NOAA Technical Report NOS 91 NGS 21

Results of Photogrammetric Control Densification in Ada County, Idaho

Rockville, Md.
December 1981

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Geodetic Survey

NOAA Technical Publications

National Ocean Survey/National Geodetic Survey subseries

The National Geodetic Survey (NGS) of the National Ocean Survey (NOS), NOAA, establishes and maintains the basic National horizontal and vertical networks of geodetic control and provides governmentwide leadership in the improvement of geodetic surveying methods and instrumentation, coordinates operations to assure network development, and provides specifications and criteria for survey operations by Federal, State, and other agencies.

NGS engages in research and development for the improvement of knowledge of the figure of the Earth and its gravity field, and has the responsibility to procure geodetic data from all sources, process these data, and make them generally available to users through a central data base.

NOAA geodetic publications, in paper form, as well as relevant geodetic publications of the former U.S. Coast and Geodetic Survey are sold by the National Geodetic Information Center. A partial listing appears on this inside cover. The stated price includes postage and handling. Check or money order should be made payable to: NOAA/National Geodetic Survey.

To order publications by mail or to obtain a complete list of available publications contact:

National Geodetic Information Center, OA/C18x2
National Ocean Survey, NOAA
Rockville, MD 20852

(301) 443-8316

Publications can also be purchased over the counter at the National Geodetic Information Center, 11400 Rockville Pike, room 14, Rockville, Md. (Do not send correspondence to this address.)

An excellent reference source for Government publications is the National Depository Library program, a network of about 1,300 designated libraries. Requests for borrowing Depository Library material may be made through your local library. A free listing of libraries currently in this system is available from the Library Division, U.S. Government Printing Office, 5236 Eisenhower Ave., Alexandria, VA 22304 (telephone: 703-557-9013).

NOAA geodetic publications

NOAA Technical Memorandums, NOS/NGS subseries

NOS NGS-1 Leffler, R. J., Use of climatological and meteorological data in the planning and execution of National Geodetic Survey field operations, 1975, 30 pp. $2.90
NOS NGS-2 Spencer, J. F., Jr., Final report on responses to geodetic data questionnaire, 1976, 39 pp. $3.15
NOS NGS-3 Whiting, M. C., and Pope, A. J., Adjustment of geodetic field data using a sequential method, 1976, 11 pp. $2.30
NOS NGS-4 Snay, R. A., Reducing the profile of sparse symmetric matrices, 1976, 24 pp. $2.70
NOS NGS-5 Dracup, J. F., National Geodetic Survey data: availability, explanation, and application, revised 1979, 45 pp. $3.40
NOS NGS-6 Vincenty, T., Determination of North American Datum 1983 coordinates of map corners, 1976, 8 pp. $2.20
NOS NGS-7 Holdahl, S. R., Recent elevation change in Southern California, 1977, 19 pp. $2.60
NOS NGS-8 Dracup, J. F., Fronczek, C. J., and Tomlinson, R. W., Establishment of calibration base lines, 1977, 22 pp. $2.70
NOS NGS-9 NGS staff, National Geodetic Survey publications on surveying and geodesy 1976, 1977, 17 pp. $2.60
NOS NGS-10 Fronczek, C. J., Use of calibration base lines, 1977, 38 pp. $3.15
NOS NGS-11 Snay, R. A., Applicability of array algebra, 1978, 22 pp. $2.70
NOS NGS-12 Schwarz, C. R., The TRAV-10 horizontal network adjustment program, 1978, 52 pp. $3.50
NOS NGS-13 Vincenty, T. and Bowring, B. R., Application of three-dimensional geodesy to adjustments of horizontal networks, 1978, 7 pp. $2.20
NOS NGS-14 Snay, R. A., Solvability analysis of geodetic networks using logical geometry, 1978, 29 pp. $2.90
NOS NGS-15 Carter, W. E. and Pettey, J. E., Goldstone validation survey - phase 1, 1978, 44 pp. $3.25
NOS NGS-16 Vincenty, T., Determination of North American Datum 1983 coordinates of map corners (second prediction), 1979, 6 pp. $2.20

(Continued at end of publication)

NOAA Technical Report NOS 91 NGS 21

Results of Photogrammetric Control Densification in Ada County, Idaho

James R. Lucas

National Geodetic Survey
Rockville, Md.
December 1981

U. S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
John V. Byrne, Administrator

National Ocean Survey
H. R. Lippold, Jr., Director

CONTENTS

RESULTS OF PHOTOGRAMMETRIC CONTROL DENSIFICATION IN ADA COUNTY, IDAHO

James R. Lucas
National Geodetic Survey
National Ocean Survey, NOAA
Rockville, Md. 20852

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.

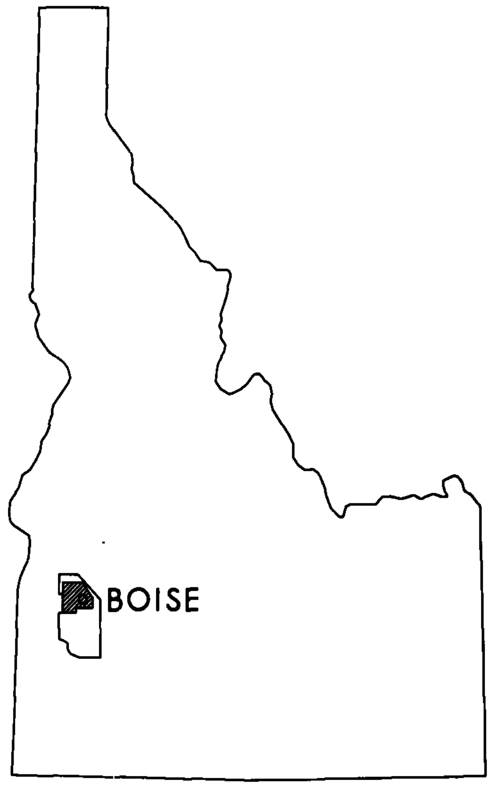

Figure 1.--Project location in northern Ada County, Idaho.

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.

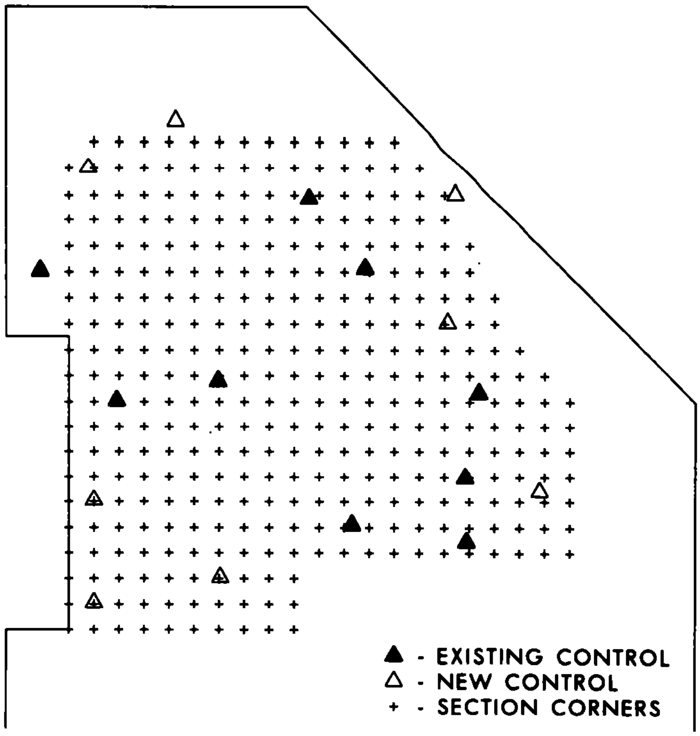

Figure 2.--Geodetic control in project area.

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

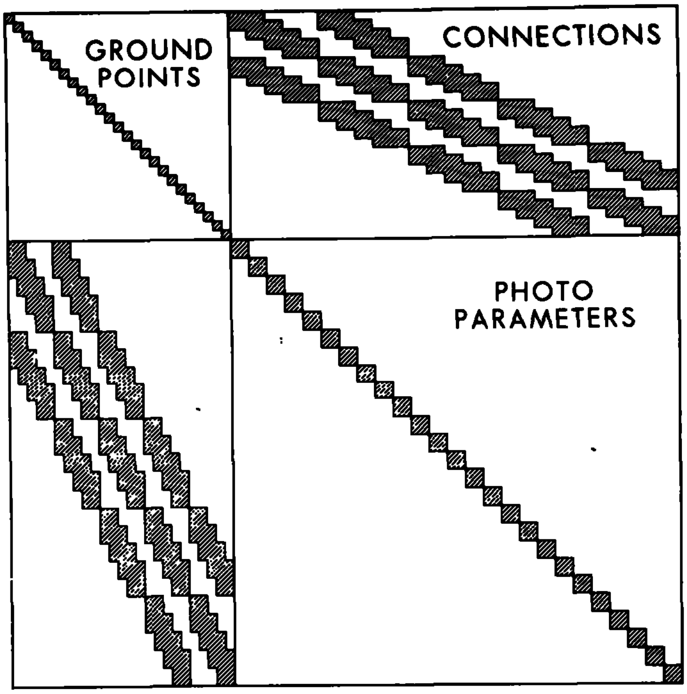

Figure 3.--Structure of photogrammetric equations.

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

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

and

$$K = A^{-1} + A^{-1} BMB^T A^{-1} \tag{2}$$

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

$$M = \hat{C}^{-1} = (C - \Sigma\, B_i^T A_i^{-1} B_i)^{-1} \tag{3}$$

and

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

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.

