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,
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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:

\[
x = \frac{(X-X_c) m_{11} + (Y-Y_c) m_{12} + (Z-Z_c) m_{13}}{(X-X_c) m_{31} + (Y-Y_c) m_{32} + (Z-Z_c) m_{33}} \quad (1)
\]

\[
y = \frac{(X-X_c) m_{21} + (Y-Y_c) m_{22} + (Z-Z_c) m_{23}}{(X-X_c) m_{31} + (Y-Y_c) m_{32} + (Z-Z_c) m_{33}} \quad (2)
\]

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 \( \omega, \phi, \) and \( \kappa \) are the unknown angular parameters. These last six parameters are the unknowns whose values will be determined in the resection.
The angles $\omega$, $\phi$, and $\kappa$ are related to the $m$'s as follows:

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

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

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:

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

\[ \quad + d\phi \{ y [(X-X_c)n_{31} + (Y-Y_c)n_{32} + (Z-Z_c)n_{33}] \]
\[ \quad - z [(X-X_c)n_{21} + (Y-Y_c)n_{22} + (Z-Z_c)n_{23}] \} + \frac{1}{R} \]

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

\[ = \] (1/R)

\[ = dX_c \quad y m_{31} - z m_{32} \]
\[ = dY_c \quad y m_{32} - z m_{33} \]
\[ = dZ_c \quad y m_{33} - z m_{33} \]

where

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

\[ m_{11} = \cos \phi \cos \kappa \]
\[ m_{12} = \cos \phi \sin \kappa + \sin \omega \sin \phi \cos \kappa \]
\[ m_{13} = \sin \omega \sin \phi - \cos \phi \sin \kappa \]
\[ m_{21} = -\cos \phi \sin \kappa \]
\[ m_{22} = \cos \omega \cos \kappa + \sin \omega \sin \phi \sin \kappa \]
\[ m_{23} = \sin \omega \cos \kappa + \cos \phi \sin \kappa \]
\[ m_{31} = \sin \phi \]
\[ m_{32} = -\sin \omega \cos \phi \]
\[ m_{33} = \cos \omega \cos \phi \]
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 \( X_c, Y_c, Z_c, \omega, \phi, \) and \( \kappa \) 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:

\[ X = (A^T A)^{-1} A^T L \]

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
- \( L \) is the vector of constant terms in the observation equations.
The following expression is computed:

\[ \text{TEST} = \sqrt{dX_c^2 + dY_c^2 + dZ_c^2} \]

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:

\[ \text{STD} = \sqrt{\frac{\sum v_X^2 + v_Y^2}{2(n-\mu)}} \]

where \( v_X \) and \( v_Y \) are the X and Y residuals

\( n \) is the number of points used

and \( \mu \) 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 coordinateograph 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

<table>
<thead>
<tr>
<th>Input Item</th>
<th>Column Number</th>
<th>Format</th>
<th>Program Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any alphabetic information</td>
<td>1-80</td>
<td>20A4</td>
<td>TITLE (1) thru TITLE (20)</td>
</tr>
</tbody>
</table>
### Card 2--Input Format for Precise Grid Data

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

### Card 3--Input Format for Measured Coordinates

<table>
<thead>
<tr>
<th>Input Item</th>
<th>Column Number</th>
<th>Format</th>
<th>Program Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any desired format for reading measured coordinates. Four fields must be provided in the following order:</td>
<td>1-80</td>
<td>20A4</td>
<td>FMT (1) thru FMT (20)</td>
</tr>
<tr>
<td>Field 1--Point number</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field 2--x coordinate of point</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field 3--y coordinate of point</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field 4--z coordinate of point</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Example: (I4,3F10.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Card 4--Specifications

