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Potential of Large Format Camera Photography

Roop C. Malhotra

National Ocean Service, NOAA
Rockville, MD
August 1988

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POTENTIAL OF LARGE FORMAT CAMERA PHOTOGRAPHY

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ABSTRACT. This simulated system study explores the potential of large format camera (LFC) photography for conducting photogrammetric control extension. The study is based on a series of error propagation analyses in photogrammetric triangulation of a block of 22 LFC photographs. The photographs, which have an approximate scale of 1:755,000, were taken during the October 1984 NASA shuttle mission STS-41G. Several present and future systems of data acquisition and reduction were simulated. A fixed geometric configuration of the block of 22 LFC photographs was used for all of the triangulation solutions in conjunction with existing ground control and simulated plate coordinates, as if they had been measured on the National Ocean Service analytical plotter. Block triangulation and error propagation solutions were obtained by statistically constraining certain combinations of parameters, such as plate coordinates, camera position and attitude, and ground control, in order to simulate a certain system. The General Integrated ANalytical Triangulation (GIANT) program was used for error propagation and block triangulation computations. The results are graphically portrayed as error curves for each of the systems simulated. The most accurate triangulation results are achievable when a system, such as Global Positioning System (GPS), is used together with ground control in LFC photography block triangulation. Average standard deviations of coordinates of triangulated ground points can be as low as ±2.9 m in planimetry and ±5.7 m in elevation. These correspond to photo accuracy of ±3.5 micrometers in planimetry and ±7.2 micrometers in elevation, or a normalized system precision of ±1 m at a photo scale of 1:264,000 in planimetry and ±1 m at a photo scale of 1:136,000 in elevation. LFC attitude information from the stellar camera array (SCA) is also useful in conjunction with GPS for areas where the ground control is not available for use in block triangulation.

INTRODUCTION

From the viewpoint of improved precision, resolution, area coverage, and other terrain mapping considerations, a working group within the National Aeronautical and Space Administration (NASA) recommended in 1965 the development of a large format camera with 30 cm focal length and a pair of stellar cameras for Apollo Applications Flights (Doyle 1985). It was not until the late 1970's that Itek Corporation was given a contract to design and construct for NASA a large format camera and the attitude reference system (ARS), composed of two stellar camera arrays (SCA).

The LFC is used for making very high resolution images of the Earth's surface from space with great geometric fidelity. The SCA takes simultaneous photographs of the two star fields at the instant of the midpoint of exposure of each LFC terrain photograph, in order to determine the precise pointing attitude of the LFC with reference to the geocentric coordinate system and, from the orbital position, to the ground nadir point. A precise relationship of the LFC optical axis to the two SCA optical axes is obtained by executing an inflight stellar calibration sequence of exposures.

The camera system LFC/ARS was carried into space October 5, 1984, on shuttle mission STS-41G. The orbit inclination was 57 degrees and the shuttle operated at nominal altitudes of 352, 272, and 222 km. A total of 2160 frames was exposed (Doyle 1985).

Description of some of the LFC parameters follows:

- fully metric design lens (focal length of 30.5 cm and fixed aperture of f/6.0),
- high resolution system with an area weighted average resolution (AWAR) of 80 line pairs per millimeter on high resolution aerial film at a contrast ratio of 2:1 (AWAR = 125 at 1,000:1 contrast),
- automatic exposure control from 1/250 to 1/30 seconds,
- rotary (between the lens) shutter,
- forward motion compensation, 0.01 to 0.045 rad/sec,
- maximum lens distortion of 20 micrometers,
- format 23 by 46 cm (longer dimension in the flight direction),
- cycling for forward overlap of 10, 60, 70, or 80 percent,
- twelve illuminated fiducials,
- backlighted 5- by 5-cm reseau grid (total of 45 reseaus),
- vacuum film flattening,
- minimum cycle time 4.3 seconds between exposures,
- film capacity of 4,000 ft or 2,400 frames, 9- by 18-inch photographs,
- weight of the camera system - 506 pounds (plus fully loaded magazine weight),
- physical size of the camera - 50 by 35 by 20 inches (height, length, and width, respectively).

Compared to a typical 9- by 9-inch aerial mapping camera, the LFC has obvious advantages. First, fewer LFC photographs in a project will result in less time needed for measurements and data reduction, more favorable error propagation, and require fewer ground control points. Second, higher resolution will enable more precise measurements because of clearer image detail and better point identification. Third, the reseau will promote higher accuracy.

However, there are other considerations which must be kept in mind. First, the triangulation solution will be weaker in the cross-flight (shorter photo dimension) direction than in the along-flight (longer photo dimension) direction. This may be compensated by using flight lines in a perpendicular pattern. Secondly, compared to the NOS-owned specially constructed Wild RC-10G camera which has reseau spacing of a 1- by 1-cm grid, the LFC has reseau spacing of a 5- by 5-cm grid. This LFC reseau pattern is relatively less effective for film distortion removal.

PHOTOGRAMMETRIC CONTROL EXTENSION

One of the most promising areas in which LFC could be used is photogeodesy, or photogrammetric control extension. In several photogeodesy projects (table 1), using a special 9- by 9-inch format aerial mapping camera, it has been established that the scale of the photography has a direct relationship to the accuracy with which ground points are positioned. In a typical project using the NOS Wild RC-10G reseau camera the normalized system precision of ± 1 meter (planimetry) can be achieved at a photo scale of 1:500,000 which corresponds to photo accuracy of ± 2 micrometers (planimetry) at the photo scale.

Table 1 lists several projects in photogrammetric control extension, giving the normalized system precision and photo accuracy. Special attention may be given to the Casa Grande, New Mexico, 1978, and the Ada County, Idaho, 1981, projects, using the Wild RC-10G (reseau) camera, in which the most accurate results were obtained. The normalized system precisions in the two projects were reported to be 516,159[1] and 641,025 or photographic accuracies of 1.9 and 1.5 micrometers, respectively. The normalized system precision is defined as (scale factor)/(accuracy in meters).

Photogeodesy projects of such high accuracies--less than 2 micrometers at photo scale and between 4 to 5 cm in the ground positions--were possible because of the well established implementation features. Some of these features involved:

- o optimization of the geometry of the block of photographs by providing cross flights, two-thirds forward and side overlaps, and well defined or targeted pass points and ground control points spaced at regular intervals throughout the entire project;

- o determination of radial and decentering lens distortion, and other camera calibration parameters using the highest degree of accuracy by means of the most precise camera calibration system available;

[1]The project adhered to the following concept (Fritz 1985: 306): "...one must strive to remove all systematic errors 'a priori' before resorting to the application of 'self calibration' parameters into an adjustment process,...."

- o calibration of comparator and grid (reseau) plate; and
- o corrections for all known systematic errors in the data reduction process, including radial and decentering lens distortion, film deformation, and atmospheric refraction.

SIMULATION STUDIES

To determine the potential of the LFC photography for photogrammetric control extension, error propagation in aerotriangulation was carried out for various present and future systems. For the purpose of error propagation, the geometric configuration, ground control, and plate coordinates were taken from an ongoing aerotriangulation project. The project used the 22 LFC photographs from NASA shuttle mission STS-41G, available ground control, image coordinates from the NOS Analytical Plotter (NOSAP), and stellar camera calibration results. In addition, a set of parameter constraints was applied to simulate a system (table 2).

Figure 1 shows the layout of the 22 LFC frame block with 80 percent forward overlap in the geographic location of the States of Montana, South Dakota, and Nebraska, covering an overall length along the strip of about 600 miles and a width across three strips of about 200 miles. Each LFC photograph covers approximately 200 by 100 miles at an average photo scale of 1:755,000. Figure 2 depicts the distribution of the existing photo identifiable ground control points in the block. Figure 3 shows the location of existing ground control points selected for simulation studies of error propagation in block triangulation. Figure 4 portrays the selection of every other frame to simulate 60 percent forward overlap LFC photography coverage of the area. Figure 5 shows the location of pass points as selected for the triangulation of the 22 LFC frame block. Generally, in the case of 80 percent forward overlap LFC photographs, each photograph has at least 15 pass points, in addition to ground control points. Pass points in one strip only, and not common to other strips, will appear in two to five photographs. Pass points common to two strips will appear in four to ten photographs.

NOS stellar calibration data for the LFC were available and used in this study. The calibration is a comprehensive determination of camera constants. (Fritz and Schmid 1974: 104.)

The following data files were input to the GIANT program for executing error propagation analysis (Elassal 1976):

CAMERA	- Camera parameters
FRAMES	- Camera station parameters, position and attitude, and their standard deviations for all frames
GROUND	- Positional coordinates and their standard deviations for all ground control points in the block
IMAGES	- Image plate coordinates of all ground and pass points, and standard deviations of their measurement for all plates

The image plate coordinates were obtained from comparator measurements of all 12 fiducials and image points in each of the LFC photographs by means of the NOSAP. For the simulation study of error propagation, it was not necessary to measure the image points by rigorous procedures, such as repeated point measurements. Camera station positions were approximated from the layout of the project on a map sheet showing the center of the photographs. Camera attitude was assumed for the normal (vertical) case of photography and the direction of flight. Minimum control (fig. 3) was obtained from the initial block triangulation solution with NOSAP measurement data and existing ground control (fig. 2). This was done by considering pass points at the desired location as ground control for the simulation studies. Also, to simulate a certain system, constraints (standard deviations) were applied to certain parameters (table 2).

SOME PRELIMINARY INVESTIGATIONS

To investigate the potential of the LFC for photogrammetric control extension or triangulation, four present and future systems (table 2) were simulated and evaluated for optimal results. To accomplish this, some of the common factors entering the block triangulation solution for all the simulated systems were considered beforehand. Preliminary investigations were undertaken to determine the effect on the accuracy of aerotriangulated ground points from the following factors: 1) errors in plate coordinate measurements; 2) 80 percent versus 60 percent forward overlap; and 3) errors in camera attitude determination.

