



## NOAA Technical Memorandum NOS NGS - 57

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### GENERAL INTEGRATED ANALYTICAL TRIANGULATION PROGRAM (GIANT), VERSION 4.0, USER'S GUIDE

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Silver Spring, MD  
July 1995

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## ENVIRONMENT

GIANT is a modular style program written in FORTRAN 77. The source code for the software, as well as sample data set (seven files in all), are on a 3.5 inch double sided, high density, 135 tracks per inch diskette 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 Information Services Branch (N/NGS12), National Geodetic Survey, National Ocean Service, National Oceanic and Atmospheric Administration (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:

Photogrammetry Division (N/NCG3)  
National Geodetic Survey  
National Ocean Service  
National Oceanic and Atmospheric Administration  
Silver Spring, MD 20910-3282

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## PREFACE

This user's guide addresses the needs of a photogrammetrist who may want to perform analytical aerotriangulation using the new version 4.0 of GIANT (General Integrated ANalytical Triangulation) program. The source of this program is the original GIANT program (Elassal 1976), explained in GIANT User's Guide (Elassal and Malhotra 1987). However, several significant changes and enhancements to the 1987 version were made and documented in the GIANT Version 3.0 User's Guide, NOAA Technical Memorandum NOS CGS 4, (Elassal and Malhotra 1991). Further enhancements lead to the present GIANT Version 4.0 and prompted the rewriting of this user's guide.

The organization of the material is similar to the one for the previous GIANT Version 3.0 User's Guide. The main text of the GIANT Version 4.0 User's Guide is kept simple by avoiding such details as project planning, preprocessing of measured data, and related considerations. The objective is to give to a photogrammetrist sufficient information to enable him to create data files, execute the program, and interpret the results. No unusual demand is required of the user, although interpretation of results will become more meaningful with experience and knowledge.

Appendices from the GIANT Version 3.0 User's Guide have been included in their entirety in this User's Guide for ready reference to some of the important background information related to the GIANT program. For more basic information on aerotriangulation in general, the reader may wish to consult the Analytical Mapping System User's Guide (Engineering Management Series, 1981). Another good reference is the Manual of Photogrammetry (American Society of Photogrammetry 1980).

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## I. INTRODUCTION

A sufficiently dense control net is required to adequately control photogrammetric instrument settings for exploitation of photographs to generate base maps by stereocompilation, orthophoto mosaic, or other methods. Control may be established photogrammetrically by one of the three well known aerotriangulation methods: analog, semianalytical, or fully analytical. The fully analytical approach is usually used. Various algorithms for analytical aerotriangulation have been developed since the 1960's when digital computers made the associated computations possible and economical. Its primary advantage is the flexibility to accept and enforce various parameters of the data acquisition system, such as, photographic formats, camera focal lengths, ground control, camera station state vector, including positional information obtained from the Global Positioning System (GPS), perform self calibration and systematic error treatment.

The three data reduction phases of an analytical system:

- o Preprocessing or data refinement. Measured image coordinates of all the points are reduced to the plate coordinate system, centered at the principal point. Effects of all known systematic errors, such as lens distortion, are removed.
- o Triangulation. Programs such as GIANT (General Integrated ANalytical Triangulation) accept pre-processed plate coordinates, focal length, ground control, initial estimates of camera station position and orientation, etc., for an iterative least squares solution to solve for camera station position and orientation, and ground coordinates of all points.
- o Postprocessing. Camera station position and orientation are subsequently transformed into instrument settings, which are then used for stereomodel setup, to generate base maps and other cartographic products.

### I.A Functions of GIANT Program

GIANT is a computer program designed to perform analytical aerotriangulation to solve for the ground coordinates of image points measured on two or more photographs in a block of photographs. The basic parameters solved by this program are the ground coordinates of each of the measured image points, and the state vector (position and attitude) parameters of each of the camera exposure stations in a block of photographs. In GIANT Version 4.0 the concept of a photo group in GIANT Version 3.0 has been extended to define hierarchy/organization of a block of photographs in a project to facilitate data entry and reduction.

### *I.A.1. Background information*

In the previous version, GIANT Version 3.0, a block of photographs in an aero-triangulation project is subdivided into sub-blocks, called photo groups. Each photo group is distinguished by the data reduction parameters associated with it. These parameters are based on the characteristics of the data acquisition system. To describe the photo group, three parameters for a photo group were introduced in GIANT Version 3.0. These three parameters represent any one of the following three mathematical models (Elassal and Malhótra 1991):

- o a model to enforce the GPS determined camera positions,
- o a model to perform camera self calibration, and
- o a model to compensate unmodelled symmetric radial errors in the image plane. For example, errors caused by a glass plate used for mounting the camera in the fuselage, cabin pressure, etc.)

GIANT Version 4.0 has been enhanced to simultaneously include parameters to represent any or all of the three mathematical models of GIANT Version 3.0, in addition to an option to include a set of three parameters of a fourth mathematical model which compensates any *unmodelled asymmetric errors* in the image plane due to the camera or an imaging system.

These parameters are introduced as observations in the least squares adjustment of the generalized photogrammetric problem. These parameters are solved for simultaneously in the adjustment.

### *I.A.2. Hierarchy/organization of block of photographs in a project and its functionality in GIANT Version 4.0*

In order to facilitate the introduction of standard deviations of measured quantities and the parameters for the mathematical models, the concept of photo group of GIANT Version 3.0 has been extended to three levels of hierarchy/organization in GIANT Version 4.0. Figure I.1 illustrates the hierarchy/organization of a block of photographs for a typical triangulation project using GIANT Version 4.0. This hierarchy/organization is based on photographs taken from one or more camera system, each camera system having one or more photo groups. The three levels of hierarchy, lowest to the highest level, are the photo group level, the camera system level, and the project level.

In case certain parameters (such as standard deviations of coordinates of a ground control point) are not given a value by definition or by default at a lower level, then it is given a value by default at the next higher level in the adjustment.

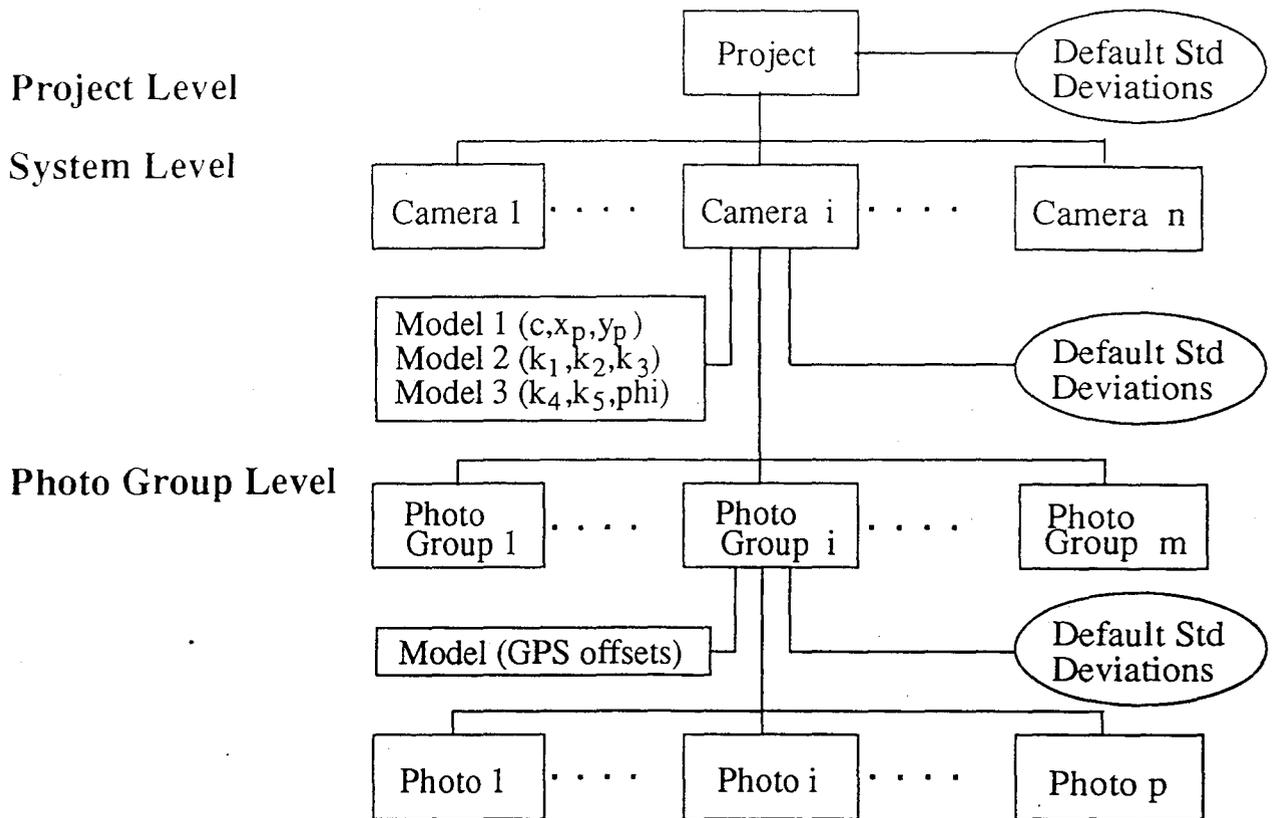


Figure I.1.--GIANT V4.0 Organization/hierarchy of a block of photographs in a triangulation project.

Photo group level:

At this level, each photo group (sub-block) of photographs is distinguished by:

- o the usage/nonusage of the model for GPS antenna offsets,
- o the standard deviation values for the image coordinates and the state vector (position and rotations) of the photographs.

(Note: If these standard deviation values are not assigned at the group level then these are assigned at the next higher level of the camera system.)

The camera system level (Figure I.1):

At this level, each camera system is characterized by:

- o The usage/nonusage of up to three camera system models, (described below), and
- o The standard deviation values (by default or definition) for the image coordinates and the state vectors of photographs.

(Note: These standard deviation values will be assigned only when not assigned at the photo group level.)

The three mathematical models are:

- o Model 1: Includes the three parameters of camera system:
  - o parameters ( $f$ - focal length, and  $x$  and  $y$  coordinates of the principal point)
- o Model 2: Includes the three parameters of unmodelled symmetrical radial errors in the image plane:
  - o parameters ( $k_1, k_2, k_3$ )
- o Model 3: Includes the three parameters of unmodelled asymmetric errors in the image plane:
  - o parameters ( $k_4, k_5$  and  $\Phi$ )

The project level (Figure I.1):

At this level, the standard deviation values of object space coordinates of control points are defined and options for various computations in the adjustment are also defined (for details see job definition record, COMMON file, Sec. II.B.1).

Functionality:

Thus, each photograph belongs to a photo group, which could be GPS controlled, and each photo group could be distinguished from other photo groups by the choice of the mathematical models, peculiar to the imaging system of the photo group.

This hierarchy or organization (Figure I.1) is conveniently used to assign values (by default or definition) to the standard deviations of measured quantities, and for the inclusion of appropriate mathematical models for:

- o GPS data input,
- o camera self calibration,
- o correcting unmodelled symmetric radial errors, and
- o correcting unmodelled asymmetric errors

### I.A.3. General considerations of GIANT program

The GIANT program uses an iterative least squares technique. All parameters are treated as weighted observations, ranging from known to unknown. Observation equations are set up as functions of the parameters. The solution assumes observations to be uncorrelated. All parameters and observations may be weighted to reflect *a priori* knowledge of their precision. This is particularly useful in differentially weighing control (ground or GPS determined), compensating for different sources of control and varying precision, as well as being able to utilize control with unknown components. By allowing the use of partial control points, any horizontal and vertical component, known with varying accuracies, can be used. The user may enforce known camera station positions and orientation, if they are determined by external sources, such as GPS or any geopositioning device on the aircraft. When these parameters can be determined with sufficient accuracy and enforced as observed quantities, the need for ground control is reduced 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 of ground coordinates. When used with a fictitious data generator, a user may predict results of various project configurations, using a set of photographs, a given control pattern, or other variables. Accuracy could be predicted, and additional or different configurations of control could be planned.

The iterative least squares approach requires an initial approximation for each unknown parameter. The user furnishes initial approximations for camera position and orientation parameters whereas, the program generates the initial estimates of the pass point coordinates and of the missing components of the ground control points. The program accepts reasonably gross approximations for these parameters.

The GIANT program expects object space coordinates to be in a space rectangular or in a spherical/geographic coordinate system. Geographic latitude, longitude and ellipsoidal heights are converted to rectangular geocentric coordinates. Any field measured orthometric height is converted off-line to ellipsoidal height before use in the program.

The rectangular coordinate system is generally required for close-range photogrammetry and the spherical/geographic system for conventional mapping projects. The camera attitude is parameterized as roll, pitch, and yaw ( $\omega$ ,  $\phi$ ,  $\kappa$ ) in a local vertical system, which express the image to object relationship.

## I.B. Program Capabilities and Restrictions

The GIANT Version 4.0 employs a highly efficient algorithm for the formation, solution, and inversion of large linear systems of equations. During installation of the program, the agency, using the program, must determine the maximum size it will ever handle for the following parameters:

Description of Parameter:	Symbol
o Maximum number of auxiliary models for camera systems (current value = 0003) .....	M0
o Maximum number of auxiliary models for photo groups (current value = 0001) .....	M1
o Maximum number of camera systems .....	N0
o Maximum number of photo groups .....	N1
o (Maximum number of camera stations) + (M0*N0 + M1*N1) .....	N2
o Maximum number of ground points .....	N3
o Maximum number of control points ( $\leq N2$ ) .....	N4
o (Maximum number of frames seeing a point) + (M0*N0 + M1*N1) .....	N5
o Normal Equations bandwidth allow for (M0*N0 + M1*N1) .....	N6
o Reduced Normal Equations (N6-1) .....	N7
o Size of coefficient matrix (N6(N6+1)/2)*36 .....	N8
o Size of Constant Vector (N6 * 6) .....	N9

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

### Other Capabilities:

- 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 ( $\omega$ ,  $\phi$ ,  $\kappa$ ) which express the relation between image and object coordinate spaces.
- o Camera station position and attitude parameters can be constrained individually, using proper weights (Sec.II.b.2)
- o Vertical and/or horizontal components of ground control can be utilized as full or partial ground control points.
- o Photographs from any number of photo groups (not to exceed N1 as defined above) and any number of imaging systems (not to exceed N0) may be triangulated simultaneously.
- o Data entries are grouped by photographs with the program performing all necessary cross-referencing and pass point ground coordinate 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 additional record (sec. II.B.1). 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 separate root-mean-square errors 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.

GIANT Version 4.0 introduces new parameters for each photo group and for each imaging system (camera) into the photogrammetric solution. The new parameters are introduced as observations and are weighted as either known or completely unknown in the least squares solution. Corresponding to each of the parameter sets there is a mathematical model which gives additional capabilities to the GIANT Version 4.0 program.

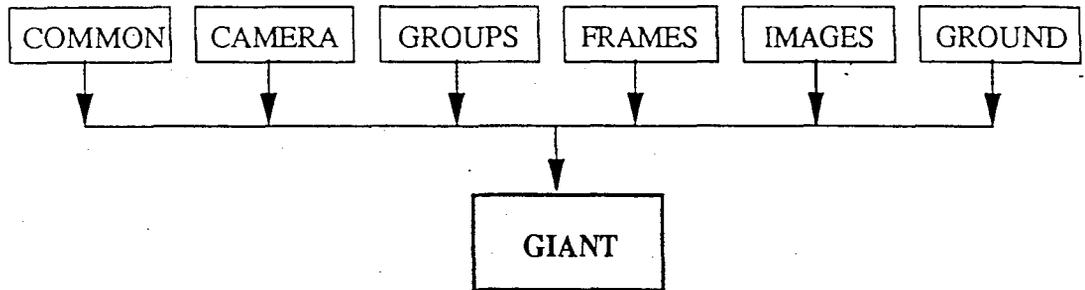
## II. DATA FILES USED

This section describes the input and output data files used in GIANT Version 4.0.

