COMPUTER PROGRAM DOCUMENTATION

NUMBER 2

Perspective Center Determination

by

John D. McLaurin

U.S. Geological Survey
Topographic Division
McLean, Virginia
May 1969

Program Number: W5344
Operating System: OS/360 with HASP
Equipment: IBM 360/65
Language: FORTRAN IV (G-Level)

Open-file Report
70-209

COMPUTER CONTRIBUTION

1. Weighted Triangulation Adjustment, by Walter L. Anderson, 1969

2. Perspective Center Determination, by John D. McLaurin, 1969

Free on application to the Chief, Computer Center Division,
U. S. Geological Survey, Washington, D. C. 20242

CONTENTS

ILLUSTRATIONS

PERSPECTIVE CENTER DETERMINATION

by John D. McLaurin

ABSTRACT

This program determines coordinates of the perspective center of a stereoplotter projector by bringing two bundles of rays into a best fit coincidence in a space-resection solution. One of the bundles of rays is defined by the perspective center and the grid intersections on a grid plate. The other bundle of rays is defined by the perspective center and the projected grid intersections in the model space.

The program is used with the independent-model method of semianalytical aerotriangulation, which requires the coordinates of perspective centers. It may also be used in checking the calibration of stereoplotters.

INTRODUCTION

Certain methods of independent-model aerotriangulation--such as those described by Inghilleri and Galetto, Schut, Thompson, and Williams and Brazier--require the coordinates of the perspective center of each projector so that the models can be joined in a strip. This documentation describes a computer program for determining the three-dimensional coordinates of these perspective centers.

DESCRIPTION

A grid of known precision is projected through a stereoplotter projector, and the coordinates of grid intersections in the model space are measured. Two bundles of rays will then originate from the same theoretical point--the perspective center. One bundle extends from the perspective center to grid intersections or image points on the precise grid plate; the other extends from the perspective center to projected grid intersections in the model space. After correcting systematic errors, the latter bundle of rays is fitted to the other bundle in a least-squares space-resection solution.

Resection is based on the condition of collinearity, which requires that each image, its object, and the perspective center lie on a straight line. The equations of collinearity have been derived in Harris, et al., and may be stated as follows:

$$\frac{x}{z} = \frac{(X-X_c)\, m_{11} + (Y-Y_c)\, m_{12} + (Z-Z_c)\, m_{13}}{(X-X_c)\, m_{31} + (Y-Y_c)\, m_{32} + (Z-Z_c)\, m_{33}} \qquad (1)$$

$$\frac{y}{z} = \frac{(X-X_c)\, m_{21} + (Y-Y_c)\, m_{22} + (Z-Z_c)\, m_{23}}{(X-X_c)\, m_{31} + (Y-Y_c)\, m_{32} + (Z-Z_c)\, m_{33}} \qquad (2)$$

In the equations, x and y are image coordinates of the grid intersections based on the principal point as origin; z is the principal distance of the projector, considered to have a negative sign; X, Y, and Z are the model space coordinates of the projected grid intersections; X_c, Y_c, and Z_c are the unknown model space coordinates of the perspective center; and the m's are unknown direction cosines indicating the relative angular orientation of the image and model space coordinate axes.

The X and Y coordinates are measured with a digitized stereoplotter with the Z coordinate set at some constant value. The x and y values are derived from the grid plate calibration; the z comes from a previous calibration of the principal distance of the projector. X_c, Y_c, and Z_c are the unknown coordinates of the perspective center, and the three angles ω, ϕ, and κ are the unknown angular parameters. These last six parameters are the unknowns whose values will be determined in the resection.

The angles ω, ϕ , and κ are related to the m's as follows:

$$M = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}$$

$$= \begin{bmatrix} \cos\phi \ \cos\kappa & \begin{matrix} \cos\omega \ \sin\kappa \\ +\sin\omega \ \sin\phi \ \sin\kappa \end{matrix} & \begin{matrix} \sin\omega \ \sin\kappa \\ -\cos\omega \ \sin\phi \ \cos\kappa \end{matrix} \\ \cos\phi \ \sin\kappa & \begin{matrix} \cos\omega \ \cos\kappa \\ -\sin\omega \ \sin\phi \ \sin\kappa \end{matrix} & \begin{matrix} \sin\omega \ \cos\kappa \\ +\cos\omega \ \sin\phi \ \sin\kappa \end{matrix} \\ \sin\phi & -\sin\omega \ \cos\phi & \cos\omega \ \cos\phi \end{bmatrix} \quad (3)$$

To solve the resection problem, the observation equations must be linearized using a Taylor series expansion, and assumed values are used for the six unknown parameters. The resection is then solved iteratively for corrections to the unknowns until a satisfactory degree of convergence is achieved. The linearized observation equations, as modified for this program, are as follows:

$$vx = d\omega \ \{x \ [\ (Z-Z_c) \ m_{32} - (Y-Y_c)m_{33} \ - z \ \ (Z-Z_c)m_{12} - (Y-Y_c) \ m_{13}]\}(+1/R) \quad (4)$$

$$+d\phi \ \{x \ [\ (X-X_c) \ n_{31} + (Y-Y_c)n_{32} + (Z-Z_c)n_{33}] - z[\ (X-X_c)n_{11} + (Y-Y_c)n_{12}$$

$$+ (Z-Z_c)n_{13}] \ \} \ (+1/R)$$

$$+dk \ \{z \ [\ (X-X_c)m_{21} + \ (Y-Y_c)m_{22} + (Z-Z_c)m_{23}] \ \} \ (-1/R)$$

$$- \ dX_c \quad \{ x \ m_{31} - z \ m_{11} \ \} \ \ (1/R)$$

$$- \ dY_c \quad \{ x \ m_{32} - z \ m_{12} \ \} \ \ (1/R)$$

$$- \ dZ_c \quad \{ x \ m_{33} - z \ m_{13} \ \} \ \ (1/R)$$

$$+ \ \{ \ x \ \ [(X-X_c)m_{31} + (Y-Y_c)m_{32} + (Z-Z_c)m_{33}]$$

$$-z \ \ [(X-X_c)m_{11} + (Y-Y_c)m_{12} + (Z-Z_c)m_{13}]\} \ (1/R)$$

and

$$
\begin{aligned}
vy = {} & d\omega \{y[(Z-Z_c)m_{32} - (Y-Y_c)m_{33}] - z\,[(Z-Z_c)m_{22} - (Y-Y_c)m_{23}]\}(+1/R) \qquad (5)\\
& +d\phi\,\{y[(X-X_c)n_{31} + (Y-Y_c)n_{32} + (Z-Z_c)n_{33}]\\
& \quad -z\,[(X-X_c)n_{21} + (Y-Y_c)n_{22} + (Z-Z_c)n_{23}]\}\ (+1/R)\\
& +dk\{z\,[(X-X_c)m_{11} + (Y-Y_c)m_{12} + (Z-Z_c)m_{13}]\}\ (-1/R)\\
& - dX_c\ \{y\, m_{31} - z\, m_{21}\}(1/R)\\
& - dY_c\ \{y\, m_{32} - z\, m_{22}\}(1/R)\\
& - dZ_c\ \{y\, m_{33} - z\, m_{23}\}(1/R)\\
& + \{y\,[(X-X_c)m_{31} + (Y-Y_c)m_{32} + (Z-Z_c)m_{33}]\\
& \quad -z\,[(X-X_c)m_{21} + (Y-Y_c)m_{22} + (Z-Z_c)m_{23}]\}(1/R)
\end{aligned}
$$

where

$$R = (X-X_c)m_{31} + (Y-Y_c)m_{32} + (Z-Z_c)m_{33}$$

$$m_{11} = \cos\phi\cos\kappa$$

$$m_{12} = \cos\omega\sin\kappa + \sin\omega\sin\phi\cos\kappa$$

$$m_{13} = \sin\omega\sin\kappa - \cos\omega\sin\phi\cos\kappa$$

$$m_{21} = -\cos\phi\sin\kappa$$

$$m_{22} = \cos\omega\cos\kappa - \sin\omega\sin\phi\sin\kappa$$

$$m_{23} = \sin\omega\cos\kappa + \cos\omega\sin\phi\sin\kappa$$

$$m_{31} = \sin\phi$$

$$m_{32} = -\sin\omega\cos\phi$$

$$m_{33} = \cos\omega\cos\phi$$

and

$$n_{11} = -\sin\phi \cos\kappa$$

$$n_{12} = \sin\omega \cos\phi \cos\kappa$$

$$n_{13} = -\cos\omega \cos\phi \cos\kappa$$

$$n_{21} = \sin\phi \sin\kappa$$

$$n_{22} = \sin\omega \cos\phi \sin\kappa$$

$$n_{23} = \cos\omega \cos\phi \sin\kappa$$

$$n_{31} = \cos\phi$$

$$n_{32} = \sin\omega \sin\phi$$

$$n_{33} = \cos\omega \sin\phi$$

Initial approximations for the unknowns X_c, Y_c, Z_c, ω , ϕ , and κ are read as input to the program. These values are used during the first cycle. One set of observation equations is formed for each grid intersection read. The normal equations are formed from these observation equations, using the usual matrix algebra method. The coefficient matrix of the normal equations is inverted using the standard Gauss-Jordan method. Corrections to the unknowns are found using the following matrix equation:

$$X = (A^T A)^{-1} A^T L \qquad (6)$$

where X is the vector of unknowns

$(A^T A)^{-1}$ is the inverse of the normal equations coefficient matrix

A is the coefficient matrix of the observation equations, and A^T is the transpose of this matrix

and L is the vector of constant terms in the observation equations.

The following expression is computed:

$$TEST = \sqrt{dX_c^2 + dY_c^2 + dZ_c^2}$$

This value is compared with a tolerance read in with the data to see if satisfactory convergence has been achieved. If TEST is larger than the tolerance, the computed corrections of the unknowns are added to the initial approximations of the unknowns, and the solution is iterated.

After the tolerance has been met or six cycles have been completed, the program proceeds to compute residuals on grid intersections in the model space. Using the values of unknowns computed in the resection, grid intersections are projected into the model space and compared with measured coordinates. In addition, the radial distance from the principal point to the grid intersection is computed for (1) the true position of the grid point on the grid plate and (2) the computed position found by transforming the measured position from the model space to the grid plate. The difference between these radial distances is printed out as a radial distortion term.

The standard error of unit weight of the grid points is computed with the following equation:

$$STD = \sqrt{\frac{\sum v_X^2 + v_Y^2}{2 \quad n-\mu}}$$

where v_X and v_Y are the X and Y residuals

n is the number of points used

and μ is the number of unknowns (usually 6).

