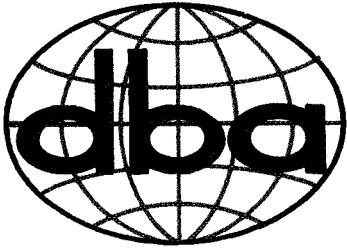


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DBA SYSTEMS, INC.

DOCUMENTATION OF PHOTOGRAMMETRIC
MISSION SIMULATOR PROGRAM
VOLUME 2
GLOBAL BLOCK ADJUSTMENT MODULE

Photogrammetry **CASE FILE COPY**

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Final Technical Report

DOCUMENTATION OF PHOTOGRAMMETRIC
MISSION SIMULATOR PROGRAM
VOLUME 2
GLOBAL BLOCK ADJUSTMENT MODULE

August 1971

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1.0 MODULE DESCRIPTION

A photogrammetric mission whose photography generates a photogrammetric net covering the lunar surface with isotropic overlap has been found to possess extraordinary geometric strength (Brown 1968). The study of such nets is of particular interest for mission planning. The Global Block Adjustment Module, acronym GBLOCK, has been designed for the specific purpose of enabling such studies. For photogrammetric schemes specified by program input, GBLOCK computes the a posteriori estimates of standard errors for exposure station position and orientation elements and for ground point coordinates.

The method employed by GBLOCK to perform these computations is based on the procedures described in detail by D. Brown (Brown 1968). The scheme for generating simulated photography involves purely geometric techniques. An algorithm is employed for generation of point patterns which approximates those patterns obtained by successive bisections of the icosahedron. Although this geometric approach precludes imposition of orbital constraints per se, the effect of orbital constraints may be approximated by means of the a priori estimates of standard errors of the exposure station parameters. These estimates, given in the local vertical coordinate system, are among the input required by the module.

The geometric approach to the problem of computing expected accuracies from photogrammetric nets of global coverage is especially advantageous for basic studies. By assuming a circular orbit, GBLOCK completely avoids the use of a numerical integration process for the determination of exposure station position and orientation. The resultant reduction in computer execution time is quite substantial. The difference in the results obtained by this method will not differ significantly from the results that would be obtained from a photogrammetric net in which the exposure station positions and orientations are determined by applying a numerical integration process to an orbit of low eccentricity.

Since GBLOCK does not solve for the unknown variables of position and orientation, but rather computes the expected values of their standard errors, the need to iterate on a solution is removed. When the initial approximations to the unknown variables are close to the adjusted values, as is the case with GBLOCK, the a posteriori estimates of the standard errors of the unknowns obtained from a zero iteration will not differ significantly from those obtained from subsequent iterations.

Specific applications of GBLOCK include the investigation of the comparative merits of trade-offs such as increased photography (more frames) versus increased imagery (more image measurements) or the incorporation of external sensors into the hardware.

As previously noted, GBLOCK is intended for the study of photogrammetric nets of global lunar coverage from a circular polar orbit. For other types of nets, the user is referred to the Multi-mission Block Adjustment Module (MBLOCK) which is presented in Volume 3.

GBLOCK consists of three submodules, the Simulated Photography Submodule, the Normal Equations Formation Submodule, and the Statistical Recovery Submodule. These submodules are discussed in the following sections.

1.1 Simulated Photography Submodule

The Simulated Photography Submodule generates a file of simulated plate measurement data. Input to this submodule is described in detail in Section 3 of this volume. Output from this submodule is a file containing one record per simulated photography. This file is called the Unsorted Working Data File. The records are in order of increasing photo numbers. The photo numbers themselves are chosen in a manner which minimizes the bandwidth of the normal equations, formed in the second submodule. The photo numbering scheme is the method called "pole-to-pole spiral ordering" by Brown (Brown, 1968). This method is alternatively called "the orange-peel method" in deference to the fact that the DBA Systems home office is located in Florida.

A brief description of the operation of this submodule is as follows:

- 1) input-simulation parameters are read in, a limited number of checks are made, and two pages of printed output are generated (see Section 4);
- 2) initialization - a file of exposure stations and a file of ground positions are generated;
- 3) simulation - photography is simulated. For each photo, a record containing all relevant data is output to a sequential file, the Unsorted Working Data File. Also for each photo, a record of ground coverage data is output to another sequential file, for possible use in producing a ground coverage plot. On option, the simulated photography is output to the printer.

1.2 Normal Equations Formation Submodule

Using the Unsorted Working Data File as input, this submodule generates the normal equations. Four subroutines are involved in this process. Three of the subroutines perform sorting functions, and utilize the random access capability of the UNIVAC 1108. The fourth subroutine forms the reduced system of normal equations (see Brown, 1968 and Section 2.5 of this volume). The present version of this subroutine incorporates two

important changes from previously developed versions, as explained in Section 2.5.

1.3 Statistical Recovery Submodule

The Statistical Recovery Submodule is the most computer-time-consuming section of the entire GBLOCK module. This submodule inverts the normal equations, and extracts certain statistics from the inverse.

The printed output consists of two tables. The first gives a posteriori estimates of standard errors of the exposure station parameters, and the second gives a posteriori estimates of the standard errors of ground position coordinates (see Section 3 for details).

The submodule consists of a series of three subroutines. The first two subroutines invert the normal equations by the Method of Recursive Partitioning. The third subroutine extracts the statistics required by the two printed output tables named above. The random access capability of the UNIVAC 1108 is utilized for enhanced computational throughout.

2.0 MATHEMATICAL ANALYSES

2.1 Preliminary Remarks on Angular Rotations

(a) Positive rotations are those which rotate X into Y, Y into Z, and Z into X. For right-handed coordinate systems, rotations are positive in a anti-clockwise direction, and for left-handed systems, rotations are positive in a clockwise direction.

(b) The notation $R_1(\alpha)$ means:

$$R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \alpha & \sin \alpha \\ 0 & -\sin \alpha & \cos \alpha \end{bmatrix}.$$

(c) The notation $R_2(\beta)$ means:

$$R_2(\beta) = \begin{bmatrix} \cos \beta & 0 & -\sin \beta \\ 0 & 1 & 0 \\ \sin \beta & 0 & \cos \beta \end{bmatrix}.$$

(d) The notation $R_3(\gamma)$ means:

$$R_3(\gamma) = \begin{bmatrix} \cos \gamma & \sin \gamma & 0 \\ -\sin \gamma & \cos \gamma & 0 \\ 0 & 0 & 1 \end{bmatrix}.$$

2.2 Explanation of Coordinate Systems Used in GBLOCK

(a) Universal Space Rectangular (USR)

Spherocentric latitude, Φ , longitude, λ , and elevation, h , are related to the USR coordinates, X, Y, and Z, by the matrix identity:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{USR}} = \begin{bmatrix} (R + h) \cos \Phi \cos \lambda \\ (R + h) \cos \Phi \sin \lambda \\ (R + h) \sin \Phi \end{bmatrix}.$$

where R is the radius of the reference sphere.

The axes form a right-handed coordinate system, and the angles Φ and λ are positive in the mathematical sense. For the case of the earth, this means latitudes are positive north of the equator, and longitudes are positive east of Greenwich. For GBLOCK, longitudes are reduced to the range $-\pi \leq \lambda \leq \pi$.

(b) Local Vertical Coordinate System at a Point

The axes are oriented such that the $X_{L.V.}$ -axis or E-axis is the direction of increasing longitude (east), the $Y_{L.V.}$ -axis or N-axis is in the direction of increasing latitude (north), and the $Z_{L.V.}$ -axis or U-axis is outward along the normal to the reference sphere through the point (up).

The subscript $(L.V.G)_i$ denotes that the origin is the i th ground point. The subscript $(L.V.C)_i$ denotes that the origin is at the i th exposure station. The subscript $(L.V.S)_k$ denotes that the origin is at the center of the reference sphere, and that the $Z_{L.V.}$ -axis is in the direction of some given point K .

(c) Photo Coordinate System

The origin of this right-handed coordinate system is at the exposure station (optical center of the lens). The Z_{photo} -axis, or optical axis, is orthogonal to the image plane, and positive directed away from the image plane towards the lens. The X_{photo} - and Y_{photo} axes are parallel to the image plane, with the positive X_{photo} -axis in the direction of the line of flight, and the positive Y_{photo} -axis, accordingly, is to the left of the line of flight. The coordinates of image points given in this system will be of the form (x_p, y_p, f) , where f is the focal length whose value is positive.

(d) Sense of Angles Used in GBLOCK

<u>Angle</u>	<u>Rotation Implied</u>	<u>Comments</u>
Φ	$R_1(\Phi)$	Positive in the mathematical sense
λ	$R_3(\lambda)$	Positive in the mathematical sense

<u>Angle</u>	<u>Rotation Implied</u>	<u>Comments</u>
$\bar{\omega}$	$R_1(\bar{\omega})$	Positive in the mathematical sense
$\bar{\varphi}$	$R_2(-\bar{\varphi})$	Positive opposite the mathematical sense
$\bar{a}$	$R_3(90^\circ - \bar{a})$	Positive opposite the mathematical sense and measured from the local vertical N-axis

2.3 The Jacobian Matrix of the Transformation From Geographic Coordinates to USR Coordinates

The relation between changes in latitude, (N), longitude, (E), and elevation (U), expressed in unites of length, and changes in X, Y, and Z in the USR coordinate system at a point K is given by:

$$\begin{bmatrix} \delta X \\ \delta Y \\ \delta Z \end{bmatrix}_{\text{USR}} = U_k \cdot \begin{bmatrix} \delta N \\ \delta E \\ \delta U \end{bmatrix}$$

where,

$$U_k = \begin{bmatrix} -\sin \Phi_k \cos \lambda_k & -\sin \lambda_k & \cos \Phi_k \cos \lambda_k \\ -\sin \Phi_k \sin \lambda_k & \cos \lambda_k & \cos \Phi_k \sin \lambda_k \\ \cos \Phi_k & 0 & \sin \Phi_k \end{bmatrix}.$$

This relation is utilized for covariance transformations, and also for the transformation of positional perturbations.

2.4 Simulated Photography

The simulated photography is generated under control of the program GLOSIM. The program GLOSIM is supplied by the programs CAMPOS, PTPOS, and several lower level routines.

The simulation proceeds by first generating a file of exposure station positions and a file of ground point positions, and then simulating near-vertical photography from the exposure stations to the ground point positions.

2.4.1 Determination of Exposure Station Positions

An algorithm is used to determine a pattern of exposure stations at which photographs are subsequently simulated. The algorithm generates patterns of points which approximate the patterns obtained by the method of successive bisections of the icosahedron (see Brown, 1968). This procedure is performed by the subprogram CAMPOS, which is called by the program GLOSIM.

The value of the input parameter LBI determines the number of positions generated. The number of positions generated is the same as the number of vertices resulting from the $(LBI)^{th}$ level of bisection of the icosahedron.

The positions generated lie on NPHIS latitudes where $NPHIS = (3) * (2)^{LBI} + 1$. These latitudes are equally spaced, so that the difference between two successive latitudes is:

$$\Delta \varphi = \pi / (NPHIS - 1).$$

The number of positions, $P(\varphi)$, on a given latitude, φ , is as follows:

$$\text{if } \varphi = \pi/2, \quad P(\varphi) = 1$$

$$\text{if } \pi/2 > \varphi > \pi/6, \quad P(\varphi) = 5 * \frac{\pi/2 - \varphi}{\Delta \varphi}$$

$$\text{if } \pi/6 \geq \varphi, \quad P(\varphi) = 5 * \frac{\pi/3}{\Delta \varphi}$$

The separation in longitude $\Delta\lambda(\varphi)$, of successive positions along a given circle of latitude, φ , is then given by:

$$\Delta\lambda(\varphi) = 2\pi/P(\varphi)$$

The longitude of the lowest numbered position $\lambda_0(\varphi)$ for each latitude, φ , is given as follows:

(a) for $|\varphi| = \pi/2$, $\lambda_o(\varphi) = 0$;

(b) for $\pi/2 > \varphi \geq \pi/6$, $\lambda_o(\varphi) = \frac{\pi}{5} - \frac{\Delta\lambda(\varphi)}{2}$;

(c) for $\pi/6 > \varphi \geq -\pi/6$

(1) if circular format photograph, $\lambda_o(\varphi) = \lambda_o(\varphi + \Delta\varphi) + \frac{\Delta\lambda(\varphi)}{2}$

(2) if square format photography, $\lambda_o(\varphi) = \lambda_o(\varphi + \Delta\varphi) + \Delta\lambda(\varphi)$

(d) for $-\pi/6 \geq \varphi > -\pi/2$;

(1) $\lambda_o(\varphi) = \frac{3\pi}{5}$ if circular format photography

(2) $\lambda_o(\varphi) = \frac{4\pi}{5}$ if square.

Numbering of the positions is accomplished by first assigning the number 1 to the north pole, then dropping to $\varphi = \pi/2 - \Delta\varphi$, and assigning 2 to the point whose longitude is $\lambda_o(\varphi)$ for this φ . Numbering continues by proceeding westward about the latitude circle, φ , then dropping to $\varphi = \pi/2 - 2 * \Delta\varphi$, etc.

The above applies to double sidelap photography. For single sidelap, which is permitted only with square format photography, alternate photos are omitted between plus and minus 30° latitude. The positions omitted are at longitudes:

$$\lambda = \lambda_o(\varphi) + k \cdot \Delta\lambda(\varphi) , \quad k = 1, 3, 5, \dots$$

2.4.2 Determination of Ground Point Positions

The ground point positions are generated by the subprogram PTPOS, which is called by the program GLOSIM. The variables which determine the generated point pattern are the level of bisections of this icosahedron, LBI, and the level of densification, LDENS, which are input parameters to the program GLOSIM.

The pattern of ground point positions is determined by the same algorithm used to determine the pattern of exposure station positions, with the following differences:

- (1) the number of latitudes and their spacing is a function of the parameters LBI and LDENS;
- (2) each point is assigned a six character label.

The scheme for labeling the points requires some explanation. The scheme is designed to provide a set of labels which identify the ground points. In addition, the scheme is designed to convey some indication of the location of the point, and the type of positional control associated with the point. The label assigned to a ground point is a function of its position and of the parameters LBI, LDENS, and IFMT. A given label may denote two different positions in two different simulations.