### II.A. An Overview

The six input data files are: COMMON, CAMERA, GROUPS, IMAGES, FRAMES, and GROUND and the output data files are the PRINT and ADJUSTED DATA files as shown in Figure II.1.

**INPUT  
FILES:**



**OUTPUT  
FILES:**

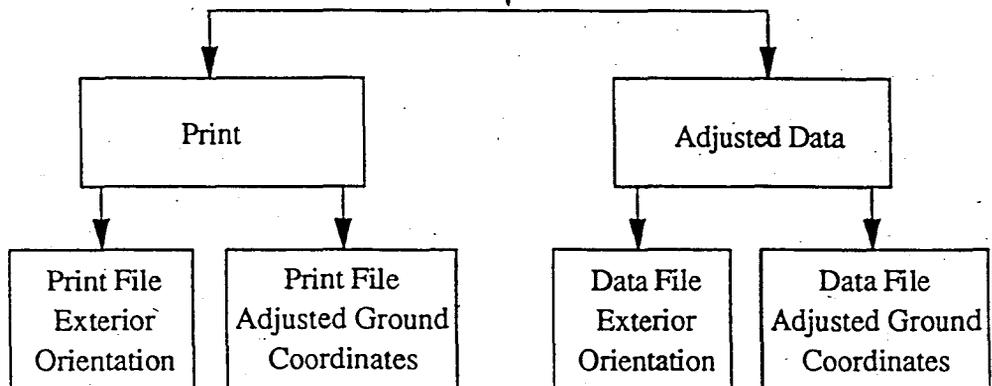


Figure II.1.--Schematic of input and output files.

There are three stages of data reduction as explained in sec.I. In the *preprocessing* stage, the measured image coordinates are reduced from machine coordinate system to the image coordinate system, and are refined by eliminating certain systematic errors before entering the GIANT V4.0 program. The corrections made are for film deformation, lens distortion, and atmospheric refraction. For a detailed description of a typical preprocessor, refer to the Engineering Management Series (1981). The switch for applying atmospheric refraction correction (sec. II.B.1, record no. 2) within GIANT Version 4.0 is turned off if the correction has already been made in the preprocessor.

GIANT Version 4.0 program has an atmospheric refraction correction model applicable up to an altitude of 9,000 m (appendix F). The dynamic nature of this model makes it possible to carry out a more accurate correction for the refraction effect. This correction is based on the *altitude* and *attitude* of the camera. In the program's iterative adjustment process, the atmospheric refraction correction is carried out according to the updated state vector of the camera. The application of this model slows down the convergence of the solution with only a slight improvement in the results. This may discourage its use by production units.

## II.B Input Files and Their Organization

In this section, the following input files: **COMMON**, **CAMERA.IN**, **FRAMES.IN**, **IMAGES.IN**, **GROUND.IN**, **GROUPS.IN** are described in detail for their contents and organization:

### II.B.1. COMMON file

The output list from the GIANT Version 4.0 execution will depend on the options used in the input COMMON file. Also, computational steps in the data reduction will be dictated by the options chosen in the *job definition* data record (Record 2). The COMMON file for the triangulation project may be prepared by an analyst using the details given below:

#### COMMON: Record 1: Project Title

Eighty (20A4) alphanumeric characters title will be printed at the top of each page of the program printout.

COMMON: Record 2: Project Job Definition - This record contains job option flags and parameters for the triangulation run.

---

Column	Content	Field
1	Definition of object space <sup>1</sup> =0, Rectangular coordinates =1, Geographic coordinates	I1

---

<sup>1</sup>In all mapping applications use geographic coordinates; and in close-range applications use rectangular coordinates.

All angles are in Degrees, Minutes and Seconds (DMS). The DMS field is +DDDMMSS.SS...SS, where DDD are degrees; MM are minutes; SS.SS...SS are seconds. For example:

In DMS field -312 deg. 42 min. 53.49 sec. is -3124253.49

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.SSSS, but leading zeros must be included in the minutes and seconds portion.

COMMON: Record 2 - Job definition (continued):

Column	Content	Field
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
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, camera position and attitude fixed	I1

COMMON: Record 2 - Job definition (continued):

Column	Content	Field
11	Error propagation switch =0, do not perform error propagation =1, perform error propagation	I1
12	A <i>posteriori</i> unit variance adjustment flag =0, unit variance based on completely free camera station parameters =1, unit variance based on constrained camera station parameters =2, Unit variance set to unity	I1
13	Sort triangulated ground points switch =0, perform ascending sort of ground points =1, do not perform sort	I1
14	Maximum 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) matching 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 no apply =1, apply	I1
18	Cabin pressure refraction model switch =0, do not apply =1, apply	I1
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 of residuals for two consecutive iterations is less than E percent. Default value of E is 5. (Reference for criteria: p 97, Manual of Photogrammetry, American Society of Photogrammetry, Ed. 1980. And for specific details see page 46 below)	I1

COMMON: Record 2 - Job definition (continued):

Column	Content	Field
31-40	Water level (linear units) 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 micrometers) =0, All images residuals listed; >0, Only those residuals whose absolute value > F listed; <0, No residuals listed	I10
51-60	Semimajor axis of the Earth's spheroid in linear units. If not specified, program will assume the value of Clarke's 1866 spheroid (=6,378,206.4 m).	F10.2
61-70	Semiminor axis of the Earth's spheroid in linear units. If not specified, program will assume the value of Clarke's 1866 spheroid (=6,356,583.8 m).	F10.2

COMMON: Record 3:

This record defines default standard deviations<sup>1</sup> or sigma values for control points.

Column No.	Content	Field
1-10	Sigma X, defaults to 1.0 units or Sigma $\Lambda$ (DMS), defaults to 0.01 DMS	F10.3
11-20	Sigma Y, defaults to 1.0 units or Sigma $\Phi$ (DMS), defaults to 0.01 DMS	F10.3
21-30	Sigma Z, defaults to 1.0 units or sigma H of ellipsoidal height(linear units), defaults to 1.0 unit	F10.3

<sup>1</sup>Standard deviation of object space coordinates of control points can be defined in the GROUND.IN file. If not specified, the program will adopt project default values as above.

## II.B.2. CAMERA.IN file

A photogrammetric triangulation project consists of one or more imaging systems and the CAMERA.IN file defines all of the imaging systems in a triangulation project.

Each of the imaging systems may be defined by one or more records (maximum of four records : one ZERO record and three Model records). ZERO record is a must. However, the model cards are optional, depending on the application.

### CAMERA.IN - Record 1 - System definition or ZERO card:

Columns	Content	Field
1 - 8	System Name	2A4
10	Switch = 0 (System definition or Zero card)	I1
11-15	Default sigma-x for x-image coord. (microns, right justified)	F5.0
16-20	Default sigma-y for y-image coord. (microns, right justified)	F5.0
21-30	Principal distance <sup>1</sup> (microns, right justified)	F10.0
31-40	Default sigma-X(=60,000 linear) or Default sigma $\lambda$ (=10 minutes) for camera	F10.0
41-50	Default sigma-Y(=60,000 linear) or Default sigma $\Phi$ (=10 minutes) for camera	F10.0
51-60	Default sigma-Z(=60,000 linear) or Default sigma-H(=60,000 linear) for camera	F10.0
61-70	Default sigma- $\Omega$ orientation(=90°) for camera	F10.0
71-80	Default sigma- $\Phi$ orientation(=90°) for camera	F10.0
81-90	Default sigma-K orientation(=90°) for camera	F10.0

<sup>1</sup>principal distance is negative if working in positive plane, and positive if working in negative plane.

CAMERA.IN - Record 2:

First model parameters (principal distance, x- and y- coordinates of principal point) are defined as Parameters 1, 2, and 3 in the format description given below.

---

CAMERA.IN - Record 3:

Second model parameters (radial lens distortion coefficients  $k_1, k_2, k_3$ ) are defined as Parameters 1, 2 and 3 in the format description given below.

---

CAMERA.IN - Record 4 :

Third model parameters (asymmetric distortion coefficients  $k_4, k_5, \Phi$ ) are defined as Parameters 1, 2 and 3 in the format description given below.

FORMAT Description for Record 2, 3, and 4.

---

Columns	Content	Field
1 - 8	System	2A4
10	Model = 1, 2 or 3	I1
11-20	Model Parameter 1 (P1)	F10.0
21-30	Model Parameter 2 (P2)	F10.0
31-40	Model Parameter 3 (P3)	F10.0
41-50	Standard deviation of P1	F10.0
51-60	Standard deviation of P2	F10.0
61-70	Standard deviation of P3	F10.0
	<u>Update switch - switch 1:</u>	
73	for P1 =0 do not update =1 update	I1
74	for P2 =0 " " =1 "	I1
75	for P3 =0 " " =1 "	I1
	<u>Solution switch - switch 2:</u>	
78	for P1 =0 solve =1 do not solve	I1
79	for P2 =0 " =1 " "	I1
80	for P3 =0 " =1 " "	I1

---

Record definitions for other systems:

Records 1 through 4: If more than one imaging system is used in the project, create similar records as for the first system and as are necessary to define the system. In other words, a system must be defined by at least Record no.1 (ZERO card) and none to as many model records (record 2 to 4) as are necessary to define the system.

### II.B.3 FRAMES.IN file

FRAMES.IN data file provides estimates of camera position (or of GPS antenna position when using GPS offset model) and of attitudes for each frame in a project. For each frame there are two records: one for position and the other for attitude. Only those frames, appearing in the FRAMES.IN file, will be considered in the triangulation process. The frames included in this file must also be included in the IMAGES.IN file (Sec. II.B.4). However, frames in the IMAGES.IN file may or may not be included in file FRAMES.IN

#### FRAMES.IN Record 1: Frame position record

Column	Content	Field
1-8	Frame identification	2A4
9-20	Primary component of frame position Coordinate (X) in space rectangular coordinate system (linear units); Longitude ( $\lambda$ ) in geographic coordinate system (DMS)	F12.3
21-32	Secondary component of frame position Coordinate (Y) in space rectangular coordinate system (linear units); Latitude ( $\phi$ ) in geographic coordinate system (DMS)	F12.3
33-44	Tertiary component of frame position: Coordinate (Z) in space rectangular coordinate system (linear units); Elevation or ellipsoidal height (H) in geographic coordinate system (linear units)	F12.3
45-54	Standard deviation of primary coordinate of frame position: $\sigma_X$ in rectangular coordinate system (default option = 60,000 units); $\sigma_{\text{Longitude } (\lambda)}$ in geographic coordinates (default option = 10 minutes) (DMS)	F10.3
55-64	Standard deviation of secondary coordinate of frame position: $\sigma_Y$ in rectangular coordinate system (default option = 60,000 units); $\sigma_{\text{Latitude } (\phi)}$ geographic coordinates (default option = 10 minutes) (DMS)	F10.3
65-74	Standard deviation of tertiary coordinate of frame position: $\sigma_Z$ in rectangular coordinate system (default option = 60,000 units); $\sigma_H$ in geographic coordinates (default option = 60000 units)	F10.3
80	<u>Solution Switch (see explanation below)</u>	I1

FRAMES.IN Record 2 Frame (photo) attitude record:

---

Column	Content	Field
1-8	Frame identification	2A4
9-20	Primary rotation angle ( $\omega$ ) frame attitude (DMS)	F12.3
21-32	Secondary rotation angle ( $\phi$ ) frame attitude (DMS)	F12.3
33-44	Tertiary rotation angle ( $\kappa$ ) <sup>1</sup> frame attitude (DMS)	F2.3
45-54	Standard deviation of primary rotation angle (default = 90 DMS)	F10.3
55-64	Standard deviation of secondary rotation angle (default = 90 DMS)	F10.3
65-74	Standard deviation of tertiary rotation angle (default = 90 DMS)	F10.3
80	<u>Solution Switch (see explanation below)</u>	I1

---

Repeat the above FRAMES.IN Record 1 and 2 above for as many frames as there are in the project.

Notes:

<sup>1</sup>( $\kappa$ ) is approximated by a clockwise angle (photo-to-ground) and counter clockwise angle (ground-to-photo) measured from east to the photo (x) in the plane of the vertical photograph.

The maximum number of frames depends on the value of the parameter (N1) which is defined during the installation of the GIANT program.  
Explanation of the Solution Switch in the FRAMES.IN tables above:

Solution Switch

- = 0 components not solved
- = 1 solve for primary component
- = 2 solve for secondary component
- = 3 solve for primary and secondary components
- = 4 solve for tertiary component
- = 7 =1+2+4 solve for all the components

#### II.B.4 IMAGES.IN file

This file contains preprocessed(refined) image measurements for all the image frames (photographs) in a block. Frames in a block may be included in this file in any order desired. For each frame:

##### Record 1 - Header record format:

Column	Content	Field
1-8	Frame (photo) identification	2A4
11-20	Imaging system principal distance(microns) with proper sign. If this data field is left blank, the principal distance will be extracted from GROUPS.IN file, Sec II.B.6.	I10
21-30	Assigned standard deviation of image x-coordinate (microns). Default value=10.	I10
31-40	Assigned standard deviation of image y-coordinate (microns). Default value=10	I10
41-48	Photo group identification: same as in GROUPS.IN file, Sec.II.B.6.	2A4

In triangulation tasks, which involve one system, the system name field may be left 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 are left blank.

##### IMAGES.IN Record 2 through N+1 format:

One record for each image point (N = Number of image points per frame). Any number of such records can be included per frame.

Column	Content	Field
1-8	Image point identification	2A4
11-20	Image x-coordinate (microns)	I10
21-30	Image y-coordinate (microns)	I10

##### IMAGES.IN Record (N+2): Frame termination record format:

Column	Content	Field
1-8	*****	2A4

Repeat above records for each subsequent frames.

## II.B.5 GROUND.IN file

The file contains coordinates of ground control points in a project. Record format for each ground control:

Column	Content	Field
1-8	Identification of ground point	2A4
9-20	Primary component of ground control <i>Coordinate-X</i> in rectangular coordinate system (linear units); <i>Longitude</i> ( $\Lambda$ ) in geographic coordinates (DMS)	F12.3
21-32	Secondary component of ground control <i>Coordinate-Y</i> in rectangular coordinate system (linear units); <i>latitude</i> ( $\Phi$ ) in geographic coordinates (DMS)	F12.3
33-44	Tertiary component of ground control <i>Coordinate-Z</i> in rectangular coordinate system (linear units); <i>Elevation</i> ( <i>h</i> ) in geographic coordinates (DMS)	F12.3
45-54	Standard deviation of primary component of ground control coordinates: <i>Sigma-X</i> in rectangular coordinate system (default to value in COMMON file) <i>Sigma-(<math>\Lambda</math>)</i> in geographic coordinate system (default to value in COMMON file)	F10.3
55-64	Standard deviation of secondary component of ground control coordinates: <i>Sigma-Y</i> in rectangular coordinate system (default to value in COMMON file); <i>Sigma-(<math>\Phi</math>)</i> in geographic coordinate system (default to value in COMMON file)	F10.3
65-74	Standard deviation of tertiary component of ground control coordinates: <i>Sigma-Z</i> in rectangular coordinate system (default to values in COMMON file); <i>Sigma-H</i> in geographic coordinate system (default to value in COMMON file)	F10.3
80	Missing component indicator: = 0, no missing component (complete control) = 1, ignore primary component = 2, ignore secondary component = 4, ignore tertiary component (planimetric control point) = X, where X is the sum of any two Of the above mentioned codes, means ignore corresponding two components <u>Example:</u> X = 1+2 = 3, means elevation point X = 1+2+3 = 7, unknown point	I1

## II.B.6 GROUPS.IN file

The photo groups are distinguished by the usage/nonusage of GPS controls for the photographs in the group. Each photo group has a unique camera or imaging system.

