

NOAA Technical Report NOS 91 NGS 21



Results of Photogrammetric Control Densification in Ada County, Idaho

Rockville, Md.
December 1981

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CONTENTS

Abstract	1
Introduction	1
System description	2
Results	8
Conclusion	12
References	12
Appendix. Documentation	13

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RESULTS OF PHOTOGRAMMETRIC CONTROL DENSIFICATION IN ADA COUNTY, IDAHO

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ABSTRACT. The urgent need to integrate all land surveys in the United States into a unified coordinate system has been well documented, but the densification of existing geodetic control networks is an expensive and time consuming prerequisite. The National Ocean Survey (NOS) has developed a system for photogrammetric control densification that can provide a precision comparable to conventional ground survey methods at less than half the cost. To better serve the needs of the land surveyor this system incorporates a unique computer program developed by the National Geodetic Survey (NGS), which obtains both the geodetic positions of densification points and the distance, azimuth, and elevation difference between intervisible point pairs. A listing of the program is included in this report. The densification system was employed by NOS to obtain precise coordinates of 346 section corners in Ada County, Idaho. This project has shown that photogrammetry can be used for densification of control networks that were established by geodetic triangulation with no significant compromise in accuracy and at a considerable saving in time and money.

INTRODUCTION

A report by the Committee on Geodesy of the National Research Council (1980) documents the urgent need for a multipurpose cadastre in the United States. The report states that the first step must be densification of the existing geodetic control network and suggests high precision photogrammetric surveys as one means of accomplishing this densification in a timely and economic manner.

About 5 years ago Duane Brown (1977) demonstrated the precision and economic advantages of photogrammetric densification by performing the first operational project of this type in Atlanta, Ga. At about the same time a precise photogrammetric survey system developed by NOS was being tested at the Casa Grande, Ariz., test range. This test showed that the NOS system was capable of positioning densification points to approximately 5 cm in each horizontal coordinate (Slama 1978) at less than half the cost of conventional triangulation or traverse. Encouraged by these results, NOS undertook the evaluation of this system in an operational environment.

In 1978, in cooperation with Ada County, Idaho, NOS performed a photogrammetric densification of approximately 400 square miles in northern Ada

County. (See fig. 1.) As expected, this project presented some problems which had not been encountered in the more ideal environment of a test range. But it demonstrated again that photogrammetry is capable of achieving 5-centimeter precision in the densification of geodetic control networks.

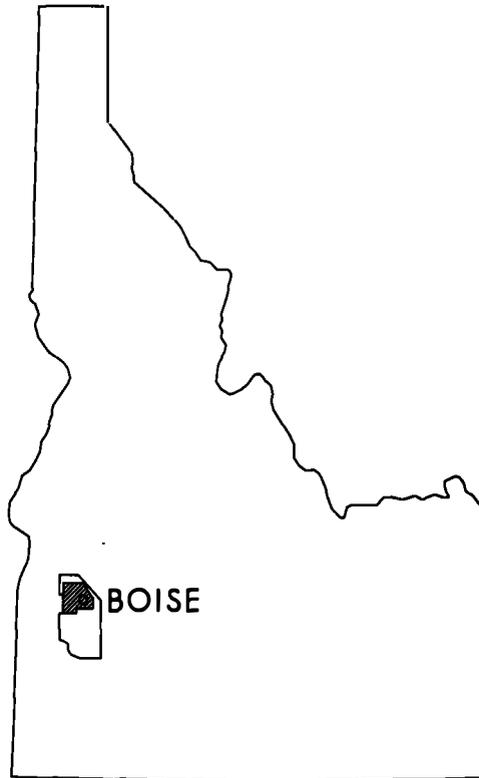


Figure 1.--Project location in northern Ada County, Idaho.

SYSTEM DESCRIPTION

Photogrammetric control densification, like any other survey method, can be logically separated into field work and office procedures. Since the instruments and methods used in both the field and office for acquiring the observational data have already been described in some detail by Slama (1978), this paper will present only a brief summary of the data acquisition phase and concentrate, instead, on the data adjustment method.

Data Acquisition

Before a densification mission can be flown, extensive field work is required. The nine existing geodetic control points in Ada County were not adequate to support photogrammetric densification, so eight new points were established, as shown in figure 2. The densification points--in this case section corners--had to be monumented for future recovery, and all ground points had to be marked with photovisible targets. Permanent marking of the section corners and target placement were completed by Ada County personnel.

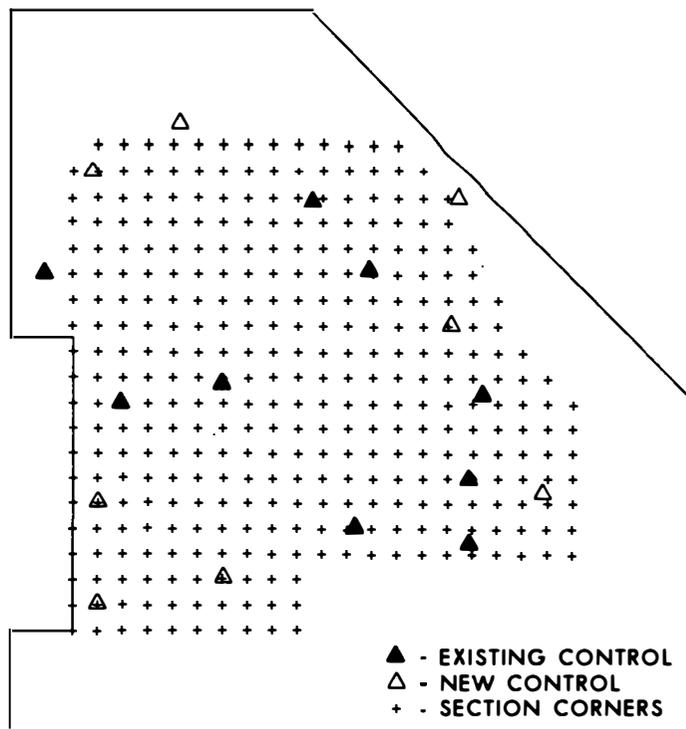


Figure 2.--Geodetic control in project area.

The photovisible targets, blaze orange discs 76 cm in diameter, are important not only for locating the ground points but for minimizing errors in image measurement. The camera lens, a Wild Universal Aviogon II with a 152-millimeter focal length, was modified by the manufacturer to provide optimum resolution in a narrow band in the orange portion of the spectrum. This produces very sharp definition of the target images at the expense of a slight degradation in overall resolution. This loss in background resolution is of little importance because only the target images are used in photogrammetric densification.

The lens cone is also equipped with a 1- by 1-centimeter projected reseau. The reseau camera is a practical alternative to using glass plates as the carrier of the photographic emulsion, because it provides a means for removing film distortion from the image measurements. Random errors in image coordinates are minimized by repeated measurements, but systematic errors, such as film and lens distortion, are removed mathematically by employing the results of an extensive calibration procedure.

The photographic mission is designed to reduce random errors, through additional observational redundancy, and to maximize geometric strength. Using a flying height of 3600 m, the exposure interval is adjusted to maintain two-thirds forward overlap and flight lines are spaced to obtain two-thirds side overlap. This overlap assures at least nine images of each ground point, except for those points around the periphery of the project. In addition, the entire area is photographed again from flight lines at right angles to the main scheme but with only one-third side overlap. The added cost of

obtaining this additional photography is minimal, and it serves to restore geometry that may be weakened by variations in the flight lines.

Data Reduction

The high precision of photogrammetric control densification depends on the extent to which systematic and random errors of observation can be minimized. Once the data preparation has been completed, any well-designed photogrammetric bundle adjustment program could be employed to produce positions of the densification points. However, to better serve the needs of the land surveyor, NGS has elected to compute the distance, azimuth, and elevation difference between all pairs of intervisible points. The computation of these additional parameters in the course of a conventional adjustment is a trivial modification, but the propagation of covariance essential for estimating their standard errors is so cumbersome that NGS developed an adjustment program designed specifically for densification.

The normal equations for a photogrammetric network may be quite large, but they are always very sparse. Figure 3 shows the structure of a small

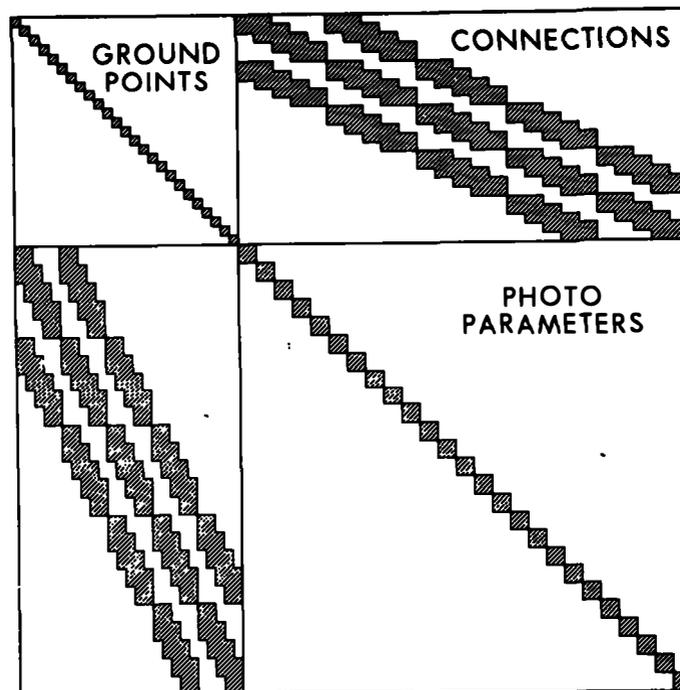


Figure 3.--Structure of photogrammetric equations.

photogrammetric network, consisting of 25 ground points and 25 photographs. The partition at the upper left is block diagonal, consisting of 3 by 3 submatrices associated with the three position components of each ground point. There are six unknowns for each photograph--three components of position and three of orientation. Therefore, the partition at the lower right is block diagonal with 6 by 6 submatrices. The off-diagonal blocks represent connections between ground points and photographs.

The natural partitioning of these normal equations by parameter type suggests application of the standard formulas

$$\begin{bmatrix} A & B \\ B & C \end{bmatrix}^{-1} = \begin{bmatrix} K & L \\ L & M \end{bmatrix}$$

where

$$M = (C - B^T A^{-1} B)^{-1} \quad (1)$$

and

$$K = A^{-1} + A^{-1} B M B^T A^{-1} \quad (2)$$

are covariance matrices of photo parameters and ground point positions, respectively. However, this brute force approach consumes too much computer time and storage to be practical for large photogrammetric adjustments. For most applications the photogrammetrist needs only the 3 by 3 covariance matrix associated with each ground point position, from which its error ellipsoid can be obtained, and perhaps the 6 by 6 covariance matrix associated with each photograph for analysis and quality control. Duane Brown (1958) demonstrated a means for obtaining these quantities while avoiding the computation of a large percentage of the elements of the matrix inverse, an important advance in the field of analytical photogrammetry.

By exploiting the block diagonal structure of matrix A, eqs. (1) and (2) can be written as

$$M = \hat{C}^{-1} = (C - \sum B_i^T A_i^{-1} B_i)^{-1} \quad (3)$$

and

$$K_i = A_i^{-1} + A_i^{-1} B_i M B_i^T A_i^{-1}. \quad (4)$$

Equation (3) shows that the matrix \hat{C} can be accumulated by processing the ground points sequentially so that only A_i and B_i , a small subset of matrices A and B, need to occupy in-core storage. Once the inverse matrix M is available, the covariance matrix of each ground point position, K_i , is obtainable from eq. (4) using again only A_i and B_i .

The transformation of C into \hat{C} produces fill-in which destroys the block diagonal structure, resulting in a banded matrix, as shown in figure 4. The bandwidth, or maximum number of photographs that become connected, can be minimized by judicial ordering of the unknowns. Bandwidth minimization is an important factor in reducing both computer time and storage. As shown in figure 4, the contribution of a single ground point to the matrix \hat{C} affects only certain elements, a symmetric block limited by the bandwidth. Furthermore, the same elements of the inverse matrix M , and no others, are required in the computation of K_i , the covariance matrix of that ground point. Hence, it is not necessary to compute the elements of M that fall outside the bandwidth. Neither is it necessary to provide in-core storage for any more of \hat{C} (or M) than a square submatrix of dimension equal to the bandwidth, which by virtue of symmetry can be reduced to the triangular array labeled "resident normal equations."

This conventional approach provides a very efficient means of solving the photogrammetric bundle adjustment problem and computing the covariance matrix of each ground point position. But the computation of standard errors of quantities such as distance, azimuth, and elevation difference, relating two ground points, requires the off-diagonal matrix of covariance between the two point positions, which is not computed in a conventional adjustment. Furthermore, the computation of some of these off-diagonal blocks involves elements of M that fall outside the bandwidth. Therefore, extending the conventional adjustment to provide these additional quantities would increase the computational burden and storage requirements substantially.

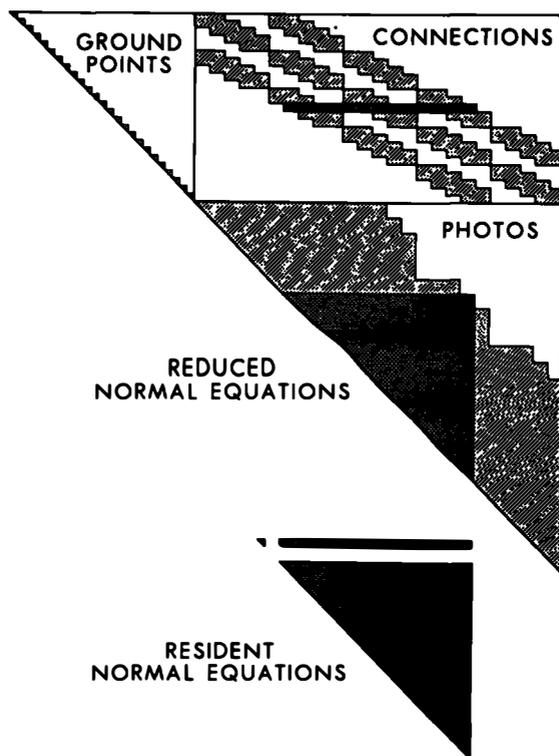


Figure 4.--Reduced normal equations produced by conventional adjustment method.

A far more practical approach results from interchanging the roles played by ground point positions and photo parameters in eq. (3). Sequential processing of the photographs then results in a matrix of connected ground point positions with a banded structure, as seen in figure 5. This preserves all of the attractive features of the conventional approach and provides a number of additional benefits. Again it is necessary and sufficient to compute those elements of the inverse that fall inside the bandwidth, but these elements include the off-diagonal covariance blocks that were inaccessible to the conventional adjustment. And, since M is now composed of 3 by 3 rather than 6 by 6 submatrices, the number of inverse terms to be computed is reduced by a factor of almost four. In practice this reduction will generally be somewhat less dramatic because the groundpoint bandwidth may be somewhat irregular. However, in the Ada County project this reduction factor was approximately 3.3.

Furthermore, having obtained the covariance matrices of all ground point positions and the requisite off-diagonal covariances, covariance propagation can be terminated. There is no need to compute the covariance matrices of the photo parameters. The mechanism for this computation is available if these quantities are desired, but the additional computing time required to obtain them can be eliminated entirely from the operational version of the program.

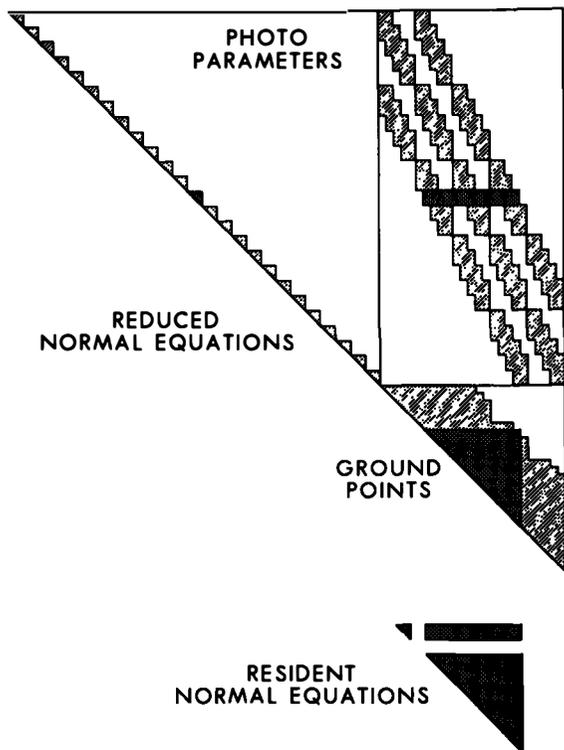


Figure 5.--Reduced normal equations produced by densification method.

The National Geodetic Survey has developed a photogrammetric densification adjustment program called DENCIPHI which employs this concept. A listing of this program appears in the appendix.

The efficiency of DENCIPHI was proven in the Ada County project. This adjustment, which involved 438 photographs and 384 ground points (a total of 3780 unknown parameters), required approximately 12 minutes of central processor time per iteration on the UNIVAC 1100/40 computer. Covariance propagation consumed less than 13 additional minutes.

