General Integrated Analytical Triangulation Program (GIANT) User's Guide

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NOAA Charting Research and Development Laboratory
Rockville, MD
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ENVIRONMENT

GIANT provides significant economic benefits by reducing the number and amount of costly manual field surveys. This modular style program is written in FORTRAN 77. The source code for the software is on a nine-track tape at 1600 bpi density in ASCII format.

Although originally written for the IBM 360/370 computers, the program has no machine dependent limitations when run on a virtual memory computer. The maximum size of a project that the program accommodates depends on the values of certain parameters. These are defined during the installation of the program.

AVAILABILITY

This documentation of the GIANT program accompanies the software sold by the National Geodetic Information Branch (N/CG174), Charting and Geodetic Services, National Ocean Service, NOAA, Rockville, Maryland 20852. See inside cover page for further information.

A list of the organizations and individuals who acquire the package will be maintained by NOAA. Future enhancements, corrections, or updates to GIANT will be announced and made available to those on the list.

Specific questions regarding GIANT should be addressed to:

Photogrammetric Technology Programs (N/CG213)
NOAA Charting Research and Development Laboratory
National Ocean Service, NOAA
Rockville, Maryland 20852
301-443-8985 (telephone number)

PREFACE

This user's guide addresses the needs of those individuals with a photo-grammetric background who will be executing the GIANT (General Integrated ANalytical Triangulation) program (Elassal 1976). The document is kept simple by avoiding such details as background mathematics, project planning, preprocessing, and related considerations. No unusual demand is required of the user, although interpretation of results will become more meaningful with experience and knowledge. For more information on aerotriangulation in general, the reader may wish to consult the Analytical Mapping System User's Guide (Engineering Management Series 1981).

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GENERAL INTEGRATED ANALYTICAL TRIANGULATION (GIANT) PROGRAM
USER'S GUIDE

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I. INTRODUCTION

A sufficiently dense control net is required to adequately control instrument settings for exploitation of photographs to generate base maps by stereocompilation, orthophoto mosaic, or other methods. Control is normally established by one of the three well known photogrammetric methods: analog, semianalytical, or fully analytical. The fully analytical approach has developed since the 1960's when digital computers made the associated computations both possible and economical. Its primary attribute is the flexibility to accept and enforce various formats, focal lenghts, and control of both camera station and ground position.

In the analytical approach, the data reduction programs normally have three phases:

o _Preprocessing_. Measured plate coordinates of all the points are reduced to the plate coordinate system, and centered at the principal point. All known systematic errors, such as lens distortion, and atmospheric refraction effects (sec. II.B) are removed.

o _Triangulation_. Programs such as GIANT accept preprocessed plate coordinates, focal length, ground control, and initial estimates of camera station position and orientation for an iterative least squares solution to solve for camera station position and orientation, and ground coordinates of all pass points.

o _Postprocessing_. Camera station position and orientation are subsequently transformed into instrument settings useful for model setup to generate base maps and other cartographic products.

A. Functions of the GIANT Program

General Integrated Analytical Triangulation (GIANT) is a computer program designed to perform analytical triangulation to solve for the ground coordinates of image points measured on two or more photographs. The parameters solved by this program are the ground coordiantes of each of the measured image points, as stated above, and the parameters of each camera station position and orientation.

The program uses an iterative leasts squares technique. All parameters are treated as weighted parameters, ranging from known to unknown. Observation equations are set up as functions of the parameters. It accepts or assumes only uncorrelated observations. All parameters and observations may be weighted to reflect a priori knowledge of their precision. This is

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particularly useful in weighting ground control differentially, compensating for different sources of control of varying precison, as well as being able to utilize control with unknown components. By allowing the use of partial control points, any horizontal and vertical component is known with varying accuracies. The user may enforce known camera station positions and orientation, if they are determined by external source, such as a navigation device on the aircraft. When these parameters can be enforced as observed quantities, the need for ground control is significantly lessened for comparable accuracy.

The program also propagates error estimates through the solution, computes the a posteriori estimate of variance of unit weight, and, on option the variance-covariance matrix and standard deviation of each parameter of camera station position and orientation, and ground coordinates. When used with a fictitious data generator, a user may predict results before using a set of photographs, a given control pattern, or other variables. Accuracy could be predicted and additional or different configurations of control planned.

The iterative least squares approach requires an initial approximation for each unknown parameter. The program requires the user to furnish initial approximations for camera position and orientation paramters, whereas, the program obtains the initial estimates of the pass point coordinates and of the missing components of the ground control points. The program has been proven to accept reasonably gross approximations for these parameters.

The program expects object space coordinates to be in a space rectangular or in a spherical/geographic coordinate system. The rectangular coordinate system is generally required for close-range photogrammetry and the spherical/geographic system for mapping projects. The camera attitudes are parameterized in terms of roll, pitch, and yaw (ω, ϕ, κ) referenced to the local vertical, and may express the relation between image and object coordinate spaces.

B. Program Capabilities and Restrictions

GIANT employs an highly efficient algorithm for the formation, solution, and inversion of large linear systems of equations. The agency using the program must determine the maximum size of a project that it will ever handle in order to define the following parameters during the installation of the program:

o Maximum number of camera stations N1

o Maximum number of ground points, including all points
of which ground coordinates are to be computed N2

o Maximum number of ground control points N3

o Maximum number of frames in which a unique point appears N4

o Maximum number of camera systems N5

o Normal equation bandwidth (Appendix A). N6

Due to the virtual memory available in computers, the size of the project that can be handled is almost unlimited.

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Other capabilities include the following:

o Object space can be expressed in a space rectangular or in a spherical/geographic coordinate system. The rectangular coordinate system is generally required for close-range photogrammetry and the spherical-geographic system for mapping projects.

o Camera attitudes are parameterized in terms of roll, pitch, and yaw (ω,ϕ,κ) and may express the relation between image and object coordinate spaces or vice versa.

o Camera station position and attitude paramaters can be constrained individually, using proper weights. Full or partial ground control can also be utilized.

o Photography from any number of camera systems (not to exceed N5 as defined above) may be triangulated simultaneously.

o Data entries are grouped by photographs with the program performing all necessary cross-referencing and pass point ground coordiante estimations.

o An error propagation facility exists for detailed statistical assessment of the triangulation results.

o A facility exists for sorting the triangulation results.

o Corrections applied to ground control point coordinates as a result of the triangulation are listed for reference.

o The internal defaults for estimated standard deviations of object space coordinates of control points can be declared on an additonal record (sec. II.B.1, Record No. 2, COMMON file). Provision still exists for declaring individual data items (sec. II.B.5).

o The unit variance of the triangulation residuals is listed.

o Camera station position and attitude corrections for each iteration are given.

o Control points can be designated as "UNHELD" and used as test points. The residuals are listed separately and a separate rms computed.

o Run time errors detected during the input phase, due to illegal format or data types, are printed showing the record number and contents of the offending record.

II. DATA FILES USED

This section describes the input/output data files.

A. An Overview

The five data files entitled COMMON, CAMERA, IMAGES, FRAMES, and GROUND are input into GIANT and are processed to give output data files as shown in figure 1.

INPUT FILES

| COMMON | CAMERAS | IMAGES | FRAMES | GROUND |

GIANT

PRINT   ADJUSTED DATA

OUTPUT FILES

| PRINT FILE EXTERIOR ORIENTATION | PRINT FILE ADJUSTED GROUND COORDINATES | DATA FILE EXTERIOR ORIENTATION | DATA FILE ADJUSTED GROUND COORDINATES |
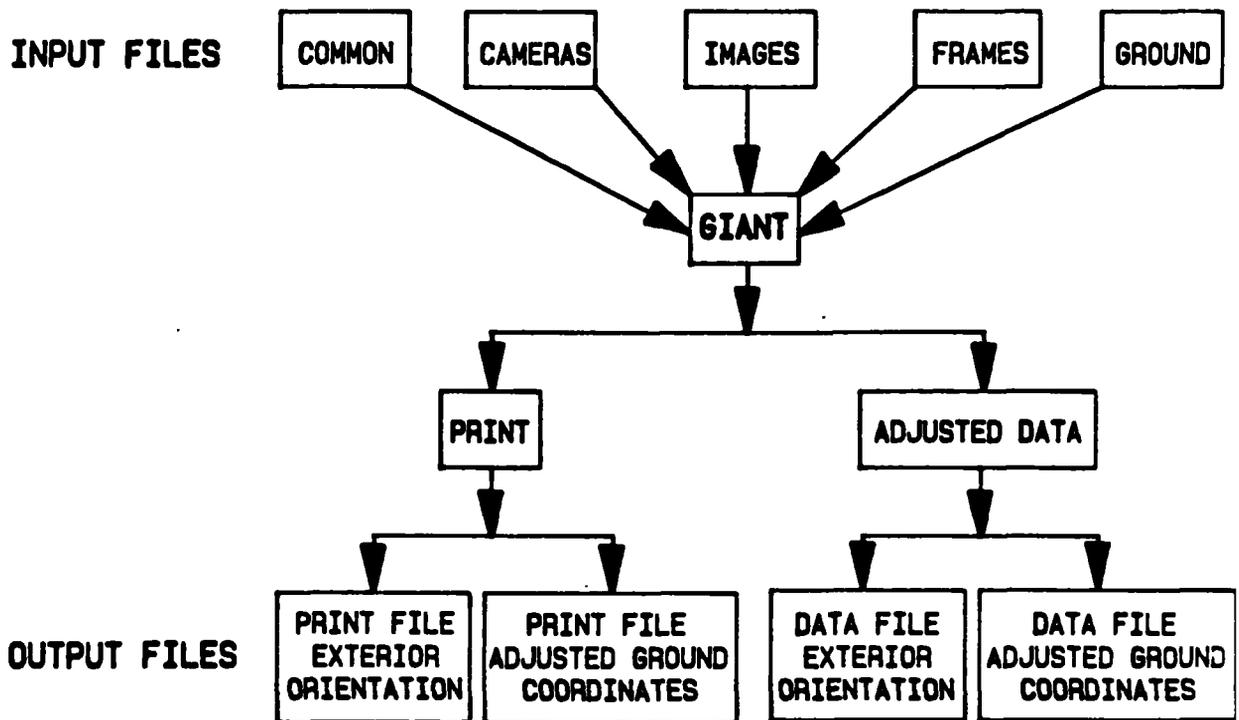
Figure II.1.--Schematic of input and output files

B. Input Files and Their Organization

A description of the five input data files, their contents, and organization is given in this section.

The IMAGES data file contains refined image coordinates, not raw measured image coordinates. The raw measured image coordinates must be refined in some "preprocessing" stage of data reduction. They are subjected to a series of transformations to correct for the effects of measuring instrument errors, film deformation, lens distortion, and atmospheric refraction.

For a detailed description of a typical preprocessor, refer to the Engineering Management Series (1981).

The GIANT program also has an atmospheric refraction correction model applicable up to an altitude of 9,000 meters. The dynamic nature of this model makes it possible to carry out a more accurate correction for the refraction effect. This correction is based not only on the altitude of the camera but also on its attitude. In the program's iterative adjustment process, the atmospheric refraction correction is carried out according to the updated state vector of the camera. The switch for applying atmospheric refraction correction within GIANT is turned off if the correction has already been made in the preprocessor. The application of this model slows down the convergence of the solution for only a slight improvement in the results which may discourage its use by production units. Also, the 9,000 meters altitude limit set by the model will have to be overcome by another more universally applicable one.

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The ouput list will depend on the options used in the input COMMON card set. Various steps in the computations will be dictated by the options chosen in the job definition data record in the COMMON file.

1. COMMON File

Record No. 1: <u>Job Title</u> - Alphanumeric characters 1-80

These 80 characters will be printed at the top of each page of the program.

Record No. 2: <u>Job Definition</u>

This record contains option flags and parameters for the triangulation run.

Character	Content	Format/Remarks
1	Definition of object space[1] =0, Rectangular coordinates =1, Geographic Coordinates	I1
2	Type of camera station rotations switch (affecting both input and output) =0, Photo-to-ground =1, Ground-to-photo	I1
3	List input camera station parameters switch =0, list =1, do not list	I1
4	List input plate coordinates switch =0, list =1, do not list	I1
5	List input ground control switch =0, list =1, do not list	I1

[1]In all mapping applications use geographic coordinates, and in close-range applications use rectangular coordinates.

All angles in <u>D</u>egrees, <u>M</u>inutes and <u>S</u>econds (DMS) are in the form:
    DMS field: +DDDMMSS.SS...SS
Where DDD are <u>degrees</u>; MM are <u>minutes</u>; and, SS.SS...SS are <u>seconds</u>. The DMS field is interpreted by the program left to right and leading zeros may be dropped. For example, an angle with zero degrees can be expressed as: MMSS.SS...SS, but leading zeros must be included in the minutes and seconds portion for obvious reasons.

| 6 | List output triangulated ground point coordinates switch
=0, list
=1, do not list | I1 |

| 7 | Save (as data file) output triangulated ground coordinates switch
=0, save
=1, do not save | I1 |

| 8 | List output adjusted camera station parameters switch
=0, list
=1, do not list | I1 |

| 9 | Save (as data file) adjusted camera station parameters switch
=0, save
=1, perform intersection only, holding camera position and attitude fixed | I1 |

| 10 | Selected process switch
=0, perform complete triangulation
=1, perform intersection only, holding camera position and attitude fixed | I1 |

| 11 | Error propagation switch
=0, do not perform error propagation
=1, perform error propagation | I1 |

| 12 | A posteriori unit variance adjustment flag
=0, unit variance is based on completely free camera parameters
=1, unit variance is based on constrained camera parameters
=2, Set unit variance equals unity | I1 |

| 13 | Sort triangulated ground points switch
=0, perform ascending sort of ground points
=1, do not perfrm sort | I1 |

| 14 | Max. allowable number of iterations in the least squares adjustment. If this field is left blank, the program will assign a maximum of four iterations | I1 |

| 15 | Any valid alphanumeric character. Leading character(s) which matches this character will be removed from name fields of camera systems, camera stations, and ground points | A1 |

| 16 | Air refraction model switch
=0, do not apply
=1, apply | I1 |

17	Water refraction model switch =0, do not apply =1, apply	I1
18-19	Criterion E for convergence of least squares adjustment. Least squares solution will be considered complete if the absolute change in the weighted sum of squares for two consecutive iterations is less than E percent. If this field is left blank, the program will assume E=5	I2
31-40	Water level (meters) with respect to the reference ellipsoid, at the time of exposure. This value applies to the whole block for bathymetric mapping application	F10.3
41-50	Plate residual listing criteria (F, in millimeters) equal to 0: All images residuals will be listed; greater than 0: Only those residuals whose absolute value is larger than F will be listed; less than 0: No residuals will be listed	F10.3
51-60	Semimajor axis of Earth's spheroid in meters. If not specified, program will assume the value of Clarke's 1866 spheroid. (=6,378,206.4)	F10.2
61-70	Semiminor axis of Earth's spheroid in meters. If not specified, program will assume the value of Clarke's 1866 spheroid. (=6,356,583.8)	F10.2

Record No 3: Default standard deviations[1] (optional) for object space
coordinates of control points.

Character	Content	Format/Remark
	Standard deviataion (planimetry)	
1-10	X (meters) or λ (DMS)	F10.3
11-20	Y (meters) or ϕ (DMS)	F10.3
	Standard deviation (elevation)	
21-30	Z (meters) H (meters)	F10.3

[1]Standard deviations of object space coordinates of control points can be
defined in the GROUND file. (See sec. II.B.5.) If not specified, the program
will adopt default values. This record is used to modify the program's built-
in default values in the GROUND file.

2. CAMERAS File

This file contains camera system(s) information. The program allows for inclusion of photography in a single triangulation run from as many camera systems as defined in this file, but less than the maximum number of camera systems defined by parameter N5. (See sec. I.B.)

Record No. 1 through No. N (N=Number of camera systems):

One record is needed for each camera system.

Character	Content	Format/Remarks
1-8	Camera system identification. A blank identification is legal and may be used in case there is only one camera system	2A4
11-20	Principal distance[1] for the camera system to produce right-handed camera coordinate system	F10.3

[1]Negative, if working in positive plane; and positive if working in negative plane.

3. IMAGES File

This file contains preprocessed image measurements for the photographic block. Frames may be included in this file in any desired order.

