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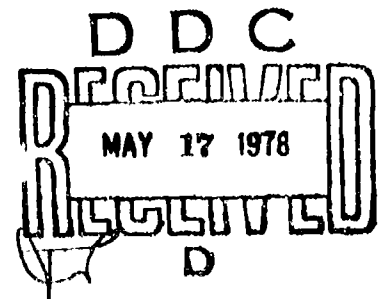
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**NEAR REAL TIME APPLICATION
OF DIGITAL TERRAIN DATA IN
A MINICOMPUTER ENVIRONMENT**

James R. Jancaitis William R. Moore

APRIL 1978

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ETL - 0142	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) NEAR REAL TIME APPLICATION OF DIGITAL TERRAIN DATA IN A MINICOMPUTER ENVIRONMENT		5. TYPE OF REPORT & PERIOD COVERED Technical Report
7. AUTHOR(s) James R. Juncaitis William R. Moore		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Engineer Topographic Laboratories Fort Belvoir, Virginia 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Engineer Topographic Laboratories Fort Belvoir, Virginia 22060		12. DATE Apr 78
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 27
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Two developments have combined to significantly impact the growing number of applications dependent upon digital terrain elevation data, mathematical terrain modeling, and minicomputer growth. Digital representation of terrain form has previously required vast amounts of mass storage with the relatively slow speed data access associated with large databases. A technique has been developed for compact digital storage of elevation data which also decreases the data		

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20. continued

access times significantly, a polynomial terrain model. Also, the mini-computer industry has been experiencing dramatic increases in the processing speeds and digital storage capabilities along with steadily declining costs. Preliminary results of a recently initiated study into the impact of these developments on utilization of digital terrain elevation data is presented.

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NEAR REAL TIME - APPLICATION OF DIGITAL TERRAIN DATA IN
MINICOMPUTER ENVIRONMENT

INTRODUCTION

The U.S. Army Engineer Topographic Laboratories (USAETL) is a Corp of Engineer facility whose charter includes research and development in the areas of mapping, charting, remote sensing and geodesy. USAETL currently employs approximately 300 personnel in its four main research and development organizational elements: the Topographic Developments, Computer Sciences and Geographic Sciences Laboratories, and the Research Institute.

The Automated Cartography Branch (ACB) is a fourteen person element of the Topographic Developments Laboratory and is tasked with the application of latest computer assisted data processing techniques and display equipment to cartographic problems. The ACB conducts research at the exploratory, advanced and engineering development levels. Their responsibilities include the development of equipment and techniques for automation of the extraction, color separation, formatting, storage, retrieval and symbolization display plotting of digital cartographic data from photographic and other source material.

A few of the problems considered by the ACB and the areas of concern of this paper are the development of techniques for the creation and efficient access of digital cartographic information databases, and their effective interface with user application software routines.

Research by the ACB over the past few years has resulted in a promising answer to these problems for terrain elevation data, a mathematical terrain description based upon polynomials. This technique describes the form of the earth's surface using a sparse matrix of simple polynomials. The main advantages of this approach are accurate terrain description with very low digital storage requirements and substantially reduced applications processing requirements.

The development of the polynomial terrain model has occurred simultaneously with substantial advances in the minicomputer industry. The ACB has recently been tasked with investigating the affect of these two developments, (namely the polynomial terrain model and the new, more powerful, low cost minicomputers) on digital terrain elevation data-related applications. This paper presents the results achieved in the first three months of a study by the ACB directed to building and evaluating the utility of a polynomial database on a minicomputer. A brief survey of the types of applications implimented to date is presented for the purpose of conveying to the reader a feeling of the speed and versatility of digital terrain elevation related applications that are readily achievable in near-real time on a minicomputer.

An overview of the polynomial terrain model approach is presented followed by a brief description of the test data and facility. The results achieved thus far are then included in the form of a series of minicomputer generated graphics.

The polynomial matrix format consists of a sparse grid of locally determined and locally valid node polynomials. These polynomials are called node because there is one polynomial centered over each node in the sparse grid. The processes involved in their generation and use (as well as this format's important characteristics) will be discussed in this section in chronological order.

The output of the automatic stereocompilation equipment is a computer magnetic tape containing numerous contiguous DTM's, each in sequential profile format. Batch processing software is utilized on a large scale digital computer to mosaick, transform, and regrid these DTM's into a single consistent DTM which covers the area of interest in the desired map projection or cartesian co-ordinate system. Further processing may be utilized to edit the DTM based upon separately digitized planimetric detail, such as lake boundaries, rivers, drainage, and ridgelines. It is at this point that the polynomial modeling process begins. Profile subsets of the DTM are sequentially defined and then square ground areas are sequentially defined along each profile subset. Each square ground area then received the following processing. (Note that since each subarea receives identical, independent processing this algorithm contains a high degree of parallelism that could be taken advantage of on one of the parallel processor digital computers, such as the Goodyear STARAN). First, the subarea is approximated with a "node" polynomial using the least-squares criteria. At this point, surface slope filtering and simple statistical measures are utilized to locate extreme errors in the data and to measure the goodness of fit. The effects of the bad data on the approximation are efficiently removed through the application of the inverse of the Kalman Filter algorithm. Program modifications are underway so that the length of the polynomial can be automatically varied to achieve the desired goodness of fit and error distribution based on the statistical analyses, independent of the size of the square area. Currently, the local polynomials are the most efficient four coefficient polynomial,

$$Z = C_0 + C_1x + C_2y + C_3xy$$

the simplest non-trivial case. The size of the square area is chosen so that this model accurately portrays the terrain. Note that this order node polynomial when combined with the weighting functions, allows for the modeling of terrain forms with a wavelength as low as the node polynomial spacing. When these processes are complete, the node polynomial's coefficients can be written out as the database.

The first step necessary in further use of the node polynomial approximations is their combination with weighting functions. An algorithm defines the final model over each square area defined by the centroids of four neighboring node polynomial approximations in the square grid as a single, different simple function using the weighting functions and the four node polynomials. The globally smooth and continuous model defined results in a simple, low order polynomial ratio in each of the square areas defined by the centroids

of the node polynomials. Grid generation and analytic solution for the contour lines are very efficient because of the simplicity of the global model.

The general characteristics and strengths of this digital terrain format can be summarized as follows: (1) automatic model accuracy definition through the use of approximation theorems, statistical analyses, and variable length polynomials. (2) the modeling algorithm is amenable to implementation on a parallel processor because of the identical independent processing steps for the local polynomial subareas. (3) automatic removal of large data errors via surface slope filtering and inverse Kalman Filter algorithms. (4) efficient model format requiring minimal core storage because of the sequential and independent determination of the local polynomials. (5) low storage overhead since the horizontal position of the local polynomials are implied by their location in the matrix. (6) a smooth and continuous globally valid model through the use of WIT. (7) efficient geographic access of the database because access to a horizontal position is given by the structure of the matrix. (8) efficient DTM grid generation due to the local low order polynomial definition of the global model.

