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STANFORD RSL TECH REPORT #67-4

"COMPUTER REDUCTION AND ANALYSIS OF AN INFRARED IMAGE"

by

Keenan Lee
(Graduate Student)
Stanford University
Stanford, California

December 31, 1967

REMOTE SENSING LABORATORY
GEOPHYSICS DEPARTMENT

STANFORD UNIVERSITY • STANFORD, CALIFORNIA

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Already Issued

67-1 "Field Infrared Analysis of Terrain - Spectral Correlation Program" Part I

67-2 "Field Infrared Analysis of Terrain - Spectral Correlation Program" Part II and Part III

67-3 "Statistical Analysis of IR Spectra - Stanford Programs Applied to USGS Spectra in Tech Letter #13"

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I. ABSTRACT

Raw infrared scan imagery comprises three variables - two direction dimensions and film tone. Film tone, or density, may be reduced to absolute temperature by digitizing the data (manually or by machine) and submitting it to a computer. A Fortran IV program has been written for the IBM 7090 to accomplish this. Another program is included which fits a three-dimensional trend surface to the temperature data and computes thermal residuals. The trend surface maps define temperature patterns, and thermal residual maps isolate local anomalies.

As an illustration, one infrared image is followed through the reduction and analysis procedure, from film to isothermal, trend and residual maps. The total cost for one complete run was $80.

II. INTRODUCTION

With most remote sensing systems, data are generated faster than they can be reduced. Computers must be used in the reduction process.

This paper describes methods developed to reduce an infrared image to an isothermal map and to analyse temperature data by trend surface fitting. The imagery used was produced by a relatively slow, fixed-position scanner, but with appropriate modifications the same procedures should be applicable to airborne scan imagery.

Scanner

The infrared scanner used was the Barnes T-4 infrared camera. This camera is made up of an optical head (the scanning system and radiometer) and an electronics unit. The system gathers incoming radiation and reflects it from a plane mirror into the radiometer, which is the Barnes R8T 8-inch (thermistor bolometer). The plane mirror is mechanically oscillated to scan the field in horizontal sweeps. The field of view is 10° by 20°, composed of approximately 180 horizontal traverses. Radiation from the scan mirror is focused on the detector by Cassegrain optics through a filter which cuts off short wavelength radiation ($<5\mu$), with an optical resolution (instantaneous f.o.v.) of 1 milliradian. The incident radiation is periodically cut out by a chopper, which in turn reflects radiation from a known temperature blackbody onto the detector. This blackbody radiation is used as a reference to which the incident radiation is compared. Target temperature differences which exceed the system noise (Noise Equivalent Temperature Difference) are 0.04°C at a chop frequency of 1 cps and 0.3°C at 50 cps. A preamplifier feeds the electric signal from the detector to the electronics unit, which in turn activates a glow tube whose intensity is approximately linearly proportional to the absolute value of the incident thermal radiation. An attenuation circuit and a temperature offset circuit are operator-controlled to adjust the system to the range of incident radiation. The light from the glow tube is collimated by a lens and aperture into a narrow beam directed at a mirror attached to the back of the target-scanning mirror, from which it is reflected to Polaroid Positive/Negative film. As the mirror system oscillates, the variable intensity light beam thus "writes" the image in raster form. The final image comprises 60,000 bits, or individual temperature measurements, recorded in six minutes.

A step-voltage mechanism produces a stepped gray scale at the top of the photo for calibration.

Image

Fig. 1 is an infrared image of a pan of water approximately 1.2 meters in diameter. The image was recorded during a series of experiments with the Barnes imager conducted at the Stanford Remote Sensing Laboratory in 1967.

The target is a standing body of water in a circular evaporation pan. A constant point discharge of warmer water is being introduced to the water surface at the bottom of the image, as shown by the lighter tone. This image was made from a point 7 meters above the target at a look angle of 14-24°from vertical.

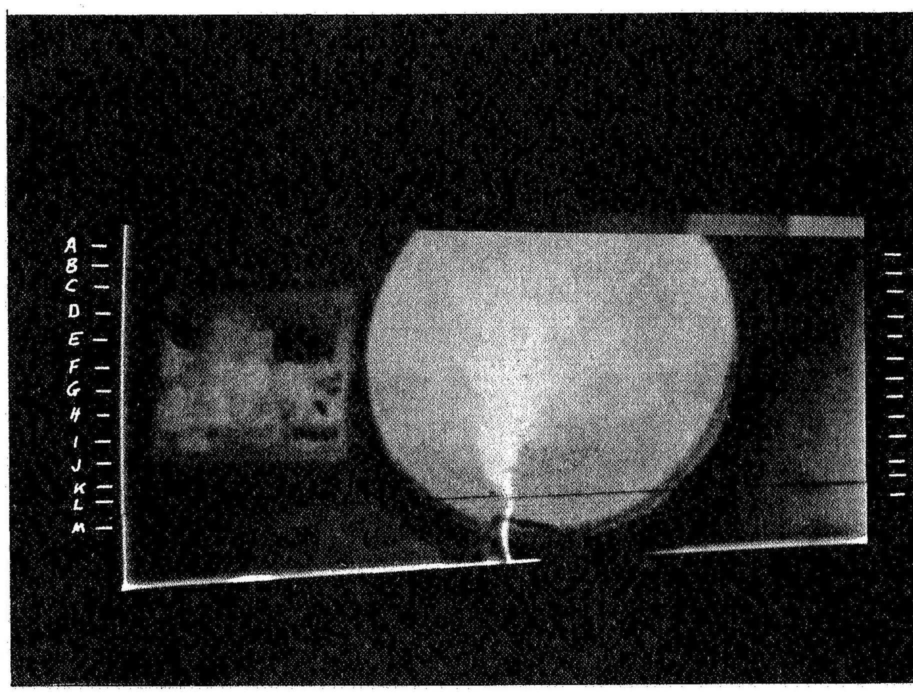


Fig. 1 Infrared image of standing body of water with point discharge of warmer water. Discharge is constant from point at lower edge of pan. Water body 1.2m diameter, $0.3m^3$. Look angles 14-24°. Fiducial marks are density profile indices. Image from Barnes camera, $5\text{-}20\mu$, 6 minute scan.

III. DIGITIZING METHODS

The raw data format of most IR scanner systems is a photo negative consisting of three variables - x,y and photo density. The first reduction process is therefore the quantification of photo density. Lacking such instruments as a dual beam scanning microdensitometer, the method used here was to measure the photo density of the negative along a series of profiles. This was done using a Jarrell-Ash Microphotometer with a strip chart recorder; an example of the output is shown in Fig. 2. Each profile represents a row of an infinite number of density values D_{x_1y}, D_{x_2y} ... D_{x_ny}. At regular or irregular increments of x, the density is determined (density scale is arbitrary, but must be identical to that used for the calibration gray scale), either manually or by use of a digitizer. The latter method was used for this program, but manual means appear more efficient unless a large number of profiles or a large number of data points for each profile is required. In this case, the optical density profiles were digitized on a Calma digitizer, which reads every 0.01 inch and records on half-inch magnetic tape on a Kennedy incremental tape recorder in BCD form. Data from each profile are recorded in a single file block with their appropriate alphameric identifier. The digital tape is then used as input with an interpolation program which determines the dependent variable (density) for any specified increment of independent variable (x). Each data point (x,y density) is punched on a card and forms the basic input for the computer program to follow.

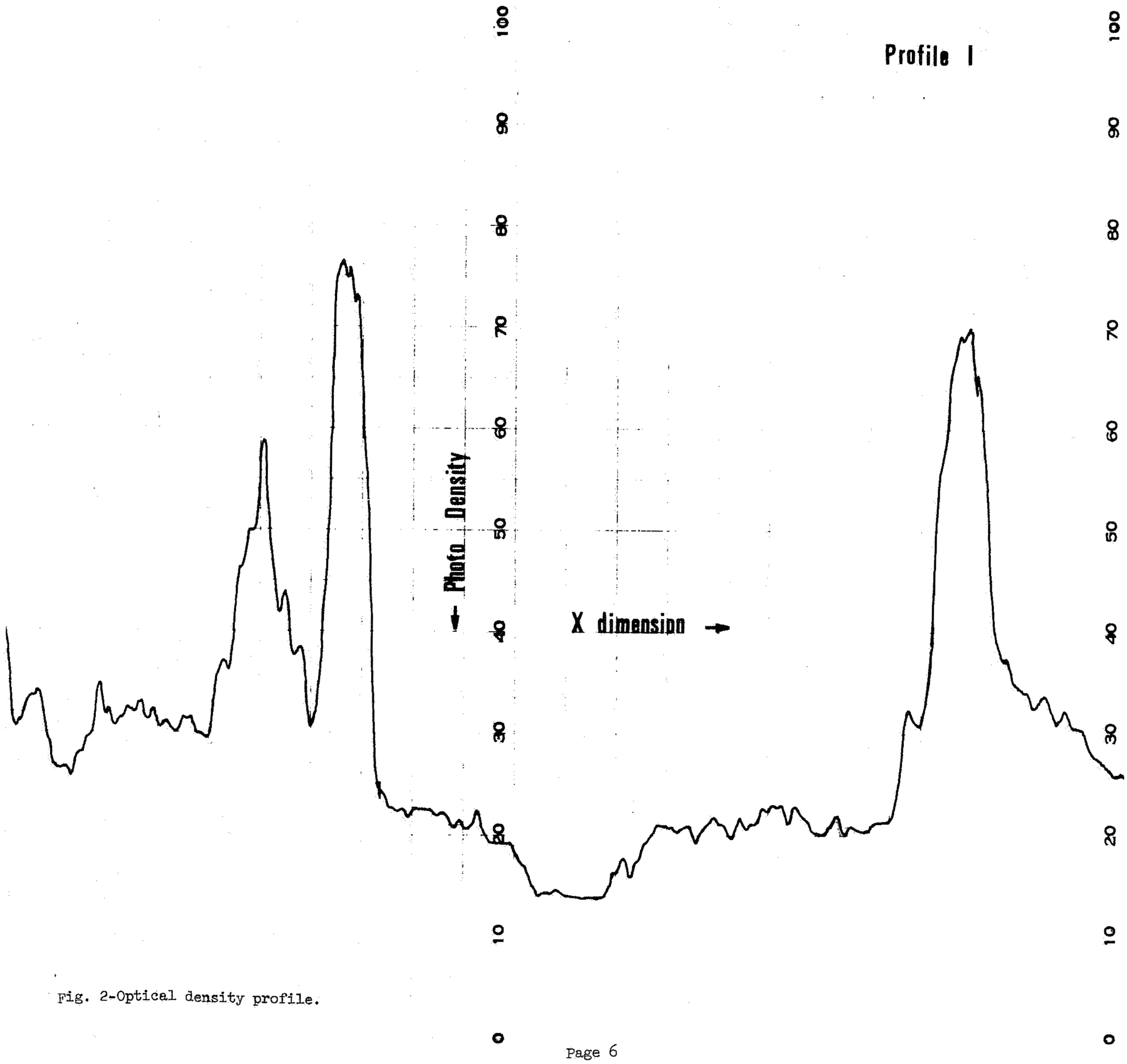


Fig. 2-Optical density profile.

IV. COMPUTER PROGRAMS

The computer programs are written in Fortran IV for the IBM 7090. A listing of each program is in the Appendix, along with an example of input and output. In these programs, the one example of infrared imagery already discussed is followed through the programs, from image density to thermal trends and residuals.

A. Photo Density Reduction Program

This program essentially converts the third input variable of each data point, density, to absolute temperature. The basic steps are:

1. For each data point, the density is assigned a gray scale value by interpolation or extrapolation of the density vs. calibration gray scale curve.
2. From the determined gray scale value, the current (to the light source) is found by interpolation/extrapolation of a gray scale vs. current curve.
3. The current value - along with the instrument constants, gain settings, etc. - determines the radiance by mathematical computation.
4. Absolute temperature is found by interpolation/extrapolation of a radiance vs. temperature curve.
5. The three variables for each data point, now x,y and temperature, are written out and/or punched on cards.

A flow chart of the program is shown in Fig. 3. Appendices A,B and C are the program listing, input and output.

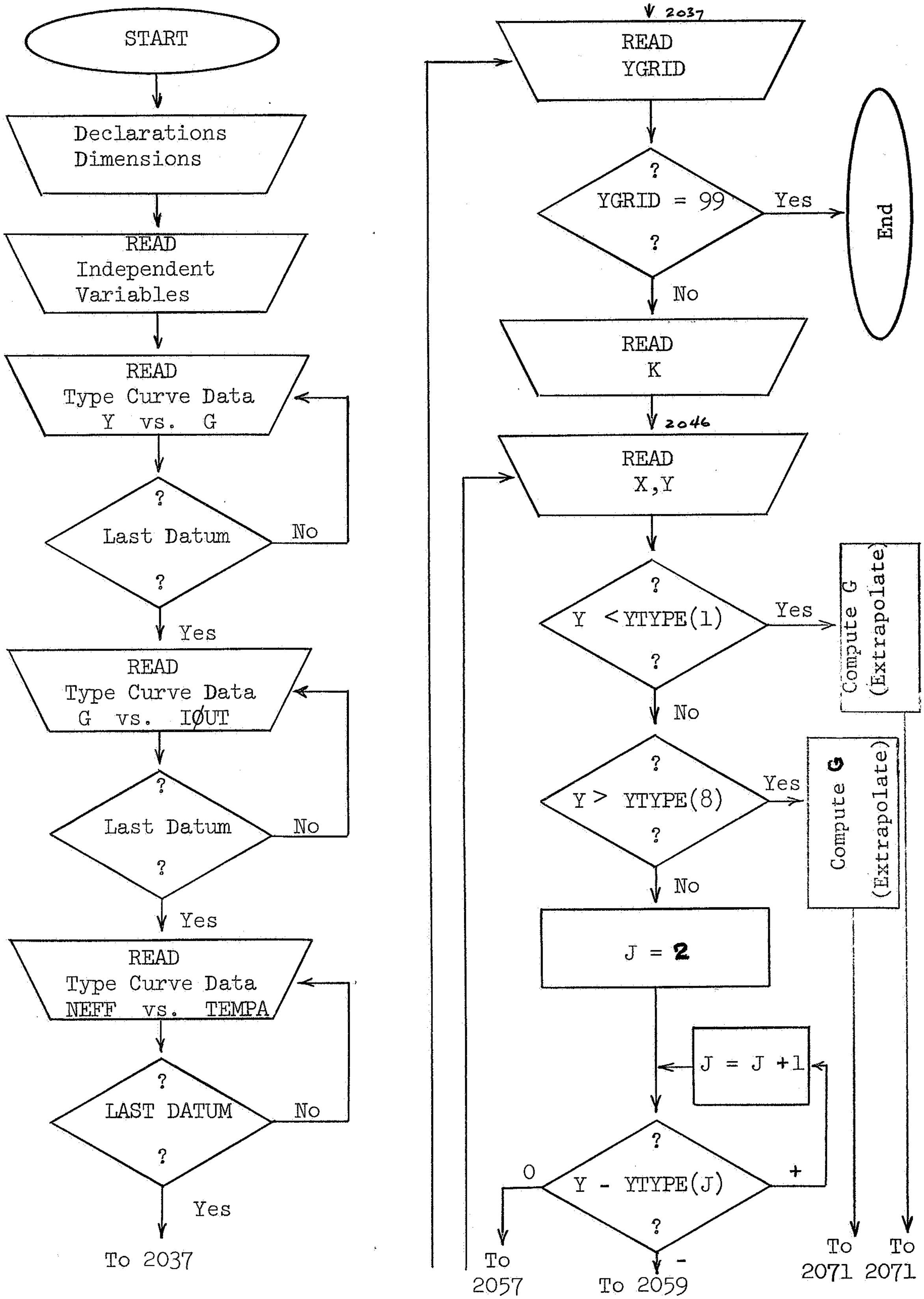


Fig. 3 Photo Density Reduction program.