Record No. 1 - Frame Header Record

Character	Content	Format/Remarks
1-8	Frame identification	2A4
11-20	Camera system principal distance with proper sign. If this data field is left blank, the principal distance will be extracted by GIANT from CAMERAS file.	F10.3
21-30	Assigned standard deviation of image x-coordinate. Default option for this field is 0.010 mm.	F10.3

8

31-40	Assigned standard deviation of image y-coordinate. Default option for this field is 0.010 mm.	F10.3
41-48	Camera system identification	2A4

‑In triangulation tasks which involve one camera system, the camera system identification can be selected as blank. This alleviates the need to enter characters in columns 41-48 of the current record. Furthermore, if the default standard deviations for image coordinates are exercised, then columns 21-40 of the Image Coordinates Header Record can be left blank.

Record No. 2 through No. (N+1) (N = Number of image points in a frame)

One record for each image point is required.

Character	Content	Format/Remarks
1-8	Image point identification	2A4
11-20	Image x-coordinate	F10.3
21-30	Image y-coordinate	F10.3

Any number of image coordinate records can be included for each frame

Record No. (N+2): Frame termination record

Character	Content	Format/Remarks
1-8 ****		2A4

4. FRAMES File

This file supplies GIANT with estimates of camera station positions and attitudes. The frames included in this file must have image coordinates included in the IMAGES file. However, frames in the IMAGES file may or may not be included in the FRAMES file. Only those frames mentioned in the FRAMES file will be considered in the triangulation process.

The order in which frames are included in this file influences the performance and efficiency of the triangulation process. This subject is discussed in appendix A.

Two records for each of the camera stations position and attitude are provided as follows:

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Record No. 1: Camera station position

Character	Content	Format/Remarks
1-8	Camera station (frame) identification	2A4
9-20	Primary component of camera station position coordinates: X-coordinate, for space rectangular coordinate system (linear units); longitude (λ) for geographic coordinate system (DMS)	F12.3
21-32	Secondary component of camera station position coordinates: Y-coordinate for space rectangular coordinate system (linear units); latitude (ϕ) for geographic coordinate system (DMS)	F12.3
33-44	Tertiary component of camera station position coordinates: Z-coordinate for space rectangular coordinate system (linear units); elevation (h) for geographic coordinate system	F12.3
45-54	Standard deviation of primary coordinate of camera statio position: X-for rectangular coordinate system (default option = 60,000 units); λ-for geographic coordinate system (default option = 10 minutes) (DMS)	F10.3
55-64	Standard deviation of secondary coordinate of camera station position: Y-for rectangular coordinate system (default option = 60,000 units); ϕ-for geographic coordinate system (default option = 10 minutes) (DMS)	F10.3
65-74	Standard deviation of tertiary coordinate of camera station position: Z-for rectangular coordinate system (default option = 60,000 units); h-for geographic coordinate system; (default option = 60000 units)	F10.3

Note: DMS field is read as real field and then interpreted as degrees, minutes, and seconds.

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Record No. 2: Camera station attitude

Camera station attitude record must be prepared in the following format:

Character	Content	Format/Remarks
1-8	Camera station (frame) identification	2A4
9-20	Primary rotation angle (ω) of camera station attitude (DMS)	F12.3
21-32	Secondary rotation angle (ϕ) of camera station attitude (DMS)	F12.3
33-44	Tertiary rotation angle (κ)[1] of camera station attitude (DMS)	F12.3
45-54	Standard deviation of primary rotation angle of camera station, attitude (default option = 90 degrees) (DMS)	F10.3
55-64	Standard deviation of secondary rotation angle of camera station, attitude (default option = 90 degrees) (DMS)	F10.3
65-74	Standard deviation of tertiary rotation angle of camera station attitude	F10.3

[1](κ) is approximated by a clockwise angle (photo to ground) and counter-clockwise (ground to photo) measured from east to the photo (x) in the plane of the vertical photograph.

The maximum number of camera stations depends on the value of the parameter (N1) which is defined during the installation of the GIANT program. (See sec. I.B.)

5. GROUND File

This file contains the ground coordinates of ground control points up to the maximum number specified by the parameter N3, explained in Section I.B. The value of N3 is assigned during the installation of GIANT.

Record No. 1 through No. N, (N = number of ground control points):

Character	Content	Format/Remarks
1-8	Identification of ground point	2A4

9-20	Primary component of ground control coordinates: X-for rectangular coordinate system (linear units); longitude (λ) for geographic coordinate system (DMS)	F12.3
21-32	Secondary component of ground control coordinates: Y-for rectangular coordinate system (linear units); latitude (ϕ) for geographic coordinate system (DMS)	F12.3
33-44	Tertiary component of ground control coordinates: Z-for rectangular coordinate system (linear units); elevation (h) for geographic coordinate system (DMS)	F12.3
45-54	Standard deviation of primary component of ground control coordinates: X-for rectangular coordinate system (default = 1.0 units) h-for geographic coordinate system (default = 0.01 DMS)	F10.3
55-64	Standard deviation of secondary component of ground control coordinates: Y-for rectangular coordinate system (default = 1.0 units); ϕ-for geographic coordinate system (default = 0.01) (DMS)	F10.3
65-74	Standard deviation of tertiary component of ground control coordinates: Z-for rectangular coordinate system (default = 1.0 units); h-for geographic coordinate system (default = 1.0 units)	F10.3
80	Missing component indicator: = 1, means primary component is to be ignored. = 2, means secondary component is to be ignored. = 4, means tertiary component is to be ignored. = X, where X is the sum of any two of the above mentioned codes, means that the corresponding two components are to be ignored.	I1

6. Sample Input Data File

   The computer printout that follows shows the input data corresponding to
the aerotriangulation project depicted in figure 2.   The input data are
in five distinct data files: COMMON, CAMERAS, FRAMES, IMAGES, and GROUND.
(See sec. II.B.)

   The sample project consists of an area covered by 20 photographs in two
flight lines, controlled by 12 ground points.
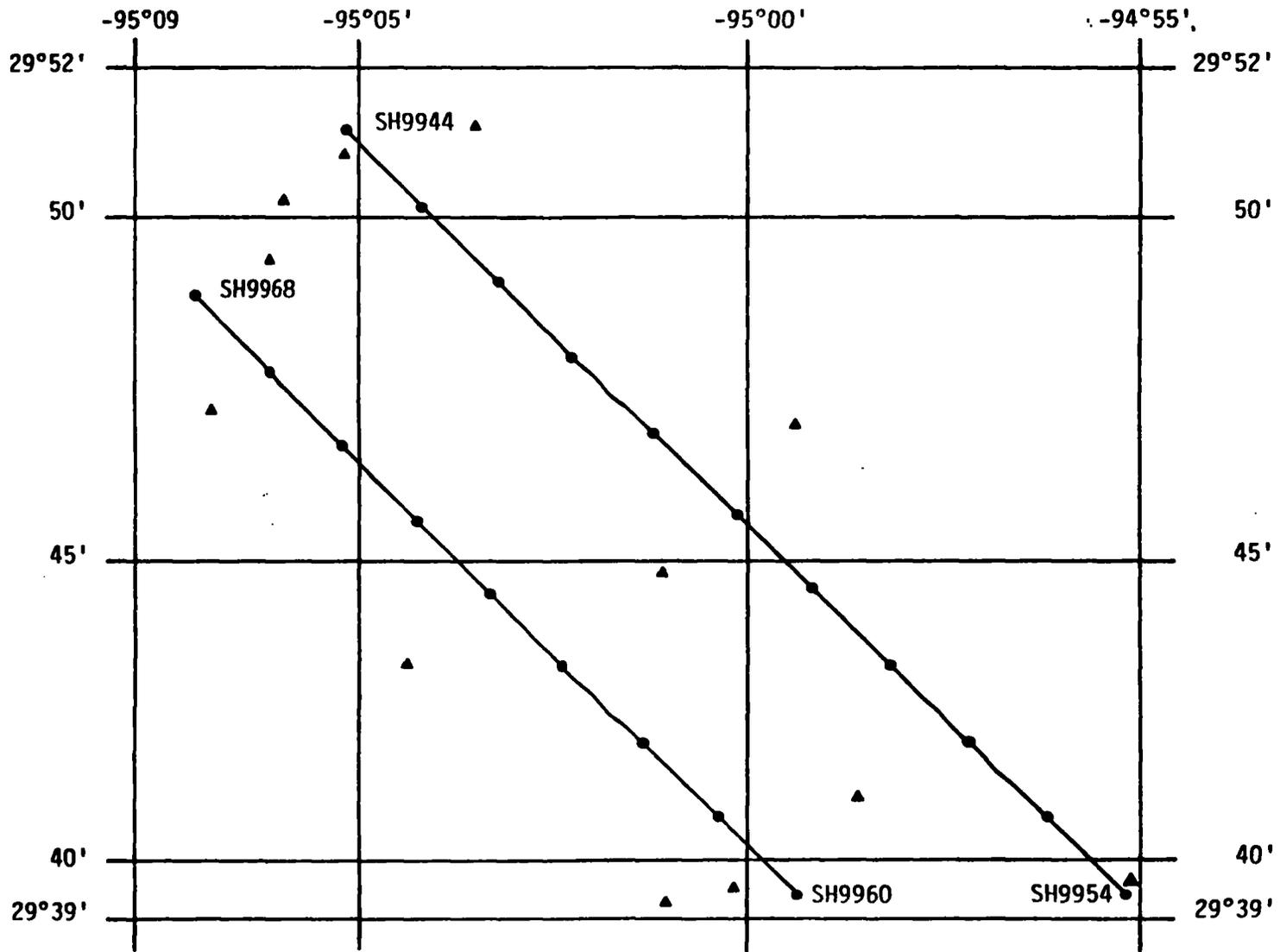
Figure II.2.--Aerotriangulation project (layout)

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```
------------------- SAMPLE DATA FOR 'COMMON' FILE -------------------------


         1         2         3         4         5         6         7         8
1234567890123456789012345678901234567890123456789012345678901234567890
-------------------------------------------------------------------

SAMPLE RUN FOR NOAA/NOS GIANT PROGRAM .........          17-SEP-86    09155138.
10000000000004011 5                 0.000     0.0006378206.406356583.80
     0.001     0.010
```

#1- Job Title
#2- Job Definition
#3- Standard Deviations

```
------------------- SAMPLE DATA FOR 'CAMERA' FILE -------------------------


         1         2         3         4         5         6         7         8
1234567890123456789012345678901234567890123456789012345678901234567890
-------------------------------------------------------------------

   P1982     -152740
```

Record Description

#1- Camera System

```
-------------------- SAMPLE DATA FOR 'IMAGES' FILE ---------------------------


          1         2         3         4         5         6         7         8
123456789012345678901234567890123456789012345678901234567890123456789012345678890
-----------------------------------------------------------------------------------
   SH9961                                        R1982
       68!       -86807    106916
       69!       -77273     95902
   SH960801      -49241     48405
       70!       -35745      3609
                                .
                                .
                                .
      126!       -46485       2046
       59!      -103584     -75317
   ********
   SH9962                                        R1982
   SH960202      -93350     -93987
       75!       -88304    -104863
       76!       -87019     -97520
       77!       -82804      2070
                                .
                                .
                                .
```

Record Description

#1- Frame Header Record
#2- Image ID, coordinates
.
.
.
.
.
#N+1 "   "   "
#N+2 Frame termination
#1-   Frame Header Record
.
.
.
.
.
.
.

```
---------------------- SAMPLE DATA FOR 'FRAMES' FILE -------------------------



          1         2         3         4         5         6         7         8
123456789012345678901234567890123456789012345678901234567890123456789012345678890
-----------------------------------------------------------------------------------
   SH9960 -945904.761  293917.784     4556.590
   SH9960    -4130.226   -1035.705  2364504.671
   SH9961  -950005.264  294034.351     4555.653
   CH9961     2818.926   -1931.409  2384240.811
   SH9962  -950059.458  294140.858     4553.571
   SH9962     1520.455     930.510  2364145.075
   SH9963  -950200.215  294240.373     4552.063
   SH9963     -855.969     259.447  2345808.755
   SH9964  -950302.375  294359.139     4553.753
   SH9964    -2050.849     -35.216  2371113.622
                              .
                              .
                              .
                              .
                              .
                              .
```

Record Description

#1- Camera Station Position
#2- Camera Station Attitude
.
.
.
.
.
.
.
.
.
.
.

16

------------------- SAMPLE DATA FOR 'GROUND' FILE ----------------------------

```
             1         2         3         4         5         6         7         8
    1234567890123456789012345678901234567890123456789012345678901234567890
    ----------------------------------------------------------------------------