The variance-covariance matrix is computed by multiplying the inverse of the normal equations coefficient matrix by the standard error of unit weight squared (unit variance). The standard errors of unknowns are computed from this matrix.

Multiple readings may be made on the projected grid intersections. The program counts the number of readings and computes the mean coordinates and standard deviation for each point. Then, if the coordinatograph of the digitized stereoplotter has been calibrated, the mean projected grid coordinates will be corrected using X- and Y-scale and perpendicularity correction factors submitted as input.

Several sets of readings using the same grid points and plate coordinates may be batched to run at once. The plate grid coordinates need only be placed in the data deck once, followed by the sets of projected coordinates. This is useful when projected coordinates are read at different Z levels.

RESTRICTIONS

The program requires at least three grid points for the computation. Using many more than three points, however, provides a more satisfactory solution, since the method of least squares is used in the adjustment. The maximum number of points that may be used is 50, but more may be used if the dimension statement is changed.

The projected grid coordinates must be arranged in the same order as the plate grid coordinates. If multiple readings are made on the projected points, all readings on each point must be grouped together. A different number of readings may be made for each point, if desired.

INPUT

Input for this program must be on punched cards. Several sets of projected grid readings may be computed using the same plate grid points and coordinates.

Data for a new computation using different grid points and coordinates begin with a new card 1. As many groups of data as desired may be computed on one job.

- Card 1--Title

Input Item	Column Number	Format	Program Variable
Any alphameric information	1-80	20A4	TITLE (1) thru TITLE (20)

- Card 2--Input Format for Precise Grid Data

Input Item	Column Number	Format	Program Variable
Any desired format for reading precise grid data. Three fields must be provided in the following order: Field 1--Point number Field 2--x coordinate of point Field 3--y coordinate of point Example: (I4,2F10.0)	1-80	20A4	FM (1) thru FM (20)

- Card 3--Input Format for Measured Coordinates

Input Item	Column Number	Format	Program Variable
Any desired format for reading measured coordinates. Four fields must be provided in the following order: Field 1--Point number Field 2--X coordinate of point Field 3--Y coordinate of point Field 4--Z coordinate of point Example: (I4,3F10.0)	1-80	20A4	FMT (1) thru FMT (20)

- Card 4--Specifications

Input Item	Column Number	Format	Program Variable
Number of grid points used	1-15	I5	NPTS
Number of sets of projected grid readings using the same plate grid points and coordinates.	6-10	I5	ICALF
Code indicating whether projected grid readings are to be corrected for coordinatograph errors. 1 = corrections will be made; card 5 will be read. 0 = corrections will not be made; card 5 will not be read.	11-15	I5	ICOR
Principal distance of projector, written as a positive real number in millimeters.	16-25	F10.0	FOCAL
Tolerance for testing convergence of the solution, written as a positive real number in millimeters.	26-35	F10.0	GDIF

- Card 5-- Coordinatograph Correction Factors--This card is read only if ICOR in columns 11-15 (see card 4) is equal to 1. These factors are used to correct projected grid coordinates for errors in the coordinatograph.

Input Item	Column Number	Format	Program Variable
X-scale correction factor	1-20	D20.8	XSCAL
Y-scale correction factor	21-40	D20.8	YSCAL
Nonperpendicularity correction factor.	41-60	D20.8	SINALP

- Card 6 thru I-1--Precise Grid Coordinates (see fig. 2)--One card is read for each grid intersection according to input format on card 2. The plate coordinate system is based on a positive plate--the Z axis is considered positive upward so that the principal distance has a negative sign. Units of the coordinates are millimeters; the origin of the coordinate system is the perspective center.

Input Item	Column Number	Format	Program Variable
Field 1-- Point number. (see card 2.)	Column nos. are specified by format on card 2.	Integer with length of field specified by format on card 2.	IDENT(I) where I designates the Ith grid intersection.
Field 2--x coordinate of grid intersection.	Same as above	Real number with length of field specified by format on card 2.	PX(I) where I designates the Ith grid intersection.
Field 3--y coordinate of grid intersection.	Same as above	Same as above	PY(I)

- <u>Card I--Initial Approximations to Unknowns</u>--The units for X_c, Y_c, and Z_c are in the same units as the projected coordinates.

Input Item	Column Number	Format	Program Variable
Initial value for ω in minutes	1-10	F10.0	AOMEGA
Initial value for ϕ in minutes	11-20	F10.0	APHI
Initial value for κ in minutes	21-30	F10.0	AKAPPA
Initial value for X_c	31-40	F10.0	XE
Initial value for Y_c	41-50	F10.0	YE
Initial value for Z_c	51-60	F10.0	ZE

- <u>Cards I+1 thru M-1--Projected Grid Coordinates (see fig. 2)</u>--Multiple readings may be made for each grid intersection according to input format on card 3. All readings for the same point are placed together in the deck. The program computes the mean coordinates and standard deviations for each point. The Z coordinate is constant for each set of projected grid coordinate readings. Points must be placed in the same order as that for plate grid coordinates in the data deck.

Input Item	Column Number	Format	Program Variable
Field 1--Point number	Column nos. as specified by format on card 3.	Integer with length of field specified by format on card 3.	ID

Cards I+1 thru M-1--Projected Grid Coordinates (con't)

Input Item	Column Number	Format	Program Variable
Field 2--X coordinate of projected grid	Same as above.	Real number with length of field specified by format on card 3. (Single precision.)	TMX(NRDG) where NRDG designates the order in which the reading was made.
Field 3--Y coordinate of projected grid	Same as above.	Same as above.	TMY(NRDG) (See item above.)
Field 4--Z coordinate of projected grid	Same as above.	Same as above.	TMH(I) where I designates the Ith grid intersection.

- Card M, Flag--End of projected grid coordinates (for one set of data). This card must be in the same format as cards I+1 thru M-1.

Input Item	Column Number	Format	Program Variable
Field 1--Must be blank or zero	See card 3.	See card 3.	ID
Field 2--Not pertinent, but must not be an alpha character	Not pertinent	Not pertinent	Not pertinent
Field 3--Same as above	Same as above	Same as above	Same as above
Field 4--Same as above	Same as above	Same as above	Same as above

PROGRAM RUN PREPARATION

The program is stored on disk on the 360/65 computer. The following deck setup (see figs. 1 and 2) includes the OS/360 control cards required to call the program from the disk. The OS/360 control cards (//'s in columns 1-2) must be as shown below. The JOB card is described in System Bulletin No. 1 of the Computer Center Division. All control cards must be punched in EBCDIC code. The symbol b denotes a blank card column, and ϕ denotes a letter O to distinguish it from a zero.

PRINTED OUTPUT

The output of the program is in the following form. (See attachment D).

1. Title

2. Number of points and principal distance used in the computation.

3. Input data: point numbers, number of readings on each point, and grid coordinates.

4. Mean projected grid coordinates and standard deviations.

5. Values of unknowns after each cycle of the solution. The first line contains initial approximations to the unknowns. The final line contains values of the unknowns to be used in further computations.

6. Residual and distortion values. Residuals are in the coordinate system of the projected points; distortion values are in plate coordinates.

7. Variance-covariance matrix.

8. Standard errors.

If more than one set of projected readings is used with the same set of grid coordinates, the output starts over again with item 2, number of points used and assumed principal distance. Output for an entirely new group of data starts at the top of a new page with the title. See attachment D for output listing for sample problem.

