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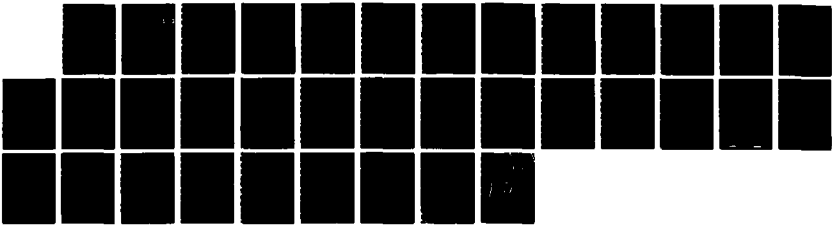

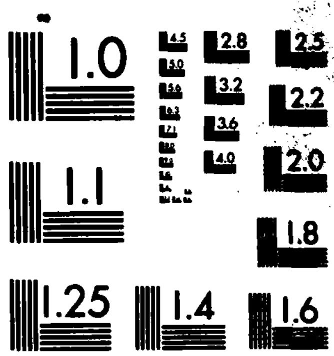
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POTENTIALS OF LARGE FORMAT CAMERA PHOTOGRAPHY

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ABSTRACT

In this paper, the potentials of a Large Format Camera (LFC) photography are explored specifically for the purpose of carrying out photogrammetric control extension. This study is based on the error propagation analysis in photogrammetric triangulation of a block of 22 LFC frames, having an approximate scale of 1:755,000 and taken during the October '84 Shuttle Mission 41-G.

A study of error propagation in photogrammetric triangulation of the block of 22 LFC frames was carried out for several simulated cases, representing various present and future systems of data acquisition and reduction. In these simulated cases, the geometric configuration of the block of photographs was obtained from the triangulation solution, using the existing ground control and the plate coordinates, measured on the National Ocean Service Analytical Plotter (NOSAP). Further, the block triangulation and error propagation solution were obtained by statistically constraining the parameters; such as, plate coordinated, camera position attitude, and ground control, in order to simulate a certain system. General Integrated Analytical Triangulation (GIANT) program was used for error propagation and block triangulation computations.

The results of the study are shown graphically as error curves for each of the simulated systems. The best results are achievable when the Geodetic Positioning System (GPS), along with minimum ground control, is used in the LFC photography block triangulation. The stellar camera is also useful in conjunction with the Geodetic Positioning System, in areas where the ground control is not available for use in the block triangulation. Average standard deviation of determination of coordinates of triangulated ground points can be as good as $\pm$ 2.7 meters (planimetry) and $\pm$ 5.4 meters (elevation). These correspond to $\pm$ 3.5 micrometers (planimetry) and $\pm$ 7.2 micrometers (elevation) at the photo scale.

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INTRODUCTION

From the viewpoint of improved precision, resolution, area coverage, and other terrain mapping considerations, in 1965 a working group within National Aeronautical and Space Administration (NASA) recommended a large format camera of 30-cm focal length, and a pair of stellar cameras to determine camera attitude, for Apollo Missions. It was not until the early 1980's that Itek Corporation designed and constructed for NASA a Large Format Camera (LFC) and the Attitude Reference System (ARS), composed of a dual lens ballistic camera called the Stellar Camera Array (SCA).

The LFC and ARS are a part of the Orbiter Camera Payload System (OCPS) for deployment on space shuttle sortie mission in low earth orbit aboard the Space Transportation System (STS) Orbiter Vehicle. The LFC is, of course, used for making very high resolution images of the earth surfaces with great geometric fidelity. The SCA is used to take simultaneous photographs of the two star fields at the instance 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 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 on shuttle Mission STS-41G on October 5, 1984. The orbit inclination was 57° and the shuttle operated at nominal altitudes of 352, 272, and 222 kms. A total of 2160 frames were exposed (Ref. #1.)