    SH944801 -950516.041  295049.918      2.797                            4
    SH944802 -950518.614  295047.727      2.179                            4
    SH949801 -950111.443  294450.268      5.932                            4
    SH949802 -950048.091  294452.226      6.189                            4
    SH954801 -945511.703  293929.564      7.619                            4
    SH954802 -945510.056  293926.314      7.173                            4
                               .
                               .
                               .
    SH968201       0.000        0.000     10.973                           3
    SH968202 -950525.594  294904.070      1.524                            3
```

Record Description

#1-   Ground control

.
.
.
.
.
.
#N-   ▪   ▪

C. Output Files

1. Printout File

Logical identification no. 6, table II.1 is a formatted data file, the contents of which depend on the print options selected in the job definition record of the COMMON input file. The printout gives the adjusted ground coordinates of the image points measured on two or more photographs, and the parameters, position, and attitude of each camera.

A typical sample of the printout file follows. Explanations of the items appearing on the computer printout are also given.

2. Updated Frames Data File

Logical identification no. 8, table II.1 contains adjusted values of parameters of each camera position and attitude. This file is created during each iteration of a successful convergent solution of GIANT. This file is used in applications such as stereocompilation and orthophoto mosaic.

Logical identification no. 20, table II.1 contains adjusted values of parameters of each camera position and attitude, irrespective of solution convergence. This file can always be used at the user's option to restart the iterative solution from where it was left off.

3. Adjusted Ground Data File

Logical identification no. 9, table II.1 contains adjusted ground coordinates of all image points measured on two or more photographs. This file is created during each iteration of a successful convergent solution of GIANT. This file is used in applications to generate images by stereo-compilation and orthophoto mosaics.

4. Sample Printout File

This section contains an explanation of a sample printout file for a typical aerotriangulation project. Figure 2 shows the layout of the aerotriangulation project. Typical pages of the printout file are selectively reproduced for this report. A page-by-page description of the printout follows. Two computer runs were made for the aerotriangulation.

o Case No. 1. Without a request for error propagation in the aerotriangulation

o Case No. 2 With a request for error propagation in the aerotriangulation.

Explanation of Sample Printout File

Case No. 1: No Error Propagation
Requested in Aerotriangulation

Page Numbers Printout/Text	Case No. 1 Contents/Explanation
0/22	A description of the options selected in the "job-definition" record of the COMMON file of the input data is printed on this page.
Example:	In the first run, error propagation was not requested, as indicated on line four. This also corresponds to option =0 in character 11 of record No. 2 (job definition) of the input file COMMON.

1/23	The following information appears on this page:
	
	o Frame number
	o Principal distance
	o Standard deviations of measurements of x and y image coordinates
	o Camera station position:
	  - Longitude and its std. dev. (deg. min. sec.)
	  - Latitude and its std. dev. (deg. min. sec.)
	  - Elevation and its std. dev. (meters)
	o Camera attitude: (photo to ground)
	  - Omega (roll) and its std. dev. (deg. min. sec.)
	  - Phi (pitch) and its std. dev. (deg. min. sec.)
	  - Kappa (yaw) and its std. dev. (deg. min. sec.)
	o Plate coordinates:
	  - ID image point
	  - x refined plate coordinate (millimeters)
	  - y refined plate coordinate (millimeters)

21/24	o Ground control data
	  - ID ground control point
	  - Longitude and its std. dev. (deg. min. sec.)
	  - Latitude and its std. dev. (deg. min. sec.
	  - Elevation and its std. dev. (meters)
	o Type of control--planimetry, vertical or both. Details are given in the description for character 80, sec. II.B.5.

24/25	Error warnings: Points not photographed. This error warning appears when ground control data are input but no x,y plate coordinates were entered in the input data. Note: Section III contains a list of error warnings and their explanation.

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25/26   Camera station corrections:

This page shows the corrections to the position and attitude
parameters of a camera after performing an iteration in the
iterative solution. The provisional weighted sum of squares
also appears at the end of the page. This total is used for
obtaining a posterior estimates for the unit weight variance.
The difference in its current value and its value in the
previous iteration forms a criterion for convergence of the
solution (character 18-19, sec. IIB.1).

The printout contains the following information:

o   Iteration number
o   Photo or camera station number (SH9960, etc.)
o   Positional corrections (meters) to X, Y, and Z
    coordinates of each of the camera stations.
o   Attitude corrections (radians) to roll, pitch,
    and yaw at each of the camera station.
o   Provisional weighted sum of squares.

29/27   The residuals in the plate coordinates appear at the end of a
least squares adjustment of the aerotriangulation computer run.

The printout shows the following:

o   ID of the image measured
o   .ID of frames in which each point was measured and image
    coordinates entered in the solution
o   Residuals (microns) in the x and y coordinates of the image
    point
o   Weighted sum of squares (camera)
o   Weighted sum of squares (ground)
o   Weighted sum of squares (plates)
o   Weighted sum of square (total)
o   Degrees of freedom
o   A posteriori estimates for unit weight variance
o   Standard deviation

The weighted sum of squares value gives the contributions of
various factors to the total residuals in the solution. The a
posteriori estimates for unit weight variance will compute near
to 1 to indicate the relative weights of the parameters entering
the solution were realistic. This value is an indication of the
soundness of the weight assignments.

30/28   This page shows the state vectors of the triangulated camera
          stations:

          o   ID of camera stations
          o   Position vector:
              -   Adjusted longitude (deg. min. sec.)
              -   Adjusted latitude (deg. min. sec.)
              -   Adjusted elevation (meters, above datum)

          o   Attitude (photo to ground)
              -   Adjusted omega (roll) (deg. min. sec.)
              -   Adjusted phi (pitch) (deg. min. sec.) ·
              -   Adjusted kappa (yaw) (deg. min. sec.)

34/29   This page contains the position vectors of the triangulated
          ground points:

          o   ID of object points (including ground control points
              indicated by type in front of ID)
          o   Type (vertical, horizontal, or both vertical and
              horizontal ground control)
          o   Adjusted longitude (deg. min. sec.)
          o   Adjusted latitude (deg. min. sec.)
          o   Adjusted elevation (meters, above datum)

35/30   This page gives the corrections applied to the ground control.
          The "type" of ground control is considered in the least squares
          solution. Accordingly, weights are assigned to constrain one,
          two, or all three components, X, Y, and Z of a control point.

          In the printout, the following appears:

          o   ID ground control point
          o   Corrections to longitude and latitude (deg. min. sec.) and
              elevation (meters) of a control point.

                  Note: In case it is a vertical control point the latitude
                          and longitude corrections appear within parentheses;
                          whereas, in the case of a horizontal ground control,
                          the elevation correction appears within parentheses.

          o   Longitude - number of components, indicates number of ground
              control whose longitude values are known and constrained
              accordingly in the least squares adjustment.
          o   Latitude - number of components, indicates number of ground
              control whose latitude values are known and constrained
              accordingly in the least squares adjustment.
          o   Elevation - number of components, indicates number of ground
              control whose elevation values are known and constrained
              accordingly in the least squares adjustment.
          o   rms - root mean square errors for longitude and latitude
              (deg. min. sec.).
          o   rms - root mean square error in elevation (meters).

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OBJECT SPACE REFERENCE SYSTEM IS GEOGRAPHIC

ROTATION ANGLES ARE PHOTO-TO-GROUND

COMPLETE TRIANGULATION PROCESS IS REQUESTED

ERROR PROPAGATION IS NOT REQUESTED

ATMOSPHERIC REFRACTION WILL NOT BE INCLUDED IN THE ADJUSTMENT

WATER REFRACTION WILL NOT BE INCLUDED IN THE ADJUSTMENT

IMAGE RESIDUALS GREATER THAN 0.010 (MM) WILL BE LISTED

LEADING 'O' WILL BE ELIMINATED FROM ALL IDENTIFICATIONS

SEMI-MAJOR AXIS OF SPHEROID = 6378206.400 METERS

SEMI-MINOR AXIS OF SPHEROID = 6356583.800 METERS

TRIANGULATED GROUND COORDINATES WILL BE SAVED

ADJUSTED CAMERA STATION PARAMETERS WILL BE SAVED

22

FRAME   SH9960

PRINCIPAL DISTANCE = -152.7400   ST. D. OF X = 0.0100   ST. D. OF Y = 0.0100

CAMERA STATION PARAMETERS

         P O S I T I O N   A T T I T U D E (PHOTO TO GROUND)

LNG = - 94 59 4.7610   ST. D. =   0 10 0.0000   OMEGA = -   0 41 30.2260   ST. D. =   90 0 0.0000
LAT =   29 39 17.7840   ST. D. =   0 10 0.0000   PHI   = -   0 10 35.7050   ST. D. =   90 0 0.0000
ELV =   4556.5900   ST. D. =   60000.0000   KAPPA =   236 45 4.6710   ST. D. =   90 0 0.0000

PLATE COORDINATES

ID	X	Y	ID	X	Y	ID	X	Y	ID	X	Y
68!	12.6600	107.8540	69!	21.7510	96.7480	SH960801	47.9600	49.0670	70!	59.9770	4.0570
71!	64.5380	6.4370	73!	-1.3600	-76.1440	74!	-1.2510	-67.7940	SH960202	88.5150	-91.9620
75!	93.6440	-103.0550	77!	98.8530	4.9780	78!	97.3900	-0.0130	79!	99.0910	98.6310
80!	96.4170	92.4890	SH960201	52.7070	95.8030	76!	95.0000	-95.5670	SH960802	52.8510	55.7040
59!	-11.4200	-73.5210	61!	-11.0180	-76.1590	53!	68.9230	-77.6700	54!	68.8690	-86.9090
126!	49.2050	2.8590									

G R O U N D   C O N T R O L   D A T A   .

SH944B01	LNG = - 95 5 16.0410 LAT = 29 50 49.9180 ELV = 2.7970	ST. D. = 0 0 0.0010 ST. D. = 0 0 0.0010 ST. D. = 0.0100	TYPE = 4
SH944B02	LNG = - 95 5 18.6140 LAT = 29 50 47.7270 ELV = 2.1790	ST. D. = 0 0 0.0010 ST. D. = 0 0 0.0010 ST. D. = 0.0100	TYPE = 4
SH949B01	LNG = - 95 1 11.4430 LAT = 29 44 50.2680 ELV = 5.9320	ST. D. = 0 0 0.0010 ST. D. = 0 0 0.0010 ST. D. = 0.0100	TYPE = 4
SH949B02	LNG = - 95 0 48.0910 LAT = 29 44 52.2260 ELV = 6.1890	ST. D. = 0 0 0.0010 ST. D. = 0 0 0.0010 ST. D. = 0.0100	TYPE = 4
SH954B01	LNG = - 94 55 11.7030 LAT = 29 39 29.5640 ELV = 7.6190	ST. D. = 0 0 0.0010 ST. D. = 0 0 0.0010 ST. D. = 0.0100	TYPE = 4
SH954B02	LNG = - 94 55 10.0560 LAT = 29 39 26.3140 ELV = 7.1730	ST. D. = 0 0 0.0010 ST. D. = 0 0 0.0010 ST. D. = 0.0100	TYPE = 4
SH960B02	LNG = - 95 0 30.1950 LAT = 29 39 29.6740 ELV = 5.5940	ST. D. = 0 0 0.0010 ST. D. = 0 0 0.0010 ST. D. = 0.0100	TYPE = 4
SH964B01	LNG = - 95 3 55.6190 LAT = 29 43 36.3240 ELV = 5.7350	ST. D. = 0 0 0.0010 ST. D. = 0 0 0.0010 ST. D. = 0.0100	TYPE = 4
SH964B02	LNG = - 95 3 36.1650 LAT = 29 43 39.2220 ELV = 4.9750	ST. D. = 0 0 0.0010 ST. D. = 0 0 0.0010 ST. D. = 0.0100	TYPE = 4
SH968B01	LNG = - 95 6 17.8040 LAT = 29 49 10.4110 ELV = 10.5210	ST. D. = 0 0 0.0010 ST. D. = 0 0 0.0010 ST. D. = 0.0100	TYPE = 4

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E R R O R   W A R N I N G S

POINTS NOT PHOTOGRAPHED

SH954202   SH968201

C A M E R A   S T A T I O N S   C O R R E C T I O N S

ITERATION   2

SH9960	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000137	0.000000286	-0.000000001
SH9961	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000123	0.000000213	0.000000013
SH9962	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000119	0.000000026	0.000000005
SH9963	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000104	-0.000000078	-0.000000005
SH9964	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000100	-0.000000096	0.000000000
SH9965	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000044	-0.000000060	0.000000004
SH9966	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000052	-0.000000005	0.000000001
SH9967	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000033	0.000000015	0.000000004
SH9968	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000026	0.000000031	0.000000005
SH9944	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000019	0.000000003	-0.000000011
SH9945	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000028	-0.000000001	-0.000000011
SH9946	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000033	0.000000027	-0.000000010
SH9947	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000043	0.000000040	-0.000000005
SH9948	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000044	0.000000022	0.000000001
SH9949	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000047	-0.000000071	0.000000011
SH9950	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000039	-0.000000068	-0.000000005
SH9951	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000091	-0.000000025	-0.000000025
SH9952	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000144	0.000000035	-0.000000011
SH9953	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000177	0.000000166	0.000000007
SH9954	POSITION	0.000000000	0.000000000	0.0	ATTITUDE	-0.000000170	0.000000320	-0.000000003

PROVISIONAL WEIGHTED SUM OF SQUARES =   273.446

T R I A N G U L A T E D   G R O U N D   P O I N T S   R E S I D U A L S

```
     47!          SH9952    SH9950    SH9951
                    -2        -2
                    16       -16


     48!          SH9952    SH9950    SH9951
                     0
                   -10


 SH951201 #3#     SH9952    SH9953    SH9951
                     6        -2
                   -16        16


     49!          SH9952    SH9953    SH9951
                   -11
                    -4


 SH954201 #3#     SH9953    SH9954
                    14       -14
                    -3         3


 SH954801 #4#     SH9953    SH9954
                     0       -12
                   -15       -14


 SH954802 #4#     SH9953    SH9954
                     0         3
                    12        15
```

```
              WEIGHTED SUM OF SQUARES (CAMERA) =              0.0
              WEIGHTED SUM OF SQUARES (GROUND) =              0.7
              WEIGHTED SUM OF SQUARES (PLATES) =            272.1

              WEIGHTED SUM OF SQUARES (TOTAL)  =            272.7
              DEGREES OF FREEDOM.............  =             296


              A POSTERIORI ESTIMATES FOR UNIT WEIGHT
              VARIANCE =              0.921
              ST. DEV. =              0.960
```

TRIANGULATED CAMERA STATIONS

IDENT	POSITION	ATT(PHOTO TO GROUND)
	LNG =- 94 59 4.7584	OMEGA =- 0 41 24.3710
SH9960	LAT = 29 39 17.7712	PHI =- 0 10 17.9136
	ELV = 4556.0635	KAPPA = 236 45 7.6484
	LNG =- 95 0 5.2715	OMEGA = 0 28 23.6767
SH9961	LAT = 29 40 34.3562	PHI =- 0 19 39.0393
	ELV = 4555.3282	KAPPA = 238 42 43.0987
	LNG =- 95 0 59.4571	OMEGA = 0 15 18.4795
SH9962	LAT = 29 41 40.8605	PHI = 0 9 28.8849
	ELV = 4553.1973	KAPPA = 236 41 42.8541
	LNG =- 95 2 0.2159	OMEGA =- 0 8 54.2962
SH9963	LAT = 29 42 48.3705	PHI = 0 3 2.5829
	ELV = 4552.5076	KAPPA = 234 58 7.5545
	LNG =- 95 3 2.3908	OMEGA =- 0 20 54.4774
SH9964	LAT = 29 43 59.1374	PHI =- 0 0 31.0700
	ELV = 4553.4255	KAPPA = 237 11 13.9764
	LNG =- 95 4 2.6792	OMEGA = 1 13 16.7764
SH9965	LAT = 29 45 11.1399	PHI = 0 9 52.0745
	ELV = 4553.7045	KAPPA = 236 27 50.4526
	LNG =- 95 5 5.0642	OMEGA =- 0 32 4.4950
SH9966	LAT = 29 46 20.4084	PHI = 0 5 18.0096
	ELV = 4555.2808	KAPPA = 235 30 29.5986
	LNG =- 95 6 6.0711	OMEGA = 0 32 47.9422
SH9967	LAT = 29 47 31.7126	PHI = 0 4 55.4632
	ELV = 4552.0072	KAPPA = 237 26 24.2821
	LNG =- 95 7 7.5601	OMEGA = 0 15 55.5151
SH9968	LAT = 29 48 42.6416	PHI =- 0 2 47.9791
	ELV = 4550.4708	KAPPA = 235 33 20.4221
	LNG =- 95 5 10.6064	OMEGA = 0 0 35.4989
SH9944	LAT = 29 51 14.6589	PHI =- 0 0 28.5105
	ELV = 4556.3120	KAPPA = 54 10 33.2683
	LNG =- 95 4 9.3668	OMEGA = 0 53 26.3893
SH9945	LAT = 29 50 2.7501	PHI =- 0 3 39.0114
	ELV = 4554.8360	KAPPA = 55 22 56.1853
	LNG =- 95 3 9.3226	OMEGA =- 0 48 42.4201
SH9946	LAT = 29 48 53.3068	PHI =- 0 11 49.0202
	ELV = 4554.1961	KAPPA = 54 28 12.5411
	LNG =- 95 2 8.1568	OMEGA = 0 21 24.8404
SH9947	LAT = 29 47 40.9429	PHI =- 0 8 8.3634
	ELV = 4554.3942	KAPPA = 54 51 50.5392

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T R I A N G U L A T E D   G R O U N D   P O I N T S

IDENT		POSITION			
110!		LNG =- 95 6 35.3090	LAT = 29 45 27.3839	ELV =	8.423
111!		LNG =- 95 6 26.6386	LAT = 29 45 32.6618	ELV =	7.378
112'		LNG =- 95 7 33.8850	LAT = 29 46 41.5368	ELV =	10.533
113!		LNG =- 95 7 27.9736	LAT = 29 46 47.3303	ELV =	10.214
114!		LNG =- 95 6 4.4026	LAT = 29 47 31.8810	ELV =	9.555
115'		LNG =- 95 6 1.1728	LAT = 29 47 32.1506	ELV =	9.503
116!		LNG =- 95 5 25.2642	LAT = 29 47 57.0267	ELV =	1.757
117'		LNG =- 95 4 52.1371	LAT = 29 48 33.7366	ELV =	3.835
118!		LNG =- 95 5 50.1185	LAT = 29 49 31.0686	ELV =	4.674
119'		LNG =- 95 6 21.9812	LAT = 29 49 10.3684	ELV =	10.974
120'		LNG =- 95 7 9.8553	LAT = 29 48 39.5607	ELV =	11.070
121'		LNG =- 95 7 18.0753	LAT = 29 48 35.3197	ELV =	11.337
122!		LNG =- 95 8 30.2280	LAT = 29 47 52.4081	ELV =	11.968
123!		LNG =- 95 8 39.8166	LAT = 29 47 54.9031	ELV =	11.453
126!		LNG =- 94 59 38.7142	LAT = 29 39 54.7204	ELV =	3.374
963501		LNG =- 95 1 13.8957	LAT = 29 42 11.6349	ELV =	2.182
963502		LNG =- 95 1 9.0705	LAT = 29 42 14.7312	ELV =	2.287
963503		LNG =- 95 1 14.0676	LAT = 29 42 19.3038	ELV =	1.375
SH944201	#3#	LNG =- 95 3 31.5220	LAT = 29 51 15.1416	ELV =	15.240
SH944202	#3#	LNG =- 95 6 2.4690	LAT = 29 50 14.3388	ELV =	0.000
SH944801	#4#	LNG =- 95 5 16.0411	LAT = 29 50 49.9180	ELV =	2.776
SH944802	#4#	LNG =- 95 5 18.6140	LAT = 29 50 47.7271	ELV =	2.157
SH948201	#3#	LNG =- 94 59 25.8747	LAT = 29 46 48.5947	ELV =	9.449
SH948202	#3#	LNG =- 95 2 2.2978	LAT = 29 44 57.8201	ELV =	0.000
SH949801	#4#	LNG =- 95 1 11.4431	LAT = 29 44 50.2679	ELV =	6.484
SH949802	#4#	LNG =- 95 0 48.0912	LAT = 29 44 52.2261	ELV =	6.295
SH951201	#3#	LNG =- 94 55 59.3565	LAT = 29 42 51.0064	ELV =	0.000
SH954201	#3#	LNG =- 94 57 10.5959	LAT = 29 38 53.5691	ELV =	6.706
SH954801	#4#	LNG =- 94 55 11.7027	LAT = 29 39 29.5641	ELV =	7.677
SH954802	#4#	LNG =- 94 55 10.0562	LAT = 29 39 26.3139	ELV =	7.246
SH960201	#3#	LNG =- 95 1 7.7730	LAT = 29 39 8.1803	ELV =	5.486
SH960202	#3#	LNG =- 94 58 34.9651	LAT = 29 41 15.9415	ELV =	0.001
SH960801	#4#	LNG =- 95 0 21.0798	LAT = 29 39 29.2370	ELV =	1.803
SH960802	#4#	LNG =- 95 0 30.1952	LAT = 29 39 29.6741	ELV =	5.385
SH964201	#3#	LNG =- 95 4 26.3592	LAT = 29 43 24.7486	ELV =	9.754
SH964801	#4#	LNG =- 95 3 55.6187	LAT = 29 43 36.3239	ELV =	5.773
SH964802	#4#	LNG =- 95 3 36.1652	LAT = 29 43 39.2221	ELV =	5.017
SH968202	#3#	LNG =- 95 5 25.5941	LAT = 29 49 4.0696	ELV =	1.524
SH968801	#4#	LNG =- 95 6 17.8042	LAT = 29 49 10.4311	ELV =	10.493
SH968802	#4#	LNG =- 95 6 21.9926	LAT = 29 49 10.3719	ELV =	11.173

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                              C O R R E C T I O N S   A P P L I E D   T O   G R O U N D   C O N T R O L