RESULTS

In Ada County the 346 section corners and 17 control points, shown in figure 2, were targeted along with more than a dozen additional points of interest. As mentioned previously, the ground points along the perimeter appear on fewer photographs than those in the interior. If maximum precision is to be maintained at the edges of the project area, it is necessary to target an additional row of points outside the area of interest to provide attitude control for the edge photographs. The positions of these points are obtained from the adjustment, but with lesser precision, nominally 10 to 12 cm in each coordinate. Ada County elected to accept this reduced accuracy at the edges of the project to avoid the trouble and expense of targeting so many extra points. Therefore, the results presented here do not include any of the section corners on the periphery.

Sixteen flight lines in an east-west direction utilizing two-thirds forward overlap and two-thirds side overlap provided 285 usable frames of primary coverage. The secondary coverage, obtained with only one-third side overlap from nine north-south flight lines, added another 153 photographs. The quality of target images on all frames was excellent.

Measurement of all target images and reseau intersections consisted of five independent pointings using the Mann Automatic Stellar Comparator. Six reseau intersections were measured along with each target image--the four surrounding the image and the two nearest neighbors. Image coordinates were then corrected for all known sources of systematic errors except atmospheric refraction, which is recomputed for each iteration in the adjustment process.

Each strip was adjusted separately using a conventional analytical adjustment program. These individual adjustments, which were performed as the coordinate data for each strip became available, served to identify measurement blunders and provide better initial estimates of the unknown parameters.

A preliminary adjustment was made using only the east-west photography and holding all geodetic control fixed. Overall the fit was good, but analysis of the residuals indicated that the photogrammetry appeared to be slightly distorted in the vicinity of the geodetic control points near the southeast corner of the project area.

Another adjustment was performed to include the north-south photography. Rather than holding the geodetic control fixed, standard deviations of 5 cm in both latitude and longitude were assigned to all control points. The

elevations of two control points were known from geodetic leveling and were, therefore, assigned standard deviations of 5 cm. All other geodetic control elevations were assigned 25 cm. As a result of the large number of photogrammetric observations of each geodetic point, the imposed constraints had little effect, allowing these points to shift to positions dictated by the photogrammetry. Nonetheless, as shown in figure 6, the maximum shift in the geodetic control was less than 6 cm, and most points shifted less than 5 cm. Moreover, the apparent distortion that had appeared in the previous adjustment disappeared with the addition of the cross-flight observation data. It was very encouraging to find that the compatibility of the photogrammetry and geodesy was consistent with their assumed precisions.

Lacking information on the intervisibility of ground points, the distance, azimuth, and elevation difference were computed from each point to all other points within a radius of 2.5 km. For a section corner, this included each of its eight neighbors. Precision of the azimuths varied between 3 and 6 arc-seconds. The elevation differences were good, considering the fact that photogrammetry does not provide a strong determination of this coordinate, with standard errors ranging from 5 to 15 cm.

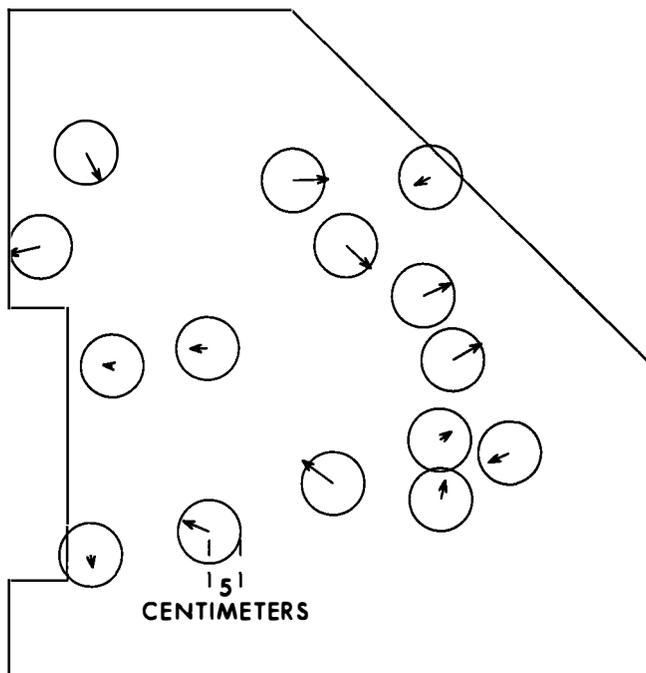


Figure 6.--Shifts of geodetic control induced by relaxed weighting factors.

Figure 7 shows the distribution of the standard errors of computed distances. Approximately 84 percent of the standard errors are less than 5 cm, and only 1.2 percent exceed 6 cm. One of the section corners was obstructed from view on all but three photographs, which resulted in a weak determination of the position. Distances involving this point account for nearly all of the standard errors that exceed 6 cm.

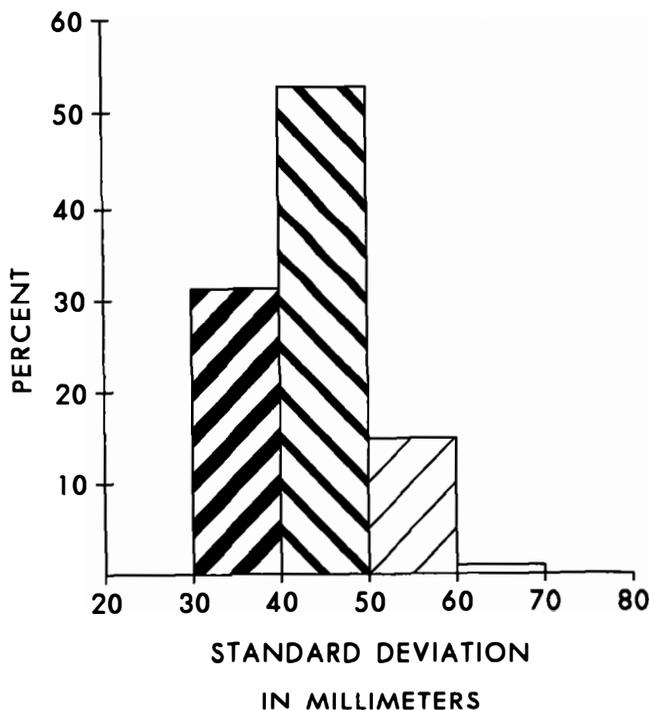


Figure 7.--Estimated precision of computed distances between section corners.

In January 1981, a field check was performed, as shown in figure 8. Geodetic traverse station IDA 80 60 1958, labeled A in the figure, and two section corners labeled B and C, were occupied to form a triangle. Traverses were run to four additional section corners over distances of 1.5 to 5 km. All distance measurements were made with a Hewlett Packard electronic distance measuring instrument, model 3808, on loan from the Pacific Marine Center. Unfortunately, station IDA 80 60 1958 was not included in the photogrammetric adjustment and the HP 3808 had not been calibrated for distances greater than 1400 m. Considering these deficiencies, the geodetic measurements compared favorably with the photogrammetric survey results shown in table 1.

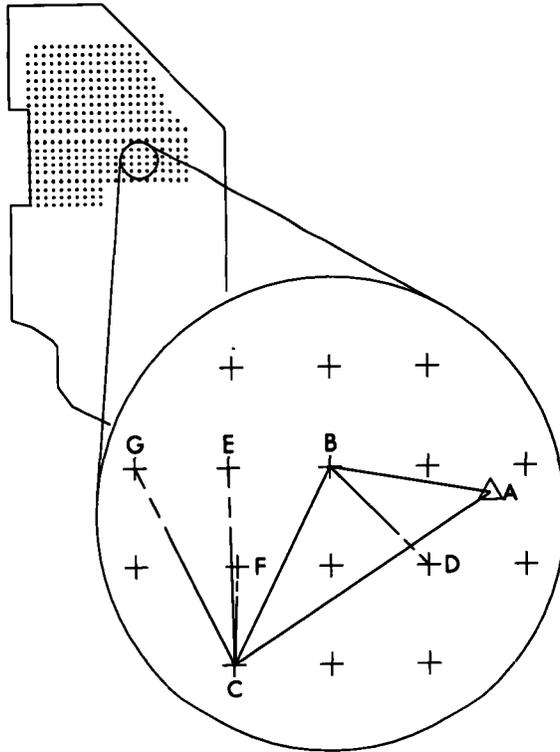


Figure 8.--Location and configuration of field check survey.

Table 1. Comparison of distances and azimuths determined by photogrammetric densification and by field survey.

Line	Distance			Azimuth		
	Photo (m)	Geodetic (m)	Difference (m)	Photo ° ' "	Geodetic ° ' "	Difference "
AB	2551.216	2551.186	+0.030	100 12 05.4	100 12 08.2	-2.8
AC	4980.958	4980.973	-0.015	55 56 22.4	55 56 21.8	+0.6
BC	3621.813	3621.815	-0.002	26 28 13.1	26 28 14.0	-0.9
BD	2291.520	2291.505	+0.015	315 13 18.8	315 13 21.9	-3.1
CF	1609.837	1609.818	+0.019	180 26 49.6	180 26 47.6	+2.0
CE	3247.790	3247.881	-0.091	179 54 52.4	179 54 53.2	-0.8
CG	3634.623	3634.667	-0.044	153 29 59.4	153 29 57.5	+1.9

All azimuth differences are small compared to the standard errors predicted from the photogrammetric adjustment and all distance differences, except line CE, are below the 5 cm level. The 9 cm difference in distance CE, although large in comparison with the other distance differences, is less than twice the standard deviation for the computed length of this line.

CONCLUSION

There is no question that densification of geodetic control can be accomplished more economically by photogrammetry than by conventional ground survey. This project has shown that a precision of 5 cm is obtainable, which should satisfy most requirements. In urban areas, where a higher degree of precision and greater density of control may be required, 2 to 3 cm should be attainable by increasing the photo scale by a factor of two, although this extrapolation remains to be verified.

The Ada County project was successful in verifying the utility of photogrammetric control densification, but the ultimate measure of the success of this endeavor depends upon its impact on the geodetic community. If other State and local governments are stimulated to densify inadequate control networks, and if other agencies and contractors are motivated to develop a capability for performing this service, both the community of land surveyors and the general public will reap a substantial benefit.

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APPENDIX.--DOCUMENTATION

PROGRAM DENCIPHI

PROGRAM DENCIPHI PERFORMS A PHOTOGRAMMETRIC CONTROL DENSIFICATION ADJUSTMENT WHICH PRODUCES THE ADJUSTED POSITIONS OF ALL DENSIFICATION POINTS, IN CARTESIAN GEOCENTRIC AND GEODETIC COORDINATES, AND THE DISTANCE, AZIMUTH AND ELEVATION DIFFERENCE BETWEEN ALL PAIRS OF INTERVISIBLE POINTS. STANDARD ERRORS FOR ALL OF THESE DATA ARE ALSO PROVIDED. THE ADJUSTMENT METHOD DIFFERS FROM A CONVENTIONAL BUNDLE ADJUSTMENT IN THAT THE OBSERVATION DATA ARE PROCESSED BY PHOTOGRAPH, RESULTING IN A BANDED MATRIX FOR THE PARTITION OF THE NORMAL EQUATIONS ASSOCIATED WITH GROUND POINT COORDINATES. THIS DATA STRUCTURE IS EMPLOYED TO FACILITATE PROPAGATION OF COVARIANCE TO THE INTER-POINT QUANTITIES (DISTANCES, ETC.) AND PROVIDES A SIGNIFICANT SAVING IN BOTH COMPUTATION AND STORAGE.

PROGRAM DENCIPHI ASSUMES THAT PROGRAM PREDEN HAS BEEN USED TO PRE-PROCESS THE OBSERVATION DATA AND CREATE A GROUND POINT DATA FILE AND A FRAME DATA FILE IN RANDOM ACCESS FORMAT. THE USER IS ADVISED TO PRESERVE THE ORIGINALS OF THESE FILES AND SUPPLY COPIES OF THEM TO THIS PROGRAM, BECAUSE BOTH FILES WILL BE ALTERED IN THE COURSE OF THE ADJUSTMENT.

THE USER MUST SUPPLY (STANDARD INPUT UNIT) FOUR DATA RECORDS:

1. PROJECT TITLE (A80)
2. NAME OF GROUND POINT DATA FILE (A28). THIS FILE WILL BECOME RANDOM ACCESS UNIT 7.
3. NAME OF FRAME DATA FILE (A28). THIS FILE WILL BECOME RANDOM ACCESS UNIT 8.
4. NAME OF FILE TO RECEIVE RESULT DATA RECORDS (A28). THIS FILE WILL BECOME RANDOM ACCESS UNIT 10.

THIS MAIN PROGRAM READS THE FOUR DATA RECORDS, ASSIGNS FILES, AND ACQUIRES STORAGE FOR ARRAYS WHOSE DIMENSIONS ARE DETERMINED BY THE PARAMETERS OF THE ADJUSTMENT TO BE PERFORMED. CONTROL IS THEN PASSED TO SUBROUTINE ADJUST, WHICH MANAGES ALL PHASES OF THE ADJUSTMENT.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

CHARACTER*28 NAME
CHARACTER*80 TITLE

PARAMETERS LGDREC (LENGTH OF GROUND POINT DATA RECORDS) AND LFDREC (LENGTH OF FRAME DATA RECORDS) SHOULD AGREE IN MAGNITUDE WITH THE EQUIVALENT PARAMETERS IN PROGRAM PREDEN. ONLY THESE TWO PARAMETERS NEED TO BE CHANGED IF THE RECORD LENGTH(S) ARE TO BE ALTERED TO INCREASE NVMAX (THE MAXIMUM NUMBER OF INTERVISIBLE GROUND POINTS) OR NIMAX (THE MAXIMUM NUMBER OF IMAGES ON A PHOTOGRAPH).

PARAMETER LGDREC = 56
PARAMETER LFDREC = 224
PARAMETER NVMAX = (LGDREC - 32)/2
PARAMETER NIMAX = (LFDREC-38)/6
PARAMETER LSCR = (LFDREC-30)/2

C
C Labeled COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS:

C NGP = TOTAL NUMBER OF GROUND POINTS
C NFR = TOTAL NUMBER OF FRAMES OF PHOTOGRAPHY
C NRG = NUMBER OF RESIDENT GROUND POINTS
C NCF = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RNE
C NCG = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RGE
C LST = NUMBER OF ELEMENTS IN ARRAY RNE
C LSS = NUMBER OF ELEMENTS IN ARRAY RGE
C LFR = LENGTH OF (FRAME PARAMETER ONLY) NORMAL EQUATION RECORDS
C LGR = LENGTH OF (GROUND POINT ONLY) NORMAL EQUATION RECORDS
C LGDR = LENGTH OF GROUND POINT DATA RECORDS
C LFDR = LENGTH OF FRAME DATA RECORDS
C

COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS,LFR,LGR,LGDR,LFDR

C
C Labeled COMMON /BLCKG/ PROVIDES A BUFFER AREA FOR READING/WRITING
C GROUND POINT DATA RECORDS OF LGDREC WORDS TO/FROM RANDOM ACCESS
C UNIT 7. THESE RECORDS CONSIST OF:

C GPID = GROUND POINT NAME
C IW = 0, UNCONSTRAINED POINT; = 1, WEIGHT MATRIX SUPPLIED
C NLF = SEQUENCE NUMBER OF LAST FRAME ON WHICH POINT IS IMAGED
C GXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)
C COR = CUMULATIVE CORRECTIONS TO INITIAL POSITION
C WT = UPPER TRIANGLE OF WEIGHT MATRIX
C NV = NUMBER OF NAMES OF INTERVISIBLE GROUND POINTS IN VGPN
C VGPN = NAMES OF UP TO NVMAX INTERVISIBLE GROUND POINTS
C ITEM = PARAMETERS OF THIS ADJUSTMENT (FIRST RECORD ONLY)
C ITEM(1) = TOTAL NUMBER OF GROUND POINTS
C ITEM(2) = TOTAL NUMBER OF FRAMES OF PHOTOGRAPHY
C ITEM(3) = NUMBER OF RESIDENT GROUND POINTS
C

COMMON/BLCKG/GPID,IW,NLF,GXYZ(3),COR(3),WT(6),NV,VGPN(NVMAX),
* ITEM(3)

C
C Labeled COMMON /BLCKF/ PROVIDES A BUFFER AREA FOR READING/WRITING
C FRAME DATA RECORDS OF LFDREC WORDS TO/FROM RANDOM ACCESS UNIT 8.
C THESE RECORDS CONSIST OF:

C FRID = FRAME NAME
C NI = NUMBER OF IMAGES
C FXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)
C ABCD = CURRENT ESTIMATE OF RODRIGUES ORIENTATION PARAMETERS
C RMAT = CURRENT ORIENTATION MATRIX
C DATI = UP TO NIMAX SETS OF GROUND POINT NAME AND IMAGE COORD.
C IDUM = 3 WORDS NOT USED
C