Given the values of LBI, LDENS, and IFMT, and a six character label of the form "abcdef", the coordinates and control associated with that position may be computed as follows:

- (a) compute $\Delta\varphi'$; $\Delta\varphi' = (\pi / (3 * (2)^{LBI}))$

- (b) compute $\Delta\varphi''$; $\Delta\varphi'' = \Delta\varphi' / (LDENS + 1)$

- (c) use Table 2.1 to determine the type of control from the first character,
a. Also obtain the integer INT from Table 2.1;

- (d) compute φ' ;
$$\varphi' = \frac{\pi}{2} - (INT * 10 + b) * (\Delta\varphi')$$

- (e) compute $\Delta\varphi_{DENS} = \frac{-f * \Delta\varphi'}{10}$

- (f) the latitude of the point is computed by:

$$\varphi = \varphi' + \Delta\varphi_{DENS}$$

(g) compute $P(\varphi)$;

(a) if $\varphi = \pi/2$, $P(\varphi) = 1$

(b) if $\pi/2 > \varphi > \pi/6$, $P(\varphi) = 5 * \frac{\pi/2 - \varphi}{\Delta\varphi''}$

(c) if $\pi/6 \geq \varphi$, $P(\varphi) = 5 * \frac{\pi/3}{\Delta\varphi''}$

(h) compute $\Delta\lambda(\varphi) = \frac{2\pi}{P(\varphi)}$;

(i) compute $\lambda_o(\varphi)$

(1) if SQUARE FORMAT (IFMT = 1), $\lambda_o(\varphi) = 0$, for all φ 's

(2) if CIRCULAR format (IFMT = 0)

(i) $\pi/2 \geq \varphi \geq \pi/6$, $\lambda_o(\varphi) = 0$

(ii) $\pi/6 > \varphi$ and $\frac{\varphi}{\Delta\varphi'}$ is odd, $\lambda_o(\varphi) = 0$

(iii) $\pi/6 > \varphi$ and $\frac{\varphi}{\Delta\varphi'}$ is even, $\lambda_o(\varphi) = -\frac{\Delta\lambda(\varphi)}{2}$

(j) the longitude of the point is computed by:

$$\lambda = \lambda_o(\varphi) = -(c \cdot 100 + d \cdot 10 + e) \cdot \Delta\lambda(\varphi)$$



TABLE 2.1

INT	Type of Control Point			
	Horiz. and Vert.	Horiz	Vert	Pass Point
0	A	J	S	0
1	B	K	T	1
2	C	L	U	2
3	D	M	V	3
4	E	N	W	4

- 1) Locate first character of label, α , in table.
- 2) Type of control is given at top of column in which the first character appears
- 3) The integer INT for use in the position computation is given at left of row in which the first character appears

2.4.3 Exposure Station Parameters

2.4.3.1 Notation

<u>Symbol</u>	<u>Description</u>
$\varphi_i^c, \lambda_i^c, H_i^c$	North latitude (+), east longitude (+) and altitude of the i th exposure station
X_i^c, Y_i^c, Z_i^c	USR coordinates of the i th exposure station
$\dot{\sigma}_N, \dot{\sigma}_E, \dot{\sigma}_U$	A priori estimates of the standard errors of the exposure station positions given in the local vertical system. (These are the same for all exposure stations).
$\bar{\omega}_i, \bar{\varphi}_i, \bar{\alpha}_i$	Roll, pitch, and azimuth of the i th exposure station. (These angles are referenced to the local vertical coordinate system).
$\dot{\sigma}_{\bar{\omega}}, \dot{\sigma}_{\bar{\varphi}}, \dot{\sigma}_{\bar{\alpha}}$	A priori estimates of the standard errors of the orientation angles of the exposure stations. (These are the same for all exposure stations).
a	Radius of the reference sphere
$\dot{U}_i$	Jacobian matrix of the i th exposure station

2.4.3.2 Computation of Exposure Station Parameters

a) The USR position of the exposure station is given by:

$$\begin{bmatrix} X_i^c \\ Y_i^c \\ Z_i^c \end{bmatrix}_{\text{USR}} = \begin{bmatrix} \cos \varphi_i^c & \cos \lambda_i^c \\ \cos \varphi_i^c & \sin \lambda_i^c \\ \sin \varphi_i^c \end{bmatrix} \begin{bmatrix} a + H_i^c \end{bmatrix}$$

- b) The local vertical orientation angles of the exposure station are given by:

$$\begin{bmatrix} \bar{\omega}_i, \bar{\varphi}_i, \bar{\alpha}_i \end{bmatrix}^T = \begin{bmatrix} 0., 0., 0. \end{bmatrix}^T$$

- c) The variance-covariance matrix of USR position elements is given by:

$$\sum_i^{XYZ} = \dot{U}_i \text{diag} (\dot{\sigma}_N^2, \dot{\sigma}_E^2, \dot{\sigma}_U^2) \dot{U}_i^T.$$

- d) The variance-covariance matrix local vertical orientation elements is given by:

$$\sum_i^{\bar{\omega}\bar{\varphi}\bar{\alpha}} = \text{diag} (\dot{\sigma}_{\bar{\omega}}^2, \dot{\sigma}_{\bar{\varphi}}^2, \dot{\sigma}_{\bar{\alpha}}^2)_i$$

- e) The weight matrix of USR position elements is given by:

$$\dot{W}_i^{XYZ} = \dot{U}_i \text{diag} \left(\left(\frac{1}{\dot{\sigma}_N} \right)^2, \left(\frac{1}{\dot{\sigma}_E} \right)^2, \left(\frac{1}{\dot{\sigma}_U} \right)^2 \right) \dot{U}_i^T.$$

- f) The weight matrix of local vertical orientation elements is given by:

$$W_i^{\bar{\omega}\bar{\varphi}\bar{\alpha}} = \text{diag} \left(\left(\frac{1}{\dot{\sigma}_{\bar{\omega}}} \right)^2, \left(\frac{1}{\dot{\sigma}_{\bar{\varphi}}} \right)^2, \left(\frac{1}{\dot{\sigma}_{\bar{\alpha}}} \right)^2 \right)_i$$

2.4.4 Ground Point Parameters

2.4.4.1 Notation

<u>Symbol</u>	<u>Description</u>
$\varphi_i, \lambda_i, h_i$	North latitude (+), east longitude (+) and elevation of i th ground point. (Elevation of all ground points is taken as zero).

<u>Symbol</u>	<u>Description</u>
X_i, Y_i, Z_i	USR coordinates of the i th ground point
$\sigma_{N_i}, \sigma_{E_i}, \sigma_{U_i}$	A priori estimates of the standard errors of ground point positions given in the local vertical coordinate system
$\ddot{U}_i$	Jacobian matrix of the i th ground point

2.4.4.2 Computation of Ground Point Parameters

- a) The USR position of the ground point is given by:

$$\begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix}_{\text{USR}} = \begin{bmatrix} \cos \varphi_i & \cos \lambda_i \\ \cos \varphi_i & \sin \lambda_i \\ \sin \varphi_i \end{bmatrix} \begin{bmatrix} a \end{bmatrix}$$

- b) The variance-covariance matrix of USR position elements is given by:

$$\sum_i^{\bullet\bullet\text{XYZ}} = \ddot{U}_i \text{diag} \left(\sigma_{N_i}^2, \sigma_{E_i}^2, \sigma_{U_i}^2 \right) \ddot{U}_i^T$$

Note: Each a priori estimate of the standard error of a ground point position or sigma, will assume one of two values. If the point is a control point, the sigma for those coordinates which are controlled is set to a value specified by the input shown. The sigmas for all coordinates of passpoints, and those coordinates of control points which are not controlled, are set to a very large number, which is internal to the program.

- c) The weight matrix of USR position elements is given by:

$$\sum_i^{\bullet\bullet\text{XYZ}} = \ddot{U}_i \text{diag} \left(\left(\frac{1}{\sigma_{N_i}} \right)^2, \left(\frac{1}{\sigma_{E_i}} \right)^2, \left(\frac{1}{\sigma_{U_i}} \right)^2 \right) \ddot{U}_i^T$$

2.4.5 Generation of Imagery

2.4.5.1 Notation

<u>Symbol</u>	<u>Description</u>
c	Focal length of camera
d	Film format = side, if square frame; diameter, if circular.
x_{ij}, y_{ij}	Image coordinates of j th ground point on i th photo
σ_p	A priori estimate of standard errors of plate measurements
a_0, a_1, a_2, a_3, a_4	Coefficients of the empirical weighting function of plate coordinates

2.4.5.2 Computations

Preliminary.

- a) Compute the local-vertical orientation matrix, $\bar{T}_i$, of the i th photo:

$$\bar{T}_i = R_1(\bar{\omega}_i) R_2(-\bar{\varphi}_i) R_3(\pi/2 - \bar{\alpha}_i).$$

- b) Compute the USR orientation matrix, R_i , of the i th photo:

$$R_i = R_1(\pi/2 - \varphi_i) R_3(\pi/2 + \lambda_i).$$

- c) Compute the spherocentric orientation matrix, T_i , of the i th photo:

$$T_i = \bar{T}_i \cdot R_i.$$

Coverage computations.

d) Compute the coordinates of the frame corners and nadir in the local vertical system having its origin at the exposure station, for the i th photo:

$$\begin{bmatrix} X_1 & X_2 & X_3 & X_4 & X_5 \\ Y_1 & Y_2 & Y_3 & Y_4 & Y_5 \\ Z_1 & Z_2 & Z_3 & Z_4 & Z_5 \end{bmatrix} = \bar{T}_i^T \begin{bmatrix} -\frac{d}{2} & \frac{d}{2} & \frac{d}{2} & -\frac{d}{2} & 0 \\ \frac{d}{2} & \frac{d}{2} & -\frac{d}{2} & \frac{d}{2} & 0 \\ -c-c & -c & -c & -c & -c \end{bmatrix} \begin{matrix} \text{(L.V.C.)}_i \\ \text{(PHOTO)}_i \end{matrix}$$

e) Compute k ; $k = 1 + \dot{h}_i/a$

f) For $n = 1, 2, 3, 4, 5$, compute $(X_n^*, Y_n^*, Z_n^*) = f(X_n, Y_n, Z_n, \dot{h}_i, a)$ as follows:

$$1. \ell_n = X_n^2 + Y_n^2 + Z_n^2.$$

$$2. t = \ell_n - k^2 (X_n^2 + Y_n^2),$$

3. If $t < 0$, set $t = 0$, and set flag to indicate that computation is for tangent ray instead of corner.

$$4. i_n = -kZ_n - \sqrt{t}.$$

5. Finally:

$$X_n^* = X_n \cdot i_n$$

$$Y_n^* = Y_n \cdot i_n$$

$$Z_n^* = \left[\ell_n^2 - i_n^2 (X_n^2 + Y_n^2) \right]^{\frac{1}{2}}.$$

g) Computes coordinates of imaged point (or tangent ray point) on unit sphere:

$$\begin{bmatrix} X_1^s & X_2^s & X_3^s & X_4^s & X_5^s \\ Y_1^s & Y_2^s & Y_3^s & Y_4^s & Y_5^s \\ Z_1^s & Z_2^s & Z_3^s & Z_4^s & Z_5^s \end{bmatrix} \text{USR} = R_i^T \begin{bmatrix} X_1^* & X_2^* & X_3^* & X_4^* & X_5^* \\ Y_1^* & Y_2^* & Y_3^* & Y_4^* & Y_5^* \\ Z_1^* & Z_2^* & Z_3^* & Z_4^* & Z_5^* \end{bmatrix} \text{(L.V.S.)}_i$$

h) Compute spherocentric latitude and longitude of imaged point (or tangent ray point) on sphere for $n = 1, 2, 3, 4, 5$:

$$\varphi_n = \sin^{-1} (Z_n^s / \rho_n)$$

$$\lambda_n = \tan^{-1} (Y_n^s / X_n^s).$$

Computation of image coordinates of ground points.

i) Compute normalized coordinates of ground point in camera local vertical system having origin at center of sphere:

$$\begin{bmatrix} X_i^G \\ Y_i^G \\ Z_i^G \end{bmatrix} (L.V.S.)_i = R_i \begin{bmatrix} \cos \varphi_i \cos \lambda_i \\ \cos \varphi_i \sin \lambda_i \\ \sin \varphi_i \end{bmatrix}.$$

- i) 1. If $Z_i^G \cdot k < 1$, point is not visible, and set IFLAG = 3 skip to next ground point.
 2. If $Z_i^G \cdot k \geq 1$, continue.

k) Translate origin to exposure station:

$$\begin{bmatrix} X_i^G \\ Y_i^G \\ Z_i^G \end{bmatrix} (L.V.C.)_i = \begin{bmatrix} X_i^G \\ Y_i^G \\ Z_i^G \end{bmatrix} (L.V.S.)_i + \begin{bmatrix} 0 \\ 0 \\ -k \end{bmatrix} (L.V.S.)_i$$

l) Rotate from local vertical to photo coordinate system:

$$\begin{bmatrix} X_{ij}^P \\ Y_{ij}^P \\ Z_{ij}^P \end{bmatrix} (PHOTO)_i = T_i \begin{bmatrix} X_i^G \\ Y_i^G \\ Z_i^G \end{bmatrix} (L.V.C.)_i$$

m) Scale such that $Z_{ij}^P \rightarrow -c$ to obtain image coordinates:

$$\begin{bmatrix} x_{ij} \\ y_{ij} \\ -c \end{bmatrix}_{(\text{PHOTO})_i} = \frac{-c}{Z_{ij}^P} \begin{bmatrix} X_{ij}^P \\ Y_{ij}^P \\ Z_{ij}^P \end{bmatrix}_{(\text{PHOTO})_i}$$

n) Set JFLAG as follows:

If $(x_{ij}^2 + y_{ij}^2 - \frac{d^2}{4}) \geq 0$, JFLAG = 0 (point is on frame).

If $(x_{ij}^2 + y_{ij}^2 - \frac{d^2}{4}) > 0$

and $|x_{ij}| < \frac{d}{2}$

and $|y_{ij}| < \frac{d}{2}$, JFLAG = 1 (point on square frame but off circular frame)

Otherwise, JFLAG = 2 (point is off frame).

o) Compute $\sigma_{x_{ij}}$, $\sigma_{y_{ij}}$

$$\sigma_{x_{ij}} = \sigma_P + \frac{x_{ij}}{r_{ij}} (a_0 + a_1 r_{ij} + a_2 r_{ij}^2 + a_3 r_{ij}^3 + a_4 r_{ij}^4)$$

$$\sigma_{y_{ij}} = \sigma_P + \frac{y_{ij}}{r_{ij}} (a_0 + a_1 r_{ij} + a_2 r_{ij}^2 + a_3 r_{ij}^3 + a_4 r_{ij}^4)$$

where,

$$r_{ij} = (x_{ij}^2 + y_{ij}^2)^{\frac{1}{2}}$$

p) Compute $w_{x_{ij}}, w_{y_{ij}}$

$$w_{x_{ij}} = \frac{1}{\frac{2}{\sigma_{x_{ij}}^2}}$$

$$w_{y_{ij}} = \frac{1}{\frac{2}{\sigma_{y_{ij}}^2}}$$

2.5 Normal Equations Formation

NEF computes the coefficients of the reduced normal equations required for a least squares adjustment of the photogrammetric network. The mathematical formulation of the system of reduced normal equations is developed in Brown (1958) and is further refined in Brown, Davis, Johnson (1964). This formulation is given in summary form in Brown (1968).

The present formulation of this program differs from previously developed versions in two important aspects. The angles of exterior orientation of exposure stations are expressed with respect to the local vertical coordinate system, where previous versions expressed these angles with respect to the USSR coordinate system. A new innovation is that provision is made to include the effect of simulated altimeter measurements.

The simulated photography is all near-vertical. Thus the range and mean of the angles of exterior orientation will be small, if the angles are given with respect to the local vertical coordinate system.