Some of the descriptive parameters of the LFC are as follows:

- Fully metric design lens (focal length of 30.5 cms and aperture of f/6.0).
- High resolution system with an area weighted average resolution (AWAR) of 80 lines per millimeter on a high resolution aerial film at a contrast ratio of 2:1.
- Automatic exposure control from 1/250 to 1/30 seconds.
- Rotary (between the lens) shutter.
- Image motion compensation, 0.01 to 0.045 rad/sec.
- Maximum lens distortion of 20 micrometers.
- Format 23x46 cms. (longer dimension in the flight direction).

- Forward overlap of 10, 60, 70, or 80 percent.
- Twelve illuminated fiducials.
- Backlighted 5x5 cms reseau grid (total of 45 reseaus).
- Vacuum film flattening.
- Minimum cycle time between exposures of 4.3 seconds.
- Film capacity of approximately 4,000 feet or 2,400 9" x 18" photographs.
- Weight of the camera - 506 pounds.
- Physical size of the camera - 50" x 35" x 20". (height, length, and width, respectively)

Compared to a 9 x 9-inch aerial mapping camera, the LFC has the following obvious advantages:

- Few photographs in a project will result in:
  - Lesser time for measurements and data reduction.
  - Lesser error propagation.
  - Lesser requirement and more likelihood of fulfilling ground control requirement.
- Higher resolution will enable more precise measurements because of clearer image detail and better point identification.

On the other hand, there are other considerations which must be kept in mind; such as, the triangulation solution will obviously 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. Also, compared to the Wild RC-10G camera which has reseau spacing on a 2 x 2 cm. grid, the LFC has reseau spacing on a 5 x 5 cm. grid, which may be a slight disadvantage as far as precision goes.

PHOTOGRAMMETRIC CONTROL EXTENSION

One of the most promising areas in which LFC could be used is in photogeodesy, or photogrammetric control extension. In several photogeodesy projects (Ref. 3), using the 9 x 9 -inch format aerial mapping cameras, 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 case of a project using Wild RC-10G reseau camera, the relationship for ground positioning error is:

$$\frac{\text{scale factor}}{500,000} = \pm 1 \quad \text{(meters)}$$

Table #1 (Ref. #3) lists several projects in photogrammetric point 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 best possible results were obtained, with normalized system precisions of 516,159 and 641,025 or photo accuracy of 1.9 and 1.5 micrometers, respectively. Cross flights were used in these projects. The achievement of accuracies less that 2 micrometers on the photographs is mainly due to (Ref. 3):

- The isolation of systematic errors and their "a priori" removal from the observations, before resorting to the application of "self-calibration" parameters into an adjustment process.

- The statistical rigor in all mensuration activities.

This involved the most accurate determination of radial and decentering lens distortions and other camera constants; determination of atmospheric refraction, comparator calibration, grid plate (reseau) calibration, film distortion, and most significantly, adjustment techniques for large systems of simultaneous equations. The basic requirement for optimization of geometry is two-thirds forward and side overlap of the photographs. The well defined points (pass points and ground control points) must be spaced at regular intervals throughout the entire project area and every photograph must contain a minimum of nine image points (Ref #3).

SIMULATION STUDIES

In order to determine the potentials of the LFC photography, for photogrammetric control extension, photogrammetric block triangulation of 22-LFC frames from Shuttle Mission 41-G was carried out by simulating data for several cases, representing various data acquisition and reduction systems with the LFC.

Figure 1 shows the layout of the 22-LFC frames 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 photo covers approximately 200 x 100 miles at the average photo scale of 1:755,000.

Figure 2 shows the distribution of the existing ground control points in the block.

Figure 3 shows the location of selected minimum ground control points for simulation studies of error propagation in block triangulation. These points were selected from the triangulated ground points whose coordinates were obtained from a real-data triangulation solution, using the existing ground control points. (Figure 2)

Figure 4 shows 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. In general, 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 2 to 5 photographs. Pass-points common to two strips will appear in 4 to 10 photographs.

National Ocean Service (NOS) stellar calibration data for the LFC was available. The calibration is a comprehensive determination of camera constant (Ref. #4.)