Each group has two records:

GROUPS.IN Record 1: consists of group and camera identification:

Column	Content	Field
1-8	Photo group identification	2A4
13-20	Camera system identification	2A4

GROUPS.IN Record 2: gives group identification, indicator for usage/non-usage of GPS antenna position, GPS offsets:  $\Delta X$ ,  $\Delta Y$ ,  $\Delta Z$  (Equation 2, Appendix K), standard deviations for each of the offsets, and two switches: the update and the solution switches.

Column	Content	Field
1-8	Photo group identification	2A4
10	Indicator = 1 (GPS usage) = 0 (no GPS)	I1
13-20	Camera system	2A4
21-30	GPS offset: $\Delta X$	F10.0
31-40	" " $\Delta Y$	F10.0
41-50	" " $\Delta Z$	F10.0
51-60	Standard deviation of $\Delta X$	F10.0
61-70	" " " $\Delta Y$	F10.0
71-80	" " " $\Delta Z$	F10.0
	<u>Update switch: = 0 (do not update) = 1 (update)</u>	
83	Update switch for $\Delta X$	I1
84	" " " $\Delta Y$	I1
85	" " " $\Delta Z$	I1
	<u>Solution switch: = 0 (solve) = 1 (do not solve)</u>	
88	Solution switch for $\Delta X$	I1
89	" " " $\Delta Y$	I1
90	" " " $\Delta Z$	I1

GROUPS.IN Record 1 and 2 are written for each photo group. Each photo group has a unique camera system distinguished by the data of these records.

## II.B.7 SAMPLE: INPUT DATA FILES

The following section illustrates input data files for GIANT Version 4.0 for a typical aerotriangulation project.

Sample COMMON file

1 2 3 4 5 6 7 8  
1234567890123456789012345678901234567890123456789012345678901234567890

SAMPLE RUN FOR NOAA/NOS GIANT V4.0 PROGRAM

1000000000000500003

15

Sample of CAMERA.IN file:

	1	2	3	4	5	6	7	8
	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890
CAMERA01			-153280					
CAMERA01 1	0.0000	0.0000	0.0000	100.0	100.0	100.0	000	000
CAMERA01 2	0.0000	0.0000	0.0000	0.00000	.1000E+050	.1000E+050	.1000E+05	000 000
CAMERA01 3	0.0000	0.0000	0.0000	0.00000	.0000E+000	.0000E+000	.0000E+00	000 000
CAMERA02			-153285					
CAMERA02 1	0.0000	0.0000	0.0000	1.000	1.000	1.000	000	000

Sample FRAMES.IN file

	1	2	3	4	5	6	7	8
1234567890123456789012345678901234567890123456789012345678901234567890								
SA1	-1224425.802	471028.525	5986.831					0
SA1	-1923.314	-3253.147	2840826.112					0
SA10	-1224959.092	471126.984	5528.250					0
SA10	21415.748	237.246	2875527.927					0
SA2	-1224353.022	471122.240	5987.671					0
SA2	21045.094	-3123.826	2845757.070					0
SA3	-1224322.808	471211.703	5988.669					0
SA3	35721.119	-3744.984	2840713.805					0
SA4	-1224226.495	471355.745	5984.082					0
SA4	20629.320	-3045.645	2805553.637					0
SA5	-1224138.093	471529.698	5984.667					0
SA5	2424.211	-4219.766	2815923.027					0
SA6	-1224045.720	471702.322	5982.361					0
SA6	21924.203	-3735.117	2830559.048					0
SA7	-1223955.156	471835.017	5980.788					0
SA7	14704.547	-3611.397	2803324.425					0
SA8	-1223905.264	472007.552	5980.358					0
SA8	11334.968	-3900.679	2824929.713					0
SA9	-1225049.182	470954.298	5525.178					0
SA9	4330.966	-300.666	2902141.461					0
SB1	-1224906.923	471308.139	5528.803					0
SB1	2726.525	-938.633	2890341.116					0
SB10	-1223625.106	471558.899	5441.291					0
SB10	14854.612	-4322.570	1144615.302					0
SB11	-1223715.241	471434.321	5436.809					0
SB11	13531.498	-5018.470	1132926.709					0
SB12	-1223807.112	471310.586	5447.685					0
SB12	23126.000	-4038.613	1134434.432					0
SB13	-1223856.541	471144.799	5443.129					0
SB13	5901.775	-4905.470	1141327.408					0
SB14	-1223949.005	471021.313	5437.854					0
SB14	3458.622	-5020.153	1154858.103					0
SB2	-1224811.159	471446.997	5530.040					0
SB2	44621.330	743.795	2891055.519					0
SB3	-1224720.987	471625.668	5530.209					0
SB3	537.866	-940.359	2881921.731					0
SB4	-1224631.594	471804.589	5528.571					0
SB4	23422.658	130.388	2861313.855					0
SB5	-1224546.302	471943.704	5525.271					0
SB5	4455.731	-1108.015	2855521.506					0
SB6	-1224455.764	472122.198	5522.157					0
SB6	21059.391	-747.839	2875317.605					0
SB7	-1223404.834	472015.737	5438.948					0
SB7	13549.398	-3929.898	1121301.643					0
SB8	-1223450.565	471850.452	5439.778					0
SB8	21754.665	-3531.348	1125311.807					0
SB9	-1223536.044	471723.817	5444.158					0
SB9	-3522.481	-3523.111	1121318.254					0

Sample IMAGES.IN file

1 2 3 4 5 6 7 8  
1234567890123456789012345678901234567890123456789012345678901234567890

SA1 GROUP1

1A 3950 16491  
2A 72504 82418  
3A 97852 -90658  
4A 108534 64790  
651100 -7411 -85842  
651200 10656 73707  
651201 51708 19789  
651202 76159 -98996

\*\*\*\*\*

SA10 GROUP1

16A -89917 -85954  
17A -12408 83520  
18A 16763 -88424  
19A -101494 -3626  
20A 92377 87325  
21A 82592 -102001  
26A 106444 -18498  
651200 16300 -109774  
679100 -40347 -43119  
679200 -73089 85801  
679201 -59735 -68021  
680200 25702 35899

\*\*\*\*\*

SA2 GROUP1

1A -42090 29441  
2A 25745 98487  
3A 51314 -74335  
4A 62767 80587  
651100 -51239 -71223  
651200 -36715 88377  
651201 5652 33484  
651202 30641 -82615

\*\*\*\*\*

SA3 GROUP1

1A -83996 41365  
2A -16301 111581  
3A 8688 -63155  
4A 21550 92353  
5A 79101 -7755  
651100 -92221 -58558  
651200 -79290 101853  
651201 -36074 44774  
651202 -11282 -70936  
653200 79960 -78755

\*\*\*\*\*

SA4 GROUP1

4A -63212 98950  
651202 -101030 -62192  
653200 -9251 -75193  
654200 85811 79663  
6A 13814 91226

\*\*\*\*\*

SAS		
31A	53334	-90994
5A	-86264	2611
653200	-84625	-70639
654200	4945	85287
655100	104707	-42121
655101	70086	-7910
655200	92312	-21828
655201	50084	-89165
6A	-66122	95021
7A	13305	-97635

GROUP1

\*\*\*\*\*

SA6		
10A	105613	44422
31A	-22406	-72356
654200	-76224	103054
655100	26448	-23720
655101	-8114	9452
655200	14215	-3975
655201	-25554	-70671
7A	-61872	-79421
8A	70434	-96660

GROUP1

\*\*\*\*\*

SA7		
10A	28475	51581
31A	-101631	-59700
655100	-51901	-12906
655101	-84982	21748
655200	-63213	7366
655201	-104664	-57871
657200	112329	94055
657201	74684	1287
8A	-9834	-88210
9A	93401	-94238

GROUP1

\*\*\*\*\*

SA8		
10A	-51178	60733
657200	29212	106066
657201	-2840	12641
8A	-82162	-80439
9A	19916	-82354

GROUP1

\*\*\*\*\*

SA9		
16A	-2387	-94951
17A	71106	78028
18A	105487	-92982
19A	-16029	-11796
679100	46717	-49009
679200	10072	77620
679201	27073	-75274
680200	109436	32964

GROUP1

\*\*\*\*\*

SB1		
17A	-106290	77520
18A	-71822	-93919
20A	-2770	83465
21A	-5118	-106892
22A	112647	-7114

GROUP2

*****			
SB10			GROUP2
11A	-91468	80535	
13A	-10479	66492	
31A	24827	-65786	
700200	64722	42980	
700201	17917	-87400	
700202	25756	-67671	
7A	67022	-50759	
8A	-80941	-59815	
*****			
SB11			GROUP2
13A	-89632	63438	
14A	57510	53146	
31A	-54547	-68542	
700200	-14420	38584	
700201	-61480	-89924	
7A	-13623	-54588	
*****			
SB12			GROUP2
14A	-24338	54504	
15A	74462	5430	
3A	102065	-63549	
700200	-94135	39672	
7A	-91593	-52564	
*****			
SB13			GROUP2
14A	-104593	45380	
15A	-6468	-2008	
3A	23355	-71123	
702200	76094	71778	
703100	76002	78157	
*****			
SB14			GROUP2
15A	-85352	-6918	
3A	-53553	-74955	
651100	59773	-57705	
702200	-5823	68391	
703100	-6508	74676	
*****			
SB2			GROUP2
20A	-99780	102416	
21A	-92367	-88040	
22A	20222	7615	
23A	-8822	-81316	
24A	86125	57920	
26A	-74795	-6209	
2A	-94400	-84964	
654200	95632	-94999	
682200	12497	107037	
*****			
SB3			GROUP2
22A	-69256	-4009	
23A	-99810	-96541	
24A	-4370	44019	
25A	7873	-39492	
654200	11018	-113811	

\*\*\*\*\*

SB4		
24A	-94398	55559
25A	-82983	-28828
27A	108384	-56986
28A	101689	67630
654200	-80530	-100416
684200	19978	50300
684201	19745	-54592

GROUP2

\*\*\*\*\*

SB5		
27A	21322	-61215
28A	11958	63537
29A	86288	-82647
30A	108107	88558
684200	-68531	46893
684201	-68141	-58152
685100	46348	-23900

GROUP2

\*\*\*\*\*

SB6		
27A	-65292	-53981
28A	-80998	70542
29A	-113	-72771
30A	14377	99598
685100	-42843	-16297

GROUP2

\*\*\*\*\*

SB7		
12A	55818	81836
697100	83059	-13306
697200	87844	42368
9A	40865	-68909

GROUP2

\*\*\*\*\*

SB8		
11A	75029	93253
697100	2627	-14337
697200	7198	41166
8A	73826	-50018
9A	-37423	-69644

GROUP2

\*\*\*\*\*

SB9		
11A	-7113	78055
12A	-103086	67042
13A	72741	60827
31A	102107	-73773
697100	-78483	-25680
697200	-71899	29140
700201	94151	-96097
8A	-6301	-62844

GROUP2

\*\*\*\*\*

Sample GROUND.IN file

	1	2	3	4	5	6	7	8
	1234567890123456789012345678901234567890123456789012345678901234567890							
651200		0.000	0.000	0.000			0.000	3
651201		0.000	0.000	0.000			0.000	3
651202		0.000	0.000	0.000			0.000	3
653200		0.000	0.000	0.000			0.000	3
654200		0.000	0.000	0.000			0.000	3
655100	-1223941.077	471724.285	0.000	0.000	0.000	0.000		4
655200		0.000	0.000	0.000			0.000	3
655201		0.000	0.000	0.000			0.000	3
657200		0.000	0.000	0.000			0.000	3
657201		0.000	0.000	0.000			0.000	3
679100	-1224900.153	471024.433	0.000	0.000	0.000	0.000		4
679200		0.000	0.000	0.000			0.000	3
679201		0.000	0.000	0.000			0.000	3
680200		0.000	0.000	0.000			0.000	3
682200		0.000	0.000	0.000			0.000	3
684200		0.000	0.000	0.000			0.000	3
684201		0.000	0.000	0.000			0.000	3
685100	-1224442.445	472026.529	0.000	0.000	0.000	0.000		4
697100	-1223522.749	471858.388	0.000	0.000	0.000	0.000		4
697200		0.000	0.000	0.000			0.000	3
700200		0.000	0.000	0.000			0.000	3
700201		0.000	0.000	0.000			0.000	3
702200		0.000	0.000	0.000			0.000	3
703100	-1223752.759	470954.028	0.000	0.000	0.000	0.000		4

Sample GROUPS.IN file

		3	4	5	6	7	8		
		1234567890123456789012345678901234567890123456789012345678901234567890							
GROUP1		CAMERA01							
GROUP1	1	CAMERA01	3.0000	5.0000	7.00000.0000E+000.0000E+000.0000E+00			000	111
GROUP2		CAMERA02							
GROUP2	1	CAMERA02	-4.0000	1.0000	-5.00000.0000E+000.0000E+000.0000E+00			000	111

II.C. LOGICAL UNIT NUMBER ASSIGNMENTS FOR  
ALL THE FILES USED IN GIANT VERSION 4.0

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

Table II.1.--Files Used By GIANT Version 4.0

Logical UNIT Number	Type	Format		Utilization	User's Guide Text Page Number
		(F) Formatted	(UF) Unformatted		
11	Input	(F)	Sec. II.B.2	Camera data set	13
12	Input	(F)	Sec. II.B.6	Groups data set	19
13	Input	(F)	Sec. II.B.3	Frame data set	15
14	Input	(F)	Sec. II.B.4	Image coordinate data set	17
15	Input	(F)	Sec. II.B.5	Ground control data set	18
16	Input	(F)	Sec. II.B.1	Common data set	9
17	Output	(F)	Sec. II.D.1	Printout	29
18	Output	(F)	Sec. II.D.2	Updated frames data set	30
19	Output	(F)	Sec. II.D.3	Adjusted ground data set	30
20	Output	(F)	Sec. II.D.2	Updated frames data set	30
21	Scratch	(UF)		Temporary storage	
.	.	.	.	.	
.	.	.	.	.	
29	.	.	.	.	
30	.	.	.	.	

Output files logical units 18 and 19 will not be generated by GIANT in case the solution fails to converge.

Output file logical unit 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.

II.D. OUTPUT FILES

**II.D.1. Printout File**

Output data file, logical identification 17, Table II.1, Sec. II.C, is a formatted printout 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 triangulated ground coordinates of points, the images of which are measured on two or more photographs, and the camera parameters, which are the position and attitude of camera at each of the exposure stations.

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

#### ***II.D.2. Updated Frames Data File***

Output data file, logical unit 18, Table II.1, Sec.II.C, 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 Version 4.0. This file is used in applications such as stereocompilation and orthophoto mosaic.

Output data file, logical unit 20, Table II.1, sec.II.C, contains updated 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 left off.

#### ***II.D.3. Adjusted Ground Data File***

Output data file, logical unit 19, Table II.1, Sec.II.C, contains adjusted ground coordinates of all points measured on two or more photographs. This file is created during each iteration of a successful convergent solution of GIANT V4.0. This file is used in applications, such as stereocompilation and orthophoto mosaics.

#### ***II.D.4. Sample Printout and Explanation***

Printout data file, logical unit 17, Table II.1, Sec.II.C, is a formatted file. The contents of the file depends on the print options selected in the job definition record of the COMMON input file, Sec.II.B.1 on input data files. The printout gives the triangulated ground coordinates of points, the images of which are measured on two or more photographs, and the camera parameters, which are the position and attitude of camera at each of the exposure stations.

*A typical sample of the printout file follows.*

Page by page explanation is given for each typical printout page, printed from the printout file, logical unit 17, Table II.1, Sec.II.C, for a typical aero-triangulation project.