For the case of global coverage, the range and mean of the same angles given with respect to the USSR coordinate system are, by comparison, quite large. In addition to facilitating meaningful interpretation of the results, the use of local vertical angles results in a computational scheme which is numerically more stable.

For those photos specified by the input data (Section 3), a distance measurement from the exposure station to a ground point near the photo nadir is simulated. The reduced normal equations are then modified to include the effect of these simulated measurements.

2.5.1 Notation

Symbol

Description

S_{ij}

Altimeter measurement from i th exposure to j th ground point

σ_s

A priori estimate of standard error of altimeter measurements (same for all measurements).

2.5.2 Computations

a) The entries of the $\dot{B}_{ij}$ and $\ddot{B}_{ij}$ matrices are computed as follows:

$$\dot{B}_{ij}^T = \begin{bmatrix} -x_{ij}y_{ij}/c & , & -(c^2 + y_{ij}^2)/c \\ y_{ij} \sin \bar{\omega} - (c^2 + x_{ij}^2)(\cos \bar{\omega}/c) & , & -x_{ij} \sin \bar{\omega} - (x_{ij}y_{ij})(\cos \bar{\omega}/c) \\ -y_{ij} \bar{F}_i - (c^2 + x_{ij}^2) \bar{C}'_i + (x_{ij}y_{ij})(C_i/c), & x_{ij} \bar{F}_i - (x_{ij}y_{ij})(\bar{C}'_i/c) + (c^2 + y_{ij}^2)(\bar{C}_i/c) \\ (x_{ij}D_i + cA_i)/M_{ij} & , & (y_{ij}D_i + cA'_i)/M_{ij} \\ (x_{ij}E_i + cB_i)/M_{ij} & , & (y_{ij}E_i + cB'_i)/M_{ij} \\ (x_{ij}F_i + cC_i)/M_{ij} & , & (y_{ij}F_i + cC'_i)/M_{ij} \end{bmatrix}$$

$$\ddot{B}_{ij} = -(1/M_{ij}) \begin{bmatrix} x_{ij}D_i + cA_i, & x_{ij}E_i + cB_i, & x_{ij}F_i + cC_i \\ y_{ij}D_i + cA'_i, & y_{ij}E_i + cB'_i, & y_{ij}F_i + cC'_i \end{bmatrix}$$

A derivation of the above expressions for $\dot{B}_{ij}$ and $\ddot{B}_{ij}$ is given in Section 2.5.3

b) The entries of the $\dot{\mathbf{B}}_{s_{ij}}$ and $\ddot{\mathbf{B}}_{s_{ij}}$ are computed as follows:

1. First compute:

$$\Delta X_{ij} = X_i^c - X_i$$

$$\Delta Y_{ij} = Y_i^c - Y_i$$

$$\Delta Z_{ij} = Z_i^c - Z_i$$

2. Then compute:

$$s_{ij} = (\Delta X_{ij}^2 + \Delta Y_{ij}^2 + \Delta Z_{ij}^2)^{\frac{1}{2}}$$

3. Finally:

$$\dot{\mathbf{B}}_{s_{ij}} = [0, 0, 0, \Delta X_{ij}/s_{ij}, \Delta Y_{ij}/s_{ij}, \Delta Z_{ij}/s_{ij}]$$

$$\text{and } \ddot{\mathbf{B}}_{s_{ij}} = -\dot{\mathbf{B}}_{s_{ij}}$$

A derivation of the above expressions for $\dot{\mathbf{B}}_{s_{ij}}$ and $\ddot{\mathbf{B}}_{s_{ij}}$ is given in Section 2.5.3.

c) The entries of the reduced normal equations matrix are computed one block row at a time as follows. (The basic block row has 6 rows). First the weight matrices of the photo coordinates and the elements of exterior orientation are set up:

$$\mathbf{W}_{ij} = \text{diag} (w_{ij}^x, w_{ij}^y)$$

$$\dot{\mathbf{W}}_i = \text{diag} (\mathbf{W}_i^{\overline{\omega\phi\alpha}}, \mathbf{W}_i^{xyz})$$

and,

$$W_{s_{ij}} = \text{diag} (0, 0, 0, w_{s_{ij}}, w_{s_{ij}}, w_{s_{ij}})$$

where,

$$w_{s_{ij}} = 1/\sigma_s^2$$

if altimeter measurement to be simulated between the i th exposure station and the i th passpoint. Otherwise, $w_{s_{ij}} = 0$. Then:

$$\dot{N}_i = \sum_j \dot{B}_{ij}^T W_{ij} \dot{B}_{ij} + \dot{W}_i + \sum_j \dot{B}_{s_{ij}}^T W_{s_{ij}} \dot{B}_{s_{ij}}$$

6x6

is computed for the i th photograph, where the summation is over all the pass points on the i th photograph. The $\bar{N}$ matrices are then computed for all the pass points on the i th photo and for all the photographs which have pass points in common with the i th photograph. The formula is:

$$\bar{N}_{ij} = \dot{B}_{ij}^T W_{ij} \ddot{B}_{ij} + \dot{B}_{s_{ij}}^T W_{s_{ij}} \ddot{B}_{s_{ij}}$$

The N matrices for all the pass points on the i th photograph are computed from:

$$\ddot{N}_i = \sum_j \ddot{B}_{ij}^T W_{ij} \ddot{B}_{ij} + \ddot{W}_i + \sum_j \ddot{B}_{s_{ij}}^T W_{s_{ij}} \ddot{B}_{s_{ij}}$$

where the summation is over all the photographs covering the j th pass point. Denoting the reduced normal equation matrix by $\hat{N}$ and a 6x6 block entry of $\hat{N}$ by $\hat{N}_{ik}$, the i th block row of $\hat{N}$ is computed as follows: Entry (ii) is given by:

$$\hat{N}_{ii} = \dot{N}_i - \sum_j \bar{N}_{ij} \ddot{N}_i^{-1} \bar{N}_{ij}^T$$

where the summation is over all the pass points covering the i th photograph. The off-diagonal elements of the i th block row is given by:

$$\hat{N}_{ik} = - \sum_j \bar{N}_{ij} \ddot{N}_i^{-1} \bar{N}_{kj}^T,$$

where the summation is over all the pass points common to both the i th and k th photographs. Thus if photos i and k do not have any common pass points $\hat{N}_{ik} = 0$. Since $\hat{N}$ is symmetric, Since N is symmetric, $\hat{N}_{ki} = \hat{N}_{ik}^T$. In practice only the upper triangular portion of $\hat{N}$ is computed and stored.

2.5.3 Derivation of Coefficients of Linearized Observation Equations

a) $\dot{B}$ and $\ddot{B}$

The perspective equations may be written as:

$$\begin{aligned} x &= -cK/M \\ y &= -cL/M \end{aligned} \quad (1)$$

where,

$$\begin{bmatrix} K \\ L \\ M \end{bmatrix} = T \begin{bmatrix} X - X^c \\ Y - Y^c \\ Z - Z^c \end{bmatrix} \quad (2)$$

and,

$$T = \begin{bmatrix} A & B & C \\ A' & B' & C' \\ D & E & F \end{bmatrix} = \bar{T} \cdot R = \begin{bmatrix} \bar{A} & \bar{B} & \bar{C} \\ \bar{A}' & \bar{B}' & \bar{C}' \\ \bar{D} & \bar{E} & \bar{F} \end{bmatrix} \cdot R$$

where T and $\bar{T}$ are orthogonal matrices. Differentiating (1) and (2) we have:

$$\begin{bmatrix} dx \\ dy \end{bmatrix} = -(1/M) \begin{bmatrix} c & 0 & x \\ 0 & c & y \end{bmatrix} \begin{bmatrix} dK \\ dL \\ dM \end{bmatrix} \quad (3)$$

and,

$$\begin{bmatrix} dK \\ dL \\ dM \end{bmatrix} = dT \begin{bmatrix} X & - & X^c \\ Y & - & Y^c \\ Z & - & Z^c \end{bmatrix} + T \begin{bmatrix} dX & - & dX^c \\ dY & - & dY^c \\ dZ & - & dZ^c \end{bmatrix} \quad (4)$$

Premultiplying (2) by T^T we have:

$$\begin{bmatrix} X & - & X^c \\ Y & - & Y^c \\ Z & - & Z^c \end{bmatrix} = T^T \begin{bmatrix} K \\ L \\ M \end{bmatrix} = \frac{M}{C} T^T \begin{bmatrix} -x \\ -y \\ c \end{bmatrix} \quad (5)$$

Substituting (5) in (4) we have:

$$\begin{bmatrix} dK \\ dL \\ dM \end{bmatrix} = \frac{M}{C} dTT^T \begin{bmatrix} -x \\ -y \\ c \end{bmatrix} + T \begin{bmatrix} dX & - & dX^c \\ dY & - & dY^c \\ dZ & - & dZ^c \end{bmatrix} \quad (6)$$

Since T is orthogonal:

$$TT^T = I. \quad (7)$$

Differentiating (7) and transposing we have, since $dl = 0$,

$$dT T^T = -T dT^T. \quad (8)$$

Note that dTT^T is skew-symmetric and may be expressed as:

$$dTT^T = \begin{bmatrix} 0 & \delta_1 & \delta_2 \\ -\delta_1 & 0 & \delta_3 \\ -\delta_2 & -\delta_3 & 0 \end{bmatrix} \quad (9)$$

Substituting (9) in (6) and the result in (3) we have:

$$\begin{bmatrix} dx \\ dy \end{bmatrix} = -(1/c) \begin{bmatrix} c & 0 & x \\ 0 & c & y \end{bmatrix} \begin{bmatrix} 0 & \delta_1 & \delta_2 \\ -\delta_1 & 0 & \delta_3 \\ -\delta_2 & -\delta_3 & 0 \end{bmatrix} \begin{bmatrix} -x \\ -y \\ -z \end{bmatrix} - (1/M) \begin{bmatrix} c & 0 & x \\ 0 & c & y \end{bmatrix} \begin{bmatrix} A & B & C \\ A' & B' & C' \\ D & E & F \end{bmatrix} \begin{bmatrix} dX-dX^c \\ dY-dY^c \\ dZ-dZ^c \end{bmatrix} \quad (10)$$

Performing the matrix multiplications in (10) and rearranging terms we have

$$\begin{bmatrix} dx \\ dy \end{bmatrix} = \begin{bmatrix} y, -(c^2 + x^2)/c, -xy/c \\ -x, -xy/c, -(c^2 + y^2)/c \end{bmatrix} \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \end{bmatrix} - (1/M) \begin{bmatrix} cA+xD, cB+xE, cC+xF \\ cA'+yD, cB'+yE, cC'+yF \end{bmatrix} \begin{bmatrix} dX-dX^c \\ dY-dY^c \\ dZ-dZ^c \end{bmatrix} \quad (11)$$

It is now necessary to express $(\delta_1, \delta_2, \delta_3)$ as functions of the differentials of the orientation angles. If the orientation matrix is given in terms of local vertical angles, we have:

$$dTT^T = d(\bar{T} \cdot R) \cdot (\bar{T} \cdot R)^T$$

or

$$dTT^T = d\bar{T} \cdot \bar{T}^T + \bar{T}dR \cdot R^T \bar{T}^T.$$

The second term, $\bar{T}dR \cdot R^T \cdot \bar{T}^T$, does not involve any differentials of the local vertical orientation angles. Furthermore, the contribution of the uncertainty of the image coordinates due to the uncertainty of the position of the exposure station is considered negligible.

Then we say:

$$d\mathbf{T}\mathbf{T}^T = d\bar{\mathbf{T}} \cdot \bar{\mathbf{T}}^T.$$

Since

$$d\bar{\mathbf{T}} \cdot \bar{\mathbf{T}}^T = \begin{bmatrix} 0 & \sin \bar{\omega} d\bar{\varphi} - \cos \bar{\omega} \cos \bar{\varphi} d\bar{\alpha}, & \cos \bar{\omega} d\bar{\varphi} + \sin \bar{\omega} \cos \bar{\varphi} d\bar{\alpha} \\ -\sin \bar{\omega} d\bar{\varphi} + \cos \bar{\omega} \cos \bar{\varphi} d\bar{\alpha}, & 0 & d\bar{\omega} - \sin \bar{\varphi} d\bar{\alpha} \\ -\cos \bar{\omega} d\bar{\varphi} - \sin \bar{\omega} \cos \bar{\varphi} d\bar{\alpha}, & -d\bar{\omega} + \sin \bar{\varphi} d\bar{\alpha} & 0 \end{bmatrix}$$

Then, by (9):

$$\begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \end{bmatrix} = \begin{bmatrix} 0 & \sin \bar{\omega} & -\cos \bar{\omega} \cos \bar{\varphi} \\ 0 & \cos \bar{\omega} & \sin \bar{\omega} \cos \bar{\varphi} \\ 1 & 0 & -\sin \bar{\varphi} \end{bmatrix} \begin{bmatrix} d\bar{\omega} \\ d\bar{\varphi} \\ d\bar{\alpha} \end{bmatrix} \quad (12)$$

Substituting (12) in (11) we have:

$$[dx, dy]^T = \dot{\mathbf{B}} [d\bar{\omega}, d\bar{\varphi}, d\bar{\alpha}, dX^c, dY^c, dZ^c]^T + \ddot{\mathbf{B}} [dX, dY, dZ]^T$$

where $\dot{\mathbf{B}}$ and $\ddot{\mathbf{B}}$ are given in Section 2.5.2(a).

b) $\dot{\mathbf{B}}_s$ and $\ddot{\mathbf{B}}_s$

The distance equation is written as:

$$S = \left[(X^c - X)^2 + (Y^c - Y)^2 + (Z^c - Z)^2 \right]^{\frac{1}{2}} \quad (13)$$

Differentiating (13) we have:

$$dS = \frac{1}{S} \left[(X^c - X), (Y^c - Y), (Z^c - Z) \right] \begin{bmatrix} dX^c & - & dX \\ dY^c & - & dY \\ dZ^c & - & dZ \end{bmatrix} \quad (14)$$

Equation (14) is then written in the form:

$$\begin{bmatrix} ds \end{bmatrix} = \dot{\mathbf{B}}_s \begin{bmatrix} d\bar{\omega}, d\bar{\varphi}, d\bar{\alpha}, dX^c, dY^c, dZ^c \end{bmatrix}^T + \ddot{\mathbf{B}}_s \begin{bmatrix} dX, dY, dZ \end{bmatrix}^T$$

where $\dot{\mathbf{B}}_s$ and $\ddot{\mathbf{B}}_s$ are given in Section 2.5.2.(b).

2.6 Statistical Recovery

The statistical recovery is performed by a series of three subroutines. They are the programs SSOLVE, REV, and PTCOV.

2.6.1 Solution and Inversion of the Normal Equations by Recursive Partitioning

The reduced normal equations, formed by the NEF program, are solved by the SSOLVE program and then inverted by the REV program. An algorithm called Recursive Partitioning is used for these operations. Recursive Partitioning is described in Brown (1968). The mathematical analysis of these subroutines is given in Gyer, Saliba, and Lewis (1969). This method was selected because it exploits the banded structure of the reduced normal equations at a substantial savings in computer time. This savings is up to several orders of magnitude by comparison with the method of Direct Gaussian Elimination.