In order to carry out error propagation analysis in block triangulation for various simulated systems, the follow data files were generated for use in the General Integrated Analytical Triangulation (GIANT) program:

- CAMERA - Camera parameters
- FRAMES - Camera station parameters, position and attitude, and standard deviations of these, for all frames.
- GROUND - Positional coordinates and standard deviations of these, 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 the comparator measurements of all the 12 fiducials and image points in each of the LFC photographs by means of the National Ocean Service Analytical Plotter (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 photocenters. Camera attitude was assumed for the normal (vertical) case of photography, and the direction of flight. Ground control for the minimum control distribution was obtained from the initial block triangulation solution with the NOSAP measurement data and the existing ground control. Pass points located at the desired ground control location were then considered as ground control for simulation studies. However, to simulate a certain system, constrainsts (standard deviations) were applied to the parameters or determined by the simulated system. Thus, the systems were simulated as shown in Table #2.

SOME PRELIMINARY INVESTIGATIONS

For investigating the potentials of the LFC in photogrammetric control extension or triangulation, various systems were simulated (Table #2) and evaluated for the best possible results in the determination of triangulated ground points. In order to do so, some of the common factors entering the block triangulation solution for all the simulated systems were considered before hand. Preliminary investigations were made to find out the effect of the following factors:

- Plate coordinate measurement precision;
- 80 percent vers s 60 percent forward overlap;
- Camera attitude precision;

on the accuracy of the triangulated ground points.

Simulated study cases were setup by using proper constraints to give the error curves from the error propagation solution thereby demonstrating the effect of the above factors.

Curve #1 (Figure #7 and Table #3) shows the effect of the precision of plate coordinate measurements on the accuracy of determination of the triangulated ground points. In the solution, the precision of the plate coordinate measurements was varied from ±3 to ±10 micrometers, and all other factors, such as, minimum ground control distribution with the accuracy of ±0.1 meters in ground coordinates; and 80 percent forward overlap LFC photography, were kept the same in all the study cases. The variation of the precision of plate coordinate determination from ±3 to ±10 micrometers would represent the degree of refinement to which the comparator coordinates are subjected to. It varies from the most elaborate refinement (Reference 2), consisting of the elimination of film and lens distortions, use of reseau and the fiducial marks, comparator calibration, etc. to the least refinement, consisting of the use of the fiducial marks only.

It is clearly seen that the results for the determination of the triangulated points are much improved with the precision of plate coordinate measurements. In this simulated systems study, the precision of plate coordinate measurements is taken to the ±3 micrometers.

Curve #2 (Figure #7 and Table #4) 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 are 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, etc. The values of such a determination were considered ranging from ±1 sec. of arc to ±30 sec. of arc., although the most likely range of values at the present time can be expected to be from ±5 sec. of arc. to ±15 sec. of arc. For all practical purposes, in the simulated systems study, ±10 sec. of arc. is considered as the precision of LFC attitude angles.

Curve #3 and #4 (Figure #8 and Tables #5 and #6) show the effect of 80 percent and 60 percent forward overlap LFC photography, respectively, on the accuracy of determination of the triangulated ground points. It is clearly seen, that the 80 percent forward overlap gives better results. Hence, in all of the simulated systems study, 80 percent forward overlap LFC photography is considered.

RESULTS AND CONCLUSIONS

Figure #9 and Figure #10 show the potentials of each of the simulated LFC photography systems as a means of photogrammetric control extension. The error propagation results from the block triangulation, using the GIANT program, were plotted as average standard deviations of determination of latitude/longitude and elevation, averaged over all the triangulated ground points, for each of the cases studied for a system. The error curves obtained for each of the LFC system study are now discussed.

LFC System with Constraints for Camera Position (GPS Type System)(Figures #9 and #10)