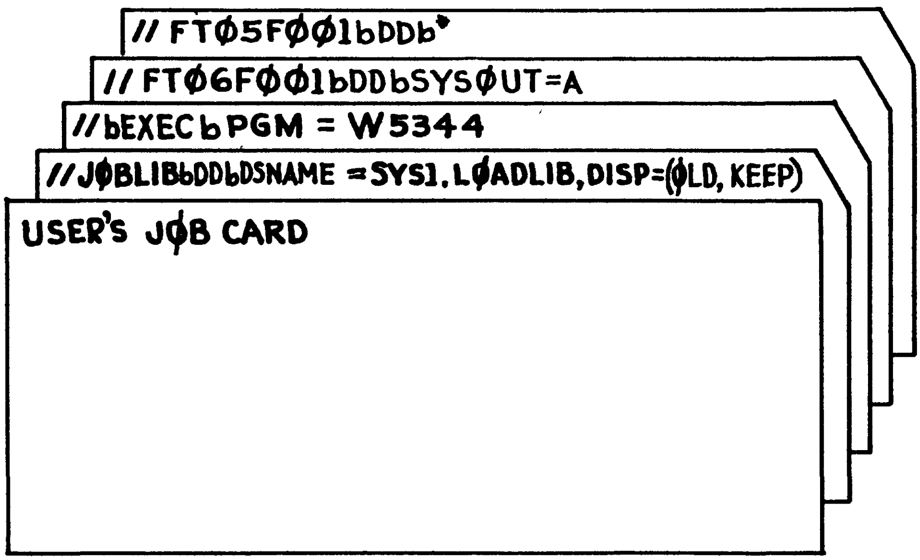


Figure 1.-- Control cards

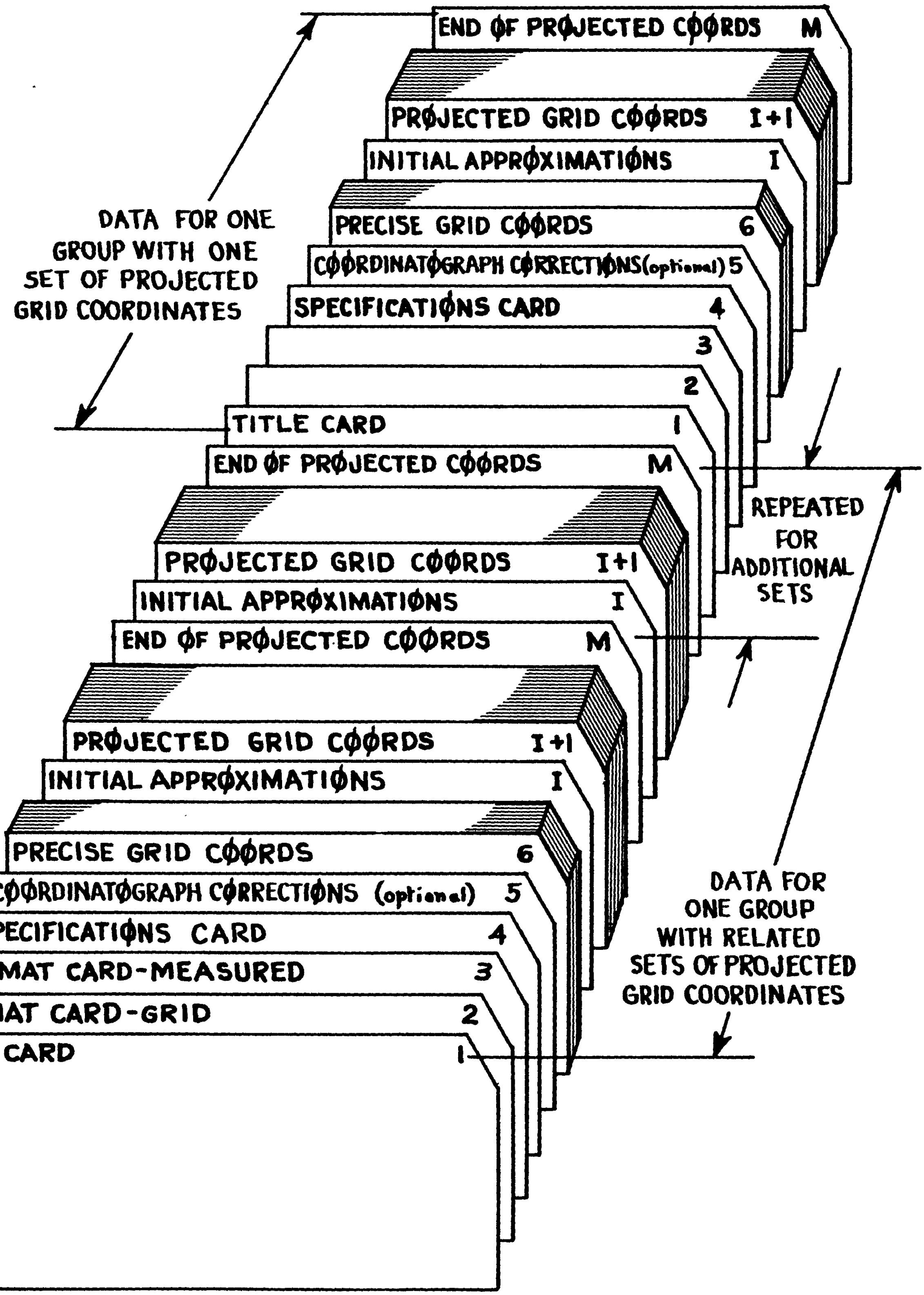


Figure 2.--Data deck files

DIAGNOSTIC MESSAGES

The following error messages may be encountered when using this program:

- ERROR - CARDS ARE OUT OF ORDER AT POINT NO.XXX -- This indicates that the projected coordinates are not in the same order as that of the plate grid coordinates. The number printed in XXX is the point number that should have appeared in the projected coordinate list. The program stops after printing this message. The input data deck should be checked, and the projected coordinates rearranged.

- NORMAL EQUATIONS MATRIX IS SINGULAR -- This message indicates trouble in the matrix inversion routine, most likely caused by not having the data deck in the correct order or not using enough points in the solution. The program stops after printing this message.

- SORRY - SOLUTION DOES NOT CONVERGE -- This message is printed if the test for convergence of the solution has not been met after six iterations, probably because the value for GDIF entered on card 3 was too small. For most uses a value of 0.01 or 0.001 is sufficient. It is also possible that initial approximations of the unknowns are too far from the correct values. The program proceeds through the computation of the residuals and standard errors after printing this message. Values of the unknowns, computed on the last iteration, are used.

STORAGE REQUIREMENTS

This program requires 21,436 bytes of internal storage as follows:

Main program	18,586 bytes
Subroutines:	
RMSE	758
DMINV	2,092
	21,436 bytes

TIMING

Average MASP time required for running a typical solution is about 0.4 minute. This is the time required if using a card object deck. Calling the program from disk should require less time.

LIBRARY ROUTINES

The subroutine, DMINV, is included with the program deck because this double-precision routine is not in the Scientific Subroutine Package.

REFERENCES

Harris, W. D., Tewinkel, G. C., and Whitten, C. A., 1962, Analytical aerotriangulation: U.S. Coast and Geodetic Survey, Technical Bulletin 21.

Inghilleri, G., and Galetto, R., 1967, Further developments of the method of aerotriangulation by independent models: Photogrammetria, v. 22, no. 1, p. 13.

Karren, R. J., 1966, An evaluation of aerial camera calibration by the multicollimator method: MS Thesis, Ohio State University.

Keller, M., and Tewinkel, G. C., 1966, Space resection in photogrammetry: U.S. Coast and Geodetic Survey, Technical Bulletin 32.

Schut, G. H., 1967, Formation of strips from independent models: National Research Council of Canada, Report NRC-9695.

Thompson, E. H., 1965, Review of methods of independent model aerial triangulation: Photogrammetric Record, v. 5, no. 26, p. 72.

Williams, V. A., and Brazier, H. H., 1965, The method of adjustment of independent models, Huddersfield test strip: Photogrammetric Record, v. 5, no. 26, p. 123.

