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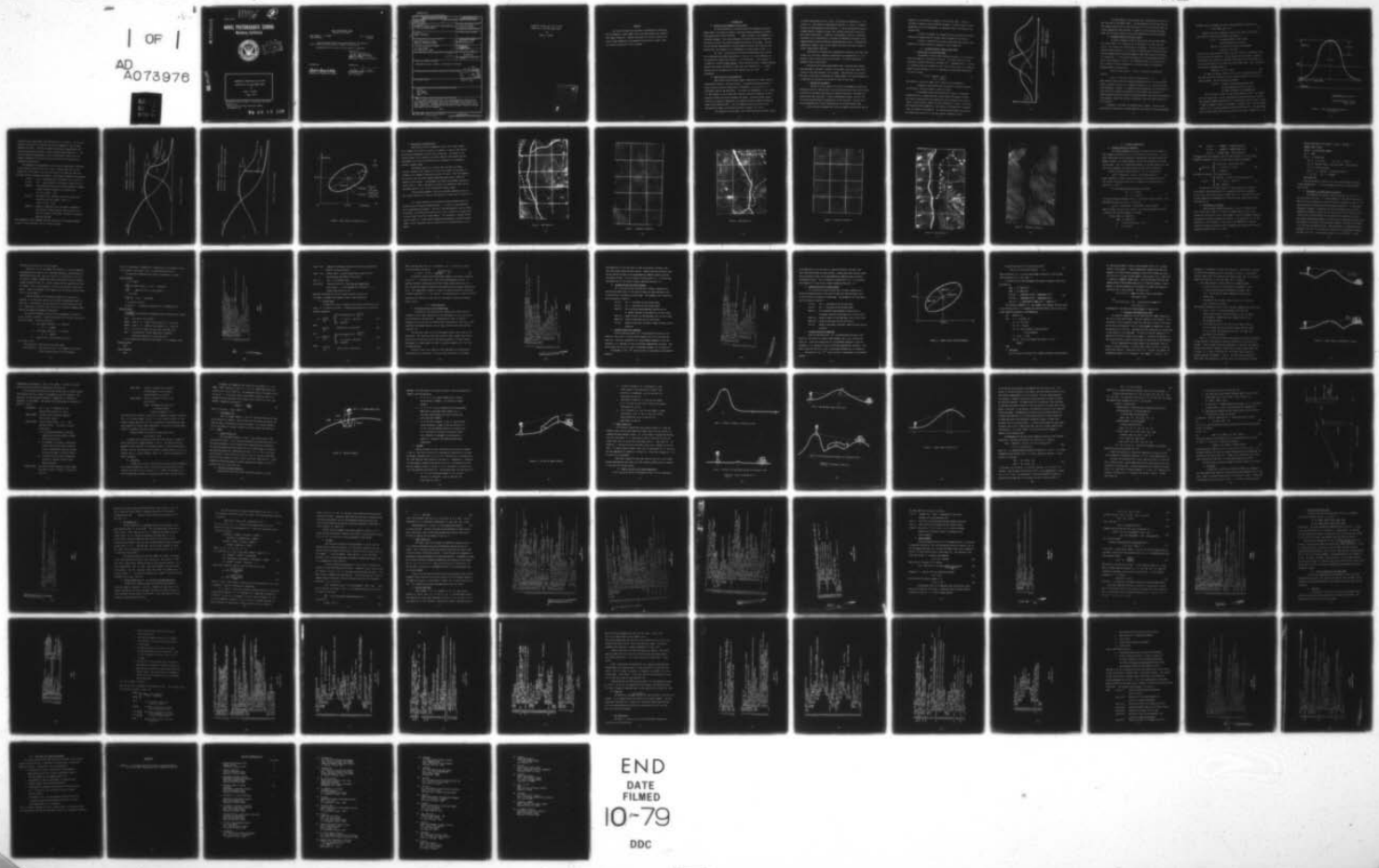

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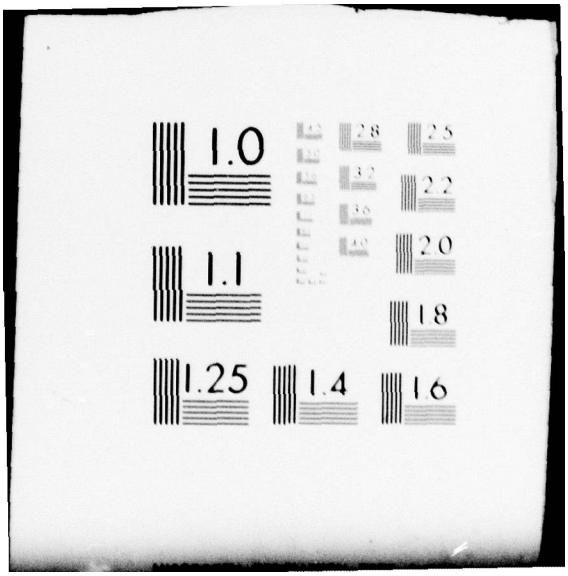
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Monterey, California

PARAMETRIC TERRAIN AND LINE OF SIGHT

MODELLING IN THE STAR COMBAT MODEL

by

James K. Hartman

August 1979

Prepared for:
The U.S. Army Training & Doctrine Command
Fort Monroe, VA.

NAVAL POSTGRADUATE SCHOOL
Monterey, California

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This report presents the motivation and mathematical background for the parametric terrain model used in the STAR Brigade level combined arms combat simulation. Computer subroutines for terrain elevation and line of sight computations are presented and explained in detail along with several preprocessor utility programs.

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Parametric Terrain and Line of Sight Modelling in the STAR Combat Model

by

James K. Hartman

ABSTRACT

This report presents the motivation and mathematical background for the parametric terrain model used in the STAR Brigade level combined arms combat simulation. Computer subroutines for terrain elevation and line of sight computations are presented and explained in detail along with several preprocessor utility programs.

I. INTRODUCTION

A. Origins of the Parametric Terrain Model

The STAR (Simulation of Tactical Alternative Responses) ground-air combat model is an extensive computer simulation program developed at the Naval Postgraduate School during 1978-1979. STAR is written in the SIMSCRIPT II.5 simulation language. This report documents the battlefield terrain representation which is used in the current Brigade-level version of the model. The idea for this terrain representation--called parametric terrain--was originally proposed by Maj. Chris Needels in his 1976 Master of Science thesis at NPS [1].

The basic function which any terrain representation must provide for a high-resolution combat simulation is, "for any X, Y map coordinates on the battlefield, compute the elevation Z of the terrain." This elevation Z is generally called the macro terrain. Macro terrain provides a somewhat smoothed replica of an actual battlefield in that very small features (e.g. a 1 meter boulder) are not represented, but major features (such as a 200 m hill) are represented.

B. Approaches to Terrain Modelling

Most current high resolution combat simulations use a macro terrain representation known as "digitized terrain". Essentially digitized terrain involves storing a (usually large) table of elevations, Z, for a grid of X, Y coordinates covering the battlefield. The process of determining Z for a given X,Y then reduces to one or more table look-ups, possibly followed by an interpolation to smooth the terrain between grid points. Digitized terrain enjoys simplicity and speed of computation, but requires extensive computer storage devoted to the elevation table. This has tended to restrict the size of the battlefield for models using digitized terrain to about 10 x 10 km.

The parametric terrain model used in STAR essentially involves storing

a (rather complicated) function f(X,Y). The process of determining Z for a given X,Y then reduces to computing the function Z = f(X,Y). Parametric terrain has the advantage that the function f can be represented using only a modest amount of computer storage, thus allowing simulations to be run on much larger battlefields. In addition, the parametric terrain is inherently continuous, so no interpolation is required for smoothing, and slopes can be computed directly with no difference approximations required. The associated computations, however, may be quite complex, and great care must be taken to achieve computational efficiency.

Since STAR is a Brigade level combined-arms simulation, with long range systems (air, artillery, resupply) represented on the battlefield, it is important to have a large terrain area available. Thus STAR incorporates a parametric macro terrain model.

Discussions with experienced modelers have indicated that attempts have been made in the past to develop terrain models which share some of the features of the STAR parametric terrain model. These efforts do not seem to have been successfully incorporated into combat models, but since documentation is generally not available, the reasons for this are not clear.

C. Overview of the Report

Section II of this report will develop the parametric terrain representation and will indicate how it can be used to emulate actual terrain areas. In Section III we detail the process of computing elevations, including the STAR routines ELEV and ELEVG. A terrain preprocessor program HILL.LIST for increasing the efficiency of computations is also discussed. Section IV discusses augmenting the terrain representation to include forested areas.

Given a terrain representation, one vital combat function which must be

computed is the existence or absence of line-of-sight (LOS). Section V discusses in general terms the STAR LOS procedure. Section VI goes into the mathematics of the LOS computations in substantial detail, and analyzes the computer code.

Section VII presents the computer code for the terrain and forest preprocessor programs and for the data read-in program for the terrain.

Finally, in Section VIII we discuss some areas which seem to have potential for further research in parametric terrain modelling.

II. The STAR Parametric Macro Terrain Model

A. General Form of the Terrain Model

The parametric terrain model proposed by Needels in [1] represents terrain by modelling individual hill masses. The overall terrain is then obtained by superpositioning the individual hills. Mathematically, if $f_I(X,Y)$ is a function giving the elevation of the Ith hill mass at any X,Y, then the overall terrain elevation at X,Y is obtained as the pointwise maximum over all the hill masses,

$$Z = f(X,Y) = \underset{I=1,2,\ldots,NHILLS}{\text{maximum}} f_I(X,Y) \qquad (1)$$

where NHILLS is the total number of hill masses on the battlefield.

A schematic cross-section view of several hill masses along with the resulting terrain elevation is shown in Figure 1.

In the Needels model each individual hill mass is represented mathematically as a scaled bivariate normal probability density function. This gives a characteristic bell-shaped hill mass cross-section as shown in Figure 1, and elliptical contours for each individual hill mass. By varying the bivariate normal parameters, a wide variety of different hill locations, sizes, and shapes can be modelled. By superpositioning several hill masses, the contour map can be fit to real map contours remarkably closely.

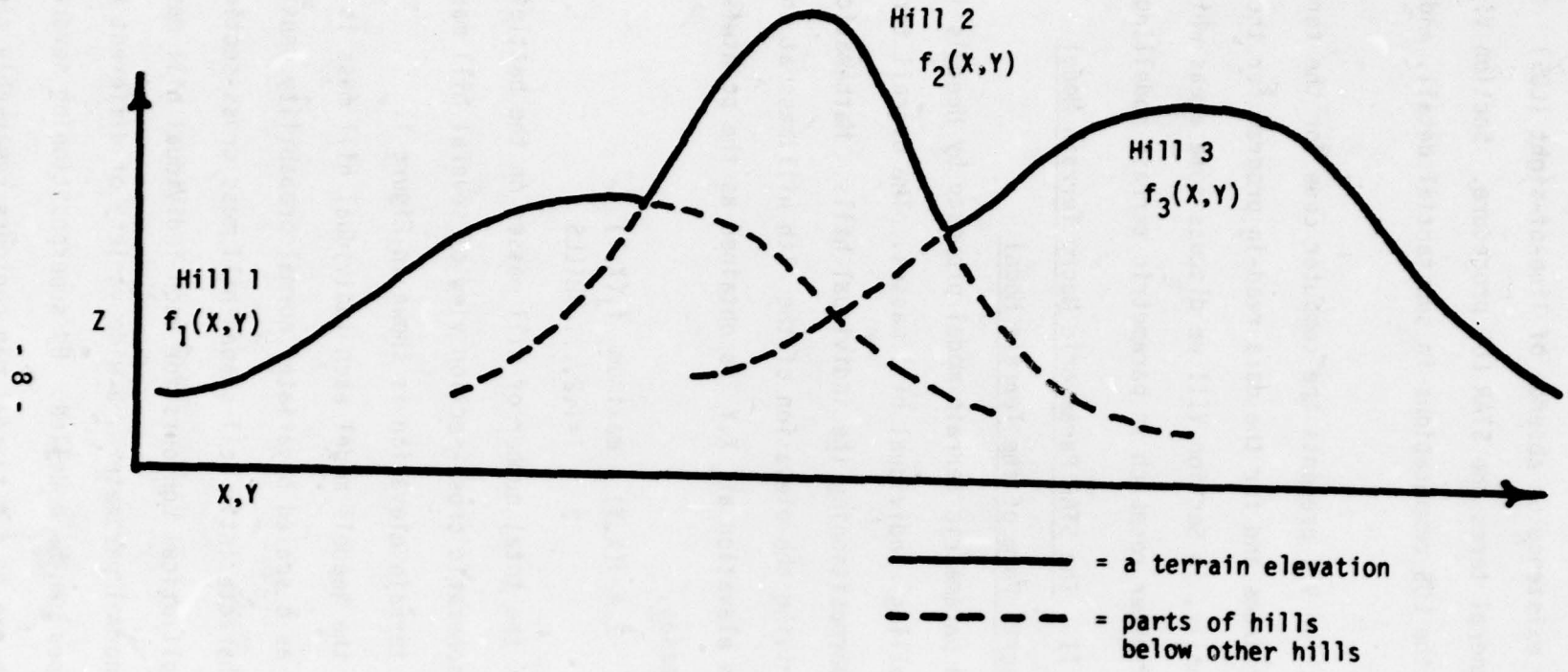

Figure 1. $f(X,Y) = \max_I f_I(X,Y)$

The STAR parametric terrain model uses a generalization of the hill mass functions of the Needels model. The representation of these functions has been changed significantly to make them easier to fit to real terrain maps and to make computations more efficient. In addition, forest features have been added, and the rather complex line-of-sight computations have been developed.

B. Parameterization for Terrain Fitting

In order to emulate a piece of real terrain with the STAR parametric terrain model, it is necessary to fit the model's hill mass functions $f_I(X,Y)$ to a contour map of the terrain to be modeled. The fitting process is currently done by hand, so it is essential to describe the hill-mass functions using a parameterization that makes geometric sense and can easily be related to a contour map. In this section we develop the "fitting-parameterization" of the hill mass functions $f_I(X,Y)$. This parameterization is not particularly well suited for efficient computation, so we will convert to a computing-parameterization in Section III.

Each hill mass function $f_I(X,Y)$ is given by an exponential function

$$f_I(X,Y) = PEAK.H(I) + HT.H(I)* [\exp (Q_I(X,Y)) - 1] \qquad (2)$$

where PEAK.H(I) and HT.H(I) are constant parameters for hill I to be described shortly, and where $Q_I(X,Y)$ is a quadratic function of X,Y which has several other parameters. $Q_I(X,Y)$ is a negative definite quadratic, so the $\exp(Q_I(X,Y))$ term yields hills having the characteristic bell-shaped cross-section of a normal probability density function, and having contour lines which are elliptical. The parameters control the location, orientation, size, and shape of the elliptical contours.

Elevations in the model are measured from 0 meters = sea-level, and the terrain as a whole has a minimum elevation level above sea level denoted BASE.

The BASE value is included as a term in the maximization of equation (1)

$$Z = \max \{BASE, \max_{I} f_I(X,Y)\} \qquad (3)$$

Several of the hill parameters relate to hill height, and are best visualized on a cross-section diagram (see Figure 2.).

HT.H(I): the maximum height of the "normal" curve describing this hill mass.

PEAK.H(I): the elevation of the hilltop measured from zero = sea-level.

Since HT.H(I) may be greater than or less than PEAK.H(I), the bottom of the hill which occurs at PEAK.H(I) - HT.H(I) need not be at sea-level. However, since normal curves have tails approaching the botom level which extend to $\pm\infty$ we require that these tails be below the terrain BASE value. Thus a constraint on the terrain parameterization is

$$PEAK.H(I) - HT.H(I) < BASE \qquad (4)$$

For some hill masses, the tails of the hill are annoying as they prevent the terrain from dropping off quickly enough to model a cliff side or a steep riverbank. Thus we include the parameter

CUT.H(I): A vertical distance measured down from the peak beyond which this hill mass is no longer considered in the computations.

Thus if CUT.H(I) is 70m., at most seven contours of hill I will appear on a 10m. contour map. The CUT.H parameter must be used with care, since it may introduce unwanted discontinuities in the terrain--vertical cliffs. Figure 3 shows an example in which this parameter is properly used. Here the gradual slope of hill 2 has been terminated using CUT.H(2) and hill 3 has been added to give a more abrupt slope to the terrain at this point. Without hill 3 the

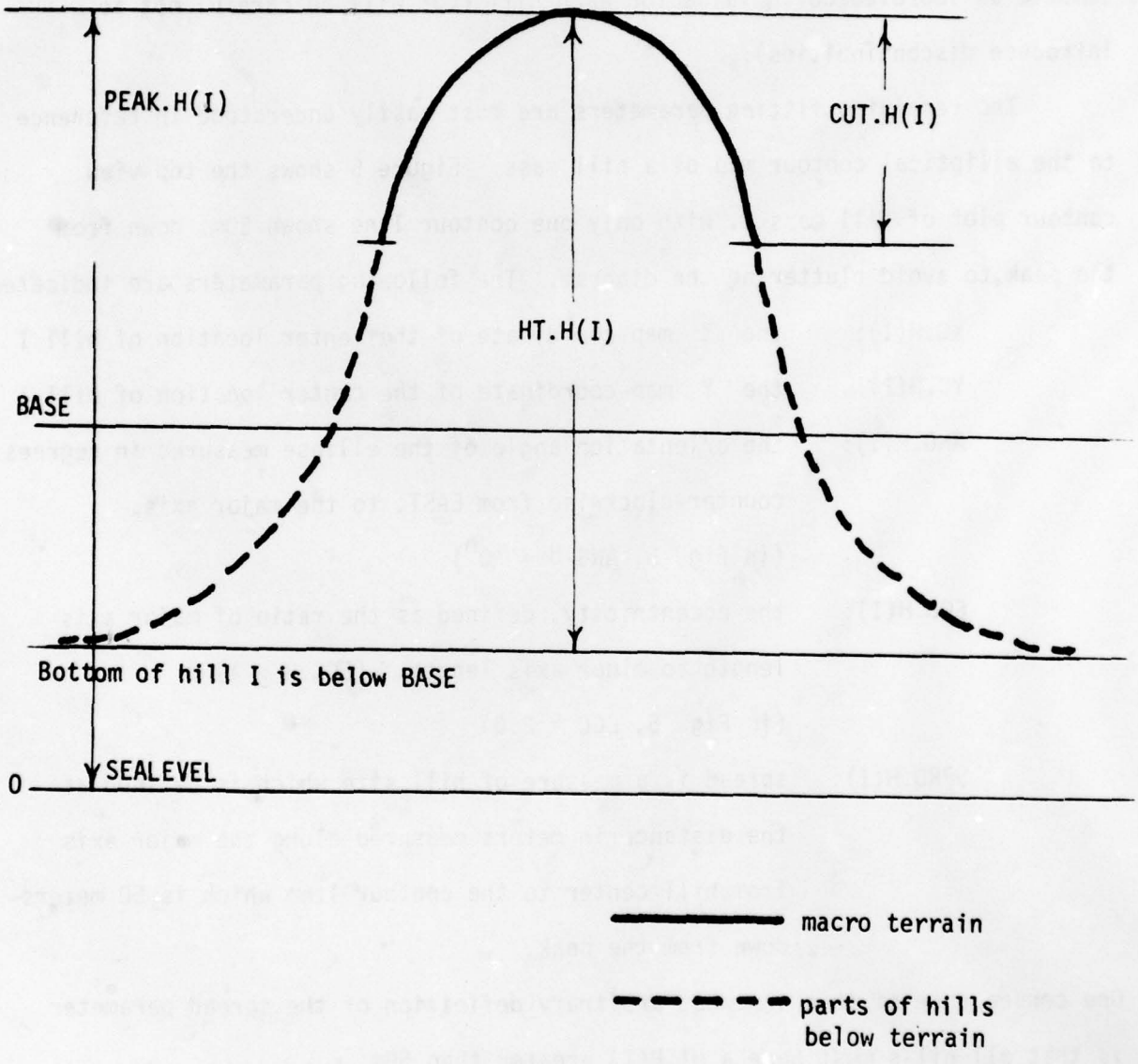

Figure 2. Cross-section through center of hill mass I.

resulting terrain would have a bad discontinuity as in Figure 4. For the vast majority of the hills not requiring the CUT.H(I) parameter it may be safely defaulted to HT.H(I). The CUT.H parameter also improves computational efficiency by restricting the region in which we need to worry about hill I. The Terrain Preprocessor program HILL.LIST to be described in Section III will compute an improved CUT.H value for each hill (but will be careful not to introduce discontinuities).

The remaining fitting parameters are most easily understood in reference to the elliptical contour map of a hill mass. Figure 5 shows the top view contour plot of hill mass I, with only one contour line shown 50m. down from the peak,to avoid cluttering the diagram. The following parameters are indicated:

XC.H(I): the X map-coordinate of the center location of hill I

YC.H(I): the Y map-coordinate of the center location of hill I

ANG.H(I): the orientation angle of the ellipse measured in degrees counter-clockwise from EAST. to the major axis. (in Fig. 5, ANG.H = 30^{o})

ECC.H(I): the eccentricity, defined as the ratio of major axis length to minor axis length. (ECC.H $\geq$ 1) (in Fig. 5, ECC = 2.0)

SPRD.H(I): spread is a measure of hill size which is defined as the distance in meters measured along the major axis from hill center to the contour line which is 50 meters down from the peak.