COMMON/BLCKF/FRID,NI,FXYZ(3),ABCD(4),RMAT(3,3),DATI(3,NIMAX),
* IDUM(3)

```

C
C   LABELED COMMON /BLCKP/ PROVIDES STORAGE FOR THE FOLLOWING:
C       F = FOCAL LENGTH OF CAMERA
C       PAR = MATRIX OF PARTIAL DERIVATIVES
C       Q = VECTOR OF OBSERVATION DISCREPANCIES
C       SCR = SCRATCH ARRAY USED IN FORMING RESULT RECORDS
C
C   COMMON/BLCKP/F,PAR(2,6),Q(2),SCR(LSCR)
C
C   LABELED COMMON /CONST/ CONTAINS THE FOLLOWING CONSTANTS USED IN
C   THIS ADJUSTMENT:
C       AE = SEMI-MAJOR AXIS OF ELLIPSOID
C       ESQ = SQUARE OF ECCENTRICITY OF ELLIPSOID
C       FLAT = FLATTENING OF ELLIPSOID
C       PI = RADIANS IN 180 DEGREES
C       TWOPI = 2*PI
C
C   COMMON/CONST/AE,ESQ,FLAT,PI,TWOPI
C
C   LABELED COMMON /STATS/ PROVIDES STORAGE FOR THE FOLLOWING DATA:
C       NOBS = NUMBER OBSERVATION EQUATIONS PROCESSED
C       NDOF = NUMBER OF DEGREES-OF-FREEDOM
C       SSD = SUM-OF-SQUARES OF DISCREPANCIES
C       REJ = REJECTION TOLERANCE
C       NREJ = NUMBER OF IMAGES REJECTED
C
C   COMMON/STATS/NOBS,NDOF,SSD,REJ,NREJ
C
C   LABELED COMMON /APPEND/ IS USED IN ACQUIRING STORAGE FOR SIX
C   ARRAYS WHOSE DIMENSIONS ARE DETERMINED BY THE PARAMETERS OF THE
C   ADJUSTMENT BEING PERFORMED.  INITIALLY LA,LB,---LF ARE SET EQUAL
C   TO THE LENGTHS OF ARRAYS A,B,---F.  A CALL TO SUBROUTINE ALLOC8
C   THEN REPLACES THE LENGTH BY LOCATIONS RELATIVE TO THE VECTOR L
C   SUCH THAT L(LA) IS EQUIVALENT TO A(1), L(LB) IS EQUIVALENT TO
C   B(1), ETC.
C
C   COMMON/APPEND/ LA,LB,LC,LD,LE,LF
C   DIMENSION L(6)
C   EQUIVALENCE(LA,L(1))
C
C   DATA LGDR,LFDR/LGDREC,LFDREC/
C   DATA AE,ESQ,PI/6378206.4D0,.6768657997D-2,3.14159265359D0/
C   DATA F/153.26D0/
C   TWOPI = PI + PI
C   FLAT = 1.D0 - DSQRT(1.D0 - ESQ)
C
C   READ AND PRINT PROJECT TITLE.
C

```

```

      READ 21, TITLE
21  FORMAT(A80)
      PRINT 41, TITLE
41  FORMAT(/' P H O T O G R A M M E T R I C   C O N T R O L   D E N S '
*      ' I F I C A T I O N ' // 1X, A80 /)

```

C
C
C
C

```

      ASSIGN GROUND POINT DATA FILE (UNIT 7) AND OPEN FILE FOR RANDOM
      ACCESS TO RECORDS OF LENGTH LGDR.

```

```

      READ 61, NAME
61  FORMAT(A28)
      CALL ASGFIL(7, NAME, $200)
      CALL OPENRA(7, LGDR)

```

C
C
C
C

```

      ASSIGN FRAME DATA FILE (UNIT 8) AND RESULT DATA FILE (UNIT 10)
      AND OPEN BOTH FILES FOR RANDOM ACCESS TO RECORDS OF LENGTH LFDR.

```

```

      READ 61, NAME
      CALL ASGFIL(8, NAME, $200)
      CALL OPENRA(8, LFDR)
      READ 61, NAME
      CALL ASGFIL(10, NAME, $200)
      CALL OPENRA(10, LFDR)

```

C
C

```

      OBTAIN PARAMETERS OF THIS RUN AND COMPUTE CONSTANTS THAT ARE
      FUNCTIONS OF THESE PARAMETERS.

```

```

      CALL READRA(7, 1, GPID)
      NGP = ITEM(1)
      NFR = ITEM(2)
      NRG = ITEM(3)
      NCG = 3*NRG + 1
      NCF = NCG + 6
      LGR = NCG*(NCG+1)
      LSS = LGR/2
      LFR = NCF*(NCF+1)
      LST = LFR/2
      LFR = LFR - LGR

```

C
C
C
C

```

      COMPUTE DIMENSIONS OF ARRAYS THAT DEPEND ON RUN PARAMETERS AND
      ACQUIRE ADDITIONAL STORAGE FOR THESE ARRAYS.

```

```

      LINDX = NFR + 2
      LA = LINDX           a NO. OF WORDS FOR INDX(NFR+2)
      LB = NRG + NRG       a NO. OF WORDS FOR RGP(NRG)
      LC = NRG             a NO. OF WORDS FOR LSTF(NRG)
      LD = 8*NRG           a NO. OF WORDS FOR GDAT(4, NRG)
      LE = LFR             a NO. OF WORDS FOR FRAME PORTION OF RNE
      LF = LGR             a NO. OF WORDS FOR RGE(LSS)
      CALL ALLOC8(L, 6, NEW)

```

C

```

v
C PRINT RUN PARAMETERS, ASSIGN SCRATCH FILE (UNIT 9) FOR TEMPORARY
C STORAGE OF NORMAL EQUATIONS, OPEN FILE FOR RANDOM ACCESS TO VARI-
C ABLE LENGTH RECORDS, AND TRANSFER CONTROL TO SUBROUTINE ADJUST.
C
PRINT 101, NFR,NGP,NRG
101 FORMAT(/' NO. OF PHOTOGRAPHS = 'I4/' NO. OF GROUND POINTS = 'I4/
*      ' NO. OF RESIDENT GROUND POINTS = 'I3)
CALL FACSF(21H@ASG,T 9.,F///3000 . )
CALL OPENMS(9,L(LA),LINDX,0)
CALL ADJUST(L(LA),L(LB),L(LC),L(LD),L(LE),L(LF))
STOP

C
C DATA FILE NAME IS NOT CORRECT. FILE IS NEITHER CATALOGUED OR
C ASSIGNED. PRINT MESSAGE AND ABORT ADJUSTMENT.
C
200 PRINT 201, NAME
201 FORMAT(//' *** FILE 'A28,' IS NOT CATALOGUED OR ASSIGNED')
STOP '*** ADJUSTMENT ABORTED ***'
END

```

SUBROUTINE ADJUST(INDX,RGPN,LSTF,GDAT,RNE,RGE)

THIS SUBROUTINE MANAGES THE FOUR PHASES OF THE DENSIFICATION ADJUSTMENT: (1) FORMATION AND FORWARD REDUCTION OF NORMAL EQUATIONS, (2) SOLUTION AND UP-DATING OF PARAMETERS, (3) COMPUTATION OF ADDITIONAL PARAMETERS AND COVARIANCE PROPAGATION, AND (4) SORTING AND PRINTING OF RESULTS.

INDX IS A VECTOR USED FOR HOLDING THE LENGTHS OF VARIABLE LENGTH NORMAL EQUATION RECORDS TO BE WRITTEN TO RANDOM ACCESS UNIT 9. RGPN IS A VECTOR USED FOR HOLDING THE NAMES OF THE RESIDENT GROUND POINTS. LSTF IS A VECTOR USED FOR HOLDING THE SEQUENCE NUMBER OF THE LAST FRAME ON WHICH EACH OF THE RESIDENT GROUND POINTS IS IMAGED. GDAT IS AN ARRAY USED FOR HOLDING THE CARTESIAN COORDINATES AND ELEVATION OF EACH RESIDENT GROUND POINT. RNE IS A ONE-DIMENSIONAL TRIANGULAR ARRAY USED FOR HOLDING THE RESIDENT NORMAL EQUATIONS AND RGE IS THE SUBSET OF RNE THAT CONTAINS THE GROUND POINT PORTION OF THE RESIDENT NORMAL EQUATIONS.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

LABELED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS USED IN THIS SUBROUTINE:

NFR = TOTAL NUMBER OF FRAMES OF PHOTOGRAPHY
NRG = NUMBER OF RESIDENT GROUND POINTS
LST = NUMBER OF ELEMENTS IN ARRAY RNE
LGR = LENGTH OF (GROUND POINT ONLY) NORMAL EQUATION RECORDS

COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS,LFR,LGR

LABELED COMMON /STATS/ CONTAINS THE FOLLOWING ITEMS USED IN THIS SUBROUTINE:

NOBS = NUMBER OF OBSERVATION EQUATIONS PROCESSED
NDOF = NUMBER OF DEGREES-OF-FREEDOM
SSD = SUM-OF-SQUARES OF DISCREPANCIES
REJ = REJECTION TOLERANCE
NREJ = NUMBER OF IMAGES REJECTED

COMMON/STATS/NOBS,NDOF,SSD,REJ,NREJ

DIMENSION INDX(1),RGPN(NRG),LSTF(NRG),GDAT(4,NRG),RNE(1),RGE(1)

ITERATE FORMATION AND SOLUTION OF NORMAL EQUATIONS UNTIL CHANGE IN RMS OF RESIDUALS IS SMALLER THAN TOLERANCE.

↳

```
SIGP = 1.D+20
REJ = SIGP
DO 60 IT = 1, 6
NOBS = 0
NDOF = 0
SSD = 0.D0
NREJ = 0
PRINT 21, IT
21 FORMAT(// ' ITERATION 'I1)
CALL FORWD(RGPN,LSTF,GDAT,RNE,RGE)
SIG = DSQRT(SSD/NDOF)
RNE(LST) = RNE(LST)/NDOF
PRINT 41, SIG,NOBS,NDOF
41 FORMAT(/5X,'RMS = 'F8.5,' NO. OF EQUATIONS = 'I4,' DEGREES OF '
*      'FREEDOM = 'I4)
IF(SIGP-SIG .LT. 0.0001D0) GO TO 80
SIGP = SIG
REJ = 3.D0*DSQRT(RNE(LST))
IF(IT .EQ. 6) CALL WRITMS(9,RGE,LGR,NFR+1)
CALL SOLVE(INDX,RNE,RGE)
60 CONTINUE
C
C COMPUTE ADDITIONAL PARAMETERS AND PROPAGATE COVARIANCE.
C
CALL READMS(9,RGE,LGR,NFR+1)
80 CALL ERPROP(INDX, RGPN, RNE, RGE)
C
C SORT AND PRINT RESULTS
C
CALL PRESLT(RGPN)
RETURN
END
```

SUBROUTINE ALLOC8(L,N,NEW)

C
C
C
C
C
C
C
C
C
C
C
C

THIS SUBROUTINE ACQUIRES A BLOCK OF ADDITIONAL CORE OF SUFFICIENT SIZE TO HOLD N ARRAYS WHOSE LENGTHS (IN SINGLE PRECISION WORDS) ARE PROVIDED IN THE VECTOR L. IF STORAGE IS TO BE ACQUIRED FOR ARRAYS A1, A2, --- AN, THEN THE INPUT VALUE OF L(I) WHOULD BE THE LENGTH OF AI. THE OUTPUT VALUE OF L(I) WILL BE LOCI SUCH THAT THE LOCATION OF L(LOCI) IS THE LOCATION OF AI(1). NEW IS THE LOCATION OF THE FIRST WORD OF THE BLOCK AND IS USED TO RETURN THIS BLOCK TO THE SYSTEM BY CALLING LCONF\$(NEW).

DIMENSION L(N)

C
C
C

DETERMINE TOTAL LENGTH OF BLOCK AND CALL MCONF\$ TO ACQUIRE CORE.

LNG = 0
DO 20 I = 1, N
20 LNG = LNG + L(I)
NEW = MCONF\$(LNG)

C
C
C

ENTER LOCATIONS (RELATIVE TO LOCATION OF L) INTO VECTOR L.

LOCL = LOC(L)
LAST = NEW - LOCL + LNG + 1
DO 40 I = N, 1, -1
LAST = LAST - L(I)
40 L(I) = LAST
RETURN
END

SUBROUTINE ASGFIL(IFILE,NAME,*)

C
C THIS SUBROUTINE ASSIGNS THE FILE "NAME", WHICH MUST BE CATALOGUED,
C AND EQUATES IT TO THE INTERNAL NUMBER "IFILE". IF THE ASSIGNMENT
C IS REJECTED FOR ANY REASON, RETURN 1 WILL BE TAKEN INSTEAD OF THE
C NORMAL RETURN.
C

CHARACTER*28 NAME
CHARACTER*40 ASG,USE

C
ENCODE(21,ASG) NAME
21 FORMAT(8H@ASG,A ,A28,4H .)
ISTAT = FACSF(ASG)
IF(ISTAT .LT. 0) RETURN 1
ENCODE(41,USE) IFILE,NAME
41 FORMAT(5H@USE ,I2,1H,,A28,4H .)
ISTAT = FACSF(USE)
RETURN
END

```

SUBROUTINE AXB(A,B,C,I,J,K)
C
C THIS SUBROUTINE OBTAINS THE MATRIX PRODUCT: C = A*B
C
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION A(I,J),B(J,K),C(I,K)
C
DO 40 II = 1, I
DO 40 KK = 1, K
C(II,KK) = 0.0
DO 20 JJ = 1, J
20 C(II,KK) = C(II,KK) + A(II,JJ)*B(JJ,KK)
40 CONTINUE
RETURN
END

```

SUBROUTINE COVIJ(RGE,NI,NJ,TC)

C
C
C
C
C
C
C
C
C
C

THIS SUBROUTINE EXTRACTS, FROM THE TRIANGULAR COVARIANCE MATRIX (RGE) OF RESIDENT GROUND POINTS. THE TRIANGULAR FORM OF THE 6 BY 6 COVARIANCE MATRIX ASSOCIATED WITH A PAIR OF GROUND POINTS AND STORES IT IN TC. NI AND NJ ARE THE RESIDENT GROUND POINT SEQUENCE NUMBERS OF THE TWO GROUND POINTS, AND NJ MUST BE GREATER THAN NI.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

C
C
C
C
C
C
C

LABELLED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS USED IN THIS SUBROUTINE:

NCG = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RGE
LSS = NUMBER OF ELEMENTS IN ARRAY RGE

COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS
DIMENSION RGE(1),TC(21)

C
C
C

SET POINTERS AND SPACERS.

NCI = NCG - 3*(NI-1)
NCJ = NCG - 3*(NJ-1)
LG = LSS - NCI*(NCI+1)/2
LC = 0
NS1 = NCI - NCJ - 3
NS2 = NCJ - 3

C
C
C

EXTRACT FIRST THREE ROWS.

DO 60 I = 1, 3
DO 20 J = I, 3
LG = LG + 1
LC = LC + 1
20 TC(LC) = RGE(LG)
LG = LG + NS1
DO 40 J = 1, 3
LG = LG + 1
LC = LC + 1
40 TC(LC) = RGE(LG)
60 LG = LG + NS2

C
C
C

EXTRACT LAST THREE ROWS.

LG = LSS - NCJ*(NCJ+1)/2
DO 100 I = 1, 3
DO 80 J = I, 3
LG = LG + 1
LC = LC + 1
80 TC(LC) = RGE(LG)
100 LG = LG + NS2
RETURN
END

SUBROUTINE DATOUT

C
C
C
C
C
C

THIS SUBROUTINE PRINTS ALL RESULTS ASSOCIATED WITH A SINGLE GROUND POINT.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
CHARACTER*4 MET,SEC,LABC(3)
CHARACTER*8 GPID,NAME(2),LABG(3)

C
C
C
C
C
C
C
C
C
C
C

LABELED COMMON /BLCKP/ CONTAINS THE FOLLOWING DATA ASSOCIATED WITH THIS GROUND POINT:

GPID = GROUND POINT NAME
NI = NUMBER OF INTERVISIBLE GROUND POINTS
XYZ = POSITION IN CARTESIAN GEOCENTRIC COORDINATES
SXYZ = STANDARD DEVIATIONS OF CARTESIAN COORDINATES
PLH = POSITION IN GEODETIC COORDINATES
SPLH = STANDARD DEVIATIONS OF GEODETIC COORDINATES
RAE = INTER-POINT PARAMETERS FOR UP TO 12 INTERVISIBLE POINTS

COMMON/BLCKP/GPID,NI,XYZ(3),SXYZ(3),PLH(3),SPLH(3),DPDX(3,3),

* RAE(7,12)

DATA MET,SEC,NAME/4H M ,4H SEC,2*8H /

DATA LABC/4HX = ,4HY = ,4HZ = /

DATA LABG/8H LAT. = ,8H LON. = ,8H HT. = /

C
C
C

PRINT GROUND POINT POSITION AND STANDARD DEVIATIONS.