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

### 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-l--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.

<table>
<thead>
<tr>
<th>Input Item</th>
<th>Column Number</th>
<th>Format</th>
<th>Program Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field 1-- Point number. (see card 2.)</td>
<td></td>
<td>Column nos. are specified by format on card 2.</td>
<td>IDENT(I) where I designates the Ith grid intersection.</td>
</tr>
<tr>
<td>Field 2--x coordinate of grid intersection.</td>
<td></td>
<td>Same as above</td>
<td>PX(I) where I designates the Ith grid intersection.</td>
</tr>
<tr>
<td>Field 3--y coordinate of grid intersection.</td>
<td></td>
<td>Same as above</td>
<td>PY(I)</td>
</tr>
</tbody>
</table>
Card I--Initial Approximations to Unknowns--The units for $X_c$, $Y_c$, and $Z_c$ are in the same units as the projected coordinates.

<table>
<thead>
<tr>
<th>Input Item</th>
<th>Column Number</th>
<th>Format</th>
<th>Program Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial value for $\omega$ in minutes</td>
<td>1-10</td>
<td>F10.0</td>
<td>AOMEGA</td>
</tr>
<tr>
<td>Initial value for $\phi$ in minutes</td>
<td>11-20</td>
<td>F10.0</td>
<td>APHI</td>
</tr>
<tr>
<td>Initial value for $\kappa$ in minutes</td>
<td>21-30</td>
<td>F10.0</td>
<td>AKAPPA</td>
</tr>
<tr>
<td>Initial value for $X_c$</td>
<td>31-40</td>
<td>F10.0</td>
<td>XE</td>
</tr>
<tr>
<td>Initial value for $Y_c$</td>
<td>41-50</td>
<td>F10.0</td>
<td>YE</td>
</tr>
<tr>
<td>Initial value for $Z_c$</td>
<td>51-60</td>
<td>F10.0</td>
<td>ZE</td>
</tr>
</tbody>
</table>

Cards I+1 thru M-1--Projected Grid Coordinates (see fig. 2)--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.

<table>
<thead>
<tr>
<th>Input Item</th>
<th>Column Number</th>
<th>Format</th>
<th>Program Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field 1--Point number</td>
<td>Column nos. as specified by format on card 3.</td>
<td>Integer with length of field specified by format on card 3.</td>
<td>ID</td>
</tr>
</tbody>
</table>
### Cards I+1 thru M-l--Projected Grid Coordinates (con't)

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

- **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-l.

<table>
<thead>
<tr>
<th>Input Item</th>
<th>Column Number</th>
<th>Format</th>
<th>Program Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field 1--Must be blank or zero</td>
<td>See card 3</td>
<td>See</td>
<td>ID</td>
</tr>
<tr>
<td>Field 2--Not pertinent, but must not be an alpha character</td>
<td>Not pertinent</td>
<td>Not pertinent</td>
<td>Not pertinent</td>
</tr>
<tr>
<td>Field 3--Same as above</td>
<td>Same as above</td>
<td>Same as above</td>
<td>Same as above</td>
</tr>
<tr>
<td>Field 4--Same as above</td>
<td>Same as above</td>
<td>Same as above</td>
<td>Same as above</td>
</tr>
</tbody>
</table>
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 @ denotes a letter 0 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.

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 21,316 bytes of internal storage as follows:

Main program 18,586 bytes

Subroutines:

<table>
<thead>
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<tr>
<td>RMSE</td>
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<tr>
<td>DMINV</td>
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</table>

21,316 bytes
TIMING

Average HASP 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

ATTACHMENTS
PROGRAM LISTING

A. PEK'SPECTIVE CENTER DETERMINATION

BRANCH IF PHOTOGRAMMETRY --- PROGRAM NO. 5344

Coomputes the coordinates of the perspective center
of a stereoplotter projector via space resection

REAL*8 N(17,7), AMX(50), AMY(50), OBSX(50,7), OBSY(50,7), U1(6,6), SOL(6)