One consequence of this somewhat arbitrary definition of the spread parameter is that all hills must have a HT.H(I) greater than 50m.

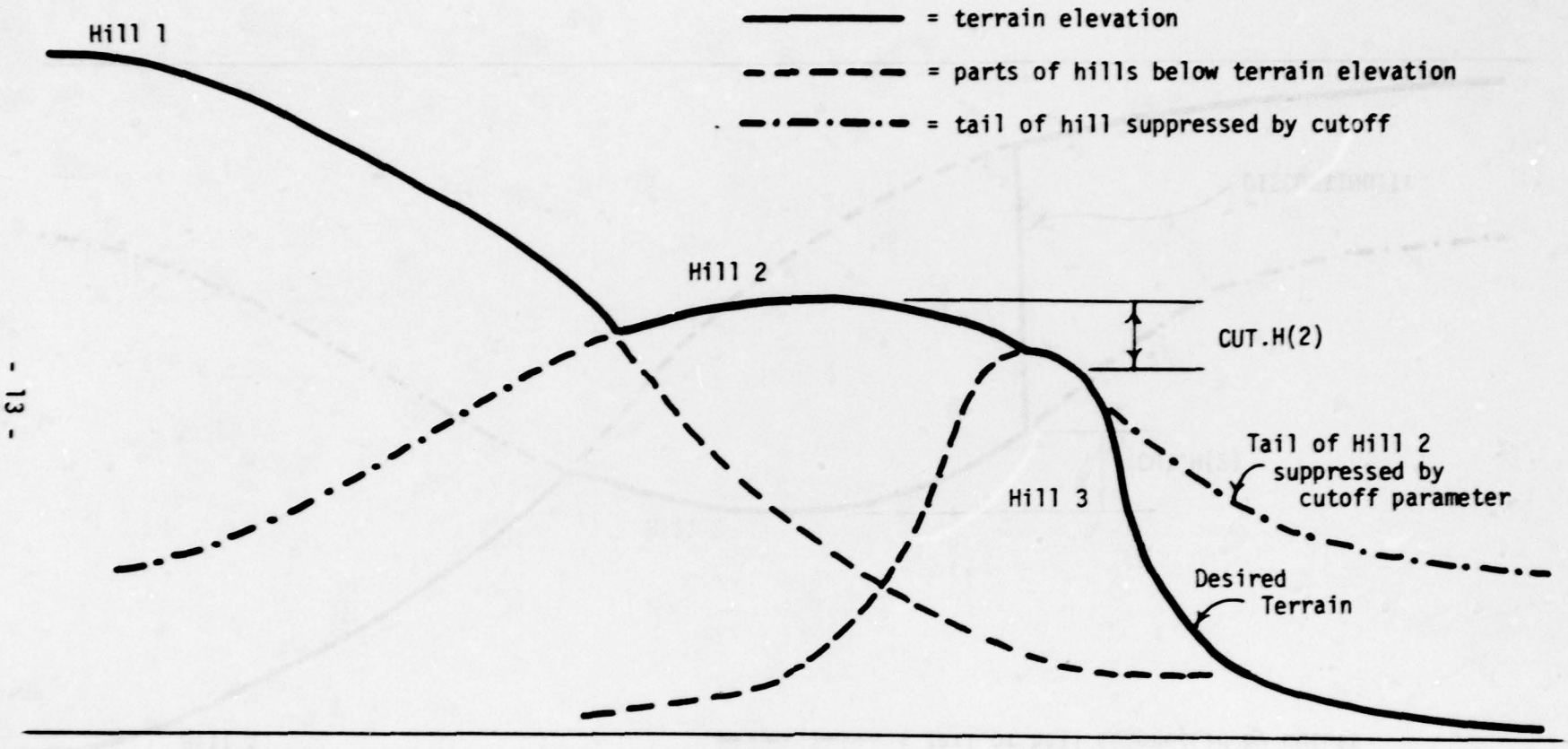

Figure 3. Use of CUT.H parameter

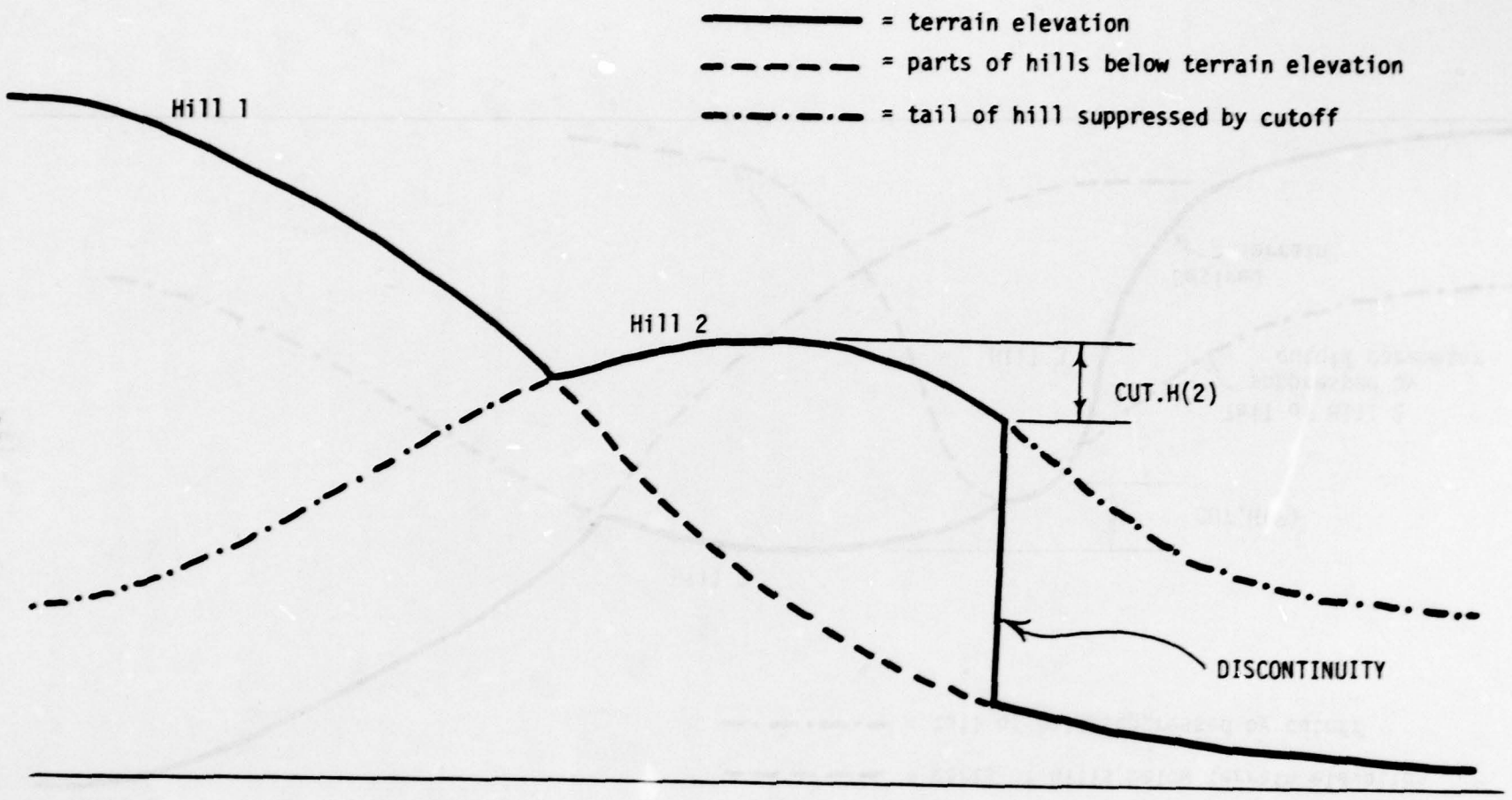

Figure 4. Misuse of CUT.H parameter

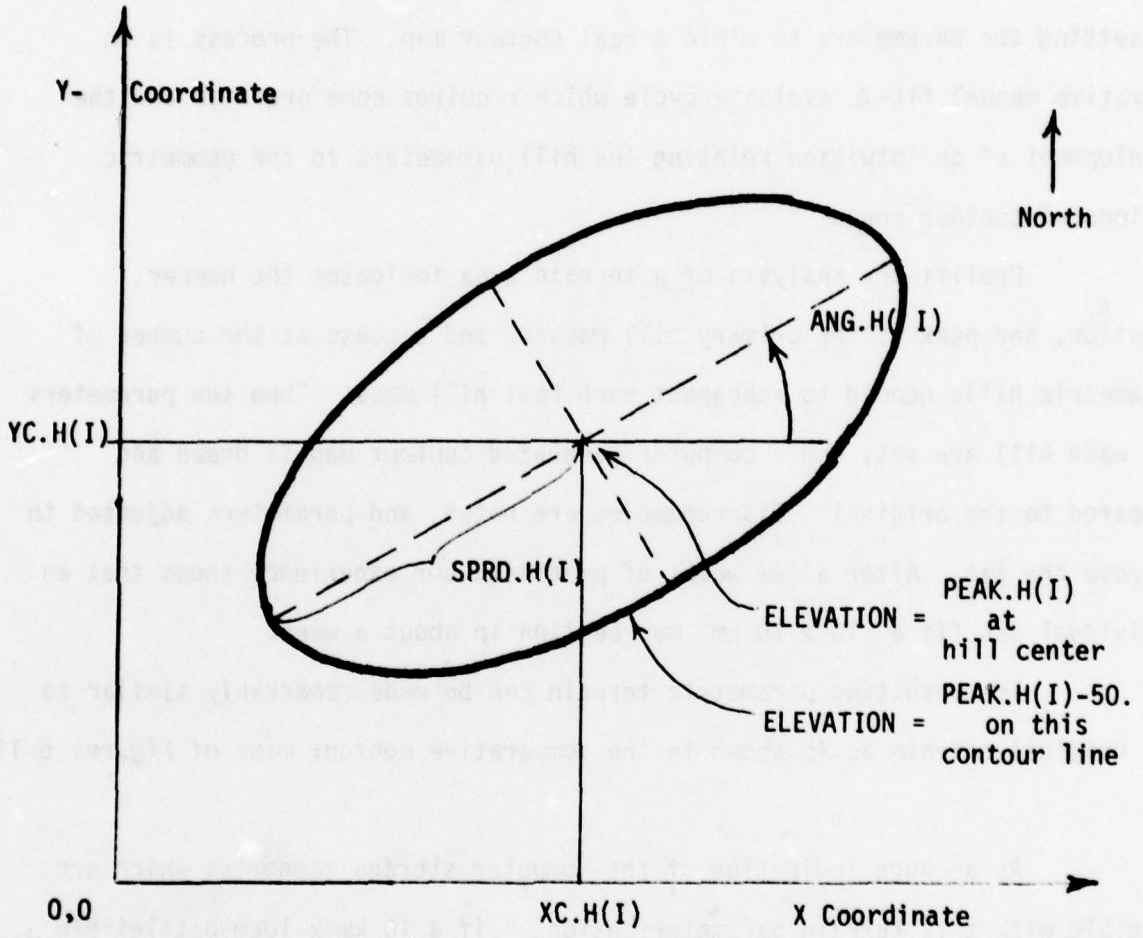

Figure 5. One elliptical contour of hill I

C. Fitting Hills to Real Terrain

Given the set of 8 hill parameters, (XC.H, YC.H, PEAK.H, ANG.H, ECC.H, SPRD.H, HT.H, CUT.H), our goal is to emulate a piece of real terrain by setting the parameters to mimic a real contour map. The process is an iterative manual fit-&-evaluate cycle which requires some practice and the development of an intuition relating the hill parameters to the geometric notions of contour shape.

Preliminary analysis of a terrain area indicates the number, location, and peak of the primary hill masses, and a guess at the number of parametric hills needed to represent each real hill mass. Then the parameters for each hill are set, and a computer generated contour map is drawn and compared to the original. Discrepancies are noted, and parameters adjusted to improve the fit. After a few weeks of practice, our experience shows that an individual can fit a 10 x 10 km map section in about a week.

The resulting parametric terrain can be made remarkably similar to the original terrain as is shown in the comparative contour maps of Figures 6-11.

As a rough indication of the computer storage economies which are possible with this terrain parameterization, if a 10 km x 10km battlefield can be represented using NHILLS = 100 hills, then 800 parameters must be stored. By contrast, a digitized terrain model working with a 100m grid size would have to store slightly more than 10,000 numbers. This represents a storage savings factor of about 12. A more careful comparison would have to consider the exact number of hills required as well as possibilities for storage packing in both models.