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 STATION PARAMETERS

CABIN PRESSURE REFRACTION WILL NOT BE INCLUDED IN THE ADJUSTMENT

ATMOSPHERIC REFRACTION WILL BE INCLUDED IN THE ADJUSTMENT

WATER REFRACTION WILL NOT BE INCLUDED IN THE ADJUSTMENT

IMAGE RESIDUALS GREATER THAN 7 (MICRONS) WILL BE LISTED

LEADING '0' WILL BE ELIMINATED FROM ALL IDENTIFICATIONS

SEMI-MAJOR AXIS OF SPHEROID = 6378137.00

SEMI-MINOR AXIS OF SPHEROID = 6356752.30

TRIANGULATED GROUND COORDINATES WILL BE SAVED

ADJUSTED STATION PARAMETERS WILL BE SAVED

EXPLANATION OF GIANT V4.0 PRINTOUT FILE

EXPLANATION: PRINTOUT Page 0 (User's Guide page 31)

-----  
 Explanation of options used in the project COMMON file:

ITEM:	OPTIONS
o Object space reference system:	Geographic or Rectangular
o Camera rotation angles:	Photo-to-ground or Ground-to-photo
o Triangulation Process:	Complete triangulation or Intersection only holding camera position and attitude fixed).
o Error propagation:	perform or do not perform
o Basis for unit variance:	camera parameters free or constrained, or unit variance set to one.
o Cabin pressure refraction:	include or do not include
o Atmospheric pressure:	include or do not include
o Water refraction:	include or do not include
o Plate residual listing:	for all images or images with absolute residuals greater than F (eg =10) microns or for no images
o Semi-major axis of the Earth:	defined or default to Clark's 1866 spheroid value.
o Semi-minor axis of the Earth:	defined or default to Clark's 1866 spheroid value.
o Triangulated ground coordinates:	save or do not save
o Adjusted exposure station parameters:	save or do not save

(Note: Station parameters are not saved but fixed during  
intersection only process.)

For angular and linear units, see page 36)

INPUT CAMERA SYSTEM PARAMETERS

Camera system : CAMERA01

Principal Distance : F = -153285  
Default image st. deviations : x = 10 y = 10  
Default camera position st. deviations : lng = 100.0000 Lat = 100.0000 Elv = 1000.0000  
Default camera attitude st. deviations : Omega = 900000.0000 Phi = 900000.0000 Kappa = 900000.0000

Angular and linear units in this sample printout:

- o Inner orientation parameters of camera and plate coordinates are in microns.
- o All angles are in degrees, minutes and seconds (DMS)  
DMS field:  $\pm$ DDMMSS.SSSS
- o All object space rectangular coordinates are in meters.

INPUT CAMERA SYSTEM PARAMETERS

Camera system: Identification number

- o Principal distance: (calibrated value)
- o Default standard deviation for:
  - o Image: x- and y-coordinates
  - o Camera Position: Longitude( $\lambda$ ), Latitude( $\phi$ ) Elevation(H)
  - o Camera Attitude (local Vertical)  
Omega( $\omega$ ), Phi( $\phi$ ), and Kappa(K)

(NOTE: In the example run, there is no output for the remaining items, as none of the following three models was used.)

o Camera system models (None or up to three models):

- o Model #1: three parameters: -principal distance (p),  
-principal point (x,y)  
-standard deviations  
-update switch  
-exclusion switch  
(exclusion switch overrides update switch)
- o Model #2: three parameters: -radial distortion  
parameters:  $k_1, k_2, k_3$   
-standard deviations of  
three parameters.  
-Update switch  
-Exclusion switch  
(exclusion switch overrides update switch)
- o Model #3: three parameters: -asymmetric distortion  
parameters  $k_4, k_5, \text{Phi}$   
-standard deviations  
-Update switch  
-Exclusion switch  
(exclusion switch overrides update switch)

(Note: The standard deviations and update switch are ignored if the exclusion switch is "on")

o Other camera systems:

The above output would repeat for each camera system in the project.

I N P U T P H O T O G R O U P S P A R A M E T E R S

Photo group : GROUP\_1 of camera system : CAMERA01  
 Default image st. deviations : X = 6 Y = 6  
 Default camera position st. deviations : lng = 100.0000 Lat = 100.0000 Elv = 1000.0000  
 Default camera attitude st. deviations : Omega = 900000.0000 Phi = 900000.0000 Kappa = 900000.0000  
 GPS Antenna Offsets model :  
 X = 0.21000D+00 Std\_X = 0.10000D+04 Updating Switch: Off Exclusion Switch: On  
 Y = 0.51800D+00 Std\_Y = 0.10000D+04 Updating Switch: Off Exclusion Switch: On  
 Z = 0.14500D+01 Std\_Z = 0.10000D+04 Updating Switch: Off Exclusion Switch: On

Photo group : GROUP\_2 of camera system : CAMERA01  
 Default image st. deviations : X = 6 Y = 6  
 Default camera position st. deviations : lng = 100.0000 Lat = 100.0000 Elv = 1000.0000  
 Default camera attitude st. deviations : Omega = 900000.0000 Phi = 900000.0000 Kappa = 900000.0000

**Angular and linear units in this sample printout:**

- o Inner orientation parameters of camera and plate coordinates are in microns.
- o All angles are in degrees, minutes and seconds (DMS)  
DMS format: DDDMMSS.SSSS
- o All object space rectangular coordinates are in meters.

**INPUT PHOTO GROUPS PARAMETERS**

- o Photo Group: GROUP\_1                      o Camera system: CAMERA01
- o Default standard deviations for:
  - image coordinates (x,y)
  - camera position:  $\lambda, \phi, H$
  - camera attitude:  $\omega, \phi, \kappa$   
(local vertical system)
- o GPS antenna offsets model (GPS assisted photography):
  - o GPS antenna offsets  $\Delta X, \Delta Y, \Delta Z$  along axes X,Y,Z
  - o standard deviations for the three offsets
  - o updating switch for the three offsets
  - o exclusion switch for the three offsets

(Note: Exclusion switch overrides the updating switch  
The standard deviations and updating switch are  
ignored if the exclusion switch is "on".)

**Other Photo Groups:**

- o Photo Group: GROUP\_2                      o Camera system: CAMERA01

The printout gives the default standard deviations for other camera systems. If GPS is used, it also gives GPS antenna offsets along with their standard deviations and switches.)

I M A G E I N P U T P A R A M E T E R S

Frame: 93AC4693 Group: GROUP\_1

Principal distance = -153285 St. D. of x = 6 St. D. of y = 6

STATION PARAMETERS

P O S I T I O N (Antenna)

A T T I T U D E (Photo to ground)

Lng = -121 35 2.4020 St. D. = 0 0 0.0024 Omega = 0 39 0.9680 St. D. = 90 0 0.0001  
 \*7\* Lat = 37 36 57.2940 St. D. = 0 0 0.0019 \*0\* Phi = 0 8 28.0580 St. D. = 90 0 0.0001  
 Elv = 2992.4470 St. D. = 0.0515 Kappa = 182 10 0.5980 St. D. = 90 0 0.0001

PLATE COORDINATES

ID	X	Y	ID	X	Y	ID	X	Y
101	-103094	84233	111	-90659	3261	121	-85597	-89117
141	11733	-24854	151	-24179	-97491	45	-96592	-48156
693202	-72063	-80383				693201	-37750	-379
						131	66657	54812

Angular and linear units in this sample printout:

- o Inner orientation parameters of camera and plate coordinates are in microns.
- o All angles are in degrees, minutes and seconds(DMS)  
DMS format: DDDMMSS.SSSS
- o All object space rectangular coordinates are in meters.

IMAGE INPUT PARAMETERS

Frame: Identification Number      o Group: Name

- o Principal distance (calibrated value)
- o Standard deviation (Sigma-x) of image x-coordinate
- o Standard deviation (Sigma-y) of image y-coordinate

STATION PARAMETERS

POSITION (Antenna):

- o Composite flag value<sup>1</sup> (e.g \*7\*)
- o Geographic: Longitude, Latitude, Ellipsoidal Height
- o Standard deviation: Longitude, Latitude, Ellipsoidal Height

ATTITUDE (Photo to ground)

(Note: Another option available is "Ground to photo" )

- o Composite flag: (e.g. value of \*0\*)
- o Rotations: Omega, Phi, Kappa (local vertical system)
- o Standard deviations: of Omega, Phi, Kappa

PLATE COORDINATES

- o Image identification: (Note: Identification number, which is followed by "!", is obtained in automatic numbering mode during measurements in order to avoid duplication)
- o Image x,y coordinates<sup>2</sup>:(plate coordinate system)

---

<sup>1</sup> Composite flag defines type of ground control. See page 40 for more details.

<sup>2</sup> Image coordinates are refined for film distortions and expressed in the coordinate system defined by the calibrated fiducials or the plate coordinate system)

## GROUND CONTROL DATA

213	Lng = -121 33 41.3210	St. D. = 0 0	0.0500	Type = 4
	Lat = 37 37 53.8230	St. D. = 0 0	0.0500	
	Elv = 0.0000	St. D. =	5.0000	
217	Lng = -121 32.24.7570	St. D. = 0 0	0.0500	Type = 4
	Lat = 37 37 44.9880	St. D. = 0 0	0.0500	
	Elv = 0.0000	St. D. =	5.0000	
45	Lng = -121 33 59.5490	St. D. = 0 0	0.0500	Type = 7
	Lat = 37 37 21.8000	St. D. = 0 0	0.0500	
	Elv = 0.0000	St. D. =	5.0000	
486201	Lng = 0 0 0.0000	St. D. = 0 0	0.0500	Type = 3
	Lat = 0 0 0.0000	St. D. = 0 0	0.0500	
	Elv = 184.4040	St. D. =	5.0000	
486202	Lng = 0 0 0.0000	St. D. = 0 0	0.0500	Type = 7
	Lat = 0 0 0.0000	St. D. = 0 0	0.0500	
	Elv = 335.2810	St. D. =	5.0000	
486203	Lng = 0 0 0.0000	St. D. = 0 0	0.0500	Type = 7
	Lat = 0 0 0.0000	St. D. = 0 0	0.0500	
	Elv = 238.0490	St. D. =	5.0000	
489201	Lng = 0 0 0.0000	St. D. = 0 0	0.0500	Type = 3
	Lat = 0 0 0.0000	St. D. = 0 0	0.0500	
	Elv = 385.2680	St. D. =	5.0000	
489202	Lng = 0 0 0.0000	St. D. = 0 0	0.0500	Type = 3
	Lat = 0 0 0.0000	St. D. = 0 0	0.0500	
	Elv = 441.3510	St. D. =	5.0000	

Angular and linear units in this sample printout:

- o All angles are in degrees, minutes and seconds (DMS)  
DMS format: DDDMMSS.SS...SS
- o All object space rectangular coordinates are in meters.

GROUND CONTROL DATA

- o Ground point identification
- o Primary coordinate of ground control point (geographic) -Longitude  $\lambda$
- o Secondary " " " -Latitude  $\phi$
- o Tertiary " " " -Ellipsoidal Elevation H (local vertical system)
- o Standard deviation of
  - Longitude (Sigma- $\lambda$ )
  - Latitude (Sigma- $\Phi$ )
  - Ellipsoidal elevation (Sigma-H)

(Note: If standard deviations are not defined here, then the default values are taken from the project COMMON file)

- o Type of ground control: missing component indicator or the composite flag value<sup>1</sup>

<sup>1</sup> Composite flag value (X)	Coordinates update		
	Primary	Secondary	Tertiary
0	Y	Y	Y
1	N	Y	Y
2	Y	N	Y
3	N	N	Y
4	Y	Y	N
5	N	Y	N
6	Y	N	N
7	N	N	N

- X =1, means primary component ignored
- =2, means secondary component ignored
- =4, means tertiary component ignored
- =7, means control not updated or ignored
- =0, means control updated

STATIONS CORRECTIONS

ITERATION 1

93AC4693	Position	-0.000000002	0.000000000	0.000016086	-0.000006607	-0.000003445
93AC2314	Position	-0.000000035	0.000000027	-0.000057041	-0.000067646	0.000000449
93AC4692	Position	0.000000002	0.000000000	0.000016911	-0.000004069	-0.000001651
93AC2313	Position	-0.000000013	0.000000028	-0.000054325	-0.000027090	0.000000539
93AC2311	Position	0.000000019	0.000000028	-0.000049964	0.000047453	0.000000384
93AC2312	Position	0.000000002	0.000000027	-0.000052718	0.000009759	0.000000420
93AC4689	Position	0.000000001	0.000000002	0.000009021	0.000011055	0.000011119
93AC4690	Position	-0.000000004	-0.000000004	0.000014281	0.000006793	0.000006567
93AC4691	Position	0.000000003	0.000000002	0.000017459	0.000000394	0.000002579

Provisional weighted sum of squares = 9278.18

ITERATION 2

93AC4693	Position	-0.000000002	0.000000000	-0.000000104	-0.000000043	0.000000003
93AC2314	Position	0.000000000	-0.000000001	0.000002283	0.000000108	0.000000035
93AC4692	Position	0.000000002	0.000000000	-0.000000095	-0.000000035	0.000000000
93AC2313	Position	0.000000000	-0.000000001	0.000002435	0.000000133	0.000000075
93AC2311	Position	0.000000000	-0.000000001	0.000002316	0.000000180	0.000000103
93AC2312	Position	0.000000000	-0.000000001	0.000002380	0.000000174	0.000000108
93AC4689	Position	0.000000001	0.000000002	-0.000000007	0.000000003	-0.000000105
93AC4690	Position	-0.000000004	-0.000000004	-0.000000066	0.000000023	-0.000000088
93AC4691	Position	0.000000003	0.000000002	-0.000000087	-0.000000024	-0.000000044

Provisional weighted sum of squares = 2007.13

ITERATION 3

93AC4693	Position	-0.000000002	0.000000000	0.000000000	0.000000000	0.000000000
93AC2314	Position	0.000000000	0.000000000	0.000000005	0.000000000	0.000000000
93AC4692	Position	0.000000002	0.000000000	0.000000000	0.000000000	0.000000000
93AC2313	Position	0.000000000	0.000000000	0.000000006	0.000000000	0.000000000
93AC2311	Position	0.000000000	0.000000000	0.000000006	0.000000001	0.000000000
93AC2312	Position	0.000000000	0.000000000	0.000000006	0.000000001	0.000000000
93AC4689	Position	0.000000001	0.000000002	0.000000000	0.000000000	0.000000000
93AC4690	Position	-0.000000004	-0.000000004	0.000000000	0.000000000	0.000000000
93AC4691	Position	0.000000003	0.000000002	0.000000000	0.000000000	0.000000000

Provisional weighted sum of squares = 2006.14

Angular and linear units in this sample printout:

- o All angles are in degrees, minutes and seconds  
e.g. DDDMMSS.SS...SS
- o All object space rectangular coordinates are in meters.

#### STATIONS CORRECTIONS

This page gives a printout of corrections to the parameters of camera position and attitude at each camera station after each iteration during the least squares block adjustment solution. The *provisional weighted sum of squares of residuals* also appear at the end of each iteration. The difference between its current value and its value from the previous iteration forms a criteria for convergent of the solution. For example, if the absolute difference between the two provisional weighted sums of squares of residuals is less than E percent of the value, then the iterations come to an end. ( Note: for details see p97 of the Manual of Photogrammetry, 1980 Ed, American Society of Photogrammetry.)

Output from each iteration of the adjustment:

#### Iteration number

Camera station: Frame number

- o Position corrections: - Longitude correction  $\Delta\lambda$
- Latitude "  $\Delta\phi$
- Elevation "  $\Delta H$

Attitude:

- o Attitude corrections: - primary rotation cor.  $\Delta\omega$
- secondary " "  $\Delta\phi$
- tertiary " "  $\Delta\kappa$

Provisional weighted sum of squares of residuals.