```
            LNG=(  0  0  0.0000)              LNG=(  0  0  0.0000)              LNG= -  0  0  0.0001              LNG= -  0  0  0.0001
  SH944201  LAT=(  0  0  0.0000)   SH948201   LAT=(  0  0  0.0000)   SH944801  LAT=    0  0  0.0000   SH949801  LAT= -  0  0  0.0001
            ELV=       0.000                  ELV=       0.000                ELV=(       0.000)               ELV=(       0.000)

            LNG=(  0  0  0.0000)              LNG=(-  0  0  0.0000)              LNG=    0  0  0.0000              LNG= -  0  0  0.0002
  SH944202  LAT=(-  0  0  0.0000)   SH948202   LAT=(-  0  0  0.0000)   SH944802  LAT=    0  0  0.0001   SH949802  LAT=    0  0  0.0000
            ELV=       0.000                  ELV=       0.000                ELV=(       0.000)               ELV=(       0.000)

            LNG=(  0  0  0.0000)              LNG=(-  0  0  0.0000)              LNG=    0  0  0.0003              LNG= -  0  0  0.0002
  SH951201  LAT=(  0  0  0.0000)   SH954201   LAT=(-  0  0  0.0000)   SH954801  LAT=    0  0  0.0001   SH954802  LAT= -  0  0  0.0001
            ELV=       0.000                  ELV=       0.000                ELV=(       0.001)               ELV=(       0.001)

            LNG=(-  0  0  0.0000)              LNG=(-  0  0  0.0000)              LNG=    0  0  0.0002              LNG=    0  0  0.0003
  SH960201  LAT=(-  0  0  0.0000)   SH964201   LAT=(-  0  0  0.0000)   SH960801  LAT= -  0  0  0.0000   SH964801  LAT= -  0  C  0.0001
            ELV=       0.000                  ELV=       0.000                ELV=(       0.000)               ELV=(       0.000)

            LNG= -  0  0  0.0002              LNG=(  0  0  0.0000)              LNG=(-  0  0  0.0000)              LNG= -  0  0  0.0002
  SH968801  LAT=    0  0  0.0001   SH960202   LAT=(-  0  0  0.0000)   SH968202  LAT=(-  0  0  0.0000)   SH960802  LAT=    0  0  0.0001
            ELV=(       0.000)                ELV=       0.001                ELV=       0.000                ELV=(       0.000)

            LNG= -  0  0  0.0002              LNG=    0  0  0.0004
  SH964802  LAT=    0  0  0.0001   SH968802   LAT= -  0  0  0.0001
            ELV=(       0.000)                ELV=(       0.000)
```

```
                        LNG .... NUMBER OF COMPONENTS =   12    RMS =    0  0  0.0002
                        LAT .... NUMBER OF COMPONENTS =   12    RMS =    0  0  0.0001
                        ELV .... NUMBER OF COMPONENTS =   10    RMS =       0.0002
```

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Explanation of Sample Printout File

Case No. 2: Error Propagation Requested
in Aerotriangulation

NOTE: Printout page number 0 and three new pages (41, 53, and 54) are given here to show the enhancement over the previous case, Case No. 1.

Page Numbers Printout/Text	Case No. 2 Contents/Explanation
0/32	A description of the options selected in the job definition record of the COMMON file of the input data is printed on this page.
Example:	Line 4 describes the option which was selected in character 11 of record No. 2 (job definition) of the input data file COMMON.
	According to this option, error propagation was selected.
41/33	This page corresponds to printout page 30 (Case No. 1), which gives adjusted longitude, latitude, and elevation of the triangulated camera stations. In addition to the position parameters, corresponding 3 by 3 covariance matrices are printed. Another 3 by 3 covariance matrix for the three rotational angles (ω,ϕ,κ) is also printed. Square root of a diagonal term gives the standard deviation with which the corresponding parameter has been determined. During the computations, all angular parameters are expressed in radians, such that the square root of a diagonal term of an angular parameter gives the standard deviation in radians.
53/34	This page gives the position vector of the triangulated ground points as shown on printout page 34 (Case No. 1), but, in addition, shows a 3 by 3 covariance matrices for the three components: longitude, latitude, and elevation. The square root of each of the diagonal terms of the covariance matrix gives the standard deviation of determination with which these components have been determined.
54/35	This is a continuation of printout page 53 (Case No. 2) giving the triangulated ground point. The rms errors in longitude, latitude, and elevation are displayed. These rms values are averaged over all the triangulated ground points.

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OBJECT SPACE REFERENCE SYSTEM IS GEOGRAPHIC

ROTATION ANGLES ARE PHOTO-TO-GROUND

COMPLETE TRIANGULATION PROCESS IS REQUESTED

ERROR PROPAGATION IS REQUESTED

UNIT VARIANCE WILL BE BASED ON COMPLETELY FREE CAMERA PARAMETERS

ATMOSPHERIC REFRACTION WILL NOT BE INCLUDED IN THE ADJUSTMENT

WATER REFRACTION WILL NOT BE INCLUDED IN THE ADJUSTMENT

ALL IMAGE RESIDUALS WILL BE LISTED

LEADING '0' WILL BE ELIMINATED FROM ALL IDENTIFICATIONS

SEMI-MAJOR AXIS OF SPHEROID = 6378206.400 METERS

SEMI-MINOR AXIS OF SPHEROID = 6356583.800 METERS

TRIANGULATED GROUND COORDINATES WILL BE SAVED

ADJUSTED CAMERA STATION PARAMETERS WILL BE SAVED

T R I A N G U L A T E D   C A M E R A   S T A T I O N S

IDENT	POSITION			COVARIANCE MATRIX			ATT(PHOTO TO GROUND)			COVARIANCE MATRIX		
	LNG =- 94 59 4.7584			0.377E-13	-0.626E-14	-0.296E-07	OMEGA =- 0 41 24.3710			0.242E-07	-0.935E-08	0.567E-08
SH9960	LAT = 29 39 17.7712			-0.626E-14	0.182E-13	0.631E-07	PHI =- 0 10 17.9136			-0.935E-08	0.486E-07	-0.181E-08
	ELV = 4556.0635			-0.296E-07	0.631E-07	0.355E+00	KAPPA = 236 45 7.6404			0.567E-08	-0.181E-08	0.569E-08
	LNG =- 95 0 5.2715			0.148E-13	0.962E-15	0.204E-07	OMEGA = 0 28 23.6767			0.190E-07	0.115E-08	-0.698E-09
SH9961	LAT = 29 40 34.3562			0.962E-15	0.140E-13	0.132E-07	PHI =- 0 19 39.0393			0.115E-08	0.203E-07	0.650E-09
	ELV = 4555.3282			0.204E-07	0.132E-07	0.145E+00	KAPPA = 238 42 43.0987			-0.698E-09	0.650E-09	0.229E-08
	LNG =- 95 0 59.4571			0.120E-13	0.230E-14	0.233E-07	OMEGA = 0 15 18.4795			0.180E-07	0.265E-08	-0.258E-09
SH9962	LAT = 29 41 40.8605			0.230E-14	0.115E-13	0.110E-07	PHI = 0 9 28.8849			0.265E-08	0.107E-07	-0.127E-09
	ELV = 4553.1973			0.233E-07	0.110E-07	0.157E+00	KAPPA = 236 41 42.8541			-0.258E-09	-0.127E-09	0.181E-08
	LNG =- 95 2 0.2159			0.135E-13	0.221E-14	0.145E-07	OMEGA =- 0 8 54.2962			0.185E-07	0.261E-08	0.639E-09
SH9963	LAT = 29 42 48.3705			0.221E-14	0.121E-13	0.147E-07	PHI = 0 3 2.5829			0.261E-08	0.123E-07	-0.528E-10
	ELV = 4552.5076			0.145E-07	0.147E-07	0.168E+00	KAPPA = 234 58 7.5545			0.639E-09	-0.528E-10	0.200E-08
	LNG =- 95 3 2.3908			0.163E-13	0.320E-14	0.234E-07	OMEGA =- 0 20 54.4774			0.222E-07	0.151E-08	0.218E-09
SH9964	LAT = 29 43 59.1374			0.320E-14	0.116E-13	0.796E-08	PHI =- 0 0 31.0700			0.151E-08	0.163E-07	0.290E-09
	ELV = 4553.4255			0.234E-07	0.796E-08	0.165E+00	KAPPA = 237 11 13.9764			0.218E-08	0.290E-09	0.221E-08
	LNG =- 95 4 2.6792			0.155E-13	0.186E-14	0.246E-07	OMEGA = 1 13 16.7764			0.217E-07	0.575E-09	-0.150E-08
SH9965	LAT = 29 45 11.1399			0.186E-14	0.136E-13	-0.132E-08	PHI = 0 9 52.0745			0.575E-09	0.164E-07	-0.186E-09
	ELV = 4553.7045			0.246E-07	-0.132E-08	0.229E+00	KAPPA = 236 27 50.4526			-0.150E-08	-0.186E-09	0.238E-08
	LNG =- 95 5 5.0642			0.207E-13	0.367E-14	0.360E-07	OMEGA =- 0 32 4.4950			0.290E-07	-0.314E-09	0.131E-08
SH9966	LAT = 29 46 20.4084			0.367E-14	0.154E-13	0.157E-07	PHI = 0 5 18.0096			-0.314E-09	0.138E-07	-0.322E-09
	ELV = 4555.2808			0.360E-07	0.157E-07	0.319E+00	KAPPA = 235 30 29.5986			0.131E-08	-0.322E-09	0.238E-08
	LNG =- 95 6 6.0711			0.265E-13	0.354E-14	0.384E-07	OMEGA = 0 32 47.9422			0.345E-07	-0.390E-08	0.232E-08
SH9967	LAT = 29 47 31.7126			0.354E-14	0.158E-13	0.199E-07	PHI = 0 4 55.4632			-0.390E-08	0.175E-07	-0.134E-08
	ELV = 4552.0872			0.384E-07	0.199E-07	0.345E+00	KAPPA = 237 26 24.2821			0.232E-08	-0.134E-08	0.363E-08
	LNG =- 95 7 7.5601			0.343E-13	0.189E-14	0.657E-07	OMEGA = 0 15 55.5150			0.407E-07	-0.729E-08	-0.194E-09
SH9968	LAT = 29 48 42.6416			0.189E-14	0.199E-12	0.178E-07	PHI =- 0 2 47.9791			-0.729E-08	0.335E-07	-0.398E-09
	ELV = 4550.4708			0.657E-07	0.178E-07	0.384E+00	KAPPA = 235 33 20.4221			-0.194E-09	-0.398E-09	0.806E-08
	LNG =- 95 5 10.6064			0.259E-13	-0.816E-14	0.295E-07	OMEGA = 0 0 35.4989			0.227E-07	0.161E-08	0.250E-08
SH9944	LAT = 29 51 14.6589			-0.816E-14	0.236E-13	-0.647E-07	PHI =- 0 0 28.5106			0.161E-08	0.560E-07	0.101E-08
	ELV = 4556.3120			0.295E-07	-0.647E-07	0.449E+00	KAPPA = 54 10 33.2683			0.250E-08	0.101E-08	0.715E-08
	LNG =- 95 4 9.3668			0.159E-13	-0.267E-14	-0.159E-07	OMEGA = 0 53 26.3893			0.201E-07	0.366E-08	-0.104E-08
SH9945	LAT = 29 50 2.7501			-0.267E-14	0.184E-13	-0.113E-07	PHI =- 0 3 39.0114			0.366E-08	0.280E-07	-0.127E-08
	ELV = 4554.8360			-0.159E-07	-0.113E-07	0.222E+00	KAPPA = 55 22 56.1853			-0.104E-08	-0.127E-08	0.364E-08
	LNG =- 95 3 9.3226			0.153E-13	-0.673E-15	-0.149E-07	OMEGA =- 0 48 42.4201			0.178E-07	0.135E-08	-0.136E-08
SH9946	LAT = 29 48 53.3068			-0.673E-15	0.141E-13	-0.386E-08	PHI =- 0 11 49.0202			0.135E-08	0.140E-07	-0.120E-08
	ELV = 4554.1961			-0.149E-07	-0.386E-08	0.256E+00	KAPPA = 54 28 12.5411			-0.136E-08	-0.120E-08	0.286E-08
	LNG =- 95 2 8.1568			0.151E-13	-0.542E-15	-0.758E-07	OMEGA = 0 21 24.8404			0.165E-07	-0.297E-09	-0.458E-09
SH9947	LAT = 29 47 40.9429			-0.542E-15	0.128E-13	-0.607E-08	PHI =- 0 8 8.3634			-0.297E-09	0.137E-07	-0.462E-09
	ELV = 4554.3942			-0.758E-09	-0.687E-08	0.264E+00	KAPPA = 54 51 50.5392			-0.458E-09	-0.462E-09	0.235E-08

TRIANGULATED GROUND POINTS

IDENT		POSITION		COVARIANCE MATRIX			STANDARD DEV		
0		LNG =- 94 55 59.3565	0.485E-14	0.805E-15	-0.219E-11	0	0	0.0144
SH951201	#3#	LAT = 29 42 51.0064	0.805E-15	0.446E-14	-0.132E-11	0	0	0.0138
		ELV = 0.0000	-0.219E-11	-0.132E-11	0.921E-04			0.0096
0		LNG =- 94 57 10.5959	0.688E-14	0.269E-14	0.282E-11	0	0	0.0171
SH954201	#3#	LAT = 29 38 53.5691	0.269E-14	0.462E-14	0.248E-11	0	0	0.0140
		ELV = 6.7057	0.282E-11	0.248E-11	0.921E-04			0.0096
0		LNG =- 94 55 11.7027	0.215E-16	-0.422E-19	-0.622E-10	0	0	0.0010
SH954801	#4#	LAT = 29 39 29.5641	-0.422E-19	0.215E-16	0.932E-10	0	0	0.0010
		ELV = 7.6765	-0.622E-10	0.932E-10	0.110E+01			1.0506
0		LNG =- 94 55 10.0562	0.215E-16	-0.415E-19	-0.626E-10	0	0	0.0010
SH954802	#4#	LAT = 29 39 26.3139	-0.415E-19	0.215E-16	0.101E-09	0	0	0.0010
		ELV = 7.2458	-0.626E-10	0.101E-09	0.112E+01			1.0563
0		LNG =- 95 1 7.7730	0.613E-14	0.198E-14	0.279E-11	0	0	0.0162
SH960201	#3#	LAT = 29 39 8.1803	0.198E-14	0.277E-14	0.177E-11	0	0	0.0109
		ELV = 5.4860	0.279E-11	0.177E-11	0.921E-04			0.0096
0		LNG =- 94 58 34.9651	0.218E-14	0.805E-16	-0.188E-12	0	0	0.0096
SH960202	#3#	LAT = 29 41 15.9415	0.805E-16	0.174E-14	0.816E-13	0	0	0.0084
		ELV = 0.0005	-0.188E-12	0.816E-13	0.921E-04			0.0096
0		LNG =- 95 0 21.0798	0.215E-16	0.467E-19	0.846E-10	0	0	0.0010
SH960801	#4#	LAT = 29 39 29.2370	0.467E-19	0.214E-16	0.892E-10	0	0	0.0010
		ELV = 1.8029	0.846E-10	0.892E-10	0.472E+00			0.6871
0		LNG =- 95 0 30.1952	0.215E-16	0.468E-19	0.100E-09	0	0	0.0010
SH960802	#4#	LAT = 29 39 29.6741	0.468E-19	0.214E-16	0.788E-10	0	0	0.0010
		ELV = 5.3845	0.100E-09	0.788E-10	0.450E+00			0.6706
0		LNG =- 95 4 26.3592	0.325E-14	0.152E-14	0.216E-11	0	0	0.0118
SH964201	#3#	LAT = 29 43 24.7486	0.152E-14	0.416E-14	0.217E-11	0	0	0.0133
		ELV = 9.7540	0.216E-11	0.217E-11	0.921E-04			0.0096
0		LNG =- 95 3 55.6187	0.215E-16	0.343E-19	0.654E-10	0	0	0.0010
SH964801	#4#	LAT = 29 43 36.3239	0.343E-19	0.215E-16	0.129E-09	0	0	0.0010
		ELV = 5.7725	0.654E-10	0.129E-09	0.475E+00			0.6895
0		LNG =- 95 3 36.1652	0.214E-16	0.149E-19	0.427E-11	0	0	0.0010
SH964802	#4#	LAT = 29 43 39.2221	0.149E-19	0.215E-16	0.155E-09	0	0	0.0010
		ELV = 5.0168	0.427E-11	0.155E-09	0.463E+00			0.6802
0		LNG =- 95 5 25.5941	0.294E-14	0.719E-15	-0.540E-11	0	0	0.0112
SH968202	#3#	LAT = 29 49 4.0696	0.719E-15	0.253E-14	-0.380E-11	0	0	0.0104
		ELV = 1.5240	-0.540E-11	-0.380E-11	0.921E-04			0.0096
0		LNG =- 95 6 17.8042	0.215E-16	0.402E-19	-0.314E-10	0	0	0.0010
SH968801	#4#	LAT = 29 49 10.4311	0.402E-19	0.215E-16	-0.157E-09	0	0	0.0010
		ELV = 10.4935	-0.314E-10	-0.157E-09	0.439E+00			0.6628

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T R I A N G U L A T E D   G R O U N D   P O I N T S

IDENT		POSITION		COVARIANCE MATRIX			STANDARD DEV		
0		LNG =- 95 6 21.9926		0.215E-16	0.362E-19	-0.135E-10	0	0	0.0010
SM968802 848		LAT = 29 49 10.3719		0.362E-19	0.216E-16	-0.161E-09	0	0	0.0010
		ELV = 11.1726		-0.135E-10	-0.161E-09	0.454E+00			0.6742

S U M M A R Y   S T A T I S T I C S   F O R   G R O U N D   P O I N T S

RMS FOR STANDARD DEVIATIONS