PRINT 21

21 FORMAT(///' POINT',12X,'CARTESIAN'9X,'STD.'17X,'GEODETIC'12X,
* 'STD.'/' NO.'14X,'POSITION'9X,'DEV.'17X,'POSITION'12X,
* 'DEV.'/)

NAME(2) = GPID

DO 40 I = 1, 2

CALL RADDMS(SPLH(I),K,M,SIG)

SIG = SIG + DFLOAT(60*(60*K + M))

CALL RADDMS(PLH(I),K,M,S)

40 PRINT 41, NAME(I),LABC(I),XYZ(I),SXYZ(I),MET,LABG(I),K,M,S,SIG,SEC

41 FORMAT(1X,A8,6X,A4,F12.3,F8.3,A4,7X,A8,2I3,2F8.4,A4)

PRINT 61, LABC(3),XYZ(3),SXYZ(3),MET,LABG(3),PLH(3),SPLH(3),MET

61 FORMAT(15X,A4,F12.3,F8.3,A4,7X,A8,F13.3,F9.3,1X,A4)

IF(NI .EQ. 0) RETURN

C
C
C
^

PRINT DISTANCE, AZIMUTH, ELEVATION DIFFERENCE, AND STANDARD DEVIATIONS FROM THIS POINT TO ALL INTERVISIBLE POINTS.

```

PRINT 81
81 FORMAT(/12X,'FROM'6X,'TO'8X,'DISTANCE'5X,'STD.'9X,'AZIMUTH'9X,
*      'STD.'8X,'CHANGE IN'5X,'STD.'/13X,'PT.'6X,'PT.'20X,'DEV.'
*      25X,'DEV.'8X,'ELEVATION'5X,'DEV.')
```

DO 100 I = 1, NI

```

CALL RADDMS(RAE(6,I),K,M,SIG)
SIG = SIG + DFLOAT(60*(60*K + M))
CALL RADDMS(RAE(3,I),K,M,S)
```

100 PRINT 101, GPID,RAE(1,I),RAE(2,I),RAE(5,I),MET,K,M,S,SIG,SEC,

```

*      RAE(4,I),RAE(7,I),MET
```

101 FORMAT(10X,A8,1X,A8,F13.3,F8.3,A4,4X,2I3,F7.3,F8.3,A4,F14.3,F8.3,

```

*      A4)
RETURN

END
```

SUBROUTINE ELIM(T,NCT,NR)

THIS SUBROUTINE PERFORMS THE FORWARD REDUCTION BY GAUSSIAN ELIMINATION WHICH TRANSFORMS THE MATRIX EQUATION $A \times X = Y$, WHERE A IS SYMMETRIC AND ONLY THE UPPER TRIANGLE IS STORED, INTO THE SIMPLER FORM $U \times X = Z$, WHERE U IS UNIT-UPPER-TRIANGULAR. THE TRIANGULAR PART OF A, APPENDED BY THE VECTOR Y, MUST BE STORED IN THE ONE-DIMENSIONAL ARRAY T AS FOLLOWS:

```
      T = A(1,1),A(1,2), - - - A(1,N),Y(1),  
          A(2,2), - - - A(2,N),Y(2),  
                      -       -  
                      A(N,N),Y(N),  
                      SS
```

WHERE SS IS THE SUM-OF-SQUARES OF DISCREPANCIES. NCT IS THE NUMBER OF ELEMENTS IN THE FIRST ROW OF T. NR IS THE NUMBER OF ROWS TO BE REDUCED, BEGINNING WITH ROW 1. THE ENTIRE MATRIX WILL BE REDUCED IF $NR \leq N = NCT - 1$.

THE TRANSFORMATION IS BASED ON THE FACTORIZATION $A = U' \times D \times U$, WHERE U' IS THE TRANSPOSE OF U AND D IS A DIAGONAL MATRIX. THE DIAGONAL ELEMENTS OF A WILL BE REPLACED BY THE DIAGONAL ELEMENTS OF THE INVERSE OF D, THE ABOVE-DIAGONAL ELEMENTS OF A WILL BE REPLACED BY THE ABOVE-DIAGONAL ELEMENTS OF U, AND Y WILL BE REPLACED BY Z. IN ADDITION, THE QUADRATIC SUM $X' \times A \times X$ WILL BE SUBTRACTED FROM SS TO FORM THE SUM-OF-SQUARES OF RESIDUALS.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION T(1)

LOOP TO REDUCE NR ROWS. SET UP POINTERS AND INVERT THE DIAGONAL ELEMENT.

```
      IJ = 0  
      DO 60 I = 1, NR  
        II = IJ + 1  
        T(II) = 1.00/T(II)  
        IJ = II  
        JK = II + NCT - 1
```

LOOP TO COMPUTE $U(I,J) = A(I,J)/D(I,I)$ AND MODIFY ROWS I+1 THRU N.

```
      DO 40 J = I+1, NCT  
        IK = IJ  
        IJ = IJ + 1
```

```

C   IF A(I,J) = 0, ROW J WILL NOT BE CHANGED.  MODIFY POINTER AND
C   SKIP THIS ROW.  OTHERWISE CONTINUE.
C
      IF(T(IJ) .EQ. 0.DO) THEN
      JK = JK + NCT - J + 1
      GO TO 40
C
      ELSE
      R = T(II)*T(IJ)
      END IF
C
C   LOOP TO COMPUTE A(J,K) = A(J,K) - U(I,J)*A(I,K) FOR K = J THRU NCT
C
      DO 20 K = J, NCT
      IK = IK + 1
      JK = JK + 1
20  T(JK) = T(JK) - R*T(IK)
C
      T(IJ) = R
40  CONTINUE
C
60  CONTINUE
      RETURN
      END

```

```

SUBROUTINE ERPROP(INDX,RGPN,RNE,RGE)
C
C
C   THIS SUBROUTINE MANAGES THE POST-SOLUTION PROCESSING.  THE SPARSE
C   COVARIANCE MATRIX OF GROUND POINT POSITIONS IS COMPUTED AND A FILE
C   OF RESULTS CREATED.
C
C   INDX IS AN INDEX VECTOR WHICH PROVIDES THE LENGTH OF FORWARD-
C   REDUCED NORMAL EQUATION RECORDS WRITTEN TO UNIT 9 BY SUBROUTINE
C   ELIM.  RGPN IS A VECTOR USED TO HOLD THE NAMES OF THE RESIDENT
C   GROUND POINTS.  RNE IS A ONE-DIMENSIONAL TRIANGULAR ARRAY USED TO
C   HOLD THE RESIDENT NORMAL EQUATIONS, AND RGE IS A SUB-SET OF RNE
C   USED TO HOLD THE GROUND POINT PORTION OF THE RESIDENT NORMAL
C   EQUATIONS.
C
C   IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C   LABELED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS USED IN
C   THIS SUBROUTINE:
C       NGP = TOTAL NUMBER OF GROUND POINTS
C       NFR = TOTAL NUMBER OF FRAMES OF PHOTOGRAPHY
C       NRG = NUMBER OF RESIDENT GROUND POINTS
C       NCF = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RNE
C       NCG = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RGE
C       LFR = LENGTH OF (FRAME PARAMETER ONLY) NORMAL EQUATION RECORDS
C
COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS,LFR
DIMENSION INDX(1),RGPN(NRG),RNE(1),RGE(1)
C
C   COMPUTE CONSTANTS
C
KR = 2*NCF + 1
KRSQ = KR**2
C
C   COMPUTE COVARIANCE MATRIX OF RESIDENT GROUND POINTS.  FOR EACH
C   POINT, CALL SUBROUTINE RESULT TO FORM A RECORD OF RESULTS AND
C   WRITE IT TO UNIT 10.
C
CALL SPCOV(RGE,NCG,NCG-1)
NGREC = NGP + 1
DO 20 NG = NRG, 1, -1
NGREC = NGREC - 1
20 CALL RESULT(RGE,NG,NGREC, RGPN,RNE)
C
C   LOOP TO RETRIEVE FORWARD-REDUCED NORMAL EQUATION RECORDS THAT
C   INCLUDE GROUND POINT EQUATIONS AND COMPLETE POST-SOLUTION
C   PROCESSING FOR EACH POINT.  DETERMINE RECORD LENGTH AND TAKE
C   APPROPRIATE ACTION.
C
DO 80 NFREC = NFR, 1, -1
LR = BITS(INDX(NFREC+1),19,18)
IF(LR .EQ. LFR) GO TO 80

```

```

C
C RECORD CONTAINS GROUND POINT EQUATIONS. DETERMINE TOTAL NUMBER OF
C ROWS (NRT) AND NUMBER OF GROUND POINT ROWS (NGR), AND MAKE SPACE
C AVAILABLE FOR THIS RECORD. NRT IS OBTAINED BY SOLVING THE
C QUADRATIC EQUATION:  $LR = KR \times NRT - NRT \times 2$ 
C
NRT = (KR - SQRT(KRSQ - 4*LR))/2
NGR = NRT - 6
CALL MUVDN(RGE, NCG, NGR)
C
C READ RECORD AND SHIFT NAMES IN RGPN TO REFLECT NEW RESIDENT
C GROUND POINT SEQUENCE.
C
CALL READMS(9, RNE, LR, NFREC)
NP = NGR/3
DO 40 I = NRG, NP+1, -1
40 RGPN(I) = RGPN(I-NP)
C
C COMPUTE COVARIANCE MATRIX OF NEW RESIDENT GROUND POINTS. FOR EACH
C NEW POINT, CALL SUBROUTINE RESULT TO FORM A RECORD OF RESULTS AND
C WRITE IT TO UNIT 10
C
CALL SPCOV(RGE, NCG, NGR)
DO 60 NG = NP, 1, -1
NGREC = NGREC - 1
60 CALL RESULT(RGE, NG, NGREC, RGPN, RNE)
C
80 CONTINUE
RETURN
END

```

SUBROUTINE FORWD(RGPN,LSTF,GDAT,RNE,RGE)

THIS SUBROUTINE MANAGES THE FORMATION AND FORWARD REDUCTION OF THE PHOTOGRAMMETRIC NORMAL EQUATIONS.

RGPN IS A VECTOR USED FOR HOLDING THE NAMES OF THE RESIDENT GROUND POINTS. LSTF IS A VECTOR USED FOR HOLDING THE SEQUENCE NUMBER OF THE LAST FRAME ON WHICH EACH OF THE RESIDENT GROUND POINTS IS IMAGED. GDAT IS AN ARRAY USED FOR HOLDING THE CARTESIAN COORDINATES AND ELEVATION OF EACH RESIDENT GROUND POINT. RNE IS A ONE-DIMENSIONAL TRIANGULAR ARRAY USED FOR HOLDING THE RESIDENT NORMAL EQUATIONS AND RGE IS THE SUBSET OF RNE THAT CONTAINS THE GROUND POINT PORTION OF THE RESIDENT NORMAL EQUATIONS.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

LABELED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS USED IN THIS SUBROUTINE:

NGP = TOTAL NUMBER OF GROUND POINTS
NFR = TOTAL NUMBER OF FRAMES OF PHOTOGRAPHY
NRG = NUMBER OF RESIDENT GROUND POINTS
NCF = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RNE
NCG = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RGE
LFR = LENGTH OF (FRAME PARAMETER ONLY) NORMAL EQUATION RECORDS

COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS,LFR

LABELED COMMON /BLCKF/ PROVIDES A BUFFER AREA FOR READING FRAME DATA RECORDS WHICH INCLUDE:

FRID = FRAME NAME
NI = NUMBER OF IMAGES
DATI = UP TO 31 SETS OF GROUND POINT NAME AND IMAGE COORDINATES

COMMON/BLCKF/FRID,NI,FXYZ(3),ABCD(4),RMAT(3,3),DATI(3,31)

LABELED COMMON /STATS/ CONTAINS THE FOLLOWING ITEMS USED IN THIS SUBROUTINE:

NOBS = NUMBER OF OBSERVATION EQUATIONS PROCESSED
NDOF = NUMBER OF DEGREES-OF-FREEDOM

COMMON/STATS/NOBS,NDOF
DIMENSION RGPN(NRG),LSTF(NRG),GDAT(4,NRG),RNE(1),RGE(1)

INITIALIZE FOR FORMING NORMAL EQUATIONS AND FILL RESIDENT GROUND POINT DATA ARRAYS.

CALL ZEROT(RGE,NCG,NCG)
NGREC = 0
DO 20 NG = 1, NRG
NGREC = NGREC + 1

```

20 CALL READG(NGREC,NG, RGNP,LSTF,GDAT,RGE)
   NPL = NGP - NGREC
C
C   LOOP TO PROCESS NFR FRAMES.  READ FRAME DATA RECORD AND INITIALIZE
C   FOR FORMING FRAME NORMAL EQUATIONS.
C
   DO 180 I = 1, NFR
   CALL READRA(8,I,FRID)

   CALL NADIR
   CALL ZEROT(RNE,NCF,6)
C
C   LOOP TO PROCESS ALL IMAGE DATA FOR THIS FRAME.  LOCATE GROUND
C   POINT CORRESPONDING TO EACH IMAGE AND FORM CONTRIBUTION TO NORMAL
C   EQUATIONS.
C
   IMAJ = 1
   DO 60 J = 1, NRG
   IF(RGNP(J) .NE. DATI(1,IMAJ)) GO TO 60
   CALL RFRCOR(GDAT(4,J),DATI(2,IMAJ))
   CALL PARTLS(GDAT(1,J),IMAJ,$40)
   NOBS = NOBS + 2
   CALL NORMS(RNE,J)
40 IF(IMAJ .EQ. NI) GO TO 80
   IMAJ = IMAJ + 1
60 CONTINUE
   GO TO 300
C
C   DETERMINE NUMBER OF NORMAL EQUATION ROWS (NR) TO BE ELIMINATED AND
C   THE RECORD LENGTH (LR) FOR WRITING THE ELIMINATED ROWS TO
C   PERIPHERAL STORAGE.
C
80 NR = 6
   LR = LFR
   IF(NPL .EQ. 0) GO TO 120
   DO 100 J = 1, NPL
   IF(LSTF(J) .GT. I) GO TO 120
   NR = NR + 3
   LR = LR + 6*(NCG - NR + 8)
100 CONTINUE
C
C   ELIMINATE NR ROWS AND WRITE THEM TO UNIT 9.
C
120 CALL ELIM(RNE,NCF,NR)
   NDOF = NDOF - NR
   CALL WRITMS(9,RNE,LR,I)
   IF(NR .EQ. 6) GO TO 180
C
C   GROUND POINT EQUATIONS HAVE BEEN ELIMINATED.  SHIFT ARRAY ENTRIES
C   TO NEW RESIDENT GROUND POINT SEQUENCE.
C

```

```

NR = NR - 6
CALL MUVUP(RGE, NCG, NR)
NP = NR/3
L = 0
DO 140 J = NP+1, NRG
L = L + 1
RGNP(L) = RGNP(J)
LSTF(L) = LSTF(J)
DO 140 K = 1, 4
140 GDAT(K, L) = GDAT(K, J)
C
C ADD NP NEW GROUND POINTS TO LIST OF RESIDENT GROUND POINTS.
C
DO 160 NG = L+1, NRG
NGREC = NGREC + 1
160 CALL READG(NGREC, NG, RGNP, LSTF, GDAT, RGE)
NPL = NPG - NGREC
C

180 CONTINUE
C
C ALL FRAMES HAVE BEEN PROCESSED. ELIMINATE REMAINING GROUND POINTS
C
NR = NCG - 1
CALL ELIM(RGE, NCG, NR)
NDOF = NDOF - NR + NOBS
RETURN
C
C IMAGE CANNOT BE MATCHED TO A RESIDENT GROUND POINT. PRINT MESSAGE
C AND ABORT RUN.
C
300 PRINT 301, DATI(1, IMAJ), FRID
301 FORMAT(' *** NON-RESIDENT GROUND POINT 'A8,' IMAGED ON FRAME 'A8)
STOP ' *** FORWD ABORT ***'
END

```



```

BAZ = S*TU2
FAZ = BAZ*TU1
X = EL1 - EL2
20 SX = DSIN(X)
CX = DCOS(X)
TU1 = CU2*SX
TU2 = SU1*CU2*CX - BAZ

SY = DSQRT(TU1*TU1 + TU2*TU2)
CY = S*CX + FAZ
Y = DATAN2(SY,CY)
SA = S*SX/SY
C2A = 1.D0 - SA*SA
CZ = FAZ + FAZ
IF(C2A .GT. 0.D0) CZ = CY - CZ/C2A
E = 2.D0*CZ*CZ - 1.D0
C = ((4.D0 - 3.D0*C2A)*F + 4.D0)*C2A*F/16.D0
D = X
X = SA*(Y + C*SY*(CZ + C*CY*E))
X = (1.D0 - C)*X*F + EL1 - EL2
IF(DABS(D-X) .GT. TOL) GO TO 20
FAZ = DATAN2(-TU1,TU2)
BAZ = DATAN2(CU1*SX,BAZ*CX - SU1*CU2)
IF(FAZ .LT. 0.D0) FAZ = FAZ + TWOPI
IF(BAZ .LT. 0.D0) BAZ = BAZ + TWOPI

```

C
C
C

COMPUTE DISTANCE.

```

X = 1.D0 + DSQRT(1.D0 - C2A*(1.D0 - 1.D0/R/R))
X = (X - 2.D0)/X
C = 1.D0 - X
C = (1.D0 + X*X/4.D0)/C
D = X*(-1.D0 + .375D0*X*X)
X = E*CY
S = 1.D0 - E*E
S = A*R*C*(Y+D*SY*(CZ+D/4.D0*(-X+S*CZ*D/6.D0*(-3.D0+4.D0*SY*SY))))
RAEB(1) = S
RAEB(2) = FAZ
RAEB(3) = PLH2(3) - PLH1(3)
RAEB(4) = BAZ

```

C
C
C

COMPUTE MATRIX OF PARTIAL DERIVATIVES.

```

DO 40 I = 1, 4
DO 40 J = 1, 6
40 DRDP(I,J) = 0.D0
SA = DSIN(FAZ)/SY
CA = DCOS(FAZ)/SY
SB = DSIN(BAZ)/SY
CB = DCOS(BAZ)/SY
DRDP(1,1) = Q1*S*CA
DRDP(2,1) = -Q1*CY*SA
DRDP(4,1) = -Q1*SA

```

```
DRDP(1,2) = -S*CU1*SA
DRDP(2,2) = CU2*CB
DRDP(3,2) = 0.D0
DRDP(4,2) = -CU1*CA
DRDP(3,3) = -1.D0
DRDP(1,4) = Q2*S*CB
DRDP(2,4) = -Q2*SB
DRDP(4,4) = -Q2*CY*SB
DRDP(1,5) = -DRDP(1,2)
DRDP(2,5) = -DRDP(2,2)
DRDP(4,5) = -DRDP(4,2)
DRDP(3,6) = 1.D0
RETURN
END
```


SUBROUTINE MSORT(DAT,N,M,SEQ,NS)

THIS SUBROUTINE REARRANGES LABELED COLUMNS OF A MATRIX INTO
ASCENDING ORDER IN ACCORDANCE WITH AN ORDERED LIST OF LABELS.