1 VCIV6,6) SUMX, SUMY, HOMEGA, RPHI, AKAPPA, A, C, AP, BP, CP, CM11, CM12, CM12
2 CM21, CM22, CM32, CM33, CN11, CN12, CN13, CN21, CN22, CN32, CN33
3, DELX, DELY, DELZ, SX, SY, X, S, T, SCFAC, S2, G, SO, PW, TMX, TEMY, FXRAD, OBRA
4, OLSNT, PX(50), PY(50), DET, XSCAL, YSCAL, SINALP, SMALX, SMALY, ABSV

DIMENSION TITLE(20), IDENT(50), FMT(20), FM(20), TMX(50), TMY(50),
L TMX(50), LEX(50), GEX(50), NRED(50), ML(6), ML(6)

CONV*3A37, 3447. T40d

READ (5,20,END=540) (TITLE(I),I=1,20)

20 FORMAT (20A4)

IF (N=0) GO TO 120

READ (5,FM) IDENT(1), PX(1), PY(1)

READ (5,90) AOMEGA, APHI, AKAPPA, XE, YE, ZE

SUMX=0.

SUMY=0.

NKDG=0.

DO 150 I=1,NPTS

NKDG=NKDG+1

READ (5,FMT) IU, TMX(NKDG), TMY(NKDG), TMNH(I)

SUMX=SUMX+TMX(NKDG)

SUMY=SUMY+TMY(NKDG)

IF (NKDG.EQ.1) GO TO 110

IF (IU.EQ.ILST) GO TO 110

SUMX=SUMX-TMX(NKDG)

SUMY=SUMY-TMY(NKDG)

TMNH(I)=HC

NRED=NRED+1

AMXI(I)=SUMX/NRED

AMY(I)=SUMY/NRED

SUMX=TMX(NRED)

SUMY=TMY(NRED)

IF (NRED.EQ.1) GO TO 120

DXE(I)=0.

DEY(I)=0.

NKDI(I)=1

NRED+1

TMX(I)=SUMX

PAGE 0001
THY III-SUMY
60 TO 130
110 NROG»NKDG+1
1LST-10
HC-TMH(I>
GO TO 100
120 CALL KMSE CNROG,TMX,THV,XDEV,YDEV)

OExm-xoEv
DtY(I)-YUEV
NRD(M*NRDG
TMX(I)«SUMX
TMY(I)«SUMY
NKDG-1
130 IF (ILST.EQ.0) IDENT(I) GO TO 150
II=I-1
IF (II.EQ.0) II=1
WRITE (6,140) IDENT(I)
FORMAT (1H0.5X,'ERROR - CARDS ARE OUT OF ORDER'/5X,'AT POINT NO.*

140 FORMAT (1HO.5X,'ERROR - CARDS ARE OUT OF ORDER'/5X,'AT POINT NO.*
117)
140
STOP
150 ILST=ID
IF (ICOR.NE.1) GO TO 190
WRITE (6,160)