ATTACHMENTS

A. PROGRAM LISTING


```
                C      PERSPECTIVE CENTER DETERMINATION
                C      BRANCH OF PHOTOGRAMMETRY---PROGRAM NO. 5344
                C      COMPUTES THE COORDINATES OF THE PERSPECTIVE CENTER
                C      OF A STEREOPLOTTER PROJECTOR VIA SPACE RESECTION
                C
0001                   REAL*8 N(7,7),AMX(50),AMY(50),OBSX(50,7),OBSY(50,7),U(6,6),SOL(6),
                      1VCV(6,6),SUMX,SUMY,ROMEGA,RPHI,RKAPPA,A,B,C,AP,BP,CP,CM11,CM12,CM1
                      23,CM21,CM22,CM23,CM32,CM33,CN11,CN12,CN13,CN21,CN22,CN23,CN32,CN33
                      3,DELX,DELY,DELZ,SX,SY,R,S,T,SCFAC,SZ,G,SO,PUU,TEMX,TEMY,FXRAD,OBRA
                      4D,DSTRT,PX(50),PY(50),DET,XSCAL,YSCAL,SINALP,SMALX,SMALY,ABSV
0002                   DIMENSION TITLE(20), IDENT(50), FMT(20), FM(20), TMX(50), TMY(50),
                      1 TMH(50), DEX(50), DEY(50), NRD(50), L1(6), M1(6)
0003                   CONV=3437.746D
0004                10 READ (5,20,END=540) (TITLE(I),I=1,20)
0005                20 FORMAT (20A4)
0006                   WRITE (6,30) TITLE
0007                30 FORMAT (1H1,T45,'PERSPECTIVE CENTER DETERMINATION'//5X,20A4)
0008                   READ (5,20) FM,FMT
0009                   READ (5,40) NPTS,ICALF,ICOR,FOCAL,GDIF
0010                40 FORMAT (3I5,2F10.0)
0011                   IF (ICOR.NE.1) GO TO 60
0012                   READ (5,50) XSCAL,YSCAL,SINALP
0013                50 FORMAT (3D20.8)
0014                60 ITEST=1
0015                   DO 70 I=1,NPTS
0016                70 READ (5,FM) IDENT(I),PX(I),PY(I)
0017                80 READ (5,90) AOMEGA,APHI,AKAPPA,XE,YE,ZE
0018                90 FORMAT (6F10.0)
0019                   SUMX=0.
0020                   SUMY=0.
0021                   NRDG=0
0022                   DO 150 I=1,NPTS
0023                   NRDG=NRDG+1
0024               100 READ (5,FMT) ID,TMX(NRDG),TMY(NRDG),TMH(I)
0025                   SUMX=SUMX+TMX(NRDG)
0026                   SUMY=SUMY+TMY(NRDG)
0027                   IF (NRDG.EQ.1) GO TO 110
0028                   IF (ID.EQ.ILST) GO TO 110
0029                   SUMX=SUMX-TMX(NRDG)
0030                   SUMY=SUMY-TMY(NRDG)
0031                   TMH(I)=HC
0032                   NRDG=NRDG-1
0033                   AMX(I)=SUMX/NRDG
0034                   AMY(I)=SUMY/NRDG
0035                   SUMX=TMX(NRDG+1)
0036                   SUMY=TMY(NRDG+1)
0037                   IF (NRDG.GT.1) GO TO 120
0038                   DEX(I)=0.
0039                   DEY(I)=0.
0040                   NRD(I)=1
0041                   NRDG=1
0042                   TMX(1)=SUMX
```

```
0043          TMY(1)=SUMY
0044          GO TO 130
0045      110 NRDG=NRDG+1
0046          ILST=ID
0047          HC=TMH(I)
0048          GO TO 100
0049      120 CALL RMSE (NRDG,TMX,TMY,XDEV,YDEV)
0050          DEX(I)=XDEV
0051          DEY(I)=YDEV
0052          NRD(I)=NRDG
0053          TMX(1)=SUMX
0054          TMY(1)=SUMY
0055          NRDG=1
0056      130 IF (ILST.EQ.IDENT(I)) GO TO 150
0057          I1=I-1
0058          IF (I1.EQ.0) I1=1
0059          WRITE (6,140) IDENT(I)
0060      140 FORMAT (1H0,5X,'ERROR - CARDS ARE OUT OF ORDER'/5X,'AT POINT NO.',
             1I7)
0061          STOP
0062      150 ILST=ID
0063          IF (ICOR.NE.1) GO TO 190
0064          WRITE (6,160)
0065      160 FORMAT (1H0,5X,'COORDINATOGRAPH ERRORS CORRECTED')
0066          SMALX=DABS(AMX(1))
0067          SMALY=DABS(AMY(I))
0068          DO 170 I=2,NPTS
0069          ABSV=DABS(AMX(I))
0070          SMALX=DMIN1(SMALX,ABSV)
0071          ABSV=DABS(AMY(I))
0072      170 SMALY=DMIN1(SMALY,ABSV)
0073          DO 180 I=1,NPTS
0074          AMX(I)=XSCAL*((AMX(I)-SMALX)+(AMY(I)-SMALY)*SINALP)+SMALX
0075      180 AMY(I)=(AMY(I)-SMALY)*YSCAL+SMALY
0076      190 WRITE (6,200) NPTS,FOCAL
0077      200 FORMAT (1H0,5X,'THE NUMBER OF POINTS USED ON THIS PLATE IS',I4/5X,
             1'THE ASSUMED PRINCIPAL DISTANCE USED IN THESE COMPUTATIONS IS',F15
             2.3)
0078          WRITE (6,210) (IDENT(I),NRD(I),PX(I),PY(I),AMX(I),DEX(I),AMY(I),DE
             1Y(I),TMH(I),I=1,NPTS)
0079      210 FORMAT (1H0,5X,'COORDINATES OF INPUT DATA'/T10,'NO. OF',T21,'CALIB
             1RATED GRID COORD',T54,'PROJECTED GRID COORDINATES'/1X,'PT NO',2X,'
             2READINGS',7X,'X',12X,'Y',9X,'MEAN X',3X,'X STD DEV',5X,'MEAN Y',3X
             3,'Y STD DEV',9X,'Z'/(I5,5X,I3,1X,3F13.3,2X,F8.3,2X,F11.3,2X,F8.3,2
             4X,F11.2))
0080          ITER=0
0081          IFIN=0
0082          WRITE (6,220) ITER,XE,YE,ZE,AOMEGA,APHI,AKAPPA
0083      220 FORMAT (1H0,'ITER',6X,'X',10X,'Y',10X,'Z',9X,'DX',8X,'DY',8X,'DZ',
             16X,'OMEGA',6X,'PHI',6X,'KAPPA'/I4,3F11.2,30X,3F10.4)
0084          ITER=1
0085          SZ=-FOCAL
```

```
  230 ROMEGA=AOMEGA/CONV                                          A1050
      RPHI=APHI/CONV                                              A1060
      RKAPPA=AKAPPA/CONV                                          A1070
      DO 240 I=1,50                                               A1080
      DO 240 J=1,7                                                A1090
      OBSX(I,J)=0.                                                A1100
  240 OBSY(I,J)=0.                                                A1110
      DO 250 I=1,7                                                A1120
      DO 250 J=1,7                                                A1130
  250 N(I,J)=0.                                                   A1140
      A=DSIN(ROMEGA)                                              A1150
      B=DSIN(RPHI)                                                A1160
      C=DSIN(RKAPPA)                                              A1170
      AP=DCOS(ROMEGA)                                             A1180
      BP=DCOS(RPHI)                                               A1190
      CP=DCOS(RKAPPA)                                             A1200
      CM11=BP*CP                                                  A1210
      CM21=-BP*C                                                  A1220
      CM32=-A*BP                                                  A1230
      CM33=AP*BP                                                  A1240
      CN11=-B*CP                                                  A1250
      CN21=B*C                                                    A1260
      CN32=A*B                                                    A1270
      CN33=-AP*B                                                  A1280
      CN12=-CP*CM32                                               A1290
      CN13=-CP*CM33                                               A1300
      CN22=C*CM32                                                 A1310
      CN23=C*CM33                                                 A1320
      CM12=AP*C+CP*CN32                                           A1330
      CM13=A*C+CP*CN33                                            A1340
      CM22=AP*CP-C*CN32                                           A1350
      CM23=A*CP-C*CN33                                            A1360
      DO 260 I=1,NPTS                                             A1370
      DELX=AMX(I)-XE                                              A1380
      DELY=AMY(I)-YE                                              A1390
      DELZ=TMH(I)-ZE                                              A1400
      SX=PX(I)                                                    A1410
      SY=PY(I)                                                    A1420
      R=1.0/(B*DELX+CM32*DELY+CM33*DELZ)                          A1430
      S=CM32*DELZ-CM33*DELY                                       A1440
      T=BP*DELX+CN32*DELY+CN33*DELZ                               A1450
      OBSX(I,1)=-R*(S*SX-SZ*(CM12*DELZ-CM13*DELY))                A1460
      OBSX(I,2)=-R*(T*SX-SZ*(CN11*DELX+CN12*DELY+CN13*DELZ))      A1470
      OBSX(I,3)=R*SZ*(CM21*DELX+CM22*DELY+CM23*DELZ)              A1480
      OBSX(I,4)=R*(B*SX-CM11*SZ)                                  A1490
      OBSX(I,5)=R*(CM32*SX-CM12*SZ)                               A1500
      OBSX(I,6)=R*(CM33*SX-CM13*SZ)                               A1510
      OBSX(I,7)=SX-R*SZ*(CM11*DELX+CM12*DELY+CM13*DELZ)           A1520
      OBSY(I,1)=-R*(S*SY-SZ*(CN22*DELZ-CM23*DELY))                A1530
      OBSY(I,2)=-R*(T*SY-SZ*(CN21*DELX+CN22*DELY+CN23*DELZ))      A1540
      OBSY(I,3)=-SX+OBSX(I,7)                                     A1550
      OBSY(I,4)=R*(B*SY-CM21*SZ)                                  A1560
```

```
      OBSY(I,5)=R*(CM32*SY-CM22*SZ)
      OBSY(I,6)=R*(CM33*SY-CM23*SZ)
  260 OBSY(I,7)=SY-OBSX(I,3)
      NO=7
      IF (IFIN.EQ.1) GO TO 430
      DO 270 K=1,NPTS
      DO 270 I=1,NO
      DO 270 J=I,NO
  270 N(I,J)=N(I,J)+OBSX(K,I)*OBSX(K,J)+OBSY(K,I)*OBSY(K,J)
      DO 280 I=1,NO
      DO 280 J=1,NO
  280 N(J,I)=N(I,J)
      ND=NO-1
      DO 290 I=1,ND
      DO 290 J=1,ND
  290 U(I,J)=N(I,J)
C
C     NOW THE NORMAL EQUATION COEFFICIENT MATRIX IS CONVERTED TO ARRAY
C     STORAGE SO THE SSP INVERSION ROUTINE CAN BE USED
C
      CALL DMINV (U,6,DET,L1,M1)
      IF (DET.NE.0.) GO TO 310
      WRITE (6,300)
  300 FORMAT (1H0,5X,'NORMAL EQUATION MATRIX IS SINGULAR')
      STOP
  310 DO 320 I=1,ND
      SOL(I)=0.
      DO 320 J=1,ND
  320 SOL(I)=SOL(I)+U(I,J)*N(J,NO)
      DOM=SOL(1)
      DPHI=SOL(2)
      DKAP=SOL(3)
      DX=SOL(4)
      DY=SOL(5)
      DZ=SOL(6)
      XE=XE+DX
      YE=YE+DY
      ZE=ZE+DZ
      AOMEGA=AOMEGA+DOM*CONV
      APHI=APHI+DPHI*CONV
      AKAPPA=AKAPPA+DKAP*CONV
      WRITE (6,330) ITER,XE,YE,ZE,DX,DY,DZ,AOMEGA,APHI,AKAPPA
  330 FORMAT (I4,3F11.2,6F10.4)
      IF (SQRT(DX*DX+DY*DY+DZ*DZ).LT.GDIF) GO TO 360
      IF (ITER.LT.6) GO TO 350
      WRITE (6,340)
  340 FORMAT (1H0,'SORRY - SOLUTION DOES NOT CONVERGE')
      GO TO 410
  350 ITER=ITER+1
      GO TO 230
  360 WRITE (6,370) GDIF
  370 FORMAT (1H0,5X,'WITH THIS ITERATION THE SQUARE ROOT OF DX2+DY2+DZ2
```

```
                1 IS LESS THAN',F10.3)                                        A2090
0186              WRITE (6,380)                                                A2100
0187        380 FORMAT (1H0,T5,'COORDINATES OF THE PERSPECTIVE CENTER'//T12,'X',T2  A2110
                13,'Y',T34,'Z')                                                A2120
0188              WRITE (6,390) XE,YE,ZE                                       A2130
0189        390 FORMAT (4X,3F11.2)                                             A2140
0190              WRITE (6,400)                                                A2150
0191        400 FORMAT (1H1,T43,'STEREOPLOTTER CALIBRATION INFORMATION')       A2160
          C                                                                    A2170
          C       NOW COMPUTE RESIDUALS                                        A2180
          C                                                                    A2190
0192        410 WRITE (6,420)                                                  A2200
0193        420 FORMAT (1H0,5X,'RESIDUAL AND DISTORTION VALUES'/1X,'POINT',3X,'PRO  A2210
                1JECTED',12X,'PROJECTED',15X,'OBSERVED',7X,'FIXED',10X,'RADIAL'/2X,  A2220
                2'NO.',8X,'X',8X,'VX',10X,'Y',8X,'VY',10X,'RADIUS',8X,'RADIUS',7X,'  A2230
                3DISTORTION')                                                  A2240
0194              IFIN=1                                                       A2250
0195              GO TO 230                                                    A2260
0196        430 PUU=0.                                                         A2270
0197              PUQ=0.                                                       A2280
0198              SCFAC=DELZ/SZ                                                A2290
0199              DO 460 I=1,NPTS                                              A2300
0200              TEMX=0.                                                      A2310
0201              TEMY=0.                                                      A2320
0202              DO 440 J=1,ND                                                A2330
0203              TEMX=TEMX+OBSX(I,J)*SOL(J)                                   A2340
0204        440 TEMY=TEMY+OBSY(I,J)*SOL(J)                                     A2350
0205              VX=(TEMX-OBSX(I,ND))                                         A2360
0206              VY=(TEMY-OBSY(I,ND))                                         A2370
0207              ZP=VX*SCFAC                                                  A2380
0208              ZQ=VY*SCFAC                                                  A2390
0209              TRUX=AMX(I)-ZP                                               A2400
0210              TRUY=AMY(I)-ZQ                                               A2410
0211              FXRAD=DSQRT(PX(I)**2+PY(I)**2)                               A2420
0212              OBRAD=DSQRT((OBSX(I,ND)-PX(I))**2+(OBSY(I,ND)-PY(I))**2)     A2430
0213              DSTRT=OBRAD-FXRAD                                            A2440
0214              WRITE (6,450) IDENT(I),TRUX,ZP,TRUY,ZQ,OBRAD,FXRAD,DSTRT     A2450
0215        450 FORMAT (I5,2(F12.3,F9.3),5X,3(F9.3,5X))                        A2460
0216              PUQ=PUQ+ZP**2+ZQ**2                                          A2470
0217        460 PUU=PUU+VX**2+VY**2                                            A2480
0218              STD=DSQRT(PUU/(2*NPTS-ND))                                   A2490
0219              STDM=SQRT(PUQ/(2*NPTS-ND))                                   A2500
0220              WRITE (6,470) STD                                            A2510
0221        470 FORMAT (1H0,1X,'STANDARD ERROR OF UNIT WEIGHT OF PLATE GRID COORDI  A2520
                1NATES =',F8.5)                                                A2521
0222              WRITE (6,480)                                                A2530
0223        480 FORMAT (1H0,5X,'VARIANCE-COVARIANCE MATRIX')                   A2540
0224              DO 490 I=1,ND                                                A2550
0225              DO 490 J=1,ND                                                A2560
0226        490 VCV(I,J)=STD**2*U(I,J)                                         A2570
0227              DO 500 I=1,6                                                 A2580
0228        500 WRITE (6,510) I,(VCV(I,J),J=1,6)                               A2590
```

```
0229       510 FORMAT (I4,3X,6D15.8)                                                  A2600
0230           STDX=(STD*DSQRT(U(4,4)))                                               A2610
0231           STDY=(STD*DSQRT(U(5,5)))                                               A2620
0232           STDZ=(STD*DSQRT(U(6,6)))                                               A2630
0233           STDO=(STD*DSQRT(U(1,1))*CONV)                                          A2640
0234           STDP=(STD*DSQRT(U(2,2))*CONV)                                          A2650
0235           STDK=(STD*DSQRT(U(3,3))*CONV)                                          A2660
0236           WRITE (6,520) STDX,STDY,STDZ,STDO,STDP,STDK,STD4                       A2670
0237       520 FORMAT (1H0,1X,'STANDARD ERRORS OF THE PERSPECTIVE CENTER PARAMETE     A2680
              1RS'/14X,'X COORDINATE =',F8.5/14X,'Y COORDINATE =',F8.5/14X,'Z COO     A2690
              2RDINATE =',F8.5/14X,'OMEGA (MINUTES) =',F8.5/14X,'PHI   (MINUTES)      A2700
              3=',F8.5/14X,'KAPPA (MINUTES) =',F8.5//2X,'STANDARD ERROR OF PROJEC     A2710
              4TED COORDINATES IN THE MODEL SPACE =',F8.5)                            A2720
0238           IF (ICALF.LE.1) GO TO 10                                               A2740
0239           IF (ITEST.EQ.ICALF) GO TO 10                                           A2750
0240           ITEST=ITEST+1                                                          A2760
0241           WRITE (6,530) ITEST                                                    A2770
0242       530 FORMAT (1H1,'DATA SET',I3)                                             A2780
0243           GO TO 80                                                               A2790
0244       540 STOP                                                                   A2810
0245           END                                                                    A2820
```