DAT IS AN N BY M MATRIX SUCH THAT THE FIRST ELEMENT OF EACH COLUMN
IS A LABEL THAT MATCHES ONE ENTRY IN THE VECTOR SEQ WHICH IS AN
ORDERED LIST CONTAINING NS LABELS.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION DAT(N,M),SEQ(NS)

LOOP TO COMPARE EACH ENTRY IN SEQ WITH THE M LABELS IN DAT.

NXT = 1
DO 100 I = 1, NS
TAG = SEQ(I)
DO 20 J = NXT, M
IF(DAT(1,J) .EQ. TAG) GO TO 40
20 CONTINUE
GO TO 100

A MATCH HAS BEEN FOUND. INTERCHANGE COLUMN J WITH COLUMN NXT AND
CONTINUE WITH COMPARISONS.

40 IF(NXT .EQ. J) GO TO 80
DO 60 K = 1, N
TAG = DAT(K,NXT)
DAT(K,NXT) = DAT(K,J)
60 DAT(K,J) = TAG
80 IF(NXT .EQ. M) RETURN
NXT = NXT + 1
100 CONTINUE

RETURN
END

SUBROUTINE MUVDN(T,NCT,NR)

C
C
C THIS SUBROUTINE MOVES THE ROWS OF THE TRIANGULAR ARRAY T DOWN IN
C ORDER TO MAKE SPACE AVAILABLE AT THE TOP FOR NR NEW ROWS. T IS
C ASSUMED TO CONTAIN THE TRIANGULAR PART OF A MATRIX A APPENDED BY
C A VECTOR Y, AND NCT IS THE NUMBER OF ELEMENTS IN THE FIRST ROW OF
C T. THE LAST NR ROWS AND COLUMNS OF A AND THE LAST NR ELEMENTS OF
C Y WILL BE DESTROYED.

C
C
C IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C DIMENSION T(1)

C
C SET UP POINTERS. N IS THE LAST ROW TO BE RETAINED.

C
C
C L = NCT*(NCT+1)/2
C NC = NR + 1
C M = L - NC*(NC+1)/2 + 1
C N = NCT - NC

C
C LOOP TO MOVE N ROWS IN REVERSE ORDER. MOVE Y(I) TO Y(I+NR).

C
C
C DO 20 I = N, 1, -1
C L = L - 1
C M = M - 1
C T(L) = T(M)
C M = M - NR

C
C LOOP TO MOVE A(I,J) TO A(I+NR,J) FOR J = N,---,I.

C
C
C DO 20 J = N, I, -1
C L = L - 1
C M = M - 1
20 T(L) = T(M)
C RETURN
C END

```

SUBROUTINE MUVUP(T,NCT,NR)
C
C
C   THIS SUBROUTINE MOVES THE ROWS OF THE TRIANGULAR ARRAY T UP AFTER
C   THE FIRST NR ROWS HAVE BEEN MOVED TO ANOTHER STORAGE AREA.  T IS
C   ASSUMED TO CONTAIN THE TRIANGULAR PART OF A MATRIX A APPENDED BY
C   VECTOR Y AND NCT IS THE NUMBER OF ELEMENTS IN THE FIRST ROW OF T.
C   THE LAST NR ROWS AND COLUMNS OF A AND LAST NR ELEMENTS OF Y WILL
C   SET TO ZERO.
C
C
C   IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C   DIMENSION T(1)
C
C   SET UP POINTERS.  N IS THE NUMBER OF ROWS TO BE MOVED.
C
C   L = 0
C   M = NCT*NR - NR*(NR-1)/2
C   N = NCT - NR - 1
C
C   LOOP TO MOVE N ROWS.  LOOP TO MOVE A(I+NR,J) TO A(I,J).
C
C   DO 60 I = 1, N
C   DO 20 J = I, N
C   L = L + 1
C   M = M + 1
20 T(L) = T(M)
C
C   LOOP TO ZERO LAST NR COLUMNS OF ITH ROW OF A AND MOVE Y(I+NR)
C   TO Y(I).
C
C   DO 40 J = 1, NR
C   L = L + 1
40 T(L) = 0.DO
C   L = L + 1
C   M = M + 1
60 T(L) = T(M)
C
C   LOOP TO ZERO LAST NR ROWS.
C
C   DO 80 I = L+1, M
80 T(I) = 0.DO
RETURN
END

```

SUBROUTINE NADIR

THIS SUBROUTINE COMPUTES THE HEIGHT ABOVE ELLIPSOID OF THE CAMERA STATION AND THE FRAME COORDINATES OF THE NADIR POINT FOR USE IN CORRECTING IMAGE COORDINATES FOR ATMOSPHERIC REFRACTION.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

LABELED COMMON /BLCKF/ CONTAINS THE FRAME DATA RECORD WHICH INCLUDES:

FXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)

RMAT = CURRENT ORIENTATION MATRIX

COMMON/BLCKF/FRID,NI,FXYZ(3),ABCD(4),RMAT(3,3)

LABELED COMMON /BLCKP/ CONTAINS THE FOLLOWING ITEMS USED IN THIS SUBROUTINE:

F = FOCAL LENGTH OF CAMERA IN MILLIMETERS

HFR = HEIGHT OF CAMERA STATION ABOVE ELLIPSOID

XN = FRAME X-COORDINATE OF NADIR POINT

YN = FRAME Y-COORDINATE OF NADIR POINT

PLH = GEODETIC COORDINATES OF CAMERA STATION

DPDX = MATRIX OF PARTIALS OF GEODETIC WITH RESPECT TO CARTESIAN

COMMON/BLCKP/F,P(2,6),Q(2),HFR,XN,YN,PLH(3),DPDX(3,3)

COMPUTE HEIGHT OF CAMERA STATION

CALL XYZPLH(FXYZ,PLH,1,DPDX)

HFR = PLH(3)

COMPUTE FRAME COORDINATES OF NADIR. ROW 3 OF DPDX, IF SCALED BY HEIGHT OF CAMERA STATION, IS THE VECTOR FROM NADIR POINT TO CAMERA STATION.

DO 20 I = 1, 3

PLH(I) = 0.D0

DO 20 J = 1, 3

20 PLH(I) = PLH(I) - RMAT(I,J)*DPDX(3,J)

PLH(3) = -F/PLH(3)

XN = PLH(1)*PLH(3)

YN = PLH(2)*PLH(3)

RETURN

END


```

C
DO 40 I = 1, 6
X = P(1,I)*Q(1) + P(2,I)*Q(2)
LA = LD
LD = LD + NCI
NCI = NCI - 1
RNE(LD) = RNE(LD) - X
IF(I .GT. 3) GO TO 20

C
C
C
I IS < OR = 3, ADD X TO E(I).

LC = LE
LE = LE + NCJ
NCJ = NCJ - 1
RNE(LE) = RNE(LE) + X
LBJ = LA + NSP
LBI = LBJ + 1

C
C
C
C
LOOP TO APPLY CONTRIBUTIONS TO 6 COLUMNS. COMPUTE X = I,J-TH
ELEMENT OF PAR*PAR AND ADD X TO A(I,J).

20 DO 40 J = 1, 6
X = P(1,I)*P(1,J) + P(2,I)*P(2,J)
LA = LA + 1
RNE(LA) = RNE(LA) + X
IF(I .GT. 3) GO TO 40

C
C
C
I IS < OR = 3, SET B(J,I) = - X.

RNE(LBI) = -X
LBI = LBI + NCF - J
IF(J .GT. 3) GO TO 40

C
C
C
J IS < OR = 3, SET B(I,J) = -X AND ADD X TO C(I,J).

LBJ = LBJ + 1
RNE(LBJ) = - X
LC = LC + 1
RNE(LC) = RNE(LC) + X
40 CONTINUE

C
C
C
ADD Q*Q TO SUM-OF-SQUARES OF RESIDUALS.

RNE(LST) = RNE(LST) + Q(1)**2 + Q(2)**2
RETURN
END

```

```

SUBROUTINE OPENMS(IU,IX,LIND,IP)
PARAMETER NUMUN=10
PARAMETER MAXSEC=262143,MAXRL=262080
IMPLICIT INTEGER(A-Z)
DIMENSION IXA(NUMUN,4),AUNIT(4),IX(LIND),IXD(1)
DIMENSION INDSEC(6)
CHARACTER*12 HEADER /'READMSWRITMS'/,MASK
EQUIVALENCE (MASK,INDSEC)
INTEGER NBLKS,NSECS,NWORDS,NEXTSC
DATA IXA/40*0/,NOPEN/0/
C IXA CONTAINS 4 CELLS FOR EACH MS FILE, USED AS FOLLOWS:
C     1. FORTRAN UNIT NUMBER (INTEGER)
C     2. BASE ADRESS FOR ADDRESSING INDEX
C     3. LENGTH OF LONGEST RECORD IN THIS FILE.
C     4. LENGTH OF LAST RECORD READ OR WRITTEN ON THIS FILE.
DEFINE NXTSEC=BITS(IXD(IBASE),1,18)
DEFINE MAXREC=BITS(IXD(IBASE),19,18)
DEFINE SECTOR(I)=BITS(IXD(IBASE+I),1,18)
DEFINE ACTUAL(I)=BITS(IXD(IBASE+I),19,18)
C
IUN=0
11 IUN=IUN+1
IF(IUN.LE.NUMUN) GO TO 13
PRINT *, 'NO MORE THAN' , NUMUN,
1 'UNITS MAY BE OPENED FOR READMS/WRITMS WITHOUT RECOMPILATION'
CALL FERR
13 CONTINUE
C
C SEARCH FOR AN OPEN SLOT
IF(IXA(IUN,1).EQ.0) GO TO 15
GO TO 11
C
C SLOT FOUND
15 IXA(IUN,1)=IU
IBASE=LOC(IX)-LOC(IXD) +1
IXA(IUN,2)=IBASE
N=6
K=0
NOPEN=NOPEN+1
C
IF (IP.EQ.0) THEN @ CREATE AND INITIALIZE NEW FILE
DO 20 I=1,LIND
20 IX(I)=0
MAXREC=LIND-1
C SET UP INDEX POINTER RECORD
CALL NTRANS(IU,10,1,6,INDSEC,L,22)
CALL CHECKR
NXTSEC=4
ELSE IF (IP.EQ.2) THEN @OPEN OLD FILE AND RETRIEVE INDEX
CALL NTRANS(IU,10,2,6,INDSEC,L,22)
CALL CHECKR
N=INDSEC(5) @ LENGTH OF INDEX ON DISK

```

```

        IF (N.GT.LIND) THEN
            PRINT *, ' INDEX ON DISK OF LENGTH',N,
1          ' WILL NOT FIT INTO OPENMS INDEX AREA OF LENGTH',
2          LIND,' FOR UNIT', IU
            CALL FERR
            END IF
            CALL NTRAN$(IU,10,6,INDSEC(4),2,N,IXD(IBASE),L,22)
        ELSE @ ALL OTHER VALUES OF IP ARE IN ERROR

            PRINT *, ' ILLEGAL VALUE OF 4TH PARAMTER IN CALL TO OPENMS=',
1          IP
            CALL FERR
            END IF
            RETURN
C
        ENTRY WRITMS(IU,FWA,LREC,KREC)
        K=KREC
        N=LREC
        CALL UCHECK
        CALL RCHECK
        CALL SECADR
        IF(N.LE.ACTUAL(K)) GO TO 110
C
C IF THE CURRENT LENGTH OF THE RECORD ON DISK IS LESS THAN THE LENGTH
C OF THE RECORD TO BE WRITTEN, A NEW RECORD WILL BE ALLOCATED AT
C THE END OF THE FILE AND THE INDEX SET TO POINT TO THE NEW
C RECORD (NOTE THAT THE INITIAL LENGTH OF ALL RECORDS IS ZERO).
100 CONTINUE
        SECTOR(K) = NXTSEC
        CALL BUMPSC
        IXA(IUN,3) = MAX(IXA(IUN,3),N) @ KEEP TRACK OF MAX RECORD LENGTH
110 CONTINUE
        ACTUAL(K)=N
        FUNCT = 1 @ 1 IS THE NTRAN$ CODE FOR A WRITE.
C
C SET UP NTRAN$ CALL
120 CONTINUE
        TRKAD = SECTOR(K)
        CALL NTRAN$(IU,10,6,TRKAD,FUNCT,N,FWA,L,22)
        CALL CHECKR
        IXA(IUN,4)=N @SAVE LENGTH OF LAST RECORD PROCESSED
        RETURN
C
        ENTRY READMS(IU,FWA,LREC,KREC)
        CALL UCHECK
        K=KREC
        CALL RCHECK
        N=MIN(ACTUAL(K),LREC)
        IF(N .NE. 0) GO TO 200
        PRINT *, ' ATTEMPT TO READ EMPTY READMS/WRITMS RECORD,FILE_ ='
1      , IU,' INDEX = ',K
        CALL FERR
        RETURN

```

```

200 CONTINUE
    FUNCT = 2
    GO TO 120
                                @NTRANS READ
C
    ENTRY CLOSMS(IU)
    CALL UCHECK
C SAVE INDEX AT END OF FILE
    N = MAXREC + 1
    CALL SECADR
    MASK=HEADER
    INDSEC(4) = NXTSEC
    CALL BUMPSC
    INDSEC(5)=N
    INDSEC(6) = IXA(IUN,3) @ MAXIMUM RECORD LENGTH FOR THIS UNIT
    CALL NTRANS(IU,10,6,INDSEC(4),1,N,IXD(IBASE),L,22) @ WRITE INDEX
    CALL CHECKR
C PUT POINTER TO THE INDEX IN THE FIRST RECORD.
    N=6
    K = 0
    CALL NTRANS(IU,10,1,N,INDSEC,L,22)
    CALL CHECKR
    IXA(IUN,1)=0
    RETURN
C
    ENTRY STINDX(IU,SUBIND,LIND)
    CALL UCHECK
    NXT=NXTSEC
    IBASE= LOC(SUBIND)-LOC(IXD) +1
    NXTSEC=NXT
    MAXREC=LIND-1
    IXA(IUN,2)=IBASE
    RETURN
C
    ENTRY SIZEMS(IU,LIND,LMAXR)
    N=6
    K=0
C READ RECORD ZERO TO GET INDEX LENGTH AND MAX RECORD LENGTH
    CALL NTRANS(IU,10,2,N,INDSEC,L,22)
    LIND=INDSEC(5)
    LMAXR=INDSEC(6)
    RETURN
C
    ENTRY RECLMS(IU,LENGTH)
    CALL UCHECK
    LENGTH=IXA(IUN,4)
    RETURN

```

```

C
  SUBROUTINE UCHECK
    IUN= 0
  310 IUN=IUN+1
      IF(IUN. GT.NOPEN) GO TO 330
      IF(IXA(IUN,1).EQ.IU) GO TO 340
      GO TO 310
  330 PRINT *, ' ILLEGAL ATTEMP TO USE UNIT', IU,
    1 ' FOR READMS/WRITMS BEFORE CALLING OPENMS.'
      CALL FERR
  340 CONTINUE
      IBASE = IXA(IUN,2)      @SET UP ADDRESSABILITY OF INDEX.
      RETURN

```

```

C
  SUBROUTINE RCHECK
    IF(K .LE. MAXREC .AND. K.GT. 0) RETURN
    PRINT *,' READMS/WRITMS RECORD OUT OF RANGE.',
    1 ' UNIT =',IU,' INDEX =',K
      CALL FERR
      RETURN

```

```

C
  SUBROUTINE CHECKR
C CHECK RESULT OF NTRANS$ ACTIVITY
    IF(L.EQ.N) RETURN
    IF(L.EQ.(-2)) PRINT *,' READMS/WRITMS FILE RAN OUT OF SPACE.'
    1 , ' FILE =',IU,' RECORD =',K
    IF(L.EQ.(-3)) PRINT *,'DEVICE ERROR ON READMS/WRITMS UNIT',
    1 IU,' RECORD =', K
      CALL FERR
      RETURN

```

```

C
  SUBROUTINE SECADR
    NBLKS=(N+111)/112
    NSECS = NBLKS * 4
    NWORDS = NBLKS * 112
    IF( N .LE. MAXRL ) RETURN
    PRINT *,'READMS/WRITMS RECORD OF', N, ' WORDS ON UNIT',IU,
    1 'EXCEEDS MAXIMUM OF ',MAXRL,' WORDS'
      CALL FERR
      RETURN

```

```

C
  SUBROUTINE BUMPSC
    NEXTSC= NXTSEC+ NSECS
    IF(NEXTSC.LT.MAXSEC) GO TO 410
    PRINT *, ' READMS/WRITMS ERROR. MAXIMUM FILE SIZE OF'
    1 , MAXSEC,' SECTORS EXCEEDED.'
      CALL FERR
  410 NXTSEC=NEXTSC
      RETURN
      END

```

SUBROUTINE OPENRA(NUNIT,LRECL)

THIS SUBROUTINE PREPARES FOR RANDOM ACCESS TO RECORDS OF LENGTH
"LRECL" WORDS ON UNIT NUMBER "NUNIT" BY ENTRY POINTS READRA AND
WRITRA.