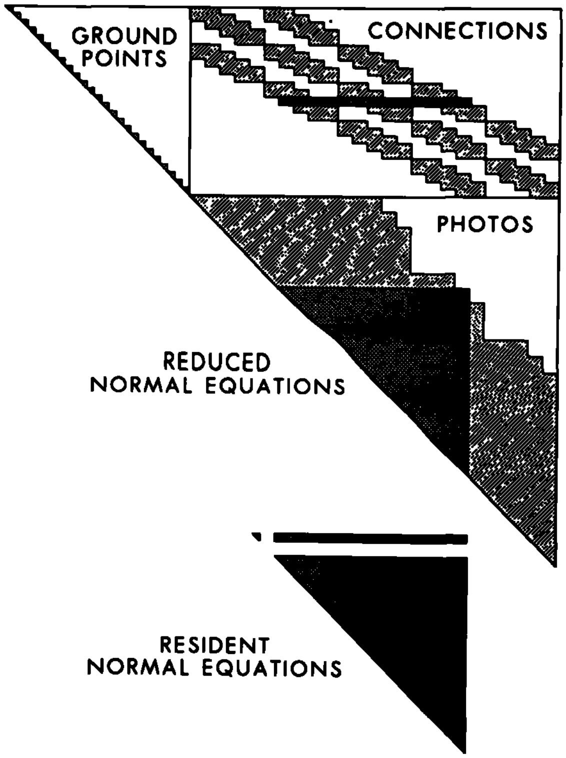

Figure 4.--Reduced normal equations produced by conventional adjustment method.

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.

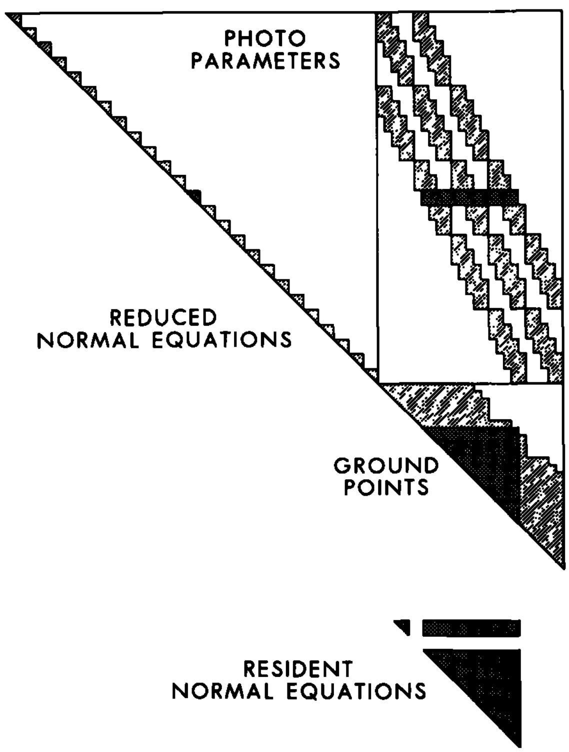

Figure 5.--Reduced normal equations produced by densification method.

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.

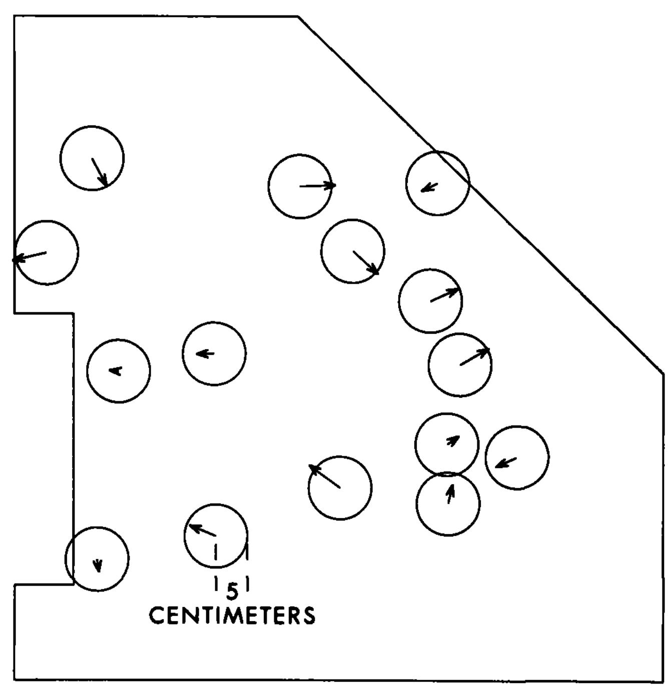

Figure 6.--Shifts of geodetic control induced by relaxed weighting factors.

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.

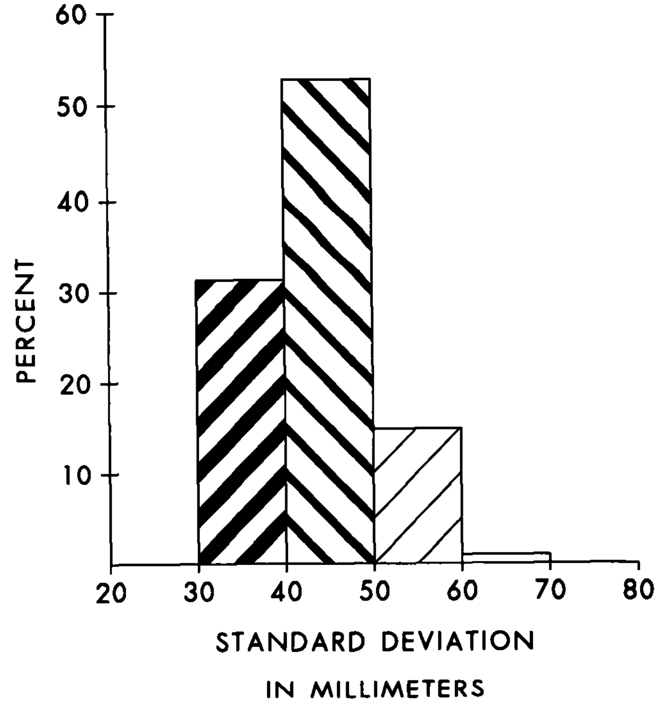

Figure 7.--Estimated precision of computed distances between section corners.

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.

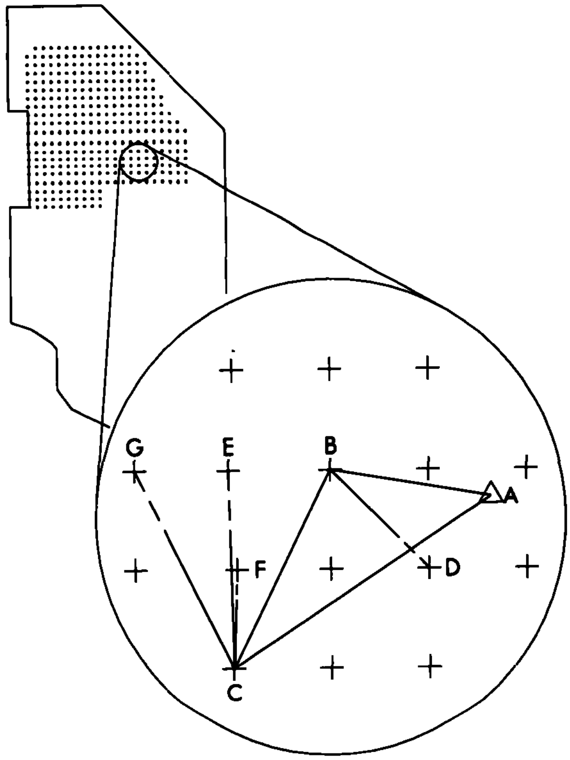

Figure 8.--Location and configuration of field check survey.

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

Line	Distance Photo (m)	Geodetic (m)	Difference (m)	Azimuth 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.

REFERENCES

Brown, D. C., 1977: Densification of urban geodetic nets. Photogrammetric Engineering and Remote Sensing, 43, 447-467.

Brown, D. C. 1958: A solution to the general problem of multiple station stereotriangulation. Air Force Missile Test Center Technical Report 58-8, Patrick Air Force Base, Florida.

National Research Council, 1980: Need for a Multipurpose Cadastre. National Academy Press, Washington, D.C., 122 pp.

Slama, C. C., 1978: High precision analytical photogrammetry using a special reseau geodetic lens cone. Proceedings of ISP Commission III International Symposium, July 31-August 5, Moscow, U.S.S.R. International Society of Photogrammetry.