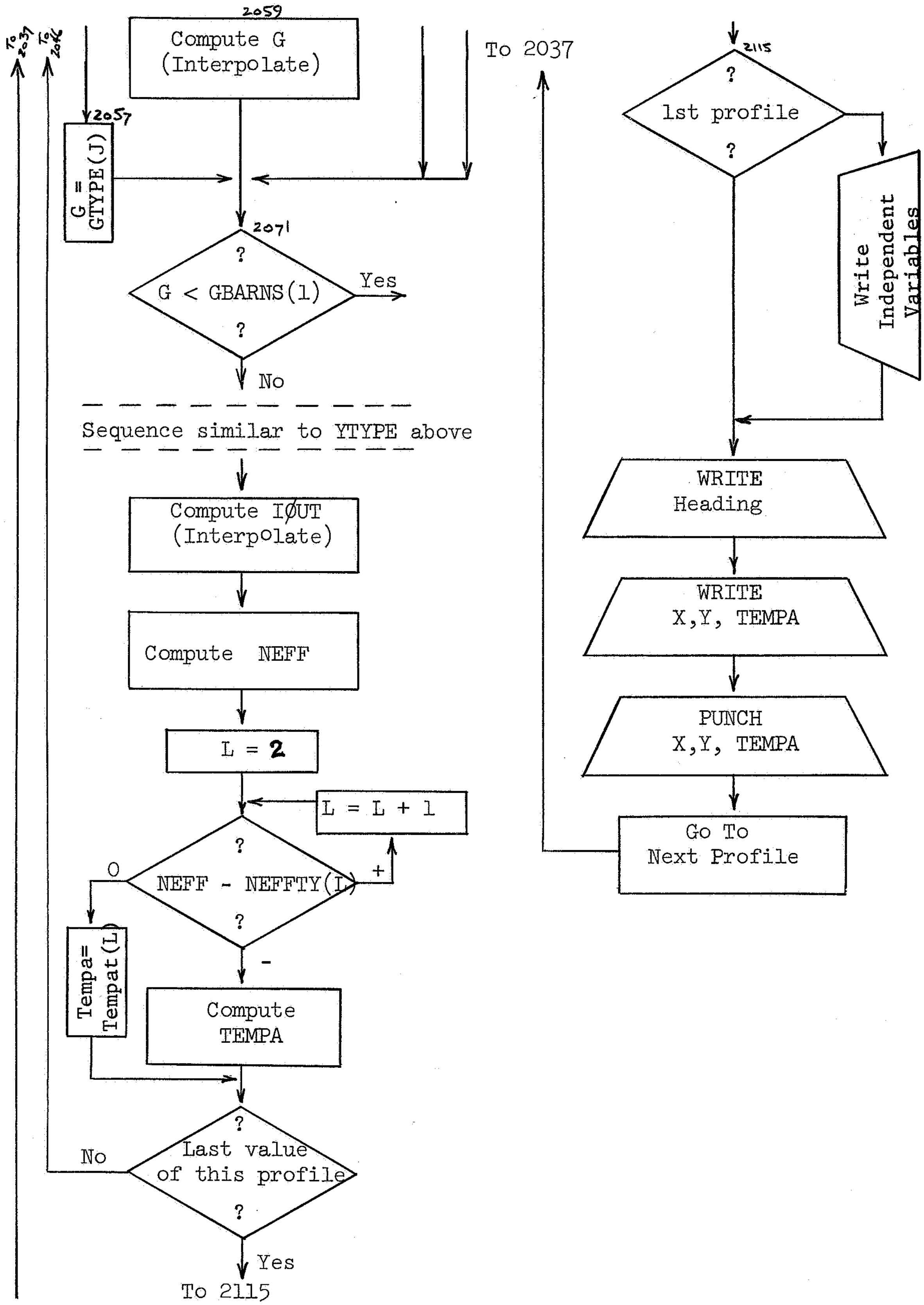

To 2037
To 2046
2059
Compute G
(Interpolate)
To 2037
2115
?
1st profile
?
2057
G =
GTYPE(J)
Write
Independent
Variables
2071
?
G < GBARNS(1)
?
Yes
No
Sequence similar to YTYPE above
WRITE
Heading
Compute IØUT
(Interpolate)
WRITE
X,Y, TEMPA
Compute NEFF
PUNCH
X,Y, TEMPA
L = 2
L = L + 1
Go To
Next Profile
?
O
NEFF - NEFFTY(L)
+
?
-
Tempa=
Tempat(L)
Compute
TEMPA
?
Last value
of this profile
?
No
Yes
To 2115

Fig. 3 (cont'd.)

B. Trend Surface/Residual Program

Once imagery has been reduced to absolute temperature, it remains to analyze and display the data. An attempt was made to analyze the data by fitting trend surfaces and determining residuals. In the application of this method to water surface temperatures, broad patterns are more clearly defined by trend surfaces and local anomalies are isolated as residuals.

The trend surface program fits a geometric surface to the observed data by satisfying the least squares criterion. The surfaces fitted by this program are planar, parabolic and hyperbolic, whose equations are:

first degree surface (planar)

$$W_{trend} = A + Bx + Cy$$

second degree surface (parabolic)

$$W_{trend} = A + Bx + Cy + Dx^2 + Exy + Fy^2$$

third degree surface (hyperbolic)

$$W_{trend} = A + Bx + Cy + Dx^2 + Exy + Fy^2 + Gx^3 + Hx^2y + Ixy^2 + Jy^3$$

To minimize the sum of the squared deviations (where deviation = $W_{observed} - W_{trend}$), the latter are expressed as functions of A,B,C...,

$$F(A,B,C\ldots) = \sum (W_{observed} - A - Bx - Cy \ \ldots)^2,$$

and the partial derivatives of F with respect to A,B,C... are set equal to zero. If the summed terms are written in matrix equation form, the coefficients may be obtained by matrix inversion and division (Sub-routine SOLVE). Fig. 4 is the matrix form for a third degree surface.

$$
\begin{bmatrix}
\Sigma N & \Sigma x & \Sigma y & \Sigma x^2 & \Sigma xy & \Sigma y^2 & \Sigma x^3 & \Sigma x^2y & \Sigma xy^2 & \Sigma y^3 \\
 & \Sigma x^2 & \Sigma xy & \Sigma x^3 & \Sigma x^2y & \Sigma xy^2 & \Sigma x^4 & \Sigma x^3y & \Sigma x^2y^2 & \Sigma xy^3 \\
 & & \Sigma y^2 & \Sigma x^2y & \Sigma xy^2 & \Sigma y^3 & \Sigma x^3y & \Sigma x^2y^2 & \Sigma xy^3 & \Sigma y^4 \\
 & & & \Sigma x^4 & \Sigma x^3y & \Sigma x^2y^2 & \Sigma x^5 & \Sigma x^4y & \Sigma x^3y^2 & \Sigma x^2y^3 \\
 & & & & \Sigma x^2y^2 & \Sigma xy^3 & \Sigma x^4y & \Sigma x^3y^2 & \Sigma x^2y^3 & \Sigma xy^4 \\
 & & & & & \Sigma y^4 & \Sigma x^3y^2 & \Sigma x^2y^3 & \Sigma xy^4 & \Sigma y^5 \\
 & & & & & & \Sigma x^6 & \Sigma x^5y & \Sigma x^4y^2 & \Sigma x^3y^3 \\
 & & & & & & & \Sigma x^4y^2 & \Sigma x^3y^3 & \Sigma x^2y^4 \\
 & & & & & & & & \Sigma x^2y^4 & \Sigma xy^5 \\
 & & & & & & & & & \Sigma y^6
\end{bmatrix}
\cdot
\begin{bmatrix} A \\ B \\ C \\ D \\ E \\ F \\ G \\ H \\ FI \\ FJ \end{bmatrix}
=
\begin{bmatrix} \Sigma z \\ \Sigma zx \\ \Sigma zy \\ \Sigma zx^2 \\ \Sigma zxy \\ \Sigma zy^2 \\ \Sigma zx^3 \\ \Sigma zx^2y \\ \Sigma zxy^2 \\ \Sigma zy^3 \end{bmatrix}
$$

Fig. 4 Matrix equation for third degree trend surface.

With the coefficients determined, the value of W_{trend} is computed for each map co-ordinate and "plotted" on the line printer.

Residual values are computed as the difference, at each data point, between the observed temperature and the trend surface temperature.

Fig. 5 is a flow chart of this program. Appendices D-G are program listings, input and output examples.