CHARACTER*8 MESAJ
DIMENSION KUR(30),LREC(30),NSEC(30)
DATA LREC/30*0/

IF(NUNIT .GT. 30) GO TO 100
IF(NUNIT .EQ. 1) GO TO 100
IF(NUNIT .EQ. 5) GO TO 100
IF(NUNIT .EQ. 6) GO TO 100
IF(LREC(NUNIT) .NE. 0) GO TO 200
NSECT = LRECL/28
IF(LRECL .GT. 28*NSECT) NSECT = NSECT + 1
CALL NTRANS(NUNIT,10,22)
LREC(NUNIT) = LRECL
NSEC(NUNIT) = NSECT
KUR(NUNIT) = NSECT
RETURN

THIS ENTRY POINT COPIES RECORD NUMBER "NOR" FROM UNIT NUMBER
"NUNIT" INTO THE ARRAY "KORE", PROVIDED THAT THIS UNIT HAS BEEN
OPENED FOR RANDOM ACCESS BY A CALL TO SUBROUTINE OPENRA.

ENTRY READRA(NUNIT,NOR,KORE)

IOP = 2
MESAJ = 8H READING
GO TO 20

THIS ENTRY POINT COPIES THE ARRAY "KORE" TO RECORD NUMBER "NOR" OF
UNIT NUMBER "NUNIT", PROVIDED THAT THIS UNIT HAS BEEN OPENED FOR
RANDOM ACCESS BY A CALL TO SUBROUTINE OPENRA.

ENTRY WRITRA(NUNIT,NOR,KORE)

IOP = 1
MESAJ = 8H WRITING

```

C
20 IF(NUNIT .GT. 30) GO TO 300
   IF(LREC(NUNIT) .EQ. 0) GO TO 300
   MOVE = NOR*NSEC(NUNIT) - KUR(NUNIT)
   IF(MOVE .NE. 0) CALL NTRAN$(NUNIT,6,MOVE,22)
   CALL NTRAN$(NUNIT,IOP,LREC(NUNIT),KORE,L,22)
   IF(L .NE. LREC(NUNIT)) GO TO 400
   KUR(NUNIT) = KUR(NUNIT) + MOVE + .NSEC(NUNIT)
   RETURN

C
100 PRINT 101, NUNIT
101 FORMAT(/' *** UNIT 'I2,' NOT AVAILABLE FOR RANDOM ACCESS ***')
   STOP '*** BAD UNIT NO. IN CALL TO OPENRA ***'

C
200 PRINT 201, NUNIT
201 FORMAT(/' *** UNIT 'I2,' ALREADY OPENED FOR RANDOM ACCESS ***')
   STOP '*** OPENRA CALLED TWICE WITH SAME UNIT NO. ***'

C
300 PRINT 301, NUNIT
301 FORMAT(/' *** UNIT 'I2,' NOT OPENED FOR RANDOM ACCESS ***')
   STOP '*** BAD UNIT NO. IN CALL TO READRA/WRITRA ***'

C
400 PRINT 401, L,MESAJ,NOR,NUNIT
401 FORMAT(/' *** NTRAN ERROR = 'I2,A8,' RECORD 'I6,' ON UNIT NO. 'I2)
   STOP '*** READRA/WRITRA ERROR ***'
   END

```

SUBROUTINE PARTLS(GXYZ,IM,*)

THIS SUBROUTINE OBTAINS THE COMPUTED FRAME COORDINATES OF A SINGLE IMAGE AND THE DISCREPANCIES (OBSERVED MINUS COMPUTED). IF THESE DISCREPANCIES ARE ACCEPTABLE, THE MATRIX OF PARTIAL DERIVATIVES OF IMAGE COORDINATES WITH RESPECT TO FRAME PARAMETERS IS COMPUTED.

GXYZ IS THE GROUND POINT POSITION VECTOR. IM IS THE LOCATION OF THE PARTICULAR IMAGE IN THE DATA ARRAY DATI (LABELED COMMON BLCKF) AND REJ IS THE IMAGE REJECTION TOLERANCE.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

LABELED COMMON /BLCKP/ WILL CONTAIN THE FOLLOWING:

F = FOCAL LENGTH OF CAMERA IN MILLIMETERS
PAR = MATRIX OF PARTIAL DERIVATIVES
EX = X-COORDINATE DISCREPANCY
EY = Y-COORDINATE DISCREPANCY

COMMON/BLCKP/F,PAR(2,6),EX,EY

LABELED COMMON /BLCKF/ CONTAINS THE FRAME DATA RECORD WHICH INCLUDES THE FOLLOWING QUANTITIES USED IN THIS SUBROUTINE:

FXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)
RMAT = CURRENT ORIENTATION MATRIX
DATI = UP TO 31 SETS OF GROUND POINT NAME AND IMAGE COORDINATES

COMMON/BLCKF/FRID,NI,FXYZ(3),ABCD(4),RMAT(3,3),DATI(3,31)

LABELED COMMON /STATS/ CONTAINS THE FOLLOWING ITEMS USED IN THIS SUBROUTINE:

SSD = SUM-OF-SQUARES OF DISCREPANCIES
REJ = REJECTION TOLERANCE
NREJ = NUMBER OF IMAGES REJECTED

COMMON/STATS/NOBS,NDOF,SSD,REJ,NREJ
DIMENSION GXYZ(3)

OBTAIN COMPUTED IMAGE COORDINATES AND DISCREPANCIES.

U = 0.0
V = 0.0
W = 0.0
DO 20 I = 1, 3
X = GXYZ(I) - FXYZ(I)
U = U + X*RMAT(1,I)
V = V + X*RMAT(2,I)
20 W = W + X*RMAT(3,I)
W = 1.0/W
FOW = -F*W
XC = U*FOW

```

YC = V*FOW
EX = DATI(2,IM) - XC
EY = DATI(3,IM) - YC
IF(EX .GE. REJ) GO TO 100
IF(EY .GE. REJ) GO TO 100
C
C COMPUTE MATRIX OF PARTIAL DERIVATIVES.
C
SSD = SSD + EX**2 + EY**2
XOW = XC*W
YOW = YC*W
DO 40 I = 1, 3
PAR(1,I) = FOW*RMAT(1,I) - XOW*RMAT(3,I)
40 PAR(2,I) = FOW*RMAT(2,I) - YOW*RMAT(3,I)
PAR(1,4) = -V*XOW
PAR(1,5) = U*XOW - F
PAR(2,4) = F - V*YOW
PAR(2,5) = -PAR(1,4)
PAR(1,6) = -YC
PAR(2,6) = XC
RETURN
C
C DISCREPANCY TOO LARGE. REJECT IMAGE.
C
100 IF(NREJ .EQ. 0) PRINT 101
101 FORMAT(/27X,'DATA REJECTED'//6X,'FRAME'4X,'IMAGE'8X,'X'9X,'Y'10X,
*      'EX'8X,'EY')
NREJ = NREJ + 1
PRINT 121, FRID,(DATI(II,IM), II=1,3),EX,EY
121 FORMAT(5X,A8,1X,A8,2F10.3,1X,2F10.3)
RETURN 1
END

```

```

SUBROUTINE PRESLT(SEQ)
C
C
C THIS SUBROUTINE MANAGES THE SORTING AND PRINTING OF ALL RESULTS
C OF THE DENSIFICATION ADJUSTMENT. SEQ IS A VECTOR FOR HOLDING AN
C ORDERED LIST OF GROUND POINT NAMES USED IN SORTING THE RESULT
C DATA FILE.
C
C
C IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C LABELED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS USED IN
C THIS SUBROUTINE:
C     NGP = TOTAL NUMBER OF GROUND POINTS
C     LGDR = LENGTH OF GROUND POINT DATA RECORDS
C     LFDR = LENGTH OF FRAME DATA RECORDS
C
C COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS,LFDR,LGR,LGDR,LFDR
C
C LABELED COMMON /BLCKP/ IS A BUFFER USED FOR READING AND WRITING
C RESULT DATA RECORDS WHICH INCLUDE:
C     GPID = GROUND POINT NAME
C     NI = NUMBER OF INTERVISIBLE GROUND POINTS
C     RAE = INTER-POINT PARAMETERS FOR UP TO 12 INTERVISIBLE POINTS
C
C COMMON/BLCKP/GPID,NI,XYZ(3),SXYZ(3),PLH(3),SPLH(3),DPDX(3,3),
*     RAE(7,12)
C DIMENSION SEQ(NGP)
C
C READ ORDERED LIST OF GROUND POINT NAMES FROM GROUND POINT DATA
C FILE. LIST STARTS IN RECORD NGP+1.
C
C     NW = LGDR/2
C     NR = NGP
C     DO 20 I = 1, NGP, NW
C     NR = NR + 1
20 CALL READRA(7,NR,SEQ(I))
C
C SORT AND PRINT RESULT DATA FILE.
C
C     NW = LFDR/2
C     DO 40 I = 1, NGP
C     CALL READRA(10,I,GPID)
C     IF(GPID .NE. SEQ(I)) CALL LOCATE(SEQ,NGP,I,GPID,NW)
C     CALL MSORT(RAE,7,NI,SEQ,NGP)
C     CALL DATOUT
40 CALL WRITRA(10,I,GPID)
C RETURN
C END

```

```

SUBROUTINE RADDMS(A,K,M,S)
C
C
C   THIS SUBROUTINE CONVERTS AN ANGLE (A), GIVEN IN RADIANS, TO
C   DEGREES (K), MINUTES (M), AND SECONDS (S) OF ARC.
C
C   IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
S = 57.295779131D0*A
GO TO 20
C
C
C   THIS ENTRY POINT CONVERTS AN ANGLE, GIVEN IN DEGREES, TO
C   DEGREES, MINUTES, AND SECONDS OF ARC.
C
C
ENTRY DEGDMS(A,K,M,S)
C
S = A
C
20 K = IFIX(S)
S = 60.D0*(S-DFLOAT(K))
M = IFIX(S)
S = 60.D0*(S-DFLOAT(M))
RETURN
END

```

SUBROUTINE READG(NGREC,NP,RGPN,LSTF,GDAT,RGE)

THIS SUBROUTINE READS A GROUND POINT DATA RECORD FROM UNIT 7 AND ENTERS THE PERTINENT DATA IN THE RESIDENT GROUND POINT DATA ARRAYS. IF THE POSITION OF THIS POINT IS TO BE CONSTRAINED, THE WEIGHTS ARE APPLIED TO THESE PARAMETERS.

NGREC IS THE GROUND POINT DATA RECORD NUMBER AND NG IS THE RESIDENT GROUND POINT SEQUENCE NUMBER. RGPN IS A VECTOR OF NAMES OF THE RESIDENT GROUND POINTS. LSTF IS A VECTOR CONTAINING THE SEQUENCE NUMBER OF THE LAST FRAME ON WHICH EACH OF THE RESIDENT GROUND POINTS IS IMAGED. RGE IS A ONE-DIMENSIONAL TRIANGULAR ARRAY CONTAINING THE GROUND POINT PORTION OF THE RESIDENT NORMAL EQUATIONS.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

LABELLED COMMON /BLCKG/ PROVIDES A BUFFER AREA FOR READING GROUND POINT DATA RECORDS WHICH INCLUDE:

GPID = GROUND POINT NAME
IW = 0, UNCONSTRAINED POINT; = 1, WEIGHT MATRIX SUPPLIED
NLF = SEQUENCE NUMBER OF LAST FRAME ON WHICH POINT IS IMAGED
GXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)
COR = CUMULATIVE CORRECTIONS TO INITIAL POSITION
WT = UPPER TRIANGLE OF WEIGHT MATRIX

COMMON/BLCKG/GPID,IW,NLF,GXYZ(3),COR(3),WT(6)
DIMENSION RGPN(1),LSTF(1),GDAT(4,1),RGE(1)

READ GROUND POINT DATA RECORD AND WEIGHT POSITION IF THIS IS A CONTROL POINT.

CALL READRA(7,NGREC,GPID)
IF(IW .EQ. 0) GO TO 20
CALL WEIGHT(RGE,NP)

ENTER DATA INTO RGPN, LSTF, AND GDAT.

20 RGPN(NP) = GPID
LSTF(NP) = NLF
CALL XYZPLH(GXYZ,COR,0)
DO 40 I = 1, 3
40 GDAT(I,NP) = GXYZ(I)
GDAT(4,NP) = COR(3)
RETURN
END

SUBROUTINE RESULT(RGE,NP,IREC,RGPN,SCR)

THIS SUBROUTINE FORMS A RECORD OF RESULTS OBTAINED FOR A PARTICULAR GROUND POINT AND WRITES THIS RECORD TO UNIT 10.

RGE IS THE TRIANGULAR COVARIANCE MATRIX OF THE RESIDENT GROUND POINTS, NP IS THE RESIDENT GROUND POINT SEQUENCE NUMBER AND IREC THE GROUND POINT DATA RECORD NUMBER OF THIS GROUND POINT. RGPN CONTAINS THE NAMES OF THE RESIDENT GROUND POINTS. SCR IS A SCRATCH ARRAY.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

LABELLED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS:

NGP = TOTAL NUMBER OF GROUND POINTS

NFR = TOTAL NUMBER OF FRAMES OF PHOTOGRAPHY

NRG = NUMBER OF RESIDENT GROUND POINTS

COMMON/SIZES/NGP,NFR,NRG

LABELLED COMMON /BLCKG/ PROVIDES A BUFFER AREA FOR READING GROUND POINT DATA RECORDS WHICH INCLUDE:

GPID = GROUND POINT NAME

NV = NUMBER OF NAMES OF INTERVISIBLE GROUND POINTS IN VGPN

VGPN = NAMES OF UP TO 12 INTERVISIBLE GROUND POINTS

COMMON/BLCKG/GPID,IW,NFL,GXYZ(3),COR(3),WT(6),NV,VGPN(12)

LABELLED COMMON /BLCKP/ PROVIDES A BUFFER AREA FOR FORMING AND WRITING RECORDS OF RESULTS WHICH INCLUDE:

GPI = GROUND POINT NAME

NI = NUMBER OF INTERVISIBLE GROUND POINTS

COMMON/BLCKP/GPI,NI

LABELLED COMMON /BLCKF/ PROVIDES A BUFFER AREA FOR READING AND WRITING RECORDS OF RESULTS FROM OTHER GROUND POINTS WHICH INCLUDE:

GPJ = GROUND POINT NAME

NJ = NUMBER OF INTERVISIBLE GROUND POINTS

COMMON/BLCKF/GPJ,NJ

DIMENSION RGE(1),RGPN(NRG),SCR(1)

READ GROUND POINT DATA RECORD FROM UNIT 7 AND FORM RESULT RECORD ENTRIES THAT DO NOT INVOLVE OTHER POINTS.