TEST DATA AND FACILITY

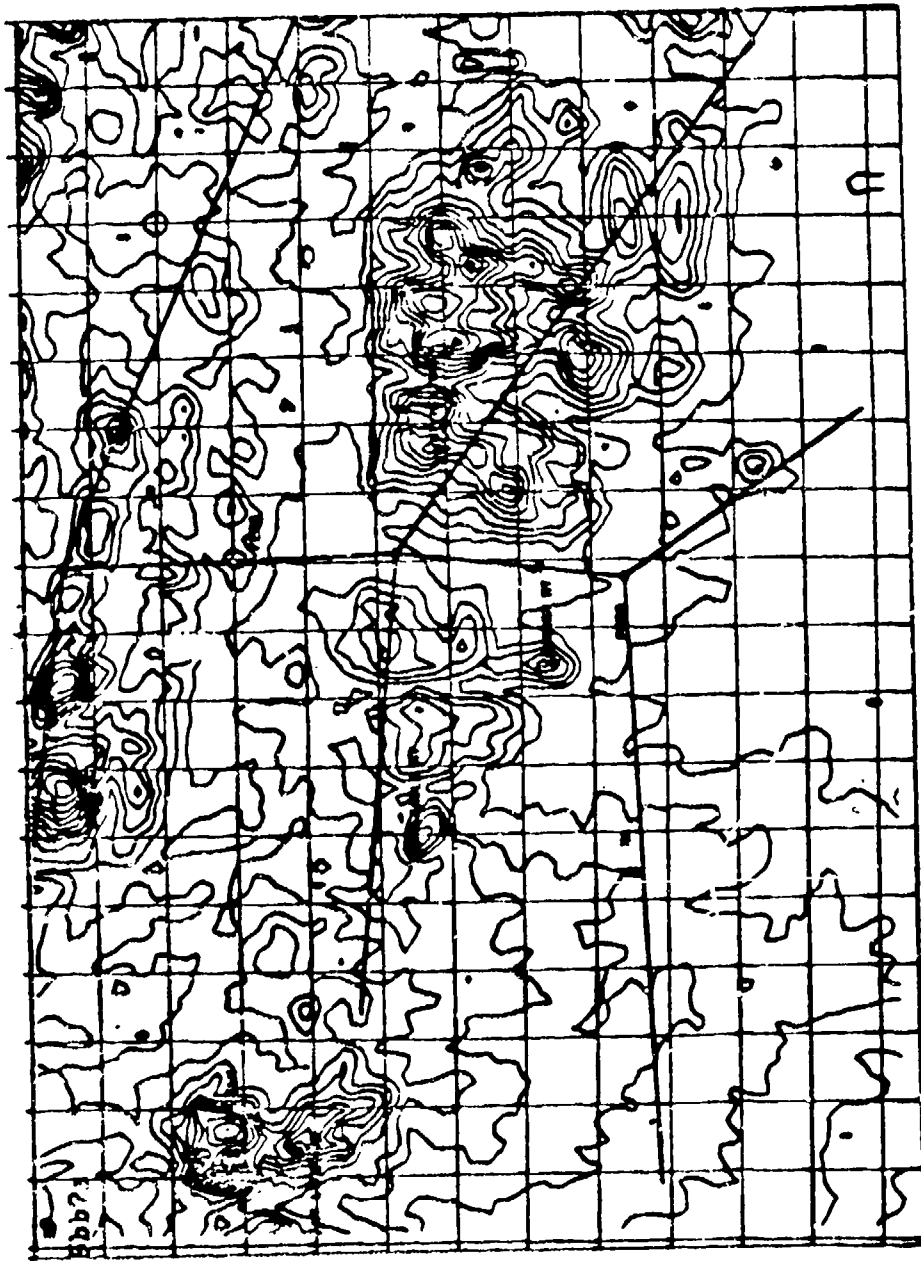
The equipment being utilized for this study are as follows: a DEC PDP11/45 minicomputer with 128k of core memory, a 4 1/2 million word disk drive, and a Tektronix 4014 line drawing storage CRT terminal. The test area is the 600+ square kilometers covered by the Cache, Oklahoma 1:50,000 mapsheet. Normally represented by over 2 million -16 bit elevation values, this area was stored on the minicomputer disk in polynomial format using only 12,000 polynomials requiring only 32 bits each--a compaction ratio of over 80 to 1.

All the following graphics were produced on the minicomputer-controlled CRT, based upon interactive user commands. Application routines are flexible in that the graphics shown can be produced at any user specified position, scale, viewing angle, etc.