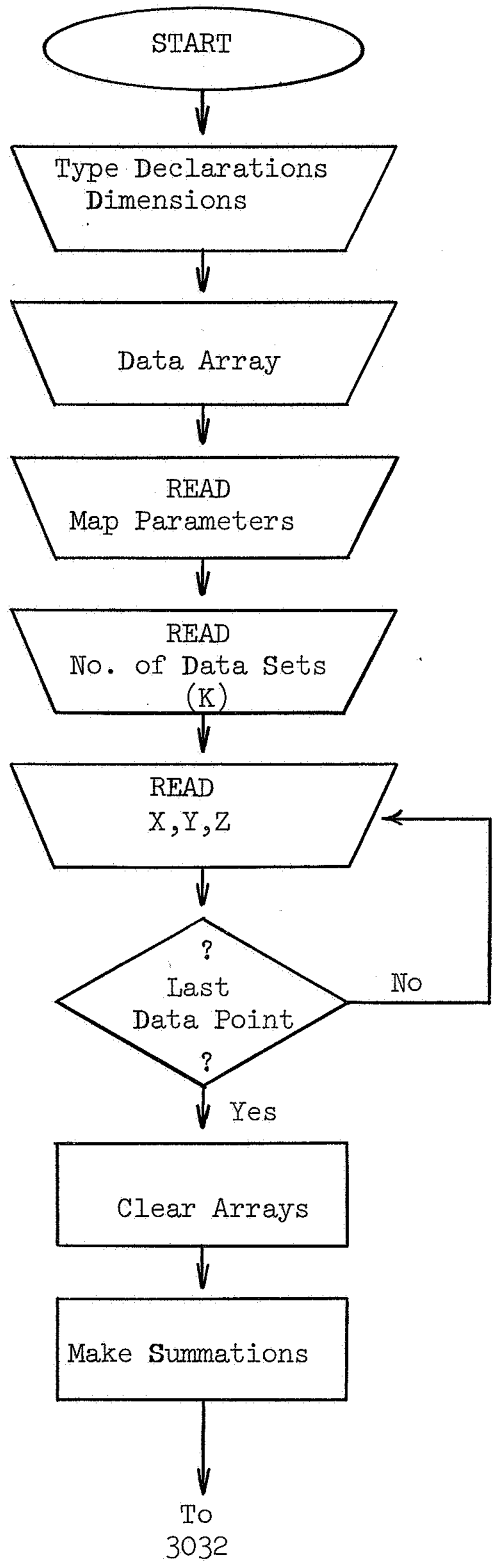


Fig. 5 Trend Surface/Residual program

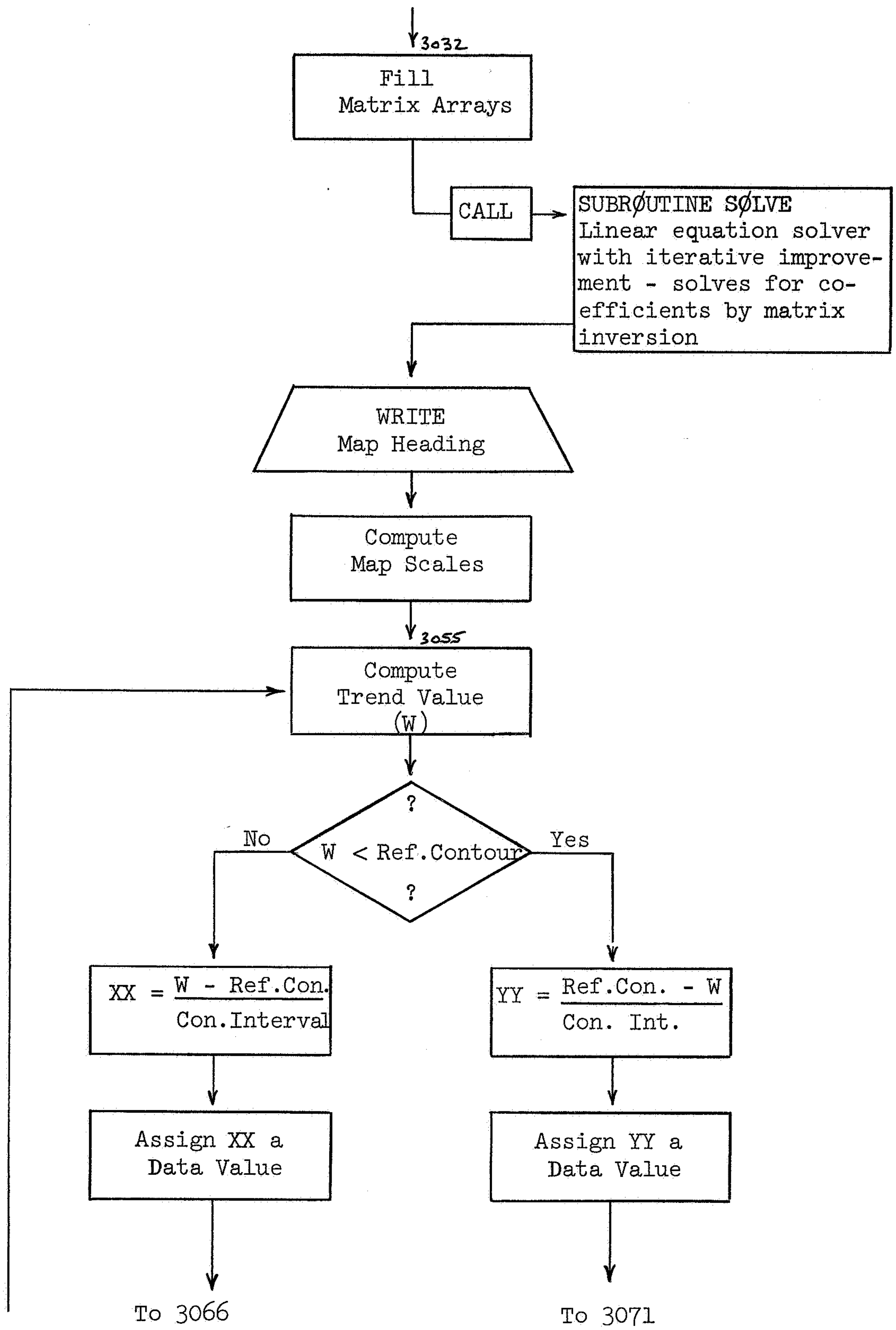

3032
Fill
Matrix Arrays
CALL
SUBRØUTINE SØLVE
Linear equation solver with iterative improvement - solves for coefficients by matrix inversion
WRITE
Map Heading
Compute
Map Scales
3055
Compute
Trend Value
(W)
?
W < Ref.Contour
?
No
Yes
XX = W - Ref.Con. / Con.Interval
YY = Ref.Con. - W / Con. Int.
Assign XX a
Data Value
Assign YY a
Data Value
To 3066
To 3071

Fig. 5 (cont'd.)

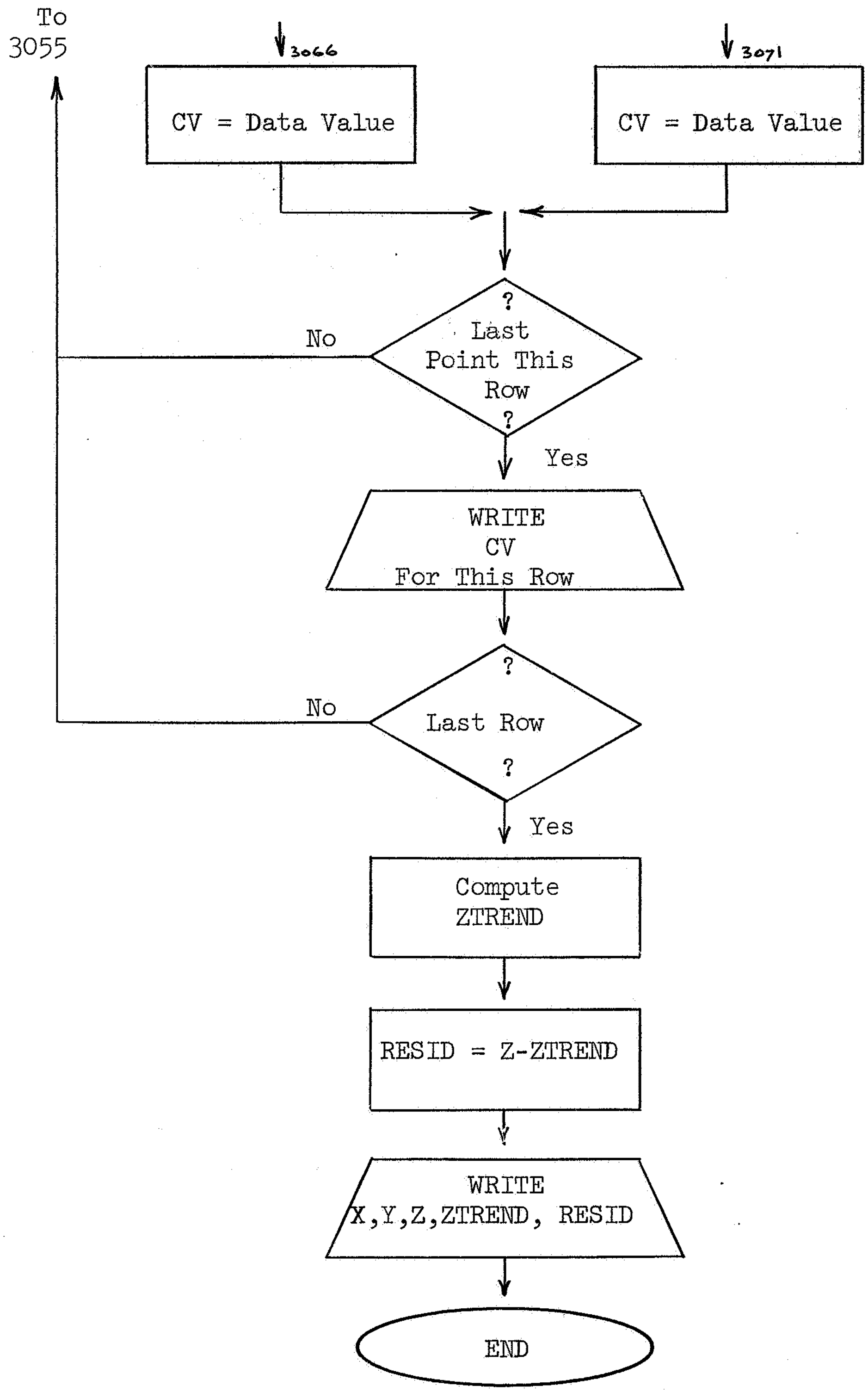

To
3055
3066
3071
CV = Data Value
CV = Data Value
No
?
Last
Point This
Row
?
Yes
WRITE
CV
For This Row
No
?
Last Row
?
Yes
Compute
ZTREND
RESID = Z-ZTREND
WRITE
X,Y,Z,ZTREND, RESID
END

Fig. 5 (Cont'd.)

V. DISPLAY

Data, whether computed temperatures or residuals, may be displayed simply by plotting the values on an x-y grid and contouring the values. This may be done manually or by computer. Hand contouring is perhaps neater, but the computer is certainly more objective. Appendix H contains examples of Calcomp contour maps of temperatures and thermal residuals. The plotting program was obtained from Dr. Graham Bonham-Carter of the Department of Geology, Stanford University.

VI. TIME/COST

Densitometer Profiles

Density profiles are time-consuming. Set-up time is about equal to the warm-up time of the microphotometer - 30 minutes. As with other methods, the time-per-unit descreases as the number of units increases. For 13 profiles, total time was 1.7 man-hours:

$$\text{Time} \doteq (0.5 + (13 \text{ profiles} \cdot 5.5 \text{ min/prof})/60) = \underline{1.7 \text{ hours}}$$

Digitizing

Density profiles in small numbers are more efficiently digitized by hand than by machine. The crossover between small and large numbers, of course, depends on the cost of computer time, wage rates and the number of points to be digitized per profile. For the case in point, where about 13 data points were used from each profile, the crossover is at about 20 profiles. The comparison is made:

Hand digitized

$$\text{Time} \doteq (13 \text{ prof} \cdot 15 \text{ min/prof})/60 = 3.25 \text{ man-hours (for digitizing)}$$

$$\text{Time} \doteq (184 \text{ data points} \cdot 0.147 \text{ min/dp})/60 = .45 \text{ m-h (for key-punch)}$$

$$\text{Total} = 3.70 \text{ m-h} \cdot \$4.50/\text{hr} = \underline{\underline{\$\ 16.60}}$$

Machine digitized

$$\text{Time} \doteq (0.4 + (13 \text{ prof} \cdot 7.2 \text{ min/prof})/60) = 2.0 \text{ m-h}$$

$$\text{Computer total use time} \doteq 3.0 \text{ min}$$

$$\text{Total} = 2.0 \text{ m-h} \cdot \$4.50/\text{hr} + 3.0 \text{ min} \cdot \$3.75/\text{min} = \underline{\underline{\$\ 20.25}}$$

Computer Programs

Following are the total computer use times for each program segment (for 184 data points). The computer used was an IBM 7090.

Photo Density Reduction	0 min	36 sec
1st Trend Surface/Residual	0	54
2nd Trend Surface/Residual	1	02
3rd Trend Surface/Residual	1	06
Plot Isotherms	3	00
Plot 1st Residuals	2	21
Plot 2nd Residuals	2	17
Plot 3rd Residuals	2	32

Normally, not all of the above segments would be used. For a complete run of all segments (without splicing), the total machine time would be 13.80 minutes, or, at \$225/hr, \$51.75.

```
C PROGRAM TO REDUCE PHOTO INTENSITY TO TARGET TEMPERATURE
C -------------------------------------------------------
C
      INTEGER YGRID
      REAL NREF,NEFF,KS,IOUTBA,NEFFTY,IOUT
      DIMENSION YTYPE(8),GTYPE(8),GBARNS(8),IOUTBA(8),NEFFTY(21),TEMPAT
     -(21),X(100),Y(100),G(100),IOUT(100),TEMPA(100),TEMPT(100),NEFF
     -(100)
C
C--------------------------
C READ INDEPENDENT VARIABLES
C--------------------------
      READ(5,50) KS,S,GAIN,TSKY,VETO,SF,EMISS,TAU,NREF,SIGMA
   50 FORMAT (5F6.1,3F6.3,F7.5,E10.4)
C
C ---------------------------
C DEFINE TYPE CURVE OF Y VS. G
C ---------------------------
      DO 1  I=1,8
    1 READ(5,51) YTYPE(I),GTYPE(I)
   51 FORMAT (2F5.1)
C
C -------------------------------
C DEFINE TYPE CURVE OF G VS. IOUT
C -------------------------------
      DO 2  I=1,8
    2 READ(5,51) GBARNS(I),IOUTBA(I)
C
C ----------------------------------
C DEFINE TYPE CURVE OF NEFF VS. TEMPA
C ----------------------------------
      DO 3 I=1,21
    3 READ(5,52) NEFFTY(I),TEMPAT(I)
   52 FORMAT(F7.5,F6.1)
      ICOUNT=1
C ------------------------------------------
C COMPUTE ALL VALUES FOR ONE PROFILE (ONE YGRID)
C ------------------------------------------
    4 READ(5,53) YGRID
   53 FORMAT (I3)
      IF (YGRID.EQ.99) GO TO 999
C     --------------------------------------
C     NUMBER OF DATA POINTS (K) IN ONE PROFILE
C     --------------------------------------
      READ(5,54) K
   54 FORMAT (I3)
      DO 1000 I=1,K
      READ(5,55) X(I),Y(I)
   55 FORMAT (I4,F5.1)
C     -------------------------------------
C     INTERPOLATE TO FIND GRAYSCALE VALUE (G)
C     -------------------------------------
      IF(Y(I).LT.YTYPE(1)) GO TO 104
```

```
      IF(Y(I).GT.YTYPE(8)) GO TO 105
      J=2
  100 IF(Y(I)-YTYPE(J)) 103,102,101
  101 J=J+1
      GO TO 100
  102 G(I) = GTYPE(J)
      GO TO 200
  103 G(I) = GTYPE(J-1) +(GTYPE(J)-GTYPE(J-1))/(YTYPE(J)-YTYPE(J-1))*(Y(
     -I)-YTYPE(J-1))
      GO TO 200
  104 G(I) = GTYPE(1)-(GTYPE(2)-GTYPE(1))/(YTYPE(2)-YTYPE(1))*(YTYPE(1)-
     -Y(I))
      GO TO 200
  105 G(I) = GTYPE(8)+(GTYPE(8)-GTYPE(7))/(YTYPE(8)-YTYPE(7))*(Y(I)-YTYP
     -E(8))
      GO TO 200
C     ----------------------------------
C     INTERPOLATE TO FIND CURRENT (IOUT)
C     ----------------------------------
  200 IF(G(I).LT.GBARNS(1)) GO TO 205
      IF(G(I).GT.GBARNS(8)) GO TO 206
      N=2
  201 IF(G(I)-GBARNS(N))204,203,202
  202 N=N+1
      GO TO 201
  203 IOUT(I)=IOUTBA(N)
      GO TO 300
  204 IOUT(I)=IOUTBA(N-1)+(IOUTBA(N)-IOUTBA(N-1))/(GBARNS(N)-GBARNS(N-1)
     -)*(G(I)-GBARNS(N-1))
      GO TO 300
  205 IOUT(I)=IOUTBA(1)-(IOUTBA(2)-IOUTBA(1))/(GBARNS(2)-GBARNS(1))*(GBA
     -RNS(1)-G(I))
      GO TO 300
  206 IOUT(I)=IOUTBA(8)+(IOUTBA(8)-IOUTBA(7))/(GBARNS(8)-GBARNS(7))*(G(I
     -)-GBARNS(8))
      GO TO 300
C     ---------------------------------
C     COMPUTE EFFECTIVE RADIANCE (NEFF)
C     ---------------------------------
  300 NEFF(I)=NREF+((S*IOUT(I))/GAIN-VETO)/(KS*SF*1000.0)
C     ----------------------------------------------
C     INTERPOLATE TO FIND APPARENT TEMPERATURE (TEMPA)
C     ----------------------------------------------
      L=2
  400 IF(NEFF(I)-NEFFTY(L)) 403,402,401
  401 L=L+1
      GO TO 400
  402 TEMPA(I)=TEMPAT(L)
      GO TO 1000
  403 TEMPA(I)=TEMPAT(L-1)+(TEMPAT(L)-TEMPAT(L-1))/(NEFFTY(L)-NEFFTY(L-1
     -))*(NEFF(I)-NEFFTY(L-1))
 1000 CONTINUE
C
C --------------------------------------
C WRITE OUT ALL VALUES FOR THIS PROFILE
```

```
C -----------------------------------------
      IF(ICOUNT,GT.1) GO TO 600
      WRITE(6,60)
   60 FORMAT(1H1)
      WRITE(6,61)
   61 FORMAT(64H    KS      S    GAIN   TSKY   VETO    SF    EMISS   TAU    NREF
     -    SIGMA)
      WRITE(6,50) KS,S,GAIN,TSKY,VETO,SF,EMISS,TAU,NREF,SIGMA
  600 WRITE(6,60)
      WRITE(6,62)
   62 FORMAT (63H          X            Y          TEMPA       GRAY        IOUT
     -  NEFF    )
      WRITE (6,63)
   63 FORMAT(57H ........................................................
     -.)
      WRITE (6,64)
   64 FORMAT(1H //)
      DO 2000 I=1,K
      F(I) = X(I)
 2000 WRITE (6,65) F(I),YGRID,TEMPA(I),G(I),IOUT(I),NEFF(I)
   65 FORMAT (3F10.1,2F10.2,F12.6)
      DO 2001  I=1,K
 2001 WRITE (6,66) F(I),YGRID,TEMPA(I),G(I),IOUT(I),NEFF(I)
   66 FORMAT (1HP,3F10.1,2F10.2,F12.6)
      ICOUNT=ICOUNT+1
C -----------------
C GO TO NEXT PROFILE
C -----------------
      GO TO 4
C
  999 RETURN
      END
```

```
117.8  44.6   3.6 296.5 160.0 1.233  .980 1.000 .00758  .5673E-11        IND VAR
21.0   1.0                                                                Y/G TYPE
30.0   2.0                                                                Y/G TYPE
40.0   3.0                                                                Y/G TYPE
51.8   4.0                                                                Y/G TYPE
68.0   5.0                                                                Y/G TYPE
81.6   6.0                                                                Y/G TYPE
90.0   7.0                                                                Y/G TYPE
95.3   8.0                                                                Y/G TYPE
 1.0  25.0                                                                G/I TYPE
 2.0  18.5                                                                G/I TYPE
 3.0  12.4                                                                G/I TYPE
 4.0   8.9                                                                G/I TYPE
 5.0   5.9                                                                G/I TYPE
 6.0   3.6                                                                G/I TYPE
 7.0   2.2                                                                G/I TYPE
 8.0   1.2                                                                G/I TYPE
.00502    0.0                                                             N/T TYPE
.00548    5.0                                                             N/T TYPE
.00598   10.0                                                             N/T TYPE
.00646   15.0                                                             N/T TYPE
.00700   20.0                                                             N/T TYPE
.00758   25.0                                                             N/T TYPE
.00820   30.0                                                             N/T TYPE
.00882   35.0                                                             N/T TYPE
.00956   40.0                                                             N/T TYPE
.01006   45.0                                                             N/T TYPE
.01110   50.0                                                             N/T TYPE
.01190   55.0                                                             N/T TYPE
.01280   60.0                                                             N/T TYPE
.01370   65.0                                                             N/T TYPE
.01470   70.0                                                             N/T TYPE
.01560   75.0                                                             N/T TYPE
.01660   80.0                                                             N/T TYPE
.01770   85.0                                                             N/T TYPE
.01880   90.0                                                             N/T TYPE
.02000   95.0                                                             N/T TYPE
.02120  100.0                                                             N/T TYPE
46                                                                           YGRID
26                                                                        K YGRID46
  0 47.0                                                            Y DATA YGRID46
  5 43.0
 11 40.6
 16 40.0
 18 30.5
 21 23.1
 26 23.4
 32 28.0
 34 37.2
 37 30.0
 40 28.9
 45 29.0
 47 29.0
 50 36.1
 53 37.2
 55 30.1
```

```
   61  31,0
   66  32.5
   68  38.7
   74  55.1
   79  60.2
   82  62.8
   84  57.3
   87  42.3
   95  35.2
   99  28.6                                                           YGRID
  76                                                              K YGRID76
  21                                                         Y DATA YGRID76
    0  42.7
    3  43.8
    5  31.1
   11  27.0
   13  41.8
   16  43.6
   21  24.5
   29  23.6
   34  39.2
   37  28.0
   42  29.6
   47  27.8
   52  39.9
   55  32.2
   63  33.0
   68  41.6
   74  64.0
   79  69.4
   84  64.1
   87  44.0
   95  38.7
   99                                                                 YGRID
```