APPENDIX.--DOCUMENTATION

```
C     PROGRAM DENCIPHI
C
C
C     PROGRAM DENCIPHI PERFORMS A PHOTOGRAMMETRIC CONTROL DENSIFICATION
C     ADJUSTMENT WHICH PRODUCES THE ADJUSTED POSITIONS OF ALL DENSIFICA-
C     TION POINTS, IN CARTESIAN GEOCENTRIC AND GEODETIC COORDINATES, AND
C     THE DISTANCE, AZIMUTH AND ELEVATION DIFFERENCE BETWEEN ALL PAIRS
C     OF INTERVISIBLE POINTS.  STANDARD ERRORS FOR ALL OF THESE DATA ARE
C     ALSO PROVIDED.  THE ADJUSTMENT METHOD DIFFERS FROM A CONVENTIONAL
C     BUNDLE ADJUSTMENT IN THAT THE OBSERVATION DATA ARE PROCESSED BY
C     PHOTOGRAPH, RESULTING IN A BANDED MATRIX FOR THE PARTITION OF THE
C     NORMAL EQUATIONS ASSOCIATED WITH GROUND POINT COORDINATES.  THIS
C     DATA STRUCTURE IS EMPLOYED TO FACILITATE PROPAGATION OF COVARIANCE
C     TO THE INTER-POINT QUANTITIES (DISTANCES, ETC.) AND PROVIDES A
C     SIGNIFICANT SAVING IN BOTH COMPUTATION AND STORAGE.
C
C     PROGRAM DENCIPHI ASSUMES THAT PROGRAM PREDEN HAS BEEN USED TO PRE-
C     PROCESS THE OBSERVATION DATA AND CREATE A GROUND POINT DATA FILE
C     AND A FRAME DATA FILE IN RANDOM ACCESS FORMAT.  THE USER IS
C     ADVISED TO PRESERVE THE ORIGINALS OF THESE FILES AND SUPPLY COPIES
C     OF THEM TO THIS PROGRAM, BECAUSE BOTH FILES WILL BE ALTERED IN THE
C     COURSE OF THE ADJUSTMENT.
C
C     THE USER MUST SUPPLY (STANDARD INPUT UNIT) FOUR DATA RECORDS:
C        1. PROJECT TITLE (A80)
C        2. NAME OF GROUND POINT DATA FILE (A28).  THIS FILE WILL BECOME
C           RANDOM ACCESS UNIT 7.
C        3. NAME OF FRAME DATA FILE (A28). THIS FILE WILL BECOME RANDOM
C           ACCESS UNIT 8.
C        4. NAME OF FILE TO RECEIVE RESULT DATA RECORDS (A28).  THIS
C           FILE WILL BECOME RANDOM ACCESS UNIT 10.
C
C     THIS MAIN PROGRAM READS THE FOUR DATA RECORDS, ASSIGNS FILES, AND
C     ACQUIRES STORAGE FOR ARRAYS WHOSE DIMENSIONS ARE DETERMINED BY THE
C     PARAMETERS OF THE ADJUSTMENT TO BE PERFORMED.  CONTROL IS THEN
C     PASSED TO SUBROUTINE ADJUST, WHICH MANAGES ALL PHASES OF THE
C     ADJUSTMENT.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER*28 NAME
      CHARACTER*80 TITLE
C
C     PARAMETERS LGDREC (LENGTH OF GROUND POINT DATA RECORDS) AND LFDREC
C     (LENGTH OF FRAME DATA RECORDS) SHOULD AGREE IN MAGNITUDE WITH THE
C     EQUIVALENT PARAMETERS IN PROGRAM PREDEN.  ONLY THESE TWO PARA-
C     METERS NEED TO BE CHANGED IF THE RECORD LENGTH(S) ARE TO BE
C     ALTERED TO INCREASE NVMAX (THE MAXIMUM NUMBER OF INTERVISIBLE
C     GROUND POINTS) OR NIMAX (THE MAXIMUM NUMBER OF IMAGES ON A
C     PHOTOGRAPH).
C
```

```
      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,NFL,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
      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
      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
      COMMON/STATS/NOBS,NDOF,SSD,REJ,NREJ
C
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
      COMMON/APPEND/ LA,LB,LC,LD,LE,LF
      DIMENSION L(6)
      EQUIVALENCE(LA,L(1))
C
      DATA LGDR,LFDR/LGDREC,LFDREC/
      DATA AE,ESQ,PI/6378206.4D0,.6768657997D-2,3.14159265359D0/
      DATA F/153.26D0/
      TWOPI = PI + PI
      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     ASSIGN GROUND POINT DATA FILE (UNIT 7) AND OPEN FILE FOR RANDOM
C     ACCESS TO RECORDS OF LENGTH LGDR.
C
      READ 61, NAME
   61 FORMAT(A28)
      CALL ASGFIL(7,NAME,$200)
      CALL OPENRA(7,LGDR)
C
C     ASSIGN FRAME DATA FILE (UNIT 8) AND RESULT DATA FILE (UNIT 10)
C     AND OPEN BOTH FILES FOR RANDOM ACCESS TO RECORDS OF LENGTH LFDR.
C
      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     COMPUTE DIMENSIONS OF ARRAYS THAT DEPEND ON RUN PARAMETERS AND
C     ACQUIRE ADDITIONAL STORAGE FOR THESE ARRAYS.
C
      LINDX = NFR + 2
      LA = LINDX              @ NO. OF WORDS FOR INDX(NFR+2)
      LB = NRG + NRG          @ NO. OF WORDS FOR RGPN(NRG)
      LC = NRG                @ NO. OF WORDS FOR LSTF(NRG)
      LD = 8*NRG              @ NO. OF WORDS FOR GDAT(4,NRG)
      LE = LFR                @ NO. OF WORDS FOR FRAME PORTION OF RNE
      LF = LGR                @ NO. OF WORDS FOR RGE(LSS)
      CALL ALLOC8(L,6,NEW)
C
```

```
C
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)
C
C
C     THIS SUBROUTINE MANAGES THE FOUR PHASES OF THE DENSIFICATION
C     ADJUSTMENT: (1) FORMATION AND FORWARD REDUCTION OF NORMAL
C     EQUATIONS, (2) SOLUTION AND UP-DATING OF PARAMETERS, (3) COMPUTA-
C     TION OF ADDITIONAL PARAMETERS AND COVARIANCE PROPAGATION, AND
C     (4) SORTING AND PRINTING OF RESULTS.
C
C     INDX IS A VECTOR USED FOR HOLDING THE LENGTHS OF VARIABLE LENGTH
C     NORMAL EQUATION RECORDS TO BE WRITTEN TO RANDOM ACCESS UNIT 9.
C     RGPN IS A VECTOR USED FOR HOLDING THE NAMES OF THE RESIDENT GROUND
C     POINTS.  LSTF IS A VECTOR USED FOR HOLDING THE SEQUENCE NUMBER OF
C     THE LAST FRAME ON WHICH EACH OF THE RESIDENT GROUND POINTS IS
C     IMAGED.  GDAT IS AN ARRAY USED FOR HOLDING THE CARTESIAN COORDIN-
C     ATES AND ELEVATION OF EACH RESIDENT GROUND POINT.  RNE IS A ONE-
C     DIMENSIONAL TRIANGULAR ARRAY USED FOR HOLDING THE RESIDENT NORMAL
C     EQUATIONS AND RGE IS THE SUBSET OF RNE THAT CONTAINS THE GROUND
C     POINT PORTION OF THE RESIDENT NORMAL 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        NFR = TOTAL NUMBER OF FRAMES OF PHOTOGRAPHY
C        NRG = NUMBER OF RESIDENT GROUND POINTS
C        LST = NUMBER OF ELEMENTS IN ARRAY RNE
C        LGR = LENGTH OF (GROUND POINT ONLY) NORMAL EQUATION RECORDS
C
      COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS,LFR,LGR
C
C     LABELED COMMON /STATS/ CONTAINS THE FOLLOWING ITEMS USED IN THIS
C     SUBROUTINE:
C        NOBS = NUMBER OF 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
      COMMON/STATS/NOBS,NDOF,SSD,REJ,NREJ
      DIMENSION INDX(1),RGPN(NRG),LSTF(NRG),GDAT(4,NRG),RNE(1),RGE(1)
C
C     ITERATE FORMATION AND SOLUTION OF NORMAL EQUATIONS UNTIL CHANGE IN
C     RMS OF RESIDUALS IS SMALLER THAN TOLERANCE.
C
```

```
C
      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     THIS SUBROUTINE ACQUIRES A BLOCK OF ADDITIONAL CORE OF SUFFICIENT
C     SIZE TO HOLD N ARRAYS WHOSE LENGTHS (IN SINGLE PRECISION WORDS)
C     ARE PROVIDED IN THE VECTOR L.  IF STORAGE IS TO BE ACQUIRED FOR
C     ARRAYS A1, A2, --- AN, THEN THE INPUT VALUE OF L(I) WHOULD BE THE
C     LENGTH OF AI.  THE OUTPUT VALUE OF L(I) WILL BE LOCI SUCH THAT THE
C     LOCATION OF L(LOCI) IS THE LOCATION OF AI(1).  NEW IS THE LOCATION
C     OF THE FIRST WORD OF THE BLOCK AND IS USED TO RETURN THIS BLOCK TO
C     THE SYSTEM BY CALLING LCORF$(NEW).
C
      DIMENSION L(N)
C
C     DETERMINE TOTAL LENGTH OF BLOCK AND CALL MCORF$ TO ACQUIRE CORE.
C
      LNG = 0
      DO 20  I = 1, N
   20 LNG = LNG + L(I)
      NEW = MCORF$(LNG)
C
C     ENTER LOCATIONS (RELATIVE TO LOCATION OF L) INTO VECTOR L.
C
      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     THIS SUBROUTINE EXTRACTS, FROM THE TRIANGULAR COVARIANCE MATRIX
C     (RGE) OF RESIDENT GROUND POINTS. THE TRIANGULAR FORM OF THE 6 BY 6
C     COVARIANCE MATRIX ASSOCIATED WITH A PAIR OF GROUND POINTS AND
C     STORES IT IN TC.  NI AND NJ ARE THE RESIDENT GROUND POINT SEQUENCE
C     NUMBERS OF THE TWO GROUND POINTS, AND NJ MUST BE GREATER THAN NI.
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
      COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS
      DIMENSION RGE(1),TC(21)
C
C     SET POINTERS AND SPACERS.
C
      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     EXTRACT FIRST THREE ROWS.
C
      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     EXTRACT LAST THREE ROWS.
C
      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     THIS SUBROUTINE PRINTS ALL RESULTS ASSOCIATED WITH A SINGLE GROUND
C     POINT.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER*4 MET,SEC,LABC(3)
      CHARACTER*8 GPID,NAME(2),LABG(3)
C
C     LABELED COMMON /BLCKP/ CONTAINS THE FOLLOWING DATA ASSOCIATED WITH
C     THIS GROUND POINT:
C        GPID  = GROUND POINT NAME
C        NI    = NUMBER OF INTERVISIBLE GROUND POINTS
C        XYZ = POSITION IN CARTESIAN GEOCENTRIC COORDINATES
C        SXYZ = STANDARD DEVIATIONS OF CARTESIAN COORDINATES
C        PLH = POSITION IN GEODETIC COORDINATES
C        SPLH = STANDARD DEVIATIONS OF GEODETIC COORDINATES
C        RAE = INTER-POINT PARAMETERS FOR UP TO 12 INTERVISIBLE POINTS
C
      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      PRINT GROUND POINT POSITION AND STANDARD DEVIATIONS.
C
      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     PRINT DISTANCE, AZIMUTH, ELEVATION DIFFERENCE, AND STANDARD
C     DEVIATIONS FROM THIS POINT TO ALL INTERVISIBLE POINTS.
C
```

```
      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)
C
C
C     THIS SUBROUTINE PERFORMS THE FORWARD REDUCTION BY GUASSIAN ELIM-
C     INATION WHICH TRANSFORMS THE MATRIX EQUATION A*X = Y, WHERE A IS
C     SYMMETRIC AND ONLY THE UPPER TRIANGLE IS STORED, INTO THE SIMPLER
C     FORM U*X = Z, WHERE U IS UNIT-UPPER-TRIANGULAR.  THE TRIANGULAR
C     PART OF A, APPENDED BY THE VECTOR Y, MUST BE STORED IN THE ONE-
C     DIMENSIONAL ARRAY T AS FOLLOWS:
C
C         T = A(1,1),A(1,2), - - - A(1,N),Y(1),
C                    A(2,2), - - - A(2,N),Y(2),
C                                    -      -
C                                  A(N,N),Y(N),
C                                         SS
C
C     WHERE SS IS THE SUM-OF-SQUARES OF DISCREPANCIES.  NCT IS THE
C     NUMBER OF ELEMENTS IN THE FIRST ROW OF T.  NR IS THE NUMBER OF
C     ROWS TO BE REDUCED, BEGINNING WITH ROW 1.  THE ENTIRE MATRIX WILL
C     BE REDUCED IF NR = N = NCT-1.
C
C     THE TRANSFORMATION IS BASED ON THE FACTORIZATION A = U'*D*U, WHERE
C     U' IS THE TRANSPOSE OF U AND D IS A DIAGONAL MATRIX.  THE DIAGONAL
C     ELEMENTS OF A WILL BE REPLACED BY THE DIAGONAL ELEMENTS OF THE
C     INVERSE OF D, THE ABOVE-DIAGONAL ELEMENTS OF A WILL BE REPLACED BY
C     THE ABOVE-DIAGONAL ELEMENTS OF U, AND Y WILL BE REPLACED BY Z.  IN
C     ADDITION, THE QUADRATIC SUM X'*A*X WILL BE SUBTRACTED FROM SS TO
C     FORM THE SUM-OF-SQUARES OF RESIDUALS.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION T(1)
C
C     LOOP TO REDUCE NR ROWS.  SET UP POINTERS AND INVERT THE DIAGONAL
C     ELEMENT.
C
      IJ = 0
      DO 60  I = 1, NR
      II = IJ + 1
      T(II) = 1.D0/T(II)
      IJ = II
      JK = II + NCT - I