2.6.2 Computation of the Required Statistics

Using the inverse of the reduced normal equations from REV as input, the PTCOV program computes the required statistics for the final output. The covariance matrix of the exposure station parameters is used to compute the a posteriori estimates of the standard errors of these parameters and to compute the coefficients of correlation between the position elements and also the coefficients of correlation between the orientation elements.

Portions of the normal equations formed in NEF together with the inverse of the reduced normal equations from REV are used to compute the covariance matrix of the ground point coordinates. This covariance matrix is then used to compute the a posteriori estimates of the standard errors of the ground point coordinates and the coefficients of correlation between them.

2.6.2.1 Notation

<u>Symbol</u>	<u>Description</u>
$\dot{Q}_{ik}$	The 6x6 submatrix of $\hat{N}^{-1}$ correlating the i th and k th photographs.
$\ddot{N}_i, \bar{N}_{ij}$	Portions of normal equations formed by NEF (See Section 2.5.2. (c))
$\dot{U}_i, \ddot{U}_i$	Jacobian matrices of i th exposure station and j th ground
$\dot{s}_{\bar{\omega}_i}, \dot{s}_{\bar{\varphi}_i}, \dot{s}_{\bar{\alpha}_i}$	A posteriori estimates of standard errors of orientation elements of the i th exposure station
$\dot{r}_{\bar{\omega}_i, \bar{\varphi}_i}, \dot{r}_{\bar{\omega}_i, \bar{\alpha}_i}, \dot{r}_{\bar{\varphi}_i, \bar{\alpha}_i}$	Coefficients of correlation between the orientation elements of the i th exposure station
$\dot{s}_{N_i}, \dot{s}_{E_i}, \dot{s}_{U_i}$	A posteriori estimates of standard errors of position elements (north, east, up) of the i th exposure station
$\dot{r}_{N_i, E_i}, \dot{r}_{N_i, U_i}, \dot{r}_{E_i, U_i}$	Coefficients of correlation between the position elements (north, east, up) of the exposure station.
$\ddot{s}_{N_i}, \ddot{s}_{E_i}, \ddot{s}_{U_i}$	A posteriori estimates of the position elements (north, east, up) of the j th ground point.
$\ddot{r}_{N_i, E_i}, \ddot{r}_{N_i, U_i}, \ddot{r}_{E_i, U_i}$	Coefficients of correlation between position elements (north, east, up) of the j th ground point.

2.6.2.2 Computations

(a) Form $\hat{U}_i$:

$$\hat{U}_i = [I_{(3,3)}, U_i]$$

where $I_{(3,3)}$ is the third-order identity matrix.

(b) Compute the covariance matrix of the local vertical orientation angles and position elements (N, E, and U) of the i th exposure station:

$$\dot{\mathbf{Q}}_i = \hat{\mathbf{U}}_i^T \dot{\mathbf{Q}}_{ii} \hat{\mathbf{U}}_i.$$

(c) Compute the statistics for the first output table:

$$1. \quad \dot{s}_{\bar{\omega}_i} = (\dot{q}_{(1,1)})_i^{\frac{1}{2}}$$

$$2. \quad \dot{s}_{\bar{\varphi}_i} = (\dot{q}_{(2,2)})_i^{\frac{1}{2}}$$

$$3. \quad \dot{s}_{\bar{\alpha}_i} = (\dot{q}_{(3,3)})_i^{\frac{1}{2}}$$

$$4. \quad \dot{r}_{\bar{\omega}_i, \bar{\varphi}_i} = (\dot{q}_{(1,2)})_i / (\dot{s}_{\bar{\omega}_i} \cdot \dot{s}_{\bar{\varphi}_i})$$

$$5. \quad \dot{r}_{\bar{\omega}_i, \bar{\alpha}_i} = (\dot{q}_{(1,3)})_i / (\dot{s}_{\bar{\omega}_i} \cdot \dot{s}_{\bar{\alpha}_i})$$

$$6. \quad \dot{r}_{\bar{\varphi}_i, \bar{\alpha}_i} = (\dot{q}_{(2,3)})_i / (\dot{s}_{\bar{\varphi}_i} \cdot \dot{s}_{\bar{\alpha}_i})$$

$$7. \quad \dot{s}_{N_i} = (\dot{q}_{(4,4)})_i^{\frac{1}{2}}$$

$$8. \quad \dot{s}_{E_i} = (\dot{q}_{(5,5)})_i^{\frac{1}{2}}$$

$$9. \quad \dot{s}_{U_i} = (\dot{q}_{(6,6)})_i^{\frac{1}{2}}$$

$$10. \quad \dot{s}_{N_i E_i} = (\dot{q}_{(4,5)})_i / (\dot{s}_{N_i} \cdot \dot{s}_{E_i})$$

$$11. \quad \dot{s}_{N_i U_i} = (\dot{q}_{(4,6)})_i / (\dot{s}_{N_i} \cdot \dot{s}_{U_i})$$

$$12. \quad \dot{s}_{E_i, U_i} = (\dot{q}_{(5,6)})_i / (\dot{s}_{E_i} \cdot \dot{s}_{U_i})$$

where, $(\dot{q}_{(I,J)})_i$ is the entry (I,J) of $\dot{Q}_i$

(d) Compute the covariance matrix of the USR coordinates of the j th ground point by:

$$\ddot{Q}_i^{USR} = \ddot{N}_i^{-1} + \sum_i \sum_k \ddot{N}_i^{-1} \bar{N}_{ji}^T \dot{Q}_{ik} \bar{N}_{kj} \ddot{N}_i^{-1}$$

where the double summation is over all the photographs covering the j th ground point.

(e) Compute the covariance matrix of the local vertical coordinates of the j th ground point by:

$$\ddot{Q}_i = \ddot{U}_i^T \ddot{Q}_i^{USR} \ddot{U}_i$$

(f) Compute the statistics for the second output table:

$$1. \ddot{S}_{N_i} = (\dot{q}_{(1,1)})_i^{\frac{1}{2}}$$

$$2. \ddot{S}_{E_i} = (\dot{q}_{(2,2)})_i^{\frac{1}{2}}$$

$$3. \ddot{S}_{U_i} = (\dot{q}_{(3,3)})_i^{\frac{1}{2}}$$

$$4. \ddot{r}_{N_i, E_i} = (\dot{q}_{(1,2)})_i / (\ddot{S}_{N_i} \cdot \ddot{S}_{E_i})$$

$$5. \ddot{r}_{N_i, U_i} = (\dot{q}_{(1,3)})_i / (\ddot{S}_{N_i} \cdot \ddot{S}_{U_i})$$

$$6. \ddot{r}_{E_i, U_i} = (\dot{q}_{(2,3)})_i / (\ddot{S}_{E_i} \cdot \ddot{S}_{U_i})$$

where, $(\ddot{q}_{(I,J)})_i$ is the entry (I,J) of $\ddot{Q}_i$.

3.0 COMPUTER PROGRAM USER PROCEDURES

Before attempting to run the GBLOCK module of programs, the user should acquaint himself with the article upon which the computational methods are based: "A Unified Lunar Control Network", (D. Brown, 1968).

3.1 Job Deck Setup

3.1.1 Page Estimates

The page estimates, in hundreds of pages, for each permitted case are given in Table 3.1. The values given for IPC = 1 assume that the raw data print option is off.

TABLE 3.1

No. of Photos	Level of Passpoint Densification	IPC (See Section 3.2 for full explanation)				
		0 Sim. Only	1 Sim. & Form	2 Forward	3 Reverse	4 Statistics
42	0	1	1	1	1	1
	1	1	1	1	1	1
	2	2	1	1	1	1
162	0	2	1	1	1	1
	1	2	1	1	1	1
	2	4	1	1	1	1
642	0	7	1	1	1	1
	1	7	1	1	1	2
	2	14	1	1	1	2

3.1.2 Estimation of Execution Time

Estimated execution times for the various segments are given in Table 3.2.

TABLE 3.2
Estimated Execution Times

No. of Photos	Level of Passpoint Densification	IPC (See Section 3.2 for full explanation)				
		0 Sim. Only	1 Sim & Form	2 Forward	3 Reverse	4 Statistics
42	0	9 sec	0.9 min	1.5min	2.2min	0.3 min
	1	36 sec	1.4 min			0.7 min
	2	81 sec	8.1 min			3.0 min
162	0	0.5 min	3.5 min	20min	32min	1.0 min
	1	2.0 min	10 min			2.5 min
	2	5.8 min	81 min			12 min
642	0	2.8 min	18 min	320min	330min	5.5 min
	1	12 min	360 min			22 min
	2	26 min	810 min			50 min

Notes:

1. These estimates are based on the results of 42 photo runs at the 0 and 1 level of passpoint densification, 162 photo rows at the 0 and 1 level of passpoint densification and a 642 photo run at the 0 level of densification.
2. Estimates are for the UNIVAC 1108. Runs made on the UNIVAC 1106 will be approximately twice the estimates given.
3. Values given for IPC = 3 and IPC = 4 for the 42 photo and 162 photo cases assume that the complete inverse is computed. For half the inverse only, times for these segments should be halved.
4. The half-the-inverse option (see card type B) must be selected for all 642 photo cases.

3.1.3 File Assignments

FORTRAN units 1,2,3, and 4 must be assigned to tape drives, whenever they are used (see Table 3.3). Assignment of these files to 432 drum will result in fatal execution errors. Assignment to FASTRAND, although permissible, will result in prodigious execution times, and will preclude the possibility of restarting execution at the next segment (see Section 3.2).

FORTRAN unit 10, which will contain the two plot files at the end of segments where $IPC = 0$ and/or $IPC = 1$, may be saved or discarded at the discretion of the user. If these files are not to be saved, they may be assigned to FASTRAND.

TABLE 3.3
File Usage

SEGMENT	UNIT 1	UNIT 2	UNIT 3	UNIT 4	UNIT 10
IPC = 0	SCRATCH	SCRATCH	SCRATCH	SCRATCH	OUT
IPC = 1	OUT/SAVE	SCRATCH	SCRATCH	OUT/SAVE	OUT
IPC = 2	IN/SAVE	UNUSED	OUT/SAVE	IN/OPT	UNUSED
IPC = 3	IN/SAVE	OUT/SAVE	IN/OPT	UNUSED	UNUSED
IPC = 4	IN/OPT	IN/OPT	UNUSED	UNUSED	UNUSED

Legend:

SCRATCH	=	Scratch file
OUT	=	Output file (ring in)
IN	=	Input file (ring out)
SAVE	=	Must be saved at end of segment to permit restart at next segment.
OPT	=	Save is optional, and recommended.
UNUSED	=	Not used by segment.

3.2 Input Description

Execution proceeds by segments. At the end of each segment, the files necessary to restart at the next segment must be saved (see Table 3.3). The execution of a segment is specified by means of an input card containing the program control word, IPC (card type A). The permitted values and their effect are given in Table 3.4.

TABLE 3.4
Program Control

IPC	Execution Specified
0	Simulation only (cannot restart)
1	Simulation and formation of normals
2	Forward course of inverse computation
3	Reverse course of inverse computation
4	Computation of statistics
-1	Terminate execution

Additional card input is required by some of the segments.

3.2.1 Input for Simulation

For IPC = 0 and IPC = 1, card input must be supplied (Deck 1). Refer to the card description sheets for details.

Specification of ground control points is by unmodified six-digit labels. To determine the labels of desired points, a simulation only run (IPC = 0) should be run with no control specified (KTYP1 = KTYP2 = KTYP3 = 0). The desired labels can be taken from the resultant output.

3.2.2 Input For the Forward Course of the Inverse

For $IPC = 2$, no input deck is required.

3.2.3 Input For the Reverse Course of the Inverse

For $IPC = 3$, a single input card is required (Card Type B). Refer to the input card sheet for Card Type B.

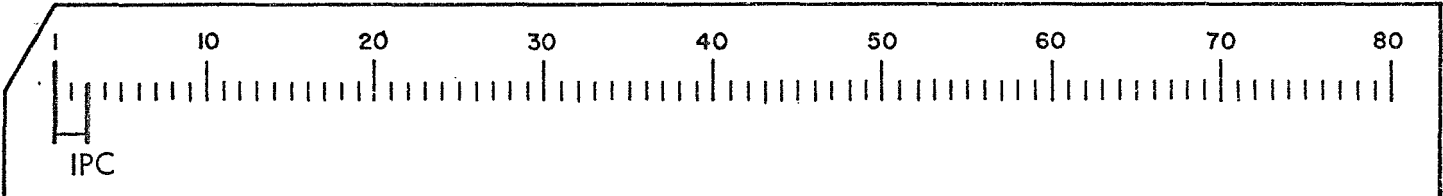
3.2.4 Input For Computation of Statistics

For $IPC = 4$, a single input card is required (Card Type C). Refer to the input card sheet for Card Type C.

3.2.5 Input Card Description Sheets

Input card description sheets for all input cards follow.