```
COUNT = 132    LNG =   0  0  0.0137
COUNT = 132    LAT =   0  0  0.0113
COUNT = 134    ELV =         0.7445
```

D. Logical Identification Number Assignments

All of the files used by GIANT have been assigned the following logical identification numbers.

Table II.1.--Files Used By GIANT

Logical ID Number	Type	Format (F) Formatted (UF) Unformatted		Utilization	Text Page Number
1	Input	(F)	sec. IIB.2	Camera data set	8
2	Input	(F)	sec. IIB.3	Image coordinate data set	8
3	Input	(F)	sec. IIB.4	Frame data set	9
4	Input	(F)	sec. IIB.5	Ground control data set	11
6	Output	(F)	sec. IIC.1	Printout	18
7	Input	(F)	sec. IIB.1	Common data set	5
8	Output	(F)	sec. IIC.2	Updated frames data set	18
9	Output	(F)	sec. IIC.3	Adjusted ground data set	18
11	Scratch	(UF)		Temporary storage	
.	.	.	.	.	
.	.	.	.	.	
.	.	.	.	.	
.	.	.	.	.	
.	.	.	.	.	
19	.	.	.	.	
20	Output	(F)	sec. IIC.2	Updated frames data set	18

Output files logical ID Nos. 8 and 9 will not be generated by GIANT in case the solution fails to converge.

Output file logical ID No. 20 will always be created whether the solution converges or not. This file can always be used at the user's option to restart the iterative solution from where it left off.

III. A LIST OF DIAGNOSTIC MESSAGES PRODUCED BY GIANT

The occurrence of errors during the execution of GIANT results in the generation of appropriate diagnostic messages. Two types of diagnostics are reported, warning messages and fatal messages. If the detected error reflects the occurrence of a fatal error, execution of the job is terminated. A warning error message does not result in the abandonment of a job. The user must, however, carefully interpret the effect of all warning messages produced by the program, as they might point to problems of which the user is not aware.

The remainder of this section contains a list of the various diagnostic messages that may be produced by GIANT. The list gives the text of each message, definition parameters, resulting action taken by GIANT, and a brief explanation of the meaning. In the list, fatal error messages are identified by the prefix"**".

ILLEGAL DMS FIELD DETECTED IN INPUT STREAM

This message will result from an attempt to read an angular field with the degrees part >360, the minutes part >60, or the seconds part >60.

ERROR IN SUBROUTINE MODID

ADDING VARIABLE XXXX

VARIABLES YYYY   YYYY   YYYY   YYYY   YYYY
    .   .   .   .   .   .
    .   .   .   .   .   .
VARIABLES YYYY   YYYY   YYYY   YYYY   YYYY

This error indicates the present input data arrangement has resulted in normal equations with a bandwidth that exceeds GIANT's capacity. Usually, a rearrangement of input data will cure this problem. The present version of GIANT has a bandwidth of N6. (See sec. I.E.) This message can only occur when GIANT is running in the triangulation mode.

In the diagnostic message, the integer number (XXXX) is the input stream sequence number of the camera station that caused overflow of the normal equations storage. The integer numbers designated by (YYYY) are the sequence numbers of camera stations occupying the normal equations storage when overflow took place.

CONTROL POINTS APPEARING ON ONE PHOTOGRAPH

XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
    .   .   .   .
    .   .   .   .
XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX

Control points with alphanumeric identifications (XXXXXXXX) appear on one photograph. Only those control points with more than one missing coordinate component will be included in this message. GIANT will ignore the control data for the listed control points.

PASS POINTS APPEARING ON ONE PHOTOGRAPH

XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
    .   .   .   .
    .   .   .   .
XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX

The message provides a list of alphanumeric identifications (XXXXXXXX) of ground points which appear on one photograph. All of the indicated image points will be dropped from the adjustment.

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PASS POINTS APPEARING ON MORE THAN N4 PHOTOGRAPHS (See sec. I.B.)

XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
  .   .   .   .
  .   .   .   .
XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX

The listed alphanumeric identifications (XXXXXXXX) are for imaged ground
points appearing on more than N4 photographs. GIANT will retain only the
first N4 image coordinates and drop the rest. (See sec. I.B.)

**CAMERA STATIONS EXCEEDED XXXX

An attempt to adjust more than (XXXX) camera stations will result in GIANT
issuing this diagnostic message. In the present version of GIANT, XXXX is
N1. (See sec. I.B.)

**IMAGE POINTS EXCEEDED XXXX

The total number of image points in the triangulation exceeded (XXXX), which
is limited by N2. (See sec. I.B.)

**GROUND CONTROL EXCEEDED XXXX

This message will result from a ground control data deck which contains more
than (XXXX) points. XXXX is N3 in the present version of GIANT. (See
sec. I.B.)

ERROR WARNINGS
POINTS NOT PHOTOGRAPHED

XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
  .   .   .   .
  .   .   .   .
XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX

This diagnostic message provides alphanumeric identifications of control
points for which no image data exist. GIANT will ignore ground control
coordinates of listed points.

ERROR WARNINGS
DUPLICATE CONTROL POINTS

XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
  .   .   .   .
  .   .   .   .
XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX

The listed alphanumeric identifications are for control points which are
repeated in the control data deck. GIANT will retain only first reference to
the listed points and ignore all subsequent duplicates.

REFERENCES

American Society of Photogrammetry, 1980: Manual of Photogrammetry, Slama, Chester C., editor, 4, Falls Church, VA, 1056 pp.

Elassal, Atef A., 1976: General integrated analytical triangulation (GIANT) program. USGS Report W5346, U.S. Geological Survey, Department of Interior, Reston, VA.

Engineering Management Series, 1981: Analytical mapping system (AMS) user's guide, II, analytical triangulation (draft), EM-7140-11, Forest Service, U.S. Department of Agriculture, Washington, DC, 215 pp.

APPENDIX A.--DATA STRUCTURING BY GIANT

Input data are reordered by GIANT to facilitate the use of an efficient algorithm for the formation, solution, and inversion of the normal equations. The purpose of the data structuring process is to produce an efficient, diagonally banded matrix of normal equations.

The overall efficiency of the adjustment process depends on the arrangement of submatrices in the normal set which produces the narrowest possible bandwidth of nonzero elements. Bandwidth for the normal system structured by GIANT is a function of input data ordering.

It is true that a particular arrangement of data for the given job will imply a certain bandwidth for the normal equation matrix. A different arrangement of the data results in a different bandwidth. Since the maximum allowable bandwidth is a function of computer available storage, there may be cases where data arrangement becomes a determining factor in whether a job can be executed. By the proper arrangement of input data, the problem of exceeding the allowable bandwidth can often be prevented, or by rearrangement of the data, the problem can be rectified. The normal matrix is formed by GIANT under the following rules:

1. Modifiable parameters are divided into sets, each set being composed of three parameters. Therefore, a single camera station's parameters constitute two parameter sets, one for position and one for attitude.

2. The first reference to a ground point through one of its images results in the inclusion, in the normal matrix, of all parameter sets associated with the point. Therefore, parameter sets for camera stations observing the point will be added to the normal system if they have not already been placed in the matrix by reference from a previous point.

A simple example will best demonstrate the data structuring process used to build the normal equation matrix. Consider a strip of six photographs, each containing three image points distributed as shown in table 1.

Table A.1.--Examples of six photographs

Photograph	Image Points
1	1 2 3
2	2 3 4
3	3 4 5
4	4 5 6
5	5 6 7
6	6 7 8

Assume that input data are arranged as shown in table A.1 from photographs
1 through 6. Following the rules outlined above, the normal matrix shown in
figure A.1 would be constructed as follows:

Image 1 of photo 1 is the first point encountered, resulting in the entry of
the two camera parameters sets (C_1,C_1) and the ground point parameter set (P_1)
into the normal matrix. Nonzero blocks occur whenever there is correlation;
shown by shading the figure. The next image point encountered is point 2
which occurs on photographs 1 and 2. The camera station parameter sets for
photograph 1 have already been included in the normal system, so only $C_2,C_2)$
and (P_2) must be added to the system. In the same fashion, image point 3 adds
(C_3,C_3) and (P_3), etc., through photograph 6. Images 7 and 8 add no more
camera parameter sets but they do add ground point parameter sets for points 7
and 8 to complete the normal system. The diagonal matrix produced is
symmetric about the dashed diagonal line. Without further exploitation of the
structural peculiarities for the normal matrix, the GIANT algorithm would
require an amount of internal computer memory equivalent to the cross-hatched
area in the figure.

GIANT logic, however, allows computer memory to be shared by a special group
of unknown parameter sets. Any parameter set which is uncorrelated with the
parameter sets that succeed it, is qualified as a member of this special
group. Therefore, parameter sets P_1, P_2, and P_3 will share a common storage
area within the cross-hatched area in the figure. This arrangement results in
a reduction of the bandwidth from the original nine parameter sets to an
effective bandwidth of seven parameter sets. The effective bandwidth notion
applies to all possible positions of the cross hatched area along the matrix
diagonal.

The reader would now be able to visualize what would happen to the normal
matrix if the order of data input was changed. If photo 1 and photo 6 were
exchanged in order in the previous example, the resulting effective bandwidth
would be approximately double the original one.

As previously stated, the maximum allowable effective bandwidth is a
function of computer system configuration. The limitation is based on the
number of 3 by 3 matrix parameter sets which will fit a work area of computer
memory, and it can be expressed in terms of the allowable number of photo-
graphs, either preceding or succeeding a given photograph, which may have
points in common with the given photograph. If K is the number of parameter
sets that will fit in the computer memory, then (K-1) camera parameter sets
will be allowable in the normal matrix, using one set for the common ground
point. Since two parameter sets are required for each photograph, a total of
(K-1)/2 photographs may be involved. This amounts to allowing a photograph in
a given input arrangement to have conjugate points with a maximum of (K-1)/2-1
photographs before or after it.

41
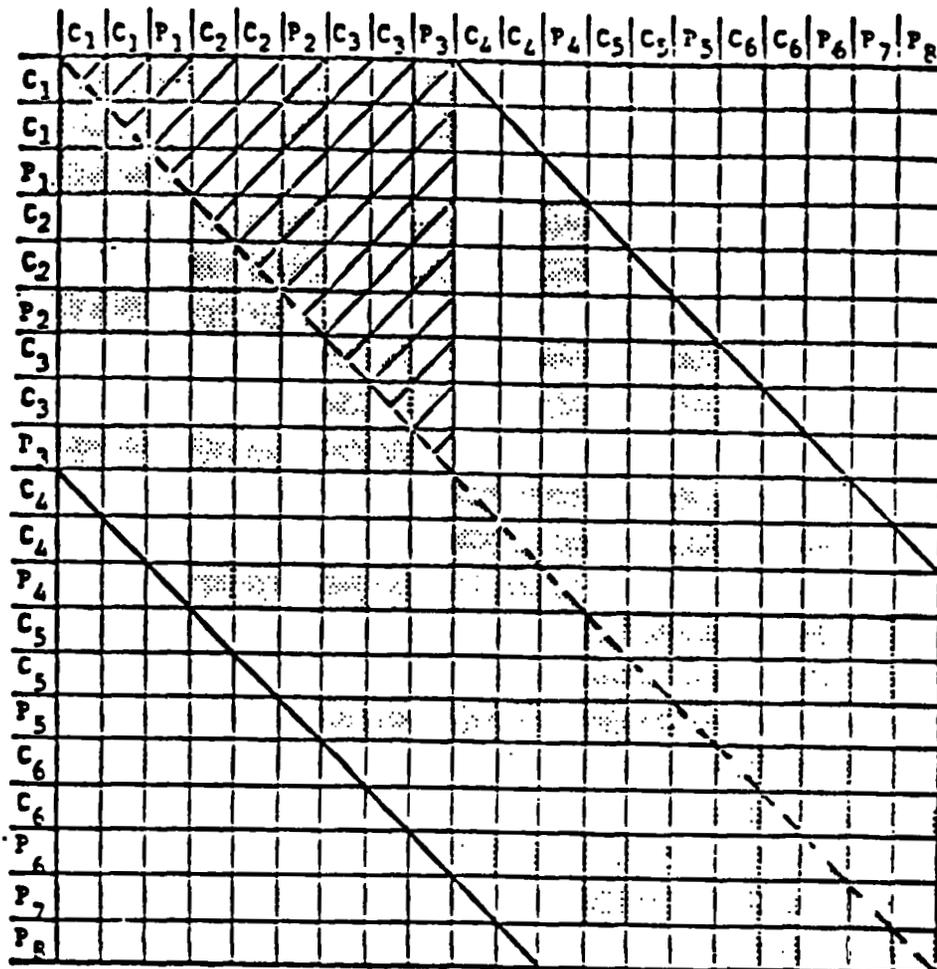
Figure A.1.--Normal matrix for the six photos
defined in table A.1.

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APPENDIX B.--COORDINATE SYSTEMS IN GIANT

Two object space coordinate systems are available on option (character no. 1) in to the GIANT program: 1) geographic (geodetic) and (2) rectangular (sec. II.B.1, Job Definition Data Record). The preferred option for almost all block adjustments is the geographic coordinate system. Using this system, the Earth's curvature is incorporated in the mathematical model and the interpretation of input and output is easier and more meaningful.

The Geodetic Coordinate System

This coordinate system is the conventional ellipsoidal coordinate system. Rigorously defined, geographic refers to a spheroidal coordinate system, and geodetic refers to a similar system based on an ellipsoid of revolution (fig. B.1). In ordinary usage, however, the two terms are used interchangeably. If the default values are accepted, the coordinate system chosen will be the ellipsoid of revolution (fig. B.2), using the semimajor and semiminor areas defined for the Clarke 1866 spheroid. The accepted vertical datum is the National Geodetic Vertical Datum of 1929 and all elevations should be referenced to this datum.