C
C     LOOP TO COMPUTE U(I,J) = A(I,J)/D(I,I) AND MODIFY ROWS I+1 THRU N.
C
      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.D0) 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
      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*NRT - NRT**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)
C
C
C     THIS SUBROUTINE MANAGES THE FORMATION AND FORWARD REDUCTION OF THE
C     PHOTOGRAMMETRIC NORMAL EQUATIONS.
C
C     RGPN IS A VECTOR USED FOR HOLDING THE NAMES OF THE RESIDENT GROUND
C     POINTS.  LSTF IS A VECTOR USED FOR HOLDING THE SEQUENCE NUMBER OF
C     THE LAST FRAME ON WHICH EACH OF THE RESIDENT GROUND POINTS IS
C     IMAGED.  GDAT IS AN ARRAY USED FOR HOLDING THE CARTESIAN COORDIN-
C     ATES AND ELEVATION OF EACH RESIDENT GROUND POINT.  RNE IS A ONE-
C     DIMENSIONAL TRIANGULAR ARRAY USED FOR HOLDING THE RESIDENT NORMAL
C     EQUATIONS AND RGE IS THE SUBSET OF RNE THAT CONTAINS THE GROUND
C     POINT PORTION OF THE RESIDENT NORMAL 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
C
C     LABELED COMMON /BLCKF/ PROVIDES A BUFFER AREA FOR READING FRAME
C     DATA RECORDS WHICH INCLUDE:
C        FRID = FRAME NAME
C        NI   = NUMBER OF IMAGES
C        DATI = UP TO 31 SETS OF GROUND POINT NAME AND IMAGE COORDINATES
C
      COMMON/BLCKF/FRID,NI,FXYZ(3),ABCD(4),RMAT(3,3),DATI(3,31)
C
C     LABELED COMMON /STATS/ CONTAINS THE FOLLOWING ITEMS USED IN THIS
C     SUBROUTINE:
C        NOBS = NUMBER OF OBSERVATION EQUATIONS PROCESSED
C        NDOF = NUMBER OF DEGREES-OF-FREEDOM
C
      COMMON/STATS/NOBS,NDOF
      DIMENSION RGPN(NRG),LSTF(NRG),GDAT(4,NRG),RNE(1),RGE(1)
C
C     INITIALIZE FOR FORMING NORMAL EQUATIONS AND FILL RESIDENT GROUND
C     POINT DATA ARRAYS.
C
      CALL ZEROT(RGE,NCG,NCG)
      NGREC = 0
      DO 20  NG = 1, NRG
      NGREC = NGREC + 1
```

```
   20 CALL READG(NGREC,NG,RGPN,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(RGPN(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
      RGPN(L) = RGPN(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,RGPN,LSTF,GDAT,RGE)
      NPL = NGP - 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
```

```
      SUBROUTINE GEOINV(PLH1,PLH2,RAEB,DRDP)
C
C
C     THIS SUBROUTINE COMPUTES THE DISTANCE, AZIMUTH, ELEVATION DIF-
C     FERENCE, AND BACK AZIMUTH FROM POINT 1 TO POINT 2, GIVEN THE
C     GEODETIC COORDINATES OF THE TWO POINTS.  ALSO COMPUTED IS THE
C     MATRIX OF PARTIAL DERIVATIVES OF THE COMPUTED QUANTITIES WITH
C     RESPECT TO THE GEODETIC POSITIONS.
C
C     PLH1 AND PLH2 ARE VECTORS OF GEODETIC COORDINATES (LATITUDE,
C     LONGITUDE, AND ELEVATION IN RADIANS, RADIANS, METERS) OF POINTS
C     1 AND 2, RESPECTIVELY.  RAEB IS THE COMPUTED VECTOR OF DISTANCE,
C     AZIMUTH, ELEVATION DIFFERENCE, AND BACK AZIMUTH.  DRDP IS THE
C     MATRIX OF PARTIAL DERIVATIVES OF RAEB WITH RESPECT TO PLH1 AND
C     PLH2.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C     LABELED COMMON /CONST/ CONTAINS THE FOLLOWING CONSTANTS USED IN
C     THIS SUBROUTINE:
C        A = SEMI-MAJOR AXIS OF ELLIPSOID
C        F = FLATTENING OF ELLIPSOID
C        PI = RADIANS IN 180 DEGREES
C        TWOPI = 2*PI
C
      COMMON/CONST/A,ESQ,F,PI,TWOPI
      DIMENSION PLH1(3),PLH2(3),RAEB(4),DRDP(4,6)
      DATA TOL/.5D-13/
C
C     COMPUTE AZIMUTH AND BACK AZIMUTH.
C
      P1 = PLH1(1)
      EL1 = PLH1(2)
      P2 = PLH2(1)
      EL2 = PLH2(2)
      R = 1.D0-F
      Q1 = DSIN(P1)
      CU1 = 1.D0/(1.D0 - Q1*Q1)
      TU1 = R*Q1*DSQRT(CU1)
      Q1 = R*CU1
      CU1 = 1.D0/(1.D0 + TU1*TU1)
      Q1 = Q1*CU1
      CU1 = DSQRT(CU1)
      SU1 = CU1*TU1
      Q2 = DSIN(P2)
      CU2 = 1.D0/(1.D0 - Q2*Q2)
      TU2 = R*Q2*DSQRT(CU2)
      Q2 = R*CU2
      CU2 = 1.D0/(1.D0 + TU2*TU2)
      Q2 = Q2*CU2
      CU2 = DSQRT(CU2)
      S = CU1*CU2
```

```
      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     COMPUTE DISTANCE.
C
      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     COMPUTE MATRIX OF PARTIAL DERIVATIVES.
C
      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 LOCATE(SEQ,NGP,NXT,DAT,NW)
C
C
C     THIS SUBROUTINE LOCATES THE RECORD IN THE RESULT FILE THAT IS
C     ASSOCIATED WITH THE GROUND POINT WHOSE NAME OCCUPIES POSITION NXT
C     IN AN ORDERED LIST OF GROUND POINT NAMES.
C
C     SEQ IS AN ORDERED LIST OF NGP GROUND POINT NAMES AND NXT IS THE
C     POSITION IN SEQ OF THE NAME OF THE GROUND POINT FOR WHICH THE
C     RESULT DATA RECORD IS TO BE LOCATED.  DAT IS A VECTOR OF LENGTH
C     EQUIVALENT TO NW DOUBLE PRECISION WORDS AND CONTAINS THE RESULT
C     RECORD CURRENTLY OCCUPYING POSITION NXT IN THE RESULT DATA FILE.
C     WHEN THE RECORD THAT SHOULD OCCUPY THIS POSITION IN THE FILE IS
C     LOCATED, IT IS RETURNED IN DAT.  ALL RECORDS ENCOUNTERED DURING
C     THE SEARCH ARE PLACED IN THEIR PROPER POSITIONS IN THE FILE SO
C     THAT THE FILE IS SORTED IN A MINIMAL NUMBER OF CALLS TO THIS
C     ROUTINE.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C     LABELED COMMON /BLCKF/ IS USED AS A BUFFER FOR READING RECORDS
C     FROM THE RESULT FILE
C
      COMMON/BLCKF/TEMP(1)
      DIMENSION SEQ(NGP),DAT(NW)
C
C     LOCATE POSITION IN THE RESULT FILE THAT THE RECORD CURRENTLY
C     RESIDING IN DAT SHOULD OCCUPY.
C
   20 TAG = DAT(1)
      DO 40  I = NXT+1, NGP
      IF(SEQ(I) .EQ. TAG) GO TO 60
   40 CONTINUE
      RETURN
C
C     THIS RECORD SHOULD OCCUPY POSITION I IN THE RESULT FILE.  EXCHANGE
C     IT WITH THE RECORD CURRENTLY OCCUPYING THAT POSITION.  IF THIS NEW
C     RECORD BELONGS IN POSITION NXT, RETURN.  OTHERWISE, CONTINUE SORT
C     UNTIL THE PROPER RECORD IS FOUND.
C
   60 CALL READRA(10,I,TEMP)
      CALL WRITRA(10,I,DAT)
      DO 80  I = 1, NW
   80 DAT(I) = TEMP(I)
      IF(DAT(1) .EQ. SEQ(NXT)) RETURN
      GO TO 20
      END
```

```
      SUBROUTINE MSORT(DAT,N,M,SEQ,NS)
C
C
C     THIS SUBROUTINE REARRANGES LABELED COLUMNS OF A MATRIX INTO
C     ASCENDING ORDER IN ACCORDANCE WITH AN ORDERED LIST OF LABELS.
C
C     DAT IS AN N BY M MATRIX SUCH THAT THE FIRST ELEMENT OF EACH COLUMN
C     IS A LABEL THAT MATCHES ONE ENTRY IN THE VECTOR SEQ WHICH IS AN
C     ORDERED LIST CONTAINING NS LABELS.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION DAT(N,M),SEQ(NS)
C
C     LOOP TO COMPARE EACH ENTRY IN SEQ WITH THE M LABELS IN DAT.
C
      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
C
C     A MATCH HAS BEEN FOUND.  INTERCHANGE COLUMN J WITH COLUMN NXT AND
C     CONTINUE WITH COMPARISONS.
C
   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
C
      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
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION T(1)
C
C     SET UP POINTERS.  N IS THE LAST ROW TO BE RETAINED.
C
      L = NCT*(NCT+1)/2
      NC = NR + 1
      M = L - NC*(NC+1)/2 + 1
      N = NCT - NC
C
C     LOOP TO MOVE N ROWS IN REVERSE ORDER.  MOVE Y(I) TO Y(I+NR).
C
      DO 20  I = N, 1, -1
      L = L - 1
      M = M - 1
      T(L) = T(M)
      M = M - NR
C
C     LOOP TO MOVE A(I,J) TO A(I+NR,J) FOR J = N,---,I.
C
      DO 20  J = N, I, -1
      L = L - 1
      M = M - 1
   20 T(L) = T(M)
      RETURN
      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 CF T.
C     THE LAST NR ROWS AND COLUMNS OF A AND LAST NR ELEMENTS OF Y WILL
C     SET TO ZERO.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION T(1)
C
C     SET UP POINTERS.  N IS THE NUMBER OF ROWS TO BE MOVED.
C
      L = 0
      M = NCT*NR - NR*(NR-1)/2
      N = NCT - NR - 1
C
C     LOOP TO MOVE N ROWS.  LOOP TO MOVE A(I+NR,J) TO A(I,J).
C
      DO 60  I = 1, N
      DO 20  J = I, N
      L = L + 1
      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
      DO 40  J = 1, NR
      L = L + 1
   40 T(L) = 0.D0
      L = L + 1
      M = M + 1
   60 T(L) = T(M)
C
C     LOOP TO ZERO LAST NR ROWS.
C
      DO 80  I = L+1, M
   80 T(I) = 0.D0
      RETURN
      END
```

```
      SUBROUTINE NADIR
C
C
C     THIS SUBROUTINE COMPUTES THE HEIGHT ABOVE ELLIPSOID OF THE CAMERA
C     STATION AND THE FRAME COORDINATES OF THE NADIR POINT FOR USE IN
C     CORRECTING IMAGE COORDINATES FOR ATMOSPHERIC REFRACTION.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C     LABELED COMMON /BLCKF/ CONTAINS THE FRAME DATA RECORD WHICH
C     INCLUDES:
C        FXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)
C        RMAT = CURRENT ORIENTATION MATRIX
C
      COMMON/BLCKF/FRID,NI,FXYZ(3),ABCD(4),RMAT(3,3)
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        PLH = GEODETIC COORDINATES OF CAMERA STATION
C        DPDX = MATRIX OF PARTIALS OF GEODETIC WITH RESPECT TO CARTESIAN
C
      COMMON/BLCKP/F,P(2,6),Q(2),HFR,XN,YN,PLH(3),DPDX(3,3)
C
C     COMPUTE HEIGHT OF CAMERA STATION
C
      CALL XYZPLH(FXYZ,PLH,1,DPDX)
      HFR = PLH(3)
C
C     COMPUTE FRAME COORDINATES OF NADIR.  ROW 3 OF DPDX, IF SCALED
C     BY HEIGHT OF CAMERA STATION, IS THE VECTOR FROM NADIR POINT TO
C     CAMERA STATION.
C
      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
```

```
      SUBROUTINE NORMS(RNE,NP)
C
C
C     THIS SUBROUTINE COMPUTES AND ADDS TO THE RESIDENT NORMAL EQUATIONS
C     THE CONTRIBUTION OF A SINGLE PAIR OF IMAGE EQUATIONS.  PAR, THE
C     2 BY 6 MATRIX OF PARTIAL DERIVATIVES OBTAINED FROM LABELED COMMON
C     BLCKP CAN BE PARTITIONED AS PAR = ¢P1 P2! WHERE P1 AND P2 CONTAIN
C     PARTIAL DERIVATIVES WITH RESPECT TO FRAME POSITION AND ORIENTATION
C     PARAMETERS, RESPECTIVELY.  THEREFORE, -P1 IS THE MATRIX OF PARTIAL
C     DERIVATIVES WITH RESPECT TO THE GROUND POINT POSITION.  THE CON-
C     TRIBUTIONS TO THE RESIDENT NORMAL EQUATIONS HAVE THE FORM:
C          A = A + PAR'*PAR      B = - PAR'*P1      D = D - PAR'*Q
C                               C = C + P1'*P1      E = E + P1'*Q
C     WHERE A IS THE 6 BY 6 SUBMATRIX ASSOCIATED WITH FRAME PARAMETERS,
C     B IS THE 6 BY 3 SUBMATRIX OF FRAME-GROUND CONNECTIONS, AND C IS
C     THE 3 BY 3 SUBMATRIX ASSOCIATED WITH THE GROUND POINT POSITION.
C     D AND E ARE THE CONSTANT TERM VECTORS ASSOCIATED WITH FRAME
C     PARAMETERS AND GROUND POINT POSITION, RESPECTIVELY.
C
C     RNE IS THE ONE-DIMENSIONAL TRIANGULAR ARRAY OF RESIDENT NORMAL
C     EQUATIONS AND NP IS THE RESIDENT GROUND POINT SEQUENCE NUMBER OF
C     THE GROUND POINT.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C     LABELED COMMON /SIZES/ CONTAINS THE FOLLOWING CONSTANTS USED IN
C     THIS SUBROUTINE:
C        NCF = NUMBER OF ELEMENTS IN FIRST ROW OF TRIANGULAR ARRAY RNE
C        LST = NUMBER OF ELEMENTS IN ARRAY RNE
C
      COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST
C
C     LABELED COMMON /BLCKP/ CONTAINS THE FOLLOWING ITEMS USED IN THIS
C     SUBROUTINE:
C        P = PARTIAL DERIVATIVES OF COMPUTED IMAGE COORDINATES WITH
C            RESPECT TO FRAME PARAMETERS
C        Q  = IMAGE COORDINATE DISCREPANCIES (OBSERVED MINUS COMPUTED)
C
      COMMON/BLCKP/F,P(2,6),Q(2)
      DIMENSION RNE(1)
C
C     SET POINTERS.
C
      LD = 0
      NCI = NCF
      NSP = 3*(NP+1)
      LE = NCF*NSP - NSP*(NSP-1)/2
      NCJ = NCF - NSP
C
C     LOOP TO APPLY CONTRIBUTIONS TO 6 ROWS.  COMPUTE X = I-TH ELEMENT
C     OF PAR'*Q AND SUBTRACT X FROM D(I).
```

```
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     I IS < OR = 3, ADD X TO E(I).
C
      LC = LE
      LE = LE + NCJ
      NCJ = NCJ - 1
      RNE(LE) = RNE(LE) + X
      LBJ = LA + NSP
      LBI = LBJ + 1
C
C     LOOP TO APPLY CONTRIBUTIONS TO 6 COLUMNS.  COMPUTE X = I,J-TH
C     ELEMENT OF PAR'*PAR AND ADD X TO A(I,J).
C
   20 DO 40  J = I, 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     I IS < OR = 3, SET B(J,I) = - X.
C
      RNE(LBI) = -X
      LBI = LBI + NCF - J
      IF(J .GT. 3) GO TO 40
C
C     J IS < OR = 3, SET B(I,J) = -X AND ADD X TO C(I,J).
C
      LBJ = LBJ + 1
      RNE(LBJ) = - X
      LC = LC + 1
      RNE(LC) = RNE(LC) + X
   40 CONTINUE
C
C     ADD Q'*Q TO SUM-OF-SQUARES OF RESIDUALS.
C
      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 NTRAN$(IU,10,1,6,INDSEC,L,22)
        CALL CHECKR
        NXTSEC=4
      ELSE IF (IP.EQ.2) THEN  @OPEN OLD FILE AND RETRIEVE INDEX
        CALL NTRAN$(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              @NTRAN$ READ
      GO TO 120
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 NTRAN$(IU,10,6,INDSEC(4),1,N,IXD(IBASE),L,22)  @ WRITE INDEX
      CALL CHECKR
C   PUT POINTER TO THE INDEX IN THE FIRST RECORD.
      N=6
      K = 0
      CALL NTRAN$(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 NTRAN$(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 NTRAN$ 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)
C
C
C     THIS SUBROUTINE PREPARES FOR RANDOM ACCESS TO RECORDS OF LENGTH
C     "LRECL" WORDS ON UNIT NUMBER "NUNIT" BY ENTRY POINTS READRA AND
C     WRITRA.
C
C
      CHARACTER*8 MESAJ
      DIMENSION KUR(30),LREC(30),NSEC(30)
      DATA LREC/30*0/
C
      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 NTRAN$(NUNIT,10,22)
      LREC(NUNIT) = LRECL
      NSEC(NUNIT) = NSECT
      KUR(NUNIT) = NSECT
      RETURN
C
C
C     THIS ENTRY POINT COPIES RECORD NUMBER "NOR" FROM UNIT NUMBER
C     "NUNIT" INTO THE ARRAY "KORE", PROVIDED THAT THIS UNIT HAS BEEN
C     OPENED FOR RANDOM ACCESS BY A CALL TO SUBROUTINE OPENRA.
C
C
      ENTRY READRA(NUNIT,NOR,KORE)
C
      IOP = 2
      MESAJ = 8H READING
      GO TO 20
C
C
C     THIS ENTRY POINT COPIES THE ARRAY "KORE" TO RECORD NUMBER "NOR" OF
C     UNIT NUMBER "NUNIT", PROVIDED THAT THIS UNIT HAS BEEN OPENED FOR
C     RANDOM ACCESS BY A CALL TO SUBROUTINE OPENRA.
C
C
      ENTRY WRITRA(NUNIT,NOR,KORE)
C
      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,*)
C
C
C     THIS SUBROUTINE OBTAINS THE COMPUTED FRAME COORDINATES OF A SINGLE
C     IMAGE AND THE DISCREPANCIES (OBSERVED MINUS COMPUTED).  IF THESE
C     DISCREPANCIES ARE ACCEPTABLE, THE MATRIX OF PARTIAL DERIVATIVES
C     OF IMAGE COORDINATES WITH RESPECT TO FRAME PARAMETERS IS COMPUTED.
C
C     GXYZ IS THE GROUND POINT POSITION VECTOR.  IM IS THE LOCATION OF
C     THE PARTICULAR IMAGE IN THE DATA ARRAY DATI (LABELED COMMON BLCKF)
C     AND REJ IS THE IMAGE REJECTION TOLERANCE.
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C     LABELED COMMON /BLCKP/ WILL CONTAIN THE FOLLOWING:
C        F = FOCAL LENGTH OF CAMERA IN MILLIMETERS
C        PAR = MATRIX OF PARTIAL DERIVATIVES
C        EX = X-COORDINATE DISCREPANCY
C        EY = Y-COORDINATE DISCREPANCY
C
      COMMON/BLCKP/F,PAR(2,6),EX,EY
C
C     LABELED COMMON /BLCKF/ CONTAINS THE FRAME DATA RECORD WHICH
C     INCLUDES THE FOLLOWING QUANTITIES USED IN THIS SUBROUTINE:
C        FXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)
C        RMAT = CURRENT ORIENTATION MATRIX
C        DATI = UP TO 31 SETS OF GROUND POINT NAME AND IMAGE COORDINATES
C
      COMMON/BLCKF/FRID,NI,FXYZ(3),ABCD(4),RMAT(3,3),DATI(3,31)
C
C     LABELED COMMON /STATS/ CONTAINS THE FOLLOWING ITEMS USED IN THIS
C     SUBROUTINE:
C        SSD = SUM-OF-SQUARES OF DISCREPANCIES
C        REJ = REJECTION TOLERANCE
C        NREJ = NUMBER OF IMAGES REJECTED
C
      COMMON/STATS/NOBS,NDOF,SSD,REJ,NREJ
      DIMENSION GXYZ(3)
C
C     OBTAIN COMPUTED IMAGE COORDINATES AND DISCREPANCIES.
C
      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
      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
      COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS,LFR,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
      COMMON/BLCKP/GPID,NI,XYZ(3),SXYZ(3),PLH(3),SPLH(3),DPDX(3,3),
     *             RAE(7,12)
      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
      NW = LGDR/2
      NR = NGP
      DO 20  I = 1, NGP, NW
      NR = NR + 1
   20 CALL READRA(7,NR,SEQ(I))
C
C     SORT AND PRINT RESULT DATA FILE.
C
      NW = LFDR/2
      DO 40  I = 1, NGP
      CALL READRA(10,I,GPID)
      IF(GPID .NE. SEQ(I)) CALL LOCATE(SEQ,NGP,I,GPID,NW)
      CALL MSORT(RAE,7,NI,SEQ,NGP)
      CALL DATOUT
   40 CALL WRITRA(10,I,GPID)
      RETURN
      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)
C
C
C     THIS SUBROUTINE READS A GROUND POINT DATA RECORD FROM UNIT 7 AND
C     ENTERS THE PERTINENT DATA IN THE RESIDENT GROUND POINT DATA
C     ARRAYS.  IF THE POSITION OF THIS POINT IS TO BE CONSTRAINED, THE
C     WEIGHTS ARE APPLIED TO THESE PARAMETERS.
C
C     NGREC IS THE GROUND POINT DATA RECORD NUMBER AND NG IS THE
C     RESIDENT GROUND POINT SEQUENCE NUMBER.  RGPN IS A VECTOR OF NAMES
C     OF THE RESIDENT GROUND POINTS.  LSTF IS A VECTOR CONTAINING THE
C     SEQUENCE NUMBER OF THE LAST FRAME ON WHICH EACH OF THE RESIDENT
C     GROUND POINTS IS IMAGED.  RGE IS A ONE-DIMENSIONAL TRIANGULAR
C     ARRAY CONTAINING THE GROUND POINT PORTION OF THE RESIDENT NORMAL
C     EQUATIONS.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C     LABELED COMMON /BLCKG/ PROVIDES A BUFFER AREA FOR READING GROUND
C     POINT DATA RECORDS WHICH INCLUDE:
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
      COMMON/BLCKG/GPID,IW,NLF,GXYZ(3),COR(3),WT(6)
      DIMENSION RGPN(1),LSTF(1),GDAT(4,1),RGE(1)
C
C     READ GROUND POINT DATA RECORD AND WEIGHT POSITION IF THIS IS A
C     CONTROL POINT.
C
      CALL READRA(7,NGREC,GPID)
      IF(IW .EQ. 0) GO TO 20
      CALL WEIGHT(RGE,NP)
C
C     ENTER DATA INTO RGPN, LSTF, AND GDAT.
C
   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)
C
C
C     THIS SUBROUTINE FORMS A RECORD OF RESULTS OBTAINED FOR A PARTICU-
C     LAR GROUND POINT AND WRITES THIS RECORD TO UNIT 10.
C
C     RGE IS THE TRIANGULAR COVARIANCE MATRIX OF THE RESIDENT GROUND
C     POINTS, NP IS THE RESIDENT GROUND POINT SEQUENCE NUMBER AND IREC
C     THE GROUND POINT DATA RECORD NUMBER OF THIS GROUND POINT.  RGPN
C     CONTAINS THE NAMES OF THE RESIDENT GROUND POINTS.  SCR IS A
C     SCRATCH ARRAY.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
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
      COMMON/SIZES/NGP,NFR,NRG
C
C     LABELED COMMON /BLCKG/ PROVIDES A BUFFER AREA FOR READING GROUND
C     POINT DATA RECORDS WHICH INCLUDE:
C        GPID = GROUND POINT NAME
C        NV   = NUMBER OF NAMES OF INTERVISIBLE GROUND POINTS IN VGPN
C        VGPN = NAMES OF UP TO 12 INTERVISIBLE GROUND POINTS
C
      COMMON/BLCKG/GPID,IW,NFL,GXYZ(3),COR(3),WT(6),NV,VGPN(12)
C
C     LABELED COMMON /BLCKP/ PROVIDES A BUFFER AREA FOR FORMING AND
C     WRITING RECORDS OF RESULTS WHICH INCLUDE:
C        GPI  = GROUND POINT NAME
C        NI   = NUMBER OF INTERVISIBLE GROUND POINTS
C
      COMMON/BLCKP/GPI,NI
C
C     LABELED COMMON /BLCKF/ PROVIDES A BUFFER AREA FOR READING AND
C     WRITING RECORDS OF RESULTS FROM OTHER GROUND POINTS WHICH INCLUDE:
C        GPJ  = GROUND POINT NAME
C        NJ   = NUMBER OF INTERVISIBLE GROUND POINTS
C
      COMMON/BLCKF/GPJ,NJ
      DIMENSION RGE(1),RGPN(NRG),SCR(1)
C
C     READ GROUND POINT DATA RECORD FROM UNIT 7 AND FORM RESULT RECORD
C     ENTRIES THAT DO NOT INVOLVE OTHER POINTS.
C
      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
      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)
C
C
C     THIS SUBROUTINE OBTAINS, FOR A SINGLE GROUND POINT, THE FOLLOWING
C     ITEMS:  GROUND POINT NAME, CARTESIAN COORDINATES AND THEIR
C     STANDARD DEVIATIONS, GEODETIC COORDINATES AND THEIR STANDARD
C     DEVIATIONS, AND THE MATRIX OF PARTIAL DERIVATIVES OF GEODETIC
C     WITH RESPECT TO CARTESIAN.  THESE ITEMS ARE ENTERED INTO THE
C     RESULT RECORD BEING FORMED IN COMMON /BLCKP/.
C
C     RGE IS THE TRIANGULAR ARRAY CONTAINING THE COVARIANCE MATRIX OF
C     THE RESIDENT GROUND POINTS AND NP IS THE RESIDENT GROUND POINT
C     SEQUENCE NUMBER OF THE POINT.
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
      COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS
C
C     LABELED COMMON /BLCKG/ CONTAINS THE GROUND POINT DATA RECORD
C     WHICH INCLUDES:
C        GPID = GROUND POINT NAME
C        GXYZ = CURRENT ESTIMATE OF POSITION (CARTESIAN GEOCENTRIC)
C        WT   = UPPER TRIANGLE OF WEIGHT MATRIX
C
      COMMON/BLCKG/GPID,IW,NFL,GXYZ(3),COR(3),WT(6)
C
C     LABELED COMMON /BLCKP/ PROVIDES A BUFFER AREA FOR FORMING THE
C     RESULT RECORD WHICH WILL INCLUDE:
C        GPI  = GROUND POINT NAME
C        NI   = NUMBER OF INTERVISIBLE GROUND POINTS
C        XYZ = POSITION IN CARTESIAN GEOCENTRIC COORDINATES
C        SXYZ  = STANDARD DEVIATIONS OF CARTESIAN COORDINATES
C        PLH = POSITION IN GEODETIC COORDINATES
C        SPLH  = STANDARD DEVIATIONS OF GEODETIC COORDINATES
C        DPDX = PARTIALS OF GEODETIC WITH RESPECT TO CARTESIAN
C
      COMMON/BLCKP/GPI,NI,XYZ(3),SXYZ(3),PLH(3),SPLH(3),DPDX(3,3)
      DIMENSION RGE(1)
C
C     GET GPID AND XYZ FROM GROUND POINT DATA RECORD.  COPY COVARIANCE
C     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     GET PLH,DPDX, AND SPLH.
C