Simulated study cases were set up for demonstrating the effect of each of the above factors by using proper parameter constraints in the error propagation solution of a block triangulation. (See table 3.) In figures 6, 7, and 8, the error curves show the effects in ground position determination as a function of perturbations of the photo measurements, camera attitude, and forward overlap, respectively.

Figure 6, curve 1 (data derived from table 3) shows the effect of the precision of plate coordinate measurements on the accuracy of determination of the triangulated ground points. The precision of the plate coordinate measurements was varied in the solution from ±3 to ±10 micrometers. All other factors, such as ground control distribution with an accuracy of ±0.1 m in ground coordinates and 80 percent forward overlap LFC photography, were kept the same for all cases. The variation of the accuracy of plate coordinate determination from ±3 to ±10 micrometers would represent the precision of measurements obtained by various photogrammetric measurement systems used by various photogrammetric firms. More elaborate refinement would consist of minimizing of film and lens distortions by using reseau and fiducial marks and comparator calibration. The least refinement would consist of using only the fiducial marks for the partial removal of film distortion.

As expected, the results for the determination of the triangulated points improve significantly with higher accuracy of plate coordinate measurements. In the simulated systems studies, discussed in the next section, the accuracy of plate coordinate measurements is taken to be ±3 micrometers.

Figure 7, (table 4) curve 2 shows the effect of the precision of the LFC attitude angles, as determined by the stellar camera, on the determination of the triangulated ground points. The precision with which the attitude angles is determined depends on the number and distribution of the stars on the stellar photography, the number and orientation of stellar cameras relative to the LFC camera, and other factors. The precision values of an LFC attitude angle determination in the case studies were considered to be ±1, ±3, ±10, ±20, and ±30 seconds of arc. The most likely range of precision values at the present time can be expected to be from ±5 to ±15 seconds of arc. In the simulated systems study, ±10 seconds of arc is considered as the precision of LFC attitude angles.

Figure 8, (tables 5 and 6) curves 3 and 4 show the effect of 80 percent and 60 percent forward overlap LFC photography, respectively, on the accuracy of determination of the triangulated ground points. Clearly, the 80 percent forward overlap gives better results. Eighty percent forward overlap LFC photography is considered in all of the simulated systems studies that follow.

SIMULATED SYSTEMS

In figures 9 and 10, curves 4 through 7, show the potential of each of the simulated LFC photography systems for photogrammetric control extension. Results of error propagation from the GIANT program block triangulation were plotted for each of the cases studied for a system. Average standard deviations of latitude, longitude, and elevation averaged over all the triangulated ground points were determined for each of the simulated cases. The results obtained for each LFC system study are plotted as error curves (figs. 9 and 10) and are explained below.

LFC System with GPS-Type Constraints for Camera Position

Curves 4P and 4E (figs. 8, 9, and 10) are the error curves generated for the system from the data given in table 6. The curves represent error trends in the determination of planimetry (latitude and longitude) and elevation. These errors are plotted as average standard deviations of triangulated ground points, due to the variations in the accuracy of camera station coordinates.

The simulated system illustrated in table 6 covers the range of accuracies for the camera station coordinates which GPS is expected to produce. Considering absolute datum, GPS may be considered operational somewhere at the higher end of the accuracy range (up to ±20 m). However, in the local coordinate system, GPS may be considered operational at the lower end of the accuracy range (±1 to ±2 m). The camera position determination to ±0.1 m is included only for a theoretical consideration of future systems. With a ±2 m constraint on the camera position, the simulation accuracy of triangulated ground points is ±4.7 m in planimetry and ±6.6 m in elevation. This corresponds to ±6.2 and ±8.7 micrometers, respectively, at the photo scale.

LFC System with Ground Control

Curves 5P and 5E (figs. 9 and 10) generated from the data given in table 7 show the error trends in the accuracy of determination of triangulated ground points caused by variations in the accuracies of the ground control points (fig. 3) used in the block triangulation. In the decimeter range of accuracies of ground control, the accuracies of triangulated ground points are ±3.2 m in planimetry and ±7.0 m in elevation, which correspond to ±4 and ±9 micrometers, respectively, at photo scale. In the simulation, the range of the ground control accuracies is considered from a decimeter to ±4 m, to allow for all possible cases, including the ones in which the ground control is obtained from maps or other approximate means.

The error curves 5P and 5E show that at the level of accuracy of ±2.3 m in the coordinates of ground control, equivalent to ±3 micrometers at photo scale, the accuracy of triangulated points is about ±3.4 m in planimetry and ±7.3 m in elevation. These values correspond to the ±4.5 and ±9.7 micrometers, respectively at the photo scale. The significance of accuracy at ±3 micrometers at photo scale is that it represents the threshold value for the measurement accuracy of plate coordinates. Therefore, under the conditions of the simulated project, the best possible accuracy of triangulated points is as stated above.

LFC System with Constraints on Camera Position (GPS-Type System) and Camera Attitude (SCA of the Attitude Reference System)

Curves 6P and 6E (figs. 9 and 10), generated from data given in table 8, show the error trends in accuracy of determination of triangulated ground points caused by variation in accuracy of the camera position (using a GPS-type system) and assuming a known accuracy (±10 seconds of arc) of camera attitude angles. The error trends are favorably compared to the simulation in which only the camera position was constrained.

Compared to the simulation with ground control (curves 5P and 5E) this simulation (curves 6P and 6E) is more accurate for elevation determination and about the same for planimetry. Given a camera position constraint of ±2 m, using a GPS type system and ±10 seconds of arc camera attitude from a stellar camera, the achievable accuracies are ±3.8 m in planimetry and ±6.3 m in elevation, which correspond to ±5.1 and ±8.4 micrometers, respectively, at photo scale.

LFC System with Constraints on Camera Position from a GPS-Type System and Ground Control (±0.1 m)

Curves 7P and 7E (figs. 9 and 10), generated from data given in table 9, show the error trends in accuracy of determination of triangulated ground points caused by variation in accuracy of the camera position, using a GPS-type system and given ground control (fig. 3) with an accuracy of ±0.1 m. This simulation gives the most accurate results compared to the rest of the simulations conducted. Note that there is only a slight variation in the accuracy of triangulated ground points: ±3.5 m to ±4.7 m in planimetry, and ±5.5 m to ±6.7 m in elevation, corresponding to a considerable variation in the accuracy of the camera position (GPS-type constraint) from ±1.0 m to 20.0 m. This indicates that the use of the ground control points (±0.1 m) minimizes the effect of variation in the GPS-type constraints. Overall, this system has a great potential for mapping purposes.

At the ±2 m GPS-type constraint on the camera position, and with an accuracy of ground control better than ±1.0 m, the accuracy of triangulated ground points is predicted to be ±2.9 m in planimetry and ±5.7 m in elevation, which correspond to ±3.8 and ±7.6 micrometers, respectively, at photo scale.

CONCLUSIONS

The following are some of the important findings from the simulation study of present and future LFC photography systems, which may be used in block triangulation for ground control extension.

1. Plate coordinates must be measured as precisely as possible and refined to the fullest extent. All the fiducials and available reseau must be used.

2. New technological advances, e.g. GPS, should be used to constrain camera position in the block triangulation solution. These GPS-type constraints provide an array of control points located at each of the camera stations.

3. Whenever possible, more accurate triangulation can be provided by using available ground control along with camera position GPS-type constraints (figs. 9 and 10, curve 7) rather than ground control only.

4. In the absence of ground control, the camera attitude (SCA-type) constraints should be used with the camera position (GPS type) constraints in the block triangulation (figs. 9 and 10, curve 6).

5. From among all the LFC systems simulated, the LFC system with camera position (GPS-type) constraints and a few ground control points of decimeter precision gives the most accurate triangulation results (figs. 9 and 10, curve 7). For example, when the LFC position coordinates are known with a standard deviation of ±2.0 m, and the ground control coordinates are known with a standard deviation of better than ±1.0 m, the accuracy of triangulated ground points is ±2.9 m in planimetry and ±5.7 m in elevation. This corresponds to photo accuracy of ±3.8 and ±7.6 micrometers, respectively, or normalized system accuracy of ±1 m at a photo scale of 1:264,000 for planimetry and ±1 m at the photo scale of 1:136,000 for elevation.

EPILOGUE[2]

Investigations to explore the potential of the large format camera (LFC) for photogrammetric control extension were conducted at the NOAA Charting Research and Development Laboratory (NCRDL). A block of 22 LFC photographs from three nonconsecutive, but physically adjacent, orbits exposed during the October 1984 NASA shuttle mission STS-41G was used in the investigations.

The initial investigations were simulations of present and proposed future LFC photography systems. These were followed by an actual production line aerotriangulation using second generation LFC photography and photographically identified ground control to obtain point positions. The simulations used various combinations of control available for the block aerotriangulation adjustment. These included control simulated from GPS, stellar camera array, and ground control points.

The aerotriangulation simulation that most closely approximated the actual flight parameters predicted average standard deviations of coordinates for points of ±5.5 m in planimetry and ±12.3 m in elevation at an average photoscale of 1:755,000 of LFC photography. The corresponding real LFC data results produced pooled standard deviations of ±6 m in planimetry and ±16 m in elevation. The accuracy checks on five ground control points not included in the adjustment gave standard errors of ±8.5 m in planimetry and ±15.8 m in elevation. For a look into the future, the best simulated LFC system was supported by a GPS system and ground control. It predicted standard deviations of ±2.9 m in planimetry and ±5.7 m in elevation.

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[2] Excerpted from Fritz and Malhotra (1987).

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Fritz, L. W. and Schmid, H. H., 1974: Stellar calibration of Orbigon lens, Photogrammetric Engineering, XL (1), 101-115.