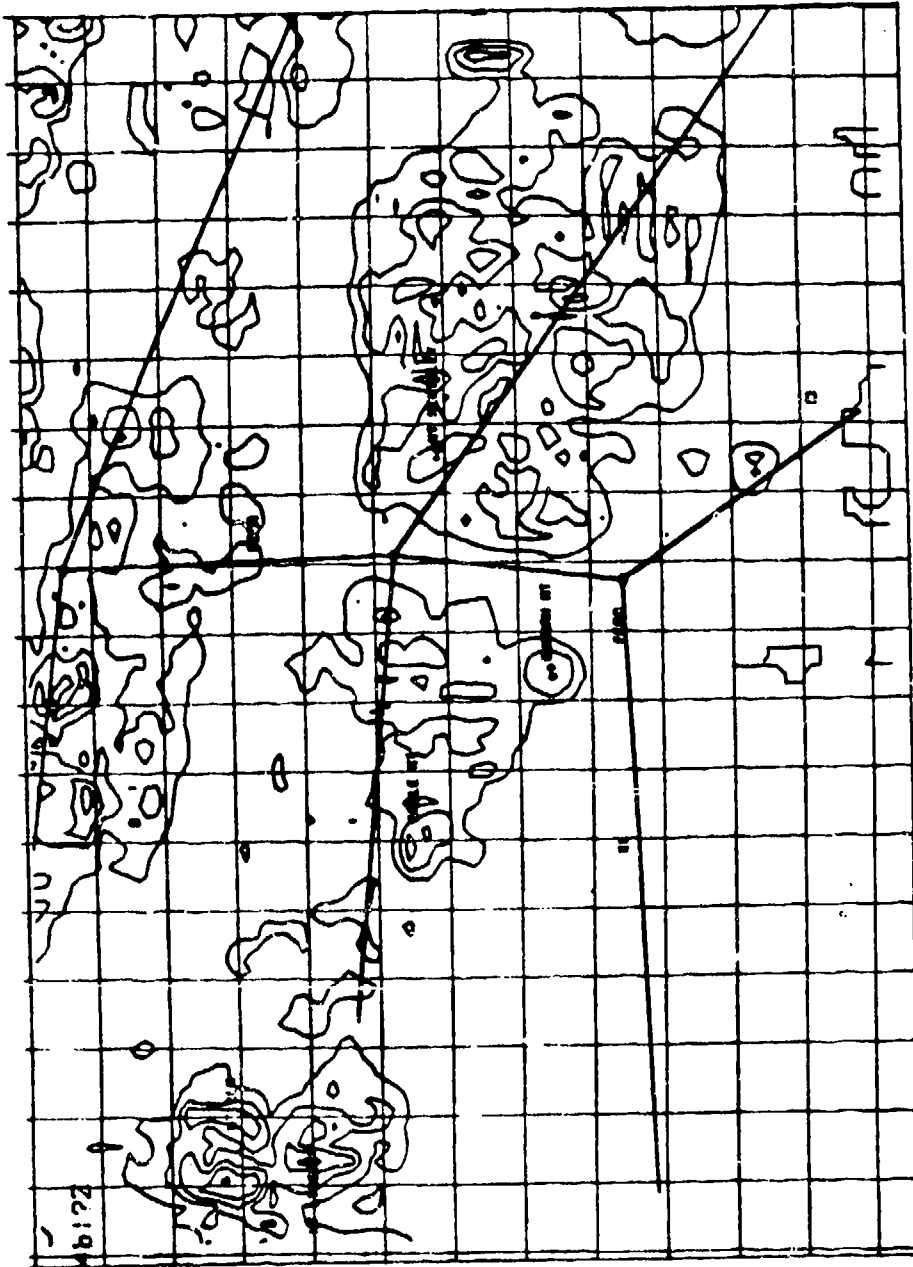
CONTOUR MAP OF ONE-FOURTH OF TEST AREA

- 25 METER CONTOURS



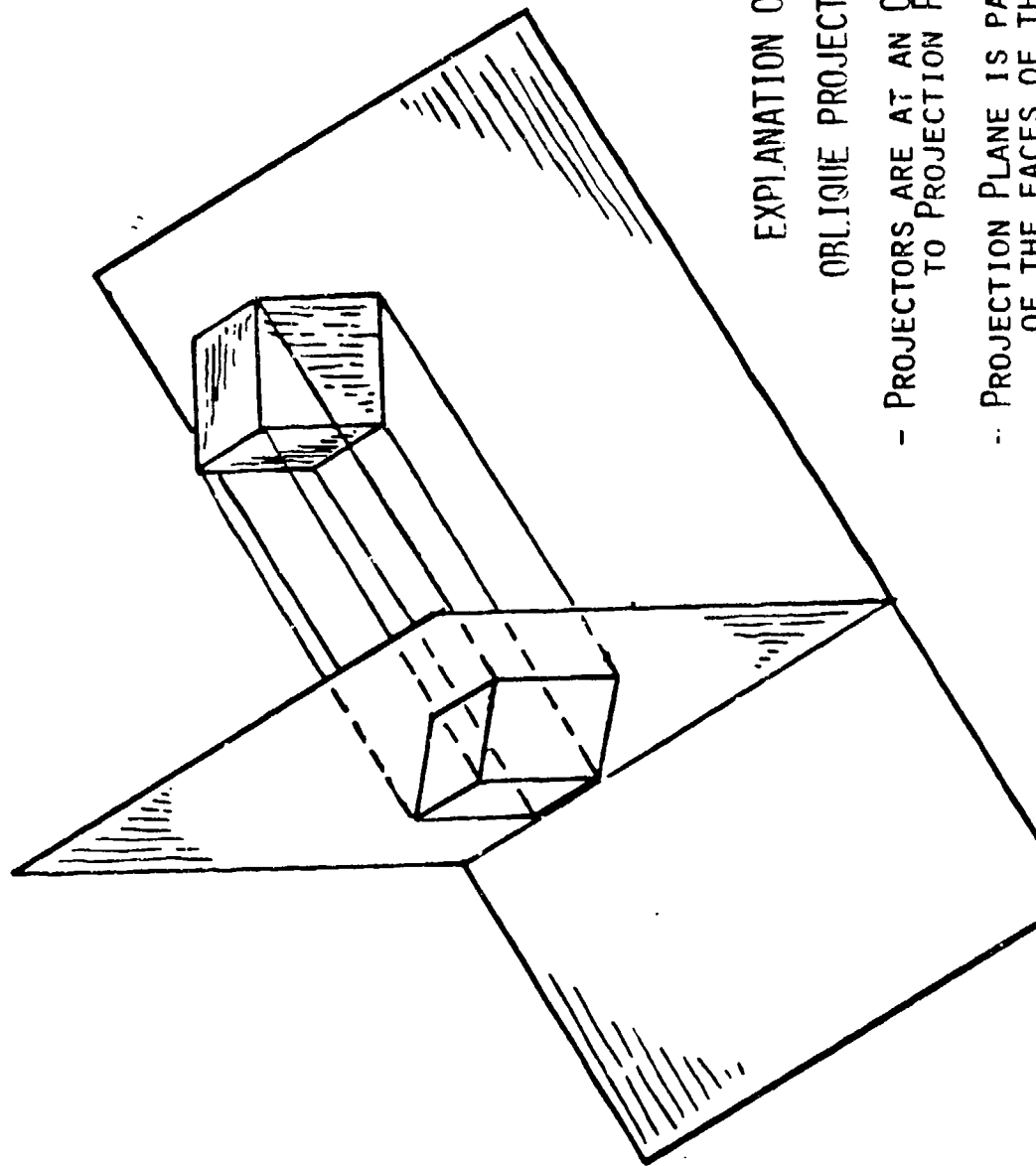
CONTOUR MAP OF ONE-FOURTH OF TEST AREA

- 25 METER CONTOURS
- ONE KILOMETER UTM GRID
- SELECTED PLACENAMES AND BOUNDARIES



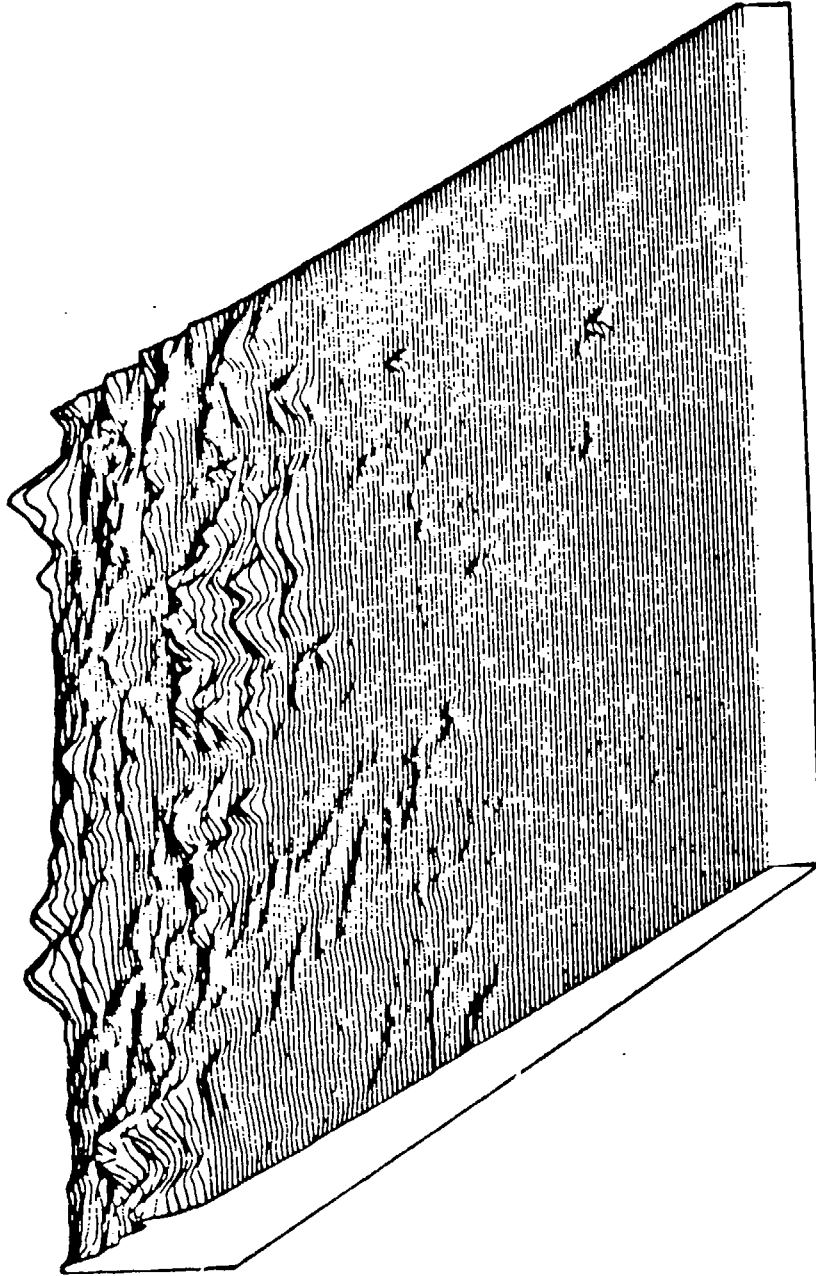
SLOPE MAP OF ONE-FOURTH OF TEST AREA

- SLOPE CONTOURS AT 0, 15, 30 AND 45°



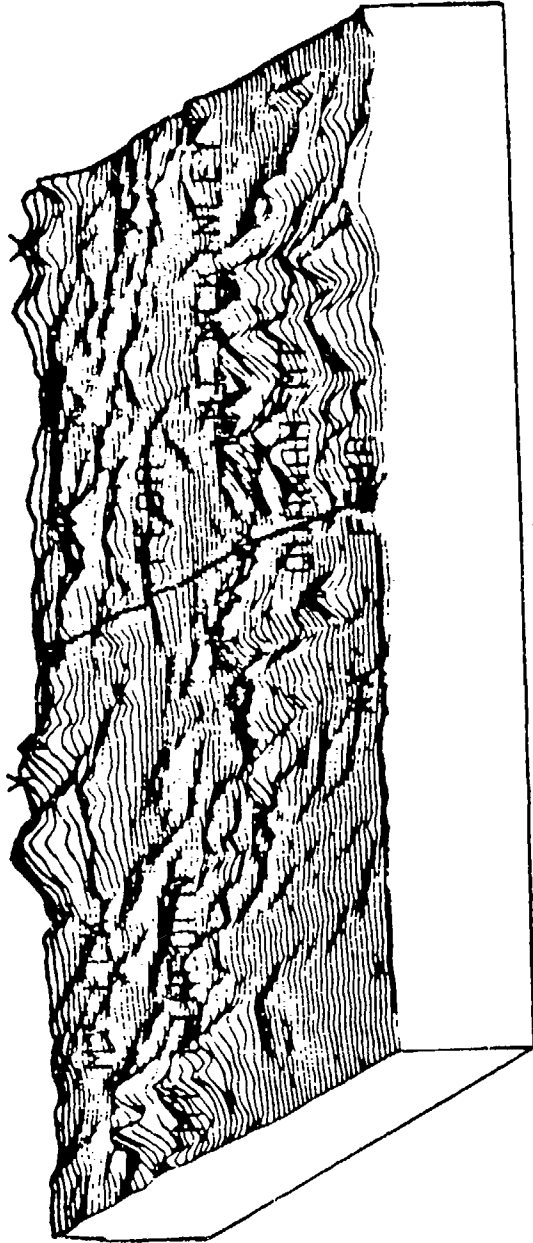