160 FORMAT (1HO.5X,'COORDINATOGRAPH ERRORS CORRECTED')
SMALX=DABS(AMX(I))
SMALY=DABS(AMY(I))
DO 170 I=2,NPTS
ABSV=DABS(AMX(I))
SMALX=DMIN1(SMALX,ABSV)
SMALY=DMIN1(SMALY,ABSV)
170 DO 180 1=1,NPTS
AMX(I)=XSCAL*((AMX(I)-SMALX)*(AMY(I)-SMALY)*SINALP)*SMALX
180 AMY(I)=YSCAL*(AMY(I)-SMALY)*SINALP
190 WRITE 16.200) NPTS.FOCAL
200 FORMAT (1HO,5X,'THE NUMBER OF POINTS USED ON THIS PLATE IS*/14/5X,
1'THE ASSUMED PRINCIPAL DISTANCE USED IN THESE COMPUTATIONS IS*F15
2.3)
210 WRITE (6,210) IENT(I),NRED(I),PX(I),PY(I),AMX(I),DEX(I),AMY(I),DE
3Y(I),TMHL(I),II=1,NPTS)
210
220 FORMAT (1HO,5X,'COORDINATES OF INPUT DATA*/T10.5,4F10.4)
1ATED GRID COORDS*,T5,*PROJECTED GRID COORDINATES*/1X,*PT NO.*2X,*
2READINGS*,TX*x,x*12X,*Y*,9X,*MEAN X*3X,*STD DEV*,5X,*MEAN Y*3X
4X,F11.2))
230 WRITE (6,220) ITER,XE,YE,ZE,OMEGA,PHI,AKAPP
3
240 FORMAT (1HO,5X,'ITER','6X,'X','10X,'Y','10X,'Z','9X,'DX','8X,'DY','8X,'DZ','
16X,'OMEGA','6X,'PHI','6X,'KAPPA*/14,3F11.2,3F10.4)
250 ITER=0
260 IF(IN=0
270 WRITE (6,220) ITER,XE,YE,ZE,OMEGA,PHI,AKAPP
280 FORMAT (1HO,5X,'ITER','6X,'X','10X,'Y','10X,'Z','9X,'DX','8X,'DY','8X,'DZ','
16X,'OMEGA','6X,'PHI','6X,'KAPPA*/14,3F11.2,3F10.4)
290 ITER=1
300 S2=-FOCAL
310
FORTRAN IV G LEVEL 1, MCD 3

DATE = 65106

0138 OBSY(I,5) = R*(CM32*SY-CM22*SZ)
0139 OBSY(I,6) = R*(CM33*SY-CM23*SZ)
0140 OBSY(I,7) = SY-OBSX(I,3)
0141 NUM = 7
0142 IF (IFIN.EQ.1) GO TO 430
0143 DO 270 K = 1, NPTS
0144 DO 270 I = 1, NO
0145 DO 270 J = 1, NO
0146 N(I,J) = N(I,J) + OBSX(K,1)*OBSX(K,J) + OBSY(K,1)*OBSY(K,J)
0147 DO 280 I = 1, NO
0148 DO 280 J = 1, NO
0149 N(I,J) = N(I,J)
0150 ND = NUM - 1
0151 DO 290 I = 1, ND
0152 DO 290 J = 1, ND
0153 U(I,J) = M(I,J)

C NOW THE NORMAL EQUATION COEFFICIENT MATRIX IS CONVERTED TO ARRAY
C STORAGE SO THE SSP INVERSION ROUTINE CAN BE USED
C
0154 CALL DMINV (U, DET, L1, M1)
0155 IF (DET.NE.0.) GO TO 310
0156 WRITE (6, 300)
0157 300 FORMAT (1H0.5X, 'NORMAL EQUATION MATRIX IS SINGULAR*')
0158 STCP
0159 310 DO 320 I = 1, ND
0160 SOL(I) = 0.
0161 DO 320 J = 1, ND
0162 SOL(I) = SOL(I) + U(I,J) * N(J, NO)
0163 DUM = SOL(I)
0164 DPHI = SOL(2)
0165 DKAP = SOL(3)
0166 DX = SOL(4)
0167 DY = SOL(5)
0168 DZ = SOL(6)
0169 XE = XE + DX
0170 YE = YE + DY
0171 ZE = ZE + DZ
0172 AOMEGA = AOMEGA + DUM * CONV
0173 APHI = APHI + DPHI * CONV
0174 AKAPPA = AKAPPA + DKAP * CONV
0175 WRITE (6, 330) ITER, XE, YE, ZE, DX, DY, DZ, AOMEGA, APHI, AKAPPA
0176 330 FORMAT (14, 5F11.2, 6F10.4)
0177 IF (SQRT(DX*DX + DY*DY + DZ*DZ) .GE. LT *.GE.) GO TO 360
0178 IF (ITER .GE. 6) GO TO 350
0179 WRITE (6, 340)
0180 340 FORMAT (1H0.5X, 'SORRY - SOLUTION DOES NOT CONVERGE*')
0181 GO TO 410
0182 ITER = ITER + 1
0183 GO TO 230
0184 WRITE (6, 370) GDIF
0185 370 FORMAT (1H0.5X, 'WITH THIS ITERATION THE SQUARE ROOT OF DX2+DY2+DZ2 = A2080