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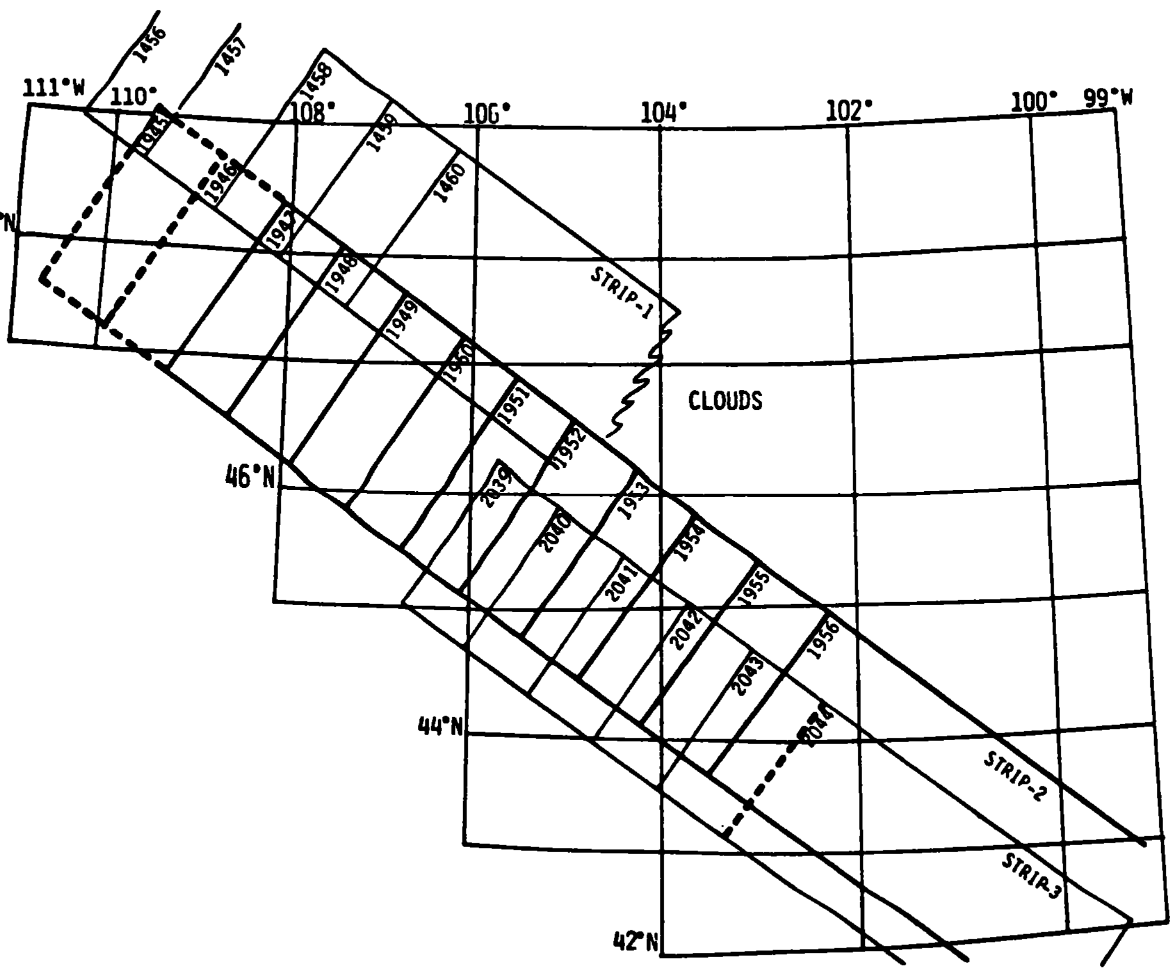

Figure 1.--LFC frame layout.

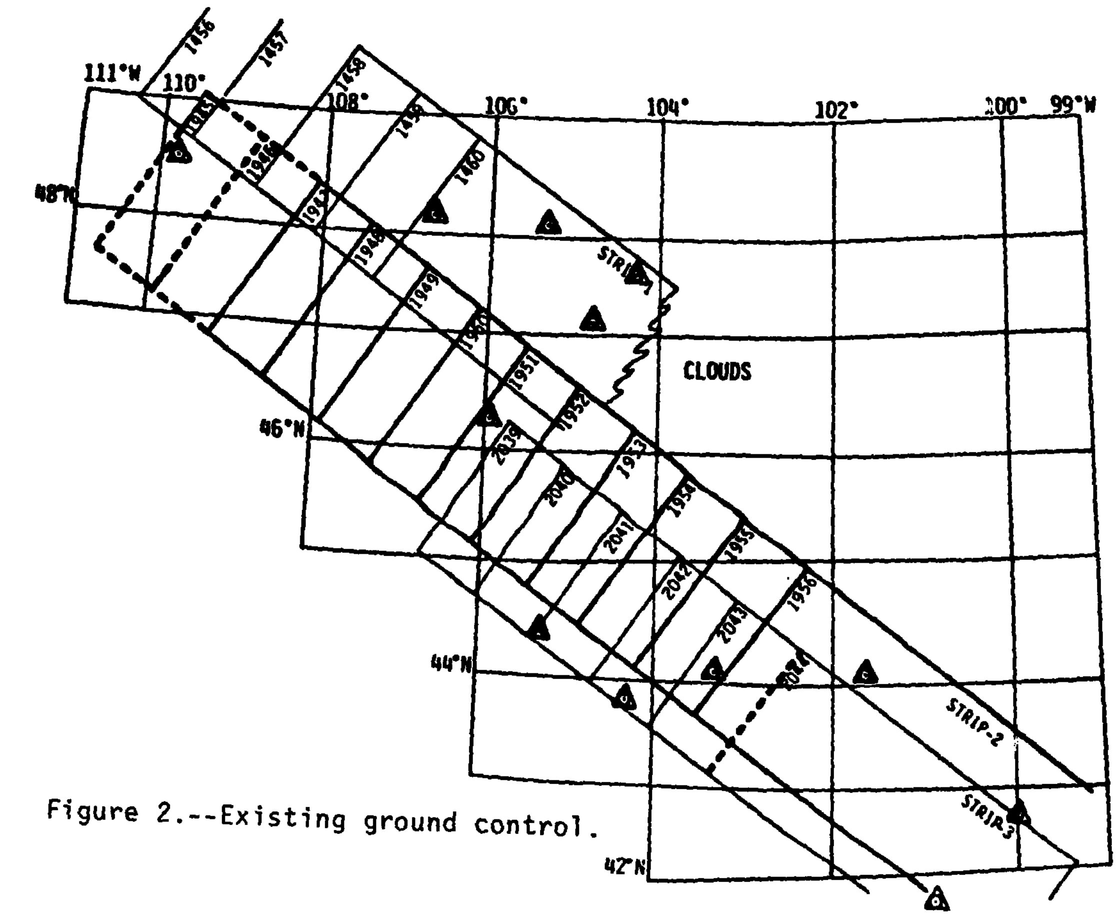

Figure 2.--Existing ground control.

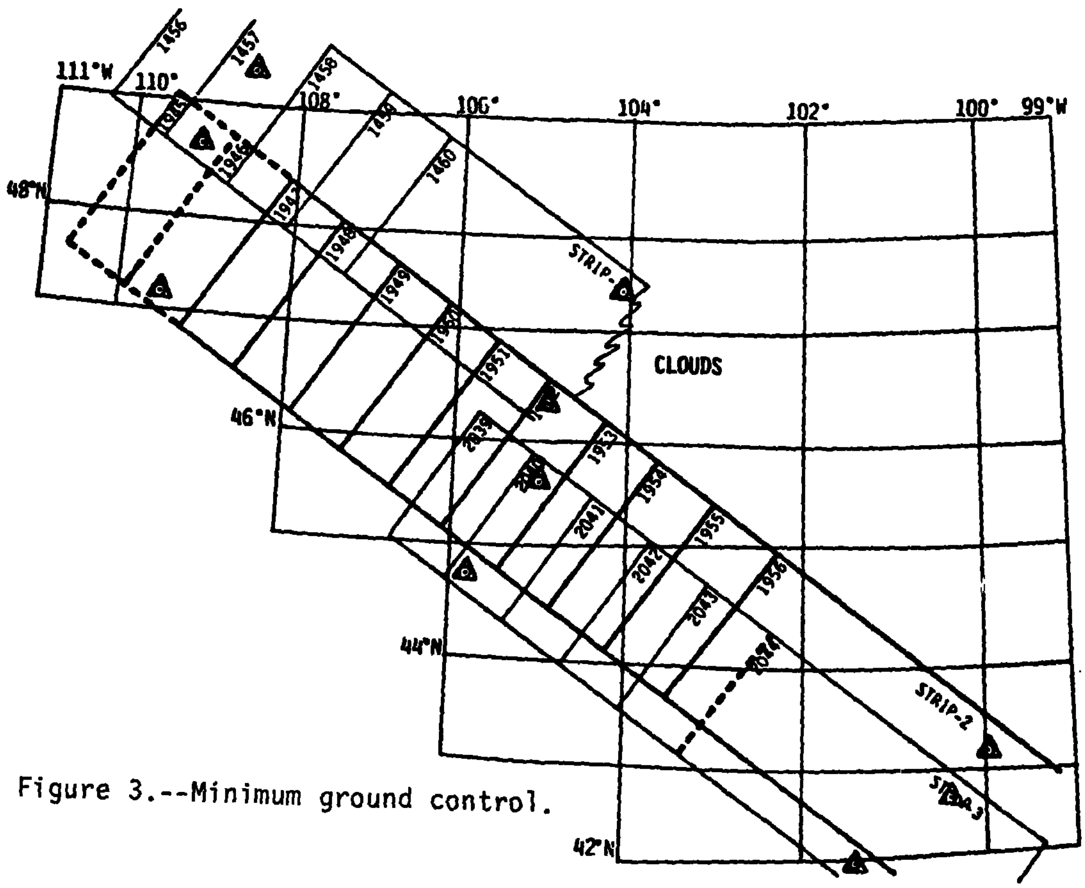

Figure 3.--Minimum ground control.