      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)
C
C
C     THIS SUBROUTINE OBTAINS THE DISTANCE, AZIMUTH, ELEVATION DIFFER-
C     ENCE, AND BACK AZIMUTH (AND THEIR STANDARD DEVIATIONS) OF A LINE
C     FROM POINT I TO POINT J, AND USES THESE DATA TO FORM ONE NEW
C     COLUMN OF EACH OF THE ARRAYS RAEI AND RAEJ.  RAEI IS AN ARRAY
C     ASSOCIATED WITH POINT I AND THE NEW COLUMN WILL CONTAIN: THE NAME
C     OF POINT J, THE DISTANCE, AZIMUTH, AND ELEVATION DIFFERENCE FROM
C     POINT I TO POINT J, AND THEIR STANDARD DEVIATIONS.  THE NEW COLUMN
C     OF RAEJ WILL CONTAIN THE EQUIVALENT QUANTITIES FROM POINT J TO
C     POINT I.
C
C     TCOV IS THE TRIANGULAR FORM OF THE 6 BY 6 COVARIANCE MATRIX
C     ASSOCIATED WITH THE CARTESIAN COORDINATES OF POINTS I AND J.
C     RAEB, SRAEB, DRDP, AND DRDX ARE SCRATCH ARRAYS THAT WILL BE USED
C     FOR TEMPORARY STORAGE.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C     LABELED COMMON /BLCKP/ CONTAINS THE FOLLOWING DATA ASSOCIATED WITH
C     POINT I:
C        GPI   = GROUND POINT NAME
C        NI    = NUMBER OF INTERVISIBLE GROUND POINTS
C        XYZI  = POSITION IN CARTESIAN GEOCENTRIC COORDINATES
C        SXYZI = STANDARD DEVIATIONS OF CARTESIAN COORDINATES
C        PLHI  = POSITION IN GEODETIC COORDINATES
C        SPLHI = STANDARD DEVIATIONS OF GEODETIC COORDINATES
C        DPDXI = PARTIALS OF GEODETIC WITH RESPECT TO CARTESIAN
C        RAEI  = INTER-POINT PARAMETERS FOR UP TO 12 INTERVISIBLE POINTS
C
      COMMON/BLCKP/GPI,NI,XYZI(3),SXYZI(3),PLHI(3),SPLHI(3),DPDXI(3,3),
     *             RAEI(7,12)
C
C     LABELED COMMON /BLCKF/ CONTAINS AN EQUIVALENT SET OF DATA
C     ASSOCIATED WITH POINT J:
C
      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)
C
C     GET VECTOR (RAEB) OF DISTANCE, AZIMUTH, ELEVATION DIFFERENCE, AND
C     BACK AZIMUTH FROM POINT I TO POINT J AND VECTOR (SRAEB) OF THEIR
C     STANDARD DEVIATIONS.  DRDX IS THE 4 BY 6 MATRIX OF PARTIALS WITH
C     RESPECT TO THE TWO SETS OF CARTESIAN COORDINATES.
C
      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
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION TOLD(1),DNDO(N,M),SDNEW(N)
C
C     LOOP TO COMPUTE N STANDARD DEVIATIONS.
C
      DO 80  I = 1, N
      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
      DO 60  J = 1, M
      L = J - M
      NC = M
      X = 0.D0
C
C      LOOP TO COMPUTE X = SUM¢TOLD(J,K)*DNDO(I,K)! FOR K = 1 THRU M
C
      DO 20  K = 1, J
      L = L + NC
      NC = NC - 1
   20 X = X + TOLD(L)*DNDO(I,K)
      IF(J .EQ. M) GO TO 60
      DO 40  K = J+1, M
      L = L + 1
   40 X = X + TOLD(L)*DNDO(I,K)
C
   60 SDNEW(I) = SDNEW(I) + DNDO(I,J)*X
C
   80 SDNEW(I) = DSQRT(SDNEW(I))
      RETURN
      END
```

```
      SUBROUTINE SOLV(T,NCT,NR)
C
C
C     THIS SUBROUTINE OBTAINS THE SOLUTION OF THE MATRIX EQUATION
C     A*X = Y, WHERE A IS SYMMETRIC AND ONLY THE UPPER TRIANGLE IS
C     STORED, AFTER TRANSFORMATION TO U*X = Z BY SUBROUTINE ELIM.  THE
C     DIAGONAL MATRIX E, THE ABOVE-DIAGONAL ELEMENTS OF U, AND THE
C     VECTOR Z ARE ASSUMED TO BE PACKED IN THE ONE-DIMENSIONAL ARRAY T
C     EXACTLY AS OUTPUT FROM SUBROUTINE ELIM, I.E.,
C
C         T = E(1,1),U(1,2), - - - U(1,N),Z(1),
C                    E(2,2), - - - U(2,N),Z(2),
C                                    -     -
C                                  E(N,N),Z(N)
C
C     THE ELEMENTS OF Z WILL BE REPLACED BY THE ELEMENTS OF X, BUT THE
C     OTHER ELEMENTS OF T WILL BE UNCHANGED.
C
C     NCT IS THE NUMBER OF ELEMENTS IN THE FIRST ROW OF T.  NR IS THE
C     NUMBER OF ROWS TO BE SOLVED.  IF NR = N = NCT-1, ALL ROWS WILL BE
C     SOLVED.  A VALUE OF NR < N ASSUMES THAT ROWS NR+1 THRU N HAVE
C     ALREADY BEEN SOLVED BY A PREVIOUS CALL TO THIS ROUTINE.
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION T(1)
C
C     SET INITIAL VALUES.
C
      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
C
C     LOOP TO SOLVE LR ROWS (IN REVERSE ORDER).  SET UP POINTERS.
C
      DO 40  I = LR, 1, -1
      IJ = IJ - 2
      IZ = IJ
      JX = LST
C
C     LOOP TO COMPUTE X(I) = Z(I) - SUM(U(I,J)*X(J)!, J = I+1 THRU N
C
      DO 20  J = N, I+1, -1
      IJ = IJ - 1
      JX = JX - NCT + J
   20 T(IZ) = T(IZ) - T(IJ)*T(JX)
C
   40 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SOLVE(INDX,RNE,RGE)
C
C
C     THIS SUBROUTINE SOLVES THE FORWARD REDUCED NORMAL EQUATICNS AND
C     MANAGES THE UP-DATING ALL PHOTO AND GROUND POINT DATA RECORDS.
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.  RNE IS A ONE-DIMENSIONAL TRIANGULAR ARRAY USED TO HOLD THE
C     RESIDENT NORMAL EQUATIONS, AND RGE IS A SUB-SET OF RNE USED TO
C     HOLD THE GROUND POINT PORTION OF THE RESIDENT NORMAL 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),RNE(1),RGE(1)
C
C     COMPUTE CONSTANTS.
C
      KR = 2*NCF + 1
      KRSQ = KR**2
C
C     SOLVE FORWARD REDUCED GROUND POINT NORMAL EQUATIONS PRESENTLY
C     RESIDING IN RGE AND UP-DATE CORRESPONDING GROUND POINT DATA
C     RECORDS.
C
      CALL SOLV(RGE,NCG,NCG-1)
      NGREC = NGP + 1
      DO 20  NG = NRG, 1, -1
      NGREC = NGREC - 1
   20 CALL UPD8G(NGREC,NG,RGE)
C
C     LOOP TO READ AND SOLVE FORWARD REDUCED NORMAL EQUATIONS WRITTEN
C     TO PERIPHERAL STORAGE BY SUBROUTINE FORWD.  DETERMINE RECORD
C     LENGTH (LR) AND TAKE APPROPRIATE ACTION.
C
      DO 80  NFREC = NFR, 1, -1
      NRT = 6
      LR = BITS(INDX(NFREC+1),19,18)
      IF(LR .EQ. LFR) GO TO 40
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*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)
C
C
C     THIS SUBROUTINE OBTAINS THE SPARSE COVARIANCE MATRIX (SPARSE
C     INVERSE SCALED BY VARIANCE-OF-UNIT-WEIGHT) ASSOCIATED WITH THE
C     SOLUTION OF A*X = Y, WHERE A IS SYMMETRIC AND ONLY THE UPPER
C     TRIANGLE IS STORED, AFTER FACTORIZATION INTO A = U'*D*U BY
C     SUBROUTINE ELIM.  THE DIAGONAL MATRIX E (D-INVERSE), THE ABOVE-
C     DIAGONAL ELEMENTS OF U (WHICH IS UNIT-UPPER-TRIANGULAR), THE
C     VECTOR W, AND THE VARIANCE-OF-UNIT-WEIGHT VV ARE ASSUMED TO BE
C     PACKED IN THE ONE-DIMENSIONAL ARRAY T AS FOLLOWS:
C
C        T = E(1,1),U(1,2), - - - U(1,N),W(1),
C                   E(2,2), - - - U(2,N),W(2),
C                                   -     -
C                                 E(N,N),W(N),
C                                         VV
C
C     THE ELEMENTS OF E AND U WILL BE REPLACED BY THE CORRESPONDING
C     ELEMENTS OF THE COVARIANCE MATRIX C, EXCEPT THAT ELEMENTS OF U
C     HAVING A VALUE OF ZERO WILL REMAIN ZERO.  W WILL BE USED FOR
C     TEMPORARY STORAGE.  THEREFORE, THE SOLUTION VECTOR MUST BE
C     EXTRACTED FROM T BEFORE THIS ROUTINE IS CALLED|||  THE SUM-
C     OF-SQUARES OF RESIDUALS MUST ALSO BE TRANSFORMED INTO VV BY
C     DIVIDING BY DEGREES-OF-FREEDOM, BUT T WILL OTHERWISE BE AS OUTPUT
C     FROM SUBROUTINE ELIM.
C
C     NCT IS THE NUMBER OF ELEMENTS IN THE FIRST ROW OF T.  NR IS THE
C     NUMBER OF COVARIANCE  TO BE COMPUTED.  IF NR = N = NCT-1, ALL ROWS
C     WILL BE COMPUTED.  A VALUE OF NR < N ASSUMES THAT ROWS NR+1 THRU N
C     HAVE ALREADY BEEN TRANSFORMED TO COVARIANCE ELEMENTS BY A PREVIOUS
C     CALL TO THIS ROUTINE.
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION T(1)
C
C     SET POINTERS, SPACERS, ETC.
C
      N = NCT - 1
      M = NCT + 1
      LVV = NCT*M/2
      IF(NR .EQ. N) THEN
C
C     ALL ROWS ARE TO BE COMPUTED.  COMPUTE ROW N AND SET LR TO N-1.
C
      II = LVV - 2
      T(II) = T(II)*T(LVV)
      LR = N - 1
C
C     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
      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
      COMMON/BLCKF/FRID,NI,FXYZ(3),ABCD(4),RMAT(3,3)
      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)
      DO 20  I = 1, 3
      X(I) = ABCD(I)
   20 ABCD(I) = 0.D0
C
C     UP-DATE POSITION AND COPY ORIENTATION PARAMETER CORRECTIONS INTO
C     ABCD.
C
      L = 0
      NC = NCF
      DO 40  I = 1, 6
      L = L + NC
      NC = NC - 1
   40 FXYZ(I) = FXYZ(I) + RNE(L)
C
C     UP-DATE ORIENTATION PARAMETERS (PRESENTLY STORED IN X).
C
      DO 80  I = 1, 3
      RMAT(I,I) = RMAT(I,I) + ABCD(4)
      R = 0.D0
      DO 60  J = 1, 3
   60 R = R + RMAT(J,I)*ABCD(J)
   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
      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
      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
      COMMON/BLCKG/GPID,IW,NFL,GXYZ(3),COR(3)
      DIMENSION RGE(1)
C
C     SET UP POINTERS AND READ GROUND POINT DATA RECORD.
C
      NC = NCG - 3*(NG-1)
      L = LSS - NC*(NC+1)/2
      CALL READRA(7,NGREC,GPID)
C
C     ADD CORRECTIONS TO BOTH POSITION VECTOR (GXYZ) AND VECTOR OF
C     CUMULATIVE CORRECTIONS (COR).
C
      DO 20  I = 1, 3
      L = L + NC
      NC = NC - 1
      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
      CALL WRITRA(7,NGREC,GPID)
      RETURN
      END
```

```
      SUBROUTINE WEIGHT(RGE,NP)
C
C
C     THIS SUBROUTINE IS USED TO WEIGHT THE A PRIORI ESTIMATE OF A
C     GROUND POINT POSITION BY INSERTING A WEIGHT MATRIX AND A
C     SUPPLIMENTAL DISCREPANCY VECTOR IN THE RESIDENT NORMAL EQUATIONS.
C     THE SUM-OF-SQUARES OF RESIDUALS IS ALSO MODIFIED TO ACCOUNT FOR
C     THIS WEIGHTING.  THIS SUBROUTINE MUST BE CALLED BEFORE ANY
C     OBSERVATIONS OF THE GROUND POINT HAVE BEEN PROCESSED|||
C
C     RGE IS A ONE-DIMENSIONAL TRIANGULAR ARRAY CONTAINING THE GROUND
C     POINT PORTION OF THE RESIDENT NORMAL EQUATIONS AND NP IS THE
C     RESIDENT GROUND POINT SEQUENCE NUMBER OF THE POINT TO BE WEIGHTED.
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
      COMMON/SIZES/NGP,NFR,NRG,NCF,NCG,LST,LSS
C
C     LABELED COMMON /BLCKG/ CONTAINS THE GROUND POINT DATA RECORD WHICH
C     INCLUDES THE FOLLOWING DATA USED BY THIS SUBROUTINE:
C        COR  = CUMULATIVE CORRECTIONS TO INITIAL POSITION
C        WT   = UPPER TRIANGLE OF WEIGHT MATRIX
C
      COMMON/BLCKG/GPID,IW,NFL,GXYZ(3),COR(3),WT(6)
      DIMENSION RGE(LSS),X(3)
C
C     SET UP POINTERS AND INITIALIZE TO COMPUTE X = WT*COR
C
      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
C
C     LOOP TO MODIFY THREE ROWS OF RGE.
C
      DO 60  I = 1, 3
C
C     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
      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
C
C     THIS SUBROUTINE ZEROS NR ROWS OF THE TRIANGULAR ARRAY T WHICH HAS
C     NC ELEMENTS IN ITS FIRST ROW.
C
C
      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
```