KS	S	GAIN	TSKY	VETO	SF	EMISS	TAU	NREF	SIGMA
117.8	44.6	3.6	253.0	90.0	1.098	0.980	1.000	0.00673	0.5673E-11

X	Y	TEMPA	GRAY	IOUT	NEFF
0.	2.2	32.3	0.90	25.65	0.008491
10.0	2.2	32.3	0.90	25.65	0.008491
20.0	2.2	33.4	0.70	26.95	0.008616
30.0	2.2	33.2	0.73	26.73	0.008595
40.0	2.2	33.7	0.63	27.38	0.008657
50.0	2.2	34.0	0.57	27.82	0.008699
60.0	2.2	33.4	0.68	27.06	0.008626
70.0	2.2	34.9	0.38	29.01	0.008813
80.0	2.2	33.3	0.72	26.84	0.008605
90.0	2.2	32.8	0.82	26.19	0.008543
100.0	2.2	33.1	0.75	26.63	0.008584
110.0	2.2	32.6	0.85	25.97	0.008522
120.0	2.2	32.7	0.83	26.08	0.008533

```
C FIRST DEGREE TREND SURFACE W/ FIRST DEGREE RESIDUALS
C ------------------------------------------------------------------
C ------------------------------------------------------------------
      INTEGER PLUS, MINUS, CV
      DIMENSION W(300),CV(300),PLUS(30),MINUS(30),AA( 3, 3),BB( 3),COEF(
     = 3),X(300),Y(300),Z(300),RESID(300),ZTREND(300)
      DATA(PLUS(I),I=1,20)/1H ,1H1,1H ,1H2,1H ,1H3,1H ,1H4,1H ,1H5,1H ,1
     1H6,1H ,1H7,1H ,1H8,1H ,1H9,1H ,1H0/,(MINUS(I),I=1,20)/1H-,1H1,1H-,
     21H2,1H-,1H3,1H-,1H4,1H-,1H5,1H-,1H6,1H-,1H7,1H-,1H8,1H-,1H9,1H-,1H
     30/
      READ (5,50) HORZ,VERT,XL,XR,YT,YB,REF,CON
   50 FORMAT (8F6.1)
      READ (5,51) K
   51 FORMAT (I4)
      DO 200 I=1,K
      READ (5,8) X(I), Y(I), Z(I)
    8 FORMAT (3F10.1)
  200 CONTINUE
C ----------------------------------------------------------
C SET DEP VARIABLES = 0.0
C ----------------------------------------------------------
      X1   =0.0
      X2   =0.0
      Y1   =0.0
      Y2   =0.0
      XY   =0.0
      Z1   =0.0
      ZY   =0.0
      ZX   =0.0
C ----------------------------------------------------------
C MAKE SUMMATIONS
C ----------------------------------------------------------
      DO 100 I=1,K
      X1   = X1+X(I)
      X2   = X2+X(I)*X(I)
      Y1   = Y1+Y(I)
      Y2   = Y2+Y(I)*Y(I)
      XY    = XY+X(I)*Y(I)
      Z1   = Z1 + Z(I)
      ZX   = ZX+Z(I)*X(I)
      ZY   = ZY+Z(I)*Y(I)
  100 CONTINUE
C ----------------------------------------------------------
C FILL ARRAY
C ----------------------------------------------------------
      RK=K
      AA(1,1)=RK
      AA(1,2)=X1
      AA(1,3)=Y1
      AA(2,1)=X1
      AA(2,2)=X2
      AA(2,3)=XY
      AA(3,1)=Y1
      AA(3,2)=XY
      AA(3,3)=Y2
```

```
      BB(1)= Z1
      BB(2)= ZX
      BB(3)= ZY
C ==========================================================
C SOLVE FOR COEFFECIENTS BY MATRIX INVERSION
C ==========================================================
      CALL SOLVE (3,AA,BB,1,0.0,10,COEF,IT)
      A = COEF(1)
      B = COEF(2)
      C = COEF(3)
C ==========================================================
C WRITE MAP HEADING
C ==========================================================
      WRITE(6,996)
  996 FORMAT (1H1,52HW= A + BX + CY                        FIRST DEGREE TREN
     =D)
      WRITE(6,98)A,B,C
   98 FORMAT(1H ,8HWHERE A=, F15,8,5X,2HB=,F15.8,5X,2HC=,F15.8)
      WRITE(6,97)HORZ,VERT
   97 FORMAT(1H ,27HARRAY DIMENSIONS ARE==HORZ=, F6.0,11H  AND VERT=,F8,
     10)
      WRITE(6,96)XL,XR,YT,YB,REF,CON
   96 FORMAT(1H ,3HXL=,F10.2,10X,3HXR=,F10.2,10X,3HYT=,F10.2,10X,3HYB=,
     1F10.2,10X,4HREF=,F10.2,10X,4HCON=,F10.2//)
C ========================================================
C FIRST DEGREE TREND SURFACE
C ========================================================
      DX=(XR=XL)/HORZ
      DY=(YB=YT)/VERT
      IHORZ=HORZ
      IVERT=VERT
      DO 1 I=1,IVERT
      RI=I
      DO 2 J=1,IHORZ
      RJ=J
      W(J)=A+B*DX*RJ+C*DY*RI
      IF(W(J).LT.REF) GO TO 3
      XX=(W(J)=REF)/CON
      IX=XX
      IA=MOD(IX,20)
      CV(J)=PLUS(IA+1)
      GO TO 2
    3 YY=(REF=W(J))/CON
      IY=YY
      IB=MOD(IY,20)
      CV(J)=MINUS(IB+1)
    2 CONTINUE
      WRITE(6, 95)(CV(K),K=1,IHORZ)
   95 FORMAT(1HT,132A1)
    1 CONTINUE
C ==========================================================
C COMPUTE RESIDUAL VALUES
C ==========================================================
      DO 431 I= 1,K
      ZTREND(I)=A + B*X(I) + C*Y(I)
```

```
431 RESID(I)=Z(I)-ZTREND(I)
    WRITE (6,606)
606 FORMAT(1H1,51H          X         Y         Z      ZTREND 1ST-RESID)
    DO 432  I=1,K
432 WRITE(6,607) X(I),Y(I),Z(I),ZTREND(I),RESID(I)
607 FORMAT(1H ,5F10.1)
102 RETURN
    END
```

```
C 2ND DEGREE TREND SURFACE W/ 2ND DEGREE RESIDUALS
C ------------------------------------------------------------
C ------------------------------------------------------------
      INTEGER PLUS, MINUS, CV
      DIMENSION W(300),CV(300),PLUS(30),MINUS(30),AA( 4, 4),BB( 4),COEF(
     - 4),X(300),Y(300),Z(300),RESID(300),ZTREND(300)
      DATA(PLUS(I),I=1,20)/1H ,1H1,1H ,1H2,1H ,1H3,1H ,1H4,1H ,1H5,1H ,1
     1H6,1H ,1H7,1H ,1H8,1H ,1H9,1H ,1H0/,(MINUS(I),I=1,20)/1H-,1H1,1H-,
     21H2,1H-,1H3,1H-,1H4,1H-,1H5,1H-,1H6,1H-,1H7,1H-,1H8,1H-,1H9,1H-,1H
     30/
      READ (5,50) HORZ,VERT,XL,XR,YT,YB,REF,CON
   50 FORMAT (8F6.1)
      READ (5,51) K
   51 FORMAT (I4)
      DO 200 I=1,K
      READ (5,8) X(I), Y(I), Z(I)
    8 FORMAT (3F10.1)
  200 CONTINUE
C ------------------------------------------------------------
C SET DEP VARIABLES = 0.0
C ------------------------------------------------------------
      X4=0.0
      X3Y=0.0
      X2Y2=0.0
      X2=0.0
      XY3=0.0
      XY=0.0
      Y4=0.0
      Y2=0.0
      ZX2=0.0
      ZXY=0.0
      ZY2=0.0
      Z1=0.0
C ------------------------------------------------------------
C MAKE SUMMATIONS
C ------------------------------------------------------------
      DO 100 I=1,K
      X4   = X4+X(I)*X(I)*X(I)*X(I)
      X3Y  = X3Y+X(I)*X(I)*X(I)*Y(I)
      X2Y2= X2Y2+X(I)*X(I)*Y(I)*Y(I)
      X2   = X2+X(I)*X(I)
      XY3  = XY3+X(I)*Y(I)*Y(I)*Y(I)
      XY   = XY+X(I)*Y(I)
      Y4   = Y4+Y(I)*Y(I)*Y(I)*Y(I)
      Y2   = Y2+Y(I)*Y(I)
      ZX2  = ZX2+Z(I)*X(I)*X(I)
      ZXY  = ZXY+Z(I)*X(I)*Y(I)
      ZY2  = ZY2+Z(I)*Y(I)*Y(I)
      Z1   = Z1+Z(I)
  100 CONTINUE
C ------------------------------------------------------------
C FILL ARRAY
C ------------------------------------------------------------
      RK=K
       AA(1,1)=X4
```

```
      AA(1,2)=X3Y                                                       303302 2
      AA(1,3)=X2Y2                                                      303303 2
      AA(1,4)=X2                                                        303304 2
      AA(2,1)=X3Y                                                       303305 2
      AA(2,2)=X2Y2                                                      303306 2
      AA(2,3)=XY3                                                       303307 2
      AA(2,4)=XY                                                        303308 2
      AA(3,1)=X2Y2                                                      303309 2
      AA(3,2)=XY3                                                       303310 2
      AA(3,3)=Y4                                                        303311 2
      AA(3,4)=Y2                                                        303312 2
      AA(4,1)=X2                                                        303313 2
      AA(4,2)=XY                                                        303314 2
      AA(4,3)=Y2                                                        303315 2
      AA(4,4)=RK                                                        303316 2
      BB(1)=ZX2                                                         303317 2
      BB(2)=ZXY                                                         303318 2
      BB(3)=ZY2                                                         303319 2
      BB(4)=Z1                                                          303320 2
C ----------------------------------------------------------            3034
C SOLVE FOR COEFFECIENTS BY MATRIX INVERSION                            3035
C ----------------------------------------------------------            3036
      CALL SOLVE (4, AA,BB,1,0.0,10,COEF,IT)                            3037   2
      A=COEF(1)                                                         303801 2
      B=COEF(2)                                                         303802 2
      C=COEF(3)                                                         303803 2
      D=COEF(4)                                                         303804 2
C ----------------------------------------------------------            3039
C WRITE MAP HEADING                                                     3040
C ----------------------------------------------------------            3041
      WRITE(6,996)                                                      3042
  996 FORMAT(1H1,28H SECOND DEGREE TREND SURFACE)                       304301 2
      WRITE(6,98)A,B,C,D                                                304302 2
   98 FORMAT(     25HZ=AXX+BXY+CYY+D, WHERE A=, F15.8,5X,2HB=,F15.8,5X, 304303 2
     12HC=,F15.8, 5X, 2HD=,F15.8 )                                      304304 2
      WRITE(6,97)HORZ,VERT                                              3044
   97 FORMAT(1H ,27HARRAY DIMENSIONS ARE--HORZ=, F6.0,11H  AND VERT=,F8.3045
     10)                                                                3046
      WRITE(6,96)XL,XR,YT,YB,REF,CON                                    3047
   96 FORMAT(1H ,3HXL=,F10.2,10X,3HXR=,F10.2,10X,3HYT=,F10.2,10X,3HYB=, 3048
     1F10.2,10X,4HREF=,F10.2,10X,4HCON=,F10.2//)                        3049
C ----------------------------------------------------------            3050
C SECOND DEGREE TREND-SURFACE CONTOUR MAP
C ----------------------------------------------------------            3052
      DX=(XR-XL)/HORZ                                                   3053
      DY=(YB-YT)/VERT                                                   3054
      IHORZ=HORZ                                                        3055
      IVERT=VERT                                                        3056
      DO 1 I=1,IVERT                                                    3057
      RI=I                                                              3058
      DO 2 J=1,IHORZ                                                    3059
      RJ=J                                                              3060
      W(J)=A*DX*RJ*DX*RJ+B*DX*RJ*DY*RI+C*DY*RI*DY*RI+D
      IF(W(J).LT.REF) GO TO 3                                           3062
      XX=(W(J)-REF)/CON                                                 3063
```

```
      IX=XX
      IA=MUD(IX,20)
      CV(J)=PLUS(IA+1)
      GO TU 2
    3 YY=(REF-W(J))/CON
      IY=YY
      IB=MUD(1Y,20)
      CV(J)=MINUS(IB+1)
    2 CONTINUE
      WRITE(6, 95)(CV(K),K=1,IHORZ)
   95 FORMAT(1HT,132A1)
    1 CONTINUE
C ----------------------------------------------------------
C COMPUTE RESIDUAL VALUES
C ----------------------------------------------------------
      DO 431 I= 1,K
      ZTREND(I)=A*X(I)*X(I)+B*X(I)*Y(I)+C*Y(I)*Y(I)+D                      2
  431 RESID(I)=Z(I)-ZTREND(I)
      WRITE (6,606)
  606 FORMAT(1H1,51H        X         Y         Z       ZTREND 2ND RESID)    2
      DO 432  I=1,K
  432 WRITE(6,607) X(I),Y(I),Z(I),ZTREND(I),RESID(I)
  607 FORMAT(1H ,5F10.1)
  102 RETURN
      END
```

```
C 3RD DEGREE TREND SURFACE W/ 3RD DEGREE RESIDUALS
C ----------------------------------------------------------------
C ----------------------------------------------------------------
      INTEGER PLUS, MINUS, CV
      DIMENSION W(300),CV(300),PLUS(30),MINUS(30),AA(10,10),BB(10),COEF(
     -10),X(300),Y(300),Z(300),RESID(300),ZTREND(300)
      DATA(PLUS(I),I=1,20)/1H ,1H1,1H ,1H2,1H ,1H3,1H ,1H4,1H ,1H5,1H ,1
     1H6,1H ,1H7,1H ,1H8,1H ,1H9,1H ,1H0/,(MINUS(I),I=1,20)/1H-,1H1,1H-,
     21H2,1H-,1H3,1H-,1H4,1H-,1H5,1H-,1H6,1H-,1H7,1H-,1H8,1H-,1H9,1H-,1H
     30/
      READ (5,50) HORZ,VERT,XL,XR,YT,YB,REF,CON
   50 FORMAT (8F6.1)
      READ (5,51) K
   51 FORMAT (I4)
      DO 200 I=1,K
      READ (5,8) X(I), Y(I), Z(I)
    8 FORMAT (3F10.1)
  200 CONTINUE
C ----------------------------------------------------------
C SET DEP VARIABLES = 0.0
C ----------------------------------------------------------
      X1   =0.0
      X2   =0.0
      X3   =0.0
      X4   =0.0
      X5   =0.0
      X6   =0.0
      Y1   =0.0
      Y2   =0.0
      Y3   =0.0
      Y4   =0.0
      Y5   =0.0
      Y6   =0.0
      XY   =0.0
      X2Y  =0.0
      XY2  =0.0
      X3Y  =0.0
      X2Y2=0.0
      XY3  =0.0
      X4Y  =0.0
      X3Y2=0.0
      X2Y3=0.0
      XY4  =0.0
      X5Y  =0.0
      X4Y2=0.0
      X3Y3=0.0
      X2Y4=0.0
      XY5  =0.0
      Z1   =0.0
      ZX   =0.0
      ZY   =0.0
      ZX2  =0.0
      ZXY  =0.0
      ZY2  =0.0
      ZX3  =0.0
```

```
      ZX2Y=0.0                                                          302235 3
      ZXY2=0.0                                                          302236 3
      ZY3 =0.0                                                          302237 3
C ----------------------------------------------------------------      3023
C MAKE SUMMATIONS                                                       3024
C ----------------------------------------------------------------      3025
      DO 100 I=1,K                                                      3026
      X1   = X1+X(I)                                                    302701 3
      X2   = X2+X(I)*X(I)                                               302702 3
      X3   = X3+X(I)*X(I)*X(I)                                          302703 3
      X4   = X4+X(I)*X(I)*X(I)*X(I)                                     302704 3
      X5   = X5+X(I)*X(I)*X(I)*X(I)*X(I)                                302705 3
      X6   = X6+X(I)*X(I)*X(I)*X(I)*X(I)*X(I)                           302706 3
      Y1   = Y1+Y(I)                                                    302707 3
      Y2   = Y2+Y(I)*Y(I)                                               302708 3
      Y3   = Y3+Y(I)*Y(I)*Y(I)                                          302709 3
      Y4   = Y4+Y(I)*Y(I)*Y(I)*Y(I)                                     302710 3
      Y5   = Y5+Y(I)*Y(I)*Y(I)*Y(I)*Y(I)                                302711 3
      Y6   = Y6+Y(I)*Y(I)*Y(I)*Y(I)*Y(I)*Y(I)                           302712 3
      XY   = XY+X(I)*Y(I)                                               302713 3
      X2Y  = X2Y+X(I)*X(I)*Y(I)                                         302714 3
      XY2  = XY2+X(I)*Y(I)*Y(I)                                         302715 3
      X3Y  = X3Y+X(I)*X(I)*X(I)*Y(I)                                    302716 3
      X2Y2= X2Y2+X(I)*X(I)*Y(I)*Y(I)                                    302717 3
      XY3  = XY3+X(I)*Y(I)*Y(I)*Y(I)                                    302718 3
      X4Y  = X4Y+X(I)*X(I)*X(I)*X(I)*Y(I)                               302719 3
      X3Y2= X3Y2+X(I)*X(I)*X(I)*Y(I)*Y(I)                               302720 3
      X2Y3= X2Y3+X(I)*X(I)*Y(I)*Y(I)*Y(I)                               302721 3
      XY4  = XY4+X(I)*Y(I)*Y(I)*Y(I)*Y(I)                               302722 3
      X5Y  = X5Y+X(I)*X(I)*X(I)*X(I)*X(I)*Y(I)                          302723 3
      X4Y2= X4Y2+X(I)*X(I)*X(I)*X(I)*Y(I)*Y(I)                          302724 3
      X3Y3= X3Y3+X(I)*X(I)*X(I)*Y(I)*Y(I)*Y(I)                          302725 3
      X2Y4= X2Y4+X(I)*X(I)*Y(I)*Y(I)*Y(I)*Y(I)                          302726 3
      XY5  = XY5+X(I)*Y(I)*Y(I)*Y(I)*Y(I)*Y(I)                          302727 3
      Z1   = Z1+Z(I)                                                    302728 3
      ZX   = ZX+Z(I)*X(I)                                               302729 3
      ZY   = ZY+Z(I)*Y(I)                                               302730 3
      ZX2  = ZX2+Z(I)*X(I)*X(I)                                         302731 3
      ZXY  = ZXY+Z(I)*X(I)*Y(I)                                         302732 3
      ZY2  = ZY2+Z(I)*Y(I)*Y(I)                                         302733 3
      ZX3  = ZX3+Z(I)*X(I)*X(I)*X(I)                                    302734 3
      ZX2Y= ZX2Y+Z(I)*X(I)*X(I)*Y(I)                                    302735 3
      ZXY2= ZXY2+Z(I)*X(I)*Y(I)*Y(I)                                    302736 3
      ZY3  = ZY3+Z(I)*Y(I)*Y(I)*Y(I)                                    302737 3
  100 CONTINUE                                                          3028
C ----------------------------------------------------------------      3029
C FILL ARRAY                                                            3030
C ----------------------------------------------------------------      3031
      RK=K                                                              3032
      AA(1,1)=RK                                                        303301 3
      AA(1,2)=X1                                                        303302 3
      AA(1,3)=Y1                                                        303303 3
      AA(1,4)=X2                                                        303304 3
      AA(1,5)=XY                                                        303305 3
      AA(1,6)=Y2                                                        303306 3
```

```
AA(1,7)=X3
AA(1,8)=X2Y
AA(1,9)=XY2
AA(1,10)=Y3
AA(2,1)=X1
AA(2,2)=X2
AA(2,3)=XY
AA(2,4)=X3
AA(2,5)=X2Y
AA(2,6)=XY2
AA(2,7)=X4
AA(2,8)=X3Y
AA(2,9)=X2Y2
AA(2,10)=XY3
AA(3,1)=Y1
AA(3,2)=XY
AA(3,3)=Y2
AA(3,4)=X2Y
AA(3,5)=XY2
AA(3,6)=Y3
AA(3,7)=X3Y
AA(3,8)=X2Y2
AA(3,9)=XY3
AA(3,10)=Y4
AA(4,1)=X2
AA(4,2)=X3
AA(4,3)=X2Y
AA(4,4)=X4
AA(4,5)=X3Y
AA(4,6)=X2Y2
AA(4,7)=X5
AA(4,8)=X4Y
AA(4,9)=X3Y2
AA(4,10)=X2Y3
AA(5,1)=XY
AA(5,2)=X2Y
AA(5,3)=XY2
AA(5,4)=X3Y
AA(5,5)=X2Y2
AA(5,6)=XY3
AA(5,7)=X4Y
AA(5,8)=X3Y2
AA(5,9)=X2Y3
AA(5,10)=XY4
AA(6,1)= Y2
AA(6,2)= XY2