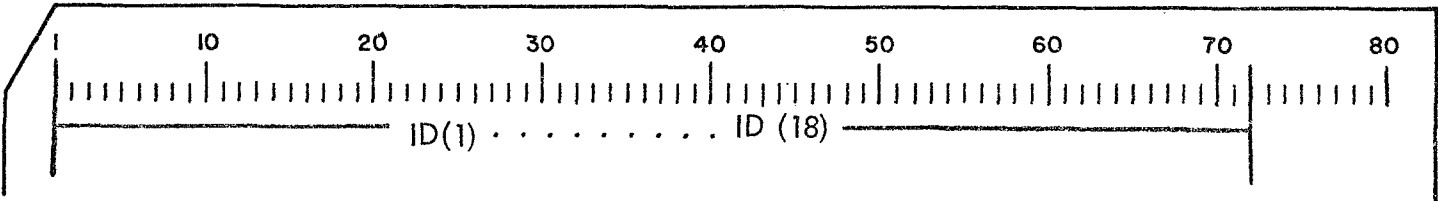
Card Type A



FORMAT (I3)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	IPC	-	I3	1-3	-	Program control word

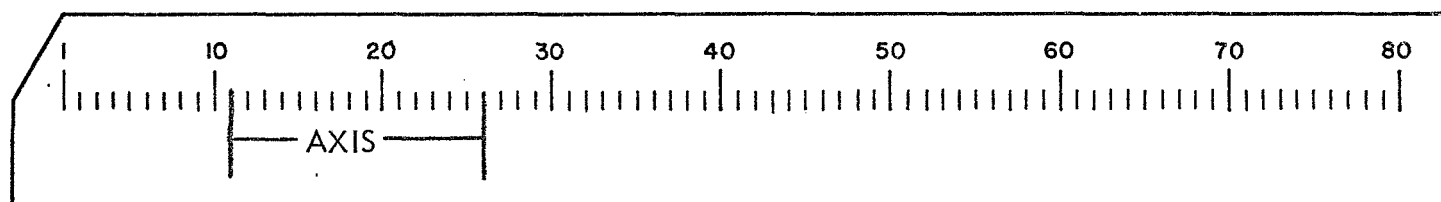
Deck 1
Card Type 1



FORMAT (18A4)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1-18	ID	-	18A4	1-72	-	Hollerith indentification

Deck 1
Card Type 2

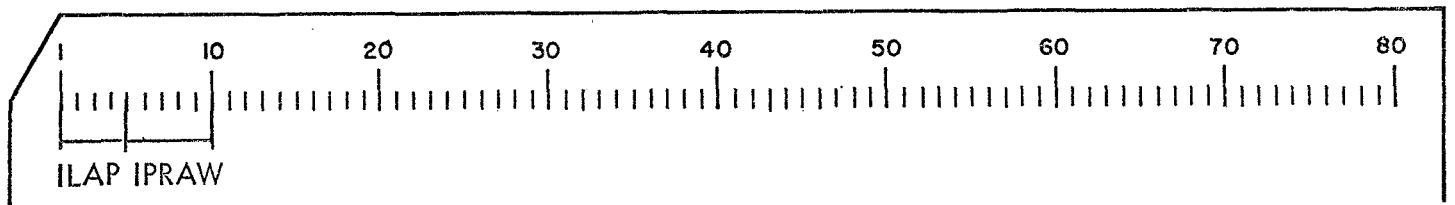


FORMAT (10X, D16.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	AXIS	m	D16.0	11-26	a	Radius of sphere

Deck 1

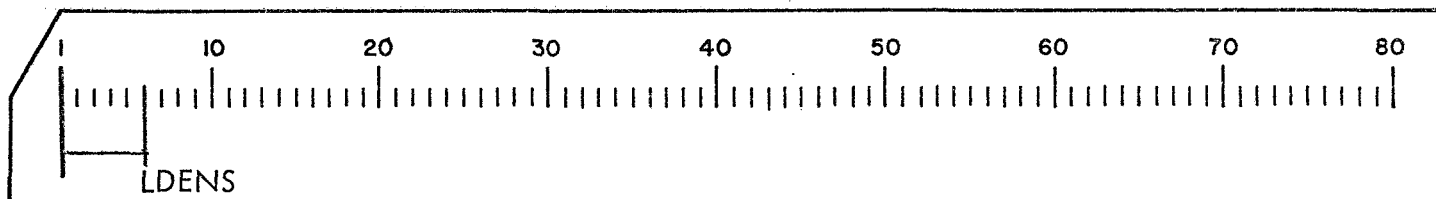
Card Type



FORMAT (215)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	ILAP	-	I5	1-5	-	Percentage of sidelap. ILAP $\leq$ 50 means single sidelap ILAP > 50 means double sidelap
2	IPRAW	-	I5	6-10	-	Raw data print flag. IPRAW = 0, print flag is off IPRAW > 0, print flag is on. (When IPC = 0, print is forced.)

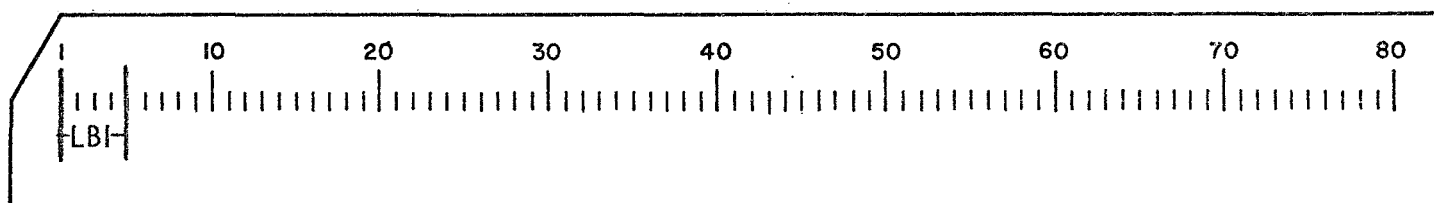
Deck 1
Card Type 4



FORMAT (I5)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	LDENS	-	I5	1-5	-	Passpoint densification 0, 1, 2 are permitted

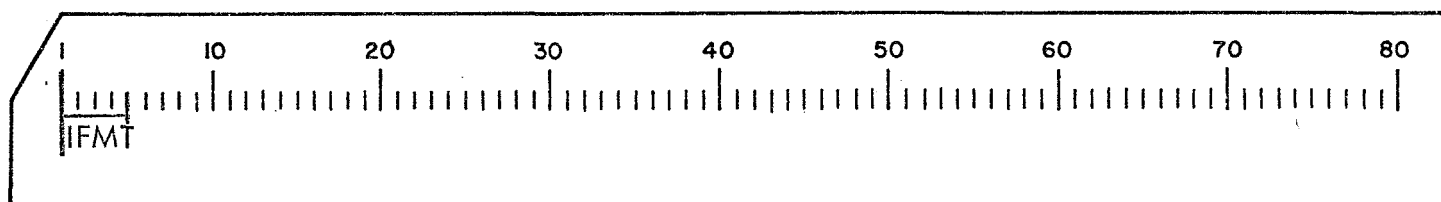
Deck 1
Card Type 5



FORMAT (15)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	LBI	-	15	1-5	-	Level of bisection of the icosahedron: LBI = 1, 42-photos LBI = 2, 162-photos LBI = 3, 642-photos No other values permitted.

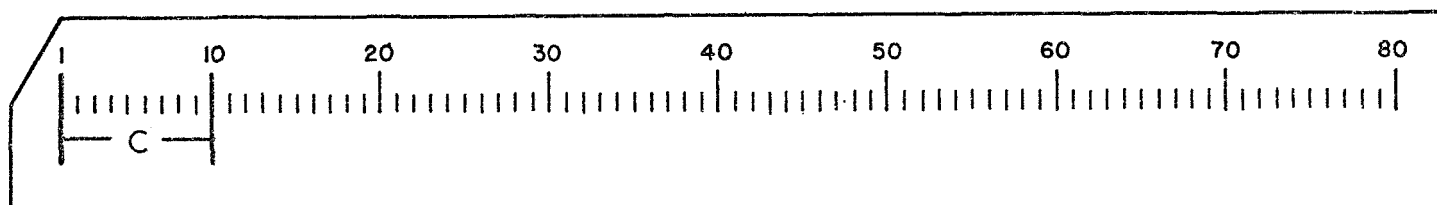
Deck 1
Card Type 6



FORMAT (15)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	IFMT	-	I5	1-5	-	Film format: IFMT = 0, circular format IFMT = 1, square format If IFMT = 0, ILAP forced to double sidelap

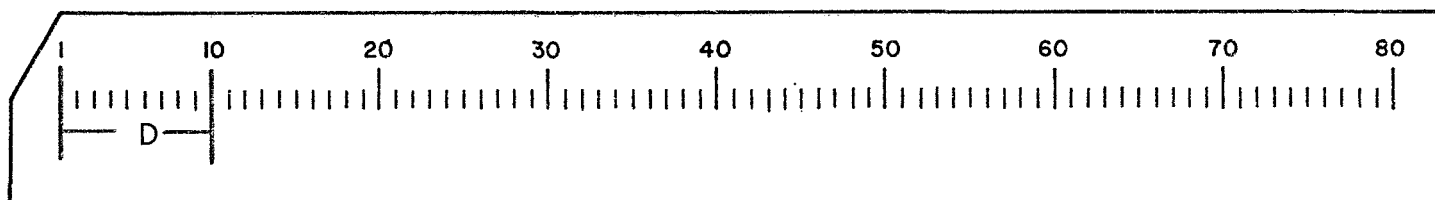
Deck 1
Card Type 7



FORMAT (G 10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	C	mm	G 10.0	1-10	c	focal length of camera

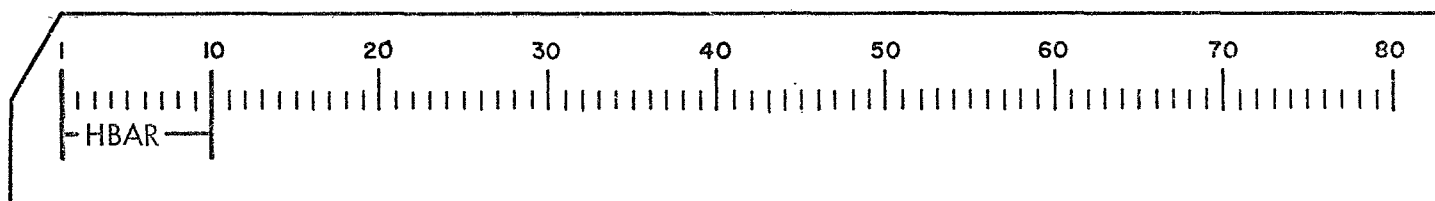
Deck 1
Card Type 8



FORMAT (G 10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	D	mm	G 10.0	1-10	d	Film format

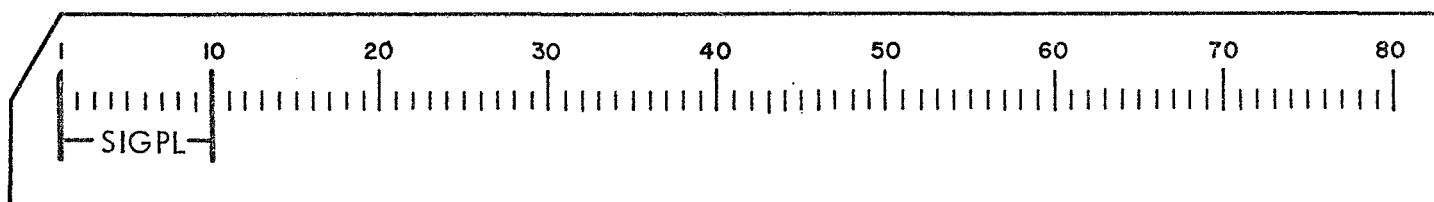
Deck 1
Card Type 9



FORMAT (G10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	HBAR	m	G10.0	1-10	$\bar{H}$	camera altitude

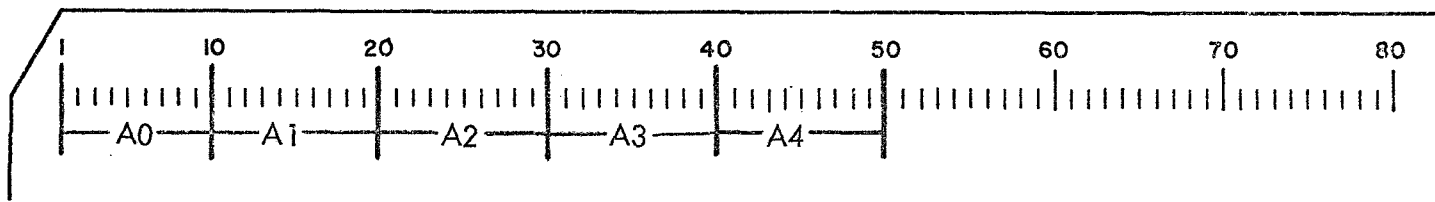
Deck 1
Card Type 10



FORMAT (G10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	SIGPL	mm	G10.0	1-10	σ_p	Plate measurement sigma

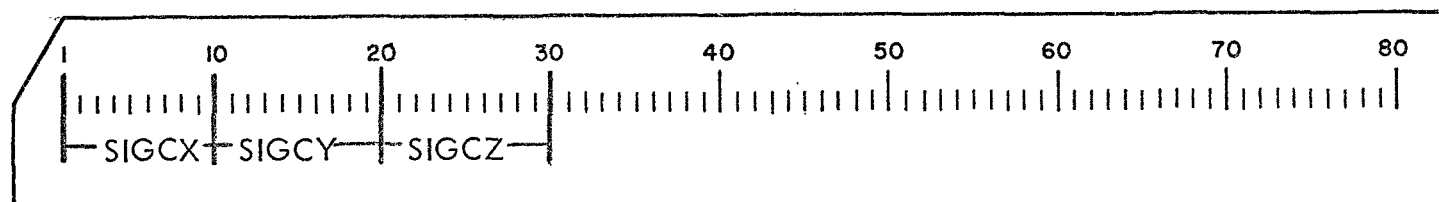
Deck 1
Card Type 11



FORMAT (5G10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	A0	-	G10.0	1-10	a_0	Coefficients of the empirical weighting function of plate coordinates. (see section 2.4)
2	A1	-	G10.0	11-20	a_1	
3	A2	-	G10.0	21-30	a_2	
4	A3	-	G10.0	31-40	a_3	
5	A4	-	G10.0	41-50	a_4	

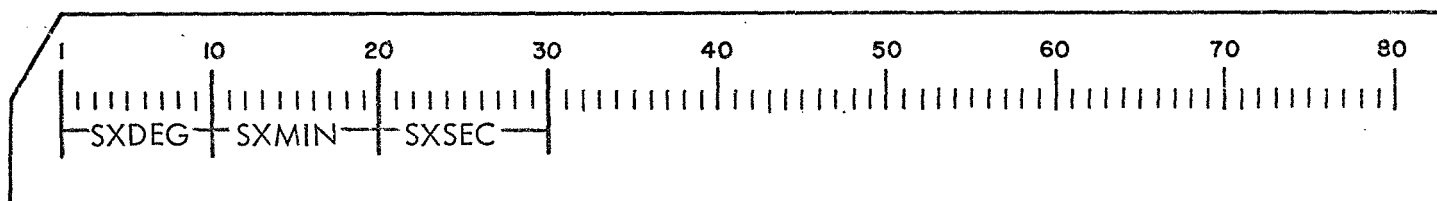
Deck 1
Card Type 12



FORMAT (3G 10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	SIGCX	m	G 10.0	1-10	σ_{X^c}	X camera position sigma
2	SIGCY	m	G 10.0	11-20	σ_{Y^c}	Y camera position sigmas
3	SIGCZ	m	G 10.0	21-30	σ_{Z^c}	Z camera position sigmas

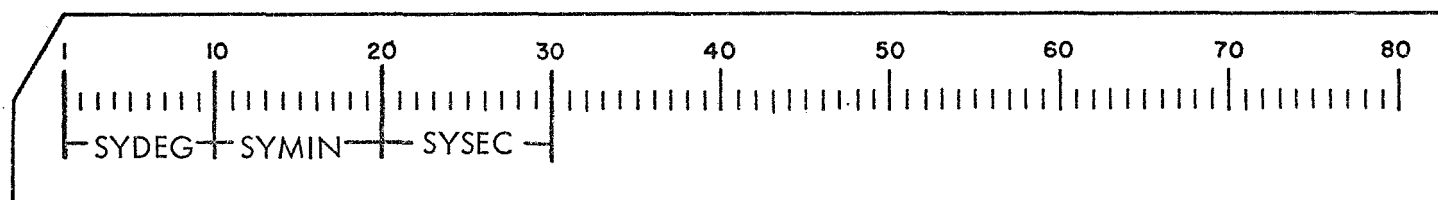
Deck 1
Card Type 13



FORMAT (3G 10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	SXDEG	DEG	G 10.0	1-10	} σ_{ω}	Sigma of camera orientation about the N -axis
2	SXMIN	MIN	G 10.0	11-20		
3	SXSEC	SEC	G 10.0	21-30		