It is possible to change ellipsoids by entering the values of semimajor and semiminor axes in character spaces 51-60 and 61-70, respectively. This is usually used when working in other parts of the world where the basic control net is on a different spheroid.

The use of feet or meters for object space coordinates is also determined by the ellipsoid constants. If the default or another spheroid in feet is chosen, all linear components (elevations) must be in feet. If spheroid constants in meters are chosen, all input using linear measure must be in meters. Output units will be determined by the choice made for input. The values required for the Clarke Spheroid of 1866 in meters are:

Semimajor axis: a = 6,378,206.4 m
Semiminor axis: b = 6,356,583.8 m

The program does not use the geographic system directly in its adjustment but converts to geocentric coordinate system X, Y, Z (fig. B.2), using the widely accepted conversion formula. Additionally, for interpretation, the camera attitude angles are referenced to a local vertical system at the position of the camera, with Y pointing north and Z pointing up. A more complete description on orientation angles is given in appendix C.

The geocentric coordinate system may be described as a right-handed, rectangular, orthogonal coordinate system. It has three axes, usually designated X, Y, and Z. They are linear measurements, and all three must be at right angles to each other. Any point may be uniquely described by giving its X, Y, and Z coordinates. The most common system of this type is the geocentric coordinate system where X and Y are in the plane of the equator, Z is then through the North Pole, and X is through the zero longitude (fig. B.2). In this system, points in the eastern United States would be +X, -Y, and +Z, while figures B-1 and B-2 points in the western United States (west of 90°W longitude or approximately New Orleans) would be -X, -Y, and +Z.
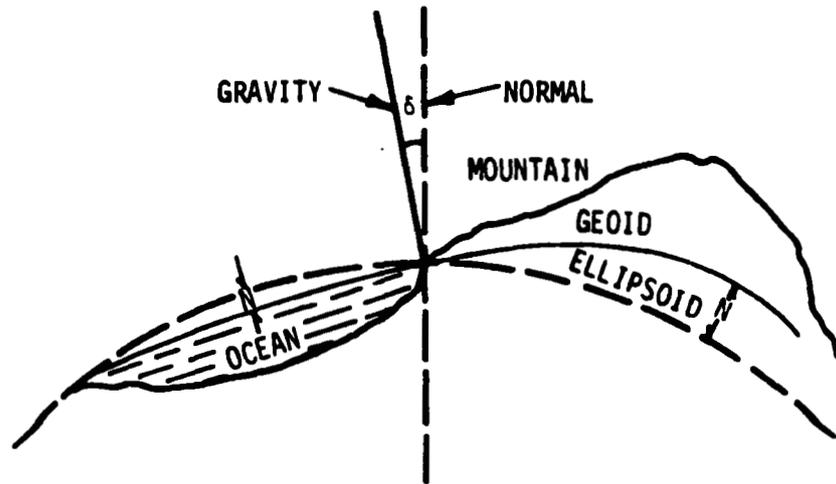
Figure B.1.--Relationship among the physical surface,
the geoid, and the ellipsoid
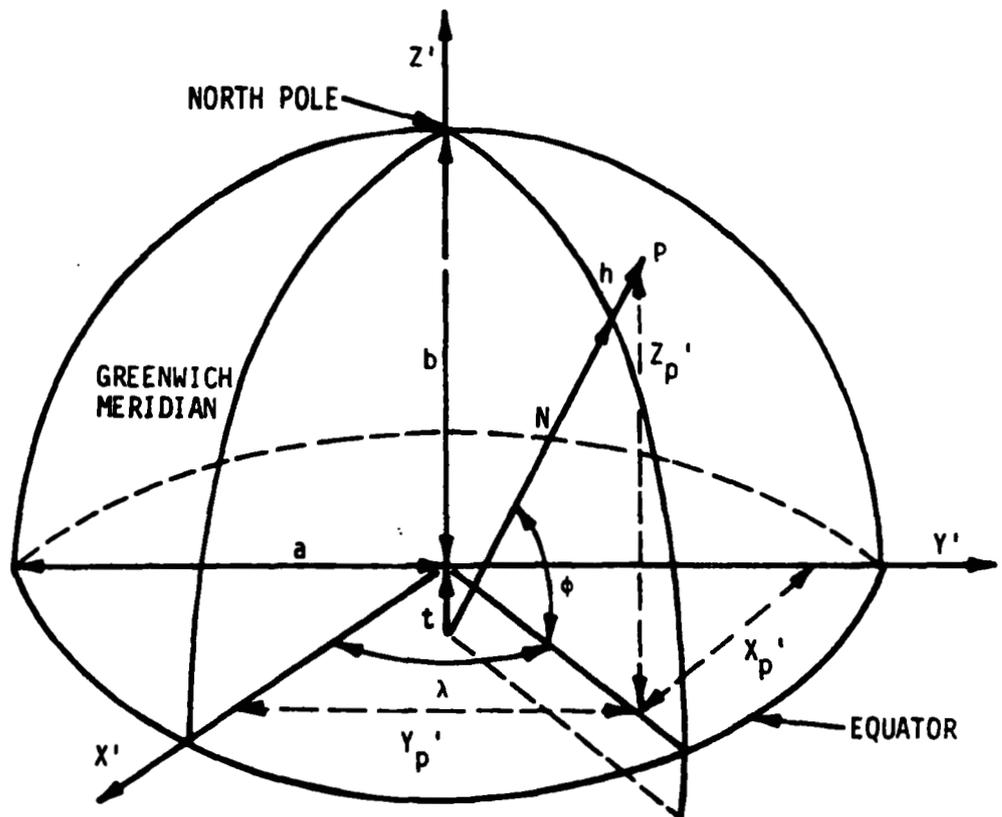
Figure B.2.--Geographic and geocenteric coordinate systems

The Rectangular Coordinate System

The other possible input coordinate system is rectangular. The primary use of this system is for "close-range" photogrammetry, although it may also be used rigorously with geocentric coordinates and with some local coordinates. The danger in this system is that the curvature of the Earth is not modeled for State plane and Universal Transverse Mercator (UTM) coordinates.

It is possible to use this option with State plane coordinates and UTM coordinates, but it is not a rigorous or correct usage. For small areas, and when the Earth's curvature is negligible, it can be used, but again, always with caution and results should be checked carefully. Interaction of the parameters can often adjust most of the errors and provide satisfactory results for small areas. Systematic error is left which cannot be correctly resolved by the least squares adjustment technique because any errors will be treated as random errors. Although the residuals themselves may appear to be satisfactory, systematic errors may remain in the solution. State plane and UTM systems, as with all map projections, are not geometrically similar to the Earth's surface and consequently they introduce distortions.

APPENDIX C.--EXTERIOR ORIENTATION

Definitions

A discussion of the exterior orientation of a photograph (fig. C.1) follows.

- 1. **The position of the camera exposure station C in the object space coordinate system.** This can be represented by the three space coordinates (X_C, Y_C, Z_C), or equivalently, by the camera station vector

$$C = \begin{bmatrix} X_C \\ Y_C \\ Z_C \end{bmatrix}$$

2. **The orientation matrix**

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

which gives the angular orientation of the image coordinate system (x, y, z) with respect to the object space coordinate system (X, Y, Z).
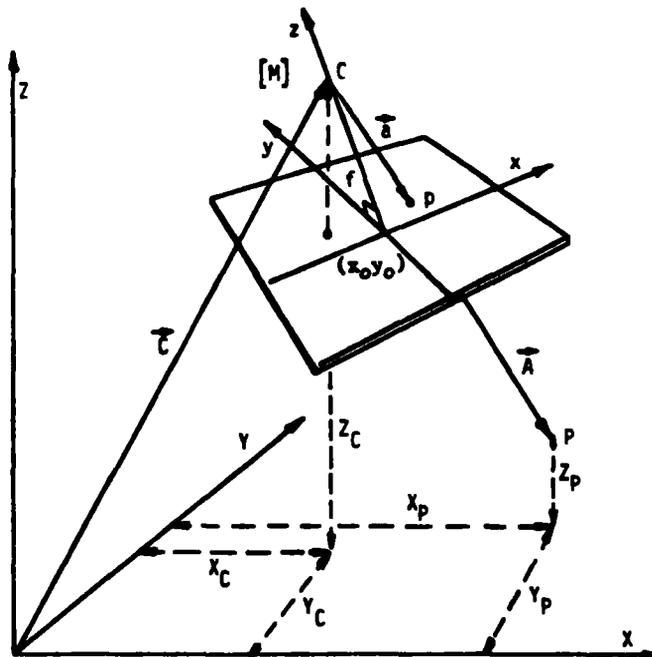
Figure C.1--Exterior orientation

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The elements of M are the cosines of the nine space angles between the three axes of the image coordinate system and the three axes of the object space coordinate system; that is

$$
M = \begin{bmatrix} \cos Xx & \cos Yx & \cos Zx \\ \cos Xy & \cos Yy & \cos Zy \\ \cos Zz & \cos Yz & \cos Zz \end{bmatrix}
$$

where $\cos Xx$, $\cos Yx$, and $\cos Zx$ are the cosines of the space angles between the x-axis and the X-, Y-, and Z-axes respectively, etc. Obviously, these elements are direction cosines.

This matrix is arranged to transform object space to image space, or as it is often called, ground to photo:

$$
\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos Xx & \cos Yx & \cos Zx \\ \cos Xy & \cos Yy & \cos Zy \\ \cos Xz & \cos Yz & \cos Zz \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}
$$

or $x = MX$.

Sequential Rotation

The orientation matrix can be factored into three orthogonal matrices, each representing a simple rotation of the image coordinate system about a particular image coordinate axis. The sequence of the three rotations must be specified because different angles of rotation result from different sequences.

In all cases, the orientation is considered in the following way. The image coordinate system is initially coincident with the object space coordinate system. The three rotations are applied to the image coordinate system in the appropriate sequence to place the system into its final position (fig. C.2.).

The orientation matrix M is an orthogonal matrix. There is one, and only one, orientation matrix, M, for a given orientation situation.

Sequence	Axis of rotation
Primary - Roll (ω)	x
Secondary - Pitch (ϕ)	y
Tertiary - Yaw (κ)	z

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Roll (ω) is an angle of rotation of about the x-axis. Positive roll rotates the positive y-axis toward the positive z-axis. -180° < ω < +180°. (left wing up)

Assume +x is direction of flight; +y is at a right angle to +x, and the positive direction is out the left wing; +z is at a right angle to the x y plane, and the positive direction is up.

Pitch (φ) is an angle of rotation about the y-axis. Positive pitch rotates the positive z-axis toward the positive x-axis. -180° < φ < +180°. (nose down)

Yaw (κ) is an angle of rotation about the z-axis. Positive yaw rotates the positive x-axis toward the positive y-axis. -180° < κ < +180°. (counterclockwise is positive)

(κ) is approximated by a clockwise angle (photo to ground) and counterclockwise (ground to photo) measured from east to the photo (x) in the plane of the vertical photograph.
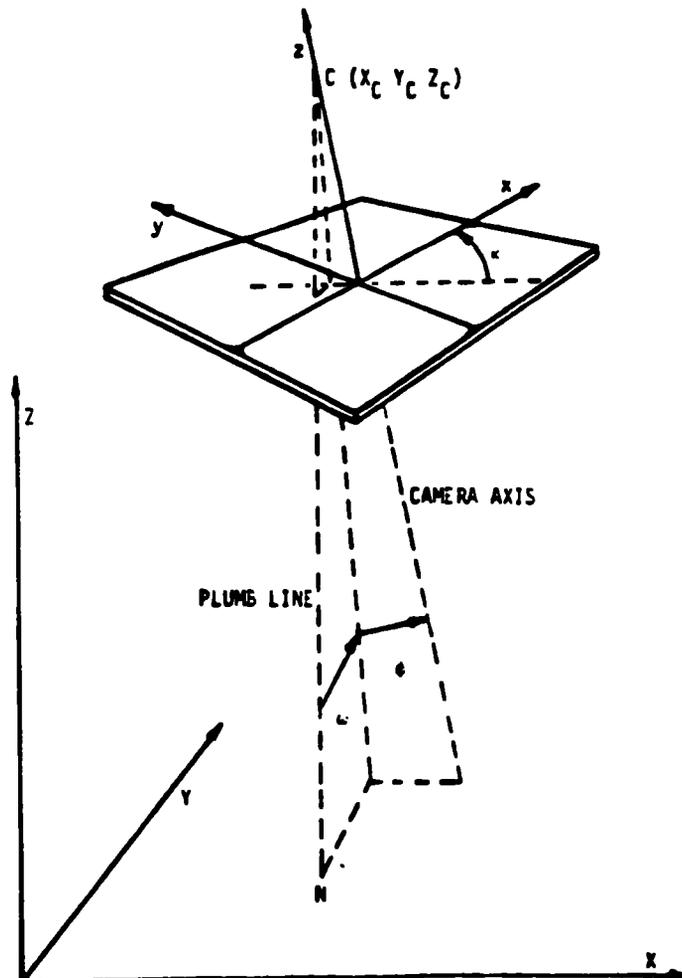
Figure C.2--Rotations

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APPENDIX D.--MATHEMATICAL MODEL

Collinearity Equations

The only mathematical model in the GIANT program is collinearity. This expresses the condition that in undistorted space, a vector from the camera station to an image point is collinear with a vector from the camera station to the corresponding point in object space. Since the "real world" is not distortion-free, preprocessing has hopefully compensated for the distortions.

The orientation matrix M transforms vectors in the object space coordinate system into corresponding vectors in the image coordinate system; that is,

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = M \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Because M is an orthogonal matrix, the length of a vector remains unchanged after the transformation. Indeed, the geometrical representation of the vector is not changed at all in length and direction by the transformation; the components of the vector are simply expressed in the image coordinate system instead of in the object space coordinate system. In fig. C.1, A = CP is such a vector. Its components in the object space coordinate system are

$$A = \begin{bmatrix} X_p - X_c \\ Y_p - Y_c \\ Z_p - Z_c \end{bmatrix}$$

and its components in the image coordinate system are

$$a = \begin{bmatrix} x_p - x_c \\ y_p - y_c \\ z_p - z_c \end{bmatrix}$$

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Now, the vector from the camera station C to the image point p is given in the image coordinate system by:

$$a = \begin{bmatrix} x_p - x_o \\ y_p - y_o \\ -f \end{bmatrix}$$

where x_o, y_o are the plate coordinates of the principal point (fig. C.1).

When the exterior orientation of a photograph has been correctly established, it is clear from fig. C.1 that the vector a is collinear with the vector A. The two vectors differ only in length. Thus, if they are both expressed in the same coordinate system, one is simply a scalar multiple of the other; that is

$$a = kA'.$$

The scalar k is called scale factor. This leads to the projective equations

$$a = k\,MA,$$

or

$$\begin{bmatrix} x_p - x_o \\ y_p - y_o \\ -f \end{bmatrix} = k \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \begin{bmatrix} X_p - X_c \\ Y_p - Y_c \\ Z_p - Z_c \end{bmatrix}$$

Expressed individually, these projective equations are:

$$(x_p - x_o) = k\,[m_{11}(X_P - X_C) + m_{12}(Y_P - Y_C) + m_{13}(Z_P - Z_C)]$$

$$(y_p - y_o) = k\,[m_{21}(X_P - X_C) + m_{22}(Y_P - Y_C) + m_{23}(Z_P - Z_C)]$$

$$(\quad -f \quad) = k\,[m_{31}(X_P - X_C) + m_{32}(Y_P - Y_C) + m_{33}(Z_P - Z_C)]$$

Dividing the first equation by the third equation and the second equation by the third equation, and multiplying throughout by -f, we obtain:

$$(x_p - x_o) = -f\,\frac{m_{11}(X_P - X_C) + m_{12}(Y_P - Y_C) + m_{12}(Z_P - Z_C)}{m_{31}(X_P - X_C) + m_{32}(Y_P - Y_C) + m_{33}(Z_P - Z_C)}$$

$$(y_P - y_o) = -f\,\frac{m_{21}(X_P - X_C) + m_{22}(Y_P - Y_C) + m_{23}(Z_P - Z_C)}{m_{31}(X_P - X_C) + m_{32}(Y_P - Y_C) + m_{33}(Z_P - Z_C)}$$

These equations express the fact that the object point P, the image point p, and the exposure station C all lie on the same straight line. They are, therefore, referred to as "collinearity equations."

Angles

If M is given, ω, ϕ, and κ can be found using the following relations:

$$\tan \omega = \frac{-m_{32}}{m_{33}}$$

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

$$\tan \kappa = \frac{-m_{21}}{m_{11}}$$

Local Vertical Coordinate System

The origin of the local space coordinate system is taken at the coordinates of each camera station. The geocentric coordinates of the origin 0 are X'_0, Y'_0, and Z'_0 (fig. D.1), and the geodetic coordinates of the origin are ϕ_0, λ_0, and h_0. The z axis of the local system is taken along the normal through the origin, with positive z directed away from the center of the Earth. The y axis is in the meridian through the origin, with positive y directed toward the north pole. The x, y, z axis form a right-handed coordinate system. Since only angular rotations are considered here, the value of h is of no importance. The local coordinates are x, y, and z. They are obtained from the geocentric coordinates using the following transformation:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sin\phi_0 & \cos\phi_0 \\ 0 & -\cos\phi_0 & \sin\phi_0 \end{bmatrix} \begin{bmatrix} -\sin\lambda_0 & \cos\lambda_0 & 0 \\ -\cos\lambda_0 & -\sin\lambda_0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X' - X'_0 \\ Y' - Y'_0 \\ Z' - Z'_0 \end{bmatrix}$$

or $\quad x = M_{\phi_0} \; M_{\lambda_0} \; X$

Combining the two orthogonal matrices, we get

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} -\sin\lambda_0 & \cos\lambda_0 & 0 \\ -\sin\phi_0 \cos\lambda_0 & -\sin\phi_0 \sin\lambda_0 & \cos\phi_0 \\ \cos\phi_0 \cos\lambda_0 & \cos\phi_0 \sin\lambda_0 & \sin\phi_0 \end{bmatrix} \begin{bmatrix} X' - X'_0 \\ Y' - Y'_0 \\ Z' - Z'_0 \end{bmatrix}$$

or $\quad x = M_{\phi_0 \, \lambda_0} \; X$

The orientation matrix $M = M_\omega \ M_\phi \ M_\kappa$

Where ω is roll, ϕ pitch, κ yaw

$$\text{and } M_\omega = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \end{bmatrix}$$

$$M_\phi = \begin{bmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{bmatrix}$$

$$\text{and } M_\kappa = \begin{bmatrix} \cos\kappa & \sin\kappa & 0 \\ -\sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix}$$
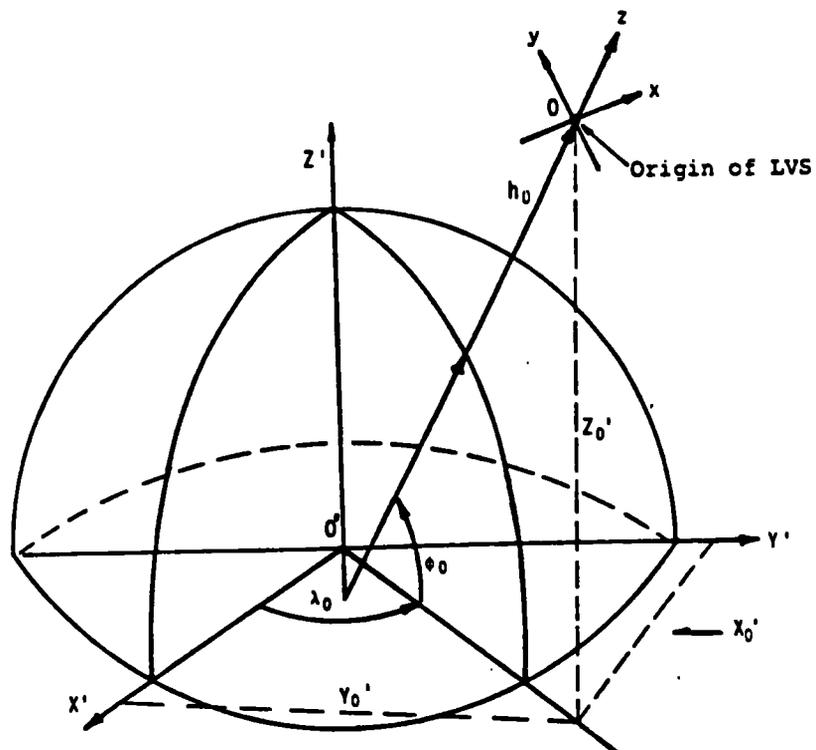
Figure D.1--Local vertical coordinate system (LVS)

Hence

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

or $x = M_{\kappa\phi\omega}X$ -- ground-to-photo

Computational Sequence

GIANT uses the following computational sequence:

Evaluate (compute) $M_{\kappa\phi\omega}$ Local-to-camera
as derived

Transpose forming $M^T_{\omega\phi\kappa}$ Camera-to-local

Form $M^T_{\phi_0\lambda_0}$ Local-to-geocentric

(Transpose of derived matrix)

Premultiply $M^T_{\phi_0\lambda_0}$ $M^T_{\omega\phi\kappa}$

Note this is equivalent to:

$$M^T_{\phi_0\lambda_0}\ M^T_{\omega\phi\kappa} = (M_{\kappa\phi\omega}\ M_{\lambda_0\phi_0})^T$$