Curves #4P and #4E (Table #6) are the error curves, showing the error trends in the determination of planimetry (latitude/longitude) and elevation, plotted as average standard deviations over the triangulated ground points, due to the variations in the accuracy of camera station coordinates, determined by systems such as the GPS. This simulated system study covers the range of accuracies for the camera station coordinates within which the GPS will be operational. Considering absolute accuracy of the GPS, it may be considered operational somewhere at the higher end of the accuracy range (up to ±20m). However, in the GPS defined coordinate system, it may be considered to be at the lower end of the accuracy range (±1 to ±2m). The camera position determination to ±0.1m is included for theoretical consideration of systems in the future. It may also be noted that the GPS type constraints inthe error proagation solution gives better results in planimetry than in elevation of the triangulated ground points when the constraints have values less than or equal to ±7.5m in the simulated study. The accuracy of suich a system mayu be as good a ±4m in planimetry and ±6m in elevation when the system constraints on the camera positions is in the decimeter range. With the ±2m constraint on the camera position, the accuracy of the triangulated ground points may be about ±4.7m in planimetry and ±6.6m in elevation, which correspond to±6.2 micrometers and ±8.7 micrometers, respectively, at the photo scale.

LFC System with Ground Control: (Figures #9 and #10)

Curves #5P and #5E (Table #7) show the error trends in the accuracy of determination of the triangulated ground points with the variations in the accuracies of the ground control points (Figure #3) used in the block triangulation. In the decimeter range of the accuracies of the ground control, the accuracies of the triangulated ground points are ±2.7m in planimetry ±5.6m in elevation, which correspond to ±3 and ±7.4 micrometers, respectively, at the photo scale. The range of the ground control accuracies are considered up to ±4 meters, in order to cover cases where the ground control is obtained from maps or other approximate means. The error curves (#5P and #5E) show that for accuracy of the ground control better than ±2.7m (±3 micrometers on the plate, and corresponding to the accuracy of plate coordinate measurements), the accuracy of the triangulated ground points is about the same: ±3.4m in planimetry and ±7.3m in elevation, which corresponds to ±4.5 micrometers and ±9.7 micrometers, respectively, at the photo scale. This clearly indicates the strong influence of the precision of the plate coordinates in the solution. However, when the ground coordinates have relative accuracy of greater than ±2.7m, the errors values increase at a higher rate.

LFC System with Constraints for Camera Position (GPS Type System) and Camera Attitude (SC):

Curves #6P and #6E (Table #8) show the error trends in the accuracy of determination of the triangulated ground points with variation in the accuracy of the camera position (using the GPS type system), given a known precision (±10 secs. of arc) of the camera attitude angles. The error trends are favorable compared to the LFC System with only the camera position (GPS type) constraints. Compared to the LFC system with ground control, this system is much better for elevation and about the same for planimetry. In case the camera position constraint is ±2m, using a GPS type system, and ±10 secs. of arc camera attitude from a stellar camera (SC), the achievable accuracy are ±3.8m in planimetry and ±6.3m in elevation, which correspond to ±5.1 micrometers and ±8.4 micrometers, respectively, at photo scale.

LFC System with Constraints for Camera Position (GPS type system) and Ground Control (±0.1m):

Curves #7P and #7E (Table #9) show the error trends in the accuracy of determination of the triangulated ground points with the variation in the accuracy of the camera position (using GPS type system), given the ground control (Figure #3) with accuracy of ±0.1m. This system gives the best possible results compared to the rest of the systems studied. It may be observed, that there is a slight variation in the accuracy of determination of triangulated ground points: ±3.5m to ±4.7m in planimetry, and ±5.5m to ±6.7m in elevation, corresponding to a considerable variation in the accuracy of the camera position (GPS type constraint): ±1.0m to 20.0m. This indicates that the use of the ground control points (±0.1m) along with the GPS type constraint helps in minimizing the effect of the variation in the GPS type constraints. Overall, this system has a great potential for mapping purposes.

At the ±2m, GPS type constraint on the camera position, and ground control of ±0.1m accuracy, the relative accuracy of determination of the triangulated ground points is ±2.9m in planimetry and ±5.7m in elevation, which corresponds to ±3.8 micrometers and ±7.6 micrometers, respectively, at the photo scale.