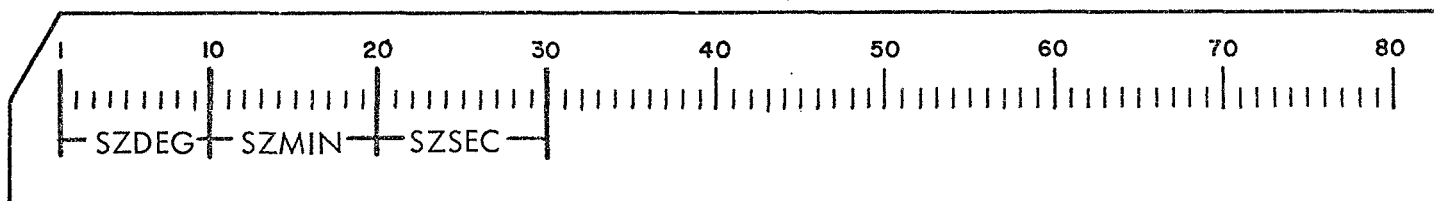
Deck 1
Card Type 14



FORMAT (3G 10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	SYDEG	DEG	G 10.0	1-10	} σ_{ϕ}	Sigma of Camera orientation about E -axis
2	SYMIN	MIN	G 10.0	11-20		
3	SYSEC	SEC	G 10.0	21-30		

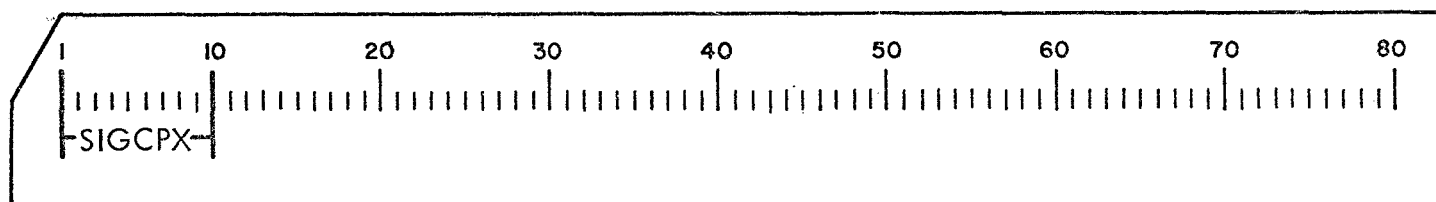
Deck 1
Card Type 15



FORMAT (3G 10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	SZDEG	DEG	G 10.0	1-10	σ_{α}	Sigma of camera orientation about the U -axis
2	SZMIN	MIN	G 10.0	11-20		
3	SZSEC	SEC	G 10.0	21-30		

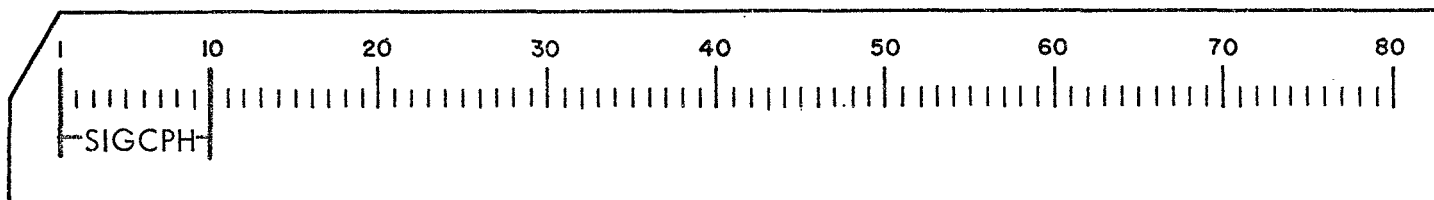
Deck 1
Card Type 16



FORMAT (G10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	SIGCPX	m	G 10.0	1-10	-	Ground control point sigma (horizontal)

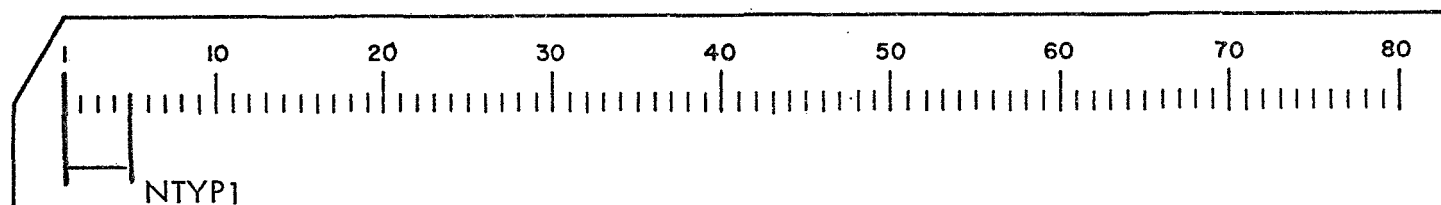
Deck 1
Card Type 17



FORMAT (G10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	SIGCPH	m	G10.0	1-10	-	Ground control point sigma (vertical)

Deck 1
Card Type 18*

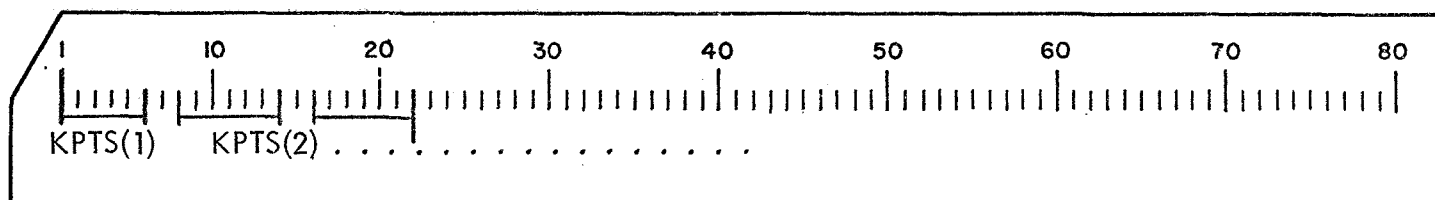


FORMAT (I5)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	NTYP1	-	I5	1-5	-	Number of horizontal and vertical control points

Card type 18 is followed by a variable number of cards sufficient to input the number of horizontal and vertical control points specified by NTYP1

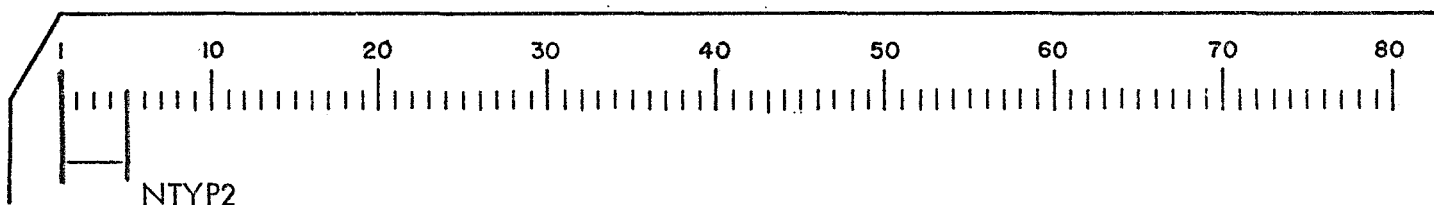
Deck 1
Card Type 18a



FORMAT (10(A6,2X))

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	KPTS(1)	-	A6	1-6	-	Horizontal and vertical control point labels
2	K PTS(2)	-	A6	9-14	-	
.						
.						
.						
.						If NTYP1 = 0, this card is omitted
.						

Deck 1
Card Type 19*



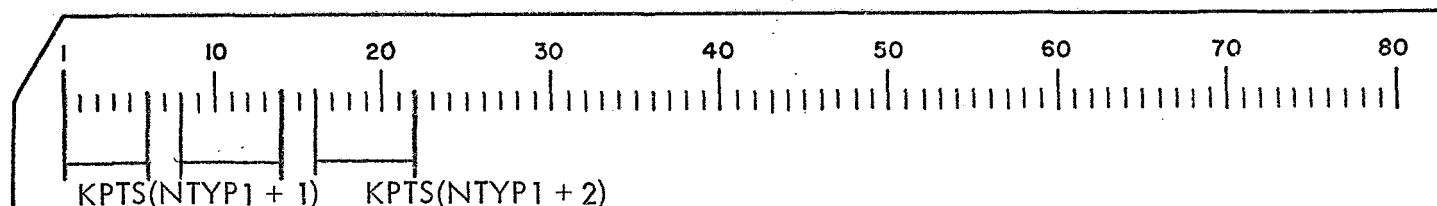
FORMAT (15)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	NTYP2	-	I5	1-5	-	Number of horizontal only control points

Card type 19 is followed by a variable number of cards sufficient to input the number of horizontal only control points specified by NTYP2

Deck 1

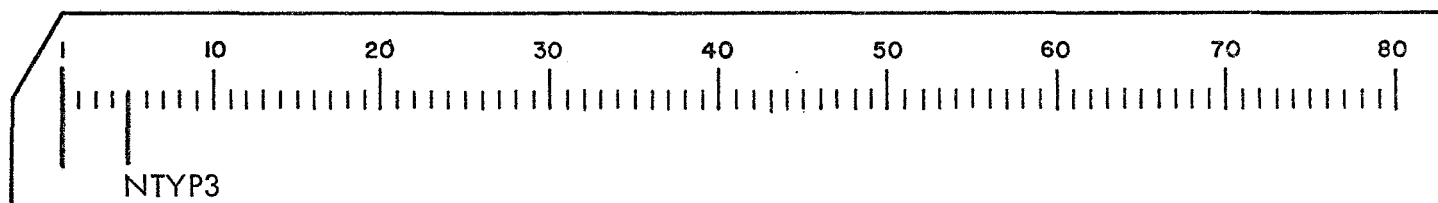
Card Type 19a



FORMAT (10(A6,2X))

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	KPTS (NTYP 1 + 1)	-	A6	1-6	-	Horizontal only control point labels If NTYP2 = 0, this card is omitted
2	KPTS (NTYP 1 + 2)	-	A6	9-14	-	
.						
.						
.						

Deck 1
Card Type 20*

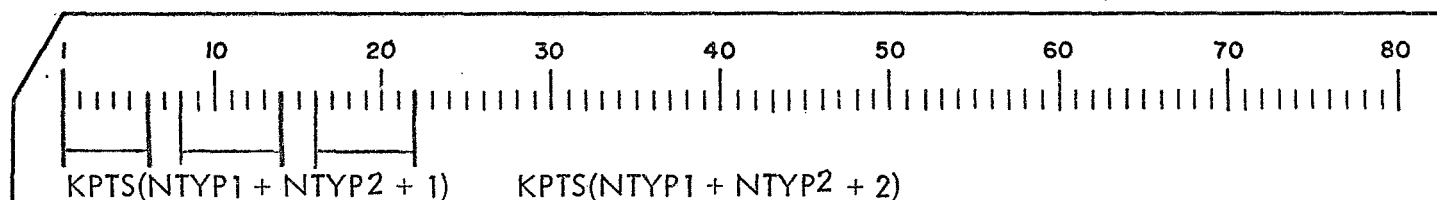


FORMAT (I5)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	NTYP3	-	I5	1-5	-	Number of vertical only control points

Card type 20 is followed by a variable number of cards sufficient to input the number of vertical only control points specified by NTYP3

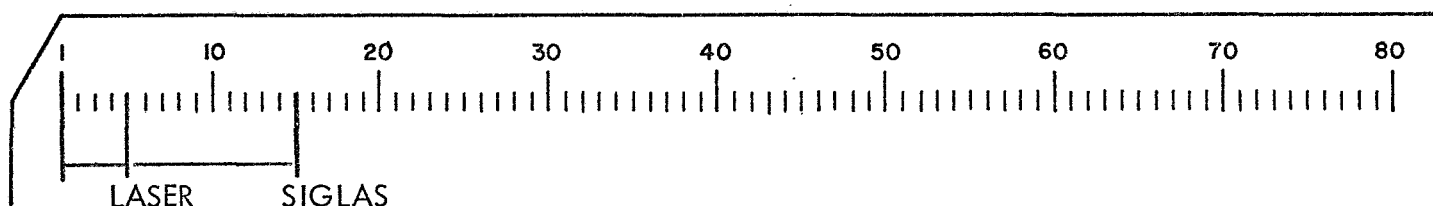
Deck 1
Card Type 20a



FORMAT (10(A6,2X))

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	KPTS (NTYP1 +NTYP2 + 1)	-	A6	1-6	-	Vertical-only control point labels
2	KPTS (NTYP1 +NTYP2 + 2)	-	A6	9-14	-	
						If NTYP3 = 0, this card is omitted

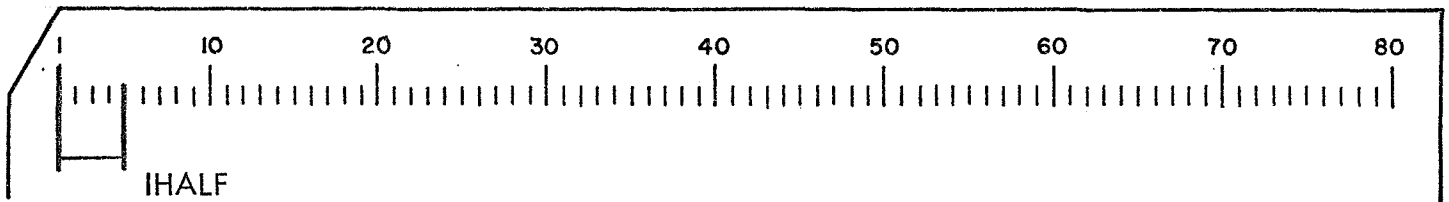
Deck 1
Card Type 21



FORMAT (15, G10.0)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	LASER	-	15	1-5	-	If $LASER \leq 0$, no laser measurements simulated If $LASER > 0$, measurement simulated from every $(n * LASER)^{th}$ photo to its nadir point, where $n = 1, 2, 3 \dots$
2	SIGLAS	m	G10.0	6-15	σ_S	Sigma of simulated laser measurements. If $SIGLAS \leq 0$, LASER forced to zero

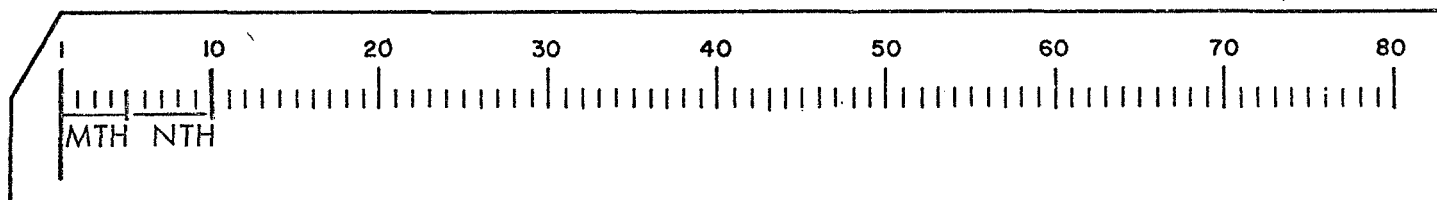
Card Type B



FORMAT (15)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	IHALF	-	15	1-5	-	1/2 Inverse option: If IHALF = 0, complete inverse computed If IHALF $\neq$ 0, the inverse is computed for only half the matrix (South Pole to and including the equator)

Card Type C



FORMAT (215)

Word No.	Program Variable	Units	Format	Column	Math Symbol	Description
1	MTH	-	I5	1-5	-	* First ground point for which statistics are desired. MTH = 0 is equivalent to MTH = 1
2	NTH	-	I5	6-10	-	* Statistics are desired for every NTH ground point starting with the MTH. NTH = 0 is forced to NTH = 1.