0186 2080}
1 IS LESS THAN *,F10.3)

WRITE (6,390)

WRITE (6,400)

WRITE (6,410)

WRITE (6,420)

WRITE (6,430)

WRITE (6,440)

WRITE (6,450)

WRITE (6,460)

WRITE (6,470)

WRITE (6,480)

WRITE (6,490)

WRITE (6,500)

WRITE (6,510)
FORTRAN IV G LEVEL 1, MOD 3

MAIN

DATE = 69106

15/50/07

FORTRAN IV G LEVEL 1, MOD 3

510 FORMAT (14,3X,6D15.8)
520 FORMAT (9H0224)
530 FORMAT (1H0230)
540 FORMAT (1H0231)
550 FORMAT (1H0232)
560 FORMAT (1H0233)
570 FORMAT (1H0234)
580 FORMAT (1H0235)
590 FORMAT (1H0236)
600 FORMAT (1H0237)
610 FORMAT (1H0238)
620 FORMAT (1H0239)
630 FORMAT (1H0240)
640 FORMAT (1H0241)
650 FORMAT (1H0242)
660 FORMAT (1H0243)
670 FORMAT (1H0244)
680 FORMAT (1H0245)

A2600
A2610
A2620
A2630
A2640
A2650
A2660
A2670
A2680
A2690
A2700
A2710
A2720
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A2800
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A2820
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## SUBPROGRAMS CALLED

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## FORMAT STATEMENT MAP

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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)

SUMXK=SUMXR/XAR(I)

10 SUMYK=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

XDLV=SQRT(SXX/(SN-1.0))
YDLV=SQRT(SYY/(SN-1.0))

RETURN
END
FORTRAN IV G LEVEL 1, MOD 3

SCALAR MAP

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NUMER

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SUBPROGRAMS CALLED

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<tr>
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TOTAL MEMORY REQUIREMENTS 00030A BYTES
SUBROUTINE OMINV (AlN,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+1
L(K)=K
M(K)=K
KK=NK+K
BIGA=A(KK)
C2120 J=K,N
C2130 IZ=N*(J-1)
DO 20 I=K,N
C2140 DU 20 I=K,N
C2150 IJ=IZ+1
C2160 IF (D20(A(IJ),DABS(A(I)J))<10,20,20
C2170 10 BIGA=A(IJ)
C2180 L(K)=I
C2190 M(K)=J
C2200 20 CONTINUE
C2210 20 J=L(K)
C2220 IF (J-K) 50,50,30
C2230 KI=K-N
C2240 DO 40 I=1,N
C2250 KI=KI+N
C2260 HOLD=-A(KI)
C2270 JI=KI-K-J
C2280 A(KI)=A(JI)
C2290 30 A(IJ)=HOLD
C2300 40 I=1, N
C2310 IF (I-K) 60,60,60
C2320 JP=N*(I-1)
C2330 DO 70 J=1,N
C2340 JK=NK+J
C2350 JI=JP+J
C2360 HOLD=-A(JK)
C2370 A(JK)=A(IJ)
C2380 A(IJ)=HOLD
C2390 70 A(IJ)=HOLD
C2400 80 IF (BIGA) 100,90,100
C2410 90 D=0.
C2420 100 D=0.
C2430 IF (I-K) 110,120,110
C2440 110 I=INK+1
C2450 A(IK)=A(IK)/(-BIGA)
C2460 120 CONTINUE
C2470 120 CONTINUE
C2480 DO 150 I=1,N
C2490 150 I=1,N
C2500 RETURN
C2510 100 DD 120 I=1,N
C2520 110 I=INK+1
C2530 A(II)=A(II)/(-BIGA)
C2540 120 CONTINUE
C2550 DO 150 J=1,N
C2560 150 J=1,N
RETURN
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
UU 170 J=1,N
KJ=KJ+N
IF (J-K) 160, 170, 160
160 A(KJ)=A(KJ)/B1GA
170 CONTINUE
D=D*B1GA
A(KK)=1./B1GA
180 CONTINUE
K=N
130 K+K-1
190 IF (K) 260, 260, 200
200 I=L(K)
210 IF (I-K) 230, 230, 210
210 JC=N*(K-1)
JK=N*(I-N)
DO 220 J=1,N
220 A(IJ)=HOLD
230 J=M(K)
IF (J-K) 190, 190, 240
240 K1=K-N
250 A(IJ)=HOLD
DO 250 I=1,N
280 K1=K-N
HULD=A(K1)
280 CONTINUE
J1=K1-K+J
AIKJ=A(J1)
290 CONTINUE
AIKI=A(IJ)
GO TO 150
260 RETURN
END
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**SCALAR MAP**