(Continued from inside front cover)

NOS NGS-17 Vincenty, T., The HAVAGO three-dimensional adjustment program, 1979, 18 pp. $2.60
NOS NGS-18 Pettey, J. E., Determination of astronomic positions for California-Nevada boundary monuments near Lake Tahoe, 1979, 22 pp. $2.70
NOS NGS-19 Vincenty, T., HOACOS: A program for adjusting horizontal networks in three dimensions, 1979, 18 pp. $2.60
NOS NGS-20 Balazs, E. I. and Douglas, B. C., Geodetic leveling and the sea level slope along the California coast, 1979, 23 pp. $2.70
NOS NGS-21 Carter, W. E., Fronczek, C. J., and Pettey, J. E., Haystack-Westford Survey, 1979, 57 pp. $3.75
NOS NGS-22 Goad, C. C., Gravimetric tidal loading computed from integrated Green's functions, 1979, 15 pp. $2.45
NOS NGS-23 Bowring, B. R. and Vincenty, T., Use of auxiliary ellipsoids in height-controlled spatial adjustments, 1979, 6 pp. $2.20
NOS NGS-24 Douglas, B. C., Goad, C. C., and Morrison, F. F., Determination of the geopotential from satellite-to-satellite tracking data, 1980, 32 pp. $2.90
NOS NGS-25 Vincenty, T., Revisions of the HOACOS height-controlled network adjustment program, 1980, 5 pp. $2.20
NOS NGS-26 Poetzschke, H., Motorized leveling at the National Geodetic Survey, 1980, 19 pp. $2.60
NOS NGS-27 Balazs, E. I., The 1978 Houston-Galveston and Texas Gulf Coast vertical control surveys, 1980, 63 pp. $3.85
NOS NGS-28 Agreen, R. W., Storage of satellite altimeter data, 1980, 11 pp. $2.30
NOS NGS-29 Dillinger, W. H., Subroutine package for processing large, sparse, least-squares problems, 1981, 20 pp. $2.60
NOS NGS-30 Groten, E., Determination of plumb line curvature by astronomical and gravimetric methods, 1981, 20 pp. $2.60
NOS NGS-31 Holdahl, S. R., A model of temperature stratification for correction of leveling refraction, 1981, 30 pp. $2.90
NOS NGS-32 Carter, W. E. and Pettey, J. E., Report of survey for McDonald Observatory, Harvard Radio Astronomy Station, and vicinity, 1981, 83 pp. $4.50

