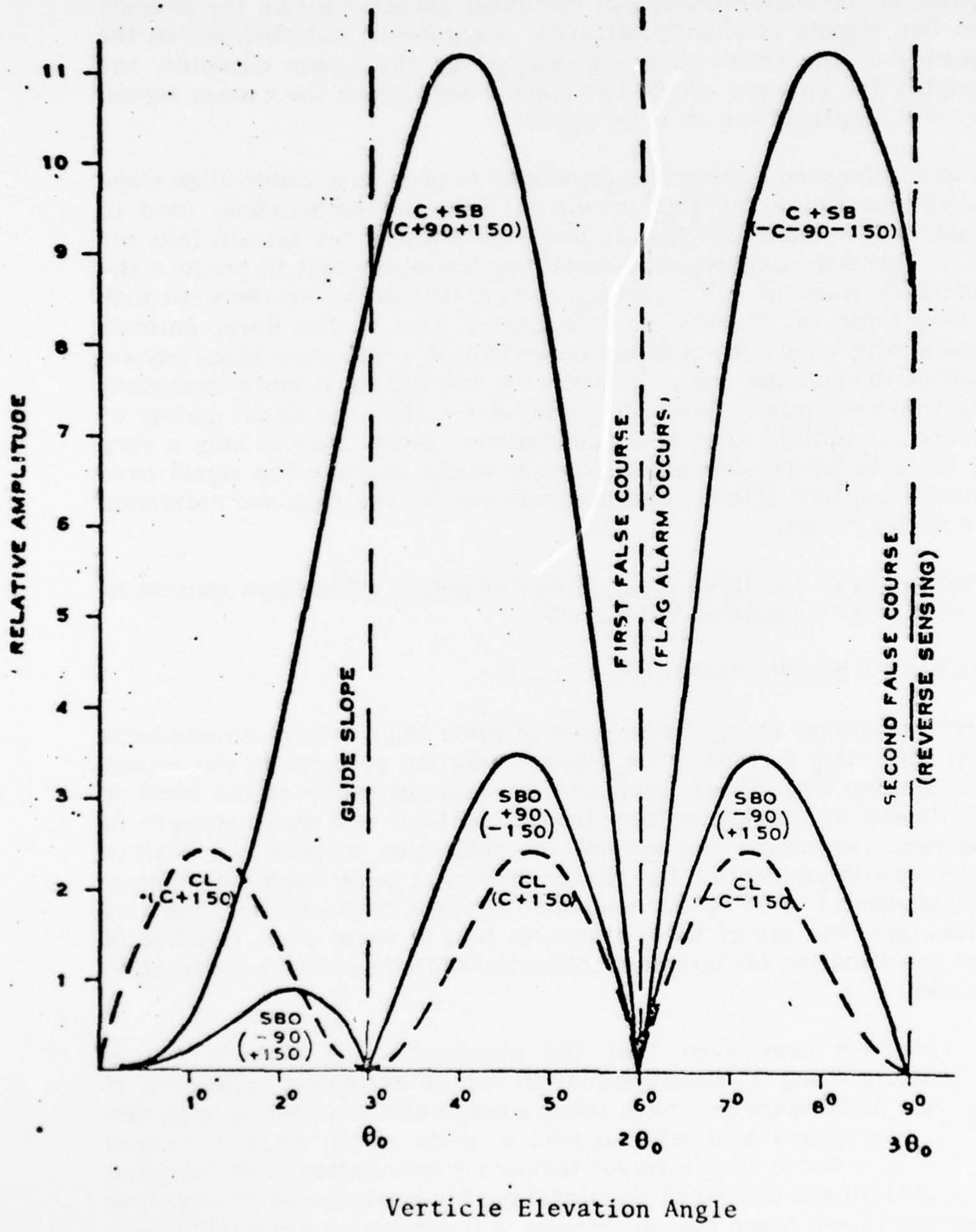
1.3.3 The sideband reference system was developed to provide a usable glide slope signal under conditions where the flat terrain in front of the antenna, used to reflect the signal, is less than 1000 feet in length and where the terrain falls off beyond this point. This is accomplished by modifying the equipment to produce the same aircraft indications as the null reference and capture-effect systems but with lower antenna height for any given glide path angle. Due to the lower antenna height, the sideband reference system is less dependent on a reflection plane beyond 1000 feet in front of the antenna array. Conversely, the system is more dependent on smooth terrain immediately in front of the antenna. Also, the signal quality of this system is more susceptible to snow accumulations. Since there is only a very limited number of sites where sideband reference would improve the signal over the null reference or capture-effect radiation, patterns for the sideband reference are not provided in this report.

1.4 General application of the three types of contemporary glide slope systems to different siting conditions is depicted in Figure 5.

2.0 THE GLIDE SLOPE SITING PROBLEM.

2.1 Most theoretical studies for all three types of glide slope involve assumptions of a smooth, flat reflecting surface. The typical radiation patterns in this report are based on this assumption. These conditions are representative of the ideal or mathematical limit and any deviation from these conditions will cause changes to the radiation patterns depicted. The amount the reflection surface can deviate from this flat and smooth assumption has for the most part never been determined. Thus, the siting standards[1] used by our engineers deviate only slightly from this assumption. Therefore, the use of these standards has, at some sites, resulted in over or incorrect specification for terrain modifications (grade and fill) in the glide slope reflection area.