* Statistics are never computed for points for which any relevant portions of the inverse are unavailable.

3.3 Output Description

The program produces at least one page of hard copy per major subroutine. In some cases the page will contain only the name of the subroutine, plus the usual header information.

The simulator produces two pages of hard copy which tabulates the input data. The two files of plot information are also generated on FORTRAN unit 10. The simulator optionally produces one page of hard copy for each simulated photograph.

FORTAN units 1, 2, 3, and 4 must be regarded as intermediate output, as they are required input for continuation of a run at the successive segment.

The final segment of the program produces two hard copy tables of statistics. The first of these tabulates statistics related to exposure station parameters. For each exposure station, the twelve statistics are given. These are the a posteriori estimates of standard errors of six exposure station parameters, and six coefficients of correlation. The entries are clearly labeled.

The second table tabulates statistics related to ground point parameters. Six statistics are given for each ground point. These are the a posteriori estimates of the standard errors of the ground point coordinates, and the coefficients of correlation between them. The entries are clearly labeled.

It will be remembered that exposure station statistics are not computed for those exposure stations for which the relevant portion of the inverse normal equations are missing. Similarly, statistics related to ground points are computed only for those specified points (see input Card Type C) for which all relevant portions of the inverse normal equations are available.

3.4 Sample Cases

The principals for determining reasonable cases are set forth in the primary reference (Brown, 1968). A complete input deck is given. The sample output resulted from running the program with the given input deck. As noted, only one of the raw data printout pages is included.

3.4.1 An Input Deck

Refer to Section 3.2 and to the output for interpretation of Table 3.5.

3.4.2 Hard Copy Output

Seven pages are given.

TABLE 3.5
An Input Deck

1	GLOBAL 42 PHOTO CASE, ZERO DENSIFICATION, CIRCULAR FORMAT		
	0.17380000000 07		
60	1		
1			
150.00			
225.00			
1074000.00			
0.005			
1000.	1000.	1000.	
1.			
1.			
1.			
0.1			
0.1			
2			
000000	480000		
1			
240000			
2			
3			
4			
-1			

DBA - G B L O C K - GLOBAL MISSION PHOTOGRAMMETRIC TRIANGULATION GDOP PROGRAM 11 JUN 71 00:08:39

GLOBAL CASE B, 42 PHOTO, ZERO DENS., CIRC FMT, SCALE ONLY PAGE 1

INPUT DATA FOR SIMULATION

RADIUS FOR REFERENCE SPHERE (M) .17380000+007

NUMBER OF BISECTIONS OF ICOSAHEDRON 1

LEVEL OF DENSIFICATION OF PASS POINT PATTERN 0

FORMAT SHAPE CODE 0 (CIRCULAR)

PHOTOS WITH LATITUDE BETWEEN PLUS AND MINUS 30. DEGREES WILL HAVE DOUBLE SIDE-LAP.

FOCAL LENGTH (MM) 150.00

FILM FORMAT (MM) 225.00

CAMERA ALTITUDE (M) 1074000.00

COEFFICIENTS OF EMPIRICAL WEIGHTING FUNCTION OF PHOTO COORDINATES

(A0,A1,A2,A3,A4) .00000000 .00000000 .00000000 .00000000

STANDARD DEVIATION OF

.005 MM

(1) SIMULATED RANDOM ERROR IN PLATE MEASUREMENTS

1000.00 M (NORTH)

1000.00 M (EAST)

1000.00 M (UP)

(2) SIMULATED RANDOM ERRORS IN CAMERA POSITION

1. 0. 0 DMS (ABOUT N-AXIS)

1. 0. 0 DMS (ABOUT E-AXIS)

1. 0. 0 DMS (ABOUT U-AXIS)

(3) SIMULATED RANDOM ERRORS IN CAMERA ATTITUDE

.10 M

(4) HORIZONTAL COORDINATES OF CONTROL POINTS

.10 M

(5) VERTICAL COORDINATES OF CONTROL POINTS

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GLOBAL CASE B, 42 PHOTO, ZERO DENS., CIRC FMT, SCALE ONLY

PAGE 2

HORIZONTAL AND VERTICAL CONTROL

000000 480000

HORIZONTAL CONTROL

240000

ALTIMETER MEASUREMENTS WITH A PRIORI STANDARD DEVIATIONS OF .10 METER(S)

TO BE SIMULATED FOR PHOTOS NUMBERED N * (1), WHERE N = 1, 2, 3, . . .

22 JANUARY 1971

GLOSIM RUN IN CIRCULAR FORMAT MODE

PAGE 2

1 IS PHOTO 1 OF LATITUDE LEVEL 1

USR (METERS)	GEOGRAPHICS	WEIGHT MATRIX (LOCAL)	WEIGHT MATRIX (USRI)
X .083	LATITUDE 90.0000000000	.10000+007 .00000	.26178+007 .00000
Y .000	LONGITUDE .0000000000	.10000+037 .00000	.00000 .26178+007
Z 2812000.000	HEIGHT 1074000.0000000000	.00000 .00000	.48025+001 .00000
			.10000+007

ORIENTATION ELEMENTS (RADIAN)

WEIGHT MATRIX

OMEGA .000000000	.10000+007 .00000	.00000
PNI .000000000	.00000 .10000+007	.00000
ALPHA .000000000	.00000 .00000	.10000+007

GROUND COVERAGE=LAT., LONG. OF NADIR AND FOUR CORNERS. TANGENT RAY USED.

(90.00 .00) (40.16 -45.00) (40.16 -135.00) (40.16 135.00) (40.16 45.00) (40.16 45.00) (

POINT LABEL	PLATE DATA		IMAGE FACTORS		A PRIORI SIGMAS		GROUND DATA		A PRIORI SIGMAS	
	X	Y	X	Y	X	Y	DEGREES	METERS	HORIZ	VERT

500000	.00000	.00000	1	1	.1000+003	.1000+003	90.000	.000	1000000.000	.000
A80000	99.7438	.00000	1	1	.1000+003	.1000+003	60.000	.000	.000	.000
080010	-30.8225	94.8620	1	1	.1000+003	.1000+003	60.000	-72.000	1000000.000	1000000.000
080020	80.6945	58.6279	1	1	.1000+003	.1000+003	60.000	-144.000	1000000.000	1000000.000
080030	80.6945	-58.6279	1	1	.1000+003	.1000+003	60.000	144.000	1000000.000	1000000.000
080040	-30.8225	-94.8620	1	1	.1000+003	.1000+003	60.000	72.000	1000000.000	1000000.000

DBA - G B L O C K - GLOBAL MISSION PHOTOGRAMMETRIC TRIANGULATION GPOP PROGRAM 11 JUN 71 00:16:05

GLOBAL CASE B, 42 PHOTO, ZERO DENS., CIRC FMT, SCALE ONLY

PAGE 3

STANDARD ERRORS AND CORRELATIONS OF CAMERA EXTERIOR ORIENTATION ELEMENTS

PHOTO NUMBER	STANDARD ERRORS			CORRELATIONS			STANDARD ERRORS			CORRELATIONS		
	ROLL(1) SECS	PITCH(2) SECS	AZIM(3) SECS	1-2	1-3	2-3	LAT(4) METERS	LONG(5) METERS	ALT(6) METERS	4-5	4-6	5-6
1	14	13	7	-.00	.00	.00	89.4	96.3	.2	.01	.44	.00
2	14	15	6	.00	.00	-.00	121.0	100.1	32.6	-.20	.20	-.02
3	11	12	6	-.00	.00	.00	105.8	88.8	32.6	.00	.20	.13
4	11	12	7	-.00	.00	.00	107.4	91.5	32.0	.02	.11	.00
5	13	15	8	-.00	.00	.00	121.1	102.1	32.9	.07	.13	-.08
6	14	15	8	-.00	.00	.00	117.5	104.2	31.0	.07	.18	-.08
7	16	13	6	.00	.00	.00	104.4	131.6	40.0	-.02	.07	-.10
8	15	14	6	-.00	.00	.00	111.4	115.2	41.6	.12	.00	.13
9	15	16	7	.00	.00	-.00	121.7	119.9	41.6	-.14	.03	.13
10	15	14	6	.00	.00	-.00	117.1	120.8	39.9	-.09	.08	.08
11	14	13	6	.00	.00	.00	107.9	121.0	39.1	.08	.09	.05
12	14	14	6	.00	.00	.00	112.2	117.6	38.1	.05	.00	.02
13	16	12	7	.00	.00	.00	106.6	137.5	40.0	.02	.01	-.05
14	15	14	7	.00	.00	.00	116.0	128.6	41.6	.11	.03	.01
15	17	14	7	-.00	.00	.00	114.7	150.4	43.1	.09	.12	-.01
16	15	14	6	.00	.00	.00	118.1	123.2	40.1	-.02	.05	-.19
17	15	13	6	.00	.00	-.00	109.8	129.7	41.9	.03	.05	.14
18	14	13	6	.00	.00	.00	105.8	110.2	40.8	.06	.05	.02
19	11	11	6	-.00	.00	.00	82.3	80.8	43.0	.01	.08	.01
20	16	14	7	.00	.00	.00	123.0	126.1	43.5	.10	.03	.04
21	14	12	6	.00	.00	.00	110.2	124.0	41.9	.02	.02	.08
22	13	12	5	.00	.00	.00	104.9	119.6	41.0	.02	.02	.14
23	16	13	7	.00	.00	.00	113.6	139.2	39.9	.01	.02	.13
24	14	13	6	.00	.00	.00	109.6	127.0	39.2	.05	.04	.05
25	13	15	6	-.00	.00	.00	127.0	127.0	44.0	.09	.09	.09
26	16	14	7	.00	.00	.00	118.2	135.3	42.9	.09	.01	.13
27	16	13	6	.00	.00	.00	108.4	137.0	41.0	.06	.02	.04
28	15	14	6	.00	.00	.00	112.8	119.2	40.1	.13	.07	.09
29	15	13	7	.00	.00	.00	106.1	119.4	39.3	.11	.10	.09
30	15	14	6	-.00	.00	.00	112.0	115.3	41.6	.26	.07	.00
31	16	15	7	.00	.00	.00	118.3	136.2	42.3	.02	.03	.04
32	15	15	6	.00	.00	.00	124.7	125.4	42.3	.08	.06	.20
33	15	13	7	.00	.00	.00	112.2	132.6	41.2	.07	.00	.13
34	14	14	7	.00	.00	.00	112.7	122.6	37.6	.04	.13	.04

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												PAGE	
35	16.	13.	7.	7.	.00	.00	.00	107.2	135.5	39.1	.01	.02	.02
36	15.	14.	7.	7.	.00	.00	.00	113.1	130.4	42.6	.04	.03	.14
37	13.	14.	7.	7.	.00	.00	.00	121.0	100.8	34.4	.09	.10	.05
38	12.	13.	6.	6.	.00	.00	.00	114.8	92.3	33.2	.12	.13	.05
39	16.	16.	7.	7.	.00	.00	.00	131.5	113.8	34.1	.06	.28	.10
40	13.	17.	7.	7.	.00	.00	.00	134.3	100.0	34.7	.18	.28	.06
41	15.	15.	9.	9.	.00	.00	.00	121.2	112.3	31.9	.05	.00	.00
42	14.	14.	8.	8.	.00	.00	.00	91.5	95.7	.2	.01	.44	.00

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STANDARD ERRORS AND CORRELATIONS OF GROUND POINT POSITIONS

POINT LABEL	LAT(1) METERS	STANDARD ERRORS		ALT(3) METERS	CORRELATIONS		
		LON(2) METERS			1-2	1-3	2-3
A00000	.1	.1		.1	-.00	-.00	-.00
080000	40.5	36.0		32.7	-.03	.01	-.08
080010	42.8	37.7		31.8	.02	-.06	.12
080020	42.3	42.9		32.1	-.03	-.09	.09
080030	42.6	45.1		33.4	-.08	-.05	-.04
080040	40.4	40.0		31.1	.07	-.00	-.13
160000	40.3	39.8		41.2	.13	.02	-.02
160010	38.3	39.0		41.3	-.09	.01	.04
160020	44.0	45.9		39.7	-.10	-.01	.13
160030	43.2	51.0		38.6	-.07	-.04	.18
160040	45.4	57.1		37.8	-.09	-.01	.15
160050	43.8	62.2		40.0	.06	-.03	.02
160060	44.5	61.0		41.7	.08	-.01	-.03
160080	45.2	55.0		40.0	.06	.04	-.17
160090	44.7	54.0		40.0	.09	-.07	-.11
240090	44.7	46.9		40.7	-.06	-.01	-.12
L40000	.1	.1		43.0	.00	.00	.00
240010	45.0	43.1		43.5	.03	.04	.08
240020	44.7	51.3		41.9	-.02	.01	.17
240030	44.5	58.9		40.9	.00	.05	.20
240040	45.9	66.3		39.8	.05	-.04	.13
240050	48.5	67.7		39.0	-.05	-.00	-.02
160070	45.6	62.8		42.7	.00	-.07	-.11
240060	57.5	65.9		44.0	.07	.03	-.13
240070	45.1	60.6		43.0	.01	.02	.18
240080	44.9	56.8		41.9	.04	.04	.18
320080	45.1	58.9		40.9	-.03	.11	-.16
320090	44.0	47.8		40.0	-.12	.02	-.09
320000	43.5	43.5		39.4	-.09	-.05	-.06
320010	45.5	44.8		41.6	.31	-.13	-.09
320020	44.7	53.5		42.2	-.09	.08	-.02
320030	50.2	53.8		41.9	.11	.17	.15
320040	44.9	58.5		41.2	.03	.12	.17
320050	44.2	63.2		37.4	-.02	.03	.08

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320060	43.8	62.8	39.3	.01	.06	-.05
320070	46.0	61.4	42.6	-.00	-.02	-.12
400040	48.1	39.2	33.6	-.17	.08	-.04
400000	42.4	36.9	33.7	.11	-.06	-.01
400010	46.1	41.3	33.7	.01	-.06	.09
400020	41.1	45.7	32.3	-.07	.15	.01
400030	45.6	44.9	35.0	-.01	.09	-.09
E80000	.1	.1	.1	.00	.00	-.00

4.0. GBLOCK PROGRAM DESCRIPTIONS

As stated in the first section, GBLOCK consists of three submodules. Execution of these submodules is controlled by a main control program. The submodules utilize an assortment of utility subroutines. The relationship of the various program elements is illustrated by Figure 4.1.