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**ARRAY MAP**

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**TOTAL MEMORY REQUIREMENTS 00083C BYTES**
**F88-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED LET, LIST, MAP**

**VARIABLE OPTIONS USED - SIZE=(194208, 45056)**

**DEFAULT OPTION(S) USED**

**MODULE MAP**

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**ENTRY ADDRESS** | 00
**TOTAL LENGTH** | 9520

"***NOW ADDED TO DATA SET"
### B. SYMBOLS AND VARIABLES

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

Arrays containing the standard deviation of the X and Y readings for each point.

Arrays containing the number of readings on each point.

Variables used in correcting the mean readings for coordinatograph errors.

Number of present iteration.

The principal distance with a negative sign.

Unknown angular elements in radians.

Factor used to convert minutes to radians.

Matrices of the observation equations.

Augmented normal equations coefficient matrix.

Sines and cosines of the unknown angles.

Variables used in forming observation equations.

Plate grid coordinates.

Number of unknowns.

Number of unknowns plus one.

Normal equations coefficient matrix and later the inverse of the normal equations coefficient matrix.

Code indicating a correct return from the matrix inversion subroutine.

Array containing corrections to unknowns.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DX, DY, DZ, DOM, DPHI, DΚΑP</td>
<td>Corrections to unknowns.</td>
</tr>
<tr>
<td>ΠUU, ΠUQ</td>
<td>Sum of the squares of the residuals.</td>
</tr>
<tr>
<td>VX, VY</td>
<td>x and y residuals in the plate grid coordinates.</td>
</tr>
<tr>
<td>ZP, ZQ</td>
<td>X and Y residuals in the projected plane.</td>
</tr>
<tr>
<td>SCFAC</td>
<td>Scale factor for converting plate grid coordinates to projected grid coordinates.</td>
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<tr>
<td>TRUX, TRUY</td>
<td>Computed projected grid coordinates.</td>
</tr>
<tr>
<td>OBRAD</td>
<td>Observed radius from principal point to grid.</td>
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<tr>
<td>FXRAD</td>
<td>True radius from principal point to grid intersection.</td>
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<tr>
<td>DSTRT</td>
<td>Radial distortion.</td>
</tr>
<tr>
<td>STD</td>
<td>Standard error of unit weight of plate grid coordinates.</td>
</tr>
<tr>
<td>STDM</td>
<td>Standard error of projected grid coordinates in the model space.</td>
</tr>
<tr>
<td>VCV</td>
<td>Variance-covariance matrix.</td>
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<tr>
<td>STDX, STDY, STDZ, STDO, STDP, STDK</td>
<td>Standard errors of the unknowns.</td>
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<tr>
<td>X, STD DEV</td>
<td>Standard deviations of readings of projected coordinates.</td>
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<tr>
<td>Y, STD DEV</td>
<td>Standard deviations of readings of projected coordinates.</td>
</tr>
</tbody>
</table>
C. MACRO FLOWCHART