CALL READRA(7,IREC,GPID)

CALL RSLTI(RGE,NP)

RGPN(NP) = GPI

IF(NV .EQ. 0) GO TO 40

C ARRAY VGPN CONTAINS THE NAMES OF NV GROUND POINTS VISIBLE FROM
C THIS POINT. LOCATE RESULT RECORD FOR EACH POINT, COMPUTE INTER-
C POINT PARAMETERS, AND ENTER DATA INTO BOTH RECORDS.
C

NI = 1

JREC = IREC

DO 20 I = NP+1, NRG

JREC = JREC + 1

IF(RGPN(I) .NE. VGPN(NI)) GO TO 20

CALL READRA(10,JREC,GPJ)

NJ = NJ + 1

CALL COVIJ(RGE,NP,I,SCR)

CALL RSLTIJ(SCR,SCR(22),SCR(26),SCR(30),SCR(54))

CALL WRITRA(10,JREC,GPJ)

IF(NI .EQ. NV) GO TO 40

NI = NI + 1

20 CONTINUE

C

C

WRITE RESULT RECORD TO UNIT 10.

C

40 CALL WRITRA(10,IREC,GPI)

RETURN

END

```

SUBROUTINE RFRCOR(HGP,XY)
C
C
C THIS SUBROUTINE CORRECTS THE COORDINATES OF AN IMAGE FOR ATMOS-
C PHERIC REFRACTION USING THE SAASTAMOINEN MODEL (PHOTOGRAMMETRIC
C ENGINEERING, MARCH, 1974).
C
C HGP IS THE HEIGHT OF THE GROUND POINT AND XY IS THE VECTOR OF
C IMAGE COORDINATES TO BE CORRECTED FOR REFRACTION.
C
C
C IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C LABELED COMMON /BLCKP/ CONTAINS THE FOLLOWING ITEMS USED IN THIS
C SUBROUTINE:
C     F = FOCAL LENGTH OF CAMERA IN MILLIMETERS
C     HFR = HEIGHT OF CAMERA STATION ABOVE ELLIPSOID
C     XN = FRAME X-COORDINATE OF NADIR POINT
C     YN = FRAME Y-COORDINATE OF NADIR POINT
C
COMMON/BLCKP/F,P(2,6),Q(2),HFR,XN,YN
DIMENSION XY(2)
C
C C1 AND C2 ARE THE SAASTAMOINEN COEFFICIENTS FOR FLYING HEIGHTS UP
C TO 9000 METERS.
C
DATA C1,C2/13.D-9,2.D-5/
C
R = C1*(HFR-HGP)*(1.D0 - C2*(2.D0*HFR + HGP))
X = XY(1) - XN
Y = XY(2) - YN
TANSQ = (X**2 + Y**2)/F**2
R = 1.D0 - R - R*TANSQ
XY(1) = R*XY(1)
XY(2) = R*XY(2)
RETURN
END

```

SUBROUTINE RSLTI(RGE,NP)

THIS SUBROUTINE OBTAINS, FOR A SINGLE GROUND POINT, THE FOLLOWING ITEMS: GROUND POINT NAME, CARTESIAN COORDINATES AND THEIR STANDARD DEVIATIONS, GEODETIC COORDINATES AND THEIR STANDARD DEVIATIONS, AND THE MATRIX OF PARTIAL DERIVATIVES OF GEODETIC WITH RESPECT TO CARTESIAN. THESE ITEMS ARE ENTERED INTO THE RESULT RECORD BEING FORMED IN COMMON /BLCKP/.

RGE IS THE TRIANGULAR ARRAY CONTAINING THE COVARIANCE MATRIX OF THE RESIDENT GROUND POINTS AND NP IS THE RESIDENT GROUND POINT SEQUENCE NUMBER OF THE POINT.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

LABELED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS USED IN THIS SUBROUTINE:

NGC = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RGE
LSS = NUMBER OF ELEMENTS IN ARRAY RGE

COMMON/SIZES/NGP,NFR,NRG,NCF,NGC,LST,LSS

LABELED COMMON /BLCKG/ CONTAINS THE GROUND POINT DATA RECORD WHICH INCLUDES:

GPID = GROUND POINT NAME
GXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)
WT = UPPER TRIANGLE OF WEIGHT MATRIX

COMMON/BLCKG/GPID,IW,NFL,GXYZ(3),COR(3),WT(6)

LABELED COMMON /BLCKP/ PROVIDES A BUFFER AREA FOR FORMING THE RESULT RECORD WHICH WILL INCLUDE:

GPI = GROUND POINT NAME
NI = NUMBER OF INTERVISIBLE GROUND POINTS
XYZ = POSITION IN CARTESIAN GEOCENTRIC COORDINATES
SXYZ = STANDARD DEVIATIONS OF CARTESIAN COORDINATES
PLH = POSITION IN GEODETIC COORDINATES
SPLH = STANDARD DEVIATIONS OF GEODETIC COORDINATES
DPDX = PARTIALS OF GEODETIC WITH RESPECT TO CARTESIAN

COMMON/BLCKP/GPI,NI,XYZ(3),SXYZ(3),PLH(3),SPLH(3),DPDX(3,3)
DIMENSION RGE(1)

GET GPID AND XYZ FROM GROUND POINT DATA RECORD. COPY COVARIANCE MATRIX FROM RGE INTO WT AND GET SXYZ.

```
GPI = GPID
NI = 0
NC = NCG - 3*(NP-1)
LG = LSS - NC*(NC+1)/2
LC = 0
NC = NC - 3
DO 40 I = 1, 3
XYZ(I) = GXYZ(I)
SXYZ(I) = DSQRT(RGE(LG+1))
DO 20 J = I, 3
LG = LG + 1
LC = LC + 1
```

```
20 WT(LC) = RGE(LG)
```

```
40 LG = LG + NC
```

```
C
C
C
```

```
GET PLH,DPDX, AND SPLH.
```

```
CALL XYZPLH(XYZ,PLH,1,DPDX)
```

```
PLH(2) = - PLH(2)
```

```
CALL SDPROP(WT,DPDX,3,3,SPLH)
```

```
RETURN
```

```
END
```

SUBROUTINE RSLTIJ(TCOV,RAEB,SRAEB,DRDP,DRDX)

THIS SUBROUTINE OBTAINS THE DISTANCE, AZIMUTH, ELEVATION DIFFERENCE, AND BACK AZIMUTH (AND THEIR STANDARD DEVIATIONS) OF A LINE FROM POINT I TO POINT J, AND USES THESE DATA TO FORM ONE NEW COLUMN OF EACH OF THE ARRAYS RAEI AND RAEJ. RAEI IS AN ARRAY ASSOCIATED WITH POINT I AND THE NEW COLUMN WILL CONTAIN: THE NAME OF POINT J, THE DISTANCE, AZIMUTH, AND ELEVATION DIFFERENCE FROM POINT I TO POINT J, AND THEIR STANDARD DEVIATIONS. THE NEW COLUMN OF RAEJ WILL CONTAIN THE EQUIVALENT QUANTITIES FROM POINT J TO POINT I.

TCOV IS THE TRIANGULAR FORM OF THE 6 BY 6 COVARIANCE MATRIX ASSOCIATED WITH THE CARTESIAN COORDINATES OF POINTS I AND J. RAEB, SRAEB, DRDP, AND DRDX ARE SCRATCH ARRAYS THAT WILL BE USED FOR TEMPORARY STORAGE.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

LABELED COMMON /BLCKP/ CONTAINS THE FOLLOWING DATA ASSOCIATED WITH POINT I:

GPI = GROUND POINT NAME
NI = NUMBER OF INTERVISIBLE GROUND POINTS
XYZI = POSITION IN CARTESIAN GEOCENTRIC COORDINATES
SXYZI = STANDARD DEVIATIONS OF CARTESIAN COORDINATES
PLHI = POSITION IN GEODETIC COORDINATES
SPLHI = STANDARD DEVIATIONS OF GEODETIC COORDINATES
DPDXI = PARTIALS OF GEODETIC WITH RESPECT TO CARTESIAN
RAEI = INTER-POINT PARAMETERS FOR UP TO 12 INTERVISIBLE POINTS

COMMON/BLCKP/GPI,NI,XYZI(3),SXYZI(3),PLHI(3),SPLHI(3),DPDXI(3,3),
* RAEI(7,12)

LABELED COMMON /BLCKF/ CONTAINS AN EQUIVALENT SET OF DATA ASSOCIATED WITH POINT J:

COMMON/BLCKF/GPJ,NJ,XYZJ(3),SXYZJ(3),PLHJ(3),SPLHJ(3),DPDXJ(3,3),
* RAEJ(7,12)
DIMENSION TCOV(21),RAEB(4),SRAEB(4),DRDP(4,6),DRDX(4,6)

GET VECTOR (RAEB) OF DISTANCE, AZIMUTH, ELEVATION DIFFERENCE, AND BACK AZIMUTH FROM POINT I TO POINT J AND VECTOR (SRAEB) OF THEIR STANDARD DEVIATIONS. DRDX IS THE 4 BY 6 MATRIX OF PARTIALS WITH RESPECT TO THE TWO SETS OF CARTESIAN COORDINATES.

CALL GEOINV(PLHI,PLHJ,RAEB,DRDP)
CALL AXB(DRDP(1,1),DPDXI,DRDX(1,1),4,3,3)
CALL AXB(DRDP(1,4),DPDXJ,DRDX(1,4),4,3,3)
CALL SDPROP(TCOV,DRDX,4,6,SRAEB)

```

C   ENTER DATA IN COLUMN NI OF RAEI.
C
   RAEI(1,NI) = GPJ
   DO 20 K = 1, 3
   RAEI(K+1,NI) = RAEB(K)
20  RAEI(K+4,NI) = SRAEB(K)
C
C   REPLACE AZIMUTH BY BACK AZIMUTH AND CHANGE SIGN OF ELEVATION DIFF.

   RAEB(2) = RAEB(4)
   SRAEB(2) = SRAEB(4)
   RAEB(3) = - RAEB(3)
C
C   ENTER DATA IN COLUMN NJ OF RAEJ.
C
   RAEJ(1,NJ) = GPI
   DO 40 K = 1, 3
   RAEJ(K+1,NJ) = RAEB(K)
40  RAEJ(K+4,NJ) = SRAEB(K)
   RETURN
   END

```

```

SUBROUTINE SDPROP(TOLD,DNDO,N,M,SDNEW)
C
C
C THIS SUBROUTINE COMPUTES THE VECTOR (SDNEW) OF STANDARD DEVIATIONS
C OF N NEW PARAMETERS FROM THE UPPER TRIANGLE OF THE COVARIANCE
C MATRIX (TOLD) OF M OLD PARAMETERS AND THE N BY M MATRIX (DNDO) OF
C PARTIAL DERIVATIVES OF NEW WITH RESPECT TO OLD.
C
C
C IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C DIMENSION TOLD(1),DNDO(N,M),SDNEW(N)
C
C LOOP TO COMPUTE N STANDARD DEVIATIONS.
C
C DO 80 I = 1, N
C SDNEW(I) = 0.D0
C
C LOOP TO COMPUTE SDNEW(I) = SUM(DNDO(I,J)*P(J,I)! FOR J = 1 THRU M
C WHERE P = TOLD*DNDO' IS COMPUTED AN ELEMENT AT A TIME IN X.
C
C DO 60 J = 1, M
C L = J - M
C NC = M
C X = 0.D0
C
C LOOP TO COMPUTE X = SUM(TOLD(J,K)*DNDO(I,K)! FOR K = 1 THRU M
C
C DO 20 K = 1, J
C L = L + NC
C NC = NC - 1
C 20 X = X + TOLD(L)*DNDO(I,K)
C IF(J .EQ. M) GO TO 60
C DO 40 K = J+1, M
C L = L + 1
C 40 X = X + TOLD(L)*DNDO(I,K)
C
C 60 SDNEW(I) = SDNEW(I) + DNDO(I,J)*X
C
C 80 SDNEW(I) = DSQRT(SDNEW(I))
C RETURN
C END

```

SUBROUTINE SOLV(T,NCT,NR)

THIS SUBROUTINE OBTAINS THE SOLUTION OF THE MATRIX EQUATION $A \times X = Y$, WHERE A IS SYMMETRIC AND ONLY THE UPPER TRIANGLE IS STORED, AFTER TRANSFORMATION TO $U \times X = Z$ BY SUBROUTINE ELIM. THE DIAGONAL MATRIX E, THE ABOVE-DIAGONAL ELEMENTS OF U, AND THE VECTOR Z ARE ASSUMED TO BE PACKED IN THE ONE-DIMENSIONAL ARRAY T EXACTLY AS OUTPUT FROM SUBROUTINE ELIM, I.E.,

T = E(1,1),U(1,2), - - - U(1,N),Z(1),
E(2,2), - - - U(2,N),Z(2),
- - - -
E(N,N),Z(N)

THE ELEMENTS OF Z WILL BE REPLACED BY THE ELEMENTS OF X, BUT THE OTHER ELEMENTS OF T WILL BE UNCHANGED.

NCT IS THE NUMBER OF ELEMENTS IN THE FIRST ROW OF T. NR IS THE NUMBER OF ROWS TO BE SOLVED. IF $NR = N = NCT - 1$, ALL ROWS WILL BE SOLVED. A VALUE OF $NR < N$ ASSUMES THAT ROWS $NR + 1$ THRU N HAVE ALREADY BEEN SOLVED BY A PREVIOUS CALL TO THIS ROUTINE.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION T(1)

SET INITIAL VALUES.

N = NCT - 1
LR = NCT - 2
IF(LR .GT. NR) LR = NR
LST = NCT*(NCT+1)/2
IJ = NCT*LR - LR*(LR-1)/2 + 2

LOOP TO SOLVE LR ROWS (IN REVERSE ORDER). SET UP POINTERS.

DO 40 I = LR, 1, -1
IJ = IJ - 2
IZ = IJ
JX = LST

LOOP TO COMPUTE $X(I) = Z(I) - \text{SUM}(U(I,J) \times X(J))$, J = I+1 THRU N

DO 20 J = N, I+1, -1
IJ = IJ - 1
JX = JX - NCT + J
20 T(IZ) = T(IZ) - T(IJ)*T(JX)

40 CONTINUE
RETURN
END

SUBROUTINE SOLVE(INDX,RNE,RGE)

THIS SUBROUTINE SOLVES THE FORWARD REDUCED NORMAL EQUATIONS AND MANAGES THE UP-DATING ALL PHOTO AND GROUND POINT DATA RECORDS.

INDX IS AN INDEX VECTOR WHICH PROVIDES THE LENGTH OF FORWARD-REDUCED NORMAL EQUATION RECORDS WRITTEN TO UNIT 9 BY SUBROUTINE ELIM. RNE IS A ONE-DIMENSIONAL TRIANGULAR ARRAY USED TO HOLD THE RESIDENT NORMAL EQUATIONS, AND RGE IS A SUB-SET OF RNE USED TO HOLD THE GROUND POINT PORTION OF THE RESIDENT NORMAL EQUATIONS.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

LABELLED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS USED IN THIS SUBROUTINE:

NGP = TOTAL NUMBER OF GROUND POINTS
NFR = TOTAL NUMBER OF FRAMES OF PHOTOGRAPHY
NRG = NUMBER OF RESIDENT GROUND POINTS
NCF = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RNE
NCG = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RGE
LFR = LENGTH OF (FRAME PARAMETER ONLY) NORMAL EQUATION RECORDS

COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS,LFR
DIMENSION INDX(1),RNE(1),RGE(1)

COMPUTE CONSTANTS.

KR = 2*NCF + 1
KRSQ = KR**2

SOLVE FORWARD REDUCED GROUND POINT NORMAL EQUATIONS PRESENTLY RESIDING IN RGE AND UP-DATE CORRESPONDING GROUND POINT DATA RECORDS.

CALL SOLV(RGE,NCG,NCG-1)

NGREC = NGP + 1
DO 20 NG = NRG, 1, -1
NGREC = NGREC - 1

20 CALL UPD8G(NGREC,NG,RGE)

LOOP TO READ AND SOLVE FORWARD REDUCED NORMAL EQUATIONS WRITTEN TO PERIPHERAL STORAGE BY SUBROUTINE FORWD. DETERMINE RECORD LENGTH (LR) AND TAKE APPROPRIATE ACTION.