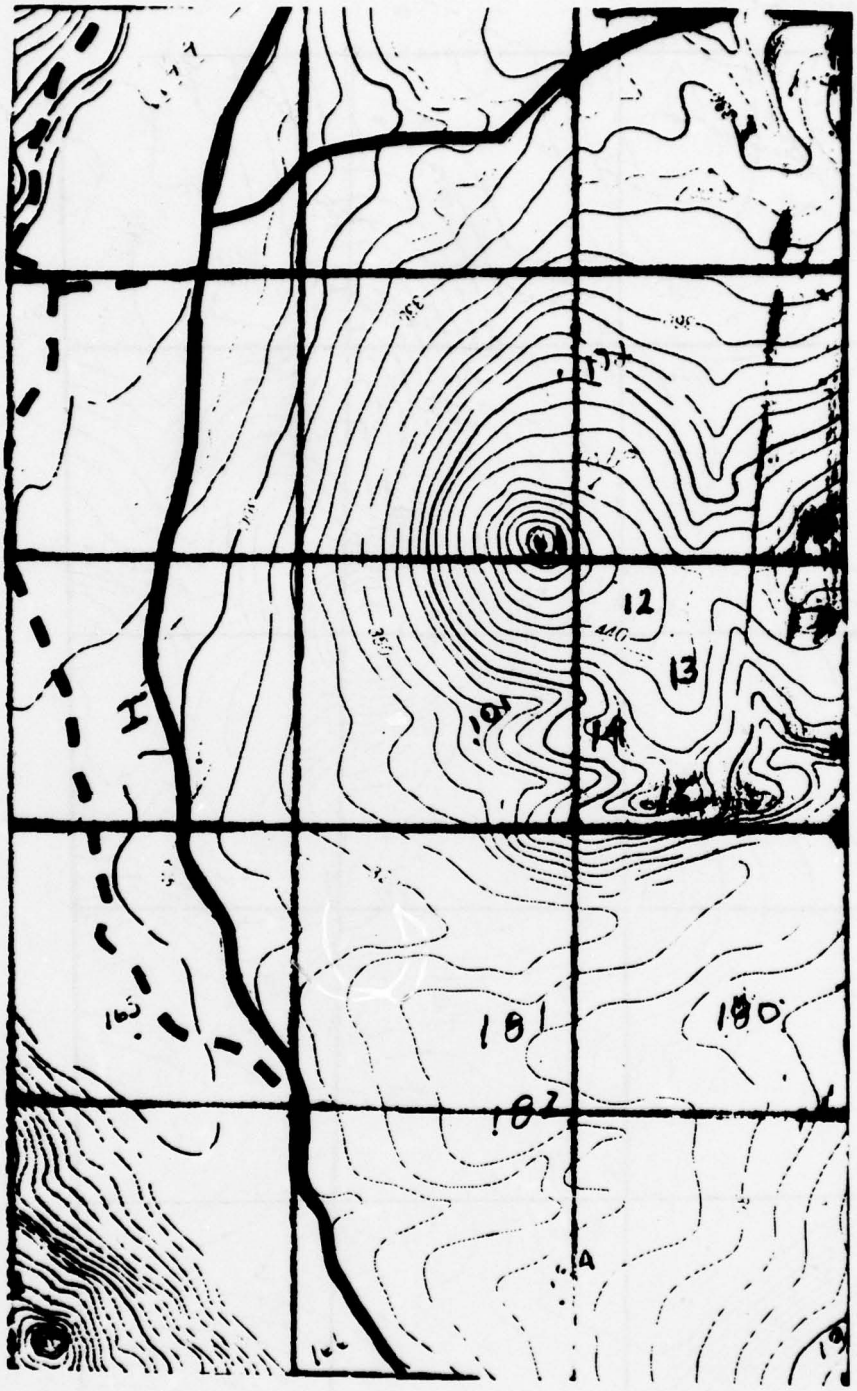

Figure 6. Map Contours A

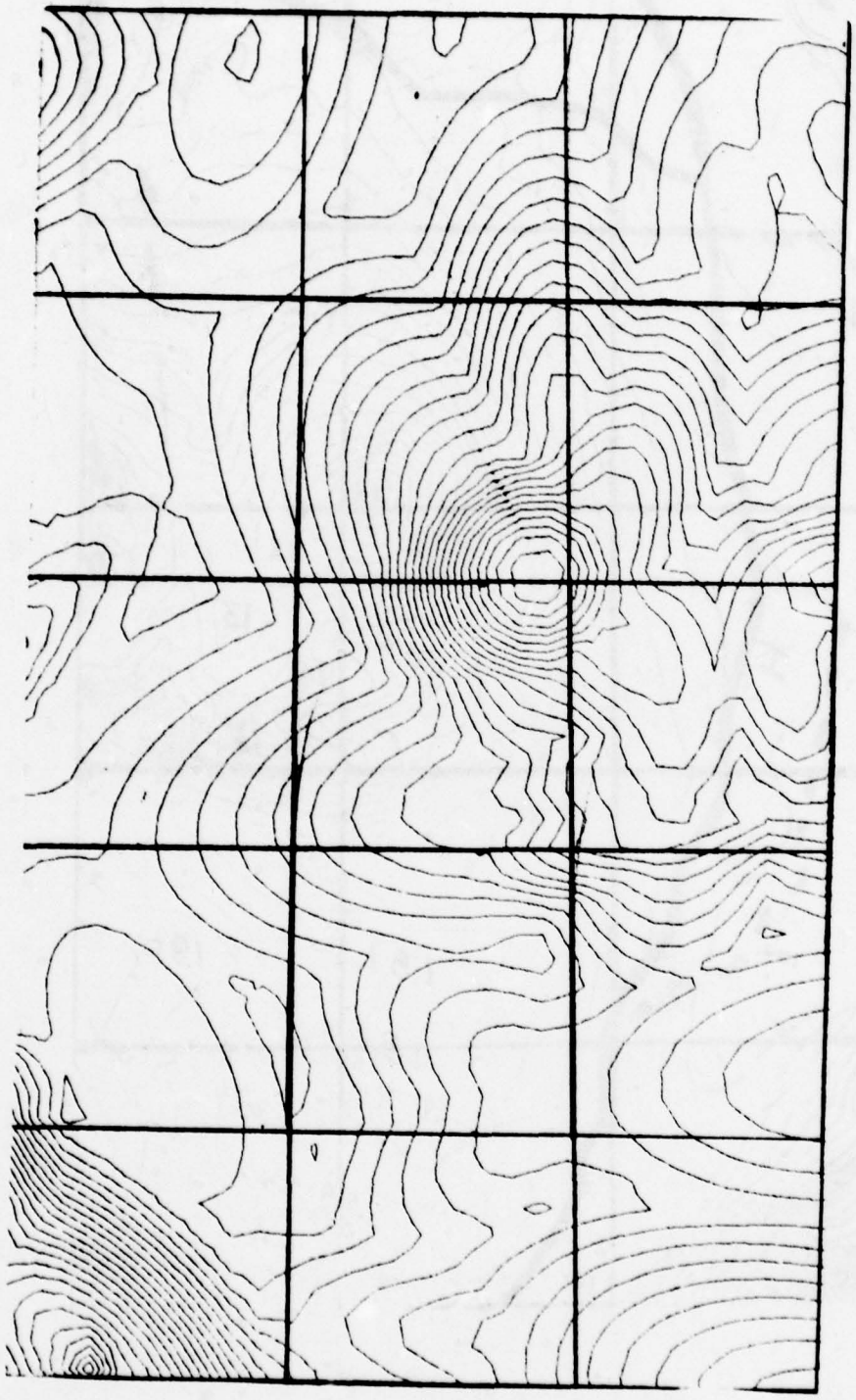

Figure 7. Parametric Contours A

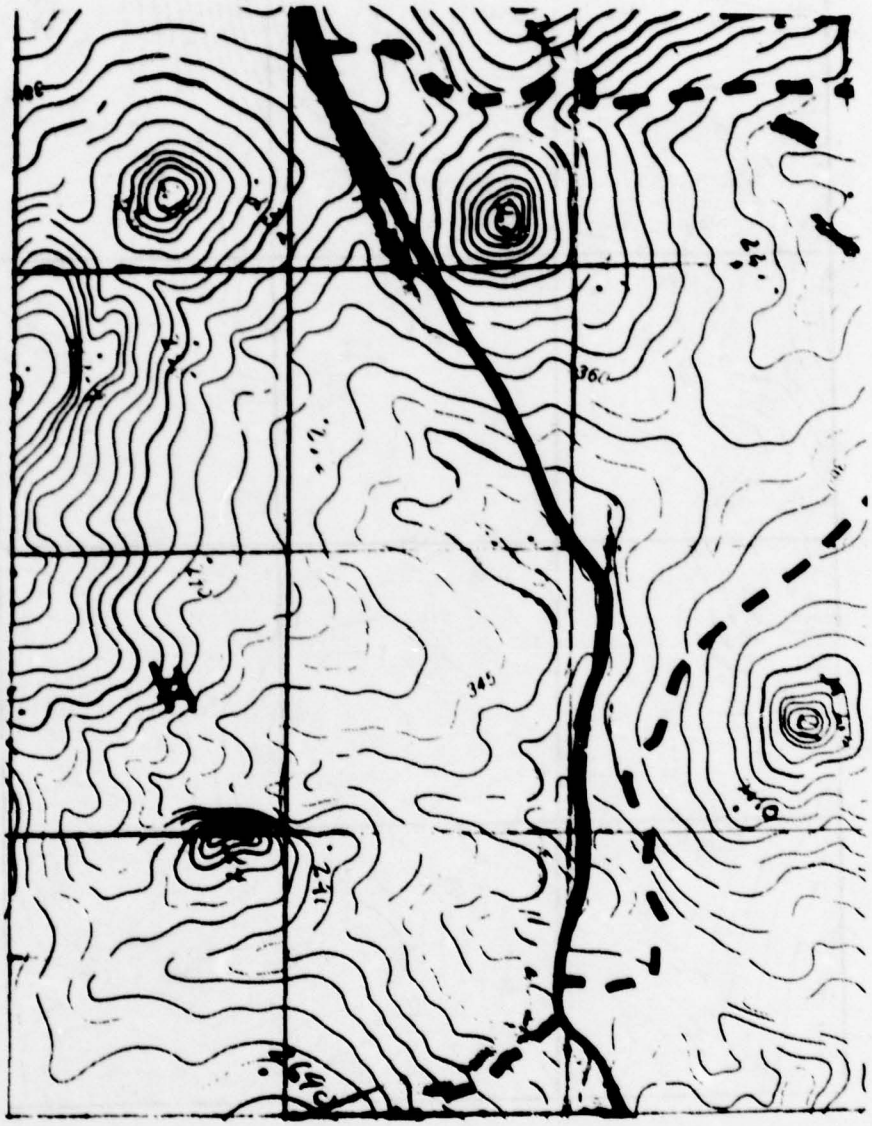

Figure 8. Map Contours B

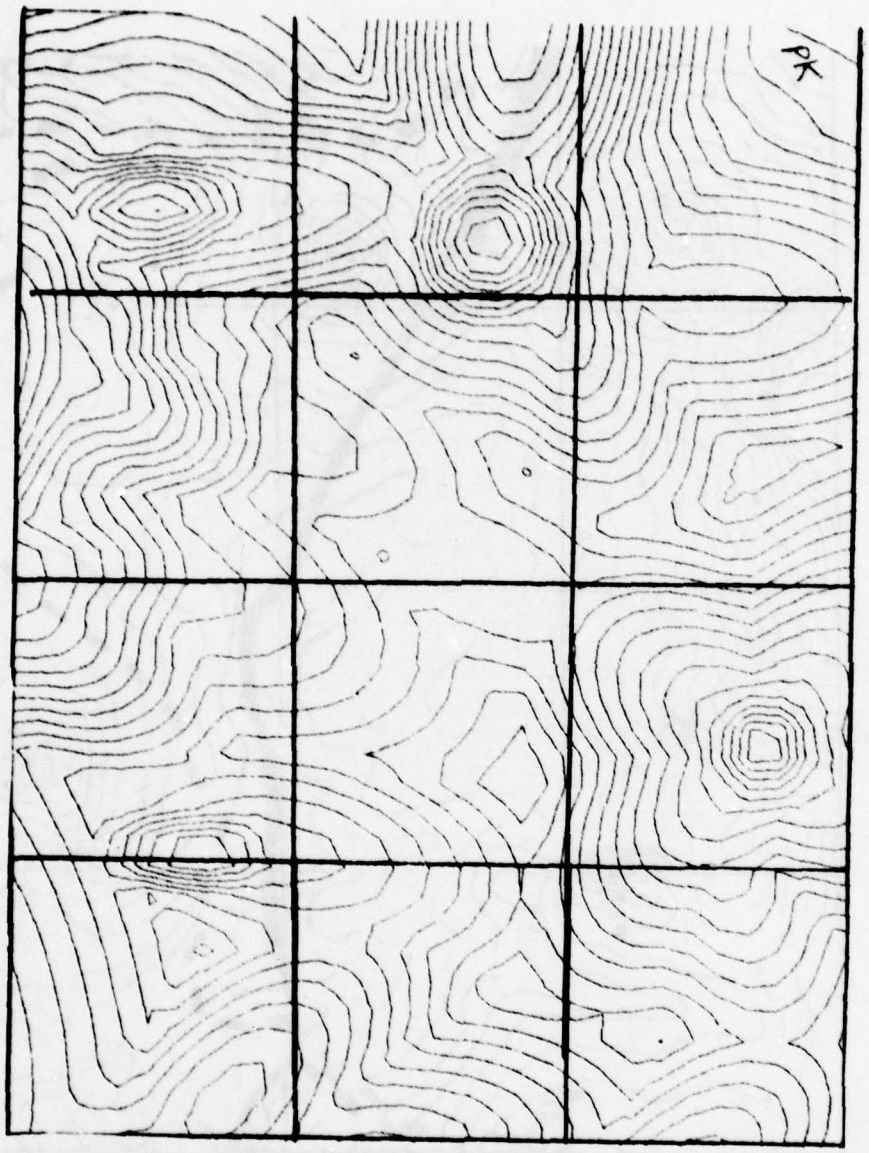

Figure 9. Parametric Contours B

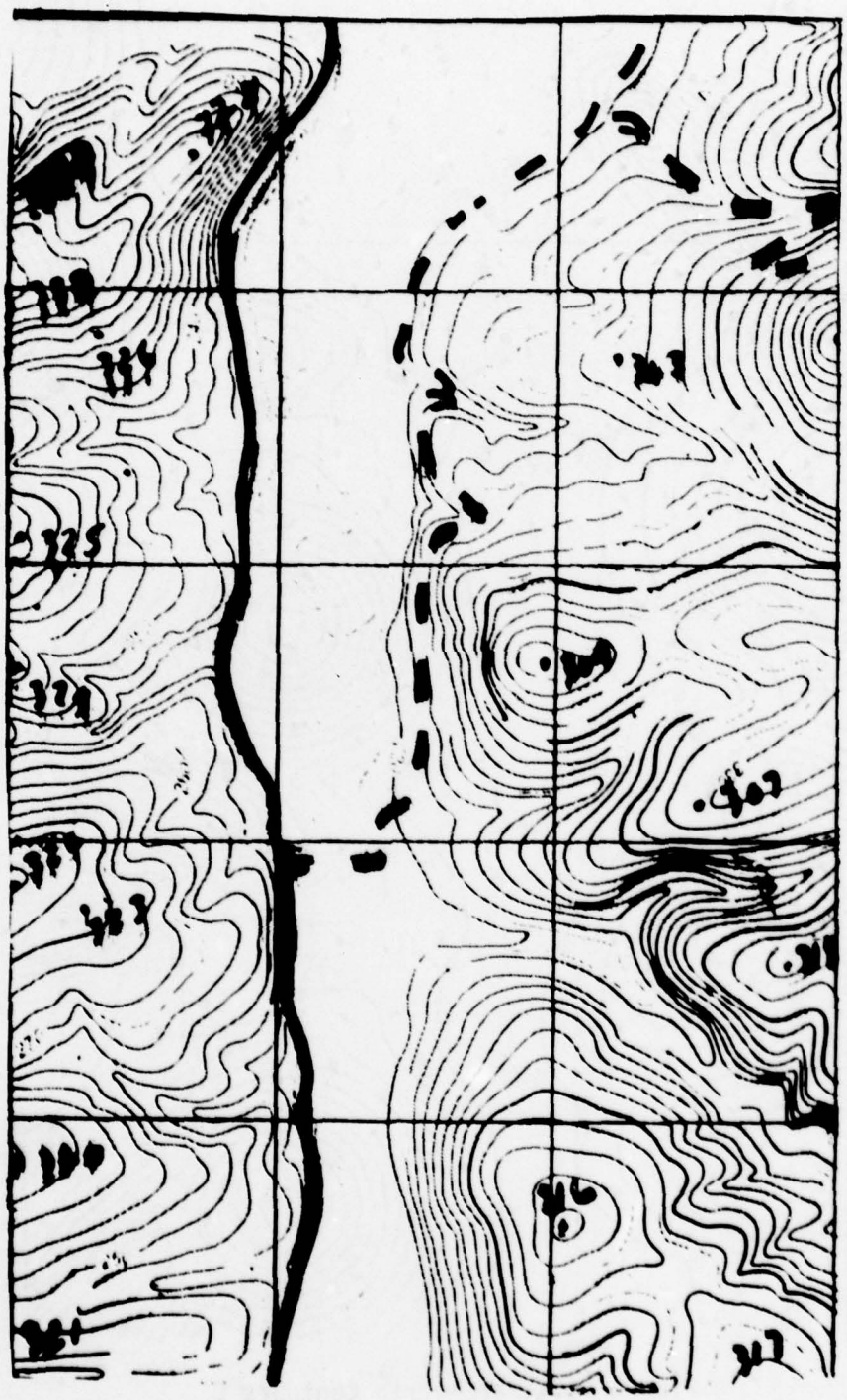

Figure 10. Map Contours C

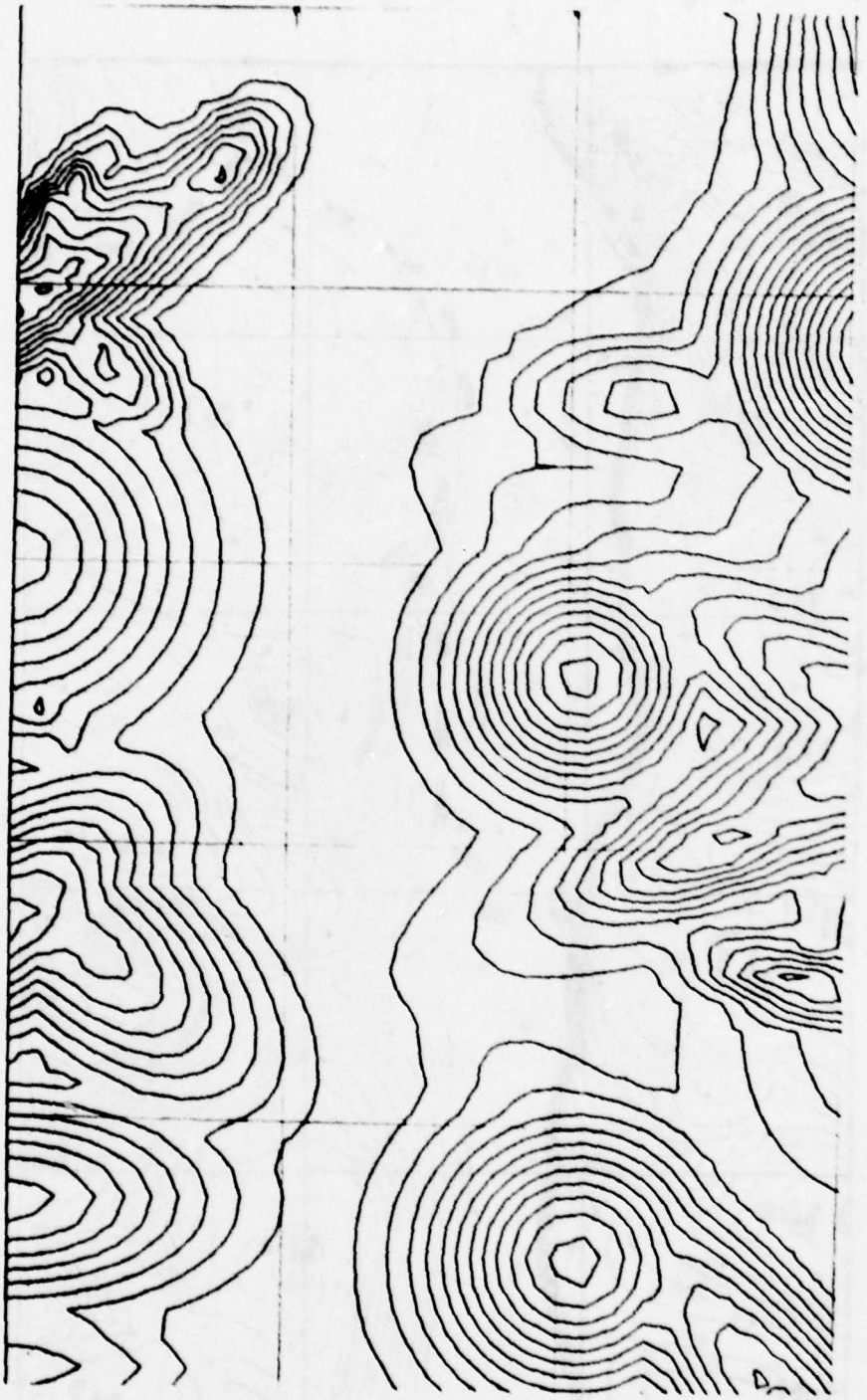

Figure 11. Parametric Contours C

III. Elevation Computations

A. Parameterization for Computing

The fitting parameters discussed in Section II were designed for their geometric connotations to aid in the terrain fitting process. For computer calculations we are interested in computational efficiency rather than geometric appeal, so a second parameter set has been developed for the STAR terrain model. This set of computing-parameters is derived algebraically from the fitting parameters and yields exactly the same terrain elevations.

The basic elevation formula for hill I is, as in equation (2),

$$f_I(X,Y) = PEAK.H(I) - HT.H(I) + HT.H(I)*\exp\,[Q_I(X,Y)] \qquad (5)$$

where PEAK.H(I) - HT.H(I) gives the elevation of the bottom of the hill, and HT.H(I) *exp $[Q_I(X,Y)]$ adds the hill mound to this bottom level as a function of X and Y .

For the computing parameterization, we define

$$\begin{aligned} XS &= X - XC.H(I) \\ YS &= Y - YC.H(I) \end{aligned} \qquad (6)$$

giving the coordinate distances from X,Y to the hill center location. Then the quadratic function $Q_I(X,Y)$ is given as

$$Q_I(X,Y) = PXX.H(I)*XS^2 + PYY.H(I)*YS^2 + PXY.H(I)*XS*YS \qquad (7)$$

where PXX.H(I), PYY.H(I), and PXY.H(I) are computing-parameters defined in terms of the fitting parameters as follows:

Letting
$$\begin{aligned} SANG &= \sin\,(ANG.H(I)) \\ CANG &= \cos\,(ANG.H(I)) \\ A &= \ln\,(HT.H(I)/(HT.H(I) - 50.)) \\ B &= A * ECC(I)^2 \end{aligned} \qquad (8)$$

$$\text{then} \quad PXX.H(I) = -(A*CANG^2 + B*SANG^2)/SPRD.H(I)^2$$
$$PYY.H(I) = -(A*SANG^2 + B*CANG^2)/SPRD.H(I)^2 \qquad (9)$$
$$PXY.H(I) = (2*CANG*SANG*(B-A))/SPRD.H(I)^2$$

Finally, the CUT.H(I) parameter, which has been ignored in all of the above formulas is related to $Q_I(X,Y)$ by defining the computing parameter

$$CRIT.H(I) = \begin{cases} \ln((HT.H(I) - CUT.H(I))/HT.H(I)) \\ \quad \text{if } CUT.H(I) < HT.H(I) \\ -\infty \text{ otherwise} \end{cases} \qquad (10)$$

and redefining the basic hill equation to be

$$f_I(X,Y) = \begin{cases} PEAK.H(I) - HT.H(I) + HT.H(I)*\exp[Q_I(X,Y)] \\ \quad \text{if } Q_I(X,Y) > CRIT.H(I) \\ BASE \text{ otherwise.} \end{cases} \qquad (11)$$

The derivation of these formulas is rather tedious, but certainly not profound, consisting primarily of a coordinate rotation, the equation of an ellipse, and the definitions of SPRD.H and CUT.H. The reader who wishes to fully understand the mathematics of the terrain model should work through these derivations.

B. A Primitive ELEV Routine

Given the above computing parameters (XC.H, YC.H, PEAK.H, HT.H, PXX.H, PYY.H, PXY.H, CRIT.H) for each of a number NHILLS of hills on our battlefield, and given an overall terrain BASE, a primitive computer subroutine can easily be written to compute the elevation Z for any point X,Y on the battlefield. Such a program is given here in the SIMSCRIPT II.5 computer simulation language, assuming the above parameters have already been stored in appropriate global arrays and variables.

```
ROUTINE FOR PRIMITIVE.ELEV GIVEN  X  AND  Y  YIELDING  Z
NORMALLY MODE IS REAL
DEFINE  I  AS AN INTEGER VARIABLE
LET  Z = BASE
FOR  I = 1  TO NHILLS DO
    LET  XS = X - XC.H(I)          LET  YS = Y - YC.H(I)
    LET  QI = PXX.H(I) *XS**2 + PYY.H(I) *YS**2 + PXY.H(I)*XS*YS
    IF  QI  LT CRIT.H(I) CYCLE
    ELSE LET  FI = PEAK.H(I) + HT.H(I)*(EXP.F(QI)-1.)
    IF  FI  GT Z    LET  Z = FI ALWAYS
LOOP RETURN END
```

Given the formulas in Section III.A, this routine should not require further documentation. It is the protopype for the ELEV routine actually used in STAR.

C. Refinements for Speeding the Calculations

The PRIMITIVE.ELEV routine, while it will work for any X,Y, is not particularly efficient. Its primary weakness is the need to loop over all NHILLS hills even though only a few hills are close enough to a given X,Y to have any chance of influencing the macro-terrain elevation Z at that point. Substantial economies in computing time can be realized by using a terrain preprocessor program to develop lists of the hills which are relevant to particular areas of the battlefield and to improve CUT.H values for all hills. The terrain preprocessor program, called HILL.LIST, divides the battlefield into grid squares of size GSIZE (our experience indicates that GSIZE in the range 1 to 3 km yields an effective grid). Each grid square is referenced by grid subscripts IX and IY. An array LIST.H (IX,IY,L) is created which contains, for each IX,IY (i.e. for each grid square) a list of the hills I which

contribute to the terrain in the grid square.

Then given X,Y we can compute the elevation Z by first computing the appropriate grid square IX,IY and then executing a routine similar to PRIMITIVE.ELEV which only loops over the hills in LIST.H(IX,IY,L) for this grid square. Dramatic computational efficiencies result with only a modest storage increase for the list. Typical results from our experience are that for GSIZE = 1 km., on the average, 4 or 5 hills are relevant to each grid square. Clearly this depends on the complexity of the terrain and the number of hills used to model it.

A further savings can be obtained by computing in HILL.LIST the elevation E of the lowest terrain point actually represented by each hill and using E with PEAK.H to get the smallest CUT.H value possible for the hill. Then the QI vs CRIT.H(I) test in ELEV will cycle more frequently hence avoiding the expensive exponential computation.

The line-by-line details of HILL.LIST are documented in Secion VII. For this section it suffices to define the global LIST.H (IX,IY,L) array which HILL.LIST creates. LIST.H has subscripts

IX: grid square subscript in X direction

IX = 1,...,NGRIDX

IY: grid square subscript in Y direction

IY = 1,...,NGRIDY

L: subscript for last coordinate of LIST.H .

For a given IX,IY,

LIST.H(IX,IY,1) = BASE value for the grid square

LIST.H(IX,IY,2), LIST.H(IX,IY,3),ETC. = hill numbers for the hills which influence terrain in this gridsquare.

LIST.H is represented in SIMSCRIPT as a ragged array, so the number of hills to be scanned in grid square IX,IY is DIM.F(LIST.H(IX,IY,*))-1 .

The resulting streamlined ELEV routine is presented in Listing 1.

Local variables

I hill number

IX, IY } grid square index in X and Y directions

KOUNT number of hills in a grid square + 1

L loop index

X, Y } input X and Y coordinates

Z resulting elevation

XS,YS,QI,FI intermediate computations as in PRIMITIVE.ELEV

Global variables

X.LO.BDRY, Y.LO.BDRY } map coordinates of southwest corner of battlefield in meters

GSIZE grid square size in meters

NGRIDX range of IX - number of grid squares in X direction

NGRIDY range of IY - number of grid squares in Y direction

LIST.H list of hill numbers for each grid, also BASE value

DUM.I one-dimensional integer dummy array to simplify coordinate computation in accessing LIST.H

XC.H,YC.H,PEAK.H,HT.H,PXX.H,PYY.H,PXY.H,CRIT.H hill parameter arrays.

Routines called

None

Events scheduled

None

```
ROUTINE FOR ELEV GIVEN X,Y YIELDING Z
**ROUTINE TO COMPUTE ELEVATION Z FOR GIVEN X,Y COORDINATES
DEFINE I,IX,IY,KOUNT,L AS INTEGER VARIABLES
DEFINE X,Y,Z,XS,YS,DI,FI AS REAL VARIABLES
LET IX=1+TRUNC.F((X-XLO.BURY)/GSIZE)
LET IY=1+TRUNC.F((Y-YLO.BURY)/GSIZE)
IF IX LT 1 LET IX=1 ALWAYS
IF IX GT NGRIDX LET IX = NGRIDX ALWAYS
IF IY LT 1 LET IY=1 ALWAYS
IF IY GT NGRIDY LET IY = NGRIDY ALWAYS
LET DUM.I(*) = LIST.H(IX,IY,*)  **DUMMY ARRAY TO SIMPLIFY INDEXING
LET KOUNT = DIM.F(DUM.I(*))
LET Z = DUM.I(1)
FOR L = 2 TO KOUNT DO
    LET I = DUM.I(L)
    LET XS=X-XC.H(I)        LET YS=Y-YC.H(I)
    LET DI=PXX.H(I)*XS*XS + PYY.H(I)*YS*YS + PXY.H(I)*XS*YS
    IF DI LT CRIT.H(I) CYCLE
    ELSE LET FI=PEAK.H(I)*HT.H(I)*(EXP.F(DI)-1.)
    IF FI GT Z LET Z=FI ALWAYS
LOOP  RETURN  END
```

ELEV

Listing 1

Lines 5-10 compute the gridsquare indices and make sure that the gridsquare is on the battlefield.