EXPLANATION OF
OBLIQUE PROJECTION

- PROJECTORS ARE AT AN OBLIQUE ANGLE TO PROJECTION PLANE
- PROJECTION PLANE IS PARALLEL TO ONE OF THE FACES OF THE CUBE



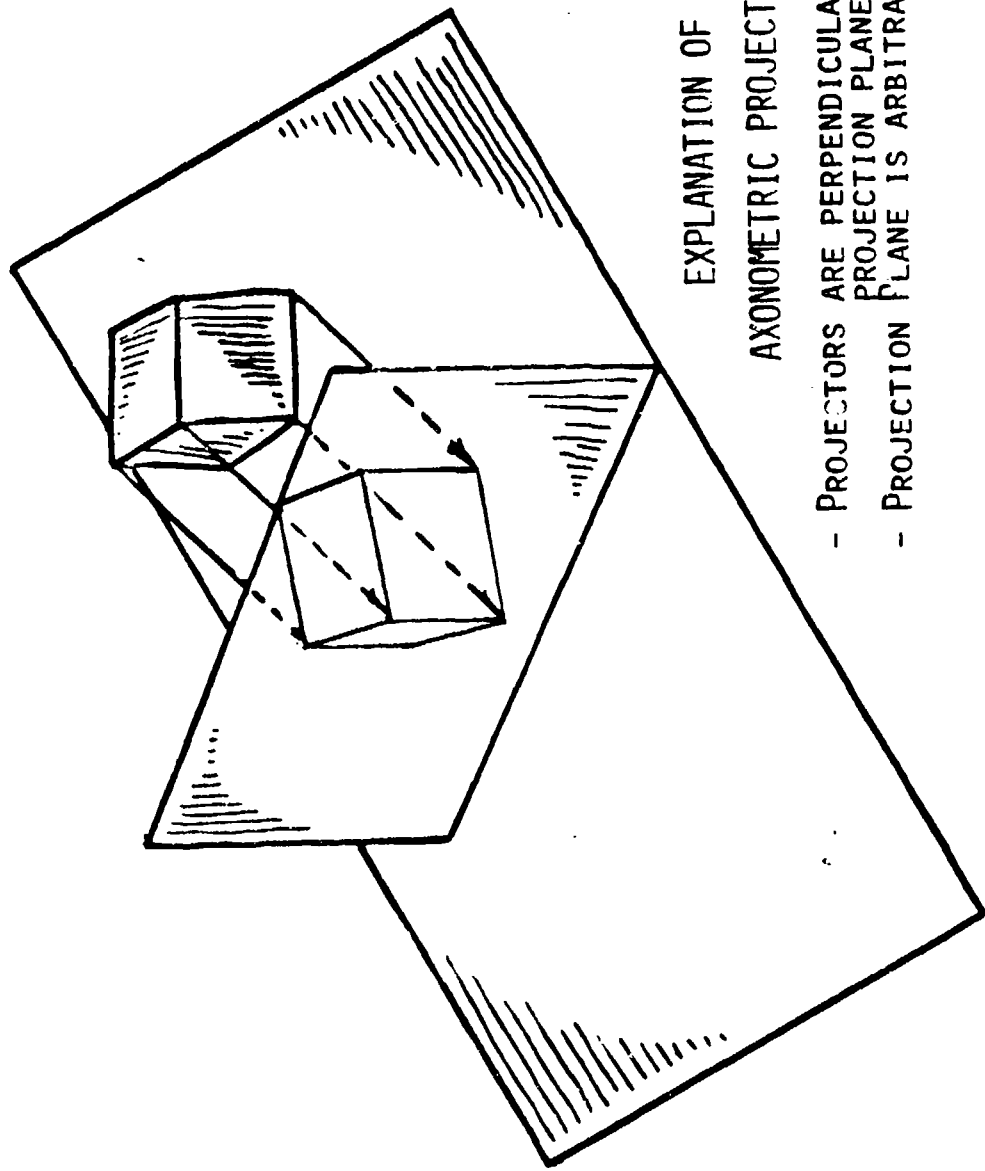
OBLIQUE VIEW OF ENTIRE TEST AREA

- TERRAIN FORM PLANE PORTRAYED WITH PROFILE LINES PARALLEL TO PROJECTION



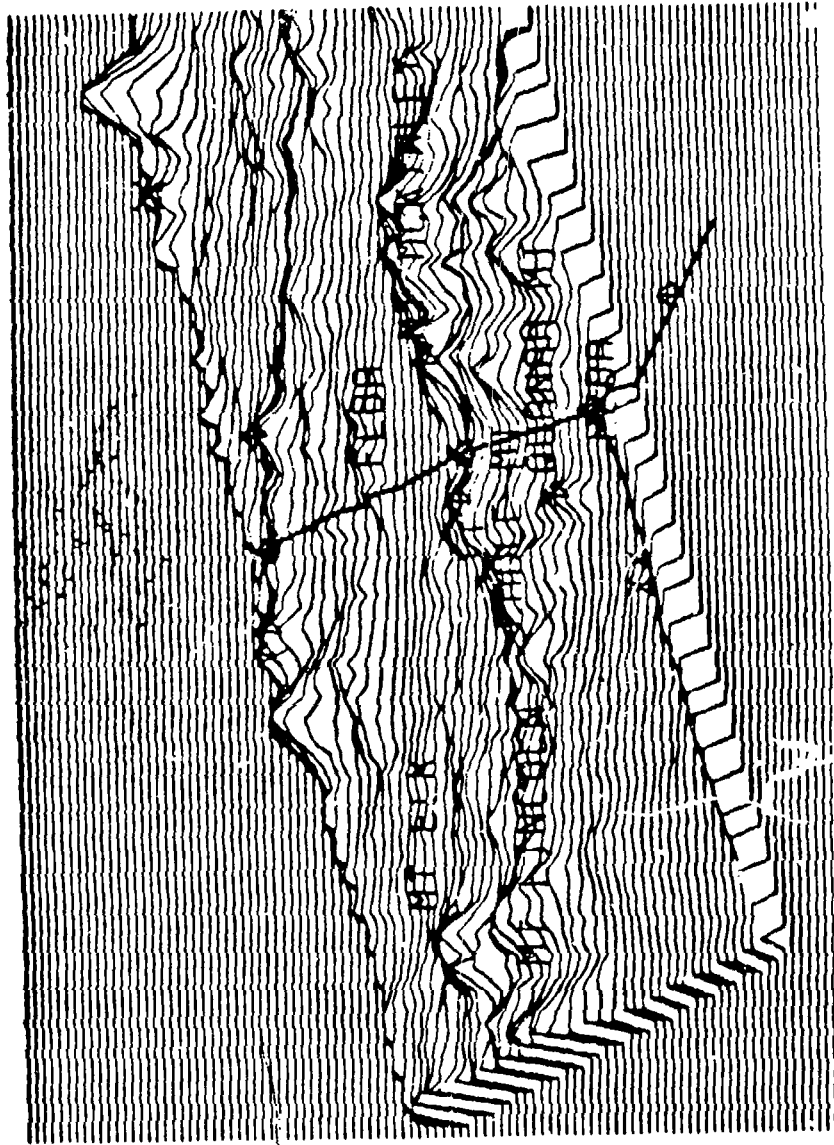
OBLIQUE PROJECTION OF AREA SHOWN IN FIG. 1.