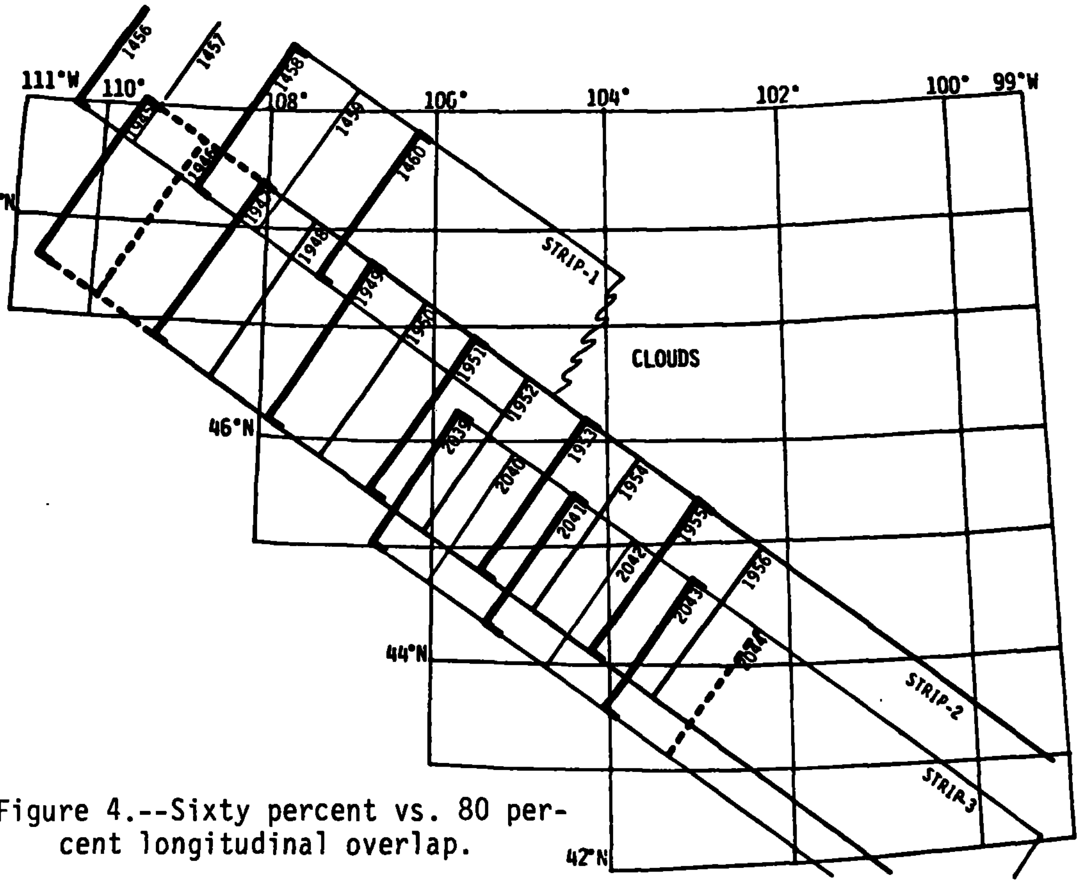

Figure 4.--Sixty percent vs. 80 percent longitudinal overlap.

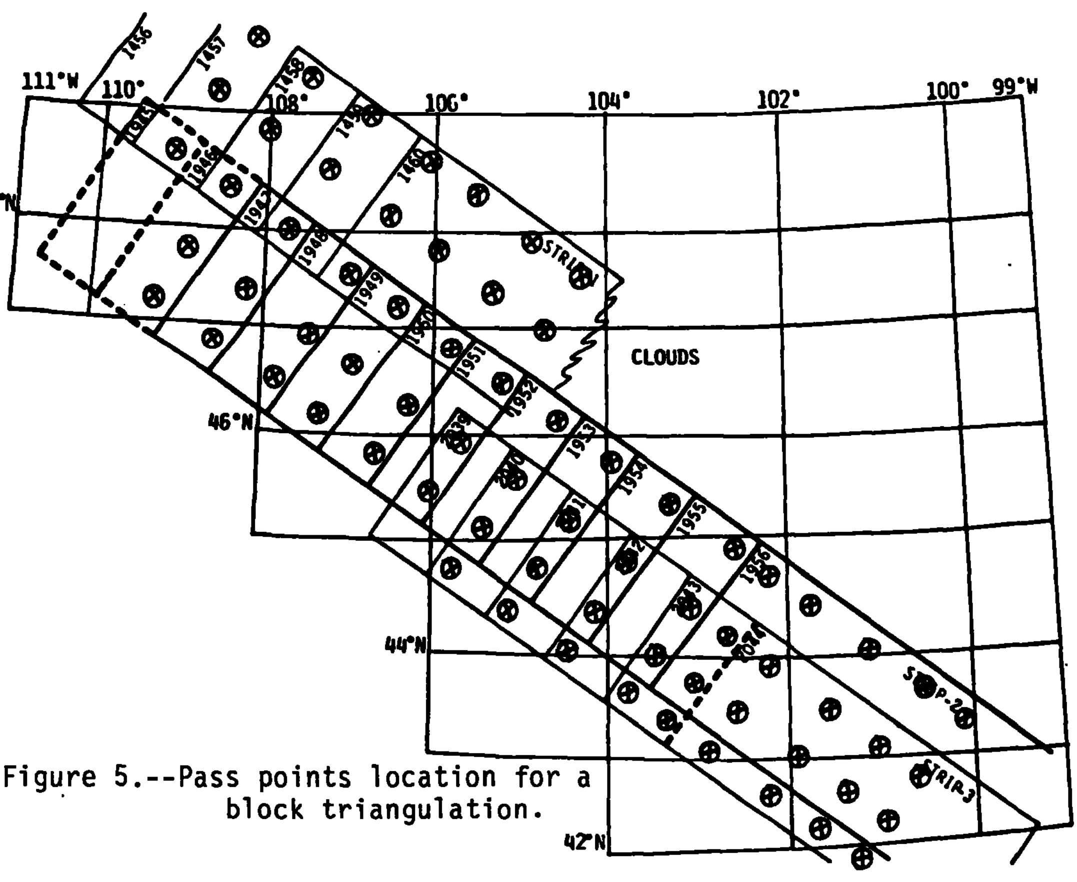

Figure 5.--Pass points location for a block triangulation.

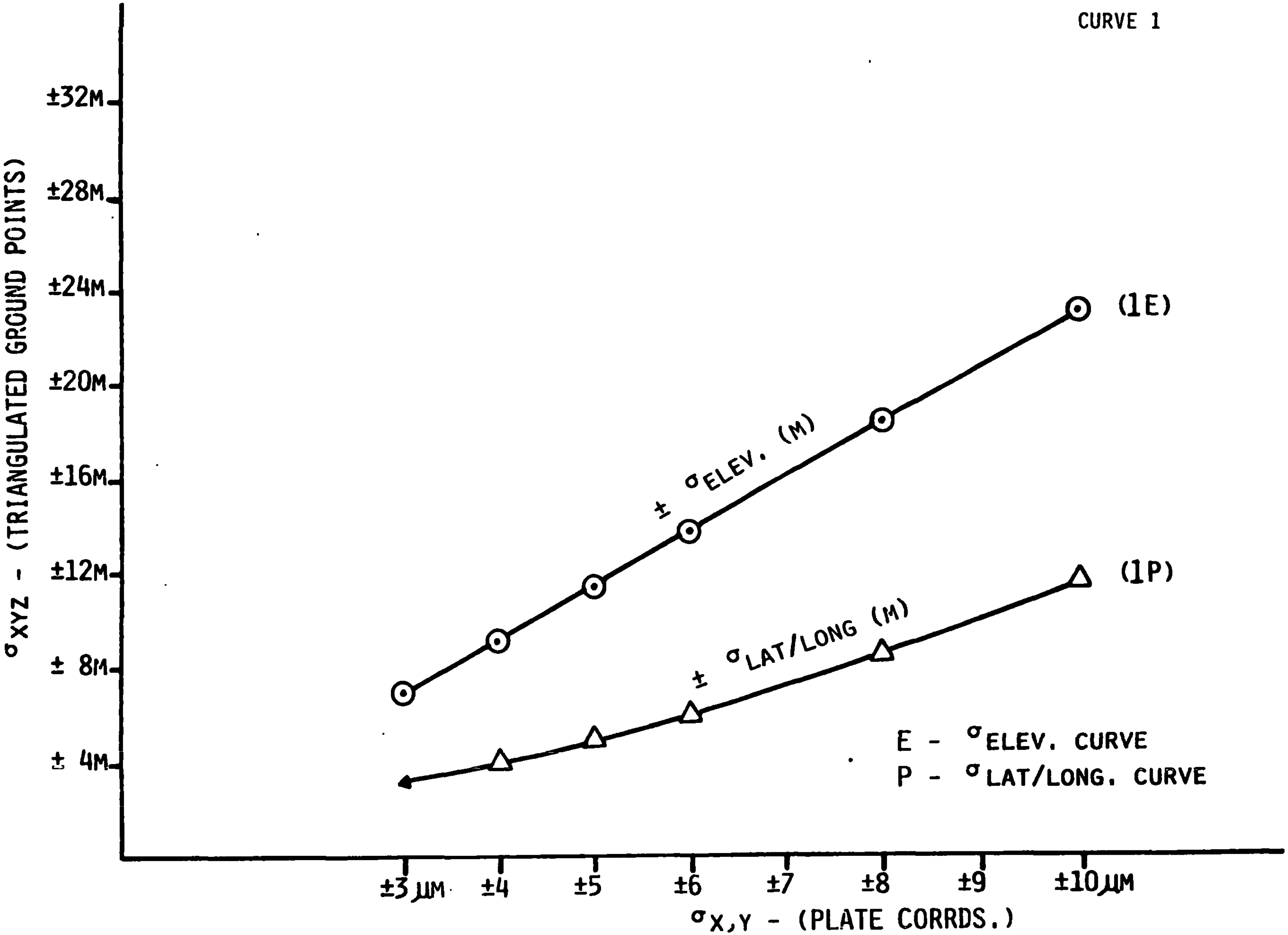

Figure 6.--Effect of plate coordinate measurements in triangulation.