TRIANGULATED GROUND POINTS RESIDUALS

121 93AC4691 93AC4693 93AC4692

0  
7

45 93AC4692 93AC4693 93AC4691

8  
5

221 93AC4692 93AC2313 93AC2312 93AC4691 93AC4690 93AC2314

7 9 -6 -5  
-2 0 14 -7

231 93AC2313 93AC2312 93AC2314

9 -5 -4  
6 -14 7

7 93AC4690 93AC4691 93AC4692

0 -1  
-9 9

81 93AC4692 93AC4690 93AC4691

0  
-7

91 93AC2313 93AC2312 93AC4690 93AC4692 93AC4691

-6 0 15  
-7 -8 8

201 93AC2312 93AC2313 93AC2311

3 -2  
7 -7

### TRIANGULATED GROUND POINTS RESIDUALS

This page gives a printout of plate residuals in x and y coordinates of image points considered in the least squares adjustment of an aerotriangulation run. The printout shows the following:

- o Identification (ID) number of an image point. If ID is followed by "!" the point number is assigned automatically during the measurement process). Only those points are printed for which the absolute value of x or y residual exceeds the threshold value adopted in the project options (Note: see pages 31 and 32 above).
- o Identification (ID) number of frames of photographs in which the measured image point appears and for which the residual in x or y coordinate exceeds the threshold value adopted for the project.
- o Plate residuals in x and y coordinates of image points in the frames in which they appear.

Note: In the project COMMON file, one of the options to be introduced is for listing the residuals. The options available are:

- o to print residuals of all images,
- o to print residuals with absolute values greater than F (eg =10 micrometers) as assigned, or
- o do not print residuals of any image.

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

Weighted sum of squares (Aux. P)	=	0.0
Weighted sum of squares (Photos)	=	1.3
Weighted sum of squares (Ground)	=	0.9
Weighted sum of squares (Images)	=	107.9
Weighted sum of squares (Total)	=	110.2
Degrees of freedom.....	=	69

A Posteriori estimates for unit weight

Variance =	1.597
St. Dev. =	1.264

### AEROTRIANGULATION STATISTICS

The printout shows the weighted sum of squares of residuals due to various factors, contributing towards the total weighted sum of squares of residuals in the least squares solution of a block adjustment of an aerotriangulation project. The *a posteriori* estimate for the unit weight variance will compute close to the value of one, provided the relative weights assigned to the parameters entering the solution are realistic. Thus, the value of the unit weight variance is an indication of the soundness of the weight assignments.

The following weighted sum of squares of residuals in a least squares solution contribute to the total variance:

- o Weighted sum of squares of residuals for auxilliary parameters. These parameters are the ones which are introduced by the mathematical models:
  - o parameters of the self calibration model: pricipal distance, principal point x and y coordinates;
  - o parameters of symmetrical radial error coefficients:  $k_1, k_2, k_3$  of polynomial expressing the error;
  - o parameters of asymmetric error coefficients:  $k_4, k_5$ , and  $\Phi$  of the polynomial expressing the error;
- o Weighted sum of squares of residuals for photo state vectors. A photo state vector consists of three coordinates of camera position and three angles of camera attitude;
- o Weighted sum of squares of residuals for ground coordinates.
- o Weighted sum of squares of residuals for image coordinates.
- o Total weighted sum of squares of residuals (total of the above)
- o Degree of freedom, considering all of the above elements.
- o A posteriori estimates of unit weight:
  - o Variance, and
  - o Standard deviation

O U T P U T P H O T O G R O U P S P A R A M E T E R S

Photo group : GROUP\_1 of camera system : CAMERA01

GPS Antenna Offsets model :

X =	0.21000D+00	Std_X =	0.12639D+04	Updating Switch:	Off	Exclusion Switch:	On
Y =	0.51800D+00	Std_Y =	0.12639D+04	Updating Switch:	Off	Exclusion Switch:	On
Z =	0.14500D+01	Std_Z =	0.12639D+04	Updating Switch:	Off	Exclusion Switch:	On

OUTPUT PHOTO GROUPS PARAMETERS

- o Photo group: identification number
- o Camera system: Camera
- o GPS Antenna offsets model:
  - o Offsts:  $\Delta X$ ,  $\Delta Y$ ,  $\Delta Z$  between camera node and antenna
  - o Standard deviations of determination of offsets:  
Std\_X, Std\_Y, and Std\_Z
  - o Updating switch Off/On (for offsets)
  - o Exclusion switch Off/On " "

Note: Exclusion switch overrides the updating switch.  
Standard deviations and updating switch values are ignored  
if the exclusion switch is "on".

TRIANGULATED STATIONS

IDENT POSITION COVARIANCE MATRIX ATT(Ground to photo) COVARIANCE MATRIX

Table with columns for station ID, position (Lng, Lat, Ely), covariance matrix, and ATT values. Includes stations AC4693, AC2314, AC4692, AC2313, AC2311, and AC2312.

SUMMARY STATISTICS FOR TRIANGULATED STATIONS

Summary statistics table showing number of components, AVI, AVI Max, and RMS values for Lng, Lat, Ely, Omega, Phi, and Kappa.

TRIANGULATED STATIONS

IDENT	POSITION	COVARIANCE MATRIX			ATT(Ground to photo)			COVARIANCE MATRIX		
AC4693	Lng --121 35 2.4024 *7*Lat = 37 36 57.2941 Ely = 2992.4568	0.212E-15	-0.276E-18	0.127E-10	Omega = 0 39 4.2644	0.174E-06	0.337E-08	0.119E-07	0.337E-08	0.119E-07
		-0.276E-18	0.132E-15	0.660E-11	*0*Phi = 0 8 26.6864	0.337E-08	0.711E-08	0.119E-08	0.711E-08	0.119E-08
		0.127E-10	0.660E-11	0.399E-02	Kappa = 182 9 59.8880	0.119E-07	0.119E-08	0.145E-07	0.119E-07	0.145E-07
AC2314	Lng --121 34 26.0433 *0*Lat = 37 38 14.8624 Ely = 3085.2318	0.485E-13	-0.195E-13	0.215E-06	Omega = 0 33 39.2596	0.657E-06	0.431E-07	0.285E-07	0.431E-07	0.285E-07
		-0.195E-13	0.968E-13	-0.320E-06	*0*Phi = 0 22 0.0655	0.431E-07	0.138E-06	0.654E-08	0.138E-06	0.654E-08
		0.215E-06	-0.320E-06	0.293E+01	Kappa = 176 59 16.0298	0.285E-07	0.654E-08	0.454E-07	0.285E-07	0.454E-07
AC4692	Lng --121 34 0.8907 *7*Lat = 37 36 56.2460 Ely = 2993.1072	0.190E-15	-0.186E-18	0.121E-10	Omega = 0 40 45.2429	0.164E-06	0.898E-09	0.744E-08	0.898E-09	0.744E-08
		-0.186E-18	0.115E-15	0.224E-10	*0*Phi = 0 10 54.8955	0.898E-09	0.427E-08	0.122E-08	0.427E-08	0.122E-08
		0.121E-10	0.224E-10	0.301E-02	Kappa = 180 51 22.8085	0.744E-08	0.129E-08	0.124E-07	0.744E-08	0.124E-07
AC2313	Lng --121 33 15.6397 *0*Lat = 37 38 14.5876 Ely = 3084.6693	0.317E-13	-0.196E-13	0.112E-06	Omega = 1 4 19.3228	0.691E-06	0.360E-07	0.391E-07	0.360E-07	0.391E-07
		-0.196E-13	0.107E-12	-0.293E-06	*0*Phi = 0 26 58.9148	0.360E-07	0.860E-07	0.770E-08	0.360E-07	0.770E-08
		0.112E-06	-0.293E-06	0.192E+01	Kappa = 176 36 45.4478	0.391E-07	0.770E-08	0.327E-07	0.391E-07	0.327E-07
AC2311	Lng --121 31 1.3319 *0*Lat = 37 38 15.5646 Ely = 3081.2154	0.483E-13	-0.263E-13	0.562E-07	Omega = 2 13 41.6669	0.689E-06	0.300E-07	0.462E-07	0.300E-07	0.462E-07
		-0.263E-13	0.131E-12	-0.215E-06	*0*Phi = 0 31 50.2781	0.300E-07	0.113E-06	0.782E-08	0.300E-07	0.782E-08
		0.562E-07	-0.215E-06	0.165E+01	Kappa = 175 58 49.6184	0.462E-07	0.782E-08	0.385E-07	0.462E-07	0.385E-07
AC2312	Lng --121 32 8.4945 *0*Lat = 37 38 15.6763 Ely = 3080.1686	0.304E-13	-0.242E-13	0.449E-07	Omega = 1 40 14.0787	0.659E-06	0.341E-07	0.435E-07	0.341E-07	0.435E-07
		-0.242E-13	0.108E-12	-0.266E-06	*0*Phi = 0 20 46.0100	0.341E-07	0.641E-07	0.480E-08	0.341E-07	0.480E-08
		0.449E-07	-0.266E-06	0.161E+01	Kappa = 176 9 28.5641	0.435E-07	0.480E-08	0.282E-07	0.435E-07	0.282E-07

SUMMARY STATISTICS FOR TRIANGULATED STATIONS

Lng ...	number of components = 4	AVI = 0 0	0.0409	Max = 0 0	0.0454	RMS = 0 0	0.0411
Lat ...	number of components = 4	AVI = 0 0	0.0685	Max = 0 0	0.0746	RMS = 0 0	0.0686
Ely ...	number of components = 4	AVI = 0 0	1.4129	Max = 1.7119	1.7119	RMS = 1.4241	1.4241
Omega ...	number of components = 9	AVI = 0 0	0.0806	Max = 0 2	51.4784	RMS = 0 2	8.8982
Phi ...	number of components = 9	AVI = 0 0	0.0098	Max = 0 1	16.6867	RMS = 0 0	44.8891
Kappa ...	number of components = 9	AVI = 0 0	0.0048	Max = 0 0	43.9639	RMS = 0 0	31.4238

This page shows the state vectors (position and orientation) of each of the triangulated camera station:

**TRIANGULATED STATIONS**

- o Identification: camera station
- o Camera POSITION:
  - o Composite flag for coordinates update:

Composite flag Value (X)	Coordinates update		
	Primary	Secondary	Tertiary
0	Y	Y	Y
1	N	Y	Y
2	Y	N	Y
3	N	N	Y
4	Y	Y	N
5	N	Y	N
6	Y	N	N
7	N	N	N

- o POSITION vector - camera station  
Adjusted Longitude, Latitude, and Elevation
- o COVARIANCE matrix (position vector)
- o Camera ATTITUDE:
  - o Composite flag for attitude/rotations update.
  - o ATTITUDE (ground to photo): Omega, Phi, Kappa (in local vertical)
  - o COVARIANCE matrix (attitude vector)

**SUMMARY STATISTICS FOR TRIANGULATED STATIONS:**

- o Number of components updated for position and attitude
- o Average values for updates: POSITION and ATTITUDE parameters
- o Maximum values for updates: POSITION and ATTITUDE parameters
- o Root Mean Square values of POSITION parameters: Longitude, Latitude, Elevation, and ATTITUDE paramters: Omega, Phi, Kappa.

TRIANGULATED GROUND POINTS

IDENT	POSITION	COVARIANCE MATRIX			STANDARD DEV
7	Lng = -121 33 6.5936 Lat = 37 36 10.8855 Elv = 573.7842	0.125E-14	-0.308E-15	0.320E-08	0 0 0.0073
		-0.308E-15	0.823E-14	-0.370E-07	0 0 0.0187
		0.320E-08	-0.370E-07	0.407E+00	0 0 0.6381
11	Lng = -121 30 58.1291 Lat = 37 36 18.0161 Elv = 475.2760	0.556E-15	-0.522E-15	0.160E-08	0 0 0.0049
		-0.522E-15	0.640E-14	-0.804E-08	0 0 0.0165
		0.160E-08	-0.804E-08	0.430E+00	0 0 0.6560
21	Lng = -121 30 47.1568 Lat = 37 36 54.2239 Elv = 273.4316	0.795E-15	-0.621E-16	-0.773E-08	0 0 0.0058
		-0.621E-16	0.779E-14	-0.259E-08	0 0 0.0182
		-0.773E-08	-0.259E-08	0.256E+00	0 0 0.5055
31	Lng = -121 30 37.0392 Lat = 37 37 53.0505 Elv = 170.2234	0.597E-14	0.514E-14	-0.453E-07	0 0 0.0159
		0.514E-14	0.203E-13	-0.409E-07	0 0 0.0294
		-0.453E-07	-0.409E-07	0.387E+00	0 0 0.6220
41	Lng = -121 31 54.8339 Lat = 37 36 13.6321 Elv = 637.3315	0.199E-14	0.166E-14	-0.151E-07	0 0 0.0092
		0.166E-14	0.122E-13	-0.201E-07	0 0 0.0228
		-0.151E-07	-0.201E-07	0.153E+00	0 0 0.3908
45	Lng = -121 33 57.5303 Lat = 37 37 21.6291 Elv = 509.2199	0.116E-14	0.147E-14	0.906E-08	0 0 0.0070
		0.147E-14	0.116E-13	0.172E-07	0 0 0.0222
		0.906E-08	0.172E-07	0.115E+00	0 0 0.3395
51	Lng = -121 31 56.7214 Lat = 37 37 4.9745 Elv = 345.1708	0.658E-15	0.277E-15	0.332E-08	0 0 0.0053
		0.277E-15	0.124E-13	0.632E-08	0 0 0.0230
		0.332E-08	0.632E-08	0.552E-01	0 0 0.2350
61	Lng = -121 31 57.0702 Lat = 37 37 51.4066 Elv = 210.4522	0.120E-14	-0.571E-16	-0.424E-08	0 0 0.0071
		-0.571E-16	0.103E-13	0.502E-07	0 0 0.0210
		-0.424E-08	0.502E-07	0.667E+00	0 0 0.8164
65 *4*	Lng = -121 31 13.3287 Lat = 37 37 39.3737 Elv = 174.6157	0.244E-14	-0.341E-14	-0.317E-07	0 0 0.0102
		-0.341E-14	0.188E-13	0.115E-06	0 0 0.0282
		-0.317E-07	0.115E-06	0.862E+00	0 0 0.9283

TRIANGULATED GROUND POINTS

- o IDENTification: ground point
  - o POSITION:
    - o Composite flag value<sup>1</sup> (or blank) for ground points
    - o Triangulated values: Longitude, Latitude, Elevation
  - o COVARIANCE MATRIX of position vector
  - o STANDARD DEVIATIONS: Longitude, Latitude, Elevation
- 

<sup>1</sup> Composite flag value (X)	Coordinates update		
	Primary	Secondary	Tertiary
0	Y	Y	Y
1	N	Y	Y
2	Y	N	Y
3	N	N	Y
4	Y	Y	N
5	N	Y	N
6	Y	N	N
7	N	N	N

---

- X =1, means primary component ignored
- =2, means secondary component ignored
- =4, means tertiary component ignored
- =7, means control not updated or ignored
- =0, (or blank) means control updated

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

Lng ... number of components =	38	AVZ =	0 0	0.0124	Max =	0 0	0.0309	RMS =	0 0	0.0143
Lat ... number of components =	38	AVZ =	0 0	0.0281	Max =	0 0	0.0399	RMS =	0 0	0.0293
Ely ... number of components =	34	AVZ =		0.9597	Max =		2.7926	RMS =		1.1918

SUMMARY STATISTICS FOR GROUND POINTS

- o Number of components of:
  - o Longitude
  - o Latitude
  - o Elevation
  
- o Average and Maximum residual values for:
  - o Longitude
  - o Latitude
  - o Elevation
  
- o Root Mean Square values for:
  - o Longitude
  - o Latitude
  - o Elevation

CORRECTIONS APPLIED TO GROUND CONTROL

65	Lng= 0 0 0 0.0073	213	Lng= 0 0 0.0046	217	Lng= - 0 0 0.0107	486201	Lng=( 0 0 0.0001)
	Lat= - 0 0 0.0003		Lat= - 0 0 0.0006		Lat= - 0 0 0.0004		Lat=(- 0 0 0.0001)
	Elv=( 0.000)		Elv=( 0.000)		Elv=( 0.000)		Elv= 1.203
489201	Lng=(- 0 0 0.0001)	489202	Lng=(- 0 0 0.0001)	689201	Lng=( 0 0 0.0001)	689202	Lng=( 0 0 0.0001)
	Lat=( 0 0 0.0001)		Lat=( 0 0 0.0001)		Lat=(- 0 0 0.0001)		Lat=( 0 0 0.0001)
	Elv= -0.256		Elv= -1.371		Elv= -1.786		Elv= -3.476
690201	Lng=(- 0 0 0.0001)	693202	Lng=(- 0 0 0.0001)				
	Lat=(- 0 0 0.0001)		Lat=(- 0 0 0.0001)				
	Elv= 1.378		Elv= 1.086				

57	Ing ... number of components = 3	AVI = 0 0 0.0075	Max = 0 0 0.0107	RMS = 0 0 0.0079
57	Lat ... number of components = 3	AVI = 0 0 0.0005	Max = 0 0 0.0006	RMS = 0 0 0.0005
	Elv ... number of components = 7	AVI = 1.5081	Max = 3.4757	RMS = 1.7625

CORRECTIONS APPLIED TO GROUND CONTROL

- o Identification: ground control point
- o Corrections to Longitude, Latitude, and Elevation  
(Note: Values in parenthesis correspond to parameters which do not update in the solution)
- o Number of components which update in the solution
- o Average, Maximum and Root Mean Square values of corrections applied to Longitudes, Latitudes, and Elevations of ground control points.