Lines 11-12 define DUM.I to be the appropriate column of LIST.H and determine the length of that column

Line 13 sets Z to the BASE value

Lines 14-20 loop over the hills I (for this grid square only) and increase Z if the computed hill elevation FI is greater than the max so far.

Note that the origin for the grid square reference system is at X.LO.BDRY, Y.LO.BDRY (the southwest corner of the battlefield).

D. Terrain Slope

In addition to terrain elevation, the slope of the terrain at any point X,Y is directly available. Differentiating equation (11) gives the gradient components

$$GX = \frac{\partial f_I(X,Y)}{\partial X} = \begin{cases} HT.H(I)*\exp[Q_I(X,Y)]* \dfrac{\partial Q_I(X,Y)}{\partial X} \\ \quad \text{if } Q_I(X,Y) > CRIT.H(I) \\ 0 \quad \text{otherwise} \end{cases} \tag{12}$$

where

$$\frac{\partial Q_I(X,Y)}{\partial X} = 2*PXX.H(I)*XS + PXY.H(I)*YS \tag{13}$$

and

$$GY = \frac{\partial f_I(X,Y)}{\partial Y} = \begin{cases} HT.H(I)*\exp[Q_I(X,Y)] * \dfrac{\partial Q_I(X,Y)}{\partial Y} \\ \quad \text{if } Q_I(X,Y) > CRIT.H(I) \\ 0 \quad \text{otherwise} \end{cases} \tag{14}$$

where

$$\frac{\partial Q_I(X,Y)}{\partial Y} = 2*PYY.H(I)*YS + PXY.H(I)*YS \; . \tag{15}$$

Then if we move away from X,Y in direction ΔX, ΔY the slope is given by the directional derivative

$$D = (GX * \Delta X + GY * \Delta Y) \Big/ \sqrt{\Delta X^2 + \Delta Y^2} \quad . \qquad (16)$$

An elevation routine called ELEVG which computes the gradient components as well as Z is available and is used by the STAR movement routines. A separate routine is used because the line of sight routine which calls ELEV does not need the gradient information and should not pay the added computational price. The computational sequence in ELEVG is slightly different to capitalize on common computations in Z, GX, and GY. The resulting code is given in Listing 2. Because of the similarity to ELEV we will not provide a line-by-line explanation of ELEVG.

IV. Forest Modelling

A. Brief Description of Forest Methodology

In addition to the macro-terrain, another factor which crucially influences line of sight computations in the STAR model (as in the real world) is the presence of forested areas. Although we will refer to "forests" throughout this discussion, the modeling tools developed here could just as well be applied to man-made features, such as towns, which provide cover and thus interrupt LOS.

The same basic ideas can also be expanded to model smoke clouds on the battlefield. The resulting clouds must be able to move, expand, and disperse (which forests do not do), and are not totally opaque to all sensor systems. Development of a smoke module for STAR is currently underway, but it will not be documented here.

Forests or other cover features in the STAR model are represented by elliptical areas on the ground. Each such cover ellipse has a tree height

```
1   ROUTINE FOR ELEVG GIVEN X,Y YIELDING Z,GX,GY
2   **ROUTINE TO COMPUTE ELEVATION Z AND GRADIENT GX,GY FOR GIVEN X,Y COORDINATES
3   DEFINE I,IX,IY,KOUNT,L AS INTEGER VARIABLES
4   DEFINE X,Y,Z,GX,GY,XS,YS,QX,QY,QXY,OI,TERM,FI AS REAL VARIABLES
5   LET IX=1+TRUNC.F((X-X.LO.BDRY)/GSIZE)
6   LET IY=1+TRUNC.F((Y-Y.LO.BDRY)/GSIZE)
7   IF IX LT 1 LET IX=1 ALWAYS
8   IF IX GT NGRIDX LET IX = NGRIDX ALWAYS
9   IF IY LT 1 LET IY=1 ALWAYS
10  IF IY GT NGRIDY LET IY = NGRIDY ALWAYS
11  LET DUM.I(*) = LIST.F(IX,IY,*)  **DUMMY ARRAY TO SIMPLIFY INDEXING
12  LET KOUNT = DIM.F(DUM.I(*))
13  LET Z = DUM.I(1)
14  FOR L = 2 TO KOUNT DO
15      LET I = DUM.I(L)
16      LET XS=X-XC.H(I)          LET YS=Y-YC.H(I)
17      LET GX = PXX.H(I)*XS      LET GY = PYY.H(I)*YS
18      LET QXY = PXY.H(I)*XS
19      LET QI = QX*XS + YS*(GY+QXY)
20      IF QI LT CRIT.H(I) CYCLE
21      ELSE LET TERM = HT.H(I)*EXP.F(QI)
22      LET FI = PEAK.H(I)+TERM-HT.H(I)
23      IF FI GT Z LET Z = FI
24          LET GX = TERM*(2.*QX + PXY.H(I)*YS)
25          LET GY = TERM*(2.*GY + QXY)
26      ALWAYS
27  LOOP  RETURN  END
```

EVEVG

Listing 2

associated with it, and the forest is thus an elliptical "cylinder" with that fixed height above the macro terrain. Forests with non-elliptical shapes and non-constant heights can be approximated by combining several possibly overlapping ellipses. The tree height at a given point X,Y is the maximum tree height for all the forest ellipses containing the point X,Y.

B. Parameterization for Forest Fitting

As is the case for macro terrain hill fitting, a geometrically motivated parameterization of the cover ellipses has been developed to aid in the fitting of the model to terrain maps. The parameters are listed below and illustrated in Figure 12.

XC.E(I): the X coordinate of the ellipse center

YC.E(I): the Y coordinate of the ellipse center

ANG.E(I): the orientation angle measured counterclockwise in degrees from east to the major axis of the ellipse

AMAJ.E(I): length in meters of the semi-major axis of the ellipse

AMIN.E(I): length of semi-minor axis of the ellipse

HT.E(I): height of the trees in ellipse I above the macro terrain elevation.

C. Parameterization for Computing

Given an arbitrary point X,Y on the battlefield we want to determine if this point is inside a forest feature, and, if so, how high the trees are. Since this computation will be performed frequently in the LOS procedure, it is important to have an efficient computational procedure. Thus the ellipses,like the hills, have a transformed parameter set for computing.

The boundary of the I^{th} forest ellipse is represented by the quadratic equation

```
1   %ROUTINE FOR ELEVG GIVEN X,Y YIELDING Z,GX,GY
2   **ROUTINE TO COMPUT ELEVATION Z AND GRADIENT GX,GY FOR GIVEN X,Y COORDINATES
3   DEFINE I,IA,IY,NCOUNT,L AS INTEGER VARIABLES
4   DEFINE X,Y,Z,GX,GY,XS,YS,CA,CY,DXY,DI,TERM,FI AS REAL VARIABLES
5   LET IX=1+TRUNC.F((X-X.LO.MDRY)/GSIZE)
6   LET IY=1+TRUNC.F((Y-Y.LO.MDRY)/GSIZE)
7   IF IX LT 1 LET IX=1 ALWAYS
8   IF IX GT NGRIDX LET IX = NGRIDX ALWAYS
9   IF IY LT 1 LET IY=1 ALWAYS
10  IF IY GT NGRIDY LET IY = NGRIDY ALWAYS
11  LET DUM.I(*) = LIST.P((IX,IY,*)  **DUMMY ARRAY TO SIMPLIFY INDEXING
12  LET NCOUNT = DIM.F(DUM.I(*))
13  LET Z = DUM.I(1)
14  FOR L = 2 TO NCOUNT IF
15      LET I = DUM.I(L)
16      LET XS=X-XC.H(I)          LET YS=Y-YC.H(I)
17      LET GX = PXX.H(I)*XS      LET GY = PYY.H(I)*YS
18      LET DXY = PXY.H(I)*XS
19      LET DI = DA**2 + YS*(GY+DXY)
20      IF DI LT EPSIT.H(I) CYCLE
21      ELSE LET TERM = HT.H(I)*EXP.F(DI)
22      LET FI = PEAK.H(I)*TERM-HT.H(I)
23      IF FI GT Z LET Z = FI
24          LET GX = 1.[illegible]*(2.*DA + PXY.H(I)*YS)
25          LET GY = T[illegible]*(2.*GY + DXY)
26      ALWAYS
27  LOOP  RETURN  END
```

EVEVG

Listing 2

associated with it, and the forest is thus an elliptical "cylinder" with that fixed height above the macro terrain. Forests with non-elliptical shapes and non-constant heights can be approximated by combining several possibly overlapping ellipses. The tree height at a given point X,Y is the maximum tree height for all the forest ellipses containing the point X,Y.

B. Parameterization for Forest Fitting

As is the case for macro terrain hill fitting, a geometrically motivated parameterization of the cover ellipses has been developed to aid in the fitting of the model to terrain maps. The parameters are listed below and illustrated in Figure 12.

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ANG.E(I): the orientation angle measured counterclockwise in degrees from east to the major axis of the ellipse

AMAJ.E(I): length in meters of the semi-major axis of the ellipse

AMIN.E(I): length of semi-minor axis of the ellipse

HT.E(I): height of the trees in ellipse I above the macro terrain elevation.

C. Parameterization for Computing

Given an arbitrary point X,Y on the battlefield we want to determine if this point is inside a forest feature, and, if so, how high the trees are. Since this computation will be performed frequently in the LOS procedure, it is important to have an efficient computational procedure. Thus the ellipses,like the hills, have a transformed parameter set for computing.

The boundary of the I^{th} forest ellipse is represented by the quadratic equation

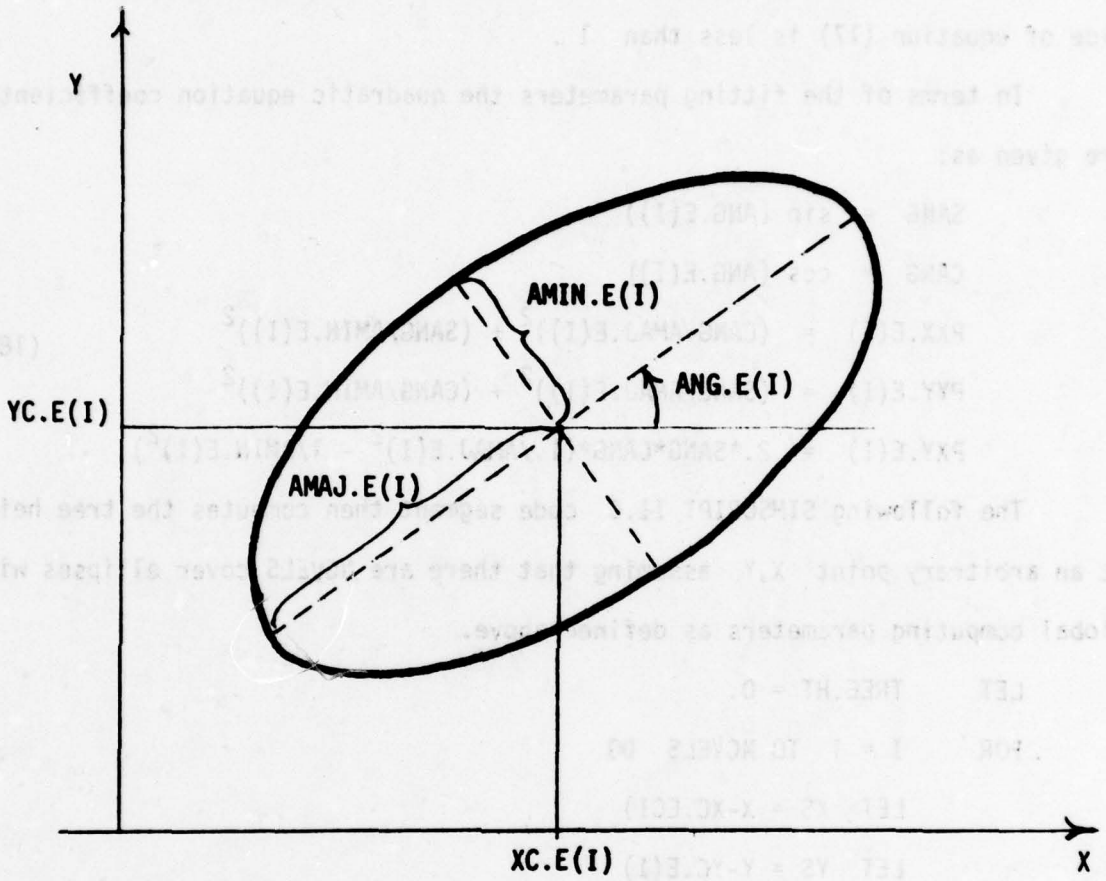


Figure 12. Forest Ellipse Fitting Parameters

$$PXX.E(I)*(X-XC.E(I))^2 + PYY.E(I)*(Y-YC.E(I))^2 + PXY.E(I)*(X-XC.E(I))*(Y-YC.E(I)) = 1.0 \quad (17)$$

Then an arbitrary X,Y is inside the ellipse if and only if the left hand side of equation (17) is less than 1 .

In terms of the fitting parameters the quadratic equation coefficients are given as:

$$\begin{aligned} SANG &= \sin(ANG.E(I)) \\ CANG &= \cos(ANG.E(I)) \\ PXX.E(I) &= (CANG/AMAJ.E(I))^2 + (SANG/AMIN.E(I))^2 \\ PYY.E(I) &= (SANG/AMAJ.E(I))^2 + (CANG/AMIN.E(I))^2 \\ PXY.E(I) &= 2.*SANG*CANG*(1./AMAJ.E(I)^2 - 1/AMIN.E(I)^2) \end{aligned} \quad (18)$$

The following SIMSCRIPT II.5 code segment then computes the tree height at an arbitrary point X,Y assuming that there are NCVELS cover ellipses with global computing parameters as defined above.

```
LET     TREE.HT = 0.
FOR     I = 1  TO NCVELS  DO
        LET  XS = X-XC.ECI)
        LET  YS = Y-YC.E(I)
        LET  QI = PXX.E(I)*XS**2 + PYY.E(I)*YS**2
                     +  PXY.E(I)*XS*YS
        IF   QI GE 1.  CYCLE
        ELSE IF   HT.E(I) GT TREE.HT LET TREE.HT = HT.E(I)
             ALWAYS
LOOP
```

D. Efficiency

As is the case for terrain hills, greater efficiency can be obtained

by limiting the number of cover ellipses checked at each X,Y to those found in a grid square. A forest preprocessor program called TREE.LIST operates in a fashion exactly analogous to HILL.LIST to develop an array LIST.C(IX,IY,L) of cover ellipse numbers in grid square IX,IY. Again this is stored as a SIMSCRIPT ragged array. The resulting more efficient code segment differs from the above code just as in the ELEV program. Since it appears in the LOS program we will not detail it further here beyond defining the LIST.C array contents. For given IX,IY

LIST.C(IX,IY,1) = number of forest ellipses overlapping grid square IX,IY.

and

LIST.C(IX,IY,2),...etc. give the ellipse numbers if LIST.C(IX,IY,1) $\geq$ 1 .

Documentation of the TREE.LIST program appears in Section VII.

V. Overview of LOS Modelling in STAR

An important computation for any high resolution combat simulation is the line of sight (LOS) routine. The basic problem is the following: Given an observer (A) and a potential target (B), what part (if any) of the target can be seen by the observer? LOS is a purely geometric computation in that we assume perfect visibility. Degraded visibility conditions are incorporated in other modules of the STAR model. The result of the LOS computation is a percent of the vertical height of the target B visible to the observer A. This percent visible is used in various ways in other parts of the STAR model.

The LOS computations are rather complex, but conceptually they are based on a simple procedure: "Find the lowest sight line from A over the terrain (and forests). Extend this line to B's location, and compare its extrapolated height to B's elevation. Thus compute % visible." This

procedure is illustrated in figure 13 for two cases. In the first, a terrain hill blocks LOS completely so 0% of the target is visible. In the second case the lowest sight line intersects the target so that 40% of its vertical height can be seen by A while the other 60% is covered.

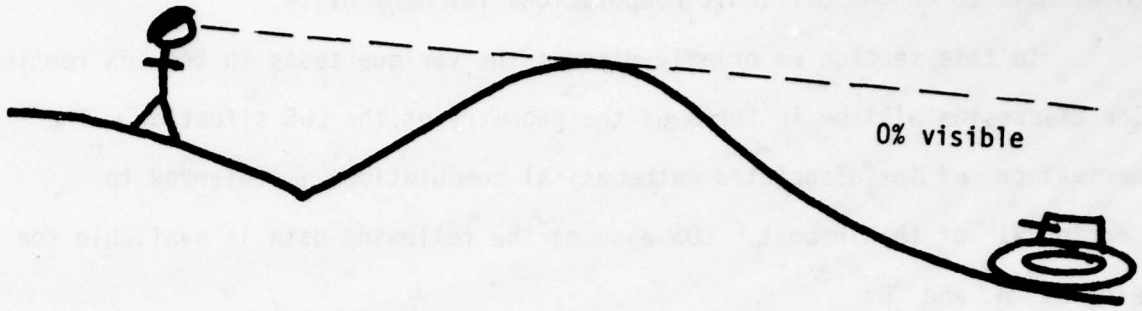
This simple concept is rather difficult to compute because

1. any one of the hills or forests which lie between A and B may be the feature which determines the lowest sight line. Thus we have to repeat computations for each such feature, and
2. the equation for the lowest sight line over a hill does not have a closed form solution.

The following observations tend to lessen the above computational difficulties:

3. Since A and B are given locations, only hills and forests which intersect the line joining A and B need to be considered. Features which are remote from this line can be ignored totally.
4. If LOS does not exist at all, (0% visible) then as soon as a hill or forest has been found which proves that the target is 0% visible, the computation can stop. All other hills and forests can be ignored.

Point 4. is particularly significant because on a typical battlefield a large fraction of the potential observer-target pairs will not have line of sight. Since the lowest sight line computation is difficult, the STAR LOS routine first performs a number of simpler tests trying to prove either that % visible = 0, or that a particular hill is so small that it could not possibly interrupt LOS between A and B. In either case the difficult lowest sight line computation is avoided, and in the first case all further



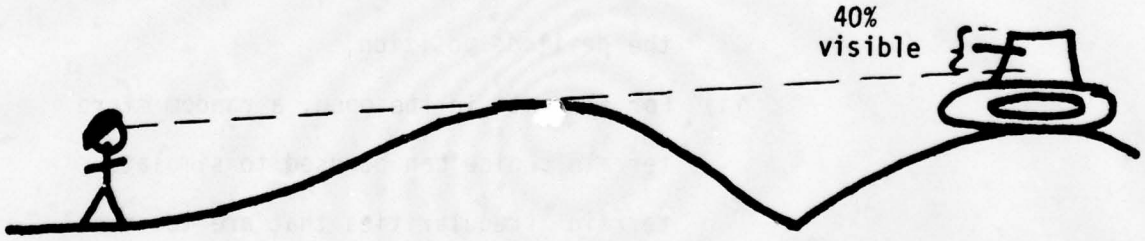


Figure 13. Lowest Sight Line Determines % Visible

computations are unnecessary. Only in cases where % visible is non zero do we have to do the difficult computations for many hills.

In this section we briefly discuss the various tests in the LOS routine. The discussion will be in terms of the geometry of the LOS situation. The derivation of the associated mathematical computations is deferred to Section VI of this report. LOS assumes the following data is available for each of A and B:

XA,YA(XB,YB) The X and Y coordinates on the battlefield for each of A and B .

TMACA,(TMACB) The macro terrain elevation computed from the ELEV routine.

TMICA (TMICB) A micro terrain offset + or - from the macro terrain. This offset is used in several ways:

i) For stationary defenders in defilade, negative micro terrain offsets simulate the defilade position.

ii) For elements in the open, a random micro terrain choice can be used to simulate terrain irregularities that are too small to explicitly model in the ELEV routine.

iii) Large positive micro terrain elevations are used to simulate aircraft flying above the terrain.

SIZEA (SIZEB) The vertical height dimension of each element. The percent visible is taken as a fraction of this size.

LAGA (LAGB) Indicator variables for air/ground

0 ⇒ the element is on the ground

1 ⇒ the element is an aircraft

LATOB (LBTOA) Indicator variables for one or two way LOS calls.

LATOB = 1 ⇒ compute LOS from A to B (yielding VISFRB)

0 ⇒ do not compute A to B

Since many of the situations in which LOS is computed are two-way situations, (Eg. A is trying to detect B, but B is also trying to detect A) the routine includes the option to do all calculations in both directions, thus saving repetition of many common computations. The result of the LOS computations is provided in the two variables

VISFRA (VISFRB) The fraction of SIZEA (SIZEB) which can be seen by B(A)

To compute LOS we evaluate terrain and forest height at a number of points along the line segment between A and B. The various tests are sequenced in the same order in the computer code as in the discussion which follows. For this discussion we will consider a one-way LOS CALL with A as observer and B as target (LATOB=1, LBTOA = 0). The two way computation is exactly analogous.

A. Initialize

To begin with, the LOS routine sets the visible fraction VISFRB=1.0 . As we proceed through the routine, various tests may decrease the visible fraction, but none will ever increase it. If VISFRB ever decreases to 0, then we immediately terminate the computations and return from the routine.