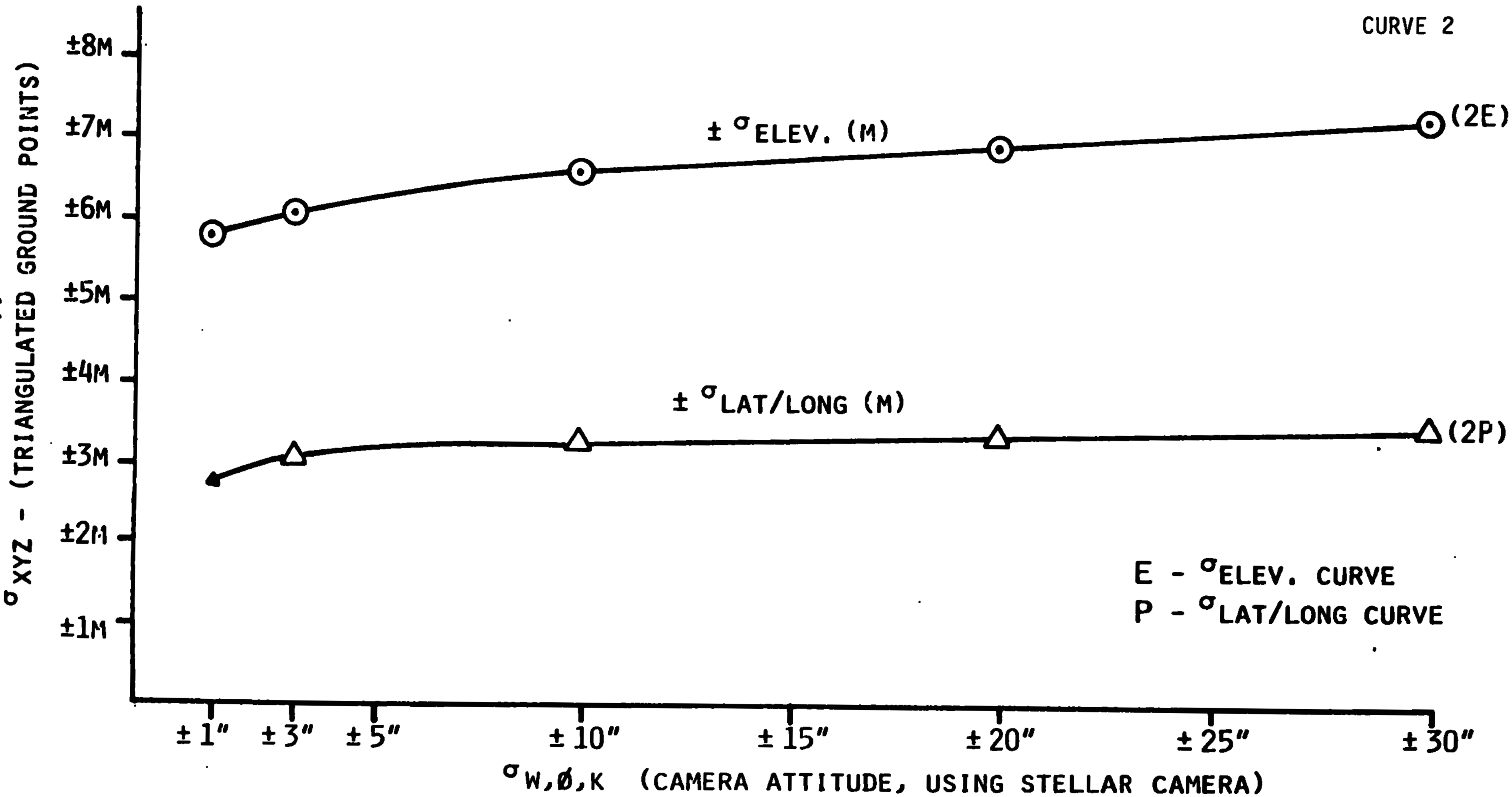

Figure 7.--Effect of constraints on camera attitude (stellar camera) in triangulation.

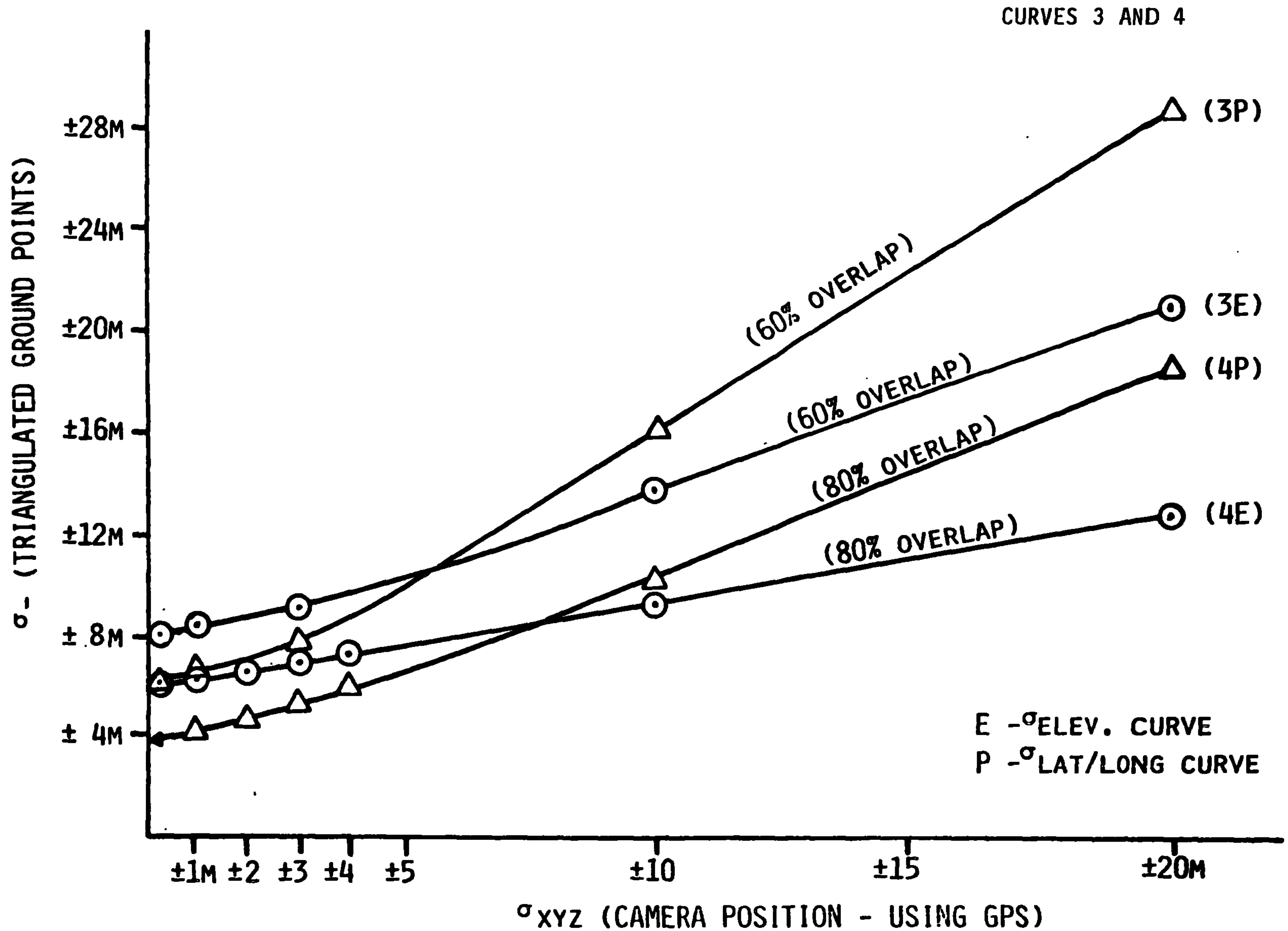

Figure 8.--Effect of 80 percent vs. 60 percent longitudinal overlap in triangulation.