(Note: These values indicate accuracy of aerotriangulation)

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## 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 parameter 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 photographs, 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.

	C <sub>1</sub>	C <sub>1</sub>	P <sub>1</sub>	C <sub>2</sub>	C <sub>2</sub>	P <sub>2</sub>	C <sub>3</sub>	C <sub>3</sub>	P <sub>3</sub>	C <sub>4</sub>	C <sub>4</sub>	P <sub>4</sub>	C <sub>5</sub>	C <sub>5</sub>	P <sub>5</sub>	C <sub>6</sub>	C <sub>6</sub>	P <sub>6</sub>	P <sub>7</sub>	P <sub>8</sub>
C <sub>1</sub>	█	█	█			█			█	█										
C <sub>1</sub>	█	█	█			█			█	█										
P <sub>1</sub>	█	█	█			█			█	█										
C <sub>2</sub>				█	█	█			█			█								
C <sub>2</sub>				█	█	█			█			█								
P <sub>2</sub>	█	█		█	█	█			█			█								
C <sub>3</sub>							█	█	█			█			█					
C <sub>3</sub>							█	█	█			█			█					
P <sub>3</sub>	█	█		█	█	█	█	█	█			█			█					
C <sub>4</sub>	█									█	█	█			█				█	
C <sub>4</sub>	█									█	█	█			█				█	
P <sub>4</sub>				█	█		█	█		█	█	█			█					
C <sub>5</sub>													█	█	█				█	█
C <sub>5</sub>													█	█	█				█	█
C <sub>5</sub>							█	█		█	█		█	█	█					
C <sub>6</sub>																█	█	█	█	█
C <sub>6</sub>																█	█	█	█	█
P <sub>6</sub>										█	█		█	█		█	█	█		
P <sub>7</sub>													█	█		█	█	█		
P <sub>8</sub>																█	█	█		█

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

## 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 axes defined for the Clarke 1866 spheroid. However, it is possible to change ellipsoids by entering the values of semimajor and semiminor axes in character spaces 51-60 and 61-70, respectively. (See II.B.1, Job Definition Data Record.) 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 figure B-2 points in the western United States (west of 90°W longitude or approximately New Orleans) would be -X, -Y, and +Z.

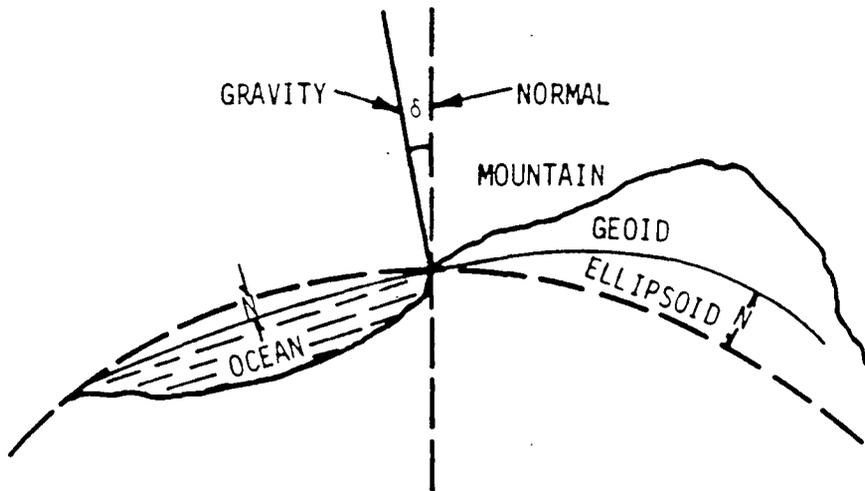


Figure B.1.--Relationship among the physical surface, the geoid, and the ellipsoid

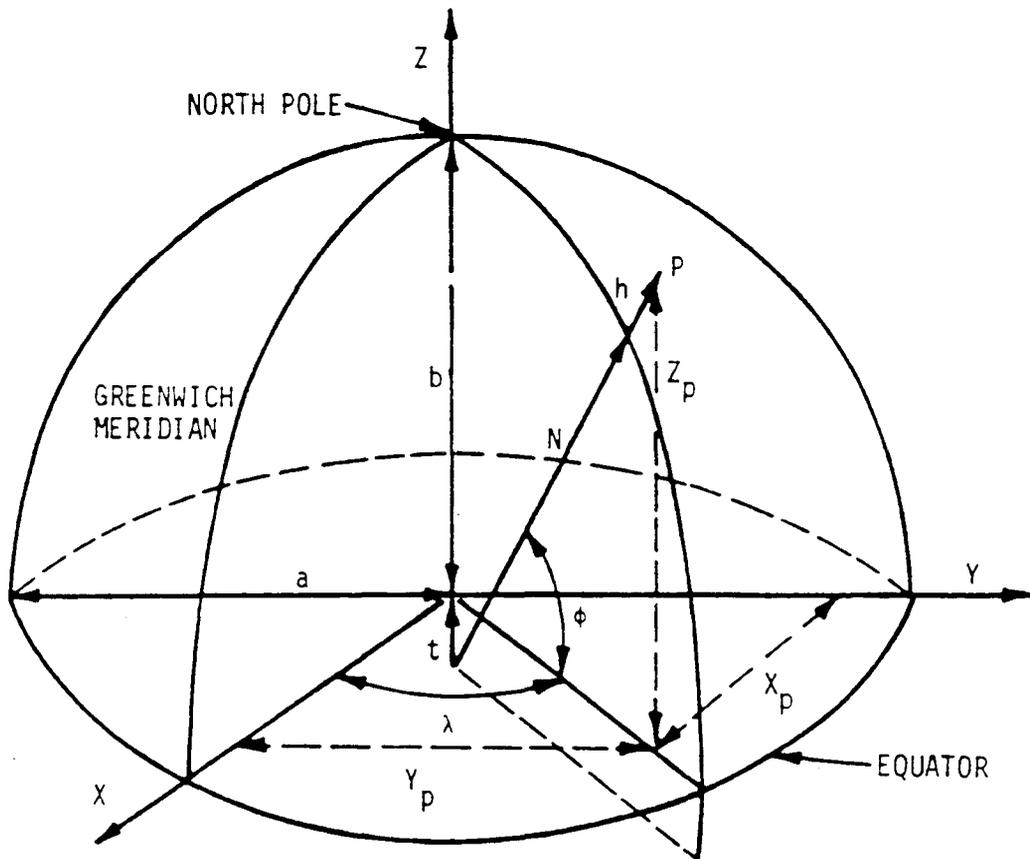


Figure B.2.--Geographic and geocentric coordinate systems

## 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

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

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  $(X, Y, Z)$ .

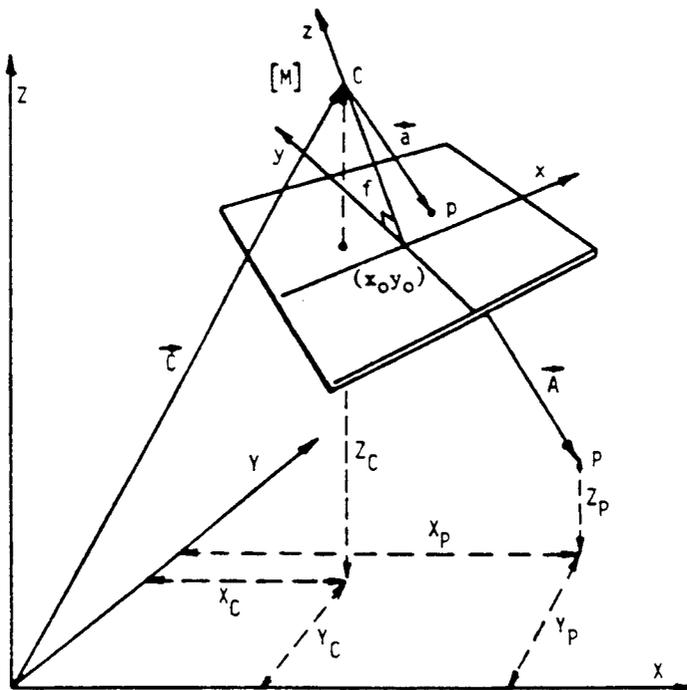


Figure C.1--Exterior orientation

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

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

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.

<u>Sequence</u>	<u>Axis of rotation</u>
Primary - Roll ( $\omega$ ) .....	x
Secondary - Pitch ( $\phi$ ) .....	y
Tertiary - Yaw ( $\kappa$ ) .....	z

Roll ( $\omega$ ) is an angle of rotation of about the x-axis. Positive roll rotates the positive y-axis toward the positive z-axis.  $-180^\circ < \omega < +180^\circ$ . (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 ( $\phi$ ) is an angle of rotation about the y-axis. Positive pitch rotates the positive z-axis toward the positive x-axis.  $-180^\circ < \phi < +180^\circ$ . (nose down)

Yaw ( $\kappa$ ) is an angle of rotation about the z-axis. Positive yaw rotates the positive x-axis toward the positive y-axis.  $-180^\circ < \kappa < +180^\circ$ . (counterclockwise is positive)

( $\kappa$ ) 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.

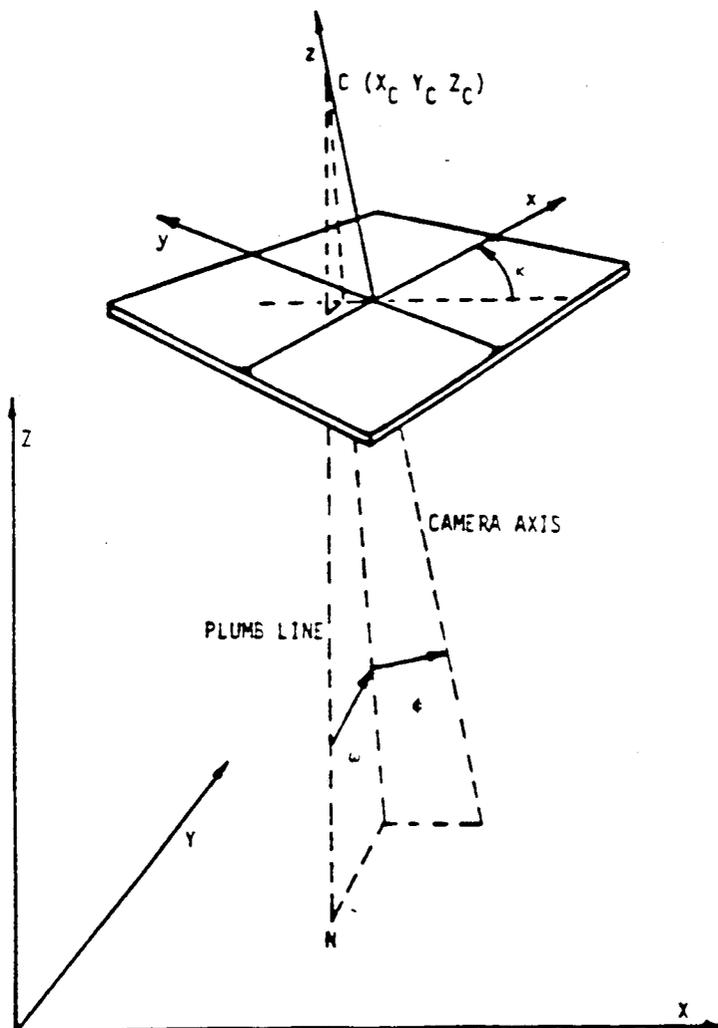


Figure C.2--Rotations

## 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,  $\vec{A} = CP$  is such a vector. Its components in the object space coordinate system are

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

and its components in the image coordinate system are

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

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

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

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

$$\vec{a} = k\vec{A}$$

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

$$\vec{a} = k \vec{MA},$$

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

Expressed individually, these projective equations are:

$$(x_p - x_o) = k [m_{11}(X_p - X_c) + m_{12}(Y_p - Y_c) + m_{13}(Z_p - Z_c)]$$

$$(y_p - y_o) = k [m_{21}(X_p - X_c) + m_{22}(Y_p - Y_c) + m_{23}(Z_p - Z_c)]$$

$$(-f) = k [m_{31}(X_p - X_c) + m_{32}(Y_p - Y_c) + m_{33}(Z_p - Z_c)]$$

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

$$(x_p - x_o) = -f \frac{m_{11}(X_p - X_c) + m_{12}(Y_p - Y_c) + m_{13}(Z_p - Z_c)}{m_{31}(X_p - X_c) + m_{32}(Y_p - Y_c) + m_{33}(Z_p - Z_c)}$$

$$(y_p - y_o) = -f \frac{m_{21}(X_p - X_c) + m_{22}(Y_p - Y_c) + m_{23}(Z_p - Z_c)}{m_{31}(X_p - X_c) + m_{32}(Y_p - Y_c) + m_{33}(Z_p - Z_c)}$$

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,  $\omega$ ,  $\phi$ , and  $\kappa$  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  $O$  are  $X'_0$ ,  $Y'_0$ , and  $Z'_0$  (fig. D.1), and the geodetic coordinates of the origin are  $\phi_0$ ,  $\lambda_0$ , 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:

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

$$\text{or } x = M_{\phi_0} M_{\lambda_0} X$$

Combining the two orthogonal matrices, we get

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

$$\text{or } x = M_{\phi_0 \lambda_0} X$$

### Orientation Matrix M

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

Where  $\omega$  is roll,  $\phi$  pitch,  $\kappa$  yaw

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

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

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

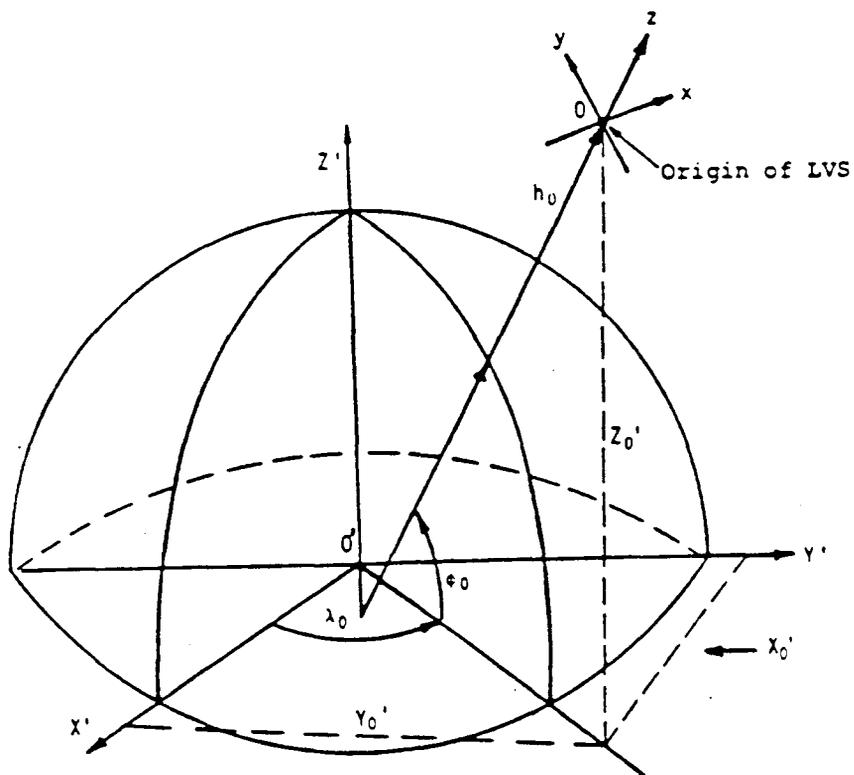


Figure D.1--Local vertical coordinate system

Composite Matrix ( $M_{\kappa\phi\omega}$ )

Hence

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

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

Computational Sequence

GIANT uses the following computational sequence:

Evaluate (compute) as derived	$M_{\kappa\phi\omega}$	Local-to-camera
Transpose forming	$M_{\omega\phi\kappa}^T$	Camera-to-local
Form	$M_{\phi_0\lambda_0}^T$	Local-to-geocentric

(Transpose of derived matrix)

Premultiply	$M_{\phi_0\lambda_0}^T$	$M_{\omega\phi\kappa}^T$
-------------	-------------------------	--------------------------

Note this is equivalent to:

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

(Camera-to-local and Local-to-geocentric)<sup>T</sup>

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  $\omega$ ,  $\phi$ ,  $\kappa$  will be obtained.