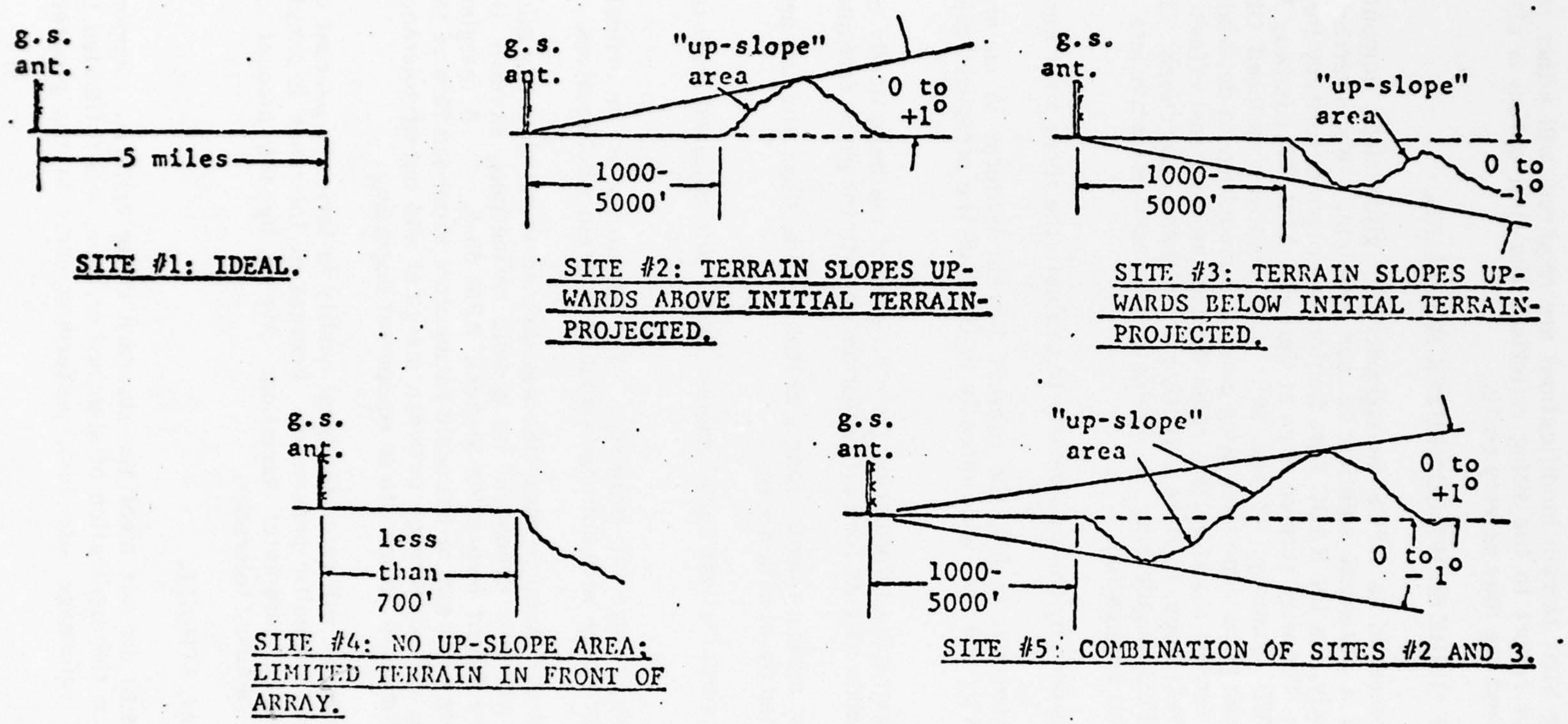
2.2 For some time we have seen that the standard siting criteria is too restrictive. At problem sites, its rigid application can be extremely expensive, if not cost prohibitive. AFCS engineers have taken a pragmatic site testing approach in determining if a proposed site will support a glide slope without terrain modifications. This type site testing involves temporary installation of an ILS glide slope on the proposed site and looking at the signal quality produced by the existing terrain. Our engineers have found that many sites will provide an acceptable glide slope signal even though the existing terrain does not meet the criteria. However, we have not had a reliable analytical tool that would permit correct identification of the terrain feature(s) causing problems at those locations where site testing yields marginal or out-of-tolerance performance. In this situation, the siting



Capture-Effect

Figure 4. Composite Vertical Radiation Pattern

Details taken from FAA Order 6750.16A



SITE #1: IDEAL.

SITE #2: TERRAIN SLOPES UPWARDS ABOVE INITIAL TERRAIN-PROJECTED.

SITE #3: TERRAIN SLOPES UPWARDS BELOW INITIAL TERRAIN-PROJECTED.

SITE #4: NO UP-SLOPE AREA; LIMITED TERRAIN IN FRONT OF ARRAY.

SITE #5: COMBINATION OF SITES #2 AND 3.

	SITE #1	SITE #2	SITE #3	SITE #4	SITE #5
PER CENT OF TOTAL SITES	5%	20%	15%	15%	45%
NULL REFERENCE	all	very few	few	none	very few
SIDEBAND REFERENCE	all	few	many	very few	few
CAPTURE EFFECT	all	most	most	none	most

Figure 5. Expected Applicability of Various Types of Glide Slope Systems to Different Siting Conditions

engineer, in determining what terrain modifications are required, will either rely on his past experience or revert to the siting criteria. The first option is often very risky, while the second one may be very costly.

3.0 INVESTIGATION OF GLIDE SLOPE COMPUTER MODELING.

3.1 Ohio University presented to AFCS an approach for glide slope computer modeling which offered a potential solution to our problem. We awarded a contract to Ohio University, via the RADC Post Doctorate Program, to study three problem glide slope sites. The sites studied were at Carswell AFB, TX (Runway 35) and Malmstrom AFB, MT (Runways 02 and 20). Our contract required Ohio University to evaluate each glide slope site, using computer modeling, to determine the minimum amount of terrain modifications required and the most cost effective transmission mode (null reference, capture effective or sideband reference). This project also enabled AFCS engineering to evaluate the cost effectiveness of computer modeling for this application.

3.2 The basic procedures used by Ohio University to evaluate the three sites were:

a. Determine precisely, (± 6"), the present terrain features in an area approximately 4,000 feet by 900 feet wide directly in front of the prosposed glide slope location.

b. Using the topographic information from a., predict mathematically the optimum phasing and antenna heights for best performance with the given terrain.

c. Perform flight measurements using a portable glide slope and the preflight information furnished by item b. above.

d. Validate the mathematical model against the results obtained from the flight measurements.

e. Mathematically change, if necessary, the terrain so as to indicate adequate glide slope performance with minimal amount of terrain modifications.

3.3 For this study an out-of-tolerance condition was defined to be when any glide slope signal parameter, which is dependent on ground reflections, exceeds the tolerance specified in the Flight Inspection Manual, AFM 55-8.[2] A marginal condition was defined to be when any of the same parameters exceeded 75% of the specified tolerance. The 25% difference between marginal and out-of-tolerance was established to allow for some future site or equipment degrading.

3.4 Throughout this report we will refer to signal quality in terms of percent of tolerance and usually tied to specific parameter. Percent of tolerance is simply the calculated or measured parameter variations divided by the amount of variations allowed by the specified tolerance.

4.0 RESULTS OF SPECIAL STUDIES.

4.1 The Carswell AFB site did not meet the standard siting criteria. Support construction cost, based on the application of standard criteria, was estimated to be $250,000.00. A null reference site test, performed early in the program indicated that the existing site would, at best, provide a signal of only marginal quality. At that time AFCS did not have the equipment necessary to conduct a capture effect site test. The preliminary computer runs indicated that the site would provide a good quality signal without terrain modifications if a capture effect system was installed. This prediction was confirmed during the model validation flight test. Good correlation was observed between computer predictions and the actual measured signal quality. The final report recommended that the system be installed in the capture effect mode without terrain modifications.[3] The system at Carswell AFB has since been installed and commissioned. It should be noted that if equipment with capture effect capability had originally been available for site testing at Carsell AFB, we would have arrived at the same conclusions without computer modeling. However, the results of computer modeling at Carswell AFB increased our confidence in it as a tool for solving future ILS siting problems.

4.2 From the beginning of this project, it was obvious the two Malmstrom sites were both much worse than the Carswell site. Due to the severity of the terrain in the glide slope reflections area, preliminary site testing was not even considered since the anticipated results could not justify the expenditure of funds required to site test.

4.3 The results of computer modeling of the Runway 20 site at Malmstrom indicated that the existing site could only provide a glide path signal with marginal quality, without terrain modification.[4] To achieve even this marginal performance, the equipment would have to be operated in a non-standard configuration i.e., four times the normal transmitted clearance power. These conditions were judged not acceptable. Efforts were then made to identify the minimum amount of terrain modifications required and the corresponding signal quality the modified terrain would produce. Efforts were also made to identify the amount of modifications that would be required if the standard siting criteria were applied and the signal quality these type modifications would produce.