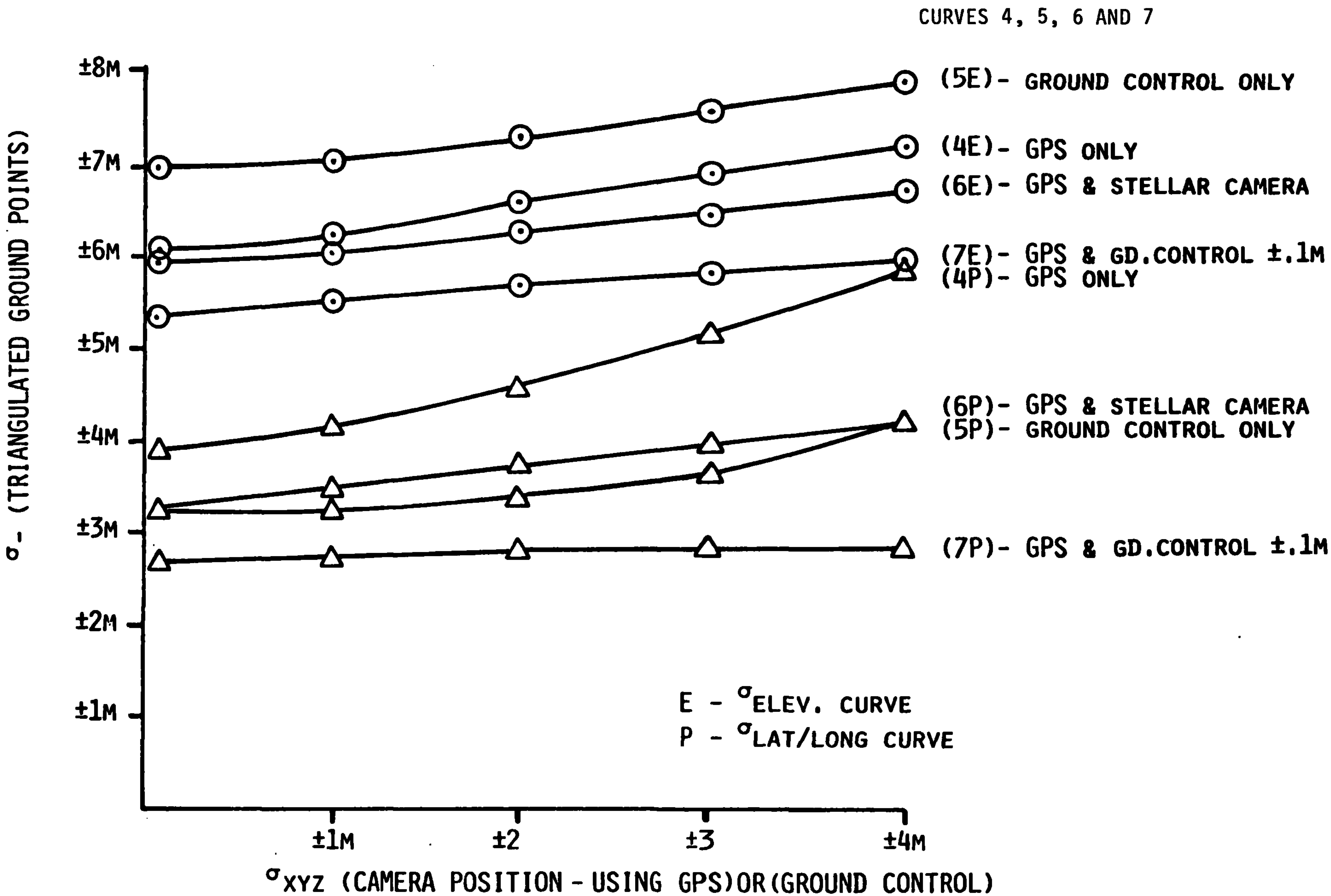

Figure 9.--Error analysis of simulated triangulation systems

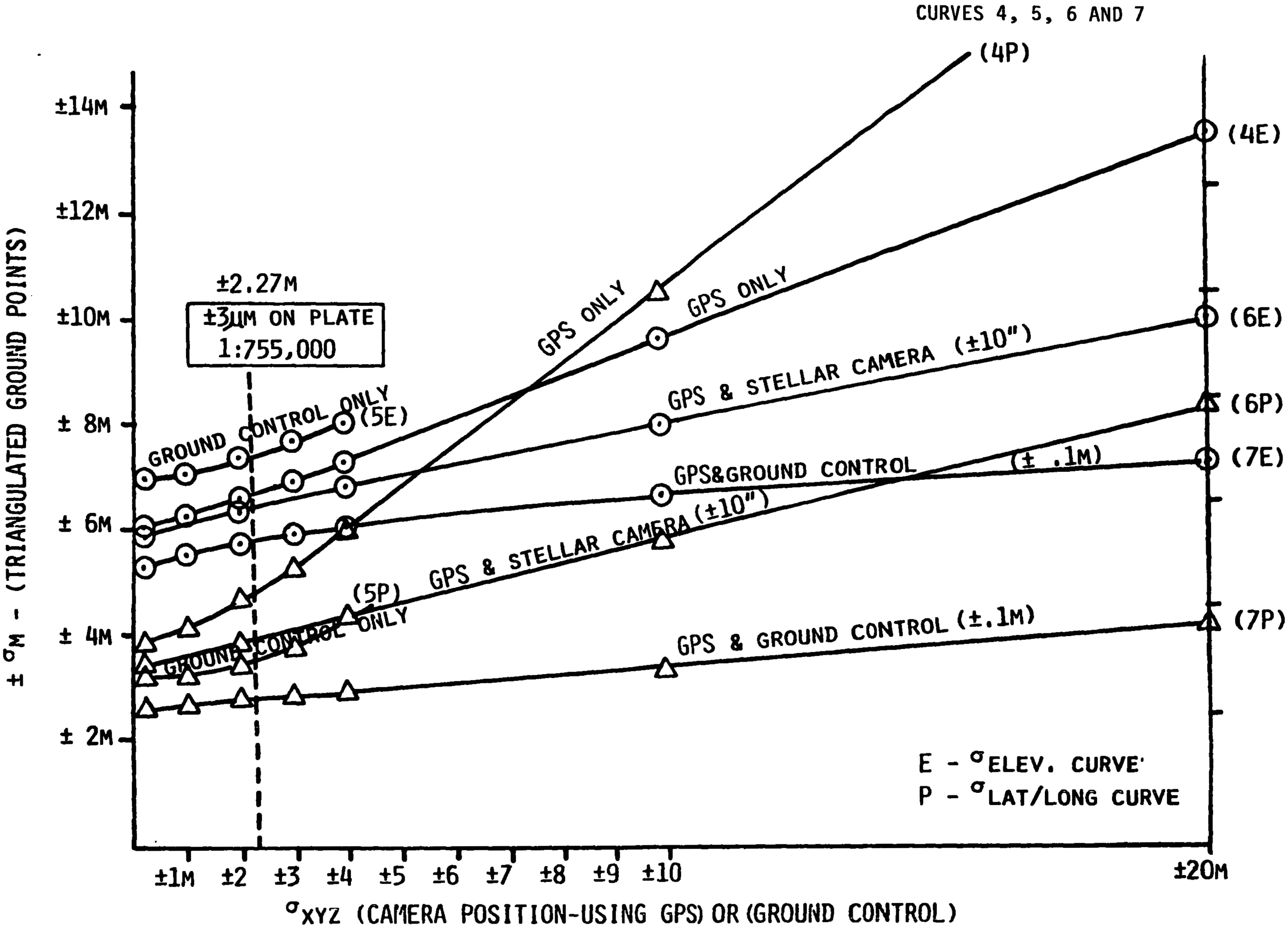

Figure 10.--Error analysis of simulated triangulation systems.

Table 1.--Photogrammetric control extension projects

Project	Camera	Altitude (m)	Scale Factor (sf)*	Number of Photos	Forward/ Side Overlap (%)	Ground Accuracy (m)	Normalized System Precision sf/m	Photo Accuracy m/sf (μm)
Salt Lake,[1] Utah, 1964	RC-7 (glass plates)	850	8,400	9	66/66	.033	254,545	3.9
Anchorage, Alaska, 1965	RC-8 (8 fiducials)	900	6,000	39	66/50-80	.028	214,286	4.6
Parsons, Kansas, 1967	RC-9 (4 fiducials)	6,100	70,000	180	60/60	.646	108,359	9.2
Tucumcari,[2] New Mexico, 1969	RC-9 (4 fiducials)	5,200	60,000	150	60/60	.640	93,750	10.6
Rockville, Maryland, 1971	RC-8 (8 fiducials)	1,600	10,000	30	60/60	.076	131,579	7.6
Casa Grande,[3] New Mexico 1978	RC-10G (Reseau)	3,600	24,000	306	66/66 CF	.046	516,159	1.9
Tallahassee, Florida, 1980	RC-10G (Reseau)	2,400	15,800	145	66/66 CF	.042	376,190	2.6
Ada County,[4] Idaho, 1981	RC-10G (Reseau)	3,800	25,000	434	66/66 CF	.039	641,025	1.5

*sf = 1/Photographic scale

[1] Woodcock & Lampton, 1964
[2] Eichert & Eller, 1969
[3] Slama, 1978
[4] Lucas, 1984, Perry, 1984

CF = crossflights

Table 2.--Simulation of LFC systems for block triangulation

SYSTEMS SIMULATED:	CONSTRAINTS (STD. DEV.)											
	PLATE COORDS.		GROUND CONTROL			CAMERA POSITION			CAMERA ATTITUDE			
	σ_x	σ_y	$\sigma_{LONG.}$	$\sigma_{LAT.}$	$\sigma_{ELEV.}$	$\sigma_{LONG.}$	$\sigma_{LAT.}$	$\sigma_{ELEV.}$	σ_ω	σ_ϕ	σ_κ	REMARKS
1. (LFC)+(GPS)	YES	YES		NONE		YES	YES	YES	NO	NO	NO	FOR "NO" CONSTRAINT USED VERY LARGE VALUES OF STD. DEV.
2. (LFC)+(GC)	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO	
3. (LFC)+(GPS)+(SC)	YES	YES		NONE		YES	YES	YES	YES	YES	YES	
4. (LFC)+(GPS)+(GC)	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO	

LFC - LARGE FORMAT CAMERA
GPS - GEODETIC POSITIONING SYSTEM (CAMERA POSITION CONSTRAINTS)
SC - STELLAR CAMERA (CAMERA ATTITUDE CONSTRAINTS)
GC - GROUND CONTROL (CONFIGURATION-FIG. 2)

σ_x, σ_y = STD. DEV. of MEASUREMENT OF PLATE COORDS - x , y.
$\sigma_{LONG.}$ = STD. DEV. LONGITUDE
$\sigma_{LAT.}$ = STD. DEV. LATITUDE
$\sigma_{ELEV.}$ = STD. DEV. ELEVATION
σ_ω = STD. DEV. ROLL
σ_ϕ = STD. DEV. PITCH
σ_κ = STD. DEV. YAW

ASSUMPTIONS:

1. FORWARD OVERLAP = 80%
2. PLATE COORDS. MEASUREMENT PRECISION

   x = y = ±3 MICROMETERS

3. GROUND CONTROL (GC) WHEN USED WITH (GPS) & (SC)

   CONFIGURATION - FIG. 3

   LONG.= LAT.= ELEV. = ±0.1m.

4. STELLAR CAMERA (SC) WHEN USED WITH (GPS):

   = ±10 sec. of arc.