AA(6,3)= Y3
AA(6,4)= X2Y2
AA(6,5)= XY3
AA(6,6)= Y4
AA(6,7)= X3Y2
AA(6,8)= X2Y3
AA(6,9)= XY4
AA(6,10)=Y5
AA(7,1)= X3
```

```
      AA(7,2)= X4                                                       303362 3
      AA(7,3)= X3Y                                                      303363 3
      AA(7,4)= X5                                                       303364 3
      AA(7,5)= X4Y                                                      303365 3
      AA(7,6)= X3Y2                                                     303366 3
      AA(7,7)= X6                                                       303367 3
      AA(7,8)= X5Y                                                      303368 3
      AA(7,9)= X4Y2                                                     303369 3
      AA(7,10)=X3Y3                                                     303370 3
      AA(8,1)= X2Y                                                      303371 3
      AA(8,2)= X3Y                                                      303372 3
      AA(8,3)= X2Y2                                                     303373 3
      AA(8,4)= X4Y                                                      303374 3
      AA(8,5)= X3Y2                                                     303375 3
      AA(8,6)= X2Y3                                                     303376 3
      AA(8,7)= X5Y                                                      303377 3
      AA(8,8)= X4Y2                                                     303378 3
      AA(8,9)= X3Y3                                                     303379 3
      AA(8,10)=X2Y4                                                     303380 3
      AA(9,1)= XY2                                                      303381 3
      AA(9,2)= X2Y2                                                     303382 3
      AA(9,3)= XY3                                                      303383 3
      AA(9,4)= X3Y2                                                     303384 3
      AA(9,5)= X2Y3                                                     303385 3
      AA(9,6)= XY4                                                      303386 3
      AA(9,7)= X4Y2                                                     303387 3
      AA(9,8)= X3Y3                                                     303388 3
      AA(9,9)= X2Y4                                                     303389 3
      AA(9,10)=XY5                                                      303390 3
      AA(10,1)= Y3                                                      303391 3
      AA(10,2)= XY3                                                     303392 3
      AA(10,3)= Y4                                                      303393 3
      AA(10,4)= X2Y3                                                    303394 3
      AA(10,5)= XY4                                                     303395 3
      AA(10,6)= Y5                                                      303396 3
      AA(10,7)= X3Y3                                                    303397 3
      AA(10,8)= X2Y4                                                    303398 3
      AA(10,9)= XY5                                                     303399 3
      AA(10,10)=Y6                                                      30331003
      BB(1)= Z1                                                         30331013
      BB(2)= ZX                                                         30331023
      BB(3)= ZY                                                         30331033
      BB(4)= ZX2                                                        30331043
      BB(5)= ZXY                                                        30331053
      BB(6)= ZY2                                                        30331063
      BBO U3 003                                                        30331073
      BB(8)= ZX2Y                                                       30331083
      BB(9)= ZXY2                                                       30331093
      BB(10)=ZY3                                                        30331103
C ----------------------------------------------------------------     3034
C SOLVE FOR COEFFECIENTS BY MATRIX INVERSION                            3035
C ----------------------------------------------------------------     3036
      CALL SOLVE (10,AA,BB,1,0,0,10,COEF,IT)                            3037   3
      A = COEF(1)                                                       303801 3
      B = COEF(2)                                                       303802 3
```

```
      C  =  COEF(3)
      D  =  COEF(4)
      E  =  COEF(5)
      F  =  COEF(6)
      G  =  COEF(7)
      H  =  COEF(8)
      FI=  COEF(9)
      FJ=  COEF(10)
C ---------------------------------------------------------------
C WRITE MAP HEADING
C ---------------------------------------------------------------
      WRITE(6,996)
  996 FORMAT(1H1,88HW=A+BX+CY+DX2+EXY+FY2+GX3+HX2Y+FIXY2+FJY3
     -           THIRD DEGREE TREND SURFACE)
      WRITE(6,98) A,B,C
      WRITE(6,998) D,E,F,G
      WRITE(6,997) H,FI,FJ
   98 FORMAT(1H , 8HWHERE A=, F15.8,5X,2HB=,F15.8,5X,2HC=,F15.8)
  998 FORMAT(2HD=,F15.8,5X,2HE=,F15.8,5X,2HF=,F15.8,5X,2HG=,F15.8)
  997 FORMAT(2HH=,F15.8,5X,3HFI=,F15.8,5X,3HFJ=,F15.8)
      WRITE(6,97)HORZ,VERT
   97 FORMAT(1H ,27HARRAY DIMENSIONS ARE--HORZ=, F6.0,11H  AND VERT=,F8.
     10)
      WRITE(6,96)XL,XR,YT,YB,REF,CON
   96 FORMAT(1H ,3HXL=,F10.2,10X,3HXR=,F10.2,10X,3HYT=,F10.2,10X,3HYB=,
     1F10.2,10X,4HREF=,F10.2,10X,4HCON=,F10.2//)
C ---------------------------------------------------------------
C  THIRD DEGREE TREND-SURFACE CONTOUR MAP
C ---------------------------------------------------------------
      DX=(XR-XL)/HORZ
      DY=(YB-YT)/VERT
      IHORZ=HORZ
      IVERT=VERT
      DO 1 I=1,IVERT
      RI=I
      DO 2 J=1,IHORZ
      RJ=J
      W(J)= A + B*DX*RJ + C*DY*RI + D*DX*RJ*DX*RJ+E*DX*RJ*DY*RI+F*DY*RI*
     -DY*RI+G*DX*RJ*DX*RJ*DX*RJ+H*DX*RJ*DX*RJ*DY*RI+FI*DX*RJ*DY*RI*DY*RI
     -+FJ*DY*RI*DY*RI*DY*RI
      IF(W(J).LT.REF) GO TO 3
      XX=(W(J)-REF)/CON
      IX=XX
      IA=MOD(IX,20)
      CV(J)=PLUS(IA+1)
      GO TO 2
    3 YY=(REF-W(J))/CON
      IY=YY
      IB=MOD(IY,20)
      CV(J)=MINUS(IB+1)
    2 CONTINUE
      WRITE(6, 95)(CV(K),K=1,IHORZ)
   95 FORMAT(1HT,132A1)
    1 CONTINUE
C ---------------------------------------------------------------
```

```
C COMPUTE RESIDUAL VALUES
C -------------------------------------------------------
      DO 431 I= 1,K
      ZTREND(I) = A+B*X(I)+C*Y(I)+D*X(I)**2+E*X(I)*Y(I)+F*Y(I)**2+G*X(I)
     -**3+H*X(I)**2*Y(I)+FI*X(I)*Y(I)**2+FJ*Y(I)**3
  431 RESID(I)=Z(I)-ZTREND(I)
      WRITE (6,606)
  606 FORMAT(1H1,51H         X          Y          Z       ZTREND 3RD-RESID)
      DO 432  I=1,K
  432 WRITE(6,607) X(I),Y(I),Z(I),ZTREND(I),RESID(I)
  607 FORMAT(1H ,5F10.1)
  102 RETURN
      END
```

```
$IBFTC SOLVEX                                                           SLV40000
CSOLVE   LINEAR EQUATION SOLVER WITH ITERATIVE IMPROVEMENT   VERSION IV SLV40010
      SUBROUTINE SOLVE(NN,A,B,IN,EPS,ITMAX,X,IT)                        SLV40020
C     SOLVES AX=B WHERE A IS NXN MATRIX AND B IS NX1 VECTOR             SLV40030
C     IN=                                                               SLV40040
C         1 FOR FIRST ENTRY                                             SLV40050
C         2 FOR SUBSEQUENT ENTRIES WITH NEW B                           SLV40060
C         3 TO RESTORE A AND B                                          SLV40070
C     EPS AND ITMAX ARE PARAMETERS IN THE ITERATION                     SLV40080
C     IT=                                                               SLV40090
C         -1 IF A IS SINGULAR                                           SLV40100
C         0 IF NOT CONVERGENT                                           SLV40110
C         NUMBER OF ITERATIONS IF CONVERGENT                            SLV40120
C     CALLS MAP SUBROUTINES ILOG2,DOT,SDOT AND DAD                      SLV40130
C                                                                       SLV40140
C     TO MODIFY DIMENSIONS, CHANGE THE NEXT 3 (NOT 2 BUT 3) CARDS.      SLV40150
      DIMENSION A( 3, 3),B( 3),X( 3),AA( 3, 3),DX( 3),R( 3),            SLV40161
     *          Z( 3),RM( 3),IRP( 3)                                    SLV40171
      MA= 3                                                             SLV40181
C     MA MUST = DECLARED DIMENSION OF SYSTEM                            SLV40190
      EQUIVALENCE(R,DX)                                                 SLV40200
      GO TO (1000,2000,3000),IN                                         SLV40210
 1000 N=NN                                                              SLV40220
      NM1=N-1                                                           SLV40230
      NP1=N+1                                                           SLV40240
C                                                                       SLV40250
C     EQUILIBRATION                                                     SLV40260
C                                                                       SLV40270
      DO 510 I=1,N                                                      SLV40280
          KTOP=ILOG2(A(I,1))                                            SLV40290
          DO 503 J=2,N                                                  SLV40300
  503     KTOP=MAXO(KTOP,ILOG2(A(I,J)))                                 SLV40310
          RM(I)=2.0**(-KTOP)                                            SLV40320
          DO 509 J=1,N                                                  SLV40330
  509     A(I,J)=A(I,J)*RM(I)                                           SLV40340
  510 CONTINUE                                                          SLV40350
C                                                                       SLV40360
C     SAVE EQUILIBRATED DATA                                            SLV40370
C                                                                       SLV40380
      DO 548 I=1,N                                                      SLV40390
      DO 548 J=1,N                                                      SLV40400
  548 AA(I,J)=A(I,J)                                                    SLV40410
C                                                                       SLV40420
C     GAUSSIAN ELIMINATION WITH PARTIAL PIVOTING                        SLV40430
C                                                                       SLV40440
      DO 99 M=1,NM1                                                     SLV40450
          TOP=ABS (A(M,M))                                              SLV40460
          IMAX=M                                                        SLV40470
          DO 12 I=M,N                                                   SLV40480
              IF(TOP-ABS (A(I,M)))10,12,12                              SLV40490
   10         TOP=ABS (A(I,M))                                          SLV40500
              IMAX=I                                                    SLV40510
   12     CONTINUE                                                      SLV40520
          IF(TOP)14,13,14                                               SLV40530
```

```
   13       IT=-1
C           *SINGULAR*
            RETURN
   14       IRP(M)=IMAX
   23       IF(IMAX-M)29,29,24
   24       DO 25 J=1,N
                 TEMP=A(M,J)
                 A(M,J)=A(IMAX,J)
   25            A(IMAX,J)=TEMP
   29       MP1=M+1
            DO 33 I=MP1,N
                 EM=A(I,M)/A(M,M)
                 A(I,M)=EM
                 IF(EM)31,33,31
   31            DO 32 J=MP1,N
   32            A(I,J)=A(I,J)-A(M,J)*EM
   33       CONTINUE
   99 CONTINUE
      IRP(N)=N
      IF (A(N,N))120,113,120
  113 IT=-1
      RETURN
  120 CONTINUE
C     STORAGE FOR A NOW CONTAINS TRIANGULAR L AND U SO THAT (L+I)*U=A
C
C     DUPLICATE INTERCHANGES IN DATA
C
      DO 229 I=1,N
          IP=IRP(I)
          IF(I-IP)221,229,221
  221     DO 222 J=1,N
               TEMP=AA(I,J)
               AA(I,J)=AA(IP,J)
  222          AA(IP,J)=TEMP
  229 CONTINUE
C
C     PROCESS RIGHT HAND SIDE
C
 2000 CONTINUE
      DO 601 I=1,N
  601     B(I)=B(I)*RM(I)
      DO 609 I=1,NM1
          IP=IRP(I)
          TEMP=B(I)
          B(I)=B(IP)
          B(IP)=TEMP
  609 CONTINUE
C
C     SOLVE FOR FIRST APPROXIMATION TO X
C
  199 DO 200 I=1,N
  200 Z(I)=-SDOT(I-1,A(I,1),MA,Z(1),1,-B(I))
      DO 201 K=1,N
      I=NP1-K
  201 X(I)=-SDOT(N-I,A(I,I+1),MA,X(I+1),1,-Z(I))/A(I,I)
```

```
C
C      ITERATIVE IMPROVEMENT
C
       IF(ITMAX)370,370,300
  300  TOP=0.0
       DO 303 I=1,N
  303  TOP=AMAX1(TOP,ABS(X(I)))
       EPSX=EPS*TOP
       DO 369 IT=1,ITMAX
C          FIND RESIDUALS
           DO 319 I=1,N
  319      R(I)=-DOT(N,AA(I,1),MA,X(1),1,-B(I))
C          FIND INCREMENT
           DO 329 I=1,N
  329      Z(I)=-SDOT(I-1,A(I,1),MA,Z(1),1,-R(I))
           DO 339 K=1,N
           I=NP1-K
  339      DX(I)=-SDOT(N-I,A(I,I+1),MA,DX(I+1),1,-Z(I))/A(I,I)
C          INCREMENT AND TEST CONVERGENCE
           TOP=0.0
           DO 342 I=1,N
                TEMP=X(I)
                X(I)=DAD(X(I),DX(I))
                DELX=ABS (X(I)-TEMP)
                TOP=AMAX1(TOP,DELX)
  342      CONTINUE
           IF(TOP-EPSX)381,381,369
  369  CONTINUE
  370  IT=0
  381  RETURN
C
C      RESTURE A AND B
C
 3000  CONTINUE
       DO 709 K=1,N
           I=NP1-K
           IP=IRP(I)
           IF(I-IP)701,709,701
  701      TEMP=B(I)
           B(I)=B(IP)
           B(IP)=TEMP
           DO 702 J=1,N
                TEMP=AA(I,J)
                AA(I,J)=AA(IP,J)
  702           AA(IP,J)=TEMP
  709  CONTINUE
       DO 729 I=1,N
           B(I)=B(I)/RM(I)
           DO 729 J=1,N
           A(I,J)=AA(I,J)/RM(I)
  729  CONTINUE
       RETURN
       END
$IBMAP DOT      84
*    DOT AND FRIENDS      ROUTINES FOR USE WITH SOLVE
```

```
         ENTRY   DOT (N,A(1),MA,B(1),MB,C)   DOUBLE INNER PRODUCT
         ENTRY   SDOT (N,A(1),MA,B(1),MB,C)  INNER PRODUCT
         ENTRY   ILOG2 (A)   FLOATING POINT EXPONENT
         ENTRY   DAD (A,B)   ADD WITH ROUND
*
SNAD     MACRO   M      STORE NEGATIVE OF ADDRESS IN DECREMENT
         SUB     =0100000         COMPLEMENT IF POSITIVE
         ALS     18
         STD     M
         ENDM    SNAD
*
DOT      SAVE    1,2,4
         STZ     S
         STZ     S+1
         CLA*    8,4              C
         LDQ     C+1
         STO     C
         CLA*    3,4              N
         TZE     NONE             SKIP LOOP IF N = 0
         STO     N
         CLA     4,4              BASE ADDRESS OF A
         PAC     ,1               X1=-(BASE OF A)
         CLA*    5,4              MA
         SNAD    MA
         CLA     6,4              BASE ADDRESS OF B
         PAC     ,2               X2=-(BASE OF B)
         CLA*    7,4              MB
         SNAD    MB
         LXA     N,4              X4=N
 LOOP    LDQ     0,1              A(I)
         FMP     0,2              B(I)
         DFAD    S
         DST     S
 MA      TXI     *+1,1,**         (X1)=(X1)+MA
 MB      TXI     *+1,2,**         (X2)=(X2)+MB
         TIX     LOOP,4,1         END OF MAIN LOOP
NONE     DFAD    C
         FRN
         RETURN  DOT
*
SDOT     SAVE    1,2,4
         STZ     S
         CLA*    8,4
         STO     C
         CLA*    3,4
         TZE     SNONE
         STO     N
         CLA     4,4
         PAC     ,1
         CLA*    5,4
         SNAD    SMA
         CLA     6,4
         PAC     ,2
         CLA*    7,4
         SNAD    SMB
```

```
         LXA     N,4                                        DOT40570
SLOOP    LDQ     0,1                                        DOT40580
         FMP     0,2                                        DOT40590
         FAD     S                                          DOT40600
         STO     S                                          DOT40610
SMA      TXI     *+1,1,**                                   DOT40620
SMB      TXI     *+1,2,**                                   DOT40630
         TIX     SLOOP,4,1                                  DOT40640
SNONE    FAD     C                                          DOT40650
         RETURN  SDOT                                       DOT40660
*                                                           DOT40670
ILOG2    CAL*    3,4                                        DOT40680
         ANA     =0377000000000                             DOT40690
         SUB     =0200000000000                             DOT40700
         ARS     27                                         DOT40710
         TRA     1,4                                        DOT40720
*                                                           DOT40730
DAD      CLA*    3,4                                        DOT40740
         FAD*    4,4                                        DOT40750
         FRN                                                DOT40760
         TRA     1,4                                        DOT40770
*                                                           DOT40780
         EVEN                                               DOT40790
C        PZE                                                DOT40800
         PZE                                                DOT40810
S        PZE                                                DOT40820
         PZE                                                DOT40830
N        PZE                                                DOT40840
         END                                                DOT40850
```