4.3.1 Reference Figures 6 thru 11, isometric computer plots and corresponding profiles showing the existing terrain, the terrain with moderate modifications and with extensive modification from the Malmstrom report is referenced to illustrate the utility of the data provided by this type study. The vertical scale on the isometric plots have been expanded by a factor of 20 to improve clarity. Figures 12 and 13 show the calculated centerline flyability of the glide slope signal with present terrain, and after moderate and extensive modifications. Also provided in these figures is a comparison of the calculated centerline flyability under existing terrain conditions to the actual centerline flyability measured during the model verification phase of the study.

4.3.2 Reference Table I for summary of findings. Computer modeling of the Runway 20 site indicated that we could save an estimated $357,000 in support construction cost by reducing the amount of terrain modifications in the glide slope reflection area by 86,000 cubic yards, without significantly reducing the signal quality that would be produced if the site were modified to meet the siting criteria.

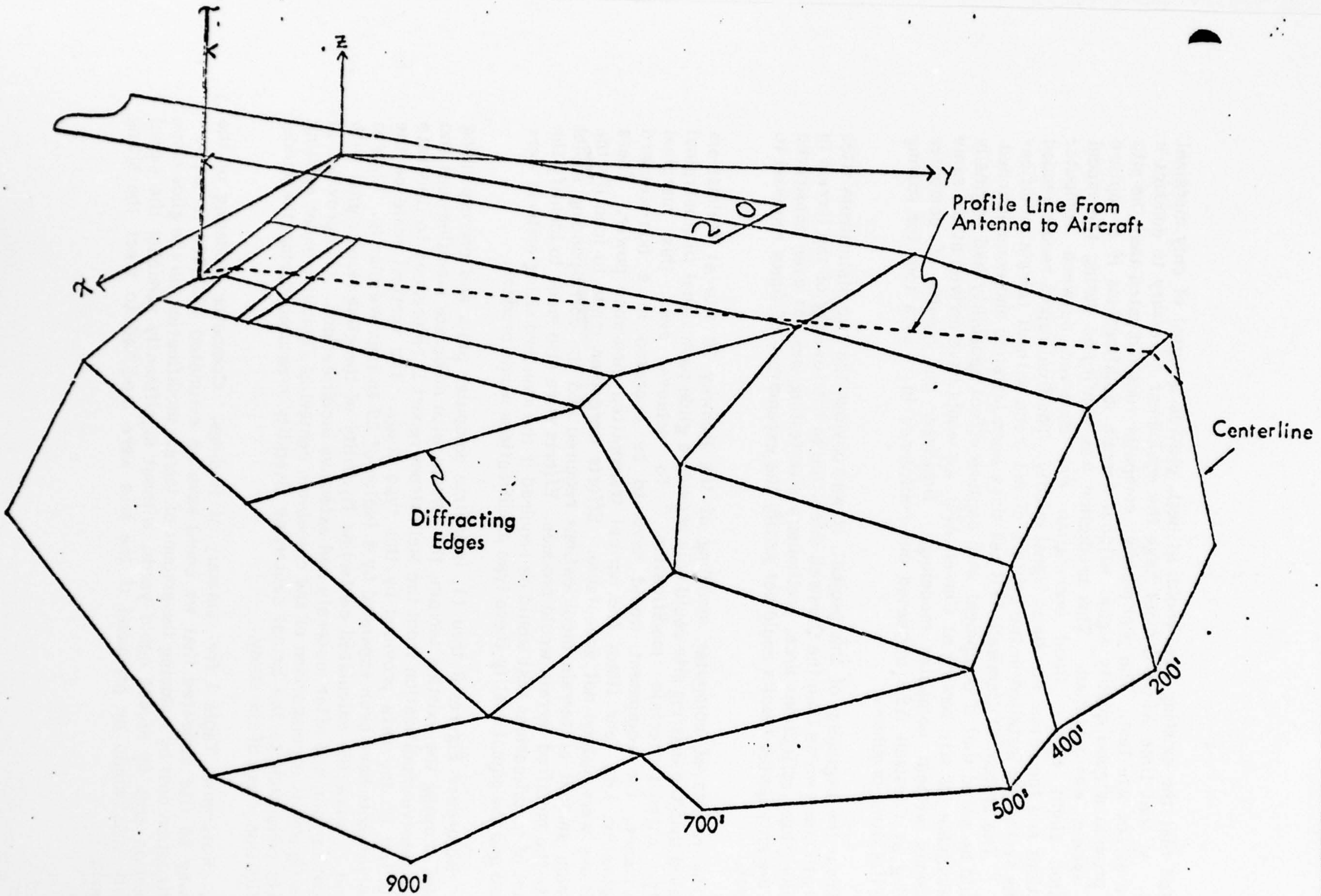


Figure 6. Isometric Computer Plot of Straight Line Approximation to Actual Terrain at North (20) End of Malmstrom AFB with Horizontal Dimensions Reduced by Factor of 20 with Respect to Vertical.