## APPENDIX E.--ERROR PROPAGATION

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 ( $\sigma^2$ ) may be estimated by the equation:

$$\sigma^2 = \frac{\sum(v_i w_i v_i)}{(n-u)}$$

where

$v_i$  is the residual of the  $i^{\text{th}}$  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 ( $\omega, \phi, \kappa$ ), 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 ( $\omega, \phi, \kappa$ ) are usually considered "unknowns," giving rise to additional numbers of unknowns equal to six times the number of camera stations.

To summarize, let:

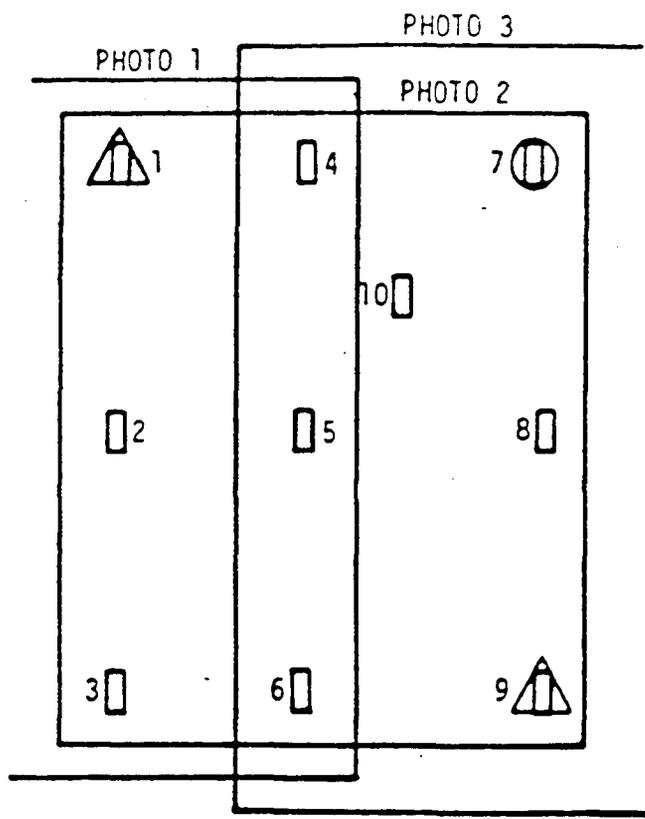
- v = the output residual for each observation.
- w = input weight which may be thought of as  $1/\sigma^2$  for each observation. (Note it is sigma squared).
- n = total number of observations.
- m = 2 \* number of plate measurements.
- c = 1 for each ground control component.
- s = 6 \* number of camera stations. (Factor 6 represents the camera parameters: the position coordinates X, Y, Z and the orientation elements  $\omega$ ,  $\phi$ ,  $\kappa$ . 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,  $\frac{\sum v^2}{\sigma^2} = (n-u)$  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.

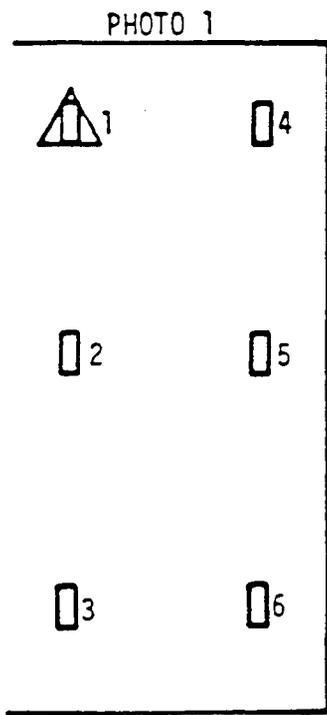
Table E.1 computes the unit variance for the solution of a typical three-photo block (fig. E.1) with case 1 considering the camera stations as unknowns and case 2 considering the camera station as constrained or known (character no. 12=1, record no. 2, COMMON file, sec. II.B.1).

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

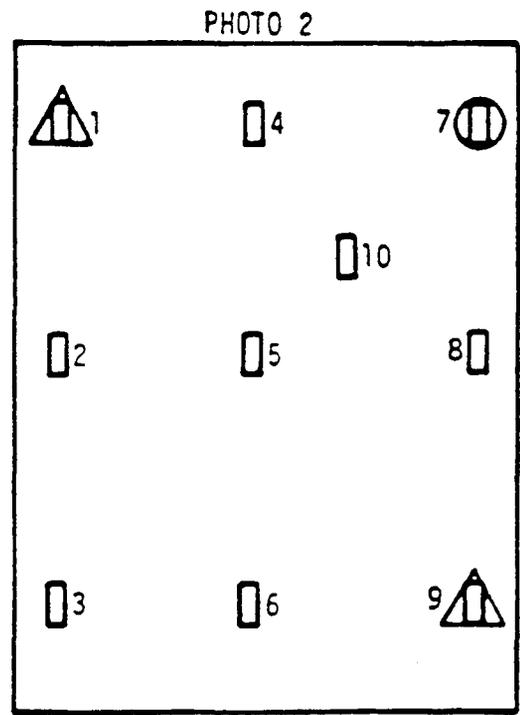
	CASE 1	CASE 2
$v w v = 1$ for each plate coordinate		
Photo 1	12	12
Photo 2	20	20
Photo 3	14	14
Camera Stations (if observed)	0	18
Ground Control (3 points, 7 components)	7	7
$v w v$	53	71
$m = 2 * \text{number of plate measurements}$		
Photo 1	12	12
Photo 2	20	20
Photo 3	14	14
$c = 1$ for each ground control component	7	7
$s = 6 * \text{number of camera stations}$	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 sq.      ( $vwv/DOF$ )	10.6	3.1
= Unit Variance	3.3	1.8



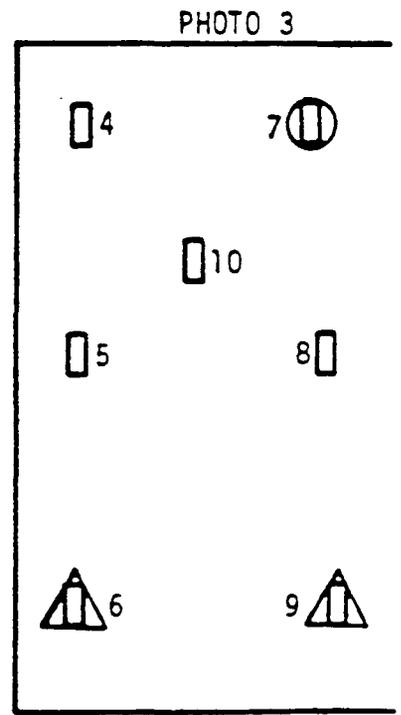
10 GROUND POINTS  
 POINT #1 FULLY KNOWN  
 POINT #9 FULLY KNOWN  
 POINT #7 ELEV. ONLY



6 POINTS  
 12 MEASUREMENTS



10 POINTS  
 20 MEASUREMENTS



7 POINTS  
 14 MEASUREMENTS

Figure E.1--A typical three-photo block

## 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

$\Delta_{\alpha}$  is the angle of displacement due to atmospheric refraction;

$\alpha$  is the angle the ray makes with the "true vertical;"

$K_{\alpha}$  is a constant related to the atmospheric conditions. (Refer to fig. F.1.)

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

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

where

H is the flying height (kilometers)

h is the ground point elevation (kilometers)

In a vertical photograph, the correction ( $\Delta_r$ ) 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):

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

The angle  $\alpha$  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

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

$$\Delta Y = (Y_o - Y_G)$$

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

This correction is easily applied in each iteration of the triangulation solution for every point.

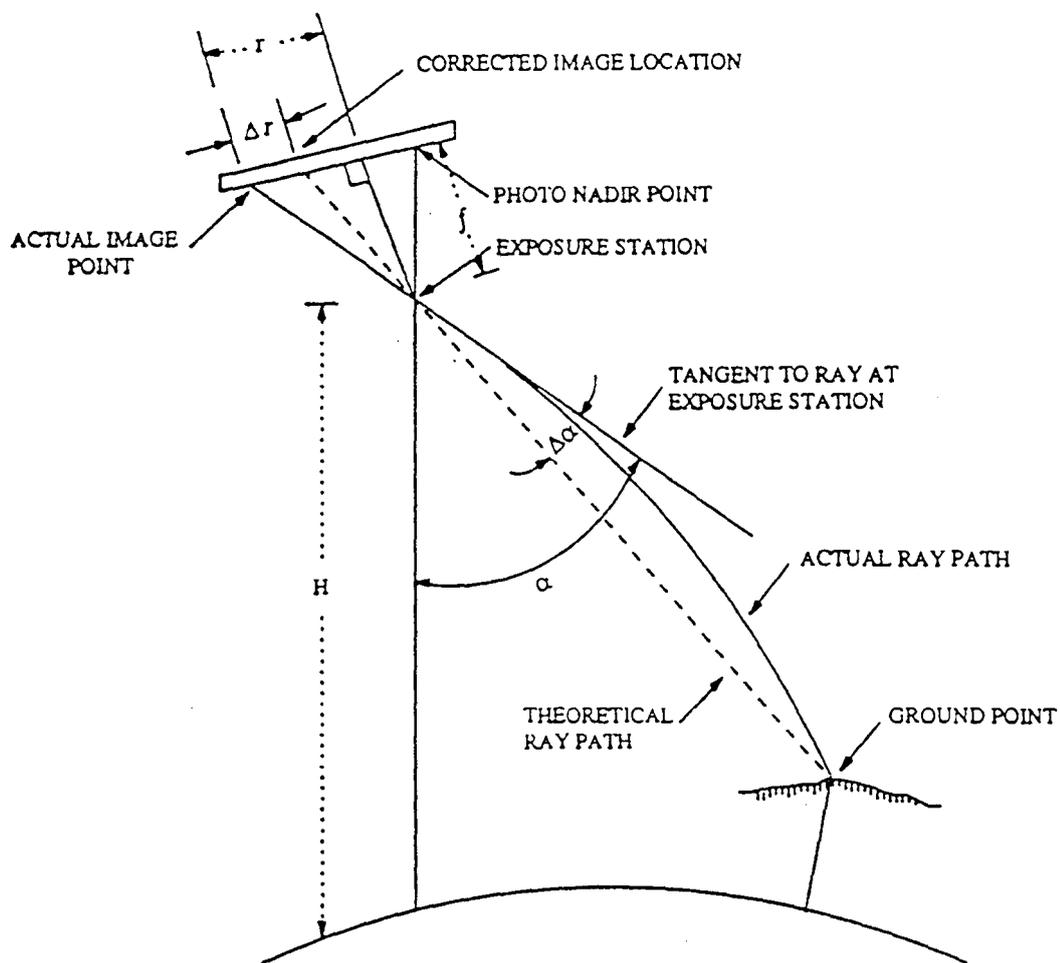


Figure F.1.--Atmospheric refraction.

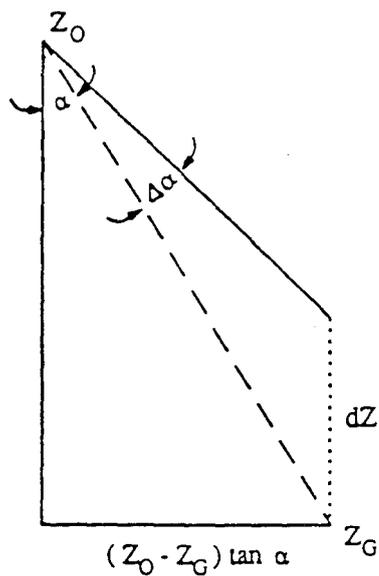


Figure F.2.--Correction for atmospheric refraction.

## APPENDIX G.--PHOTOBATHYMETRY

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

$\Delta_{\alpha}$  is the angle of displacement

$\alpha$  is the angle the ray makes with the true vertical at the camera station

$K_{\omega}$  is the constant related to water refraction for an underwater feature

It can be shown that the value of  $K_{\omega}$  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 ( $\Delta_r$ ) for water refraction (fig. G.2):

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

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 ( $\Delta_r$ ) is similar to the air refraction correction (appendix F) except that the constant  $K_{\omega}$  replaces  $K_{\alpha}$  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:

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

The angle  $\alpha$  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

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

where  $(K_w + K_a)$  replaces  $K_w$  or  $K_a$  in the expression for the correction. For points at or above water level  $K_w = 0$  in the algorithm, such that the correction is only for the air refraction.