120.0 58.0 0.0 120.0 0.0 80.0 30.0 0.5
184

0.0	2.2	32.4	310PAA
10.0	2.2	32.4	
20.0	2.2	33.4	
30.0	2.2	33.2	
40.0	2.2	33.7	
50.0	2.2	34.0	
60.0	2.2	33.4	
70.0	2.2	34.9	
80.0	2.2	33.3	
90.0	2.2	32.8	
100.0	2.2	33.1	
110.0	2.2	32.6	
120.0	2.2	32.7	
0.	7.6	32.2	310PAB
10.	7.6	32.4	
20.	7.6	33.4	
30.	7.6	34.9	
40.	7.6	35.4	
50.	7.6	35.9	
60.	7.6	34.7	
70.	7.6	33.7	
80.	7.6	32.9	
90.	7.6	33.0	
100.	7.6	33.7	
110.	7.6	33.8	
120.	7.6	32.8	
0.	13.2	34.0	310PAC
10.	13.2	34.4	
20.	13.2	34.9	
30.	13.2	36.1	
40.	13.2	36.3	
46.	13.2	36.7	
50.	13.2	35.9	
60.	13.2	34.4	
70.	13.2	35.0	
80.	13.2	34.0	
90.	13.2	33.0	
100.	13.2	33.9	
110.	13.2	34.3	
120.	13.2	33.7	
0.	20.	33.9	310PAD
10.	20.	34.9	
20.	20.	34.4	
30.	20.	35.9	
40.	20.	37.1	
50.	20.	37.1	
60.	20.	36.1	
70.	20.	35.6	
80.	20.	34.9	
90.	20.	33.4	
100.	20.	32.8	
110.	20.	34.4	
120.	20.	33.5	