In conclusion, from amongst all of the LFC systems studied, the LFC system with GPS type constraints and a few well distributed ground control (Figure #3) of decimeter accuracy, gives the best possible results. Accuracies of ±2.9m in planimetry and ±5.7m in elevation at the photo scale (1:755,000) are achievable in the determination of photogrammetric ground control when the camera positions are known with an accuracy of ±2m and the ground control with an accuracy of ±0.1m. In areas where there is no ground control, the best system for obtaining photogrammetric ground control is the LFC system with GPS type (camera position) and SC type (camera attitude) constraints. In the present configuration, with the camera position accurate to ±2m and camera attitude angles known to ±10 sec. of arc, the accuracies achievable for the photogrammetric ground control are ±3.8 meters in planimetry and ±6.3 meters in elevation, which corresponds to ±5.1 micrometers and ±8.4 micrometers at photo scale, respectively.

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TABLE 1 - (Ref.#3)

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	254,549	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 SYSTEMS (LFC - BLOCK TRIANGULATION)

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

σ_x, σ_y = STD. DEV. OF MEASUREMENT OF PLATE COORDS – x, y.
σ_{LONG} = STD. DEV. LONGITUDE
σ_{LAT} = STD. DEV. LATITUDE
σ_{ELEV} = STD. DEV. ELEVATION
σ_ω = STD. DEV. ROLL (ω)
σ_ϕ = STD. DEV. PITCH (ϕ)
σ_κ = STD. DEV. YAW (κ)

ASSUMPTIONS:

1. FORWARD OVERLAP = 80%
2. PLATE COORDS. MEASUREMENT PRECISION
   $\sigma_x = \sigma_y = \pm 3$ MICROMETERS
3. GROUND CONTROL (GC) WHEN USED WITH (GPS) & (SC)
   CONFIGURATION - FIG. 3
   $\sigma_{LONG} = \sigma_{LAT} = \sigma_{ELEV} = \pm 0.1$ m.
4. STELLAR CAMERA (SC) WHEN USED WITH (GPS):
   $\sigma_\omega = \sigma_\phi = \sigma_\kappa = \pm 10$ sec. of arc.

ERROR PROPAGATION STUDY

TABLE # 3 - STUDY OF THE EFFECT OF ACCURACY OF PLATE COORDINATE MEASUREMENTS ON THE DETERMINATION OF TRIANGULATED GROUND POINTS

CURVE # 1

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE #					
CONSTRAINTS	UNITS	1	2	3	4	5	6
IMAGE:							
**S.D. OF IMAGE COORD	MICRONS	3	4	5	6	8	10
FRAME:							
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 (W)	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 (0)	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 (k)	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 (MINIMUM)	NUMBER MINM.	— MINM.	— MINM.	— MINM.	— MINM.	— MINM.	— MINM.
RESULTS & ANALYSIS							
PLANIMETRY: (LAT/LONG)							
S.D.: MAX.	METERS	6.9	12.7	21.9	22.5	28.7	35.9
MIN. +M	METERS	1.4	1.8	2.3	2.5	3.7	4.7
AVG.	METERS	3.25	4.19	5.21	6.30	9.02	10.65
(AVG. OVER 96 POINTS)							
ELEVATION:							
S.D.: MAX.	METERS	13.4	21.4	26.8	32.2	42.9	53.6
MIN. +M	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
(AVG. OVER 96 POINTS)							
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							

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

NOTE: BLOCK TRIANGULATION: 22 LFC FRAMES
COMPUTER PROGRAM USED: "GIANT"

ERROR PROPAGATION STUDY

TABLE # 4 - STUDY OF THE EFFECT OF THE USE OF THE STELLAR CAMERA ON THE DETERMINATION OF TRIANGULATED GROUND POINTS

CURVE # 2

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE #					
CONSTRAINTS	UNITS	1	2	3	4	5	6
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 (W)	D.M.S.	00 00 01.	00 00 03.	00 00 10.	00 00 20.	00 00 30.	
S.D. OF PITCH (0)	D.M.S.	00 00 01.	00 00 03.	00 00 10.	00 00 20.	00 00 30	
S.D. OF YAW (k)	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 (MINIMUM)	NUMBER MINM.	— MINM.	— MINM.	— MINM.	— MINM.	— MINM.	
RESULTS & ANALYSIS							
PLANIMETRY: (LAT/LONG)							
S.D.: MAX.	METERS	13·2	13·9	15·4	15·9	16·3	
MIN. +M	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. +M	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 *SF/+M PLAN.	FACTOR	272,563.	247,541.	235,938.	228,097.	220,117.	
ELEV.	FACTOR	130,172.	124,382.	115,798.	108,633	103,142	
PHOTO-ACCURACY M/SF PLAN.	MICRONS	3·7	4·0	4·2	4·4	4·5	
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: BLOCK TRIANGULATION: 22 LFC FRAMES
COMPUTER PROGRAM USED: "GIANT"