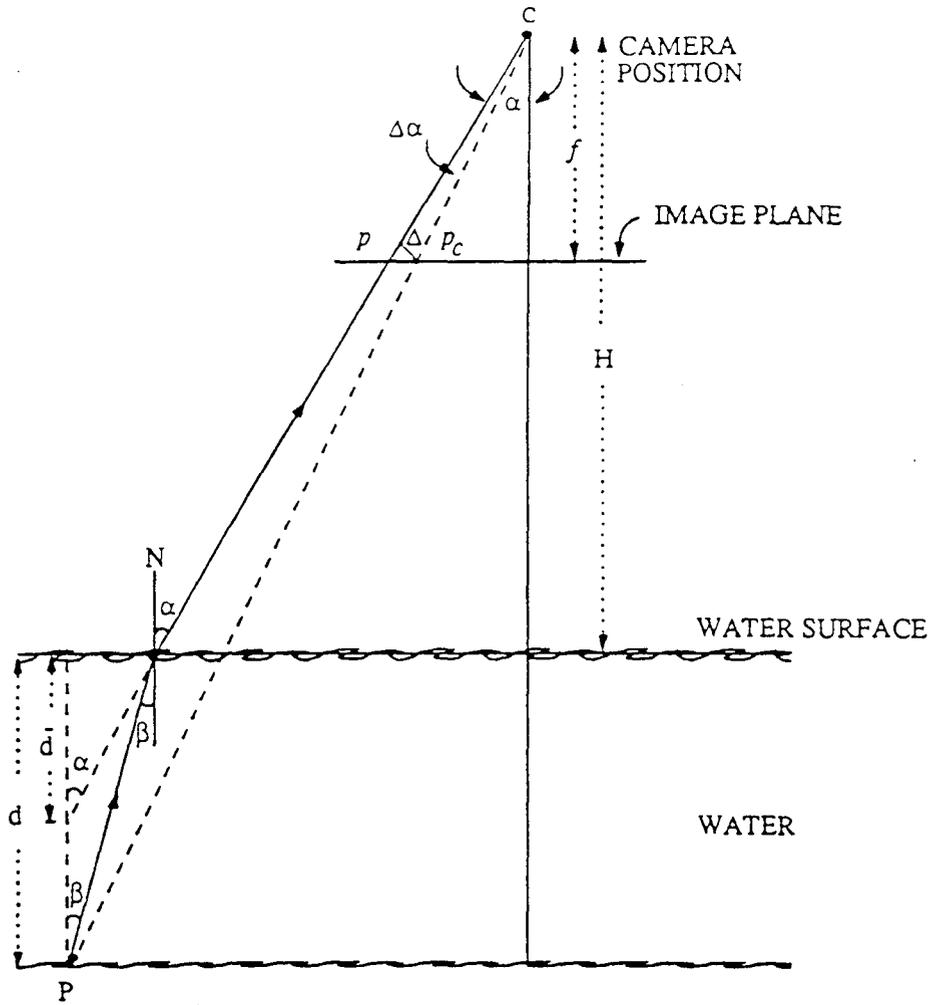


Figure G.1.--Water refraction of underwater target (P).

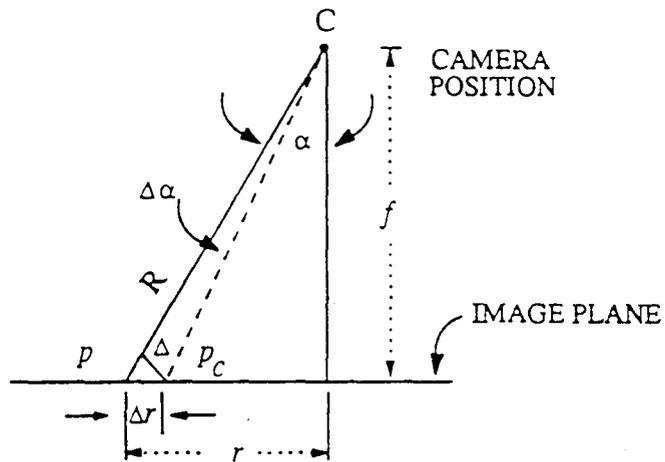


Figure G.2.--Image displacement due to water refraction.

## 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.

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 break 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.

Sign of f. 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.

Yaw. The other probable cause is that the yaw angle ( $\kappa$ ) 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.

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.

APPENDIX I.-- SELF CALIBRATION OF PRINCIPAL DISTANCE AND  
PRINCIPAL POINT LOCATION OF A CAMERA  
(Model No. 1 in GIANT V3.0)

Precise location of the principal point in the image plane and the principal distance of a camera are important in the reconstruction of photogrammetric stereomodels, and are the fundamental parameters determined in camera calibration. These parameters can be calibrated by laboratory methods, or in-flight, during a mission for aerotriangulation. A note of caution in calibrating the principal distance is that it is highly correlated with flying height. Therefore, the camera station position must be known precisely in order to be able to calibrate principal distance. However, the in-flight method may be used to determine principal point location without the above constraint.

In the generalized photogrammetric solution, two parameters of the principal point coordinates,  $x_0$ , and  $y_0$ , and one for the principal distance,  $f$ , are included in the data reduction for aerotriangulation. Using collinearity condition equations, model no. 1 in GIANT V3.0 enables the determination of these three parameters in addition to the usual aerotriangulation parameters.

The collinearity condition (fig. K.1) gives the following relationship (eqn. 1, appendix K):

$$\begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} = \lambda \begin{bmatrix} M \\ (\omega, \phi, \kappa) \end{bmatrix} \begin{bmatrix} X_p - X_c \\ Y_p - Y_c \\ Z_p - Z_c \end{bmatrix} \quad (1)$$

where,

- $x, y$  - plate coordinates of an image point  $p$
- $x_0, y_0$  - principal point coordinates in the plate coordinate system
- $f$  - principal distance of the camera (sensor)
- $M$  - rotation matrix in terms of rotations  $\omega, \phi, \kappa$

The equations can be reduced to two linear observation equations in which  $x_0$ ,  $y_0$  and  $f$  are carried into the least squares adjustment. The aerotriangulation solution, using model no. 1 in GIANT V3.0 program, gives the calibrated coordinates of the principal point location and the calibrated principal distance.

APPENDIX J.--COMPENSATION OF UNMODELLED SYMMETRIC RADIAL ERRORS  
(Model No. 2 in GIANT V3.0)

INTRODUCTION

Symmetric radial errors introduced in the data acquisition system could be the ones which may not lend themselves easily to mathematical modelling (e.g., due to the dynamics of the situation) or the ones whose models may not have been incorporated in the data reduction scheme. A good example of such an error is the one caused by the glass plate in front of the camera lens at the time of photography. In GIANT V3.0 a generalized mathematical model based on an odd order polynomial has been selected to simulate such errors. The coefficients of the polynomial are introduced as the additional parameters in the generalized photogrammetric least squares solution for higher precision in a photogrammetric project.

Most of the times in photogrammetric applications precise value of the altitude (Z coordinate) of photography is not needed such that symmetric radial errors are compensated for by the adjusted value of the camera altitude. However, when GPS is utilized in aerotriangulation, the camera position is determined precisely such that this compensation for the symmetric radial errors is not possible. Therefore, with the introduction of GPS in photogrammetric solutions it is necessary to compensate for such errors by some sort of a mathematical model. A polynomial (eqn. 1) in the generalized photogrammetric solution is used.

An odd order polynomial to express x and y components of the symmetric radial errors ( $\Delta x$  and  $\Delta y$ ) are derived from the radial error ( $\Delta r$ ):

$$\Delta r = K_1 r^3 + K_2 r^5 + K_3 r^7 + \quad (1)$$

such that

$$\Delta x = ((\Delta r)/r) * (x - x_0) \quad (2a)$$

and

$$\Delta y = ((\Delta r)/r) * (y - y_0) \quad (2b)$$

where,

x , y image coordinates of a point p at a radial distance r from the point of symmetry (principal point).

$x_0, y_0$  principal point coordinates

$\Delta r$  symmetric radial error

r radial distance of the image point under consideration.

Substituting value of  $\Delta r$  from equation (1):

$$\begin{aligned} \Delta x &= (K_1 * r^2 + K_2 * r^4 + K_3 * r^6) * (x - x_0) \\ \Delta x &= C * (x - x_0) \end{aligned} \quad (3a)$$

similarly,

$$\Delta y = C * ( y - y_0 ) \quad (3b)$$

where,

$$C = (K_1 * r^2 + K_2 * r^4 + K_3 * r^6)$$

The collinearity relationship (eqn.1, appendix K) can be further expressed as:

$$\frac{x-x_0+\Delta x}{f} = \frac{m11*(X_p - X_c) + m12*(Y_p - Y_c) + m13*(Z_p - Z_c)}{m31*(X_p - X_c) + m32*(Y_p - Y_c) + m33*(Z_p - Z_c)} = \frac{Mx}{Mz}$$

In functional form:

$$F(x) = (x - x_0 + \Delta x) + f * (Mx/Mz) = 0 \quad (4a)$$

similarly,

$$F(y) = (y - y_0 + \Delta y) + f * (My/Mz) = 0 \quad (4b)$$

where,

m11, m12, m13, ... , m32, m33 are the components of rotation matrix M:

$$M = \begin{bmatrix} m11 & m12 & m13 \\ m21 & m22 & m23 \\ m31 & m32 & m33 \end{bmatrix}$$

and

x, y measured plate coordinates

x<sub>0</sub>, y<sub>0</sub> principal point plate coordinates

f principal distance

Δx, Δy symmetric radial errors in terms of K<sub>1</sub>, K<sub>2</sub>, K<sub>3</sub>

In the solution of collinearity equations of the form above, the coefficients K<sub>1</sub>, K<sub>2</sub>, K<sub>3</sub> for the polynomial are solved for to obtain their adjusted values. This procedure, using model no. 3 in the GIANT V3.0 program, is suitable to compensate unmodelled symmetric errors in the data acquisition system.

APPENDIX K.--PRECISION KINEMATIC GPS IN AEROTRIANGULATION  
(Model No. 3 in GIANT V3.0)

INTRODUCTION

NAVSTAR Global Positioning System (GPS) has been used in obtaining camera positions at the instant of photographic exposure. The GPS-derived camera positions were then used to compute the positions of the ground targets. It has been shown (Lucas 1987) that if the positions of a photogrammetric camera can be independently determined to an accuracy of 5 cm, then comparable accuracies may be obtained for points on the ground with little or no ground control required. Thus, the economic benefit of precision kinematic GPS in aerotriangulation is obvious. Also, this procedure can be effectively used with other imaging and nonimaging sensors.

DETERMINATION OF FIXED VECTOR: (ANTENNA TO CAMERA NODE)

To apply kinematic GPS in aerotriangulation, fixed antenna to camera-node vector must be determined precisely. The GPS measurements give the position of the receiver antenna located on the aircraft at the instant of photographic exposure. The antenna to camera-node vector then relates the antenna position to the camera position at exposure. Collinearity condition equations are then generated for a generalized photogrammetric aerotriangulation solution to obtain coordinates of ground points.

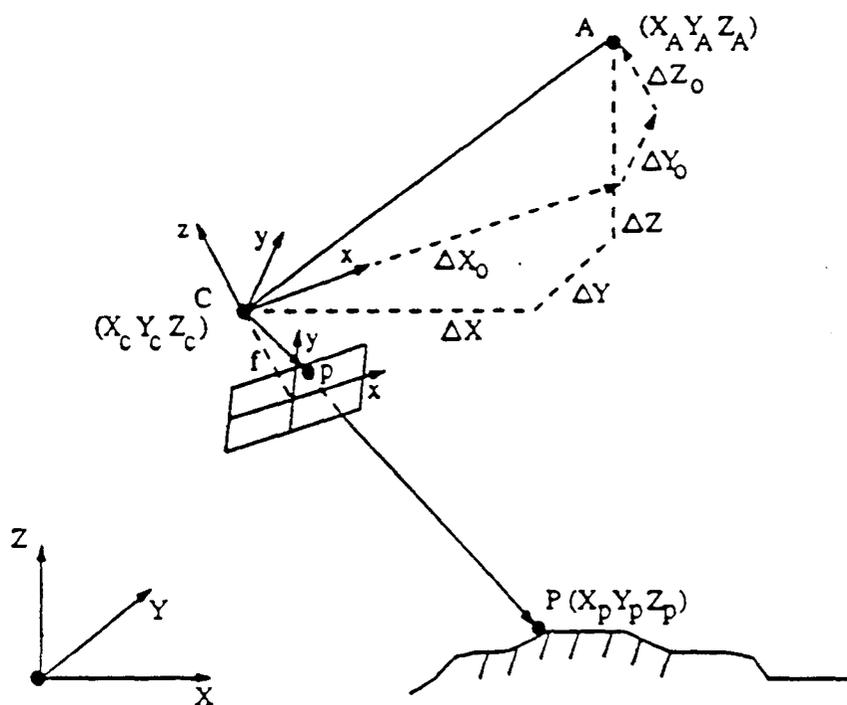
In the GPS experiments (Lucas 1987 and Lucas and Mader 1989) the antenna to camera-node offset vector was measured with the help of steel tape and a level. The offset components measured were fore/aft (x), starboard/port (y), and up/down (z). These components were then used to relate the camera position to the observed antenna position.

MATHEMATICAL MODEL

Model no. 3 of photogrammetric triangulation in GIANT V3.0 determines the three offset components of the antenna to camera-node vector in the image coordinate system, in addition to:

- o the adjusted values of all other conventional parameters solved for in the generalized photogrammetric solution, and
- o the adjusted coordinates of all ground (target) points.

The modified collinearity equations (eqn. 3) used in the model include the antenna to camera-node offsets. (See fig. K.1.)



LEGEND

- P - Ground point
- C - Camera node
- A - Antenna
- X, Y, Z - Geodetic coordinate system
- x, y, z - Plate coordinate system
- f - Principal distance of the camera
- p - Image point corresponding to P
- $\Delta X, \Delta Y, \Delta Z$  - Offsets in geodetic coordinate system
- $\Delta X_0, \Delta Y_0, \Delta Z_0$  - Offsets in plate coordinate system

Figure K.1--Offsets: antenna to camera node.

Considering the ground point P, the image point p, and the camera-node C, we obtain the following collinearity condition relationship (eqn.1):

$$\begin{bmatrix} x \\ y \\ -f \end{bmatrix} = \lambda \begin{bmatrix} M \\ (\omega, \phi, \kappa) \end{bmatrix} \begin{bmatrix} X_p - X_c \\ Y_p - Y_c \\ Z_p - Z_c \end{bmatrix} \quad (1)$$

where,

x,y - measured and refined plate coordinates of point P

f - principal distance of the camera scale factor

M - rotation matrix, ground to photo coord.system conversion, implicit in  $\omega, \phi, \kappa$

$\omega, \phi, \kappa$  - rotations about x, y and z axes

$X_p, Y_p, Z_p$  - Geodetic coordinates of a point P

$X_c, Y_c, Z_c$  - Geodetic coordinates of camera node

Also,

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = \begin{bmatrix} X_A - \Delta X \\ Y_A - \Delta Y \\ Z_A - \Delta Z \end{bmatrix} = \begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} - M^T \begin{bmatrix} \Delta X_o \\ \Delta Y_o \\ \Delta Z_o \end{bmatrix} \quad (2)$$

$X_A, Y_A, Z_A$  - geodetic coordinates of antenna

$M^T$  - rotation matrix, photo to ground

$\Delta X, \Delta Y, \Delta Z$  - offsets, antenna to camera node, in geodetic coordinate system

$\Delta X_o, \Delta Y_o, \Delta Z_o$  - offsets, antenna to camera node, in image (photo) coordinate system

Thus,

$$\begin{bmatrix} x \\ y \\ -f \end{bmatrix} = \lambda \begin{bmatrix} M \\ (\omega, \phi, \kappa) \end{bmatrix} \begin{bmatrix} X_p - X_A \\ Y_p - Y_A \\ Z_p - Z_A \end{bmatrix} + \begin{bmatrix} \Delta X_o \\ \Delta Y_o \\ \Delta Z_o \end{bmatrix} \quad (3)$$

Knowing  $X_A, Y_A, Z_A$  from GPS, and the measured and refined plate coordinates x,y of a target point, the unknown parameters:

$\Delta X_o, \Delta Y_o, \Delta Z_o; \omega, \phi, \kappa; X_p, Y_p, Z_p$

are solved for.

The complexity of the generalized collinearity equations is not brought out in this presentation. This only illustrates as to how the three components:  $\Delta X_0$ ,  $\Delta Y_0$ ,  $\Delta Z_0$ , of the fixed vector, antenna to camera node, are introduced into the formation of equations based on collinearity condition.

Observation equations of the form described above provide a formal solution to the problem of aerotriangulation without ground control, but additional conditions must be satisfied before an unambiguous solution is possible. It can be seen that some ground control is required for a single strip of GPS-controlled photography. Aerotriangulation using GPS without any ground control is possible only when multiple photo strips with side overlap are used. Ground points, where only the elevation is known, are sufficient constraints for a single strip of GPS-controlled photography, provided this elevation control is far enough away from the vertical projection of the line through the antenna positions (Lucas and Mader 1989).