X	Y	Z	ZTREND	1ST-RESID
C.	2.2	32.4	34.8	-2.4
10.0	2.2	32.4	34.8	-2.4
20.0	2.2	33.4	34.8	-1.4
30.0	2.2	33.2	34.8	-1.6
40.0	2.2	33.7	34.7	-1.0
50.0	2.2	34.0	34.7	-0.7
60.0	2.2	33.4	34.7	-1.3
70.0	2.2	34.9	34.6	0.3
80.0	2.2	33.3	34.6	-1.3
90.0	2.2	32.8	34.6	-1.8
100.0	2.2	33.1	34.6	-1.5
110.0	2.2	32.6	34.5	-1.9
120.0	2.2	32.7	34.5	-1.8
0.	7.6	32.2	34.7	-2.5
10.0	7.6	32.4	34.7	-2.3
20.0	7.6	33.4	34.7	-1.3
30.0	7.6	34.9	34.6	0.3
40.0	7.6	35.4	34.6	0.8
50.0	7.6	35.9	34.6	1.3
60.0	7.6	34.7	34.6	0.1
70.0	7.6	33.7	34.5	-0.8
80.0	7.6	32.9	34.5	-1.6
90.0	7.6	33.0	34.5	-1.5
100.0	7.6	33.7	34.4	-0.7
110.0	7.6	33.8	34.4	-0.6
120.0	7.6	32.8	34.4	-1.6
C.	13.2	34.0	34.6	-0.6
10.0	13.2	34.4	34.6	-0.2
20.0	13.2	34.9	34.5	0.4
30.0	13.2	36.1	34.5	1.6
40.0	13.2	36.3	34.5	1.8
46.0	13.2	36.7	34.5	2.2
50.0	13.2	35.9	34.5	1.4
60.0	13.2	34.4	34.4	-0.0
70.0	13.2	35.0	34.4	0.6
80.0	13.2	34.0	34.4	-0.4
90.0	13.2	33.0	34.3	-1.3
100.0	13.2	33.9	34.3	-0.4
110.0	13.2	34.3	34.3	0.0
120.0	13.2	33.7	34.3	-0.6
C.	20.0	33.9	34.5	-0.6
10.0	20.0	34.9	34.4	0.5
20.0	20.0	34.4	34.4	0.0
30.0	20.0	35.9	34.4	1.5
40.0	20.0	37.1	34.3	2.8
50.0	20.0	37.1	34.3	2.8
60.0	20.0	36.1	34.3	1.8
70.0	20.0	35.6	34.3	1.3
80.0	20.0	34.9	34.2	0.7
90.0	20.0	33.4	34.2	-0.8
100.0	20.0	32.8	34.2	-1.4
110.0	20.0	34.4	34.1	0.3
120.0	20.0	33.5	34.1	-0.6
C.	27.2	32.7	34.3	-1.6
10.0	27.2	33.2	34.3	-1.1
20.0	27.2	34.9	34.2	0.7
30.0	27.2	35.4	34.2	1.2
40.0	27.2	37.1	34.2	2.9
44.0	27.2	37.2	34.2	3.0

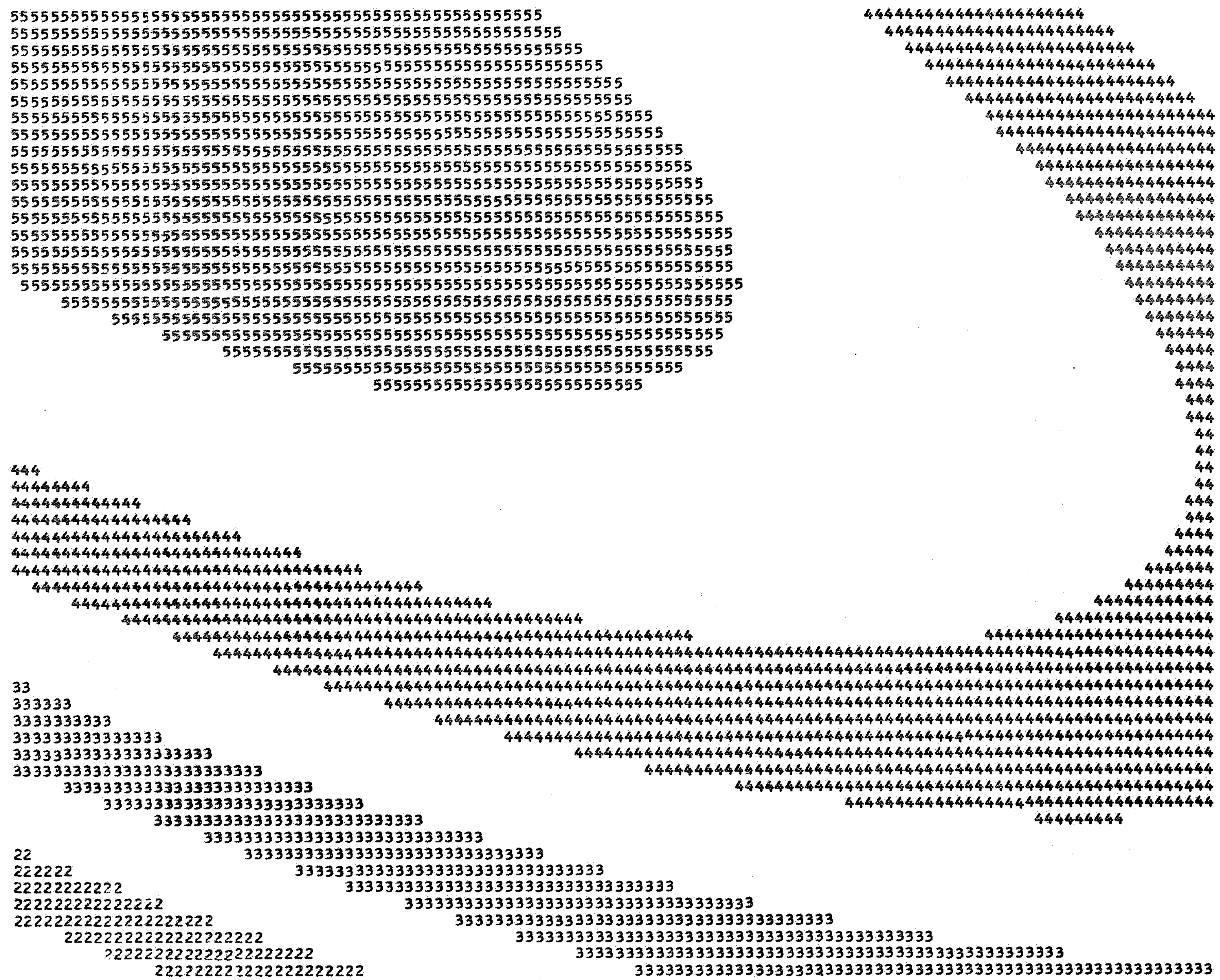
```
W= A + BX + CY                      FIRST DEGREE TREND
WHERE A=    34.89680433     B=     -0.00285308     C=     -0.02229199
ARRAY DIMENSIONS ARE--HORZ=  120.  AND VERT=     58.
XL=      0.             XR=    120.00          YT=      0.              YB=     80.00            REF=     30.00            CON=       0.50
```

SECOND DEGREE TREND SURFACE

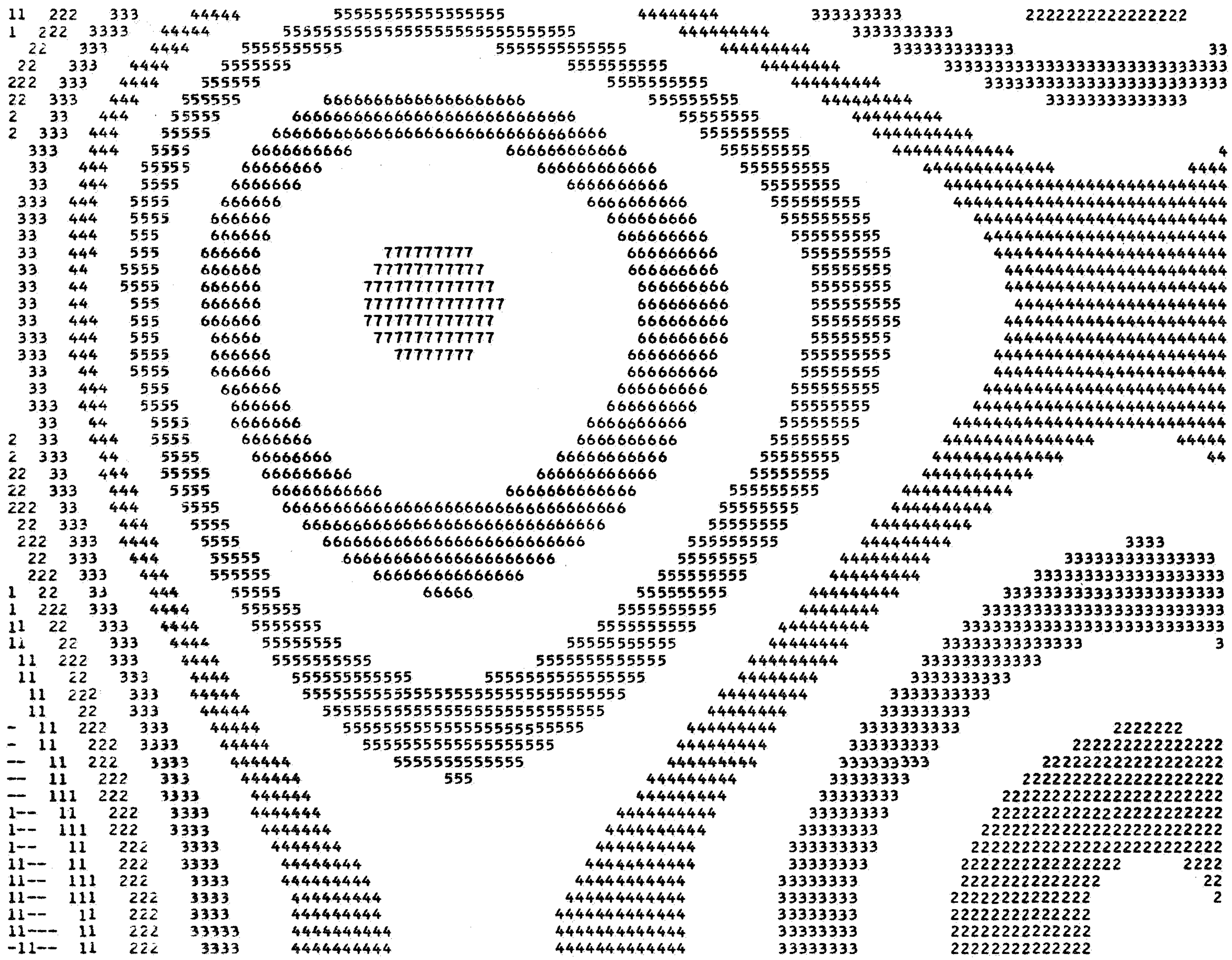
Z=AXX+BXY+CYY+D, WHERE A= -0.00011689 B= 0.00037003 C= -0.00057872 D= 34.80860996

ARRAY DIMENSIONS ARE--HORZ= 120. AND VERT= 58.