SCALAR MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
XSCAL	1B8	YSCAL	1C0	SINALP	1C8	SUMX	1D0	SUMY	1D8
SMALX	1E0	SMALY	1E8	ABSV	1F0	SZ	1F8	ROMEGA	200
AFHI	208	RKAPPA	210	A	218	B	220	C	228
AP	230	BP	238	CP	240	CM11	248	CM21	250
CM32	258	CM33	260	CN11	268	CN21	270	CN32	278
CN33	280	CN12	288	CN13	290	CN22	298	CN23	2A0
CM12	2A8	CM13	2B0	CM22	2B8	CM23	2C0	DELX	2C8
DELY	2D0	DELZ	2D8	SX	2E0	SY	2E8	K	2F0
S	2F8	T	300	DET	308	PUU	310	SCFAC	318
TEMX	320	TEMY	328	FXRAD	330	OBRAD	338	DSTRT	340
CONV	348	I	34C	NPTS	350	ICALF	354	ICOR	358
FCCAL	35C	GDIF	360	ITEST	364	AOMEGA	368	APHI	36C
AKAPPA	370	XE	374	YE	378	ZE	37C	NRDG	380
ID	384	ILST	388	HC	38C	XDEV	390	YDEV	394
I1	398	ITER	39C	IFIN	3A0	J	3A4	NO	3A8
K	3AC	ND	3B0	DOM	3B4	DPHI	3B8	DKAP	3BC
DX	3C0	DY	3C4	DZ	3C8	PUQ	3CC	VX	3D0
VY	3D4	ZP	3D8	ZQ	3DC	TRUX	3E0	TRUY	3E4
SID	3E8	SIDM	3EC	STDX	3F0	STDY	3F4	STDZ	3F8
STDO	3FC	STDP	400	STDK	404				

25

ARRAY MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
N	406	AMX	590	AMY	720	OBSX	8B0	OBSY	13A0
U	1E90	SOL	1FBC	VCV	1FE0	PX	2100	PY	2290
TITLE	2420	IDENT	2470	FMT	2538	FM	2588	TMX	25D8
TMY	26A0	TMH	2768	DEX	2830	DEY	28F8	NRD	29C0
L1	2A88	M1	2AA0						

SUBPROGRAMS CALLED

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
IBCOM#	2AB8	RMSE	2ABC	DMINV	2AC0	DMIN1	2AC4	DSIN	2AC8
DCOS	2ACC	SQRT	2AD0	DSQRT	2AD4				

FORMAT STATEMENT MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
20	2B64	30	2B6A	40	2B98	50	2BA6	90	2BAD
140	2BB4	160	2BEE	200	2C17	210	2C90	220	2D6C
300	2DC0	330	2DEB	340	2DF9	370	2E22	380	2E6D
390	2EAC	400	2EB5	420	2EE3	450	2F8D	470	2FA4
480	2FE9	510	30CC	520	3017	530	3126		

TOTAL MEMORY REQUIREMENTS 0048A4 BYTES

```
      SUBROUTINE RMSE (NUM,XAR,YAR,XDEV,YDEV)
      DIMENSION XAR(50), YAR(50)
      SUMXR=0.
      SUMYR=0.
      SXX=0.
      SYY=0.
      IF (NUM.LT.2) GO TO 30
      DO 10 I=1,NUM
      SUMXR=SUMXR+XAR(I)
   10 SUMYR=SUMYR+YAR(I)
      SN=NUM
      XMEAN=SUMXR/SN
      YMEAN=SUMYR/SN
      DO 20 I=1,NUM
      SXX=SXX+(XAR(I)-XMEAN)**2
   20 SYY=SYY+(YAR(I)-YMEAN)**2
      XDEV=SQRT(SXX/(SN-1.0))
      YDEV=SQRT(SYY/(SN-1.0))
   30 RETURN
      END
```

```
FORTRAN IV G LEVEL 1, MOD 3          RMSE          DATE = 69106          15/50/07          PAGE 0002

                                  SCALAR MAP
SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION
SUMXR        44         SUMYR        A6         SXX          AC         SYY          B0         NUM          B4
I            B8         SN           6C         XMEAN        C0         YMEAN        C4         XDEV         C8
YDEV         CC

                                  ARRAY MAP
SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION
XAR          D0         YAR          D4

                                  SUBPROGRAMS CALLED
SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION
SQRT         D8

   TOTAL MEMORY REQUIREMENTS 00030A BYTES
```

```
      SUBROUTINE DMINV (A,N,D,L,M)
      DIMENSION A(1), L(1), M(1)
      REAL*8 A,D,BIGA,HOLD
      D=1.0
      NK=-N
      DO 180 K=1,N
      NK=NK+N
      L(K)=K
      M(K)=K
      KK=NK+K
      BIGA=A(KK)
      DO 20 J=K,N
      IZ=N*(J-1)
      DO 20 I=K,N
      IJ=IZ+I
      IF (DABS(BIGA)-DABS(A(IJ))) 10,20,20
   10 BIGA=A(IJ)
      L(K)=I
      M(K)=J
   20 CONTINUE
      J=L(K)
      IF (J-K) 50,50,30
   30 KI=K-N
      DO 40 I=1,N
      KI=KI+N
      HOLD=-A(KI)
      JI=KI-K+J
      A(KI)=A(JI)
   40 A(JI)=HOLD
   50 I=M(K)
      IF (I-K) 80,80,60
   60 JP=N*(I-1)
      DO 70 J=1,N
      JK=NK+J
      JI=JP+J
      HOLD=-A(JK)
      A(JK)=A(JI)
   70 A(JI)=HOLD
   80 IF (BIGA) 100,90,100
   90 D=0.
      RETURN
  100 DO 120 I=1,N
      IF (I-K) 110,120,110
  110 IK=NK+I
      A(IK)=A(IK)/(-BIGA)
  120 CONTINUE
      DO 150 I=1,N
      IK=NK+I
      HOLD=A(IK)
      IJ=I-N
      DO 150 J=1,N
      IJ=IJ+N
```

```
          IF (I-K) 130,150,130
      130 IF (J-K) 140,150,140
      140 KJ=IJ-I+K
          A(IJ)=HOLD*A(KJ)+A(IJ)
      150 CONTINUE
          KJ=K-N
          DO 170 J=1,N
          KJ=KJ+N
          IF (J-K) 160,170,160
      160 A(KJ)=A(KJ)/BIGA
      170 CONTINUE
          D=D*BIGA
          A(KK)=1./BIGA
      180 CONTINUE
          K=N
      190 K=K-1
          IF (K) 260,260,200
      200 I=L(K)
          IF (I-K) 230,230,210
      210 JQ=N*(K-1)
          JR=N*(I-1)
          DO 220 J=1,N
          JK=JQ+J
          HOLD=A(JK)
          JI=JR+J
          A(JK)=-A(JI)
      220 A(JI)=HOLD
      230 J=M(K)
          IF (J-K) 190,190,240
      240 KI=K-N
          DO 250 I=1,N
          KI=KI+N
          HOLD=A(KI)
          JI=KI-K+J
          A(KI)=-A(JI)
      250 A(JI)=HOLD
          GO TO 190
      260 RETURN
          END
```

SCALAR MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
D	168	BIGA	170	HOLD	178	NK	180	N	184
K	188	KK	18C	J	190	IZ	194	I	198
IJ	19C	KI	1A0	JI	1A4	JP	1A8	JK	1AC
IK	1B0	KJ	1B4	JQ	1B8	JR	1BC		

ARRAY MAP

SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
A	1C0	L	1C4	M	1C8				

TOTAL MEMORY REQUIREMENTS 00083C BYTES

F88-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED LET,LIST,MAP
VARIABLE OPTIONS USED - SIZE=(94208,45056)　　　DEFAULT OPTION(S) USED
IEW0000　　NAME W5344

MODULE MAP

CONTROL SECTION			ENTRY							
NAME	ORIGIN	LENGTH	NAME	LOCATION	NAME	LOCATION	NAME	LOCATION	NAME	LOCATION
MAIN	00	48A4								
RMSE	48A8	30A								
DMINV	4DB8	83C								
IHCLSCN *	53F8	27C	DCOS	53F8	DSIN	5416				
IHCFMAXD*	5678	6D	DMAX1	5678	DMIN1	568E				
IHCLSQRT*	56E8	142	DSQRT	56E8						
IHCFCOMH*	5830	DA1	IBCOM#	5830	FDIOCS#	58EC	INTSWTCH	65BE		
IHCCOMH2*	65D8	1D8	SEQDASD	66A6						
IHCSSQRT*	67B0	149	SQRT	67B0						
IHCFCVTH*	6900	116D	ADCON#	6900	FCVAOUTP	69AA	FCVLOUTP	6A3A	FCVZOUTP	6B8A
			FCVIOUTP	6F16	FCVEOUTP	7418	FCVCOUTP	7632	INT6SWCH	7913
IHCFINTH*	7A70	39E	ARITH#	7A70	ADJSWTCH	7D28				
IHCFIOSH*	7E10	DE1	FIOCS#	7E10						
IHCTRCH *	8BF8	2E4	IHCERRM	8BF8						
IHCUOPT *	8EE0	8								
IHCUATBL*	8EE8	638								