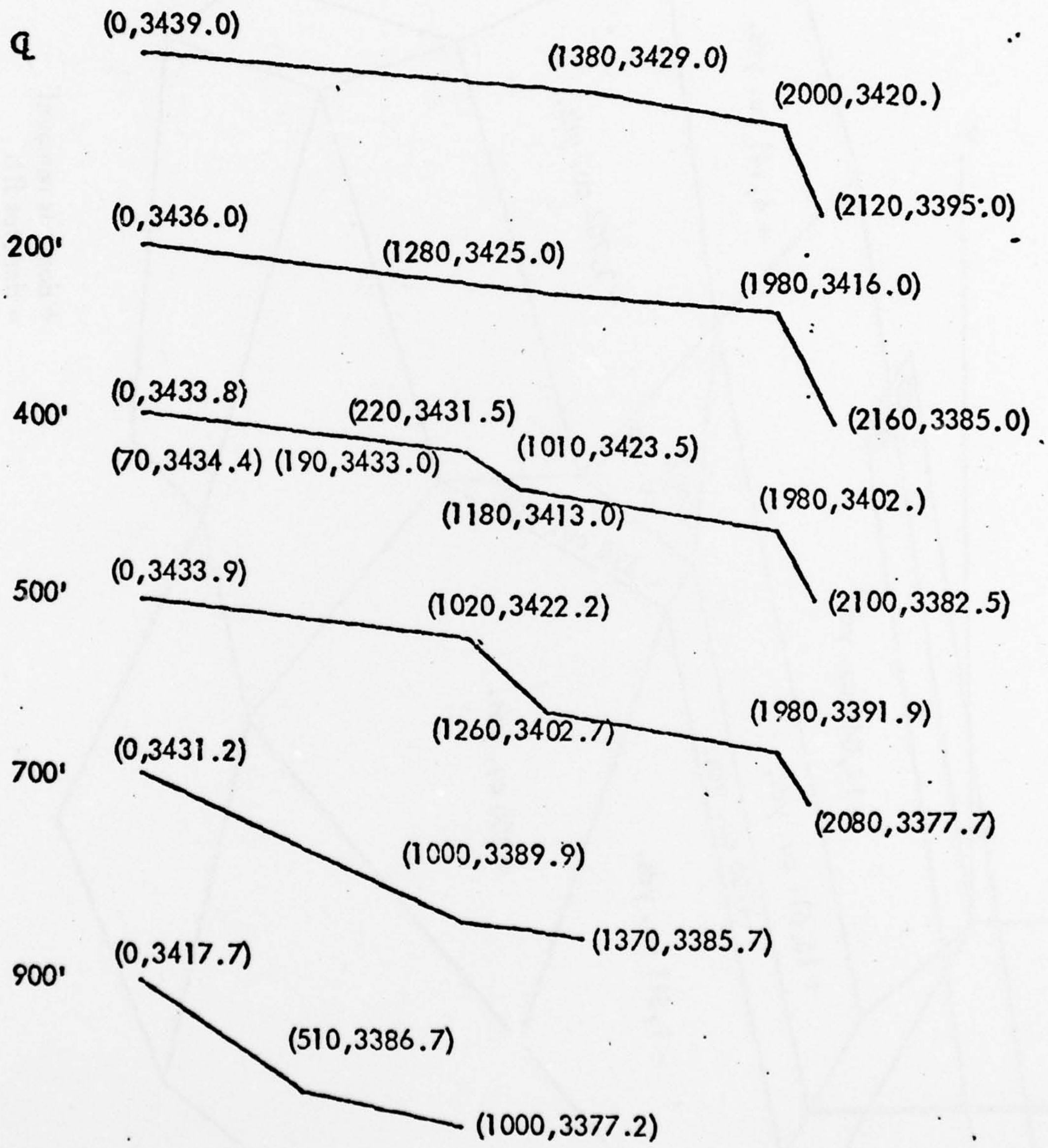


Figure 7. Linear Approximation Terrain Profiles Parallel to the Runway Centerline for the North (20) End, Present Terrain.

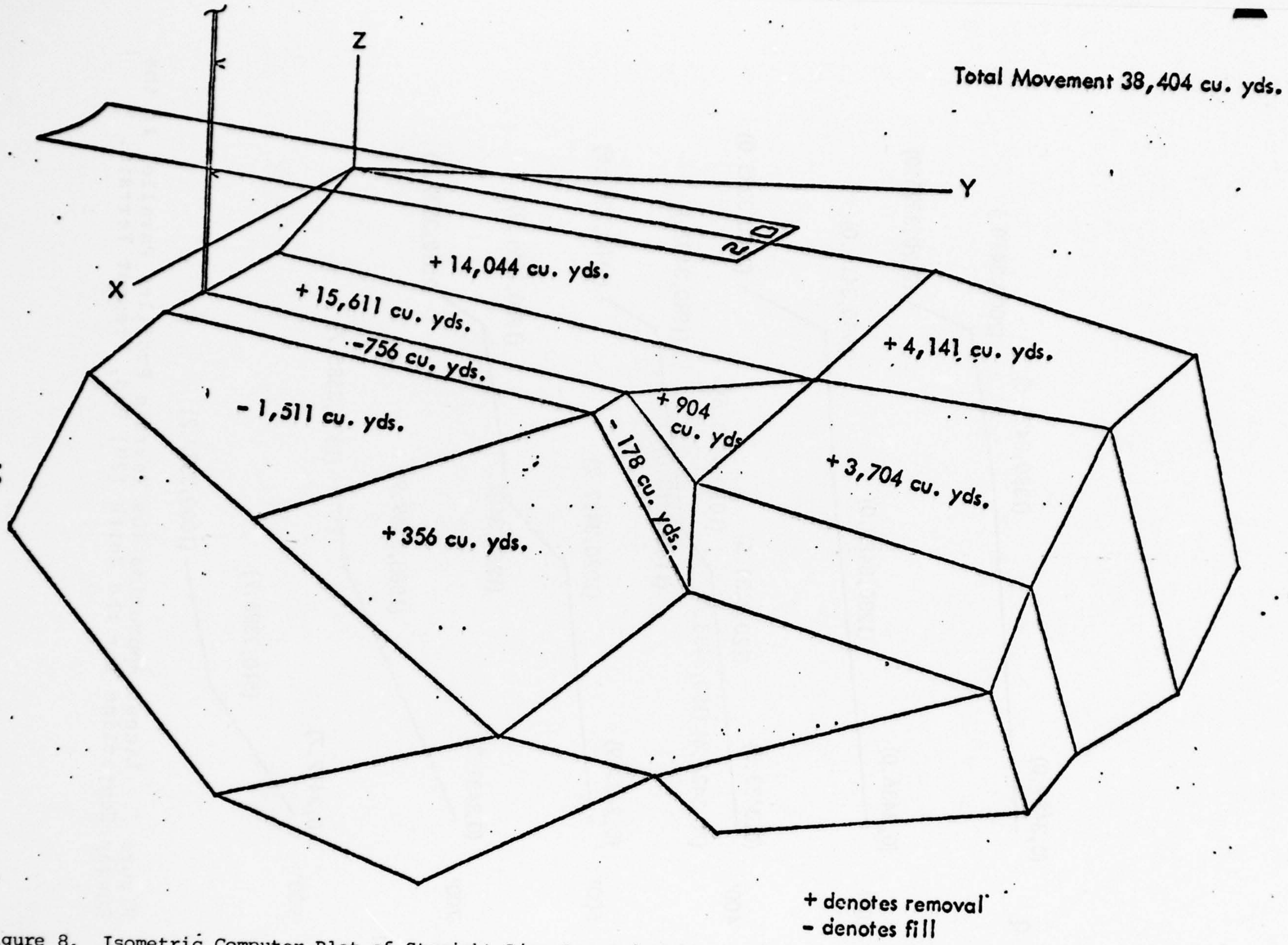


Figure 8. Isometric Computer Plot of Straight Line Approximation to Terrain in Front of the North (20) End Runway Glide Slope with Vertical Dimension Scaled by Factor of 20 After Moderate Earth Movement. Numbers denote amount of earth removed or filled in given area.