Throughout the computations we assume that the bottom of A is at TMACA + TMICA and that the top of A is at ZA = TMACA+TMICA+SIZEA and similarly for B (see Figure 14). The observation device is assumed to be at the top of A. If the micro terrain value TMICB is negative, then it is assumed that the bottom part of the target is not visible, so in this case VISFRB is immediately decreased to

$$\text{VISFRB} = 1. + \frac{\text{TMICB}}{\text{SIZEB}} \qquad (19)$$

which is less than 1 when TMICB < 0 .

B. Grid Square List

The line segment between A and B's positions crosses over some of the terrain grid squares. Thus the only hills and forests we need to consider are those associated with these grid squares. The routine develops a list of the NGRSQ grid squares crossed in the arrays IGX(K) and IGY(K) for K=1,...,NGRSQ.

C. Forest Ellipse List

The line segment between A and B may intersect some of the forest cover ellipses. If so, we must know where the intersection points lie. The routine develops a list of these ellipse intersections by considering, for each grid square only the ellipses (in LIST.C) which appear in the grid, and then testing each for intersection with the A to B line. The intersection points (if they exist) are called S1 and S2 and are stored along with the ellipse numbers in arrays IEL(K), CS1(K) and CS2(K) for K=1,...,NELS. Although an ellipse may appear in several adjacent grid squares, it will be stored on the list at most one time.

D. LOS Test at Forest Boundaries

One point at which lack of LOS can often be proved is a forest

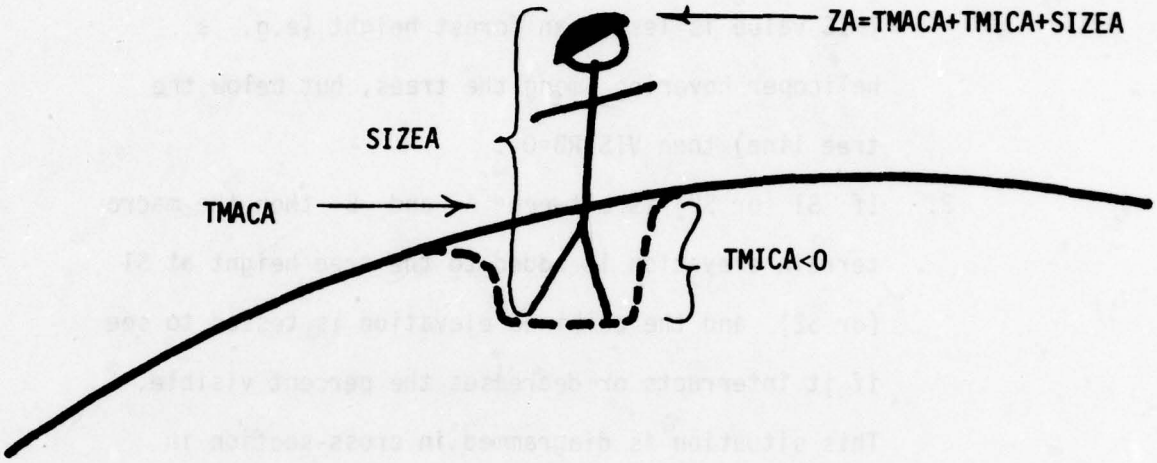


Figure 14. Observer Geometry

boundary, so as the above list of forest ellipses is being developed LOS is tested in the following ways:

1. If A or B is a ground element and is inside a forest ellipse, VISFRB=0. (no visibility through forests)
2. If A or B is an air element but the corresponding TMIC value is less than forest height (e.g. a helicoper hovering among the trees, but below the tree line) then VISFRB=0 .
3. If S1 (or S2) is between A and B then the macro terrain elevation is added to the tree height at S1 (or S2) and the combined elevation is tested to see if it interrupts or decreases the percent visible. This situation is diagrammed in cross-section in Figure 15. Subroutine TREE.CHECK performs these computations.

E. HILLTOPS

Next we consider all macro terrain hills that might lie between A and B. The list of such hills is developed by scanning LIST.H for each grid square crossed by the A to B line. Each such hill is processed one at a time from this point through to the end of the computations. Although a hill may appear in several grid squares, each hill is considered only once. We first compute a point W on the A to B line which is the top of the hill cross-section cut by that line. The following tests are then done on W.

1. If W is far from being between A and B, then this hill is irrelevant; go on to the next hill (see Figure 16, part 1).

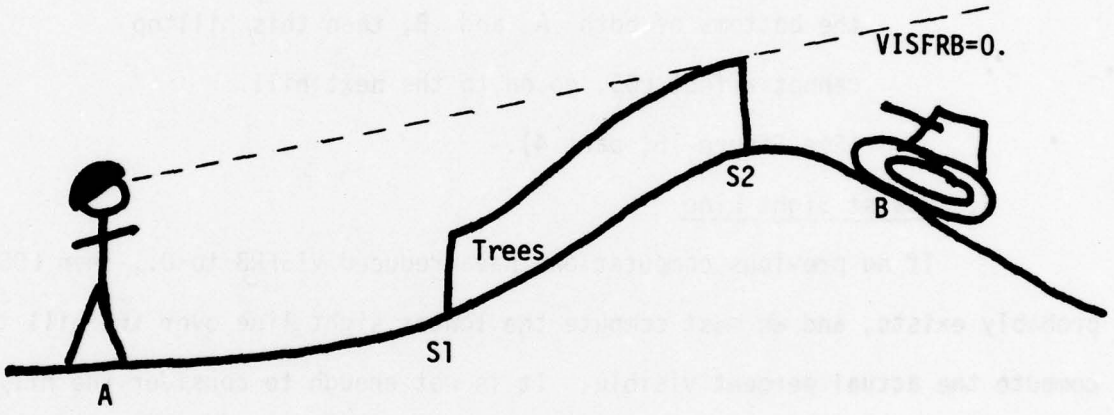


Figure 15. LOS Test at Edge of Forest

2. If the hill height at W is negligible (i.e. the cross section is far from the hill center) then this hill is irrelevant; go on to the next hill. (See Figure 16, part 2).

3. Test the hill height at W plus the tree height at W (if any) to see if LOS is totally interrupted. (See Figure 16, part 3).

4. If hill height at W plus the tree height is below the bottoms of both A and B, then this hilltop cannot affect LOS, go on to the next hill. (See Figure 16, part 4).

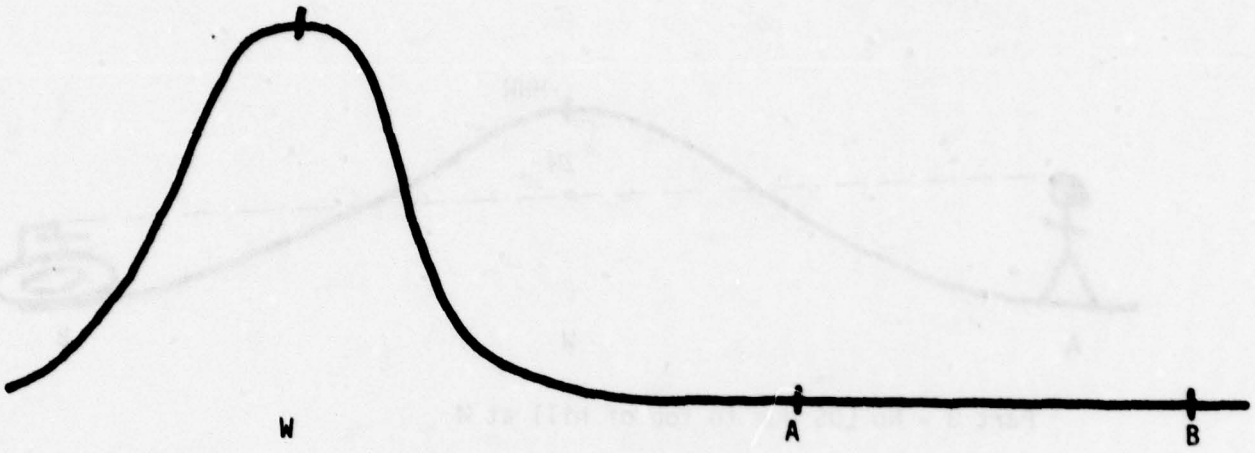
F. Lowest Sight Line

If no previous computations have reduced VISFRB to 0., then LOS probably exists, and we must compute the lowest sight line over the hill to compute the actual percent visible. It is not enough to consider the hilltop, since for cases where A is significantly above or below the hilltop, the lowest sight line will graze the hilltop away from W . (See Figure 17). We denote by V the point at which the lowest sight line is tangent to the hill. Once V is found, then the lowest sight line is extrapolated to B's position for the computation of VISFRB (as in Figure 13). Any forest coverage at V is, of course, also considered.

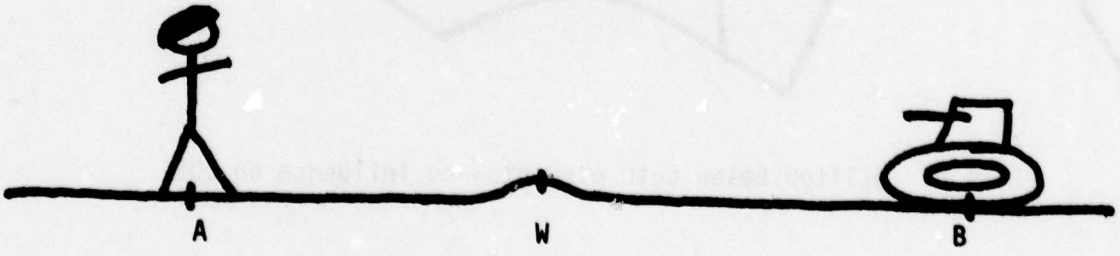
When these computations have been done for each hill, with VISFRB possibly decreased at each step, the final resulting VISFRB value is returned as the result of the LOS routine.

VI. Details of the Line of Sight Computations

In this section we derive the mathematical basis for the computations

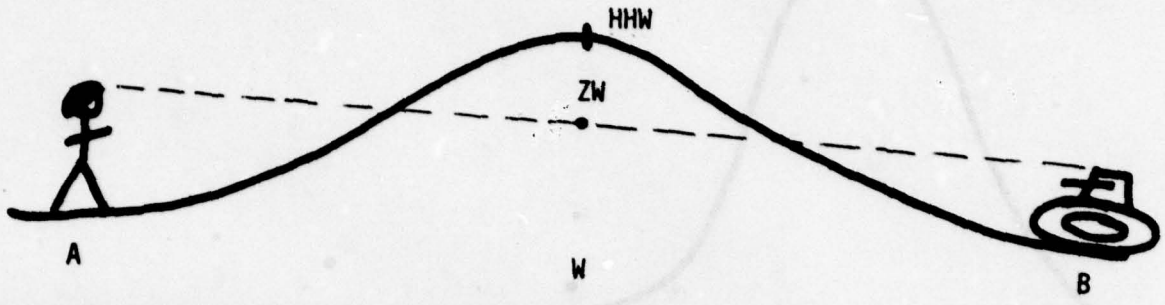


Part 1 - Hilltop is remote--no influence on LOS

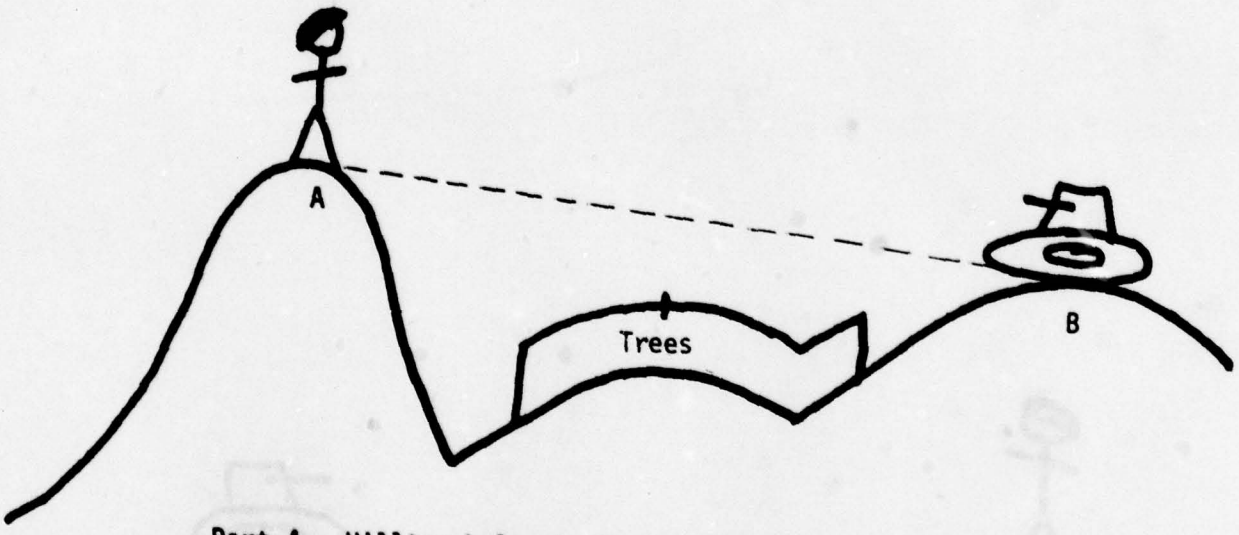


Part 2 - Hilltop is of negligible height--no influence on LOS

Figure 16. Cases to consider at W .
(1 & 2)



Part 3 - No LOS due to top of hill at W



Part 4 - Hilltop below both elements--no influence on LOS

Figure 16 (3 & 4). (continued) Cases at W

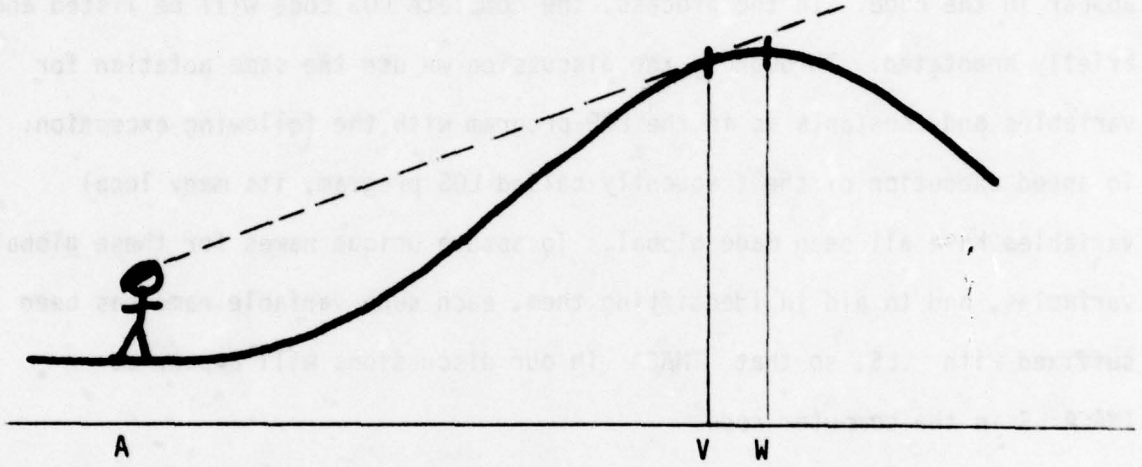


Figure 17. Lowest Sight Line Not at W

in the LOS routine and examine the SIMSCRIPT LOS code line by line. This section is the most technical of the report, and the following sections can be read without comprehending all of this material. Thorough understanding of this section is, however, required for anyone who wants to adjust or modify the STAR LOS procedure. The computations will be detailed in the same order as they were discussed in Section V, and in essentially the same order as they appear in the code. In the process, the complete LOS code will be listed and briefly annotated. Throughout the discussion we use the same notation for variables and constants as in the LOS program with the following exception: To speed execution of the frequently called LOS program, its many local variables have all been made global. To assure unique names for these global variables, and to aid in identifying them, each such variable name has been suffixed with .LS, so that TMACA in our discussions will appear as TMACA.LS in the computer code.

The mathematics of the LOS routine depends crucially on the following observation. Consider the elevation of a single hill I given by

$$\begin{aligned} Z(X,Y) &= PEAK.H(I) - HT.H(I) + HT.H(I) * \exp [Q_I(X,Y)] \\ &= C1 + C2 * \exp [Q_I(X,Y)] \end{aligned} \tag{20}$$

where Q_I is a negative definite quadratic function of X and Y in 2-space. Parameterize the straight line in X,Y space between an observer A and a target B as follows:

$$\begin{aligned} X(S) &= XA + S*(XB - XA) \\ Y(S) &= YA + S*(YB - YA) \end{aligned} \tag{21}$$

so that when S=0 we are at A's location, and when S=1 we are at B's location. Then consider the elevation of hill I as a function of S along the A to B line. The observation is that the elevation is given by a function of the same form as (20) except now with a single variable S .

$$Z(S) = C1 + C2 \exp [P(S)] \qquad (22)$$

where $P(S)$ is a negative definite quadratic function of the parameter S.

To obtain the coefficients of $P(S)$ we plug $X(S)$ and $Y(S)$ from (21) into (20). For notational simplicity let XC, YC, PXX, PYY, PXY denote the computational parameters for hill I, then we have

$$Q_I(X,Y) = Q_I(X(S),Y(S)) =$$

$$= PXX*(X(S)-XC)^2 + PYY*(Y(S)-YC)^2 + PXY*(X(S)-XC)*(Y(S)-YC)$$

$$= PXX*(XA+S*XBA-XC)^2 + PYY*(YA+S*YBA-YC)^2$$

$$+ PXY*(XA+S*XBA-XC)*(YA+S*YBA-YC)$$

(where XBA = XB - XA and YBA = YB - YA)

$$= PXX*(RX+S*XBA)^2 + PYY*(RY+S*YBA)^2$$

$$+ PXY*(RX+S*XBA)*(RY+S*YBA)$$

(where RX = XA - XC and RY = YA - YC)

$$= S^2*[PXX * XBA^2 + PYY * YBA^2 + PXY * XBA * YBA]$$

$$+ S*[2PXX * XBA * RX + 2PYY * YBA * RY$$

$$+ PXY * (XBA * RY + YBA * RX)]$$

$$+[PXX * RX^2 + PYY * RY^2 + PXY * RX * RY]$$

$$= S^2 * GQ + S * FQ + EQ$$ defining the quadratic coefficients GQ,FQ,EQ and giving the formula for $P(S)$. (23)

Given this equation, all future LOS computations can deal with the single dimensional computation along the A to B line parameterized by S.

We begin the discussion with a simple subroutine which is called from LOS in several places. Routine KOVER abstracts the LOS percent visible computation to its bare essence. Consider parameterizing an observer-to-target line in XY space with a distance parameter S so that $S=0$ represents the observer's position and $S=1$ represents the target's location. Assume: (See Figure 18)

1. The observation device has elevation ZØ.
2. The target has a macro-terrain elevation TMACT, a micro terrain offset TMICT and a size of SIZET. Thus its top is at ZT = TMACT + TMICT + SIZET.
3. At some point S between observer and target ($0 \leq S \leq 1$) there is an obstruction to line of sight whose top has elevation HTS.
4. Other previous computations have established a visible fraction of VISFIN due to other obstructions.

To determine: Does the obstruction at S reduce the percent visible?

Let $$ZS = ZØ + S*(ZT - ZS) \quad (24)$$

If HTS $\geq$ ZS, then the obstacle totally blanks LOS and the resulting percent visible is VISFOUT=0.

If HTS < ZS,

Let $$EVIST = \max (TMACT, ZØ + (HTS - ZØ)/S) \quad (25)$$

giving the elevation of the lowest point on the target which can be seen.

if EVIST $\geq$ ZT then LOS is blocked, and otherwise

$$VISFOUT = \min (VISFIN, (ZT-EVIST)/SIZET) \quad (26)$$

possibly decreasing the previously computed visible fraction VISFIN. Given the above formulas, the code for routine KOVER should be self-explanatory. All variables in the routine are local. KOVER is only called from LOS or from other routines which LOS calls. For the KOVER program see Listing 3.

We now consider the various segments of the LOS routine in Listing 4.