XL= 0. XR= 120.00 YT= 0. YB= 80.00 REF= 30.00 CON= 0.50

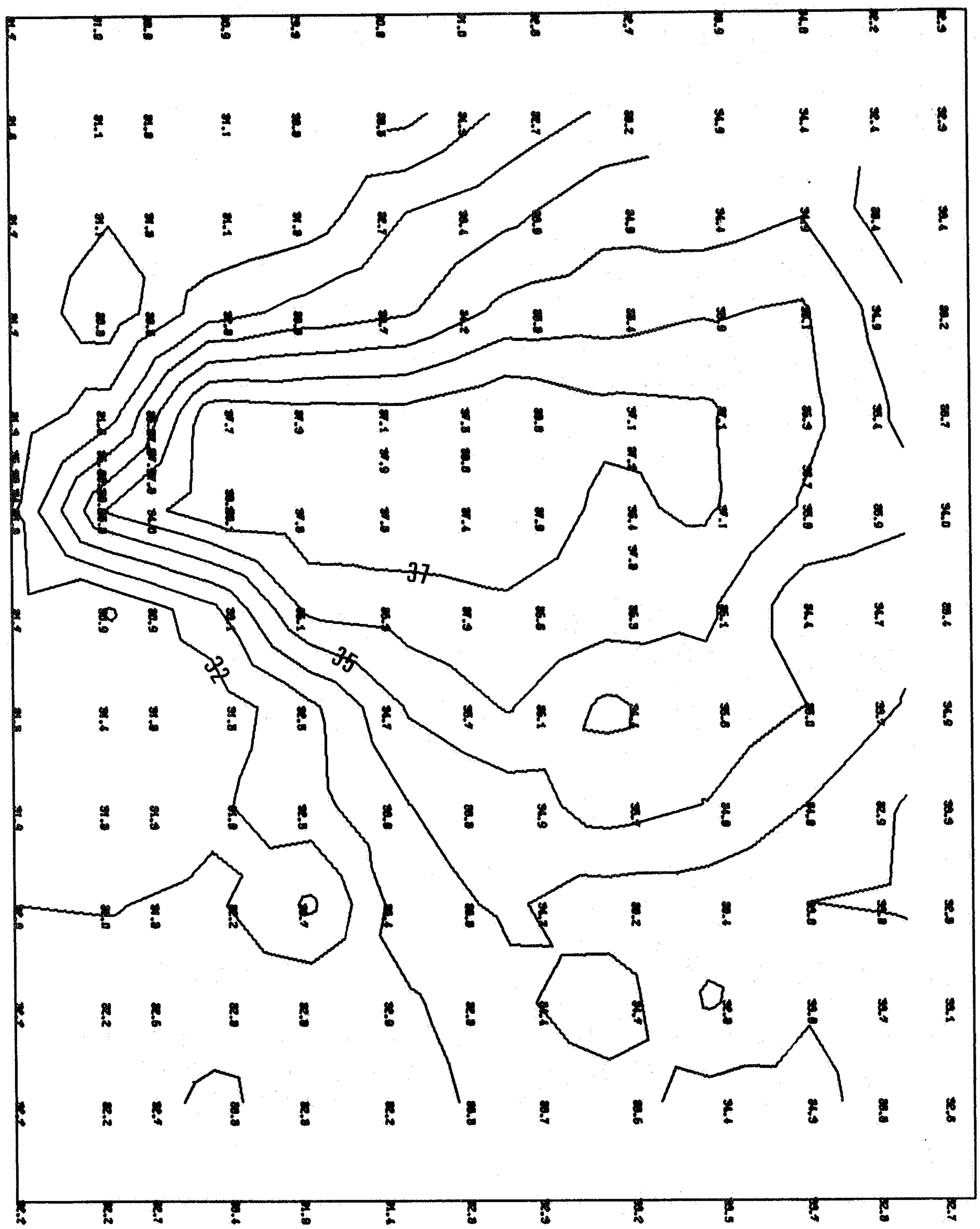


```
W=A+BX+CY+DX2+EXY+FY2+GX3+HX2Y+FIXY2+FJY3                    THIRD DEGREE TREND SURFACE
WHERE A=     30.24840212      B=     0.22954420      C=     0.18988518
D=    -0.00386152      E=     0.00043566      F=    -0.00546198      G=     0.00001717
H=    -0.00000340      FI=    0.00000128      FJ=     0.00003555
ARRAY DIMENSIONS ARE--HORZ=  120.  AND VERT=   58.
XL=      0.          XR=    120.00        YT=      0.           YB=     80.00         REF=    30.00         CON=      0.50
```



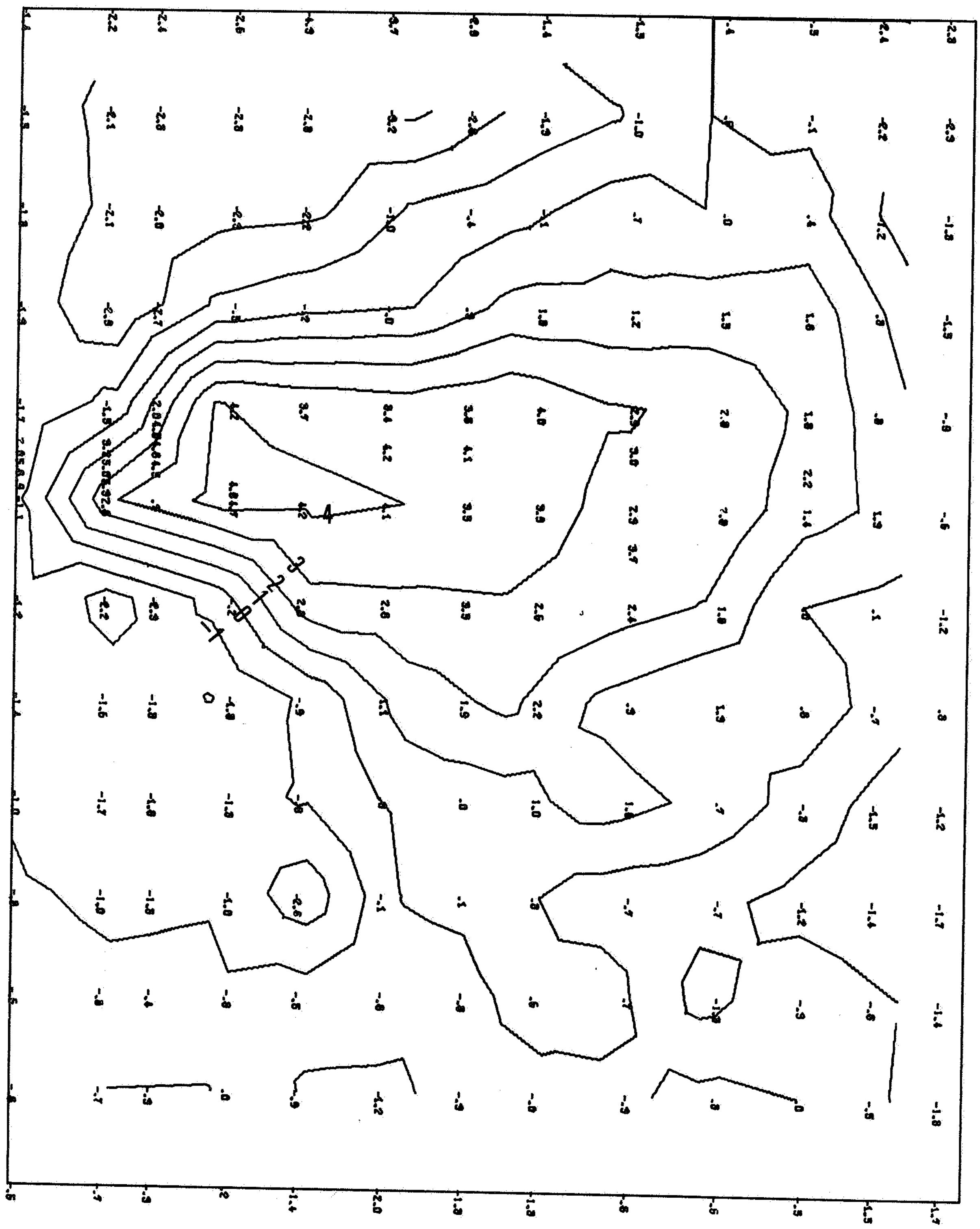
IRSATS -- APPARENT TEMPERATURES

1 INCH = 10.000 MM.



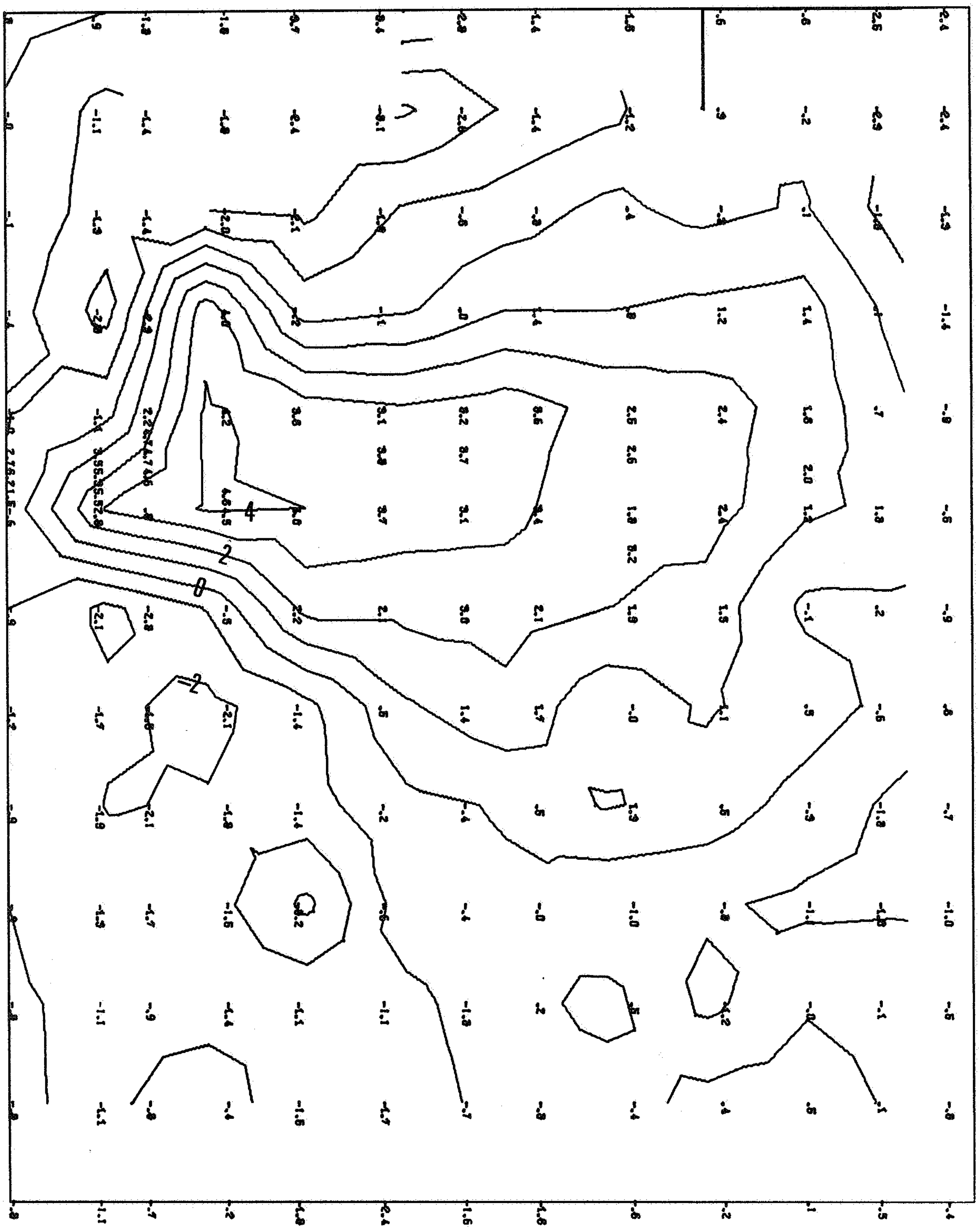
IRSATS -- FIRST DEGREE RESIDUALS

1 INCH = 10.000 MM.



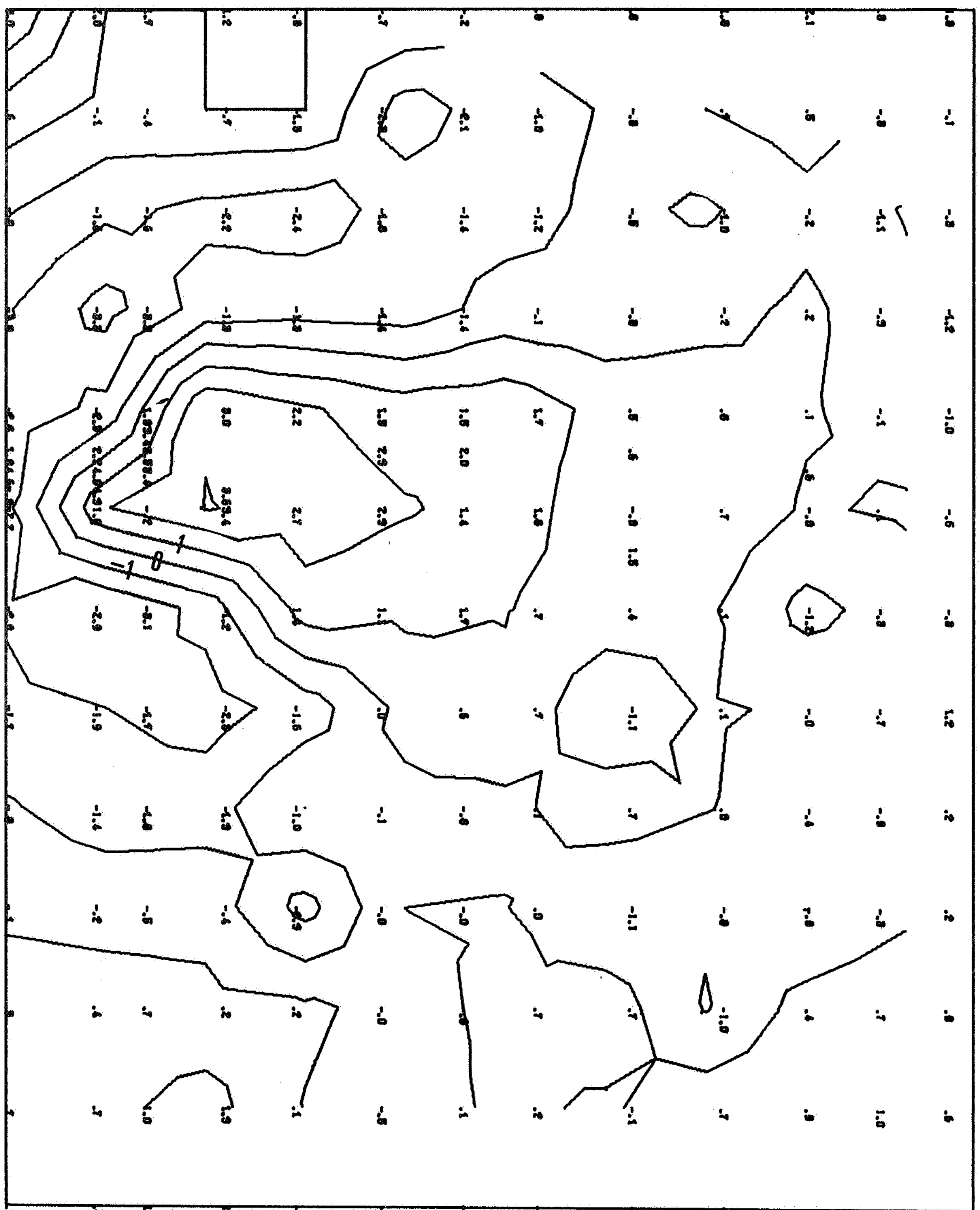
IRSATS -- SECOND DEGREE RESIDUALS

1 INCH = 10.000 MM.



IRSATS -- THIRD DEGREE RESIDUALS

1 INCH = 10.000 MM.



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