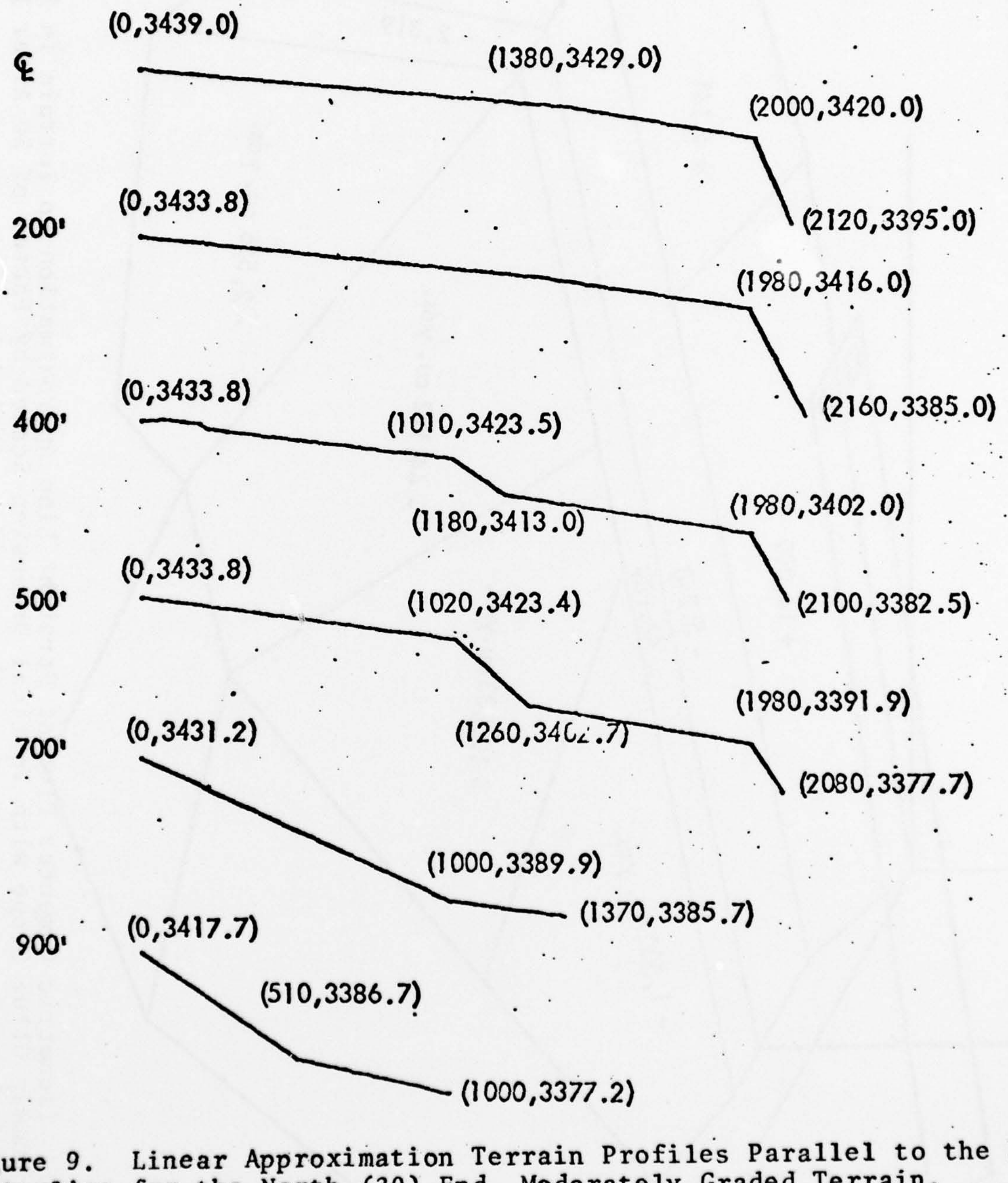


Figure 9. Linear Approximation Terrain Profiles Parallel to the Runway Centerline for the North (20) End, Moderately Graded Terrain.

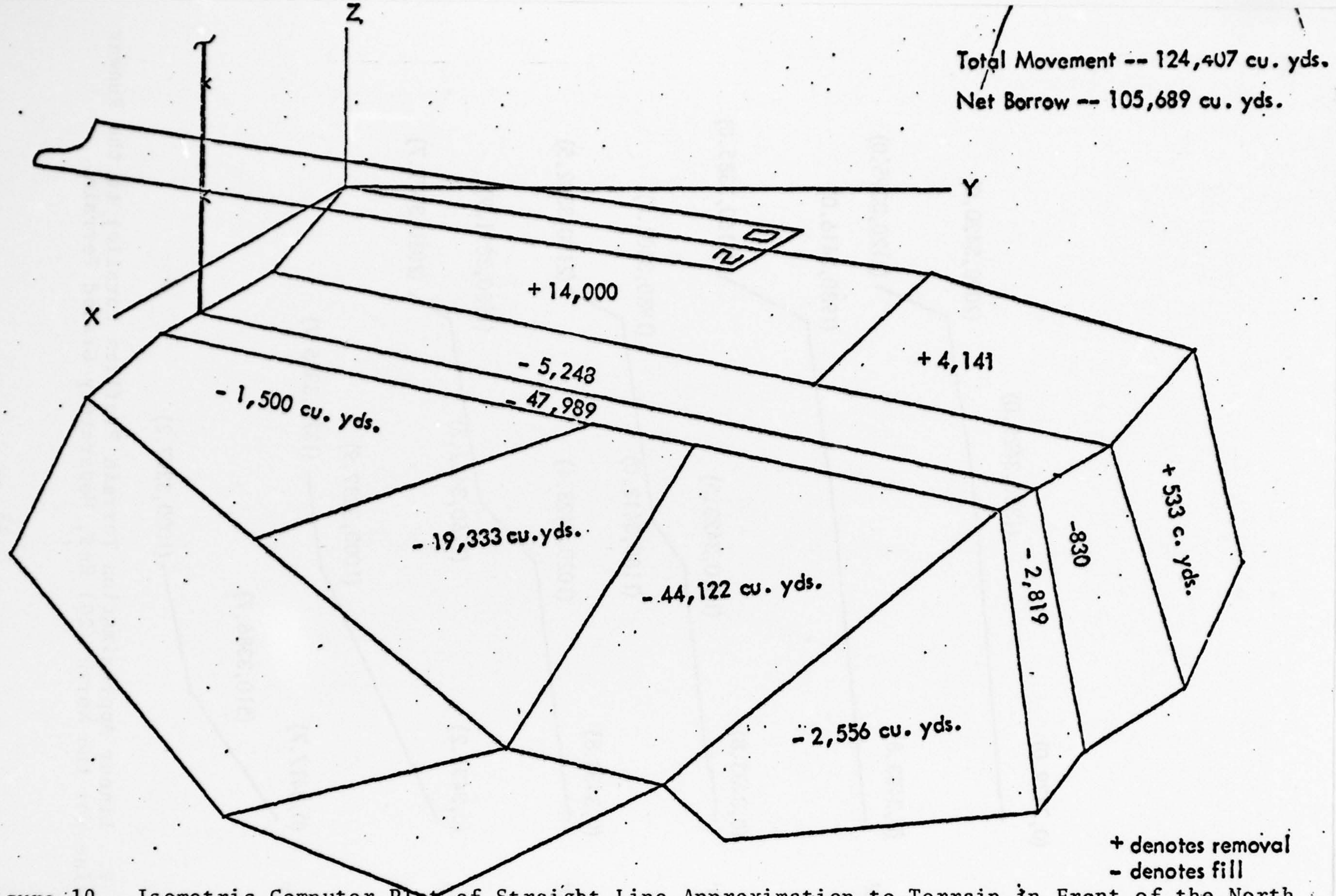


Figure 10. Isometric Computer Plot of Straight Line Approximation to Terrain in Front of the North (20) End Runway Glide Slope with Vertical Dimension Scaled by Factor of 20 After Extensive Earth Movement. Numbers Denote amount of earth removed or filled in given area.