A. Initialize

In addition to initializing VISFRA and VISFRB, this segment of the code computes some temporary values which are used repeatedly later in the code. KTREP is a global counter which is initialized to -INF.C in RES.TERR and increases by one on each call to LOS. It is used to avoid processing a

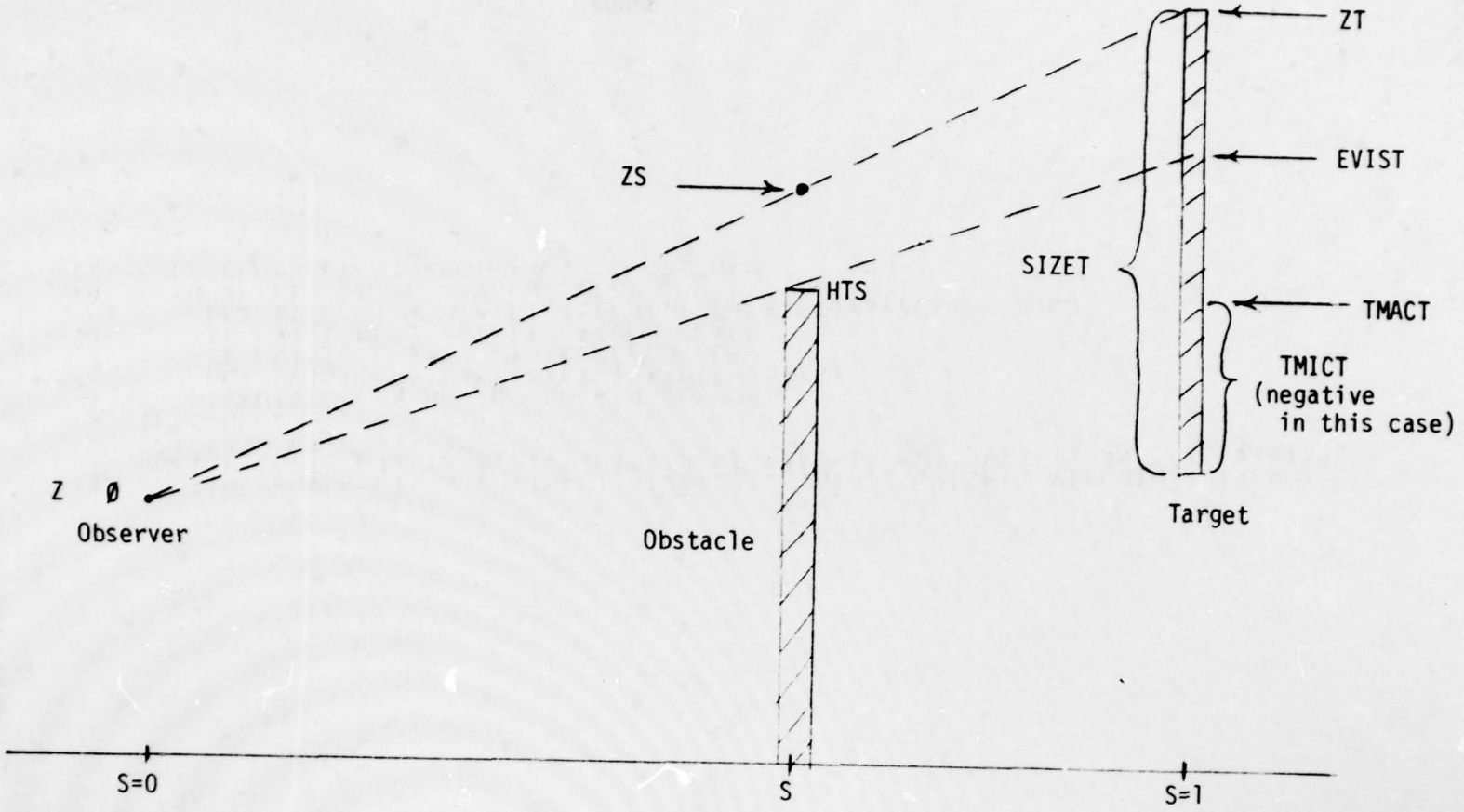


Figure 18. KOVER Geometry

```
1  ROUTINE KOVER, GIVEN A, IMACT,SIZET,ZT,S,HTS,ZS,VISEIN,VISEOUT,VIST
2  DEFINE ZOOTMSC1,SIZET,ZT,S,HTS,ZS,VISEIN,VISEOUT,VIST AS REAL VARIABLES
3  LET VISEOUT = VISEIN
4  IF S IS 0.0
5     IF HTS OR ZS OR IMACT IS UNDEFINED ELSE
6     LET VIST = MAX.F(IMACT,ZT+(HTS-ZT)/S)
7     IF VIST IS LESS THAN ZT ALSOWED ELSE
8     IF VIST IS LESS THAN ZT+SIZET RETURN ELSE
9     LET VISEOUT = MIN.F(VISEOUT,(ZT-VIST)/SIZET) RETURN
10 ELSE IF HTS IS LT ZT RETURN ELSE
11 RECORD 10. LET VISEOUT = 0.0      RETURN      END
```

KOVER

Listing 3

given hill or forest ellipse more than one time. Note in lines 9 and 10 that if the micro terrain offset is negative, then part of the target is assumed masked by the terrain, so the visible fraction starts out at less than 1.0 .

B. Grid Square List

The grid square list is developed starting at grid square IX,IY which contains point B (lines 29-34). This grid square goes on the list as IGX(1), IGY(1). ISGX, ISGY are set to $\pm$ 1 depending on whether the grid square indices IX, IY increase or decrease as we move from B to A. (Lines 20-27). XSTEP and YSTEP are initialized (in lines 35-36) to the fraction of the distances XBA and YBA we have moved as we map out the grid squares from B to A . XINC and YINC are set to the increment in XSTEP and YSTEP which is added when we move across one grid square in the X or Y directions (Lines 20-27).

The loop from lines 37 to 47 sets XSTEP and YSTEP to the next X-grid intersection and the next Y-grid intersection. The smaller of XSTEP and YSTEP signals which intersection we hit first and hence which of IX, IY gets incremented by ISGX or ISGY. After each increment a new grid square is recorded in IGX, IGY. When both XSTEP and YSTEP are greater than 1.0 we have passed A, and the loop terminates with NGRSQ grid square indices recorded in the arrays IGX, IGY.

C. Forest Ellipse List and D. LOS Test at Forest Boundaries

If there are no forest ellipses on the battlefield (NCVELS=0) then this segment is bypassed. (Line 52). Otherwise we loop over all grid squares crossed, and for each grid square loop over all forest ellipses, IC, which intersect the grid square (lines 53-58). Lines 59-60 ensure that each ellipse is accessed at most one time.

For each such ellipse, we want to know whether or not the A to B line intersects the ellipse, and if so, where. The ellipse boundary equation is stored as

$$PXX*(X-XC)^2 + PYY*(Y-YC)^2 + PXY*(X-XC)*(Y-YC) = 1 \qquad (27)$$

and X,Y on the A to B line are given parametrically as in (21). Solving (21) and (27) simultaneously for S gives the intersection points (if any) as follows:

$$\begin{aligned} &PXX*(XA-XC + S*XBA)^2 + PYY*YA-YC + X*YBA)^2 + \\ &\quad PXY*(XA-XC + S*SBA)*CYA-YC + S*YBA) = 1 \\ &PXX*(RX + S*XBA)^2 + PYY*(RY + S*YBA)^2 + \\ &\quad PXY*(RX + S*XBA)*(RY + S*YBA) = 1 \end{aligned} \qquad (28)$$

where RX = XA - XC and RY = YA - YC .

This simplifies as in (23) to the simple quadratic equation in S;

$$\begin{aligned} AA &= PXX*XBA^2 + PYY*YBA^2 + PXY*XBA*YBA \\ BB &= 2PXX*XBA*RX + 2PYY*YBA*RY + PXY*(XBA*RY + YBA*RX) \\ CC &= PXX*RX^2 + PYY*RY^2 + PXY*RX*RY - 1.0 \end{aligned} \qquad (30)$$

Applying the quadratic formula gives the intersection points,

$$S1 = \frac{-BB- \sqrt{BB^2-4.*AA*CC}}{2*AA} \qquad (31)$$

$$S2 = \frac{-BB+ \sqrt{BB^2-4.*AA*CC}}{2*AA} \qquad (32)$$

(with $S1 \leq S2$) if the radical is positive, and no intersection if the radical is negative. Lines 61-71 perform this computation.

If S1 and S2 exist then we need to consider whether the tree height at the forest boundaries S1, S2 interrupts LOS. Depending on whether one or both of S1 and S2 lie between A and B (that is between S=0 and S=1), and depending on whether A and B are air or ground platforms, it may be necessary to compute macro terrain elevation plus tree height at

either or both of S1 and S2 and see if the resulting obstacle decreases the percent visible. Subroutine TREE.CHECK does the terrain computation and LOS check (using KOVER), and will be documented following the LOS code. Lines (72-94) enumerate the possible cases which determine if TREE.CHECK is to be called at S1 and/or S2 .

Finally, for this segment, the ellipse number IC, and the S1, S2 values for any ellipse which intersects the A-to-B line are saved in arrays IEL, CS1, CS2 for later use in the LOS procedure. (Lines 95-98).

E. Hilltops

Next the macro-terrain hills lying between A and B must be checked to see if they interrupt LOS. As indicated in Section V, we loop over all NGRSQ grid squares and for each, consult the LIST.H array to get the hill numbers I to be considered. (Lines 105-111). As for the forest ellipses, if a hill has already been considered in another grid square, then it is skipped over (Lines 112-113).

The only interesting computation in this section is finding the location W and height HHW of the hilltop. In general W will not be at the hill center, since the A to B line need not pass through the center. Thus HHW is usually somewhat less than PEAK.H(I). The hilltop location is easy to compute because of equations (22) and (23) which give the hill's elevation along the A to B line as

$$Z(S) = PEAK.H(I)-HT.H(I) + HT.H(I)*\exp[GQ*S^2 + FQ*S + EQ] \quad (33)$$

The hilltop must occur where $dZ/dS = 0$, so differentiating (33) and setting the result to zero gives

$$\frac{dZ}{dS} = HT.H(I)*\exp[GQ*S^2+FQ*S+EQ]*[2GQ*S+FQ] = 0 \quad (34)$$

if and only if

$$[2GQ*S + FQ] = 0 \quad (35)$$

or

$$W = S = -FQ/(2*GQ) \qquad (36)$$

Lines 114-124 compute GQ, FQ, EQ as in (23) and W as in (36). The hill height HHW at W is obtained by substituting W back into (33) giving

$$HHW=Z(W)=PEAK.H(I) - HT.H(I) + HT.H(I)*\exp[EQ-FQ^2/(4*GQ))] \qquad (37)$$

in (lines 125-128). The tests of Figure 16 are performed in lines 129-141, and in particular, lines 133-139 loop through the previously saved forest ellipses to compute the tree height (if any) at W .

F. Lowest Sight Line

The lowest sight line procedure to compute the tangency point V , is an iterative procedure using the Newton-Raphson equation solving procedure. This is necessary because the equations describing the lowest sight line do not have a closed form solution. In the LOS code this computation is delegated to subroutine NEWTON (to be described shortly). The NEWTON procedure uses slightly different parameters depending on the direction of the computation A to B or B to A . Both calls are set up in lines 144-153 of the LOS code. The details of the NEWTON iteration will be documented along with routine NEWTON.

Finally, the LOS routine returns to the calling program either with the computed visible fractions (on line 157) after all hills have been checked in all NGRSQ grid squares, or with VISFRA = VISFRB = 0.0 if no LOS exists (line 159). This completes the detailed documentation of the LOS routine.

G. Routine TREE.CHECK

Given element A at S=0, element B at S=1, and a forest boundary at a point SS=S1 or S2 with $0 \leq SS \leq 1$, the TREE.CHECK routine tests whether the forest edge interrupts LOS from A to B or from B to A. The routine has no local variables, sharing the LS global variables with LOS.

```
ROUTINE LOS
DEFINE I,K,D,L,IC,M          AS INTEGER VARIABLES
** ALL VARIABLES EXCEPT THOSE DECLARED ABOVE ARE GLOBAL FOR USE IN LOS AND
**      ITS ASSOCIATED ROUTINES
LET VISERA.LS = 1.0          LET VISERB.LS = 1.0
LET XBA.LS = XB.LS - XA.LS       LET YBA.LS = YB.LS - YA.LS
IF XBA.LS EQ 0 AND YBA.LS EQ 0 RETURN ELSE
IF (SIZEA.LS + TMICA.LS LE 0.) OR (SIZEB.LS+TMICB.LS LE 0.) GO TO NO.LOS ELSE
IF TMICA.LS LT 0. LET VISERA.LS = 1. + TMICA.LS / SIZEA.LS  ALWAYS
IF TMICB.LS LT 0. LET VISERB.LS = 1. + TMICB.LS / SIZEB.LS   ALWAYS
LET ZA.LS = TMACA.LS + TMICA.LS + SIZEA.LS
LET ZB.LS = TMACB.LS + TMICB.LS + SIZEB.LS
LET ZBA.LS = ZB.LS - ZA.LS          ADD 1 TO KTREP
LET XBASQ.LS = XBA.LS **2    LET YBASQ.LS = YBA.LS **2
LET XYBA.LS = XBA.LS * YBA.LS
LET TWOXBA.LS = 2. * XBA.LS      LET TWOYBA.LS = 2. * YBA.LS
LET LAG.LS = LAGA.LS + LAGB.LS      LET CRTMAX.LS = 0.
**COMPUTE LIST OF GRIDSQUARES CROSSED BY A TO B LINE
LET NGRSQ.LS = 0
IF XBA.LS EQ 0. LET XBA.LS = 0.1 ALWAYS
IF XBA.LS GT 0.
    LET ISGX.LS = -1   LET XINC.LS = GSIZE/XBA.LS      JUMP AHEAD
ELSE LET ISGX.LS = 1      LET XINC.LS =-GSIZE/ XBA.LS
HERE      IF YBA.LS EQ 0. LET YBA.LS = 0.1 ALWAYS
IF YBA.LS GT 0.
    LET ISGY.LS = -1        LET YINC.LS = GSIZE/YBA.LS       JUMP AHEAD
ELSE LET ISGY.LS = 1    LET YINC.LS = -GSIZE/YBA.LS
HERE
LET IX.LS = 1 + TRUNC.F((XB.LS-X.LO.BDRY)/GSIZE)
LET IY.LS = 1 + TRUNC.F((YB.LS - Y.LO.BDRY) /GSIZE)
IF IX.LS LT 1 LET IX.LS = 1 ALWAYS
IF IY.LS LT 1 LET IY.LS = 1 ALWAYS
IF IX.LS GT NGRIDX LET IX.LS = NGRIDX ALWAYS
IF IY.LS GT NGRIDY LET IY.LS = NGRIDY ALWAYS
LET XSTEP.LS = (XB.LS-X.LO.BDRY-GSIZE*(IX.LS+0.5*(ISGX.LS-1.)))/XBA.LS
LET YSTEP.LS = (YB.LS-Y.LO.BDRY-GSIZE*(IY.LS+0.5*(ISGY.LS-1.)))/YBA.LS
*GRID.LOOP*   ADD 1 TO NGRSQ.LS
LET IGX.LS(NGRSQ.LS) = IX.LS      LET IGY.LS(NGRSQ.LS) = IY.LS
IF XSTEP.LS LT 1. OR YSTEP.LS LE 1.
    IF XSTEP.LS LT YSTEP.LS
        ADD ISGX.LS TO IX.LS      ADD XINC.LS TO XSTEP.LS
        GO TO GRID.LOOP
    ELSE
    IF XSTEP.LS GT YSTEP.LS JUMP AHEAD
    ELSE ADD ISGX.LS TO IX.LS      ADD XINC.LS TO XSTEP.LS
    HERE ADD ISGY.LS TO IY.LS      ADD YINC.LS TO YSTEP.LS
    GO TO GRID.LOOP
ALWAYS   **GRID LIST NOW COMPLETE IN IGX.LS, IGY.LS WITH NGRSQ.LS ENTRIES
```


LOS
Listing 4, Part 1

```
** NOW FILL WHILE OVER ELLIPSES INTERSECT THE A TO B LINE
** AND CHECK LOS AT S1 AND S2 FOR EACH SUCH ELLIPSE
LET NFLS.LS = 0
IF NOVELS .LE. 0 GO TO FILL.PROCESSING ELSE
FOR K = 1 TO NGRSQ.LS DO
    LET IX.LS = IGX.LS(K)      LET IY.LS = IGY.LS(K)
    LET DUM.I(*) = LIST.C(IX.LS,IY.LS,*)      LET N = DUM.I(1) + 1
    IF N .EQ 1 CYCLE ELSE
    FOR L = 2 TO N DO
        LET IC = DUM.I(L)      LET CPK.LS = HT.E(IC)
        IF KCREF(IC) .EQ KTREP CYCLE ELSE
        LET KCREF(IC) = KTREP
        LET RX.LS = XA.LS - XC.E(IC)      LET RY.LS = YA.LS - YC.E(IC)
        LET PXX.LS = PXX.E(IC)   LET PYY.LS = PYY.E(IC)   LET PXY.LS = PXY.E(IC)
        LET AA.LS = PXX.LS*XBASQ.LS + PYY.LS*YBASQ.LS  + PXY.LS*XYBA.LS
        LET BB.LS = PXX.LS*TWOXBA.LS*RX.LS + PYY.LS*TWOYBA.LS*RY.LS
            +PXY.LS*(RX.LS*YBA.LS + RY.LS*XBA.LS)
        LET CC.LS = PXX.LS*RX.LS**2 + PYY.LS*RY.LS**2 + PXY.LS*RX.LS*RY.LS -1.0
        LET ARG.LS = BB.LS**2 - 4.0*AA.LS*CC.LS
        IF ARG.LS LE 0. CYCLE ELSE

        LET SQ.LS = SQRT.F(ARG.LS)
        LET S1.LS = -(BB.LS+SQ.LS)/(2.0*AA.LS)
        LET S2.LS = (SQ.LS-BB.LS)/(2.0*AA.LS)
        IF S1.LS GE 1.0 CYCLE ELSE
        IF S2.LS LE 0.0 CYCLE ELSE
        IF LAG.LS NE 0 GO TO AIR ELSE
    **BOTH A AND B ARE GROUND PLATFORMS
        IF S1.LS LT 0. GO TO NO.LOS ELSE
        IF S2.LS GT 1. GO TO NO.LOS ELSE
    **FOREST IS BETWEEN A AND B
'GROUND' LET SS.LS = S2.LS      CALL TREE.CHECK
        LET SS.LS = S1.LS      CALL TREE.CHECK
        GO TO SAVE.ALL
'AIR'   IF S1.LS GE 0. AND S2.LS LE 1. GO TO GROUND ELSE
        IF S1.LS LT 0. AND S2.LS LE 1. GO TO A.IS.IN ELSE
        IF S1.LS GE 0. AND S2.LS GT 1. GO TO B.IS.IN ELSE
**BOTH A AND B ARE IN A OVER TREES
        IF LAG.LS .LT. 0 .OR. TMIDA.LS LT CPK.LS OR TMIDB.LS LT CPK.LS GO TO NO.LOS
        ELSE GO TO SAVE.ALL
'A.IS.IN'  **A IS IN OVER TREES, B IS NOT
        IF LAG.LS .NE. 0 OR TMIDA.LS LT CPK.LS GO TO NO.LOS ELSE
        LET SS.LS = S2.LS      CALL TREE.CHECK
        GO TO SAVE.ALL
'B.IS.IN'  **  B IS IN OVER TREES, A IS NOT
        IF LAG.LS .EQ 0 OR TMIDB.LS LT CPK.LS GO TO NO.LOS ELSE
        LET SS.LS = S1.LS      CALL TREE.CHECK
```

LOS
Listing 4, Part 2

```
 95   *SAVE.ELL* IF LATOB.LS EQ 1 AND VISFRA.LS LE 0. GO TO NO.LOS ELSE
 96             IF LATOB.LS EQ 1 AND VISFRA.LS LE 0. GO TO NO.LOS ELSE
 97             ADD 1 TO NELS.LS     LET IEL.LS(NELS.LS) = IC
 98             LET CS1.LS(NELS.LS) = S1.LS    LET CS2.LS(NELS.LS) = S2.LS
 99             IF CPK.LS GT CHTMAX.LS LET CHTMAX.LS = CPK.LS     ALWAYS
100        LOOP   **BACK FOR NEXT ELLIPSE IN THIS GRID SQUARE
101   LOOP    **BACK FOR NEXT GRID SQUARE
102   **    ALL ELLIPSES CHECKED AND SAVED
103   **   NOW START ON THE HILLS
104   *HILL.PROCESSING*
105   FOR K = 1 TO NGRSQ.LS DO
106        LET IX.LS = IGX.LS(K)     LET IY.LS = IGY.LS(K)
107        LET DUM.I(*) = LIST.H(IX.LS,IY.LS,*)
108        LET N = DIM.F(DUM.I(*))
109        LET BASE.LS = DUM.I(1)
110        FOR L = 2 TO 4 DO
111             LET I = DUM.I(L)    ** GIVING THE HILL NUMBER
112             IF KHKEP(I) EQ KTEEP CYCLE ELSE
113             LET KHKEP(I) = KTEEP
114   ** COMPUTE W = TOP OF HILL I ALONG A TO B LINE
115             LET PXX.LS = PXX.H(I)  LET PYY.LS = PYY.H(I)  LET PXY.LS = PXY.H(I)
116             LET RX.LS = XA.LS - XC.H(I)     LET RY.LS = YA.LS - YC.H(I)
117             LET GO.LS = PXX.LS*XBASQ.LS + PYY.LS*YBASQ.LS + PXY.LS*XYBA.LS
118             LET FO.LS = 2.0*(PXX.LS*RX.LS*XBA.LS + PYY.LS*RY.LS*YBA.LS) +
119                  PXY.LS*(RX.LS*YBA.LS + RY.LS*XBA.LS)
120             IF GO.LS EQ 0.0 CYCLE ELSE
121             LET W.LS = -FO.LS / (2.0*GO.LS)
122             IF ABS.F(W.LS) GT 5. CYCLE ELSE
123             LET FSQ.LS = FO.LS**2
124             LET CO.LS = PXX.LS*RX.LS**2 + PYY.LS*RY.LS**2 + PXY.LS*RX.LS*RY.LS
125             LET POW.LS = CO.LS - FSQ.LS / (4.0*GO.LS)
126             IF POW.LS LT -4.0 CYCLE ELSE
127             LET PK.LS = PEAK.H(I)     LET HT.LS = HT.H(I)
128             LET HHW.LS = PK.LS + HT.LS*(EXP.F(POW.LS)-1.)
129             IF HHW.LS LE BASE.LS CYCLE ELSE
130             LET ZW.LS = ZA.LS + W.LS*ZBA.LS
131             IF W.LS LT 0. OR W.LS GT 1. JUMP AHEAD ELSE
132             IF HHW.LS GE ZW.LS GO TO NO.LOS ELSE
133             IF NELS.LS EQ 0 JUMP AHEAD ELSE
134             LET CVHTW.LS = 0.
135             FOR M = 1 TO NELS.LS DO
136                  IF (CS1.LS(M) GE W.LS OR CS2.LS(M) LE W.LS CYCLE ELSE
137                  LET IC = IEL.LS(M)
138                  IF (VHTW.LS LT HT.F(IC) LET CVHTW.LS = HT.F(IC) ALWAYS
139             LOOP
140             IF DUM.LS + CVHTW.LS GE ZW.LS GO TO NO.LOS ELSE
141   NEXT      IF DUM.LS + CHTMAX.LS LT BIG.F(ZA.LS-SIZE4.LS,ZB.LS-SIZE4.LS) CYCLE ELSE
```


LOS
Listing 4, Part 3

```
142   ** IF WE GET TO HERE, THEN NEED TO FIND LOWEST SIGHT LINE OVER HILL
143   ** NEWTON ITERATION FROM A TO B GIVING VISFRB.LS
144              IF LATOB.LS EQ 1
145                 LET ZZ.LS = ZA.LS + HT.LS - PK.LS      LET VSUB.LS = 0.
146                 CALL NEWTON
147                 IF VISFRB.LS LE 0. GO TO NO.LOS ELSE
148              ALWAYS
149   ** NEWTON ITERATION FROM B TO A GIVING VISFRA.LS
150              IF LATOA.LS EQ 1
151                 LET ZZ.LS = ZB.LS + HT.LS - PK.LS      LET VSUB.LS =  1.
152                 CALL NEWTON
153                 IF VISFRA.LS LE 0. GO TO NO.LOS ELSE
154              ALWAYS
155           LOOP    **BACK FOR NEXT HILL
156   LOOP    **BACK FOR NEXT GRID SQUARE
157   RETURN
158   'NO.LOS' LET VISFRA.LS = 0.    LET VISFRB.LS = 0.
159   RETURN END
```


LOS

Listing 4, Part 4

The TREE.CHECK Code is given in Listing 5

Line 2 computes the X and Y coordinates of the forest boundary at SS using equation (21).