ENTRY ADDRESS　　00
TOTAL LENGTH　　9520

****W5344　　NOW ADDED TO DATA SET

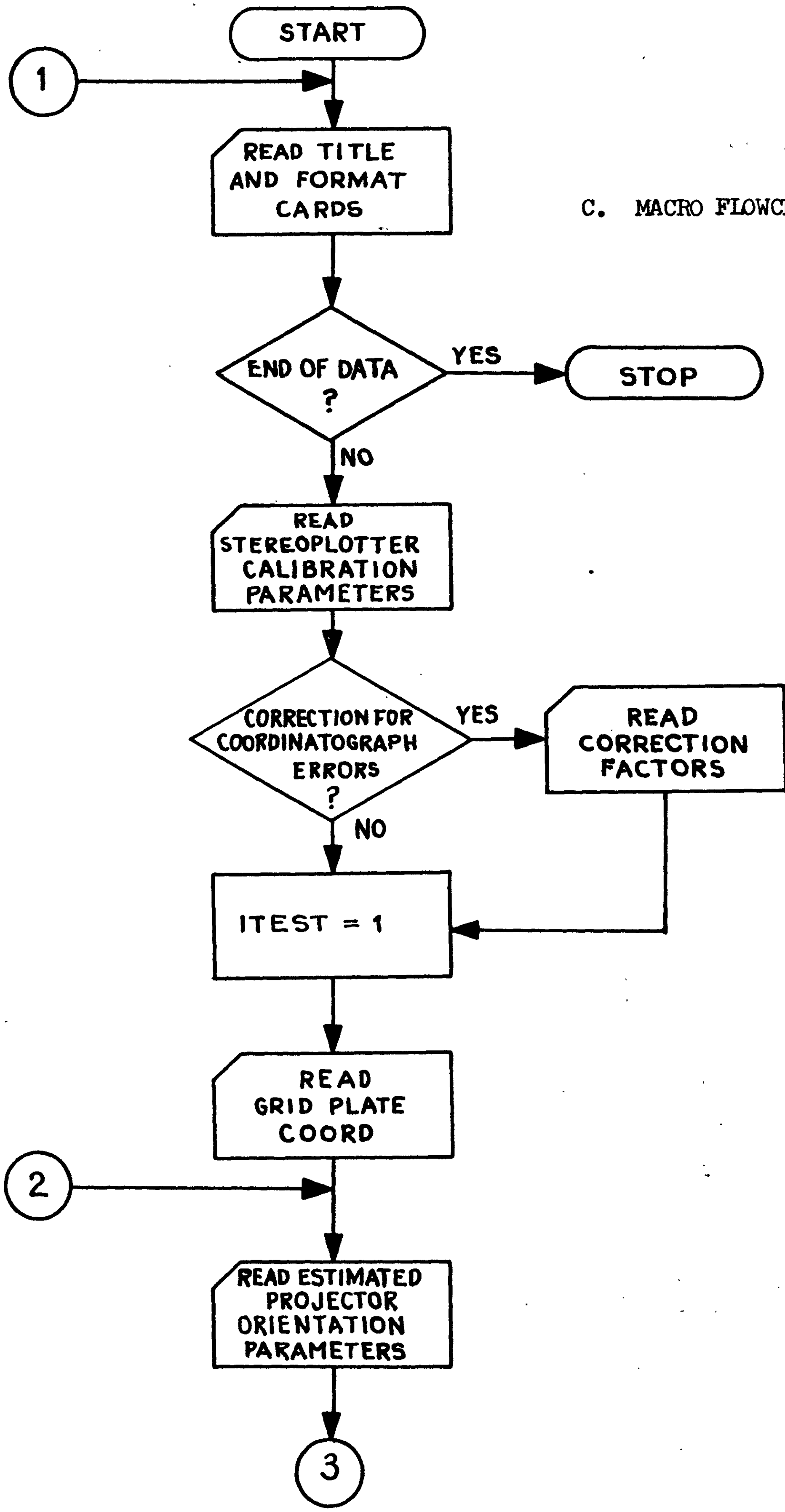
B. SYMBOLS AND VARIABLES

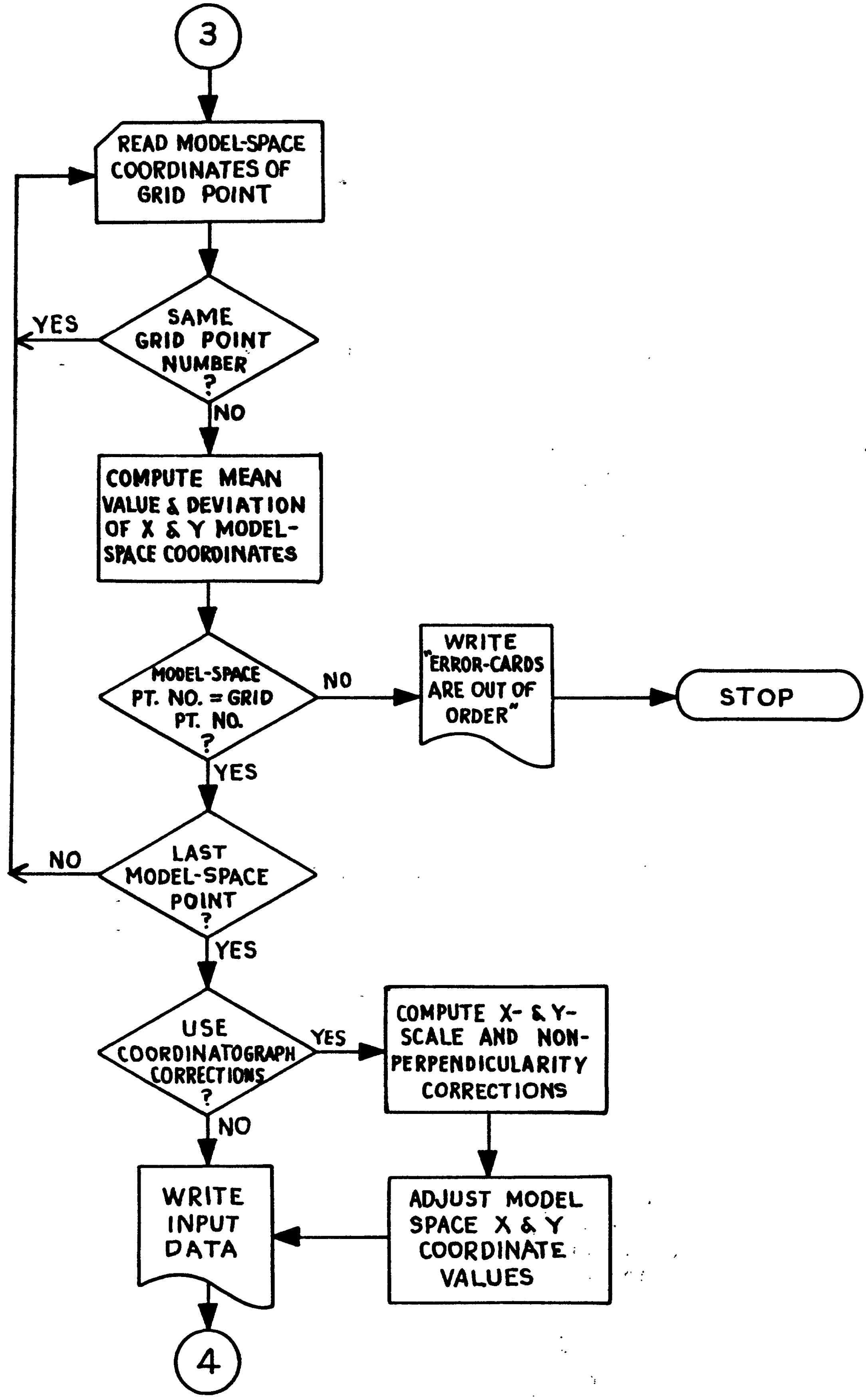
TITLE	Array containing title information.
FM	Array containing the format for reading plate grid coordinates.
FMT	Array containing the format for reading projected grid coordinates.
NPTS	Number of grid points used in computation.
ICALF	Number of sets of data using the same set of plate grid points and coordinates.
ICOR	Code indicating whether projected grid coordinates should be corrected for coordinatograph errors.
FOCAL	Principal distance of the projector.
GDIF	Tolerance for testing the solution for convergence.
XSCAL, YSCAL, SINALP	Coordinatograph correction factors.
ITEST	Code to count the number of data sets that have been computed with the same grid points and coordinates.
IDENT, PX, PY	Arrays containing the point number, and X and Y coordinates of the plate grid intersections.
AOMEGA, APHI AKAPPA	Unknown angular elements in minutes.
XE, YE, ZE	Unknown coordinates of the perspective center.
SUMX, SUMY, ID, ILST, XDEV, YDEV	Variables used in handling multiple reading data for each point.
NRDG	Number of readings on a point.
ID	Point number of projected grid reading.
TMX, TMY, TMH	Arrays containing the X, Y, and Z readings on a point.