$$(\text{Camera-to-local and Local-to-geocentric})^T$$

Yielding $(M_{\phi_0\lambda_0\omega\phi\kappa})^T$
which will transform geocentric-to-camera

Either photo-to-ground or ground-to-photo angles may be used. The final results will be numerically the same for ground point positions, although differing values for ω, ϕ, κ will be obtained.

The error propagation options (characters 11 and 12 of record 2 of COMMON file, sec. II.B.1) are expensive to exercise, requiring additional computations and printing. Based on the input and the solution, the results are estimates of how well the camera station and the ground points are determined. These options are exercised only on the last two or three runs, because the solution does not provide much information while the data are being "cleaned up" and edited.

A variance covariance matrix for each set of parameters is determined from the inverse of the normals. This is then multiplied by the estimate of variance of unit weight. The standard deviation for each element is the square root of the diagonal terms of that matrix.

Variance of unit weight (σ_o^2) may be estimated by the equation:

$$\sigma_o^2 = \frac{\Sigma(v_i w_i v_i)}{(n-u)}$$

where

v_i is the residual of the ith observation

w_i is the weight

n is the number of observations

u is the number of "unknowns" or "solvable parameters"

(n-u) is the degree of freedom.

In the photogrammetric problem the number (n) of observations is equal to the numbers of plate coordinates, one for x, and one for y, or two times the numbers of image points measured. Add to this the number of measurements for ground control coordinates, one for each of the known coordinates (latitude, longitude and elevations). Depending on the external source of information, camera station position (X_c, Y_c, Z_c) and orientation elements (ω, ϕ, κ), as well, can be added to the number of observations as six times the numbers of camera stations. Although these are considered as solvable parameters, they can also be treated as weighted observations if sufficient information is available.

The unknowns or solvable parameters (u) are the ground control positions. For each unique point in the adjustment, three unknowns are counted. Camera station position (X, Y, Z) and orientation (ω, ϕ, κ) are usually considered "unknowns," giving rise to additional numbers of unknowns equal to six times the number of camera stations.

To summarize, let:

v = the output residual for each observation.

w = input weight which may be thought of as $1/\sigma^2$ for each observation. (Note it is sigma squared).

n = total number of observations.

m = 2 * number of plate measurements.

c = 1 for each ground control component.

s = 6 * number of camera stations. (Factor 6 represents the camera parameters: the position coordinates X, Y, Z and the orientation elements ω, ϕ, κ. These parameters are always treated as unknowns; however, depending on the external source of information, these may also be treated as weighted observations contributing to the number of direct weighted observation equations. When the weights of the direct observations are small, the camera parameters may be treated as completely free and no contribution is then made to the direct weighted observations).

p = 3 * number of points (X, Y, Z). (Note: one, two, or three of these components may have also been counted as observations under "c."

Again simplistically, the estimate of variance of unit weight is defined as the summation of the input weights $(1/\sigma^2)$ multiplied by the output residuals squared (v^2). If all is perfect, $\frac{\Sigma v^2}{\sigma^2}$ = (n-u) for all observations. This summation, when divided by the **degree of freedom** (the number of observations minus the number of parameters) results in a value close to 1.0.

Table E.1 computes the unit variance for the solution of a typical three-photo block (fig. E.1) with case 1 considering the camera stations as unknowns and case 2 considering the camera station as constrained or known (character no. 12=1, record no. 2, COMMON file, sec. II.B.1).

Table E.1--Computations of unit variance for a typical three-photo block (see fig. E.1)

	CASE 1	CASE 2
v w v = 1 for each plate coordinate		
Photo 1	12	12
Photo 2	20	20
Photo 3	14	14
Camera Stations (if observed)	0	18
Ground Control (3 points, 7 components)	7	7
v w v	53	71
m = 2 * number of plate measurements		
Photo 1	12	12
Photo 2	20	20
Photo 3	14	14
c = 1 for each ground control component	7	7
s = 6 * number of camera stations	0	18
n = m + c + s	53	71
MINUS		
s	18	18
p	30	30
u = s + p	48	48
DOF (Degrees of Freedom) = n - u	5	23
= Unit Variance (vwv/DOF)	10.6	3.1

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PHOTO 3

PHOTO 1

PHOTO 2

△1   □4   7◍

10□

□2   □5   8□

3□   6□   9△
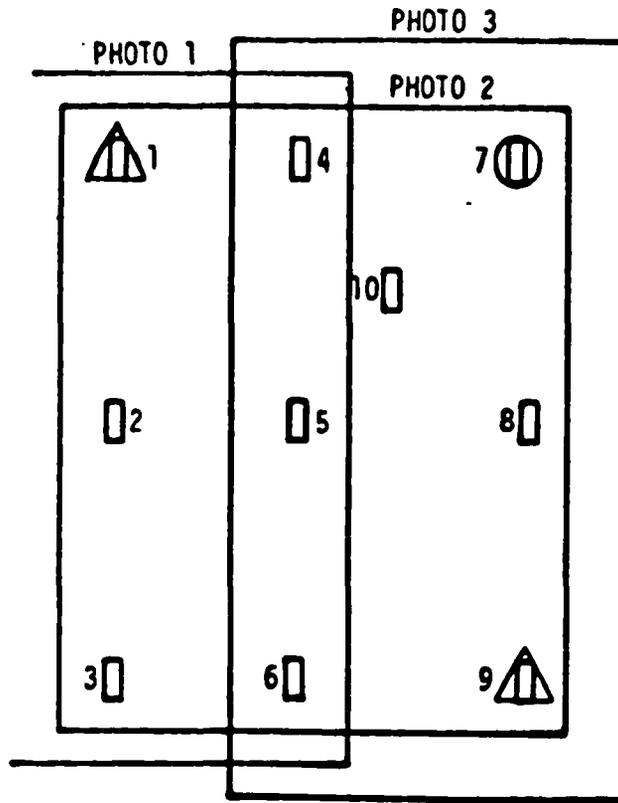
10 GROUND POINTS

POINT #1 FULLY KNOWN
POINT #9 FULLY KNOWN
POINT #7 ELEV. ONLY

PHOTO 1

△1   □4

□2   □5

□3   □6

6 POINTS
12 MEASUREMENTS

PHOTO 2

△1   □4   7◍

□10

□2   □5   8□

□3   □6   9△

10 POINTS
20 MEASUREMENTS

PHOTO 3

□4   7◍

□10

□5   8□

△6   9△

7 POINTS
14 MEASUREMENTS
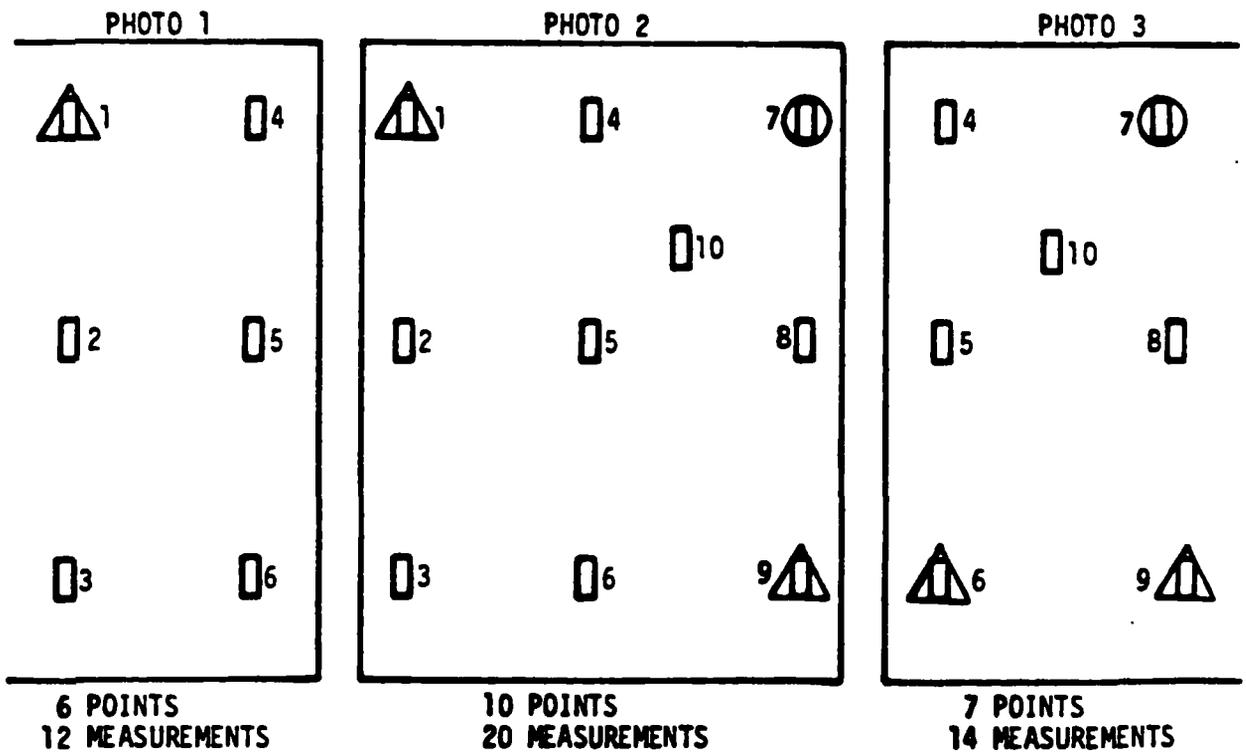
Figure E.1--A typical three-photo block

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APPENDIX F.--ATMOSPHERIC REFRACTION

The GIANT program has an atmospheric refraction correction model applicable up to an altitude of 9,000 meters. The dynamic nature of this model makes it possible to execute a more accurate correction to the refraction effect. This correction is based not only on the altitude of the camera but also on its attitude. In the iterative adjustment process, the atmospheric refraction correction is carried out according to the updated state vector of the camera. The switch for applying an atmospheric refraction correction to the GIANT program (character 16, record no. 2, sec. II.B.1) is turned off if the correction has already been made in the "preprocessor." The application of this model slows down the convergence of the solution for only a slight improvement in results. This may discourage its use by production units as long as the results, obtained without its use, are good enough for their work. Also, the 9,000-meter limit on altitude will have to be overcome by replacing the model by another more universally applicable version.

Mathematical Model

In its simplest form, atmospheric refraction can be expressed by (American Society of Photogrammetry 1980):

$$\Delta_\alpha = K_\alpha \tan \alpha$$

where

Δ_α is the angle of displacement due to atmospheric refraction;
α is the angle the ray makes with the "true vertical;"
K_α is a constant related to the atmospheric conditions. (Refer to figs. F.1 and F.2)

The constant K_α can be varied as the amount of displacement (angular) attributable to a ray at 45 degrees from the vertical. K_α is a constant related to the atmospheric conditions. For flying heights (H) up to 9,000 meters, K_α can be given by:

$$K_\alpha = 13(H-h)[1-0.02(2H + h)] \text{ microradians}$$

where

H is the flying heighth (kilometers)
h is the ground point elevation (kilometers)

In a vertical photograph, the correction (Δ_r) for the effect of atmospheric refraction can be shown as:

$$\Delta_r = K_\alpha \left(r + \frac{r^3}{f^2}\right) \text{ or } K_\alpha r \left(\frac{R^2}{f^2}\right)$$

where

$$R^2 = (r^2 + f^2)$$

r is the radial distance of a point image from the photo nadir;
f is the focal length of the camera.

Obviously, the approach will work for near vertical photographs only.

However, tilts of the photograph must be considered, and computation of the correction made during the iterative solution. This can be accomplished quite simply by a change in the approximate Z (in a local system) coordinate. The change in the Z ground coordinate which will produce the same effect at the plate as the atmospheric refraction is given by (fig. F.2):

$$dZ = \frac{(Z_O - Z_G) \tan \Theta \quad (\Delta_\alpha)}{\sin^2 \Theta}$$

The angle Θ is the difference in the direction between true vertical and the point in question. The correction then can be written as:

$$dZ = \frac{\Delta X^2 + \Delta Y^2 + \Delta Z^2}{\Delta Z} K_\alpha$$

where

$$\Delta X = (X_O - X_G)$$

$$\Delta X = (Y_O - Y_G)$$

$$\Delta Z = (Z_O - Z_G)$$

This correction is easily applied in each iteration of the triangulation solution for every point.
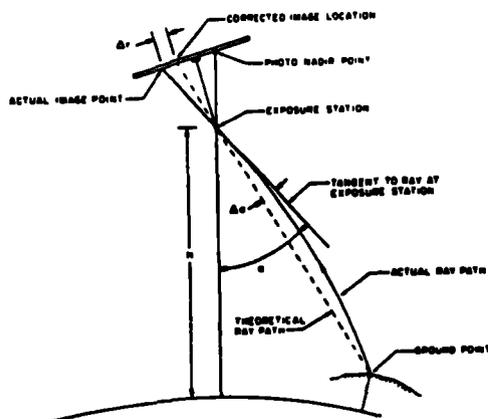
Figure F.1.--Atmospheric refraction.
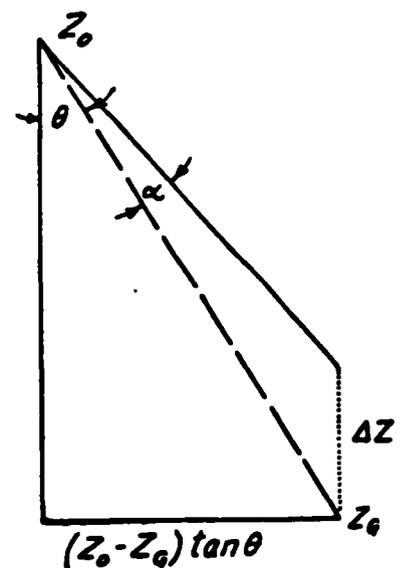
Figure F.2.--Correction for atmospheric refraction.

To account for errors caused by water refraction of the light rays from underwater features, corrections are applied to each and every underwater point during each iteration of the triangulation solution. The switch for applying water refraction correction is character 17, record no. 2 of COMMON file. To apply the correction to underwater points, water level (meters) with respect to the reference ellipsoid at the time of photography is entered in characters 31-40, record no. 2 of COMMON file.

The basic approach for applying water refraction correction is similar to applying atmospheric refraction correction. The water refraction model may be expressed by (fig. G.1):

$$\Delta_\alpha = K_\omega \tan \alpha$$

where

Δ_α is the angle of displacement

α is the angle the ray makes with the true vertical at the camera station

K_ω is the constant related to water refraction for an underwater feature

It can be shown that the value of K_ω is given by (fig. G.1):

$$K_\omega = [\{\tan (\alpha + \Delta_\alpha)/ \tan \alpha\} - 1]/[1 + \tan (\alpha + \Delta_\alpha) \tan \alpha]$$

or, $$K_\omega = [(H + d)/(H + \bar{d}) - 1] / [1 + \tan^2\alpha]$$

and the correction (Δ_r) for water refraction (fig. G.2):

$$\Delta_r = K_\omega(r + \frac{r^3}{f^2}) = K_\omega r(\frac{R^2}{f^2})$$

where

$$R^2 = r^2 + f^2$$

r = radial distance of the image point from the photo nadir

f = focal length of the camera

The equation for water refraction correction (Δ_r) is similar to the air refraction correction (appendix F) except that the constant K_ω replaces K_α in the expression.

In the GIANT program the air and water refraction corrections are applied as a change (dz) in the Z coordinate (fig. F.2) given by:

$$dZ = \frac{(Z_o - Z_G) \tan \Theta \, (\Delta_\alpha)}{\sin^2\Theta}$$

The angle Θ is the difference in the directions between true vertical and the point in question. The correction dZ can be expressed as

$$dZ = \frac{\Delta X^2 + \Delta Y^2 + \Delta Z^2}{\Delta Z} (K_\omega)$$

where

$$\Delta X = X_o - X_G$$

$$\Delta Y = Y_o - Y_G$$

$$\Delta Z = Z_o - Z_G$$

This correction is easily applied to every underwater point (with negative elevation) and in every iteration of the solution. The expression is similar to the expression for air refraction correction. Both the air and water refraction corrections to the Z coordinate of a point can be applied by the formula

$$dZ = \frac{\Delta X^2 + \Delta Y^2 + \Delta Z^2}{\Delta Z} (K_\omega + K_\alpha)$$

where $(K_\omega + K_\alpha)$ replaces K_ω or K_α in the expression for the correction. For points at or above water level $K_\omega = 0$ in the algorithm, such that the correction is only for the air refraction.
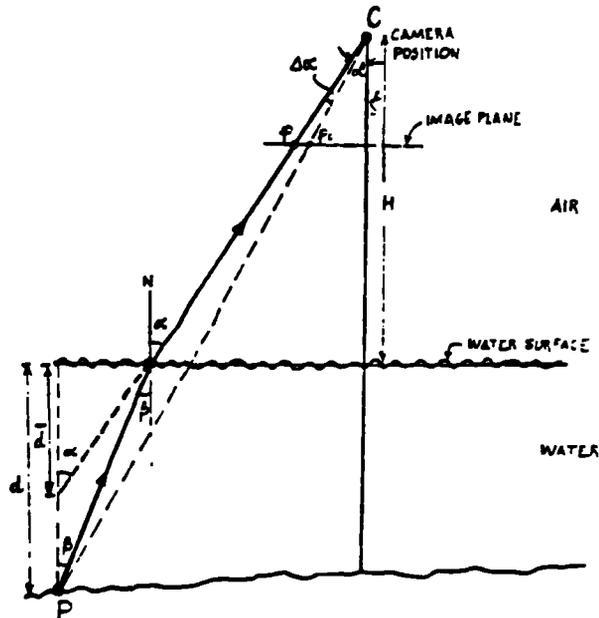
Figure G.1.--Water refraction of underwater target (P).
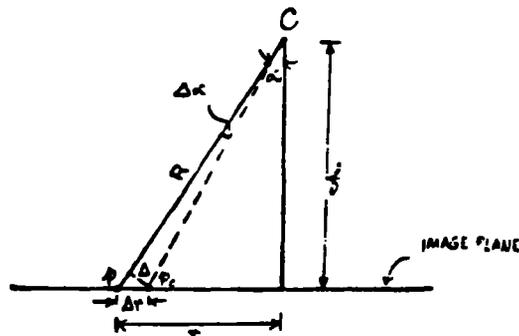
Figure G.2.--Image displacement due to water refraction.

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APPENDIX H.--RUN STRATEGIES AND DATA EDITING

INTRODUCTION

The flexibility which makes GIANT useful also makes it difficult to establish a unique procedure for data editing and evaluation. The circumstances of any given job may necessitate a change in the procedure. However, the following discussion will help in establishing a logical procedure.

In general, aerotriangulation tasks performed by GIANT have the following characteristics:

1. The objective is to establish a sufficiently dense net of control to enable stereomodel setup for compilation.

2. Photography is flown with flight height of less than 9,000 meters above mean sea level with a calibrated mapping camera and near vertical orientation. (The atmospheric refraction model is valid up to the altitude of 9,000 meters. For higher altitudes, a more suitable model would be necessary).

3. External information for the camera parameters are enforceable. In any case, a close approximation of the camera parameters is desirable.

DATA EDITING

In a measured data set, such as plate coordinates, there are three general types of errors:

1. **Accidental** or fortuitous errors, which the least square technique minimizes;