1. READ TITLE AND FORMAT CARDS

2. READ STEREOPLOTTER CALIBRATION PARAMETERS

3. READ CORRECTION FACTORS

4. END OF DATA?

   YES → STOP

   NO → READ STEREOPLOTTER CALIBRATION PARAMETERS

5. CORRECTION FOR COORDINATOGRAPH ERRORS?

   YES → READ CORRECTION FACTORS

   NO → ITEST = 1

6. READ GRID PLATE COORD

7. READ ESTIMATED PROJECTOR ORIENTATION PARAMETERS
READ MODEL-SPACE COORDINATES OF GRID POINT

SAME GRID POINT NUMBER?

COMPUTE MEAN VALUE & DEVIATION OF X & Y MODEL-SPACE COORDINATES

MODEL-SPACE PT. NO. = GRID PT. NO.?

LAST MODEL-SPACE POINT?

USE COORDINATOGRAPH CORRECTIONS?

WRITE INPUT DATA

WRITE "ERROR-CARDS ARE OUT OF ORDER"

STOP

COMPUTE X- & Y-SCALE AND NON-PERPENDICULARITY CORRECTIONS

ADJUST MODEL SPACE X & Y COORDINATE VALUES

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

SUM OF RESIDUALS < TOLERANCE? NO

WRITE "WITH THIS ITERATION THE SQ.RT. OF DX2 + DY2 + DZ2 IS LESS THAN"

WRITE PERSPECTIVE CENTER COORDINATES

WRITE "RESIDUAL & DISTORTION VALUES"

IFIN = 1

ITER < 6?

YES

ITER = ITER + 1

NO

WRITE "SORRY SOLUTION DOES NOT CONVERGE"

6
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?

YES

ITEST = ITEST?

YES

ITEST = ITEST + 1

NO

ICALF > 1?

NO

ITEST = ITEST + 1

YES
### PERSPECTIVE CENTER DETERMINATION

A-7 NO.310 DATA FROM INTERNATIONAL TESTS - HALLERT ISP SUD-COMM LV64

#### 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  

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<th>Z</th>
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</table>

ITER | X | Y | Z | DX | DY | DZ | OMEGA | PHI | KAPPA
---|---|---|---|----|----|----|--------|-----|-----
0  | 500.00 | 500.00 | 300.00 | 0.0125 | -0.0091 | 0.1388 | 0.2354 | -0.0543 | -0.9418
1  | 500.02 | 499.99 | 300.14 | 0.0002 | 0.0001 | 0.0002 | 0.2355 | -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

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### Stereoplotter Calibration Information

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**Standard Error of Unit Weight of Plate Grid Coordinates:** 0.00447

**Variance-Covariance Matrix:**

1. 0.377362850-09 0.359134130-14 0.173016801-10 0.163760860-08 0.135837510-06 0.131821540-10
2. 0.589134130-14 0.377404090-09 0.173955640-13 0.135851670-06 0.163774440-11 0.318641310-11
3. 0.173016801-10 0.377404090-09 0.173051670-06 0.163774440-11 0.318641310-11 0.112844500-08
4. 0.163760860-11 0.313842210-10 0.653006120-11 0.513218910-04 0.454516560-09 0.112898440-08
5. 0.313842210-10 0.653006120-11 0.513218910-04 0.454516560-09 0.513170420-04 0.456084640-08
6. 0.112898440-08 0.456084640-08 0.513170420-04 0.466084640-08 0.607109580-05

**Standard Errors of the Perspective Center Parameters:**

- X Coordinate = 0.00716
- Y Coordinate = 0.00716
- Z Coordinate = 0.00246
- Omega (Minutes) = 0.04678
- Phi (Minutes) = 0.06678
- Kappa (Minutes) = 0.02822

**Standard Error of Projected Coordinates in the Model Space:** 0.00894