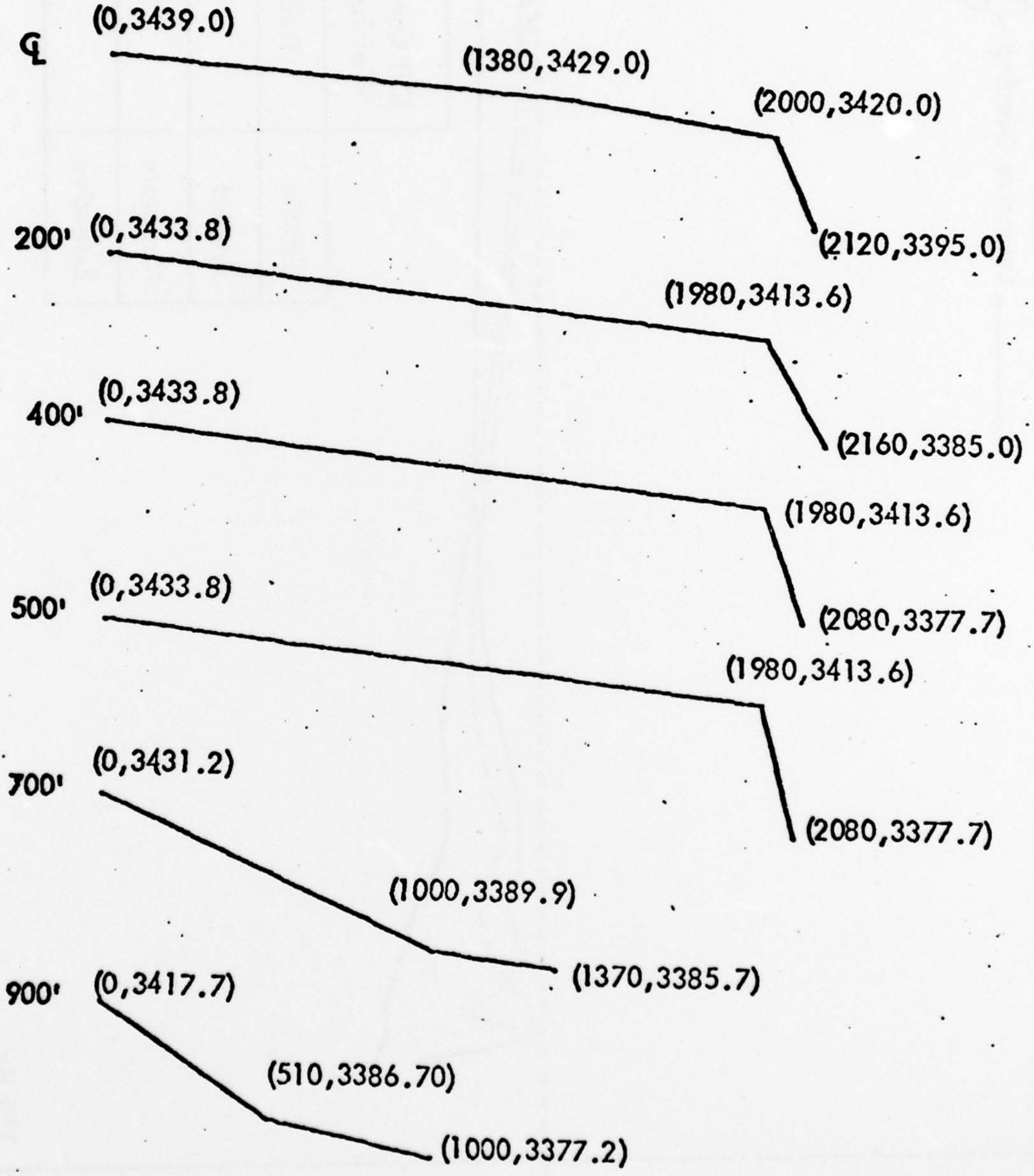
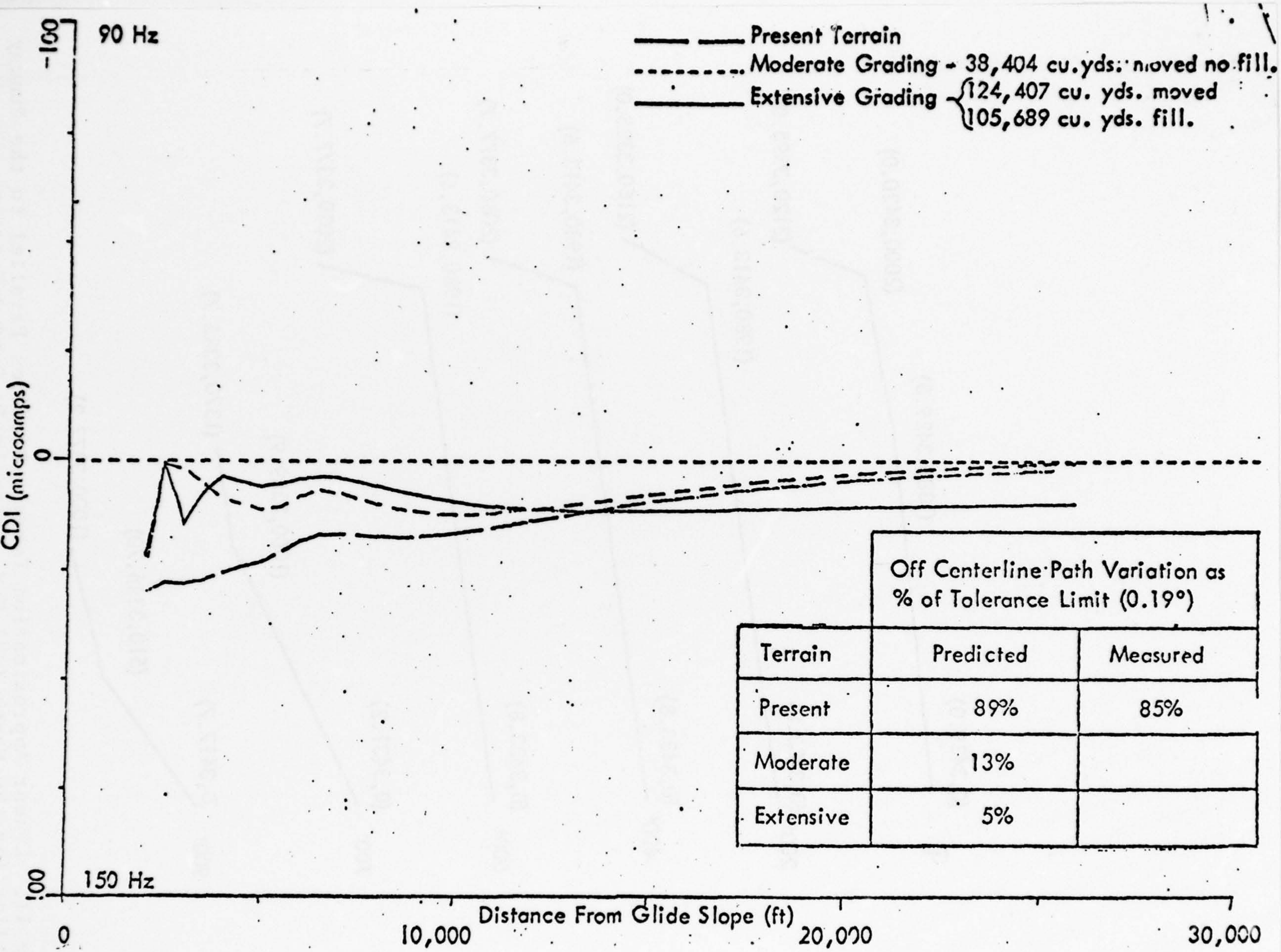


Figure 11. Linear Approximation Terrain Profiles Parallel to the Runway Centerline for the North (20) End, Extensively Graded Terrain.