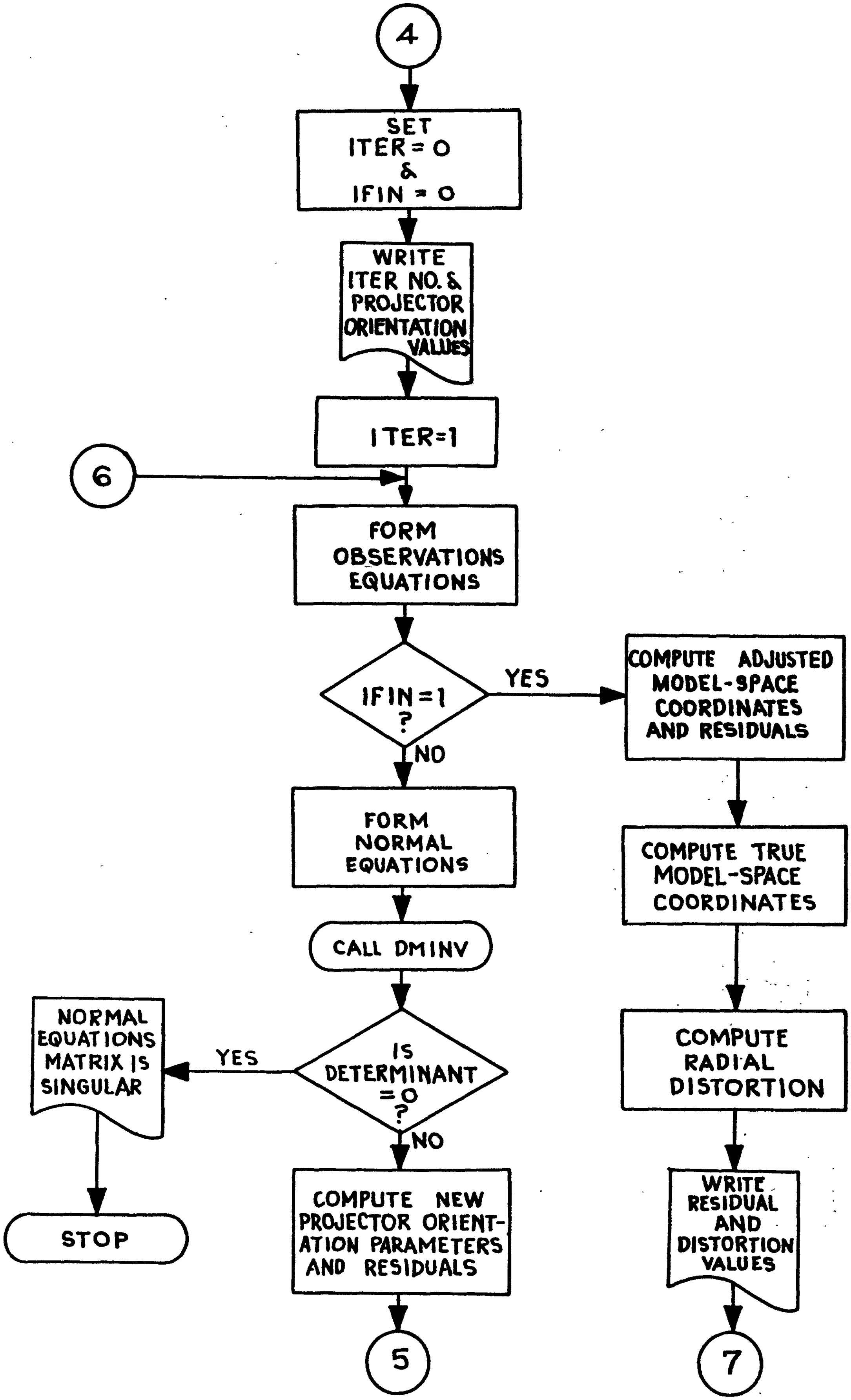
AMX, AMY	Arrays containing the mean X and Y readings on the projected grid points.
DEX, DEY	Arrays containing the standard deviation of the X and Y readings for each point.
NRD	Arrays containing the number of readings on each point.
SMALX, SMALY, ABSV	Variables used in correcting the mean readings for coordinatograph errors.
ITER	Number of present iteration.
SZ	The principal distance with a negative sign.
ROMEGA, RPHI, RKAPPA	Unknown angular elements in radians.
CONV	Factor used to convert minutes to radians.
OBSX, OBSY	Matrices of the observation equations.
N	Augmented normal equations coefficient matrix.
A, B, C, AP, BP, CP	Sines and cosines of the unknown angles.
CM11, CM12, CM13, CM21, CM22, CM23, CM32, CM33, CN11, CN12, CN13, CN21, CN22, CN23, CN32, CN33, R, S, T, DELX, DELY, DELZ	Variables used in forming observation equations.
SX, SY	Plate grid coordinates.
ND	Number of unknowns.
NO	Number of unknowns plus one.
U	Normal equations coefficient matrix and later the inverse of the normal equations coefficient matrix.
DET	Code indicating a correct return from the matrix inversion subroutine.
SOL	Array containing corrections to unknowns.

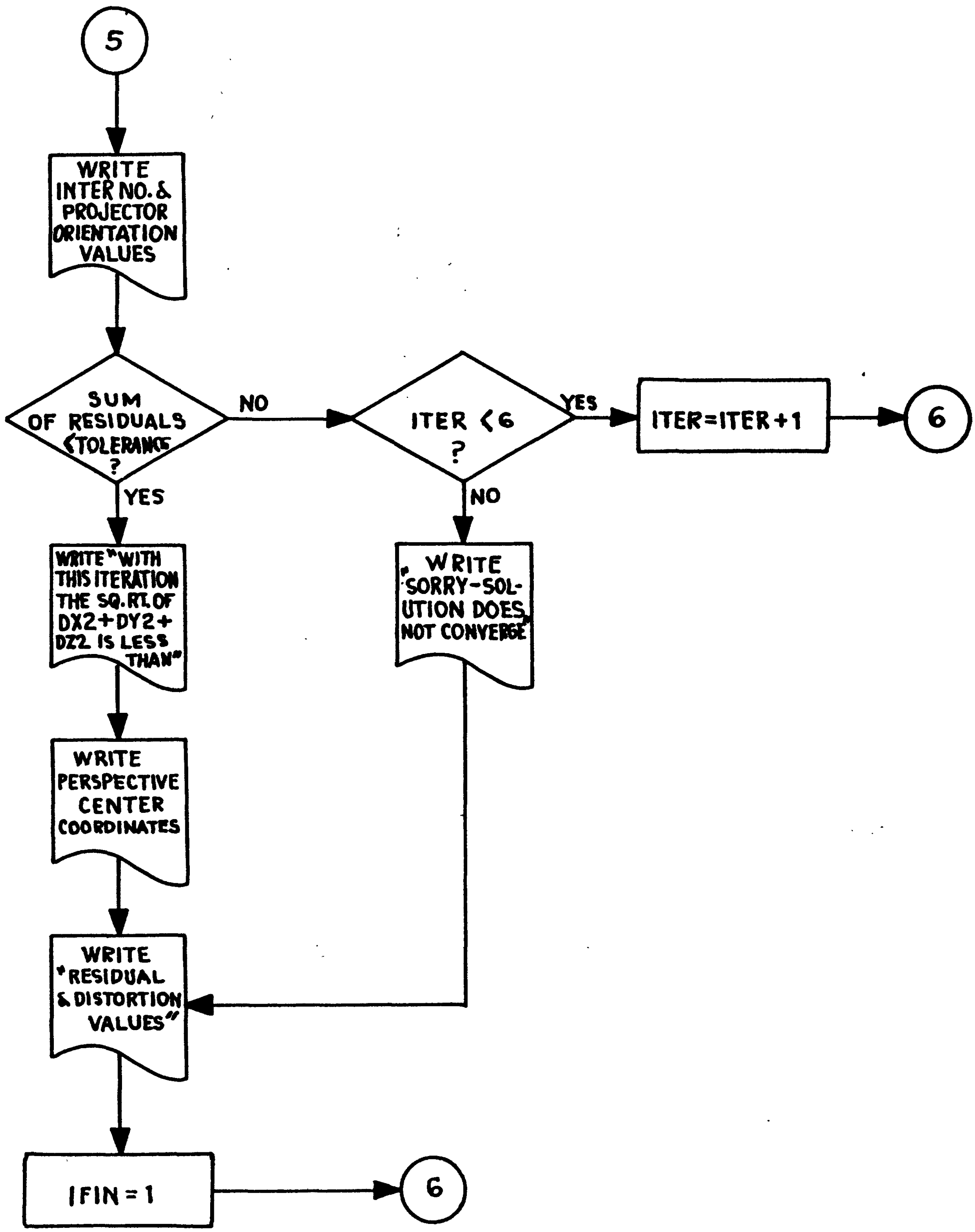
DX, DY, DZ, DOM, DPHI, DKAP	Corrections to unknowns.
PUU, PUQ	Sum of the squares of the residuals.
VX, VY	x and y residuals in the plate grid coordinates.
ZP, ZQ	X and Y residuals in the projected plane.
SCFAC	Scale factor for converting plate grid coordinates to projected grid coordinates.
TRUX, TRUY	Computed projected grid coordinates.
OBRAD	Observed radius from principal point to grid.
FXRAD	True radius from principal point to grid intersection.
DSTRT	Radial distortion.
STD	Standard error of unit weight of plate grid coordinates.
STDM	Standard error of projected grid coordinates in the model space.
VCV	Variance-covariance matrix.
STDX, STDY, STDZ, STDO, STDP, STDK	Standard errors of the unknowns.
X, STD DEV Y, STD DEV	Standard deviations of readings of projected coordinates.

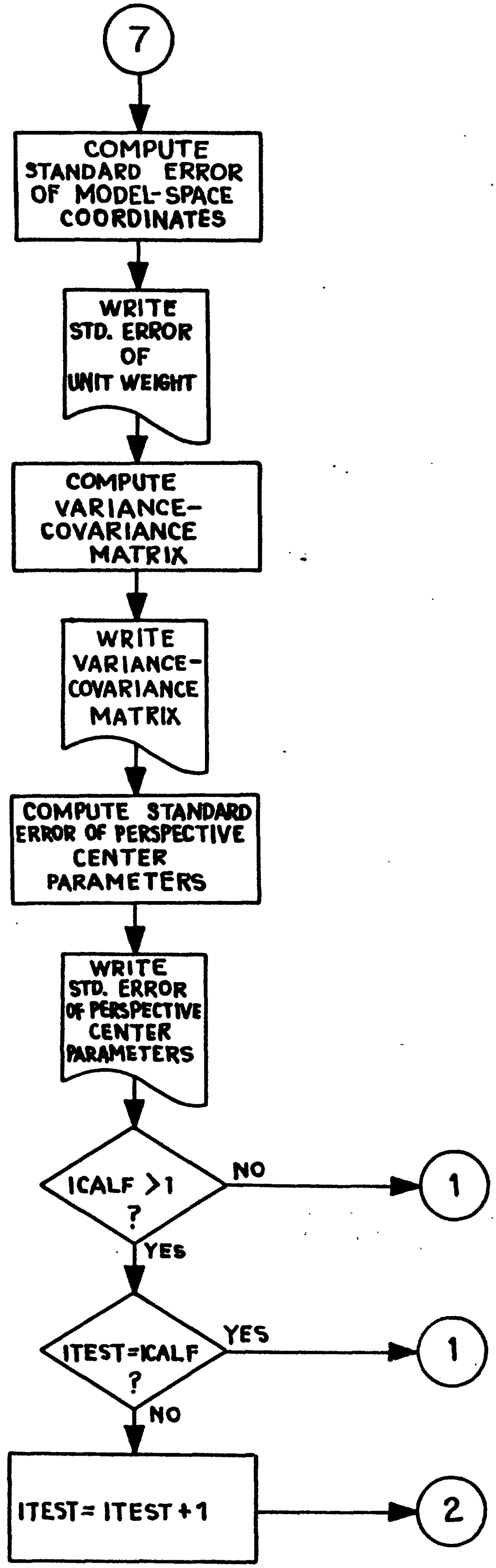
C. MACRO FLOWCHART




3
READ MODEL-SPACE COORDINATES OF GRID POINT
SAME GRID POINT NUMBER ?
YES
NO
COMPUTE MEAN VALUE & DEVIATION OF X & Y MODEL-SPACE COORDINATES
MODEL-SPACE PT. NO. = GRID PT. NO. ?
NO
WRITE "ERROR-CARDS ARE OUT OF ORDER"
STOP
YES
LAST MODEL-SPACE POINT ?
NO
YES
USE COORDINATOGRAPH CORRECTIONS ?
YES
COMPUTE X- & Y-SCALE AND NON-PERPENDICULARITY CORRECTIONS
NO
WRITE INPUT DATA
ADJUST MODEL SPACE X & Y COORDINATE VALUES
4