- TERRAIN FORM PORTRAYED WITH PROFILE LINES
- SELECTED PLACENAMES AND BOUNDARIES SHOWN



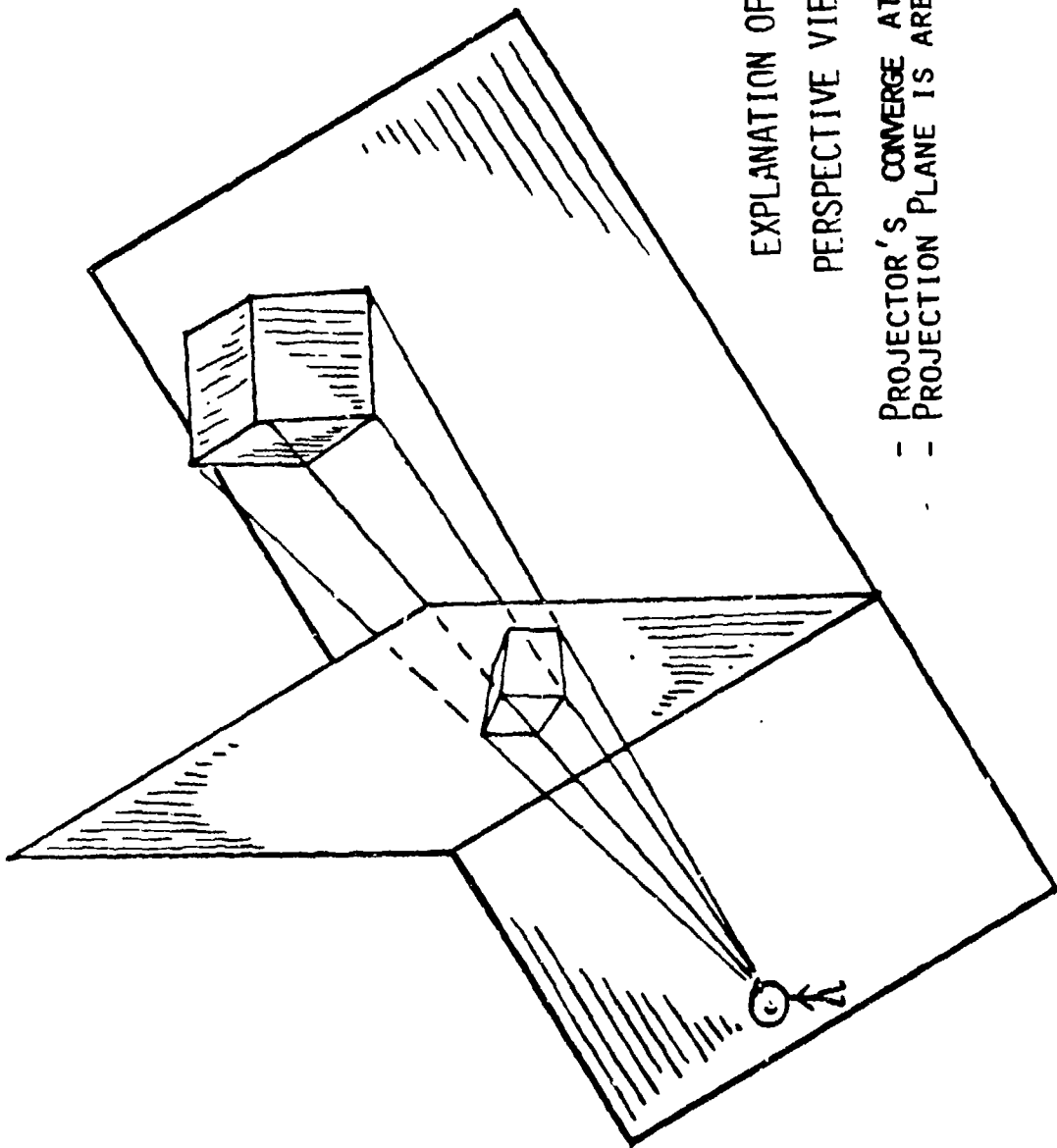
EXPLANATION OF
AXONOMETRIC PROJECTION

- PROJECTORS ARE PERPENDICULAR TO THE PROJECTION PLANE
- PROJECTION PLANE IS ARBITRARILY LOCATED



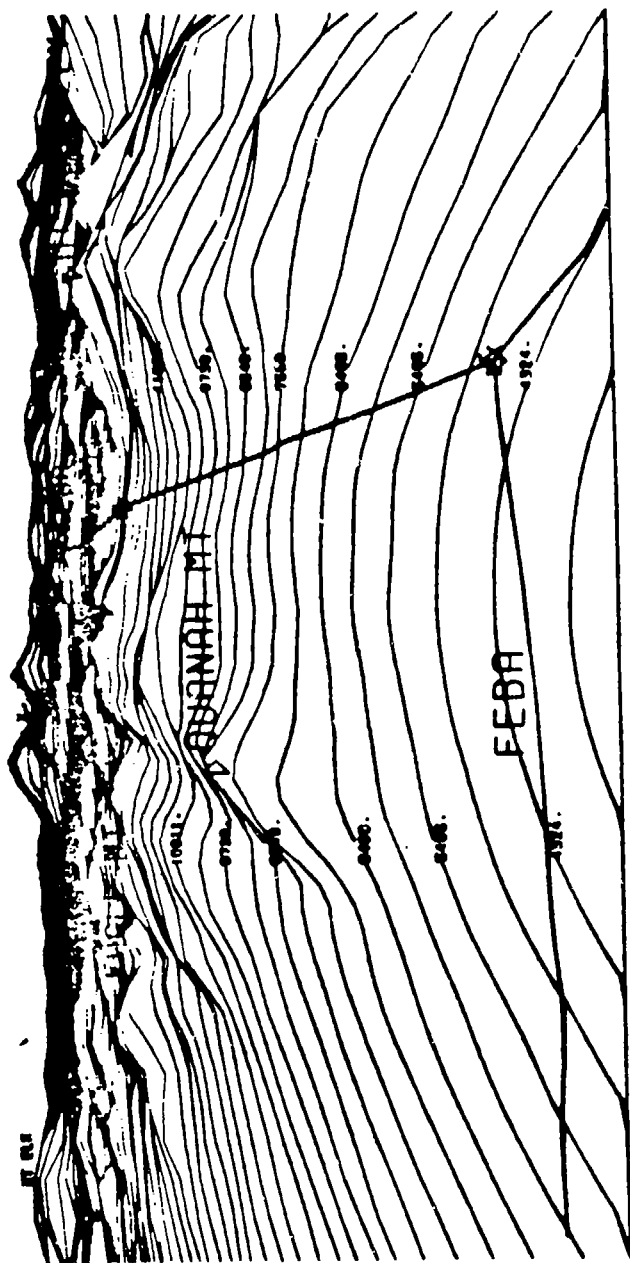
AXONOMETRIC PROJECTION OF AREA SHOWN IN FIG. 1.