Terrain	Off Centerline Path Variation as % of Tolerance Limit (0.19°)	
	Predicted	Measured
Present	89%	85%
Moderate	13%	
Extensive	5%	

Figure 12. Calculated Centerline Flyability for Malmstrom North (20) End Capture Effect Glide Slope for Present Terrain, Moderate Terrain grading, and Extensive Terrain grading. The Table Indicates the Improvement in Off-Centerline Path Angle Variation.

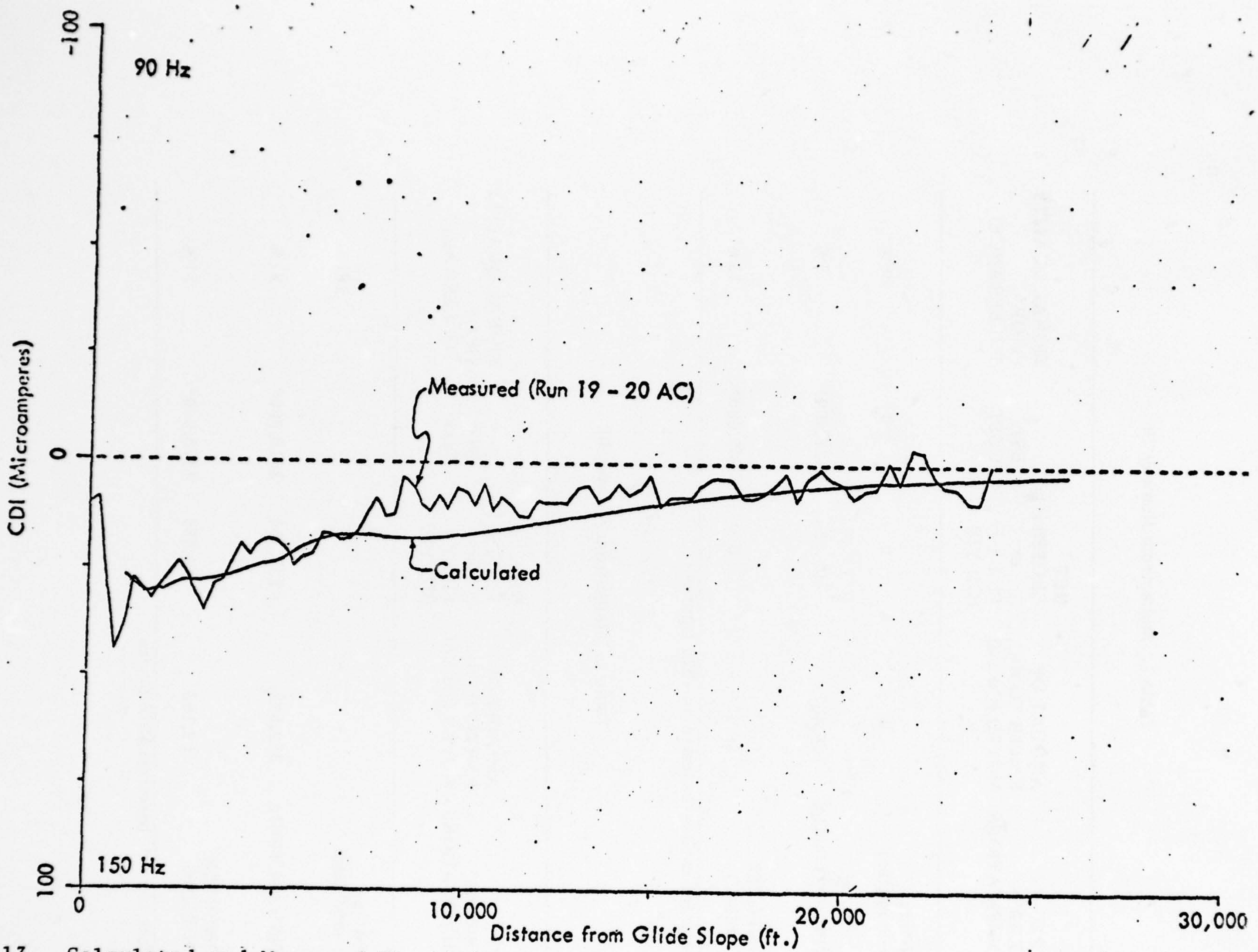


Figure 13. Calculated and Measured Flyability Runs for the North (20) End for an Approach Along the Runway Centerline. Measured August 19, 1977.

Table 1. Malmstrom Runway 20

TYPE TERRAIN MODIFICATIONS	AMOUNT OF EARTH TO BE MOVED (Cu Yd)	NET EXCESS (+) or FILL (-) (CU YD)	EST. COST	SIGNAL QUALITY (% OF TOLLERANCE)
Existing (un-modified)	0	0	0	89%
by SITING CRITERIA	124,407	-105,584	$422,000*	5%
by COMPUTER MODELED	38,404	0	$65,000*	13%

*Desk top estimates based on 1976 figures.

Table 2. Malmstrom Runway 02

TYPE TERRAIN MODIFICATIONS	AMOUNT OF EARTH TO BE MOVED (Cu Yd)	NET EXCESS (+) or FILL (-) (CU YD)	EST. COST	SIGNAL QUALITY (% OF TOLLERANCE)
Existing (un-modified)	-	-	-	187%
by SITING CRITERIA	322,522	+233,358	$610,000*	51%
by COMPUTER MODELING	92,163	+2,999	$175,000*	51%

*Desk top est. based on 1976 prices

4.4 The Runway 02 site at Malmstrom was deleted from the AN/GRN-29 installation program during this study. However, the study for this site was continued for academic purposes since it clearly represents one of the most difficult sites that we ever expect to encounter.

4.4.1 A preliminary computer run for the Runway 02 site indicated that the site, without modification, would provide a well out-of-tolerance glide slope signal. This prediction was confirmed by flight measurements. The flight measurements did correlate with the computer model but not as well as they did for the Runway 20 site. The reduced correlation was attributed to reflections from rising terrain on the opposite side of the runway from the glide slope antenna, for which terrain data was not collected - a lesson learned.

4.4.2 Reference Table 2 for a summary of findings. Computer modeling of the Runway 02 site indicated that we could save an estimated $435,000 in support construction cost by reducing the amount of terrain modifications in the glide slope reflectors area by 226,359 cubic yards without reducing the predicted signal quality that would be produced if the site were modified to meet the siting criteria.

4.4.3 Figure 14 shows the calculated centerline flyability of the glide slope signal with present terrain and after moderate and extensive modifications. Also provided in this figure is a comparison of the calculated centerline flyability, given existing conditions, to the actual centerline flyability measured during the model verfication phase of the study.