DO 80 NFREC = NFR, 1, -1
NRT = 6
LR = BITS(INDX(NFREC+1),19,18)
IF(LR .EQ. LFR) GO TO 40

```

C   RECORD CONTAINS GROUND POINT EQUATIONS.  DETERMINE TOTAL NUMBER OF
C   ROWS (NRT) AND NUMBER OF GROUND POINT ROWS (NGR) AND MAKE SPACE
C   AVAILABLE FOR THIS RECORD.  NRT IS OBTAINED BY SOLVING THE
C   QUADRATIC EQUATION:  LR = KR*NRT - NRT**2.
C
      NRT = (KR - SQRT(KRSQ - 4*LR))/2
      NGR = NRT - 6
      CALL MUVDN(RGE, NCG, NGR)
C   READ RECORD, SOLVE NEW ROWS, AND UP-DATE PHOTO DATA RECORD.
C
40  CALL READMS(9, RNE, LR, NFREC)
      CALL SOLV(RNE, NCF, NRT)
      CALL UPD8F(NFREC, RNE, NCF)
      IF(NRT .EQ. 6) GO TO 80
C
C   UP-DATE GROUND POINT DATA RECORD(S).
C
      NP = NGR/3
      DO 60  NG = NP, 1, -1
      NGREC = NGREC - 1
60  CALL UPD8G(NGREC, NG, RGE)
80  CONTINUE
      RETURN
      END

```

SUBROUTINE SPCOV(T,NCT,NR)

THIS SUBROUTINE OBTAINS THE SPARSE COVARIANCE MATRIX (SPARSE INVERSE SCALED BY VARIANCE-OF-UNIT-WEIGHT) ASSOCIATED WITH THE SOLUTION OF $A \cdot X = Y$, WHERE A IS SYMMETRIC AND ONLY THE UPPER TRIANGLE IS STORED, AFTER FACTORIZATION INTO $A = U' \cdot D \cdot U$ BY SUBROUTINE ELIM. THE DIAGONAL MATRIX E (D-INVERSE), THE ABOVE-DIAGONAL ELEMENTS OF U (WHICH IS UNIT-UPPER-TRIANGULAR), THE VECTOR W, AND THE VARIANCE-OF-UNIT-WEIGHT VV ARE ASSUMED TO BE PACKED IN THE ONE-DIMENSIONAL ARRAY T AS FOLLOWS:

```

T = E(1,1),U(1,2), - - - U(1,N),W(1),
      E(2,2), - - - U(2,N),W(2),
      -           -
      E(N,N),W(N),
      VV

```

THE ELEMENTS OF E AND U WILL BE REPLACED BY THE CORRESPONDING ELEMENTS OF THE COVARIANCE MATRIX C, EXCEPT THAT ELEMENTS OF U HAVING A VALUE OF ZERO WILL REMAIN ZERO. W WILL BE USED FOR TEMPORARY STORAGE. THEREFORE, THE SOLUTION VECTOR MUST BE EXTRACTED FROM T BEFORE THIS ROUTINE IS CALLED||| THE SUM-OF-SQUARES OF RESIDUALS MUST ALSO BE TRANSFORMED INTO VV BY DIVIDING BY DEGREES-OF-FREEDOM, BUT T WILL OTHERWISE BE AS OUTPUT FROM SUBROUTINE ELIM.

NCT IS THE NUMBER OF ELEMENTS IN THE FIRST ROW OF T. NR IS THE NUMBER OF COVARIANCE TO BE COMPUTED. IF $NR = N = NCT - 1$, ALL ROWS WILL BE COMPUTED. A VALUE OF $NR < N$ ASSUMES THAT ROWS $NR + 1$ THRU N HAVE ALREADY BEEN TRANSFORMED TO COVARIANCE ELEMENTS BY A PREVIOUS CALL TO THIS ROUTINE.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
 DIMENSION T(1)

SET POINTERS, SPACERS, ETC.

```

N = NCT - 1
M = NCT + 1
LVV = NCT * M / 2
IF(NR .EQ. N) THEN

```

ALL ROWS ARE TO BE COMPUTED. COMPUTE ROW N AND SET LR TO N-1.

```

II = LVV - 2
T(II) = T(II) * T(LVV)
LR = N - 1

```

NR IS LESS THAN N. SET LR TO NR.

```

ELSE
LR = NR
II = NCT*LR - LR*(LR-1)/2 + 1
END IF

C
C LOOP TO COMPUTE FIRST LR ROWS OF C IN REVERSE ORDER. MULTIPLICA-
C TION BY VV IS ACOMPLISHED BY MULTIPLYING ONLY THE DIAGONAL
C ELEMENTS.

C
DO 100 I = LR, 1, -1
JW = II - 1
II = II - M + I
T(II) = T(II)*T(LVV)
IJ = II

C
C LOOP TO COMPUTE C(I,J) AND SUBTRACT U(I,J)*C(I,J) FROM E(I,I).
C U(I,J) IS SAVED IN W(J).
C
DO 80 J = I+1, N
IJ = IJ + 1
JW = JW + M - J
T(JW) = T(IJ)
IF(T(IJ) .EQ. 0.D0) GO TO 80

C
C U(I,J) IS NONZERO. COMPUTE C(I,J) = SUM U(I,K)*C(K,J)!, K = I+1
C THRU N.
C
T(IJ) = 0.D0
KJ = IJ
DO 20 K = I+1, J
KJ = KJ + M - K
IK = KJ + NCT - J
20 T(IJ) = T(IJ) - T(IK)*T(KJ)
IF(J .EQ. N) GO TO 60
IK = IJ
DO 40 K = J+1, N
IK = IK + 1
KJ = KJ + 1
40 T(IJ) = T(IJ) - T(IK)*T(KJ)

C
60 T(II) = T(II) - T(JW)*T(IJ)
80 CONTINUE

C
100 CONTINUE
RETURN
END

```

SUBROUTINE UPD8F(NF,RNE,NCF)

C
C
C THIS SUBROUTINE EXTRACTS THE VECTOR OF CORRECTIONS TO THE PARA-
C METERS OF A FRAME FROM THE SOLVED RESIDENT NORMAL EQUATIONS AND
C UP-DATES THE PARTICULAR FRAME DATA RECORD. NF IS THE NUMBER OF
C THE PHOTO DATA RECORD. RNE IS A TRIANGULAR ARRAY CONTAINING
C THE RESIDENT NORMAL EQUATIONS AND NCF IS THE NUMBER OF ELEMENTS IN
C THE FIRST ROW OF RNE.

C
C
C IMPLICIT DOUBLE PRECISION (A-H,O-Z)

C
C Labeled COMMON /BLCKF/ PROVIDES A BUFFER AREA FOR READING FRAME
C DATA RECORDS WHICH INCLUDE:

C FRID = FRAME NAME

C FXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)

C ABCD = CURRENT ESTIMATE OF RODRIGUES ORIENTATION PARAMETERS

C RMAT = CURRENT ORIENTATION MATRIX

C
C COMMON/BLCKF/FRID,NI,FXYZ(3),ABCD(4),RMAT(3,3)
C DIMENSION RNE(1),X(3)

C
C READ PHOTO DATA RECORD AND COPY CURRENT VALUES OF ORIENTATION
C PARAMETERS TO VECTOR X.

C CALL READRA(8,NF,FRID)

C DO 20 I = 1, 3

C X(I) = ABCD(I)

C 20 ABCD(I) = 0.D0

C
C UP-DATE POSITION AND COPY ORIENTATION PARAMETER CORRECTIONS INTO
C ABCD.

C L = 0

C NC = NCF

C DO 40 I = 1, 6

C L = L + NC

C NC = NC - 1

C 40 FXYZ(I) = FXYZ(I) + RNE(L)

C
C UP-DATE ORIENTATION PARAMETERS (PRESENTLY STORED IN X).

C DO 80 I = 1, 3

C RMAT(I,I) = RMAT(I,I) + ABCD(4)

C R = 0.D0

C DO 60 J = 1, 3

C 60 R = R + RMAT(J,I)*ABCD(J)

C 80 X(I) = X(I) + 0.25D0*R

C
C UP-DATE ORIENTATION MATRIX. COMPUTE SCALE FACTOR AND DIAGONAL
C ELEMENTS.

```

DO 100 I = 1, 3
ABCD(I) = X(I)
100 X(I) = X(I)**2
ABCD(4) = 1.D0 + X(1) + X(2) + X(3)
RMAT(1,1) = 1.D0 + X(1) - X(2) - X(3)
RMAT(2,2) = 1.D0 - X(1) + X(2) - X(3)
RMAT(3,3) = 1.D0 - X(1) - X(2) + X(3)

```

```

C
C COMPUTE OFF-DIAGONAL ELEMENTS.
C

```

```

DO 120 I = 1, 3
120 X(I) = ABCD(I) + ABCD(I)
R = ABCD(1)*X(2)
RMAT(2,1) = R - X(3)
RMAT(1,2) = R + X(3)
R = ABCD(1)*X(3)
RMAT(3,1) = R + X(2)
RMAT(1,3) = R - X(2)
R = ABCD(2)*X(3)
RMAT(3,2) = R - X(1)
RMAT(2,3) = R + X(1)

```

```

C
C WRITE UP-DATED PHOTO DATA RECORD BACK TO PERIPHERAL STORAGE.
C
CALL WRITRA(8,NF,FRID)
RETURN
END

```

```

SUBROUTINE UPD8G(NGREC,NG,RGE)
C
C
C THIS SUBROUTINE EXTRACTS THE VECTOR OF CORRECTIONS TO THE POSITION
C OF A SINGLE GROUND POINT FROM THE SOLVED RESIDENT NORMAL EQUATIONS
C AND UP-DATES THE GROUND POINT DATA RECORD.
C
C NGREC IS THE GROUND POINT DATA RECORD NUMBER AND NG IS THE RESI-
C DENT GROUND POINT SEQUENCE NUMBER. RGE IS A TRIANGULAR ARRAY
C CONTAINING THE GROUND POINT PORTION OF THE RESIDENT NORMAL
C EQUATIONS.
C
C
C IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C LABELED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS USED IN
C THIS SUBROUTINE:
C   NCG = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RGE
C   LSS = NUMBER OF ELEMENTS IN ARRAY RGE
C
C COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS
C
C LABELED COMMON /BLCKG/ PROVIDES A BUFFER AREA FOR READING GROUND
C POINT DATA RECORDS WHICH INCLUDE:
C   GPID = GROUND POINT NAME
C   GXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)
C   COR  = CUMULATIVE CORRECTIONS TO INITIAL POSITION
C
C COMMON/BLCKG/GPID,IW,NFL,GXYZ(3),COR(3)
C DIMENSION RGE(1)
C
C SET UP POINTERS AND READ GROUND POINT DATA RECORD.
C
C   NC = NCG - 3*(NG-1)
C   L  = LSS - NC*(NC+1)/2
C   CALL READRA(7,NGREC,GPID)
C
C ADD CORRECTIONS TO BOTH POSITION VECTOR (GXYZ) AND VECTOR OF
C CUMULATIVE CORRECTIONS (COR).
C
C   DO 20 I = 1, 3
C     L = L + NC
C     NC = NC - 1
C     GXYZ(I) = GXYZ(I) + RGE(L)
20 COR(I) = COR(I) + RGE(L)
C
C WRITE UP-DATED GROUND POINT DATA RECORD BACK TO PERIPHERAL STORAGE
C
C CALL WRITRA(7,NGREC,GPID)
C RETURN
C END

```

SUBROUTINE WEIGHT(RGE,NP)

THIS SUBROUTINE IS USED TO WEIGHT THE A PRIORI ESTIMATE OF A GROUND POINT POSITION BY INSERTING A WEIGHT MATRIX AND A SUPPLEMENTAL DISCREPANCY VECTOR IN THE RESIDENT NORMAL EQUATIONS. THE SUM-OF-SQUARES OF RESIDUALS IS ALSO MODIFIED TO ACCOUNT FOR THIS WEIGHTING. THIS SUBROUTINE MUST BE CALLED BEFORE ANY OBSERVATIONS OF THE GROUND POINT HAVE BEEN PROCESSED|||

RGE IS A ONE-DIMENSIONAL TRIANGULAR ARRAY CONTAINING THE GROUND POINT PORTION OF THE RESIDENT NORMAL EQUATIONS AND NP IS THE RESIDENT GROUND POINT SEQUENCE NUMBER OF THE POINT TO BE WEIGHTED.

IMPLICIT DOUBLE PRECISION %A-H,O-Z<

LABELED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS USED IN THIS SUBROUTINE:

NCG = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RGE
LSS = NUMBER OF ELEMENTS IN ARRAY RGE

COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS

LABELED COMMON /BLCKG/ CONTAINS THE GROUND POINT DATA RECORD WHICH INCLUDES THE FOLLOWING DATA USED BY THIS SUBROUTINE:

COR = CUMULATIVE CORRECTIONS TO INITIAL POSITION
WT = UPPER TRIANGLE OF WEIGHT MATRIX

COMMON/BLCKG/GPID,IW,NFL,GXYZ(3),COR(3),WT(6)
DIMENSION RGE(LSS),X(3)

SET UP POINTERS AND INITIALIZE TO COMPUTE $X = WT * COR$

NC = NCG - 3*(NP - 1)
LG = LSS - NC*(NC+1)/2
NC = NC - 3
LW = 0

DO 20 I = 1, 3
20 X(I) = 0.D0

LOOP TO MODIFY THREE ROWS OF RGE.

DO 60 I = 1, 3

LOOP TO INSERT ROW I OF WT AND COMPUTE X(I)

```

C
DO 40 J = I, 3
  LW = LW + 1
  LG = LG + 1
  RGE(LG) = WT(LW)
  IF(J .EQ. I) GO TO 40
  X(I) = X(I) + WT(LW)*COR(J)
40 X(J) = X(J) + WT(LW)*COR(I)
C
C   INSERT -X(I) INTO CONSTANT TERM VECTOR AND MODIFY SUM-OF-SQUARES
C
  LG = LG + NC
  RGE(LG) = -X(I)
60 RGE(LSS) = RGE(LSS) + COR(I)*X(I)

RETURN
END

```

```

SUBROUTINE XYZPLH(XYZ,PLH,KP,DPDX)
C
C
C THIS SUBROUTINE COMPUTES GEODETIC COORDINATES--LATITUDE, LONGI-
C TUDE, AND HEIGHT ABOVE ELLIPSOID--OF A POINT WHOSE GEOCENTRIC
C CARTESIAN COORDINATES ARE GIVEN. THE MATRIX OF PARTIAL DERIVA-
C TIVES OF GEODETIC WITH RESPECT TO CARTESIAN WILL ALSO BE OBTAINED,
C IF DESIRED. THE REFERENCE ELLIPSOID IS CLARKE 1866, BUT ANOTHER
C CAN BE SUBSTITUTED BY MODIFYING THE PARAMETERS IN LABELED COMMON.
C
C XYZ IS A VECTOR OF CARTESIAN COORDINATES IN METERS AND PLH IS THE
C VECTOR OF GEODETIC COORDINATES IN RADIANS, RADIANS, AND METERS.
C IF KP IS UNEQUAL TO ZERO, THE MATRIX DPDX OF PARTIAL DERIVATIVES
C WILL BE COMPUTED. IF KP = 0, PARTIALS WILL NOT BE COMPUTED AND
C DPDX NEED NOT BE INCLUDED IN THE CALL STATEMENT.
C
C
C IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C LABELED COMMON /CONST/ SUPPLIES THE SEMI-MAJOR AXIS (A) AND THE
C SQUARE OF THE ECCENTRICITY (ESQ) OF THE REFERENCE ELLIPSOID.
C
COMMON/CONST/A,ESQ
DIMENSION XYZ(3),PLH(3),DPDX(3,3)
DATA A,ESQ/6378206.4D0,0.6768657997D-2/
C
C COMPUTE GEODETIC COORDINATES.
C
X = XYZ(1)
Y = XYZ(2)
Z = XYZ(3)
RSQ = X*X + Y*Y
H = ESQ*Z
DO 20 I = 1, 6
ZP = Z + H
R = DSQRT(RSQ + ZP*ZP)
SP = ZP/R
GSQ = 1.0 - ESQ*SP*SP
EN = A/DSQRT(GSQ)
P = EN*ESQ*SP
IF(ABS(H-P) .LT. 0.0005) GO TO 40
20 H = P
40 P = DATAN(ZP/DSQRT(RSQ))
H = R - EN
PLH(1) = P
PLH(2) = DATAN2(Y,X)
PLH(3) = H
IF(KP .EQ. 0) RETURN
C
C KP IS UNEQUAL TO ZERO. COMPUTE MATRIX OF PARTIALS.

```

```

RSQ = 1.0/RSQ
DPDX(2,1) = -Y*RSQ
DPDX(2,2) = X*RSQ
DPDX(2,3) = 0.0
RSQ = DSQRT(RSQ)
CP = DSQRT(1.0 - SP*SP)
SL = Y*RSQ
CL = X*RSQ
DPDX(3,1) = CP*CL
DPDX(3,2) = CP*SL
DPDX(3,3) = SP
EN = (EN - ESQ*EN)/GSQ + H
EN = 1.0/EN
DPDX(1,3) = EN*CP
EN = EN*SP
DPDX(1,1) = -EN*CL
DPDX(1,2) = -EN*SL

```

C

```

RETURN
END

```

```
SUBROUTINE ZEROT(T,NC,NR)
```

```
C
```

```
THIS SUBROUTINE ZEROS NR ROWS OF THE TRIANGULAR ARRAY T WHICH HAS  
NC ELEMENTS IN ITS FIRST ROW.
```

```
IMPLICIT DOUBLE PRECISION (A-H,O-Z)  
DIMENSION T(1)
```

```
C
```

```
N = NC*NR - (NR*(NR-1))/2
```

```
DO 20 I = 1, N
```

```
20 T(I) = 0.D0
```

```
RETURN
```

```
END
```

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