NOAA Technical Reports, NOS/NGS subseries

NOS 65 NGS 1 Pope, A. J., The statistics of residuals and the detection of outliers, 1976, 133 pp. $6.00
NOS 66 NGS 2 Moose, R. E. and Henriksen, S. W., Effect of Geoceiver observations upon the classical triangulation network, 1976, 65 pp. $4.00
NOS 67 NGS 3 Morrison, F., Algorithms for computing the geopotential using a simple-layer density model, 1977, 41 pp. $3.25
NOS 68 NGS 4 Whalen, C. T. and Balazs, E., Test results of first-order class III leveling, 1976, 30 pp. $2.90
NOS 70 NGS 5 Doyle, F. J., Elassal, A. A., and Lucas, J. R., Selenocentric geodetic reference system, 1977, 53 pp. $3.65
NOS 71 NGS 6 Goad, C. C., Application of digital filtering to satellite geodesy, 1977, 73 pp. $4.25
NOS 72 NGS 7 Henriksen, S. W., Systems for the determination of polar motion, 1977, 55 pp. $3.65
NOS 73 NGS 8 Whalen, C. T., Control leveling, 1978, 23 pp. $2.70
NOS 74 NGS 9 Carter, W. E. and Vincenty, T., Survey of the McDonald Observatory radial line scheme by relative lateration techniques, 1978, 33 pp. $3.00
NOS 75 NGS 10 Schmid, E., An algorithm to compute the eigenvectors of a symmetric matrix, 1978, 5 pp. $2.20
NOS 76 NGS 11 Hardy, R. L., The application of multiquadric equations and point mass anomaly models to crustal movement studies, 1978, 63 pp. $3.85
NOS 79 NGS 12 Milbert, D. G., Optimization of horizontal control networks by nonlinear programing, 1979, 44 pp. $3.25
NOS 82 NGS 13 Grundig, L., Feasibility study of the conjugate gradient method for solving large sparse equation sets, 1980, 22 pp. $2.70
NOS 83 NGS 14 Vanicek, P., Tidal corrections to geodetic quantities, 1980, 30 pp. $2.90
NOS 84 NGS 15 Bossler, J. D. and Hanson, R. H., Application of special variance estimators to geodesy, 1980, 16 pp. $2.45
NOS 85 NGS 16 Grafarend, E. W., The Bruns transformation and a dual setup of geodetic observational equations, 1980, 73 pp. $4.25
NOS 86 NGS 17 Vanicek, P. and Grafarend, E. W., On the weight estimation in leveling, 1980, 36 pp. $3.00

(Continued on inside back cover)

(Continued)

NOS 87 NGS 18 Snay, R. A. and Cline, M. W., Crustal movement investigations at Tejon Ranch, Calif., 1980, 35 pp. $3.00

NOS 88 NGS 19 Dracup, J. F., Horizontal Control, 1980, 40 pp. $3.15

NOS 90 NGS 20 Groten, E., Precise determination of the disturbing potential using alternative boundary values, 1981, 70 pp. $4.10

NOS 91 NGS 21 Lucas, J. R., Results of photogrammetric control densification in Ada County, Idaho, 1981, 74 pp. $4.25

NOAA Manuals, NOS/NGS subseries

NOS NGS 1 Floyd, Richard P., Geodetic bench marks, 1978, 56 pp. $3.65

NOS NGS 2 Input formats and specifications of the National Geodetic Survey data base:
Pfeifer, L., Vol. I--Horizontal control data, 1980, 205 pp. $8.20
Pfeifer, L. and Morrison, N., Vol. II--Vertical control data, 1980, 136 pp.
(Distribution of this loose-leaf manual and revisions is maintained by the National Geodetic Survey, NOS/NOAA, Rockville, MD 20852.) $6.00

Federal Geodetic Control Committee

The following two documents of the Federal Geodetic Control Committee are published as a set and are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. (Check or money order should be made payable to: Superintendent of Documents.) Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys, 1974, reprinted 1980, 12 pp; and Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys, 1975, 51 pp. $4.25

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey
National Geodetic Survey, OA/C18x2
Rockville, Maryland 20852

OFFICIAL BUSINESS

LETTER MAIL

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE
COM-210

U.S.MAIL

THIRD CLASS

NOAA--S/T 82-40