4.5 The glide slope computer modeling identified significant reductions in terrain modifications that would have been required by the siting criteria, resulting in a total cost savings of $1,024,000 in support construction for the three sites. It must be pointed out that the cost estimates are desk top type, we suspect they may be low. However, it is of grater importance to note the differences in the amount of earth movement compared to the improvement in signal quality.

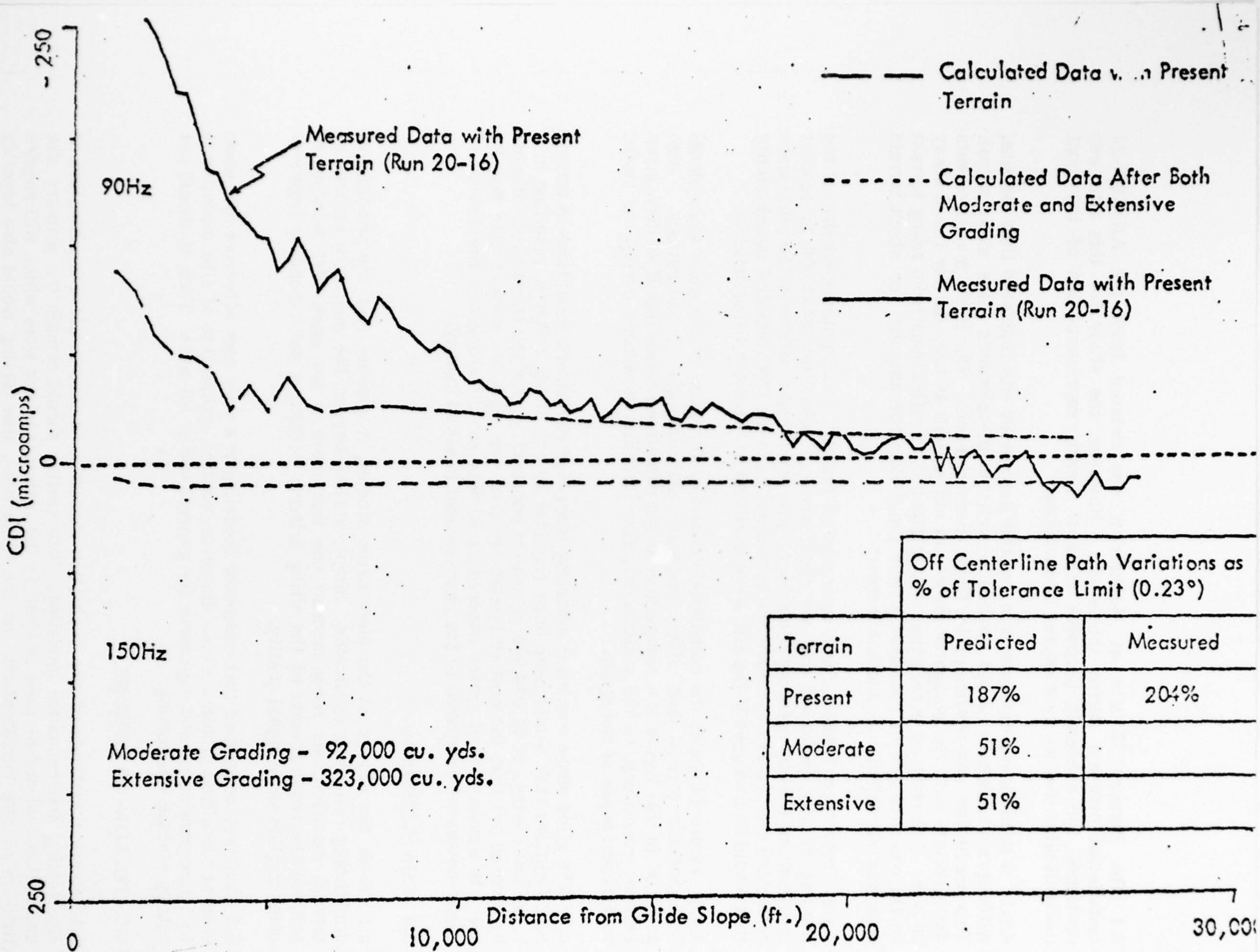
5.0 CONCLUSIONS.

5.1 From the results of the Malmstrom studies, it appears that the principle of diminishing returns is applicable. Simply stated, beyond the moderate amount of terrain modifications recommended one can move a lot more dirt working to achieve the requirements of the siting criteria without a corresponding improvement in glide slope signal quality.

5.2 We have concluded that computer modeling is a very cost effective tool when used at identified problem sites. However, routine application of site modeling is too time-consuming and expensive for general use at all sites. Thus, it should not totally replace site testing.

6.0 FOLLOW-UP ACTIONS.

6.1 Current methods of site evaluation should be revised to use a combination of site testing and computer modeling. Site testing should remain the primary site evaluation tool and be used to identify the majority of the sites which will require little or no site modification. At the same time, site testing would also identify



	Off Centerline Path Variations as % of Tolerance Limit (0.23°)	
Terrain	Predicted	Measured
Present	187%	204%
Moderate	51%	
Extensive	51%	

Figure 14. Calculated and Measured Centerline Flyability for Malmstrom South (02) End Capture Effect Glide Slope for Present Terrain and Calculated Centerline Flyability for Modified Terrain. The Table indicates the improvement in off-centerline path angle variation.

those marginal or problem sites which are candidates for computer modeling. This revised procedure requires test equipment that is capable of all three glide slope transmission modes (null reference, capture effect and sideband reference).

6.2 If computer modeling is to be used at only identified problem sites, the number of applications will be limited. We have determined that it is not cost effective to procure the software and establish the competent and specified staff necessary to organically operate a computer modeling program of this complexity. Thus, the 1842 EEG has a contract with Ohio University to study from one to eight problem sites over the next year with options to extend the contract for two years.

6.3 The procedure of using a combination of site testing and computer modeling should eliminate installation of marginal glide slope systems and/or over specification of terrain modification. Computer modeling will enable the siting engineer to reduce the terrain modifications at high cost problem glide slope sites, with the reduced requirements based on sound analytical procedures.

APPENDIX A. REFERENCES

REFERENCES.

1. "Siting Criteria for Instrument Landing system," Department of Transportation, Federal Aviation Administration. (FAA Order 6750.16A)

2. "United Standard Flight Inspection Manual," AFM 55-8.

3. Lawrence H. Mitchell, Raymond J. Lubbers, Vichate Ungvichian, Richard H. McFarland "Mathematical Modeling of Terrain Effects on ILS Glide-Slope Performance at Carswell AFB" Final Task Report EER 30-1, Air Force Contract No. F30602-75-C-0082. Avionics Engineering Center, Department of Electrical Engineering, Ohio University, Athens, Ohio.

4. Raymond J. Lubbers, Richard H. McFarland, Lawrence H. Mitchell, "Investigation of Glide Slope Performance at Malmstrom AFB" Final Task Report EER 30-2, Air Force Contract No. F30602-75-C-0082. Avionics Engineering Center, Department of Electrical Engineering, Ohio University, Athens, Ohio.

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