Line 3 calls ELEV to get the macro terrain elevation HTS at SS

Line 4 adds to HTS the tree height for this forest ellipse

Lines 6-12 set up the A to B and B to A calls to routine KOVER to see if percent visible is decreased by the forest obstacle.

H. Routine NEWTON

Given the equation (33) for a hill parameterized in S, and given an observer's location at S=0 with observation device at elevation ZA, we wish to compute the point S=V at which the lowest sight line is tangent to the hill (if such a point exists), (See Figure 17). The elevation of the sight line at any S is given by the equation

$$L(S) = ZA + S*SLOPE \tag{38}$$

While the hill elevation is, as before,

$$Z(S) = PEAK.H-HT.H + HT.H*\exp [\underbrace{GQ*S^2 + FQ * S + EQ}_{P(S)}] \tag{39}$$

Tangency at V requires that the elevations be equal,

$$L(V) = Z(V) \tag{40}$$

and also that the slopes be equal at V .

$$L'(V) = Z'(V) \tag{41}$$

Unfortunately this set of equations does not have any closed form solution known to this author. Instead we apply the Newton Raphson iteration to solve for V in the following fashion:

```
 1  ROUTINE TREE.CHECK
 2  LET XS.LS = XA.LS + SS.LS*XBA.LS     LET YS.LS = YA.LS + SS.LS*YBA.LS
 3  CALL ELEV GIVEN XS.LS, YS.LS YIELDING HTS.LS
 4  ADD CPK.LS TO HTS.LS
 5  LET ZS.LS = ZA.LS + SS.LS * ZBA.LS
 6  IF LATOB.LS EQ 1
 7       CALL KOVER(ZA.LS,TMACB.LS,SIZEB.LS,ZB.LS,SS.LS,HTS.LS,ZS.LS,VISBKB.LS)
 8       YIELDING VISBKB.LS
 9  ALWAYS
10  IF LBTOA.LS EQ 1
11       CALL KOVER(ZB.LS,TMACA.LS,SIZEA.LS,ZA.LS,1.0-SS.LS,HTS.LS,ZS.LS,VISBKA.LS)
12       YIELDING VISBKA.LS
13  ALWAYS    RETURN  END
```


TREE,CHECK
Listipg 5

$$Z(V) = L(V) = ZA + L'(V)*V \tag{42}$$

by (40) and since $L(S)$ is linear. Thus, using (41),

$$Z(V) = ZA + Z'(V)*V \tag{43}$$

Also, from (34)

$$Z'(V) = HT.H*\exp[P(V)]*P'(V) \tag{44}$$

Plugging (39) and (44) into (43) gives an equation for V:

$$\begin{aligned} PEAK.H - HT.H + HT.H*\exp[GQ*V^2 + FQ*V + EQ] = \\ ZA + V*HT.H*\exp[GQ*V^2 + FQ*V + EQ]*[2GQ*V+FQ] \end{aligned} \tag{45}$$

Or, collecting terms

$$\begin{aligned} FCN(V) \triangleq HT.H*\exp[GQ*V^2+FQ*V+EQ]*(2GQ*V^2+F*V-1) \\ + ZA + HT.H - PEAK.H = 0 \end{aligned} \tag{46}$$

To find the V which makes $FCN(V) = 0$, we use the iterative Newton Raphson procedure, starting with the reasonable guess $V_1 = W$ and repeatedly applying the iteration formula

$$V_{k+1} = V_k - \frac{FCN(V_k)}{DFCN(V_k)} \tag{47}$$

where DFCN is the derivative of FCN. If the iteration leads to a V value which is remote from the location of A at S=0 and B at S=1, then the iteration is abandoned, and we cycle to the next hill. If the iteration converges to a V fo which

$$Z(V) \approx ZA + Z'(V)*V \tag{48}$$

then this V is tested for its effect on LOS by calling the KOVER routine.

The actual code which follows in Listing 6 is slightly more involved than this description since it must be able to compute LOS in both directions. This is accomplished using the parameter VSUB which is 0 for an A to B call and 1 for a B to A call.

```
ROUTINE NEWTON
DEFINE M, IC AS INTEGER VARIABLES
** ALL VARIABLES ARE REAL AND GLOBAL EXCEPT M,IC AS ABOVE AND
**NCT.LS, NELS.LS, IEL.LS  WHICH ARE INTEGER GLOBAL
LET NCT.LS = 0
LET V.LS = W.LS      LET VM.LS = V.LS - VSUB.LS
LET HHV.LS = HHW.LS + HT.LS - PK.LS
LET TWOGV.LS = 2.*GQ.LS * V.LS
'TOP'  LET FCNV.LS = ZZ.LS + HHV.LS*((FQ.LS+TWOGV.LS)*VM.LS-1.)
LET DFCNV.LS = HHV.LS*VM.LS*(TWOGV.LS**2 + 2.*(GQ.LS + TWOGV.LS*FQ.LS)+FSQ.LS)
IF ABS.F(FCNV.LS) LT 0.000000001  RETURN ELSE
LET V.LS = V.LS - FCNV.LS/DFCNV.LS
IF ABS.F(V.LS) GT 5. RETURN ELSE
LET VM.LS = V.LS - VSUB.LS
LET TWOGV.LS = 2.*GQ.LS*V.LS
LET POW.LS = FQ.LS + FQ.LS*V.LS + GQ.LS*V.LS**2
IF POW.LS LT -4. RETURN ELSE
LET HHV.LS = HT.LS*EXP.F(POW.LS)
LET ELV.LS = ZZ.LS + VM.LS*(HHV.LS*(FQ.LS+TWOGV.LS))
IF ABS.F(ELV.LS - HHV.LS) GT 1.
    LET NCT.LS = NCT.LS + 1
    IF NCT.LS LT 10 GO TO TOP ELSE
ALWAYS
IF V.LS LT 0. OR V.LS GT 1. RETURN ELSE
** WE HAVE A GOOD VALUE OF V  --  CHECK IT FOR FOREST COVERAGE
LET CVHTV.LS = 0.
FOR M = 1 TO NELS.LS DO
    IF CS1.LS(M) GE V.LS OR CS2.LS(M) LE V.LS CYCLE ELSE
    LET IC = IEL.LS(M)
    IF CVHTV.LS LT HT.F(IC) LET CVHTV.LS = HT.F(IC) ALWAYS
LOOP
LET HTV.LS = HHV.LS + PK.LS + CVHTV.LS - HT.LS
LET ZV.LS = ZA.LS + V.LS*ZPA.LS
IF VSUB.LS EQ 0.
CALL KOVER(ZA.LS,TMACB.LS,SIZFB.LS,ZB.LS,V.LS,HTV.LS,ZV.LS,VISFRB.LS) YIELDING
    VISFRB.LS
ELSE
CALL KOVER(ZB.LS,TMACA.LS,SIZFA.LS,ZA.LS,-VM.LS,HTV.LS,ZV.LS,VISFRA.LS) YIELDING
    VISFRA.LS
ALWAYS RETURN END
```


NEWTON

Listing 6

I. Interface of LOS with STAR

To use the LOS routine the STAR model must set 14 parameters: (all global variables with the .LS suffix)

XA, YA, TMACA, TMICA, SIZEA, LAGA, LATOB

XB, YB, TMACB, TMICB, SIZEB, LAGB, LBTOA

and CALL LOS. On return VISFRA and VISFRB have the fraction of A visible to B and the fraction of B visible to A respectively. If a one-way call was requested (say LBTOA = 0) then one of the visible fractions (VISFRA in this case) will contain a meaningless value and should be ignored.

Since the most frequent use for LOS is between entities in the simulation, a driver routine SIGHT has been written./ (see Listing 7). Given the pointers A and B to the two entities, SIGHT sets up the 14 global variables from the appropriate entity attributes, and calls LOS. Note that this routine assumes both A and B are ground elements. The generalization to air elements is tr vial. On return, the global variable PCT.VIS is set to VISFRB scaled by the size of the target B relative to the size of the M60 tank because the detection model in STAR is based on the DYNTACS field experiments which used the M60 as a target.

VII. Terrain Preprocessors and Data Input

The efficient computation of the STAR macro-terrain and forest representations requires prior execution of the HILL.LIST and TREE.LIST programs and the routine RES.TERR which reads terrain and forest data into the simulation.

A. HILL.LIST

As indicated in Section III, the HILL.LIST program preprocesses the macro terrain hill data to improve execution efficiency. The preprocessing consists of the following steps.

```
 1  ROUTINE SIGHT(A,B)
 2  DEFINE A,B AS INTEGER VARIABLES     '' ALL OTHERS ARE GLOBAL
 3  LET XA.LS=X.CURRENT(A)                          LET XB.LS=X.CURRENT(B)
 4  LET YA.LS=Y.CURRENT(A)                          LET YB.LS=Y.CURRENT(B)
 5  LET  TMACA.LS=Z.CURRENT(A)                      LET TMACB.LS=Z.CURRENT(B)
 6  LET TMICA.LS=MICRO(A)                           LET TMICB.LS=MICRO(B)
 7  LET SIZEA.LS=TARDIM(SYS.TYPE(A),WPN.TYPE(A),4)
 8  LET SIZEB.LS=TARDIM(SYS.TYPE(B),WPN.TYPE(B),4)
 9  LET LAGA.LS=0                                   LET LAGB.LS=0
10  LET LATOB.LS=FWD.LOOK                           LET LBTOA.LS=BWD.LOOK
11  CALL LOS
12  LET PCA.VIS(1)=VISFRA.LS                        LET PCB.VIS(1)=VISFRB.LS
13  LET PCA.UNC(1)=1.0                              LET PCB.UNC(1)=1.0
14  LET PCT.VIS=VISFRB.LS*TARDIM(SYS.TYPE(B),WPN.TYPE(B),11)
15  RETURN      END
```


SIGHT

Listing 7

1. Define the battlefield and an array of grid squares covering it.
2. Scan each grid square to build a list of which hills actually contribute to the macro terrain in that square.
3. For each grid square, sort the list of hills so that the biggest are first on the list. Thus if a hill interrupts LOS we are likely to find it sooner.
4. For each hill, find the lowest point on that hill that actually contributes to the macro terrain, and thus (possibly) improve the cutoff value for the hill.
5. Output a deck of data cards with hill parameters and the LIST.H array ready to be read into STAR by routine RES.TERR.

The Code is given in Listing 8.

Input to HILL.LIST is SIMSCRIPT free format from cards. The following values are required (in order): (Lines 5-6)

NGRIDX, NGRIDY	number of grid squares in X and Y directions
GSIZE	size in meters of each grid square (eg. 1000.)
SPACING	increment in meters for scanning each grid square (eg. 50.)
X.LO.BDRY, Y.LO.BDRY	battlefield coordinates in meters of the southwest corner origin of the grid square system
NHILLS	number of hills to be used on the battlefield.

```
1   '' MAIN PROGRAM HILL.LIST FOR PREPROCESSING MACRO TERRAIN HILL DATA TO
2   ''      PRODUCE LIST.H ARRAY AND IMPROVED CUTOFFS FOR EACH HILL
3   PREAMBLE
4   NORMALLY MODE IS REAL
5   DEFINE NGRIDX,NGRIDY,NHILLS AS INTEGER VARIABLES
6   DEFINE IIX,IIY AS 1-DIMENSIONAL INTEGER ARRAYS
7   DEFINE BASE AS A 2-DIMENSIONAL INTEGER ARRAY
8   DEFINE LIST.H AS A 3-DIMENSIONAL INTEGER ARRAY
9   DEFINE TEMP, ZHILL AS 1-DIMENSIONAL INTEGER ARRAYS
10  DEFINE XC, YC, PEAK.H, HT.H, ANG.H, ECC.H, SPRD.H, CUT.H, XC.H, YC.H,
11      PXX.H, PYY.H, PXY.H, CRIT.H, MINZ.H AS 1-DIMENSIONAL REAL ARRAYS
12  END

1   MAIN
2   NORMALLY MODE IS REAL
3   LET LINES.V = 70
4   DEFINE I,J,K,L,N,LMAX,IX,IY,JX,JY,NINCS,KOUNT AS INTEGER VARIABLES
5   READ NGRIDX, NGRIDY, GSIZE, SPACING, X.LO.BDRY, Y.LO.BDRY
6   READ NHILLS
7   RESERVE BASE(*,*) AS NGRIDX BY NGRIDY
8   RESERVE LIST.H(*,*,*) AS NGRIDX BY NGRIDY BY *
9   RESERVE TEMP(*), ZHILL(*) AS 100
10  RESERVE IIX(*),IIY(*) AS 25
11  RESERVE XC(*),YC(*),XC.H(*),YC.H(*),PEAK.H(*),ANG.H(*),HT.H(*),ECC.H(*),
12      SPRD.H(*),CUT.H(*),PXX.H(*),PYY.H(*),PXY.H(*),CRIT.H(*),MINZ.H(*) AS NHILLS
13  DEFINE TITLE AS A 2-DIMENSIONAL ALPHA ARRAY
14  RESERVE TITLE(*,*) AS 3 BY NHILLS
15  FOR I = 1 TO NHILLS DO
16      START NEW CARD
17      READ TITLE(1,I),TITLE(2,I),TITLE(3,I),XC(I),YC(I),PEAK.H(I),ANG.H(I),
18      ECC.H(I),SPRD.H(I),HT.H(I) AS A 4, A 4, A 2, 7 D(10,0)
19      LET CUT.H(I)=HT.H(I)
20      LET A = LOG.E.F(HT.H(I)/(HT.H(I)-50.))    LET B = A * ECC.H(I)**2
21      LET ANG = ANG.H(I)/RADIAN.C   LET SANG = SIN.F(ANG)  LET CANG=COS.F(ANG)
22      LET PXX.H(I)=-(A*CANG**2+B*SANG**2)/(SPRD.H(I)**2)
23      LET PYY.H(I)=-(A*SANG**2+B*CANG**2)/(SPRD.H(I)**2)
24      LET PXY.H(I)=(2.*CANG*SANG*(B-A))/(SPRD.H(I)**2)
25      LET XC.H(I)=XC(I)*100.   LET YC.H(I)=YC(I)*100.
26      IF CUT.H(I) GE HT.H(I) LET CRIT.H(I)=-10.
27      ELSE LET CRIT.H(I)=LOG.E.F((HT.H(I)-CUT.H(I))/HT.H(I))
28      ALWAYS LET MINZ.H(I)=PEAK.H(I)
29  LOOP
30  FOR IX = 1 TO NGRIDX DO
31  FOR IY = 1 TO NGRIDY DO
32  IF IX LT 10 LET BASE(IX,IY)=230
33  ELSE IF IX LT 20 LET BASE(IX,IY) = 250
34  ELSE LET BASE(IX,IY)=280
35  ALWAYS ALWAYS LOOP LOOP
```

HILL.LIST

Listing 8, Part 1

```
LET NINCS = 1+INT.F(GSIZE/SPACING)
FOR IX = 1 TO NGRIDX DO
FOR IY = 1 TO NGRIDY DO
    LET KOUNT=0
    LET X=X.LO.BDRY + GSIZE*(IX-1)  LET Y=Y.LO.BDRY+GSIZE*(IY-1)
    FOR JX = 1 TO NINCS DO
    FOR JY = 1 TO NINCS DO
        LET Z = BASE(IX,IY)   CALL ELV1(X,Y,Z) YIELDING ZZ,I
        LET Z = ZZ
        IF I NE 0
            IF Z LT MINZ.H(I) LET MINZ.H(I)=Z
            ALWAYS
            IF KOUNT NE 0
                FOR N=1 TO KOUNT DO
                    IF I EQ TEMP(N) LET ZHILL(N)=ZHILL(N)+Z  GO TO NEXTY
                    ELSE
                LOOP
            ALWAYS  ADD 1 TO KOUNT
            LET TEMP(KOUNT)=I
            LET ZHILL(KOUNT)=Z
        ALWAYS 'NEXTY'   ADD SPACING TO Y
    LOOP                 ADD SPACING TO X
    LET Y = Y.LO.BDRY +GSIZE*(IY-1)
    LOOP
''NOW SORT TEMP FOR THIS GRID SQUARE
    IF KOUNT NE 0
        FOR K = 1 TO KOUNT DO
            LET ZMAX = -1000.   LET LMAX = 0
            FOR L = K TO KOUNT DO
                IF ZHILL(L) GT ZMAX
                    LET ZMAX=ZHILL(L)  LET LMAX=L
                ALWAYS
            LOOP
            LET N = TEMP(K)  LET ZT = ZHILL(K)     LET TEMP(K)=TEMP(LMAX)
            LET ZHILL(K)=ZHILL(LMAX)  LET TEMP(LMAX)=N  LET ZHILL(LMAX)=ZT
        LOOP
    ALWAYS
    RESERVE LIST.H(IX,IY,*) AS KOUNT+1
    LET LIST.H(IX,IY,1)=BASE(IX,IY)
    IF KOUNT NE 0
        FOR N = 1 TO KOUNT
        LET LIST.H(IX,IY,N+1)=TEMP(N)
ALWAYS LOOP LOOP ''ALL GRID SQUARES NOW PROCESSED  NOW OUTPUT
```

HILL.LIST

Listing 8, Part 2

```
   79  START NEW PAGE
   80  PRINT 1 LINE WITH NGRIDX,NGRIDY,GSIZE,SPACING AS FOLLOWS
NGRIDX = ****    NGRIDY = ****    GSIZE = ****.*    SPACING = ****.*
   81  PRINT 1 LINE WITH X.LO.BDRY,Y.LO.BDRY AS FOLLOWS
BOUNDARIES ARE X.LO.BDRY = ******.*    Y.LO.BDRY = ******.*
   82  PRINT 1 DOUBLE LINE AS FOLLOWS
    I  TITLE          XC      YC      PEAK   ANG   ECC    SPRD     HT      CUT       PXX             PYY
       PXY             CRIT
   83  USE UNIT 7 FOR OUTPUT
   84  PRINT 1 LINE WITH NGRIDX ,NGRIDY,GSIZE,X.LO.BDRY,Y.LO.BDRY AS FOLLOWS
*****  *****  *****.**  ******.**  ******.**
   85  PRINT 1 LINE WITH NHILLS AS FOLLOWS
******
   86  USE UNIT 6 FOR OUTPUT
   87  **UPDATE CUTOFFS
   88  FOR I = 1 TO NHILLS DO
   89      LET ZT = 10. + PEAK.H(I) - MINZ.H(I)
   90      IF ZT LT CUT.H(I) LET CUT.H(I) = ZT
   91      ALWAYS
   92      IF CUT.H(I) GE HT.H(I) LET CRIT.H(I)=-10.
   93      ELSE LET CRIT.H(I)=LOG.E.F((HT.H(I)-CUT.H(I))/HT.H(I))
   94      ALWAYS
   95      START NEW OUTPUT LINE
   96      PRINT 1 DOUBLE LINE WITH I,TITLE(1,I),TITLE(2,I),TITLE(3,I),XC(I),YC(I),
   97      PEAK.H(I),ANG.H(I),ECC.H(I),SPRD.H(I),HT.H(I),CUT.H(I),PXX.H(I),PYY.H(I),
   98      PXY.H(I),CRIT.H(I) AS FOLLOWS
**** ****|***|*** ***.* ***.* ***.* ***.* **.* *****.* ***.* ***.* ..........  ..........
..........  ..........
   99      USE UNIT 7 FOR OUTPUT
  100      WRITE I,TITLE(1,I),TITLE(2,I),TITLE(3,I),XC(I),YC(I),PEAK.H(I),ANG.H(I),
  101      ECC.H(I),SPRD.H(I),HT.H(I),CUT.H(I)
  102      AS I 4,S 1,A 4,A 4,A 2,S 1,D(7,2),S 1,D(7,2),S 1,D(7,2),S 1,D(7,2),
  103      S 1,D(7,2),S 1,D(8,2),S 1,D(7,2),S 1,D(7,2), /
  104      USE UNIT 6 FOR OUTPUT
  105  LOOP
```