4
SET ITER=0 & IFIN=0
WRITE ITER NO. & PROJECTOR ORIENTATION VALUES
ITER=1
6
FORM OBSERVATIONS EQUATIONS
IFIN=1 ?
YES
NO
COMPUTE ADJUSTED MODEL-SPACE COORDINATES AND RESIDUALS
COMPUTE TRUE MODEL-SPACE COORDINATES
COMPUTE RADIAL DISTORTION
WRITE RESIDUAL AND DISTORTION VALUES
7
FORM NORMAL EQUATIONS
CALL DMINV
IS DETERMINANT =0 ?
YES
NO
NORMAL EQUATIONS MATRIX IS SINGULAR
STOP
COMPUTE NEW PROJECTOR ORIENTATION PARAMETERS AND RESIDUALS
5


5
WRITE INTER NO. & PROJECTOR ORIENTATION VALUES
SUM OF RESIDUALS <TOLERANCE ?
NO
YES
ITER <6 ?
YES
NO
ITER=ITER+1
6
WRITE "WITH THIS ITERATION THE SQ. RT. OF DX2+DY2+DZ2 IS LESS THAN"
WRITE "SORRY-SOLUTION DOES NOT CONVERGE"
WRITE PERSPECTIVE CENTER COORDINATES
WRITE "RESIDUAL & DISTORTION VALUES"
IFIN=1
6


7
COMPUTE STANDARD ERROR OF MODEL-SPACE COORDINATES
WRITE STD. ERROR OF UNIT WEIGHT
COMPUTE VARIANCE-COVARIANCE MATRIX
WRITE VARIANCE-COVARIANCE MATRIX
COMPUTE STANDARD ERROR OF PERSPECTIVE CENTER PARAMETERS
WRITE STD. ERROR OF PERSPECTIVE CENTER PARAMETERS
ICALF >1 ?
NO
1
YES
ITEST=ICALF ?
YES
1
NO
ITEST= ITEST+1
2

D. PRINTED OUTPUT

PERSPECTIVE CENTER DETERMINATION

A-7 NO.310 DATA FROM INTERNATIONAL TESTS - HALLERT ISP SUB-COMM IVC4

COORDINATOGRAPH ERRORS CORRECTED

THE NUMBER OF POINTS USED ON THIS PLATE IS 33
THE ASSUMED PRINCIPAL DISTANCE USED IN THESE COMPUTATIONS IS 150.000

COORDINATES OF INPUT DATA

PT NO	NO. OF READINGS	CALIBRATED GRID COORD X	Y	PROJECTED GRID COORDINATES MEAN X	X STD DEV	MEAN Y	Y STD DEV	Z
0	1	0.0	0.0	500.026	0.0	500.002	0.0	0.0
11	1	20.000	20.000	540.054	0.0	540.012	0.0	0.0
21	1	-20.000	20.000	460.017	0.0	540.034	0.0	0.0
31	1	-20.000	-20.000	459.999	0.0	460.005	0.0	0.0
41	1	20.000	-20.000	540.024	0.0	459.978	0.0	0.0
12	1	40.000	40.000	580.105	0.0	580.032	0.0	0.0
22	1	-40.000	40.000	420.004	0.0	580.073	0.0	0.0
32	1	-40.000	-40.000	419.957	0.0	419.983	0.0	0.0
42	1	40.000	-40.000	580.040	0.0	419.958	0.0	0.0
13	1	60.000	60.000	620.112	0.0	620.042	0.0	0.0
23	1	-60.000	60.000	380.002	0.0	620.102	0.0	0.0
33	1	-60.000	-60.000	379.925	0.0	379.981	0.0	0.0
43	1	60.000	-60.000	620.042	0.0	379.934	0.0	0.0
14	1	80.000	80.000	660.154	0.0	660.058	0.0	0.0
24	1	-80.000	80.000	340.009	0.0	660.132	0.0	0.0
34	1	-80.000	-80.000	339.930	0.0	340.000	0.0	0.0
44	1	80.000	-80.000	660.054	0.0	339.900	0.0	0.0
15	1	100.000	100.000	700.170	0.0	700.072	0.0	0.0
25	1	-100.000	100.000	299.986	0.0	700.181	0.0	0.0
35	1	-100.000	-100.000	299.892	0.0	299.971	0.0	0.0
45	1	100.000	-100.000	700.052	0.0	299.867	0.0	0.0
101	1	0.0	100.000	500.096	0.0	700.114	0.0	0.0
102	1	-60.000	80.000	380.011	0.0	660.120	0.0	0.0
103	1	-80.000	60.000	340.002	0.0	620.118	0.0	0.0
104	1	-100.000	0.0	299.932	0.0	500.052	0.0	0.0
105	1	-80.000	-60.000	339.932	0.0	380.004	0.0	0.0
106	1	-60.000	-80.000	379.922	0.0	339.977	0.0	0.0
107	1	0.0	-100.000	499.962	0.0	299.932	0.0	0.0
108	1	60.000	-80.000	620.035	0.0	339.922	0.0	0.0
109	1	80.000	-60.000	660.070	0.0	379.910	0.0	0.0
110	1	100.000	0.0	700.118	0.0	499.950	0.0	0.0
111	1	80.000	60.000	660.138	0.0	620.039	0.0	0.0
112	1	60.000	80.000	620.128	0.0	660.060	0.0	0.0

ITER	X	Y	Z	DX	DY	DZ	OMEGA	PHI	KAPPA
0	500.00	500.00	300.00				0.0	0.0	0.0
1	500.02	499.99	300.14	0.0215	-0.0091	0.1388	0.2354	-0.0543	-0.9418
2	500.02	499.99	300.14	0.0002	0.0001	0.0002	0.2355	-0.0543	-0.9418

WITH THIS ITERATION THE SQUARE ROOT OF DX2+DY2+DZ2 IS LESS THAN 0.001

COORDINATES OF THE PERSPECTIVE CENTER

X	Y	Z
500.02	499.99	300.14

STEREOPLOTTER CALIBRATION INFORMATION

RESIDUAL AND DISTORTION VALUES

POINT NO.	PROJECTED X	VX	PROJECTED Y	VY	OBSERVED RADIUS	FIXED RADIUS	RADIAL DISTORTION
0	500.026	-0.000	500.011	-0.009	0.005	0.0	0.005
11	540.056	-0.002	540.019	-0.007	28.281	28.284	-0.003
21	460.018	-0.002	540.041	-0.007	28.282	28.284	-0.002
31	459.997	0.002	460.004	0.001	28.283	28.284	-0.001
41	540.033	-0.010	459.982	-0.004	28.283	28.284	-0.002
12	580.087	0.018	580.028	0.004	56.576	56.569	0.008
22	420.010	-0.006	580.071	0.002	56.571	56.569	0.003
32	419.969	-0.012	419.998	-0.015	56.578	56.569	0.010
42	580.040	-0.000	419.953	0.004	56.567	56.569	-0.002
13	620.119	-0.007	620.038	0.004	84.852	84.853	-0.001
23	380.001	0.001	620.102	-0.001	84.852	84.853	-0.001
33	379.942	-0.017	379.993	-0.012	84.863	84.853	0.010
43	620.046	-0.004	379.925	0.008	84.848	84.853	-0.004
14	660.151	0.002	660.049	0.009	113.141	113.137	0.004
24	339.991	0.017	660.134	-0.002	113.130	113.137	-0.007
34	339.915	0.014	339.988	0.012	113.128	113.137	-0.009
44	660.052	0.002	339.898	0.002	113.137	113.137	0.000
15	700.185	-0.015	700.060	0.011	141.420	141.421	-0.001
25	299.981	0.004	700.166	0.015	141.425	141.421	0.004
35	299.890	0.002	299.985	-0.014	141.426	141.421	0.004
45	700.057	-0.005	299.871	-0.004	141.421	141.421	-0.000
101	500.081	0.015	700.113	0.001	100.000	100.000	0.000
102	380.011	0.000	660.123	-0.003	99.999	100.000	-0.001
103	339.982	0.020	620.113	0.005	99.993	100.000	-0.007
104	299.936	-0.004	500.066	-0.014	100.002	100.000	0.002
105	339.925	0.007	380.004	-0.000	99.997	100.000	-0.003
106	379.932	-0.010	339.977	-0.000	100.003	100.000	0.003
107	499.971	-0.009	299.928	0.004	99.998	100.000	-0.002
108	620.034	0.001	339.909	0.013	99.995	100.000	-0.005
109	660.064	0.005	379.914	-0.004	100.004	100.000	0.004
110	700.121	-0.003	499.957	-0.007	99.999	100.000	-0.001
111	660.139	-0.001	620.027	0.011	100.003	100.000	0.003
112	620.131	-0.003	660.059	0.000	99.999	100.000	-0.001

STANDARD ERROR OF UNIT WEIGHT OF PLATE GRID COORDINATES = 0.00447

VARIANCE-COVARIANCE MATRIX

```
1    0.377362850D-09 0.559134130D-14 0.173016810D-14 0.163760880D-11-0.135837510D-06-0.131821540D-10
2    0.559134130D-14 0.377404090D-09-0.173955540D-13 0.135851670D-06-0.163774460D-11 0.318442310D-11
3    0.173016810D-14-0.173955540D-13 0.673942210D-10-0.653006120D-11-0.574592190D-12-0.200985460D-15
4    0.163760880D-11 0.135851670D-06-0.653006120D-11 0.513218910D-04-0.454516560D-09 0.112684450D-08
5   -0.135837510D-06-0.163774460D-11-0.574592190D-12-0.454516560D-09 0.513170420D-04 0.466084640D-08
6   -0.131821540D-10 0.318442310D-11-0.200985460D-15 0.112684450D-08 0.466084640D-08 0.607109580D-05
```

STANDARD ERRORS OF THE PERSPECTIVE CENTER PARAMETERS

X COORDINATE = 0.00716
Y COORDINATE = 0.00716
Z COORDINATE = 0.00246
OMEGA (MINUTES) = 0.06678
PHI (MINUTES) = 0.06678
KAPPA (MINUTES) = 0.02822

STANDARD ERROR OF PROJECTED COORDINATES IN THE MODEL SPACE = 0.00894