4.1 Main Control Program

The main control program directs execution, based on the input program control variable, IPC (see Section 3). Figure 4.2 is a flow diagram which shows all possible activities of this program.

4.2 Simulated Photography Programs

The simulated photography is simulated under control of the program GLOSIM. The remaining programs in this submodule are used by GLOSIM.

4.2.1 Subroutine GLOSIM

GLOSIM reads the simulation input data deck and generates photography resulting in global coverage. All computations are described in detail in Section 2.4. GLOSIM creates the unsorted working data file.

4.2.1.1 Subroutine CAMPOS

CAMPOS generates a file of camera positions.

4.2.1.2 Subroutine PTPOS

PTPOS generates a file of ground point positions with labels.

4.2.1.2.1 Subroutine CPCHK

CPCHK detects control points and modifies their labels.

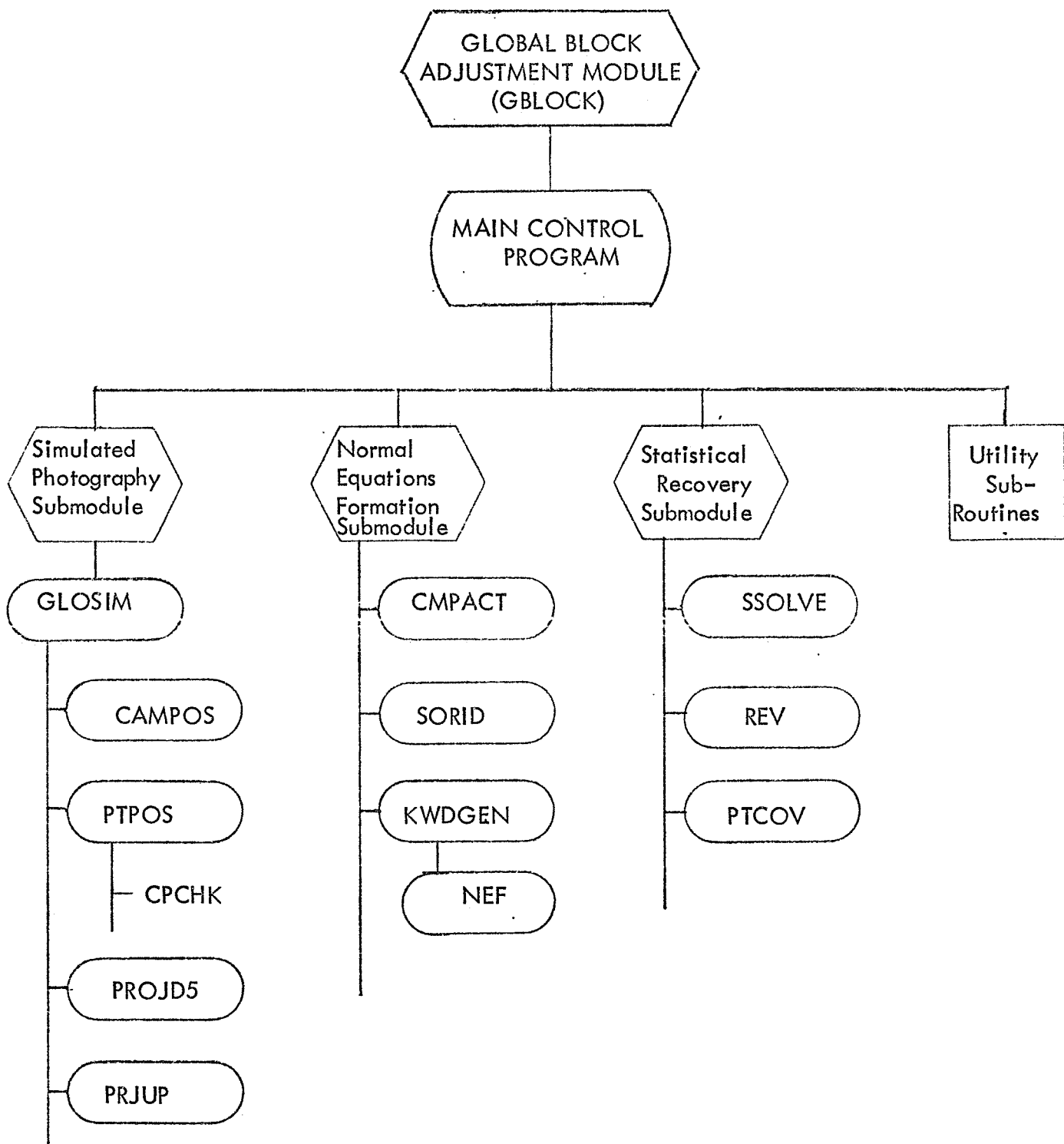


FIGURE 4.1

Tree Content Diagram Global Block Adjustment Module (GBLOCK)

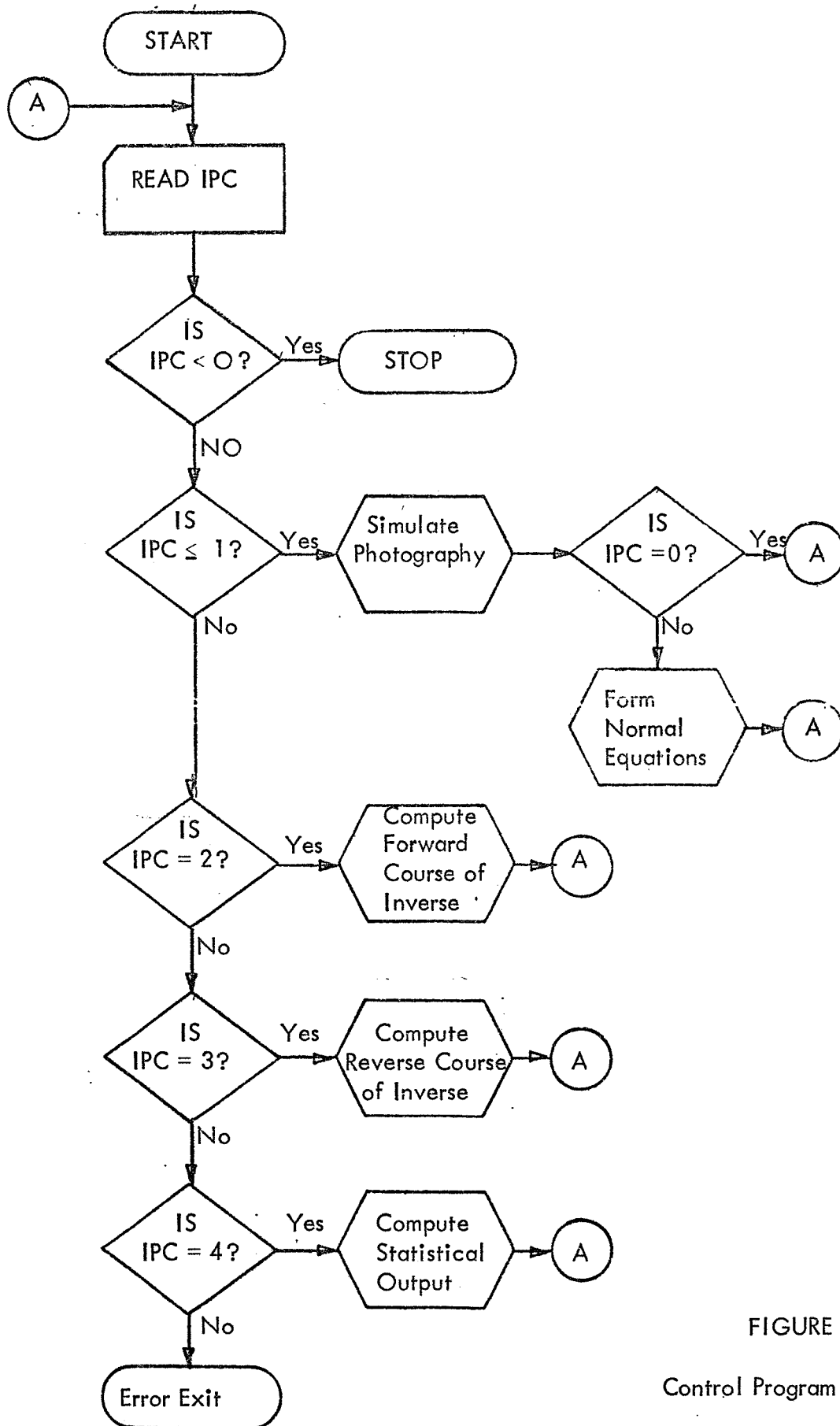


FIGURE 4.2

Control Program Flow Diagram

4.2.1.3 Subroutine PROJ5

4.2.1.3.1 Entry PROJ5

PROJ5 projects frame corners and principal point to the sphere .

4.2.1.3.2 Entry PRJDWR

PRJDWR outputs a record of photo coverage to a tape file .

4.2.1.4 Subroutine PRJUP

PRJUP projects ground points to the image plane .

4.3 Normal Equations Formation Programs

The normal equations are formed from the unsorted working data by four subroutines. The sequence of execution is shown by Figure 4.3.

4.3.1 Subroutine CMPACT

CMPACT creates a randomly accessible file of compacted measurement data from the unsorted working data .

4.3.2 Subroutine SORID

SORID forms arrays of sorted identification data for use in collecting data for the formation of the normal equations .

4.3.3 Subroutines KWDGEN and NEF

KWDGEN and NEF work together to form the normal equations, and output them to a file .

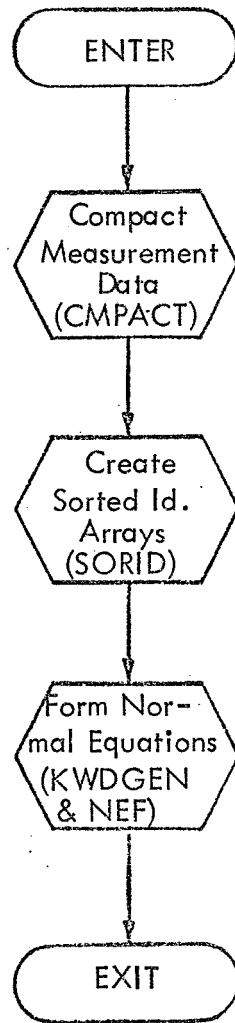


FIGURE 4.3
Normal Equations Formation Submodule

4.3.3.1 Subroutine KWDGEN

KWDGEN assembles an internal record of measurement data for each image measurement. KWDGEN then calls NEF to compute the contribution to the normal equations. The file of normal equations is output from KWDGEN.

4.3.3.2 Subroutine NEF

NEF computes contributions to the normal equations using measurement data assembled by KWDGEN.

4.4 Statistical Recovery Programs

The statistical recovery programs invert the normal equations and compute statistics from the inverse. Each of the three programs utilizes the random access capability.

4.4.1 Subroutine SSOLVE

SSOLVE computes the forward course of the inversion of the normal equations.

4.4.2 Subroutine REV

REV computes the reverse course of the inversion of the normal equations. On option, only half of the reverse course is computed.

4.4.3 Subroutine PTCOV

PTCOV computes a posteriori estimates of errors in exposure station and ground point parameters. Some coefficients of correlation are also computed.

4.5 Utility Subroutines

4.5.1 Function ATAN3

ATAN3 computes the quadrant justified arc tangent.

4.5.2 Subroutine AUGVRT

AUGVRT computes the inverse of a matrix. If the matrix is augmented by a discrepancy matrix, the solution matrix is obtained simultaneously.

4.5.3 Subroutine BKSP

BKSP is an I/O interface routine which simply calls the system routine BAKREC.

4.5.4 Subroutine Package BRAN

BRAN is a package of subroutines for the purpose of performing I/O operations on the random access device, where the number of words transmitted each time is a constant.

4.5.4.1 Entry BRANOP

BRANOP is the initialization entry to the group of routines, and must be called prior to any other random access I/O operation.

4.5.4.2 Entry BRANRD

BRANRD causes a "record" to be transmitted from the random access device to core.

4.5.4.3 Entry BRANWR

BRANWR causes a "record" to be transmitted from core to the random access device.

4.5.4.4 Entry MBRAN

MBRAN is a special purpose entry point which modifies the addressing procedure. MBRAN is invoked for those cases in which the entire file of records to be randomly accessed exceeds the capacity of the random access device.

4.5.5 Subroutine CLEAR

CLEAR sets the elements of a real array to zero.

4.5.6 Subroutine INSERT

INSERT is a subroutine designed to get the elements of one matrix properly placed in an equal or larger matrix.

4.5.7 Function IRGHT

IRGHT determines the integer value of the right half of a word.

4.5.8 Subroutine KLEAR

KLEAR sets the elements of an integer array to zero.

4.5.9 Function LBLCHK

LBLCHK, used only by the simulator, examines the first character of a point label to determine the level of control associated with the point.

4.5.10 Function LBLMOD

LBLMOD, used only by the simulator, modifies the first character of a point label to reflect the level of control associated with the point.

4.5.11 Function LEFT

LEFT determines the integer value of the left half of a word.

4.5.12 Subroutine LPERP

LPERP is a printed output routine which maintains a line count and calls NUPAGE whenever required.

4.5.13 Subroutine MADAT

MADAT computes the matrix product ADA^T , where D is a diagonal matrix. MADAT requires a minimum array of temporary storage.

4.5.14 Logical Function MATCH6

MATCH6 is .TRUE. if the first six characters of the two arguments compare. Otherwise, MATCH6 is .FALSE. .

4.5.15 Subroutine MATMPY

MATMPY is a multi-purpose matrix multiplication package.

4.5.16 Function MERGE

MERGE merges two positive integers. The right half of the first argument is set into the left half of MERGE, and the right half of the second argument is set into the right half of MERGE.

4.5.17 Subroutine MOVE

MOVE moves a contiguous block of data from one working array to another.

4.5.18 Subroutine NUPAGE

NUPAGE is a printed-output routine which prompts a new page, prints a header including the current clock time and calendar date, and updates the line and page counters.

4.5.19 Subroutine RDBIN

RDBIN is an I/O interface subroutine with two entries.

4.5.19.1 Entry BUFSIZ

BUFSIZ is an initialization entry to RDBIN, and must be called prior to any calls to RDBIN.

4.5.19.2 Entry RDBIN

RDBIN calls the system routine MREAD.

4.5.20 Function RE

RE is a random number from the set whose mean is zero and standard deviation is the specified sigma (real argument). The random value obtained is repeatable for any given pair of integer arguments.

4.5.21 Function-Subroutine SQROOT

SQROOT is the square root of the absolute value of the first argument. The first character of the second argument is set to hollerith blank or hollerith minus depending as the first argument is non-negative or negative.

4.5.22 Subroutine WRBIN

WRBIN is an I/O interface routine which calls the system routine MWRITE.

5.0 REFERENCES

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