2. **Systematic** error, which is not amenable to solution and has hopefully been removed by preprocessing;

3. **Blunders** or mistakes, which are the result of incorrect observations or recording.

It is this last type of error, the blunders, which must be recognized and removed. The first two types of errors must be recognized and accounted for, but the third type must be removed for a valid solution. It occasionally becomes difficult to differentiate between large accidental errors and blunders. The "rule of thumb" is that errors exceeding the 3 sigma (standard deviations) level may be considered blunders.

Editing Plate Coordinate Data and Other
Input Data by Using Intersection-Only Run

An intersection-only computer run allows identification and removal of the following gross errors:

1. Very large errors in plate coordinate or misidentification.

2. Incorrect combinations of photograph numbers and associated points which appear on the photograph.

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3. Consistently bad photographs which either have a blunder in one or more of the camera station parameters or in the preprocessing of the plate coordinate data.

4. Differences in ground control coordinates which are proofread for differences.

In this computer run, one must only look for gross errors (blunders). Gross errors could be due to misidentification of points, recording errors, etc. Since this run is made with initial approximations only, large patterned residuals should be expected, especially in plate residuals. What one looks for then is a <u>break</u> in the pattern.

If examination of the run shows the computed elevation of a ground control point to be higher than the camera station position, one of the two most probable blunders occurred.

<u>Sign of f</u>. The most probable blunder is the sign of the focal length being incorrect. If the plate coordinate data, as preprocessed, should be reconstructing a photo positive, the sign of the focal length should be negative; if a photo negative, the sign should be positive.

<u>Yaw</u>. The other probable cause is that the yaw angle (κ) is incorrect. This may be checked by plotting several points from a photo positive on a map and rechecking the relationship of image space 'y' and north.

Editing by the Study of Plate Residuals in a Photogrammetric Adjustment Run

Major blunders are easy to identify and rectify in plate coordinate data. Difficulty occurs when gross errors are eliminated and a judgment must be made on eliminating points such that the large residuals are removed. There is a human tendency to start eliminating plate coordinates with large residuals until a run is produced with all small residuals. This procedure may be carried over several runs. In this procedure, the user may inadvertently eliminate readings in an area until all readings connecting adjoining plates have been dropped. This leads to weak solutions and results in poor coordinate determinations.

Listed below are some phenomena which should occur as one approaches the best solution and which will not be obvious to the casual user. When editing, the following must be kept in mind:

Residuals will be grouped by the number of photos (rays) "seeing" a point. The residuals will appear larger for those points seen by more rays.

Residuals in the direction of flight will tend to become zero. The error resolves itself in the vertical component. This is especially true for two-ray points. The elevation of the computed ground position should be watched along with the plate residuals.

Ground control will tend to show a different residual grouping than for uncontrolled points. This tendency is directly related to the weighting of the plate coordinates and the control coordinates.

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The residuals should balance for each point, i.e., the positive and negative residuals should add to zero. This will be approximate, but generally true for a well-adjusted run.

There should not be any undesirable pattern of errors, i.e., no systematic component. The residuals should conform with the laws of normal distribution: small errors are more likely than large errors, the error zero is most probable, and positive and negative errors are equally likely.

Editing by the Study of Camera Parameters

When editing photogrammetric computer runs with unconstrained camera stations, the camera stations are reflecting only the influence of the other data, the plate coordinate, and the ground control. The rule of thumb is twofold: mapping photography is flown straight and level as far as possible; and an aircraft never flies exactly straight and level.

On each run, the user should examine the camera positions and orientations, and ensure they are following a consistent path. Any deviation should be explained.

Editing by the Study of Ground Control

Three possibilities may cause errors: misidentification of control; poor point transfer; and bad coordinates of the point.

Remedial action is determined by the cause. Options for the remedial action are:

o downgrading the "type" of point; e.g., from fully known to horizontal, only if the elevation component is bad;

o increasing the associated standard deviations to reflect the point is not as well known as others;

o changing the type from control to a passpoint; and

o removing or rereading bad plate coordinates;

All coordinates of ground control points are treated as weighted unknowns. Furthermore, the program provides initial estimates of the values and their weights for the unknown components of ground points, referred to as UNHELD components. In determining the degree of freedom for the solution, direct weighted equations for UNHELD components of ground control are not counted. On the other hand, the HELD coordinate components of ground control are held in the solution to the extent of their assigned weights. The program uses its supplied values as best estimates and counts the direct weighted equations in determining the degree of freedom for the adjustment.

The following "key numbers" should be watched carefully:

A Posteriori Estimate of Variance of Unit Weight

This is an important single number by which to judge a run. For a normal case, this number should approach one (1.0). The number starts out very large and as data editing and bootstrapping improve the data, it comes down to a

reasonable value. Remember, this number only reflects the balance between the input standard deviations and the output residuals. If for some reason the weighting is not realistic, this number may not approach one (1.0). Watch it carefully as an indicator of overall performance along with the contributing components of the number.

Weighted Sum of the Squares

This number, along with the changes in camera station parameters, is printed for each iteration. It can be used to judge how much each iteration is changing the solution and, to some extent, where the change is occurring. This number, which most often is huge at the beginning, is an estimate of the sum of the squares of the plate residuals. It is used as a convergence test, i.e., when this number changes less than a predetermined percentage the solution is stable and iterations stop. If the number increases between iterations, the run has "diverged," usually because of bad data or weak geometry, and is incapable of reaching a good solution. Edit the data or submit with fewer iterations and then edit.

Number of Iterations

The default value for this input number is four which is sufficient for most runs. This represents the maximum number of times it can compute a correction and update the solvable parameters to improve a solution. A run may cut off before reaching the maximum number of iterations because of other established criteria. The reason for having this number variable is that in some cases one may want to perform a less amount of iterations to isolate blunders from the solution. In other cases, one may want to extend the number of iterations to reach the best solution, regardless of computer time involved.

Weighting

The weight matrix is the inverse of the input variance-covariance matrix, which is composed of the input standard deviations for all measurements. It is possible to "warp" the solution in any manner desired by manipulating the weights. The best available guide is to assign realistic values to weights. If control is scaled from a 1:24,000 map, make the weights appropriate to the accuracy of the map and scaling error. Plate coordinates, likewise, should reflect the care and accuracy of the equipment and personnel and requirements of the job; 5 to 15 micrometers (microns) is the normal range of standard deviations assigned in the input data.

Invariably, an occasion may arise when insufficient information is available. When things are not working right and the user does not know why, it may be helpful to change the weights: lock the control, loosen the camera positions, tighten the orientations. Any combination can be manipulated until the cause of the problem can be identified. In the absence of sufficient information, these are legitimate data editing techniques done deliberately. If possible, the weights are changed back to realistic values.

RUN STRATEGY

From the above discussions, run strategy should suit the job. Multiple runs will be required to produce the best solution. The objectives of these runs are listed below. A run may achieve one or more objective from a single

run, or multiple runs may be required for each objective, depending on the amount of data and the number of blunders.

Blunder Edit

The first run should be with the INTERSECTION ONLY option exercised. This option overrides the normal solution and allows the program to go through all the motions. Taking only the initial approximations, it computes plate residuals and ground coordinates. No adjustment is performed. This is extremely useful in the first run to eliminate large blunders before they mess up an adjustment beyond recognition.

Clean-up Plate Coordinates

The second objective should be to tie the plates together; i.e., to achieve consistent and low-plate coordinate residuals. This can be achieved with little or no control and the camera station parameters relatively "loose;" i.e., free to adjust. If there are many problems, it may be necessary to constrain the camera station parameters more tightly to prevent them from over-reacting to the errors. It may also be desirable to cut the number of interactions to one or two.

Fit the Control

The objective now is the twofold requirement of improving camera station position and orientation, and fitting them to the ground control. A run is made with only those ground control points which seem to fit or show systematic discrepancies from the preliminary runs. If the solution shows marked improvement, it may be desirable to save the camera station parameters and change the initial approximations to those of the last run. This is often called "bootstrapping." DO NOT tighten the weights (lower the values of the input standard deviations) because no new information has been received, nor are the parameters known any better.

Error Propagation

The last run should include the error propagation option. This is an expensive option to exercise and does not yield much information in the initial phases. The output shows the spread of accuracies of the points and camera station parameters.

Bandwidth Errors

Bandwidth errors are the result of a point appearing on photographs beyond the program limit. The first and last appearances of a point may not exceed a certain number (program limit) of photographs. The most common cause of this error is the duplication of a point number, inadvertently, or separate sets of photographs.

If this message appears during a run, or other very bad unexplained results occur, rerun the job with the INTERSECTION only option exercised. An error message identifying the point in question will be listed. If this is not the cause, the user will probably be able to isolate the problem.

Adding Points After Job Completion

A common occurrence is to finish a triangulation project and then later receive a request for additional point coordinates from the same project. This may be accomplished easily by saving the last set of camera station parameters and setting up an INTERSECTION only run. The new points are marked, measured, and preprocessed as were the points used in the previous adjustment. They are then either added to the appropriate frames or run in the program by themselves, preferably with some other points previously determined for checks. If this is done, the solution will not be affected and a consistent set of coordinates will be produced.