- TERRAIN FORM PORTRAYED WITH PROFILE LINES PARALLEL TO PROJECTION PLANE
- SELECTED PLACENAMES AND BOUNDARIES SHOWN



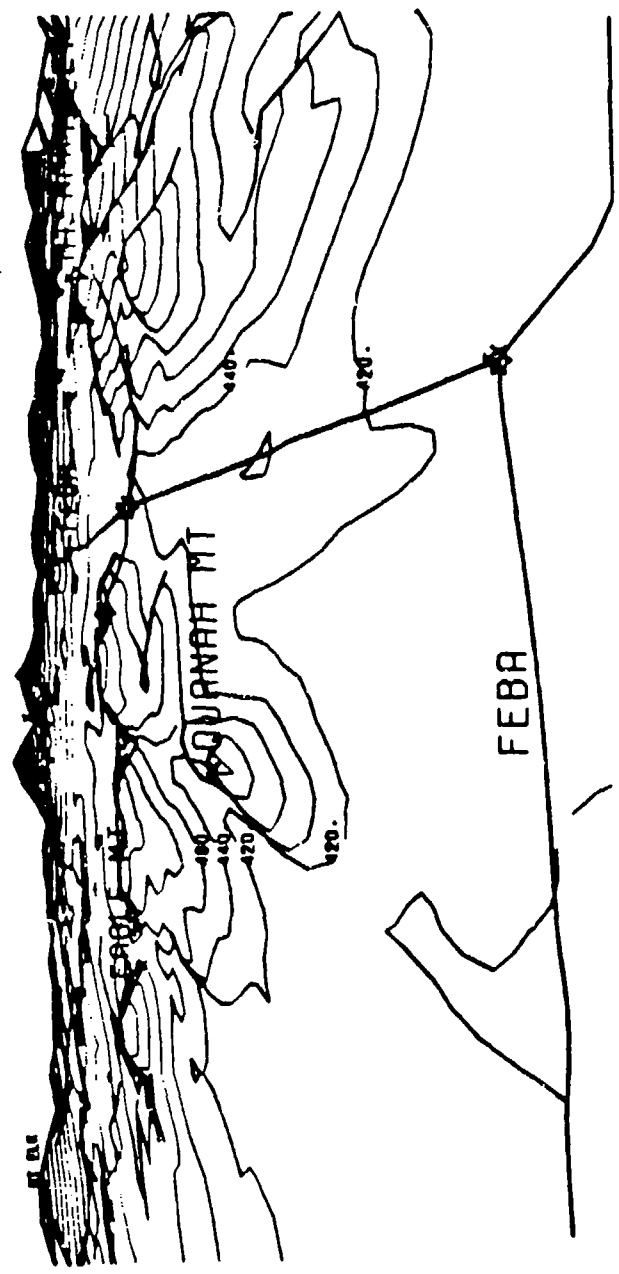
EXPLANATION OF
PERSPECTIVE VIEW

- PROJECTOR'S CONVERGE AT VIEWER'S EYE
- PROJECTION PLANE IS ARBITRARILY LOCATED



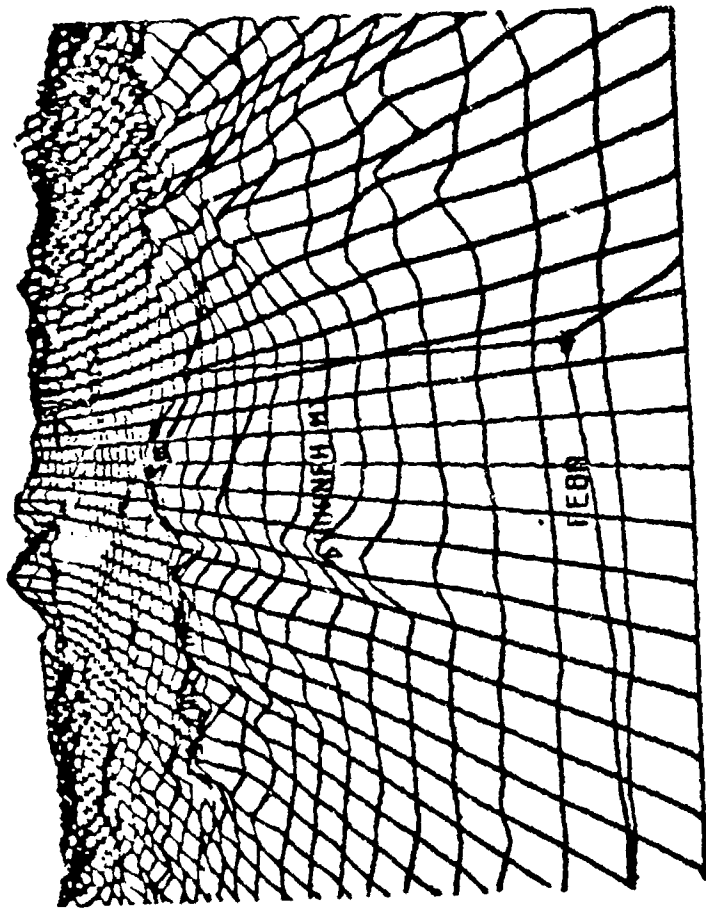
PERSPECTIVE VIEW #1 OF AREA SHOWN IN FIG. 1.

- TERRAIN FORM SHOWN WITH LINES OF CONSTANT RANGE FROM THE OBSERVER
- RANGE LINES ARE LABELED IN FEET
- SELECTED PLACENAMES AND BOUNDARIES ARE SHOWN



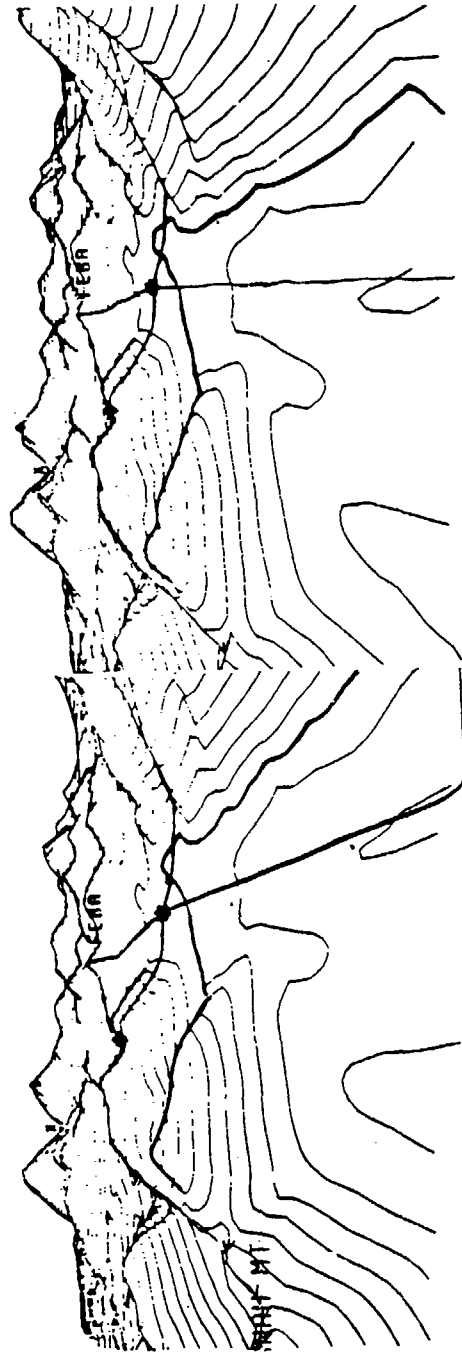
PERSPECTIVE VIEW #2 OF AREA SHOWN IN FIG. 1

- TERRAIN FORM SHOWN USING CONTOUR LINES
- LABELED CONTOUR LINES IN METERS
- SELECTED PLACENAMES AND BOUNDARIES SHOWN



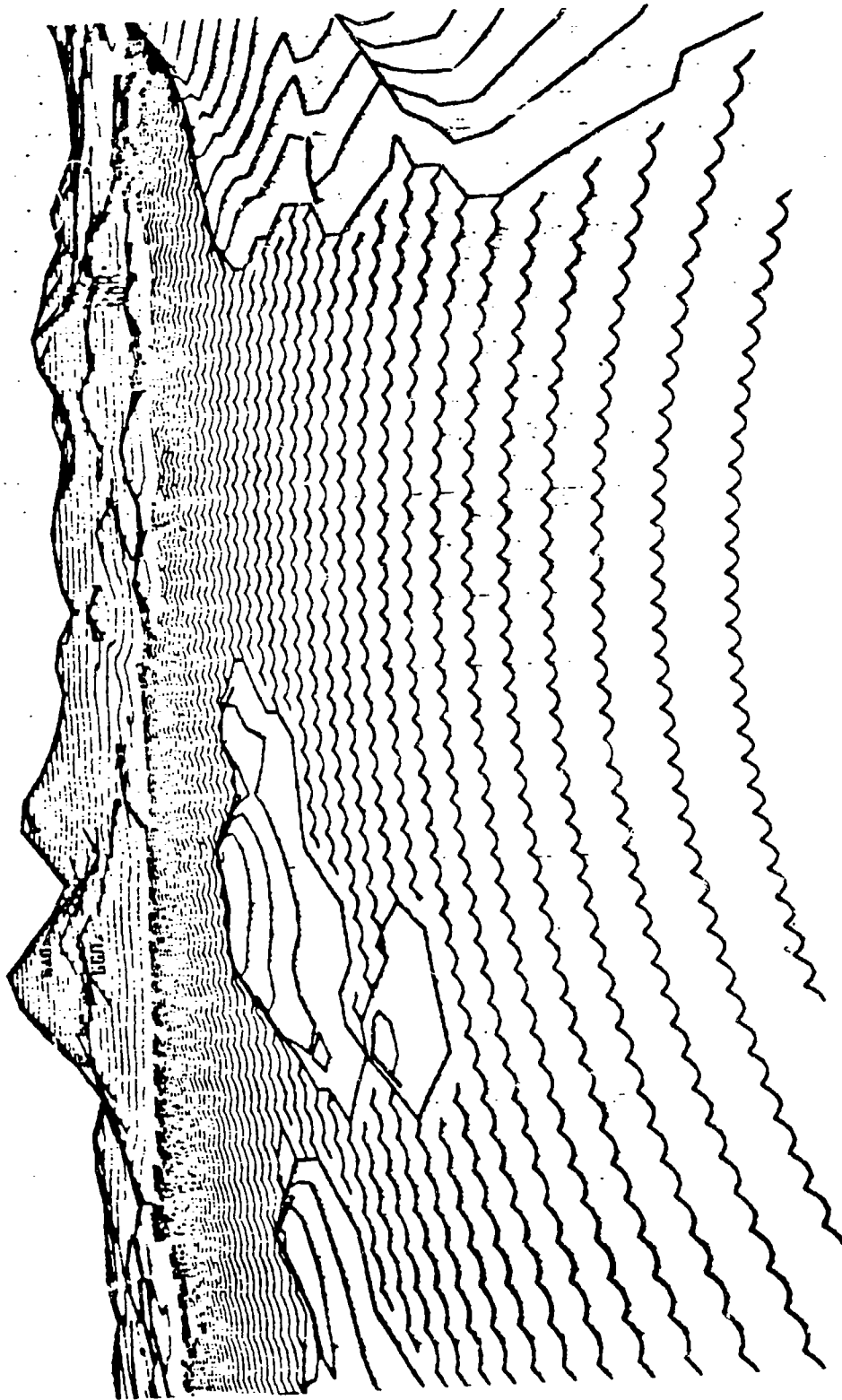
PERSPECTIVE VIEW #3 OF AREA SHOWN IN FIG. 1