HILL.LIST

Listing 8, Part 3

```
  106  START NEW PAGE
  107  FOR IX = 1 TO NGRIDX DO
  108  FOR IY = 1 TO NGRIDY DO
  109       LET KOUNT = DIM.F(LIST.H(IX,IY,*))-1
  110       START NEW OUTPUT LINE
  111       PRINT 1 LINE WITH IX,IY,KOUNT,LIST.H(IX,IY,1) AS FOLLOWS
IX = ****     IY = ****     NO.HILLS = ****     BASE = *****
  112       FOR I=2 TO KOUNT+1 WRITE LIST.H(IX,IY,I) AS      (16)I 6
  113       USE UNIT 7 FOR OUTPUT
  114       PRINT 1 LINE WITH IX,IY,KOUNT,LIST.H(IX,IY,1) AS FOLLOWS
***** ***** ***** *****
  115       FOR I = 2 TO KOUNT + 1 WRITE LIST.H(IX,IY,I) AS (16)I 5
  116       USE UNIT 6 FOR OUTPUT
  117  LOOP LOOP
  118  **NOW TALLY FOR EACH HILL
  119  START NEW PAGE
  120  FOR I = 1 TO NHILLS DO
  121       LET J = 0
  122       FOR IX = 1 TO NGRIDX DO
  123       FOR IY = 1 TO NGRIDY DO
  124            LET KOUNT = DIM.F(LIST.H(IX,IY,*))
  125            FOR L = 2 TO KOUNT+1    DO
  126                 IF LIST.H(IX,IY,L) EQ I
  127                      ADD 1 TO J     LET IIX(J) = IX    LET IIY(J)=IY
  128                 ALWAYS
  129       LOOP LOOP LOOP
  130       START NEW OUTPUT LINE
  131       PRINT 1  LINE WITH I,J AS FOLLOWS
HILL **** APPEARS IN ***** GRID SQUARES
  132       FOR L=1 TO J WRITE IIX(L) AS (25)I 5
  133       FOR L=1 TO J WRITE IIY(L) AS (25)I 5
  134  LOOP
  135  STOP
  136  END
```

```
    1  ROUTINE ELV1(X,Y,Z) YIELDING ZZ,J
    2  NORMALLY MODE IS REAL
    3  DEFINE I,J AS INTEGER VARIABLES
    4  LET J=0
    5  LET ZZ = Z
    6  FOR I = 1 TO NHILLS DO
    7       LET XS = X -XC.H(I)    LET YS = Y - YC.H(I)
    8       LET FACTOR = PXX.H(I)*XS*XS + PYY.H(I)*YS*YS + PXY.H(I)*XS*YS
    9       IF FACTOR LT CRIT.H(I) CYCLE
   10       ELSE LET ELV = PEAK.H(I)+HT.H(I)*(EXP.F(FACTOR)-1.)
   11       IF ELV GT ZZ LET ZZ = ELV      LET J = I
   12  ALWAYS LOOP RETURN END
```

HILL.LIST
Listing 8, Part 4

Next the fitting parameters for each hill are input: (line 17-18)
XC.H, YC.H, PEAK.H, ANG.H, ECC.H, SPRD.H, HT.H.
The current program does not read CUT.H since cutoffs were not used in the original battlefield coding. These could easily be added. The fitting parameters are converted to computing parameters in lines 19-27.

Finally, BASE values for each grid square are entered. The current code has these hard wired since only 3 distinct base values were used on the original battlefield. A card read could easily replace this. (Lines 30-35).

Lines 37-59 perform the battlefield scan, computing elevation every SPACING meters and recording which hill was responsible for the final elevation. This hill number is entered in a temporary array TEMP if it is not already there. (Lines 48-55). Array ZHILL records the contribution of each hill to this grid square for the upcoming sort.

Lines 60-78 sort the TEMP array and store it in the appropriate column of LIST.H. The rest of the program prints and punches the output data deck. This deck is ready for immediate input to the simulation via routine RES.TERR .

B. TREE.LIST

The TREE.LIST program in Listing 9 has exactly the same structure as the HILL.LIST program. It is presented here with essentially no further comment. The data output deck from TREE.LIST is ready to be read by RES.TERR except that the first card (battlefield definition) which duplicates the first card from HILL.LIST should be discarded.

C. RES.TERR Routine

RES.TERR is a routine called from the STAR MAIN program which initializes the following data:

```
1   ** MAIN PROGRAM TREE.LIST FOR PERPROCESSING FOREST ELLIPSE DATA
2   **     TO PRODUCE LIST.E ARRAY
3   PREAMBLE
4   NORMALLY MODE IS REAL
5   DEFINE NGRIDX, NGRIDY , NCVELS, I, J, K, L, N, LMAX, IX, IY, JX, JY,
6       NINCS, KOUNT                                    AS INTEGER VARIABLES
7   DEFINE LIST.E AS A 3-DIMENSIONAL INTEGER ARRAY
8   DEFINE TEMP, ZCV AS 1-DIMENSIONAL INTEGER ARRAYS
9   DEFINE XC,YC,HT.E,AMAJ.E,AMIN.E,ANG.E,PXX.E,PYY.E,PXY.E,XC.E,YC.E AS
10      1-DIMENSIONAL REAL ARRAYS
11  DEFINE IIX,IIY AS 1-DIMENSIONAL INTEGER ARRAYS
12  END
```

```
1   MAIN
2   NORMALLY MODE IS REAL
3   LET LINES.V = 70
4   READ NGRIDX, NGRIDY, CSIZE, SPACING, X.LO.BDRY, Y.LO.BDRY
5   READ NCVELS
6   RESERVE LIST.E(*,*,*) AS NGRIDX BY NGRIDY BY *
7   RESERVE TEMP(*), ZCV(*) AS 100
8   RESERVE IIX(*),IIY(*) AS 50
9   RESERVE XC(*),YC(*),XC.E(*),YC.E(*),HT.E(*),ANG.E(*),AMAJ.E(*),AMIN.E(*),
10      PXX.E(*),PYY.E(*),PXY.E(*) AS NCVELS
11  DEFINE TITLE AS A 2-DIMENSIONAL ALPHA ARRAY
12  RESERVE TITLE(*,*) AS 3 BY NCVELS
13  FOR I = 1 TO NCVELS DO
14      START NEW CARD
15      READ TITLE(1,I),TITLE(2,I),TITLE(3,I),XC(I),YC(I),HT.E(I),ANG.E(I),
16          AMAJ.E(I),AMIN.E(I) AS A 4, A 4, A 2, 6 D(10,0)
17      LET ANG = ANG.E(I)/RADIAN.C    LET SANG = SIN.F(ANG)  LET CANG=COS.F(ANG)
18      LET PXX.E(I)=  (CANG/AMAJ.E(I))**2+(SANG/AMIN.E(I))**2
19      LET PYY.E(I) = (SANG/AMAJ.E(I))**2 + (CANG/AMIN.E(I))**2
20      LET PXY.E(I) = 2.*SANG*CANG*(1./AMAJ.E(I)**2 - 1./AMIN.E(I)**2)
21      LET XC.E(I)=XC(I)*100.   LET YC.E(I)=YC(I)*100.
22  LOOP
```

TREE.LIST

Listing 9, Part 1

```
LET NINCS = 1+INT.F(GSIZE/SPACING)
FOR IX = 1 TO NGRIDX DO
FOR IY = 1 TO NGRIDY DO
    LET KOUNT=0
    LET X=X.LO.BDRY + GSIZE*(IX-1)  LET Y=Y.LO.BDRY+GSIZE*(IY-1)
    FOR JX = 1 TO NINCS DO
    FOR JY = 1 TO NINCS DO
        FOR I = 1 TO NCVELS DO
            LET XS = X -XC.E(I)      LET YS = Y - YC.E(I)
            LET FACTOR = PXX.E(I)*XS*XS + PYY.E(I)*YS*YS + PXY.E(I)*XS*YS
            IF FACTOR LT 1
                IF KOUNT NE 0
                    FOR N = 1 TO KOUNT DO
                        IF I EQ TEMP(N) GO TO NEXTI
                        ELSE
                    LOOP
                ALWAYS ADD 1 TO KOUNT
                LET TEMP(KOUNT) = I
            ALWAYS
'NEXTI' LOOP
        ADD SPACING TO Y
    LOOP    ADD SPACING TO X
        LET Y = Y.LO.BDRY +GSIZE*(IY-1)
    LOOP
**NOW SORT TEMP FOR THIS GRID SQUARE
    IF KOUNT NE 0
        FOR K = 1 TO KOUNT DO
            LET ZMAX = -1000.   LET LMAX = 0
            FOR L = K TO KOUNT DO
                IF HT.E(TEMP(L)) GT ZMAX
                    LET ZMAX = HT.E(TEMP(L))   LET LMAX=L
                ALWAYS
            LOOP
            LET N = TEMP(K)                    LET TEMP(K)=TEMP(LMAX)
            LET TEMP(LMAX) = N
            LOOP
    ALWAYS
    RESERVE LIST.E(IX,IY,*) AS KOUNT + 1
    LET LIST.E(IX,IY,1) = KOUNT
    IF KOUNT NE 0
        FOR N = 1 TO KOUNT
        LET LIST.E(IX,IY,N+1) = TEMP(N)
    ALWAYS
LOOP LOOP **ALL GRID SQUARES NOW PROCESSED  NOW OUTPUT
```

TREE.LIST

Listing 9, Part 2

```
   67  START NEW PAGE
   68  PRINT 1 LINE WITH NGRIDX,NGRIDY,GSIZE,SPACING AS FOLLOWS
NGRIDX = ****    NGRIDY = ****    GSIZE = ****.*    SPACING = ****.*
   69  PRINT 1 LINE WITH X.LO.BDRY,Y.LO.BDRY AS FOLLOWS
BOUNDARIES ARE X.LO.BDRY = ******.*    Y.LO.BDRY = ******.*
   70  USE UNIT 7 FOR OUTPUT
   71  PRINT 1 LINE WITH NGRIDX ,NGRIDY,GSIZE,X.LO.BDRY,Y.LO.BDRY AS FOLLOWS
*****  *****  *****.**  ******.**  ******.**
   72  PRINT 1 LINE WITH NCVELS AS FOLLOWS
******
   73  USE UNIT 6 FOR OUTPUT
   74  PRINT 1 DOUBLE LINE AS FOLLOWS
    I    TITLE        XC      YC       HT ANGLE   AMAJ    AMIN       PXX          PYY          PXY
   75  FOR I = 1 TO NCVELS DO
   76      PRINT 1 DOUBLE LINE WITH I,TITLE(1,I),TITLE(2,I),TITLE(3,I),XC(I),YC(I),
   77      HT.E(I),ANG.E(I),AMAJ.E(I),AMIN.E(I),PXX.E(I),PYY.E(I),PXY.E(I)
   78      AS FOLLOWS
**** ****|***|*** ***.* ***.* ***.* ***.* ****.* ****.* ..... ..... .....
   79      USE UNIT 7 FOR OUTPUT
   80      WRITE I,TITLE(1,I),TITLE(2,I),TITLE(3,I),XC(I),YC(I),HT.E(I),ANG.E(I),
   81      AMAJ.E(I), AMIN.E(I)
   82      AS I 4,S 1,A 4,A 4,A 2,S 1,D(7,2),S 1,D(7,2),S 1,D(7,2),S 1,D(7,2),
   83      S 1,D(7,2),S 1,D(7,2), /
   84      USE UNIT 6 FOR OUTPUT
   85  LOOP
   86  START NEW PAGE
   87  FOR IX = 1 TO NGRIDX DO
   88  FOR IY = 1 TO NGRIDY DO
   89      LET KOUNT = LIST.E(IX,IY,1)
   90      START NEW OUTPUT LINE
   91      PRINT 1 LINE WITH IX,IY,KOUNT                    AS FOLLOWS
IX = *****    IY = *****    NO.ELLIPSES = *****
   92      START NEW OUTPUT LINE
   93      FOR I=1 TO KOUNT WRITE LIST.E(IX,IY,I+1) AS    (16)I 6
   94      USE UNIT 7 FOR OUTPUT
   95      PRINT 1 LINE WITH IX,IY,KOUNT AS FOLLOWS
***** ***** *****
   96      FOR I = 1 TO KOUNT  WRITE LIST.E(IX,IY,I+1) AS (16)I 5
   97      USE UNIT 6 FOR OUTPUT
   98  LOOP LOOP
```

TREE.LIST

Listing 9, Part 3

```
  99  ** NOW TALLY FOR EACH ELLIPSE
 100  START NEW PAGE
 101  FOR I = 1 TO NCVELS DO
 102       LET J = 0
 103       FOR IX = 1 TC NGRIDX DC
 104       FOR IY = 1 TC NGRIDY DO
 105            LET KOUNT = LIST.E(IX,IY,1)
 106            FOR L = 1 TO KCUNT DC
 107                 IF LIST.E(IX,IY,L+1) EQ I
 108                      ADD 1 TO J
 109                      LET IIX(J) = IX
 110                      LET IIY(J) = IY
 111                 ALWAYS
 112       LOOP LOOP LOOP
 113       START NEW OUTPUT LINE
 114       PRINT 1 LINE WITH I,J AS FOLLOWS
COVER ELLIPSE **** APPEARS IN **** GRID SQUARES
 115       FOR L = 1 TO J WRITE IIX(L) AS (25)I 5
 116       FOR L = 1 TO J WRITE IIY(L) AS (25)I 5
 117  LOOP
 118  STOP
 119  END
```


TREE.LIST

Listing 9, Part 4

1. Battlefield definition and grid square system
2. Macro-terrain hill computing parameters
3. LIST.H array
4. Forest ellipse computing parameters
5. LIST.C array

Input to RES.TERR consists of

1. The punched output deck from HILL.LIST followed by
2. Either a single card with a 0 (zero) if there are no forest ellipses or else the punched output deck from TREE.LIST minus its first card (which duplicates the battlefield definition card from HILL.LIST)

RES.TERR is set up to dynamically reserve and dimension the various arrays so that no more core is required than is absolutely necessary. For example, if there are no forest ellipses, then no data arrays are reserved for ellipse parameters or for LIST.C. This first implementation of RES.TERR makes no attempt to pack data values, although if required some packing should be possible. The program listing appears in Listing 10.

Code:	Lines 6-12	Define the battlefield and dimension the hill arrays
	Lines 14-30	Read the hill fitting parameters and convert to computing parameters
	Lines 31-37	Reserve and read in the ragged array LIST.H
	Lines 38-39	Determine whether there are any forest ellipses
	Lines 40-42	Dimension the forest ellipse arrays
	Lines 43-54	Read the ellipse fitting parameters and convert to computing parameters
	Lines 55-61	Reserve and read in the ragged array LIST.C .

```
      1  ROUTINE RES.TERR
      2  **ROUTINE TO RESERVE AND READ IN DATA ARRAYS FOR TERRAIN HILLS, COVER
      3  **        ELLIPSES, AND BATTLEFIELD COORDINATES
      4  NORMALLY 'ONE' IS REAL
      5  DEFINE I,IX,IY,KOUNT,J,JX,JY                                  AS INTEGER VARIABLES
      6  USE UNIT 14 FOR INPUT
      7  READ NGRIDX,NGRIDY,GSIZE,X.LO.BDRY,Y.LO.BDRY,NHILLS    **ALL GLOBAL
      8  RESERVE IGX.LS(*), IGY.LS(*) AS NGRIDX + NGRIDY
      9  RESERVE IEL.LS(*), CSL.LS(*),CS2.LS(*) AS 100
     10  RESERVE LIST.H(*,*,*) AS NGRIDX BY NGRIDY BY *
     11  RESERVE XC.H(*),YC.H(*),PEAK.H(*),HT.H(*),PXX.H(*),PYY.H(*),PXY.H(*),CRIT.H(*)
     12      AS NHILLS
     13  RESERVE KHREP(*) AS NHILLS
     14  LET KTREP=-INF.0
     15  FOR I=1 TO NHILLS DO
     16      READ J
     17      IF I IS J PRINT A LINE WITH I AS FOLLOWS
XXXXX INPUT DATA SEQUENCE ERROR IN HILL DATA FOR HILL ***** XXXXX
     18      ALWAYS
     19      READ XC,YC,PEAK.H(I),ANG,ECC,SPRD,HT.H(I),CUTOFF
     20      LET A=1.0-ECC**2/(1.0+ECC*COS.F(2.0*(HT.H(I)-50.)))          LET H=A*ECC**2
     21      LET ANG=ANG/RADIAN.C          LET SANG=SIN.F(ANG)     LET CANG=COS.F(ANG)
     22      LET PXX.H(I)=-(A*SANG**2 + B*CANG**2)/(SPRD**2)
     23      LET PYY.H(I)=-(A*CANG**2 + B*SANG**2)/(SPRD**2)
     24      LET PXY.H(I)=(2.0*(CANG*SANG*(B-A))/(SPRD**2)
     25      LET XC.H(I)=XC*100.
     26      LET YC.H(I)=YC*100.
     27      LET KREP(I)=-INF.0
     28      IF CUTOFF GE HT.H(I) LET CRIT.H(I)=-5.
     29      ELSE LET CRIT.H(I)=LOG.F((HT.H(I)-CUTOFF)/HT.H(I))
     30      ALWAYS
     31  END
```

RES.TERR

Listing 10, Part 1

```
    32   FOR IX = 1 TO NGRIDX DO
    33   FOR IY = 1 TO NGRIDY DO
    34        READ JX,JY,KOUNT
    35        IF IX NE JX OR IY NE JY PRINT 1 LINE WITH IX,IY AS FOLLOWS
XXXXX INPUT DATA SEQUENCE ERROR IN LIST.H DATA FOR GRID **** **** XXXXX
    36        ALWAYS RESERVE LIST.H(IX,IY,*) AS KOUNT+1
    37        FOR I = 1 TO KOUNT+1 READ LIST.H(IX,IY,I)
    38   LOOP      LOOP
    39   READ NOVELS
    40   IF NOVELS EQ 0 USE UNIT 5 FOR INPUT  RETURN
    41   ELSE RESERVE LIST.C(*,*,*) AS NGRIDX BY NGRIDY BY *
    42   RESERVE XC.E(*),YC.E(*),HT.E(*),PXX.E(*),PYY.E(*),PXY.E(*),KOREP(*) AS NOVELS
    43   FOR I = 1 TO NOVELS DO
    44        READ J
    45        IF I NE J PRINT 1 LINE WITH I AS FOLLOWS
XXXXX INPUT DATA SEQUENCE ERROR IN COVER ELLIPSE NUMBER ***** XXXXX
    46        ALWAYS
    47        READ XC,YC,HT.E(I),ANG,AMAJ,AMIN
    48        LET ANG = ANG/RADIAN.C    LET SANG = SIN.F(ANG)    LET CANG = COS.F(ANG)
    49        LET PXX.E(I) = (CANG/AMAJ)**2 + (SANG/AMIN)**2
    50        LET PYY.E(I) = (SANG/AMAJ)**2 + (CANG/AMIN)**2
    51        LET PXY.E(I) = 2.*SANG*CANG*(1./AMAJ**2 - 1./AMIN**2)
    52        LET XC.E(I) = XC * 100.    LET YC.E(I) = YC * 100.
    53        LET KOREP(I) = -INT.C
    54   LOOP
    55   FOR IX = 1 TO NGRIDX DO
    56   FOR IY = 1 TO NGRIDY DO
    57        READ JX,JY,KOUNT
    58        IF IX NE JX OR IY NE JY PRINT 1 LINE WITH IX,IY AS FOLLOWS
XXXXX INPUT DATA SEQUENCE ERROR IN LIST.C DATA FOR GRID **** **** XXXXX
    59        ALWAYS RESERVE LIST.C(IX,IY,*) AS KOUNT+1
    60        LET LIST.C(IX,IY,1) = KOUNT
    61        FOR I = 2 TO KOUNT + 1  READ LIST.C(IX,IY,I)
    62   LOOP      LOOP
    63   USE UNIT 5 FOR INPUT
    64   RETURN END
```

RES.TERR

Listing 10, Part 2

VIII. Some Areas for Further Development

The current version of the STAR terrain and LOS models form a working core for terrain modelling in STAR.There are several areas in which work remains to be done. A preliminary list is presented here.

1. Incorporation of terrain features from the Army Mobility Model patch data for micro terrain, concealment, vehicle limiting speeds (for the movement model), etc.
2. Development of a dynamic smoke model in conjunction with detection models for the "dirty battlefield".
3. Investigation of computer assisted terrain fitting to speed the hill definition task and possibly result in better terrain fitting.
4. Replacement of the iterative Newton algorithm in LOS with a guaranteed accuracy approximation using splines or some other appropriate class of functions.

Work is currently underway on several of these areas. As they become ready for incorporation into the main STAR model, they will be documented separately.

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