Table 3.--Study of the effect of accuracy of plate coordinate measurements on the determination of triangulated ground points

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE #					
		1	2	3	4	5	6
CONSTRAINTS	UNITS						
IMAGE:							
**S.D. OF IMAGE COORD	MICRONS	3	4	5	6	8	10
CAMERA STATION:							
S.D. OF LONGITUDE	D.M.S	10 00	10 00	10 00	10 00	10 00	10 00
S.D. OF LATITUDE	D.M.S	10 00	10 00	10 00	10 00	10 00	10 00
S.D. OF ALTITUDE	METERS	60000	60000	60000	60000	60000	60000
S.D. OF ROLL (ω)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00
S.D. OF PITCH (ϕ)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00
S.D. OF YAW (κ)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00
OVERLAP:							
(LONGITUDINAL)	PERCENT (%)	80	80	80	80	80	80
GROUND CONTROL:							
S.D. OF LONGITUDE	D.M.S.	.004	.004	.004	.004	.004	.004
S.D. OF LATITUDE	D.M.S.	.003	.003	.003	.003	.003	.003
S.D. OF ELEVATION	METERS	0.1	0.1	0.1	0.1	0.1	0.1
NUMBER OF POINTS	NUMBER	--	--	--	--	--	--
MINIMUM POINTS (FIG 3)		MIN	MIN	MIN	MIN	MIN	MIN
RESULTS & ANALYSIS							
PLANIMETRY: (LAT/LONG)							
S.D.: MAX.	METERS	6.9	12.7	21.9	22.5	28.7	35.9
MIN.	METERS	1.4	1.8	2.3	6.30	3.7	4.7
AVG.	METERS	3.25	4.19	5.21	6.30	9.02	10.65
ELEVATION:							
S.D.: MAX.	METERS	13.4	21.4	26.8	32.2	42.9	53.6
MIN.	METERS	3.2	3.5	5.6	6.2	8.4	10.6
AVG.	METERS	6.97	9.30	11.62	13.94	18.59	23.27
SYSTEM PRECISION:							
NORMALIZED *SF/+M+ PLAN.	FACTOR	232,308	180,191	145,192	119,841	83,703	70,892
ELEV.	FACTOR	109,420	81,183	64,974	54,161	40,613	32,445
PHOTO-ACCURACY M/SF PLAN.	MICRONS	4.3	5.5	6.9	8.3	11.9	14.1
ELEV.	MICRONS	9.1	12.3	15.4	18.4	24.6	30.8
CURVE NUMBER: #1P / #1E shown on Figure 6							

*SF - SCALE FACTOR = 755,000
+M - AVG. S.D. (ELEV. OR PLAN.)
**S.D.- STANDARD DEVIATION

NOTE:
a) COMPUTER PROGRAM USED: GIANT
b) BLOCK TRIANGULATION: 22 LFC FRAMES
c) BLOCK TRIANGULATION: 96 ground points computed
d) BLOCK TRIANGULATION: Minimum ground control points (Fig 3) used

Table 4.--Study of the effect of the use of the stellar camera on the determination of triangulated ground points

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE #					
		1	2	3	4	5	6
CONSTRAINTS	UNITS						
IMAGE:							
**S.D. OF IMAGE COORD	MICRONS	3	3	3	3	3	
FRAME:							
S.D. OF LONGITUDE	D.M.S	10 00	10 00	10 00	10 00	10 00	
S.D. OF LATITUDE	D.M.S	10 00	10 00	10 00	10 00	10 00	
S.D. OF ALTITUDE	METERS	60000	60000	60000	60000	60000	
S.D. OF ROLL (ω)	D.M.S.	00 00 01	00 00 03	00 00 10	00 00 20	00 00 30	
S.D. OF PITCH (ϕ)	D.M.S.	00 00 01	00 00 03	00 00 10	00 00 20	00 00 30	
S.D. OF YAW (κ)	D.M.S.	00 00 01	00 00 03	00 00 10	00 00 20	00 00 30	
OVERLAP:							
(LONGITUDINAL)	PERCENT (%)	80	80	80	80	80	
GROUND CONTROL:							
S.D. OF LONGITUDE	D.M.S.	.004	.004	.004	.004	.004	
S.D. OF LATITUDE	D.M.S.	.003	.003	.003	.003	.003	
S.D. OF ELEVATION	METERS	0.1	0.1	0.1	0.1	0.1	
NUMBER OF POINTS	NUMBER	--	--	--	--	--	
MINIMUM POINTS (FIG3)	MIN	MIN	MIN	MIN	MIN	MIN	
RESULTS & ANALYSIS							
PLANIMETRY: (LAT/LONG)							
S.D.: MAX.	METERS	13.2	13.9	15.4	15.9	16.3	
MIN.	METERS	2.5	2.7	3.0	3.1	3.2	
AVG. +M	METERS	2.77	3.05	3.20	3.31	3.43	
(AVG. OVER 96 POINTS)							
ELEVATION:							
S.D.: MAX.	METERS	9.2	9.6	10.4	10.7	11.0	
MIN.	METERS	1.4	1.5	1.6	1.7	1.7	
AVG. +M	METERS	5.80	6.07	6.59	6.95	7.32	
(AVG. OVER 96 POINTS)							
SYSTEM PRECISION:							
NORMALIZED PLAN.	FACTOR	272,563	247,541	235,938	228,097	220,117	
*SF/+M+ ELEV.	FACTOR	130,172	124,382	115,798	108,633	103,142	
PHOTO-ACCURACY PLAN.	MICRONS	3.7	4.0	4.2	4.4	4.5	
M/SF ELEV.	MICRONS	7.7	8.0	8.6	9.2	9.7	
CURVE NUMBER: #2P / #2E							

*SF - SCALE FACTOR = 755,000
+M - AVG. S.D. (ELEV. OR PLAN.)
**S.D.- STANDARD DEVIATION

NOTE:
a) COMPUTER PROGRAM USED: GIANT
b) BLOCK TRIANGULATION: 22 LFC FRAMES
c) BLOCK TRIANGULATION: 96 ground points computed
d) BLOCK TRIANGULATION: Minimum ground control points (Fig 3) used

Table 5.--Study of the effect of 80 percent vs. 60 percent forward overlap on the determination of triangulated ground points

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE # 1	2	3	4	5	6
CONSTRAINTS	**UNITS**						
IMAGE:							
**S.D. OF IMAGE COORD	MICRONS	3	3	3	3	3	
FRAME:							
S.D. OF LONGITUDE	D.M.S	.004	.04	.13	.42	.85	
S.D. OF LATITUDE	D.M.S	.003	.03	.09	.33	.66	
S.D. OF ALTITUDE	METERS	0.1	1.0	3.0	10.0	20.0	
S.D. OF ROLL (ω)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	
S.D. OF PITCH (φ)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	
S.D. OF YAW (κ)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	
OVERLAP: (LONGITUDINAL)	PERCENT (%)	60	60	60	60	60	
GROUND CONTROL:		NONE	NONE	NONE	NONE	NONE	
S.D. OF LONGITUDE	D.M.S.						
S.D. OF LATITUDE	D.M.S.						
S.D. OF ELEVATION	METERS						
NUMBER OF POINTS	NUMBER						
MINIMUM POINTS (FIG 3)	MIN						
RESULTS & ANALYSIS							
PLANIMETRY: (LAT/LONG)							
S.D.: MAX.	METERS	10.0	12.4	14.9	20.9	36.8	
MIN. +M	METERS	4.2	4.9	6.7	13.3	23.0	
AVG.	METERS	6.05	6.59	7.51	16.35	28.65	
(AVG. OVER 96 POINTS)							
ELEVATION:							
S.D.: MAX.	METERS	12.3	13.4	14.1	22.1	31.3	
MIN. +M	METERS	4.5	4.7	5.8	8.4	12.5	
AVG.	METERS	7.92	8.20	9.41	13.95	20.98	
(AVG. OVER 96 POINTS)							
SYSTEM PRECISION:							
NORMALIZED *SF/+M+ PLAN.	FACTOR	124,793	114,568	100,533	46,177	26,353	
ELEV.	FACTOR	95,328	92,073	80,234	54,121	35,987	
PHOTO-ACCURACY M/SF PLAN.	MICRONS	8.0	8.7	9.9	21.7	37.9	
ELEV.	MICRONS	10.5	10.9	12.5	18.5	27.8	
CURVE NUMBER: #3P / #3E							

*SF - SCALE FACTOR = 755,000
+M - AVG. S.D. (ELEV. OR PLAN.)
**S.D.- STANDARD DEVIATION

NOTE:
a) COMPUTER PROGRAM USED: GIANT
b) BLOCK TRIANGULATION: 22 LFC Frames
c) BLOCK TRIANGULATION: 96 ground points computed

Table 6.--Study of the effect of constraints on camera position (GPS type system) on the determination of triangulated ground points

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE # 1	2	3	4	5	6
CONSTRAINTS	UNITS						
IMAGE:							
**S.D. OF IMAGE COORD	MICRONS	3	3	3	3	3	3
FRAME:							
S.D. OF LONGITUDE	D.M.S	.004	.04	.08	.17	.42	.85
S.D. OF LATITUDE	D.M.S	.003	.03	.06	.12	.33	.66
S.D. OF ALTITUDE	METERS	0.1	1.0	2.0	4.0	10.0	20.0
S.D. OF ROLL (ω)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00
S.D. OF PITCH (ϕ)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00
S.D. OF YAW (κ)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00
OVERLAP:							
(LONGITUDINAL)	PERCENT (%)	80	80	80	80	80	80
GROUND CONTROL:		NONE	NONE	NONE	NONE	NONE	NONE
S.D. OF LONGITUDE	D.M.S.						
S.D. OF LATITUDE	D.M.S.						
S.D. OF ELEVATION	METERS						
NUMBER OF POINTS	NUMBER						
MINIMUM POINTS (FIG 3)	MIN						
RESULTS & ANALYSIS							
PLANIMETRY: (LAT/LONG)							
S.D.: MAX.	METERS	9.4	9.8	9.9	12.1	16.4	26.1
MIN.	METERS	2.6	3.1	3.2	4.1	7.8	13.6
AVG. +M	METERS	3.90	4.20	4.69	5.95	10.29	17.65
(AVG. OVER 96 POINTS)							
ELEVATION:							
S.D.: MAX.	METERS	12.8	13.1	13.7	14.7	17.6	22.7
MIN.	METERS	3.0	3.1	3.2	3.8	5.9	8.0
AVG. +M	METERS	6.07	6.26	6.61	7.25	9.31	12.88
(AVG. OVER 96 POINTS)							
SYSTEM PRECISION:							
NORMALIZED PLAN.	FACTOR	193,590	179,762	160,981	127,750	73,372	42,776
*SF/+M+ ELEV.	FACTOR	124,382	120,607	115,091	104,861	81,096	58,618
PHOTO-ACCURACY PLAN.	MICRONS	5.2	5.5	6.2	7.8	13.6	23.3
M/SF ELEV.	MICRONS	8.0	8.3	8.7	9.5	12.3	17.1
CURVE NUMBER: #4P / #4E							