- TERRAIN FORM SHOWN USING PROFILE LINES
- RUNNING NORTH-SOUTH AND EAST-WEST
- SELECTED PLACENAMES AND BOUNDARIES SHOWN



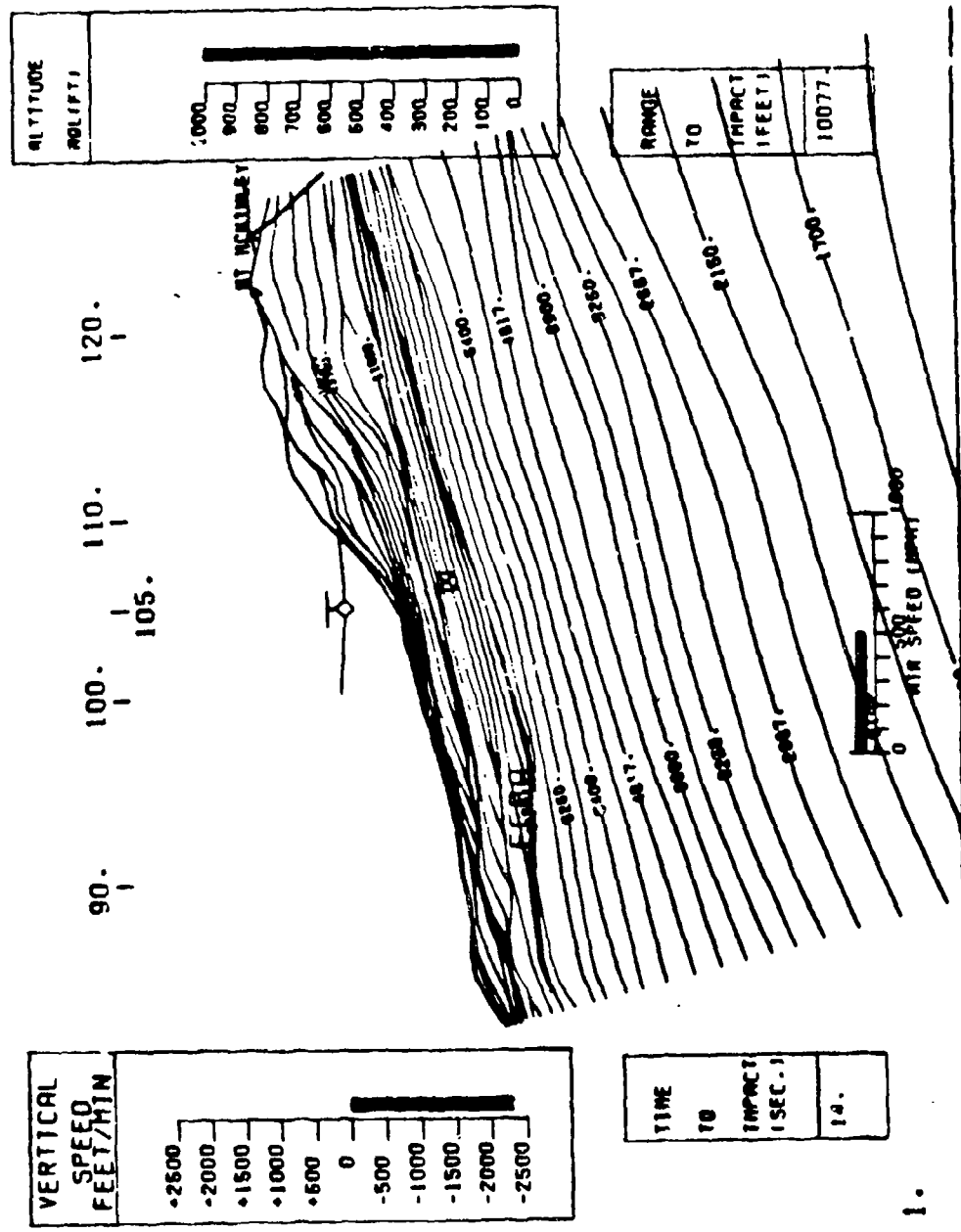
STEREO PAIR OF CENTER OF ARFA SHOWN IN FIG. 1

- TERRAIN FORM SHOWN USING CONTOUR LINES
- SELECTED PLACENAMES AND BOUNDARIES SHOWN



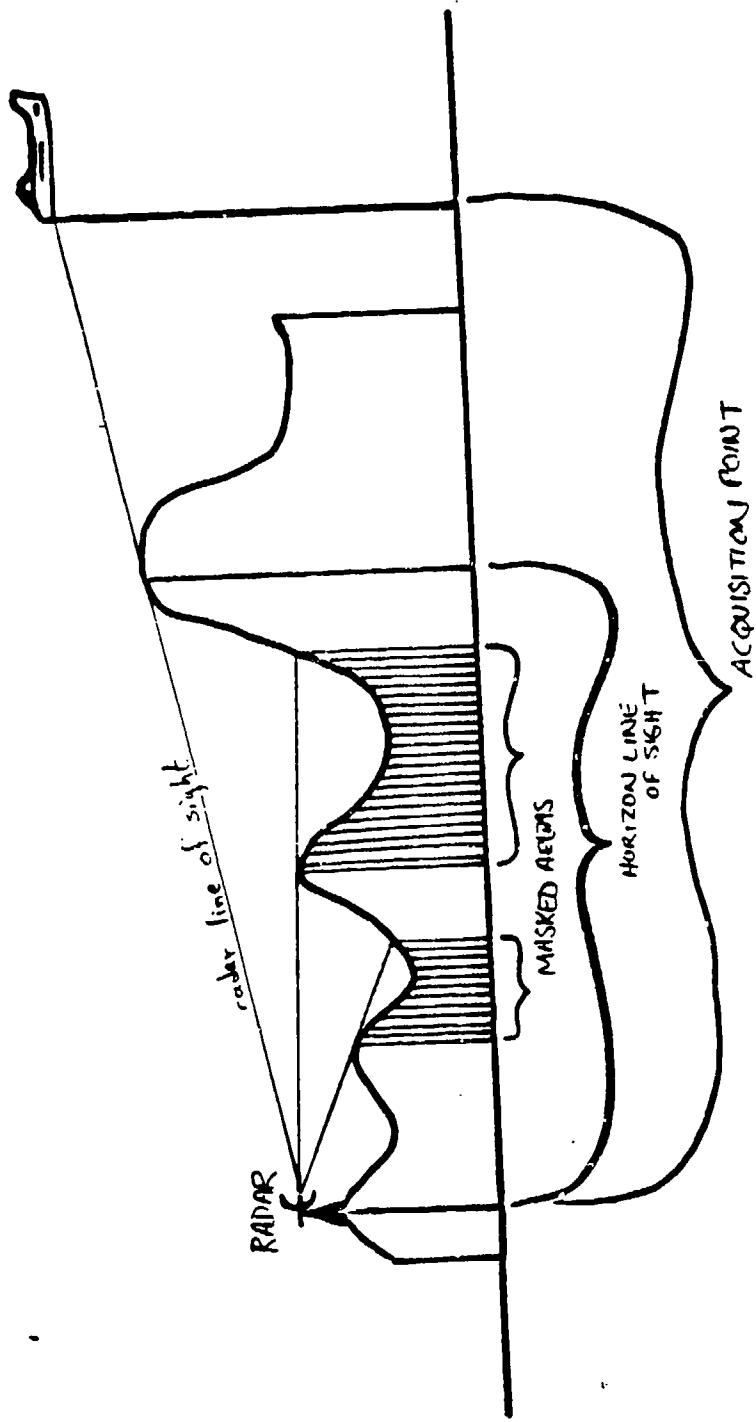
PERSPECTIVE VIEW OF CENTER OF AREA SHOWN IN FIG. 1