*SF - SCALE FACTOR = 755,000
+M - AVG. S.D. (ELEV. OR PLAN.)
**S.D.- STANDARD DEVIATION

NOTE:
a) COMPUTER PROGRAM USED: GIANT
b) BLOCK TRIANGULATION: 22 LFC FRAMES
c) BLOCK TRIANGULATION: 96 ground points computed

Table 7.--Study of the effect of ground control accuracy (minm. control)*** on the determination of triangulated ground points

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE #					
		1	2	3	4	5	6
CONSTRAINTS	UNITS						
IMAGE:							
**S.D. OF IMAGE COORD	MICRONS						
FRAME:							
S.D. OF LONGITUDE	D.M.S	10 00	10 00	10 00	10 00	10 00	
S.D. OF LATITUDE	D.M.S	10 00	10 00	10 00	10 00	10 00	
S.D. OF ALTITUDE	METERS	60000	60000	60000	60000	60000	
S.D. OF ROLL (ω)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	
S.D. OF PITCH (φ)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	
S.D. OF YAW (κ)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	
OVERLAP:							
(LONGITUDINAL)	PERCENT (%)	80	80	80	80	80	
GROUND CONTROL:							
S.D. OF LONGITUDE	D.M.S.	.004	.04	.08	.13	.17	
S.D. OF LATITUDE	D.M.S.	.003	.03	.06	.09	.12	
S.D. OF ELEVATION	METERS	0.1	1.0	2.0	3.0	4.0	
NUMBER OF POINTS	NUMBER	--	--	--	--	--	
MINIMUM POINTS (FIG 3)	MIN	MIN	MIN	MIN	MIN	MIN	
RESULTS & ANALYSIS							
PLANIMETRY: (LAT/LONG) S.D.: MAX.	METERS	6.9	9.6	11.2	10.9	14.9	
MIN.	METERS	1.4	1.5	1.6	1.9	2.8	
AVG. +M	METERS	3.25	3.26	3.43	3.73	4.23	
(AVG. OVER 96 POINTS)							
ELEVATION: S.D.: MAX.	METERS	13.4	15.3	15.9	16.5	20.5	
MIN.	METERS	3.0	2.9	3.3	3.7	4.6	
AVG. +M	METERS	6.97	7.08	7.32	7.62	7.93	
(AVG. OVER 96 POINTS)							
SYSTEM PRECISION:							
NORMALIZED *SF/+M+ PLAN.	FACTOR	232,308	231,595	220,117	202,413	178,487	
ELEV.	FACTOR	108,321	106,638	103,142	99,081	95,208	
PHOTO-ACCURACY M/SF PLAN.	MICRONS	4.3	4.2	4.5	4.9	5.6	
ELEV.	MICRONS	9.2	9.4	9.7	10.1	10.5	
CURVE NUMBER: #5P / #5E							

*SF - SCALE FACTOR = 755,000
+M - AVG. S.D. (ELEV. OR PLAN.)
**S.D.- STANDARD DEVIATION
***MINM. CONTROL CONFIGURATION (FIG #3)

NOTE:
a) COMPUTER PROGRAM USED: GIANT
b) BLOCK TRIANGULATION: 22 LFC FRAMES
c) BLOCK TRIANGULATION: 96 ground points computed
d) BLOCK TRIANGULATION: Minimum ground control points (FIG 3) used

Table 8.--Study of the effect of constraints: camera position (GPS) and attitude (SC) on the determination of triangulated ground points

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE #					
		1	2	3	4	5	6
CONSTRAINTS	UNITS						
IMAGE:							
**S.D. OF IMAGE COORD	MICRONS	3	3	3	3	3	
FRAME:							
S.D. OF LONGITUDE	D.M.S	.004	.08	.17	.42	.85	
S.D. OF LATITUDE	D.M.S	.003	.06	.12	.33	.66	
S.D. OF ALTITUDE	METERS	0.1	2.0	4.0	10.0	20.0	
S.D. OF ROLL (ω)	D.M.S.	00 00 10	00 00 10	00 00 10	00 00 10	00 00 10	
S.D. OF PITCH (φ)	D.M.S.	00 00 10	00 00 10	00 00 10	00 00 10	00 00 10	
S.D. OF YAW (κ)	D.M.S.	00 00 10	00 00 10	00 00 10	00 00 10	00 00 10	
OVERLAP: (LONGITUDINAL)	PERCENT (%)	80	80	80	80	80	
GROUND CONTROL:		NONE	NONE	NONE	NONE	NONE	
S.D. OF LONGITUDE	D.M.S.						
S.D. OF LATITUDE	D.M.S.						
S.D. OF ELEVATION	METERS						
NUMBER OF POINTS (MINIMUM)	NUMBER MIN						
RESULTS & ANALYSIS							
PLANIMETRY: (LAT/LONG)							
S.D.: MAX.	METERS	9.3	10.0	10.9	12.9	15.1	
MIN. +M	METERS	2.2	2.4	2.8	3.6	5.7	
AVG.	METERS	3.49	3.83	4.30	5.58	7.72	
(AVG. OVER 96 POINTS)							
ELEVATION:							
S.D.: MAX.	METERS	12.7	13.6	14.4	15.8	17.0	
MIN. +M	METERS	2.8	3.1	3.5	5.1	6.8	
AVG.	METERS	5.93	6.33	6.77	7.75	9.34	
(AVG. OVER 96 POINTS)							
SYSTEM PRECISION:							
NORMALIZED PLAN.	FACTOR	216,332	197,128	175,581	135,305	97,798	
*SF/+M+ ELEV.	FACTOR	127,319	119,273	111,521	97,419	80,835	
PHOTO-ACCURACY PLAN.	MICRONS	4.6	5.1	5.7	7.4	10.2	
M/SF ELEV.	MICRONS	7.9	8.4	9.0	10.2	12.4	
CURVE NUMBER: #6P / #6E							

*SF - SCALE FACTOR = 755,000
+M - AVG. S.D. (ELEV. OR PLAN.)
**S.D.- STANDARD DEVIATION

NOTE:
a) COMPUTER PROGRAM USED: GIANT
b) BLOCK TRIANGULATION: 22 LFC Frames
c) BLOCK TRIANGULATION: 96 Ground points computed

Table 9.--Study of the effect of constraints: camera position (GPS) and gd. control (±0.1m) on the determination of triangulated ground points

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE #					
		1	2	3	4	5	6
CONSTRAINTS	**UNITS**						
IMAGE:							
**S.D. OF IMAGE COORD	MICRONS	3	3	3	3	3	3
FRAME:							
S.D. OF LONGITUDE	D.M.S	.004	.04	.08	.17	.42	.85
S.D. OF LATITUDE	D.M.S	.003	.03	.06	.12	.33	.66
S.D. OF ALTITUDE	METERS	0.1	1.0	2.0	4.0	10.0	20.0
S.D. OF ROLL (ω)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00
S.D. OF PITCH (ϕ)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00
S.D. OF YAW (κ)	D.M.S.	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00	90 00 00
OVERLAP:							
(LONGITUDINAL)	PERCENT (%)	80	80	80	80	80	80
GROUND CONTROL:							
S.D. OF LONGITUDE	D.M.S.	.004	.004	.004	.004	.004	.004
S.D. OF LATITUDE	D.M.S.	.003	.003	.003	.003	.003	.003
S.D. OF ELEVATION	METERS	0.1	0.1	0.1	0.1	0.1	0.1
NUMBER OF POINTS	NUMBER	--	--	--	--	--	--
MINIMUM POINTS (FIG 3)	MIN	MIN	MIN	MIN	MIN	MIN	MIN
RESULTS & ANALYSIS							
PLANIMETRY: (LAT/LONG)							
S.D.: MAX.	METERS	8.7	9.0	9.2	9.6	10.3	10.6
MIN.	METERS	1.4	1.4	1.4	1.5	1.5	1.6
AVG. +M	METERS	2.68	2.72	2.86	2.88	3.14	3.73
(AVG. OVER 96 POINTS)							
ELEVATION:							
S.D.: MAX.	METERS	12.3	12.6	13.2	13.9	15.1	15.7
MIN.	METERS	2.1	2.1	2.2	2.4	2.9	3.0
AVG. +M	METERS	5.34	5.56	5.72	5.97	6.42	6.71
(AVG. OVER 96 POINTS)							
SYSTEM PRECISION:							
NORMALIZED *SF/+M+ PLAN.	FACTOR	281,716	277,574	263,986	263,066	262,153	202,413
ELEV.	FACTOR	139,042	135,791	131,993	126,466	126,466	112,519
PHOTO-ACCURACY M/SF PLAN.	MICRONS	3.5	3.6	3.8	3.8	3.8	4.9
ELEV.	MICRONS	7.2	7.4	7.6	7.9	7.9	8.9
CURVE NUMBER:	#7P / #7E						

*SF - SCALE FACTOR = 755,000
+M - AVG. S.D. (ELEV. OR PLAN.)
**S.D.- STANDARD DEVIATION

NOTE:
a) COMPUTER PROGRAM USED: GIANT
b) BLOCK TRIANGULATION: 22 LFC Frames
c) BLOCK TRIANGULATION: 96 Ground points computed
d) BLOCK TRIANGULATION: Minimum ground control (FIG 3) used

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