- TERRAIN FORM SHOWN USING CONTOUR LINES
- EFFECT OF FLOODING, WATER LEVEL SHOWN



FLIGHT SIMULATION PERSPECTIVE VIEW #2

- SAME AS FIG 15 EXCEPT
- AIRCRAFT IS EXECUTING A RIGHT TURN AND TERRAIN BANKS LEFT AS IT WOULD APPEAR TO DO FROM THE COCKPIT OF A REAL AIRCRAFT

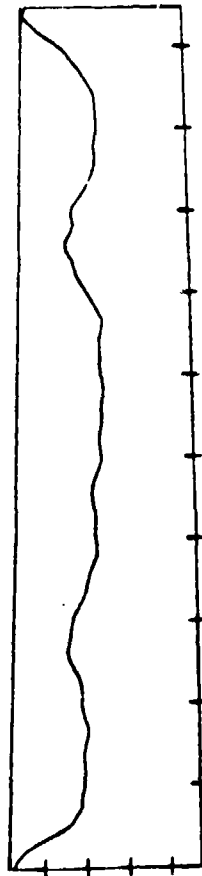


EXPLANATION OF TERRAIN MASKING TERMINOLOGY

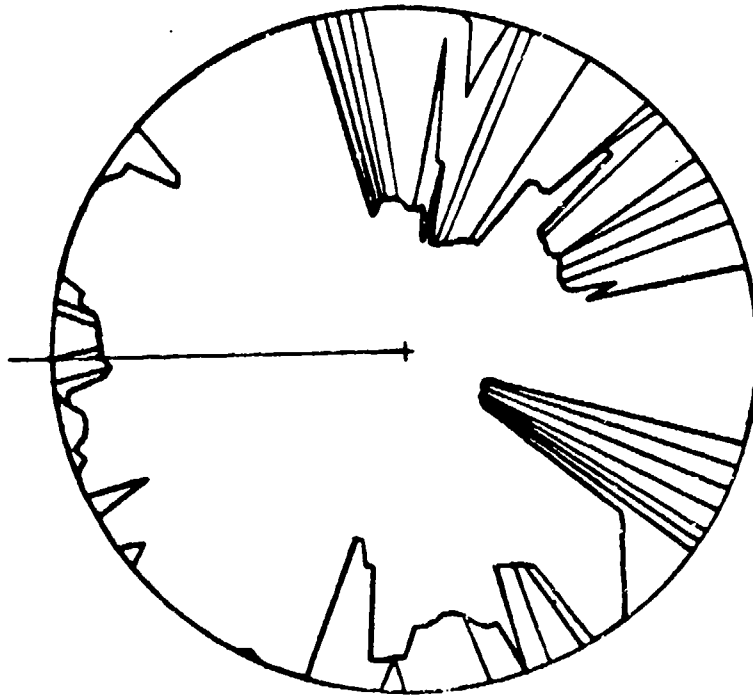
ENTER COORDINATES OF POSITION
AND HEIGHT ABOVE GROUND, AND NAME
2.17,19.46,10.
ENTER COORDINATES OF TARGET
AND HEIGHT ABOVE GROUND, AND NAME
10.05,17.10.
ENTER # PTS ALONG LOS
100
ENTER VERTICAL SCALING FACTOR
5.

VISIBLE

ENTER 1 TO HALT EXECUTION



TERRAIN LINE-OF-SIGHT PROFILE



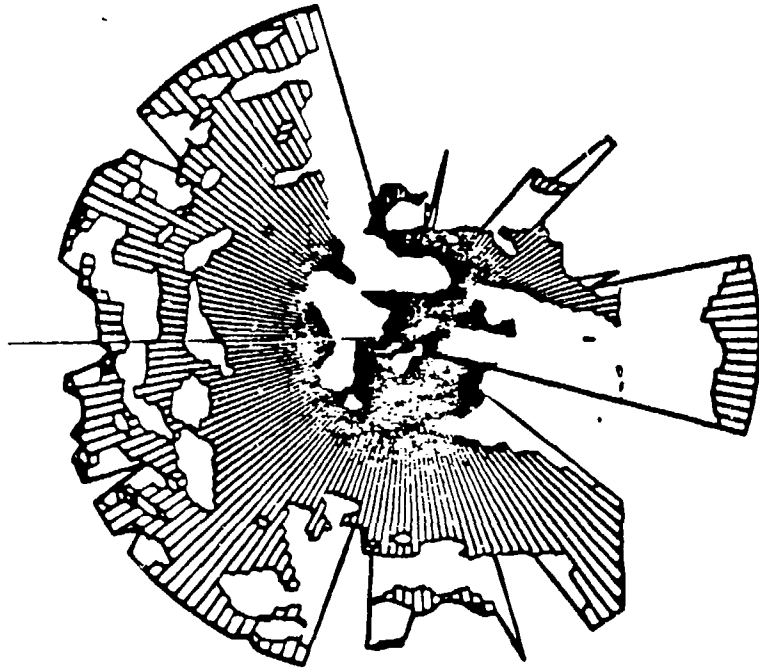
AIRCRAFT ACQUISITION CONTOURS AS A FUNCTION OF FLIGHT HEIGHT

- RADAR LOCATED ATOP MT. MCKINLEY IN CACKE, OKLAHOMA
- INNER CONTOUR IS RADAR'S HORIZON LINE-OF-SIGHT
- RADAR PLOT SHOWN IN HORIZONTAL PLANE



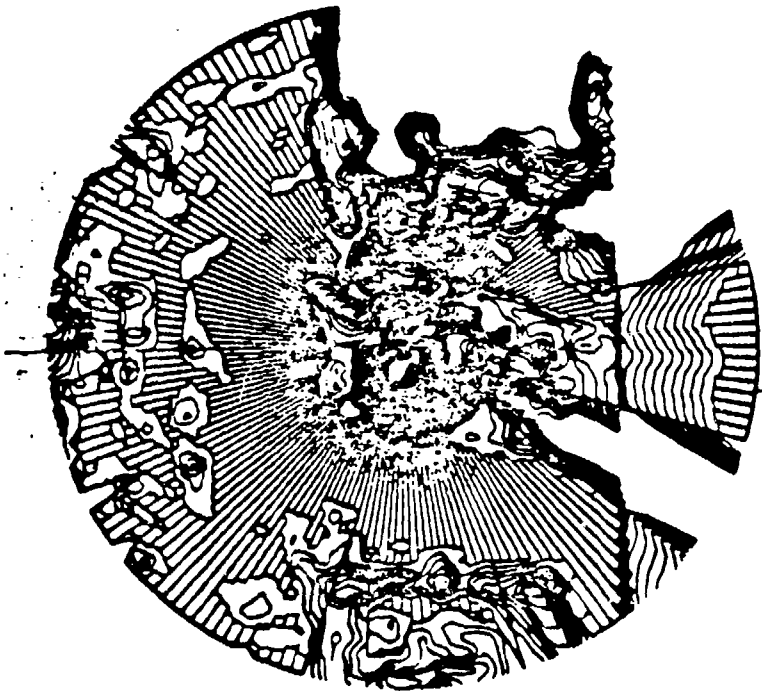
GROUND AREA VISIBILITY

- CLEAR AREAS ARE VISIBLE TO THE OBSERVER/RADAR LOCATED AT THE +
- LINED AREAS ARE NOT VISIBLE TO OBSERVER/RADAR



GROUND AREA MASKING

- CLEAR AREAS ARE HIDDEN/MASKED FROM AN OBSERVER/RADAR
- LINED AREAS ARE VISIBLE TO THE OBSERVER/RADAR



GROUND AREA MASKING CONTOURS

- SAME AS FIG. 21 EXCEPT
- MASKED AREAS CONTAIN CONTOURS WHICH INDICATE THE DEGREE (DEPTH) OF MASKED AREAS