ERROR PROPAGATION STUDY

TABLE # 5 - STUDY OF THE EFFECT OF 80% versus 60% FORWARD OVERLAP ON THE DETERMINATION OF TRIANGULATED GROUND POINTS

CURVE # 3

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 (W)	D.M.S.	90 00 00.	90 00 00.	90 00 00.	90 00 00.	90 00 00.	
S.D. OF PITCH (0)	D.M.S.	90 00 00.	90 00 00.	90 00 00.	90 00 00.	90 00 00.	
S.D. OF YAW (k)	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 (MINIMUM)	NUMBER MINM.						
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: BLOCK TRIANGULATION: 22 LFC FRAMES
COMPUTER PROGRAM USED: "GIANT"

ERROR PROPAGATION STUDY

TABLE # 6 - STUDY OF THE EFFECT OF CONSTRAINTS ON CAMERA POSITION (GEODETIC POSITIONING SYSTEM-GPS) ON THE DETERMINATION OF TRIANGULATED GROUND POINTS — CURVE # 4

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE #					
CONSTRAINTS	UNITS	1	2	3	4	5	6
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 (W)	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 (0)	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 (k)	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 (MINIMUM)	NUMBER MINM.						
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 *SF/+M PLAN.	FACTOR	193,590.	179,762.	160,981	127,750	73,372.	42,776
ELEV.	FACTOR	124,382.	120,607.	115,091	104,861	81,096	58,618
PHOTO-ACCURACY M/SF PLAN.	MICRONS	5.2	5.5	6.2	7.8	13.6	23.3
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: BLOCK TRIANGULATION: 22 LFC FRAMES
COMPUTER PROGRAM USED: "GIANT"

ERROR PROPAGATION STUDY

TABLE # 7 - STUDY OF THE EFFECT OF GROUND CONTROL ACCURACY (MINM. CONTROL)*** CURVE # 5 ON THE DETERMINATION OF TRIANGULATED GROUND POINTS

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE #					
CONSTRAINTS	UNITS	1	2	3	4	5	6
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.	1000.	
S.D. OF ALTITUDE	METERS	60000.	60000.	60000	61000.	60000.	
S.D. OF ROLL (W)	D.M.S.	90 00 00.	90 00 00.	90 00 00.	90 00 00.	90 00 00.	
S.D. OF PITCH (0)	D.M.S.	90 00 00.	90 00 00.	90 00 00.	90 00 00.	90 00 00.	
S.D. OF YAW (k)	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 (MINIMUM)	NUMBER MINM.	MINM.	MINM.	MINM.	MINM.	MINM.	
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: BLOCK TRIANGULATION: 22 LFC FRAMES
COMPUTER PROGRAM USED: "GIANT"

ERROR PROPAGATION STUDY

TABLE # 8 - STUDY OF THE EFFECT OF CONSTRAINTS: CAMERA POSITION (GPS) & ATTITUDE (STELLAR CAMERA) CURVE # 6 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 (W)	D.M.S.	00 00 10.	00 00 10.	00 00 10.	00 00 10.	00 00 10.	
S.D. OF PITCH (0)	D.M.S.	00 00 10.	00 00 10.	00 00 10.	00 00 10.	00 00 10.	
S.D. OF YAW (k)	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 MINM.						
RESULTS & ANALYSIS							
PLANIMETRY: (LAT/LONG)							
S.D.: MAX.	METERS	9·3	10·0	10·9	12·9	15·1	
MIN.	METERS	2·2	2·4	2·8	3·6	5·7	
AVG. +M	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.	METERS	2·8	3·1	3·5	5·1	6·8	
AVG. +M	METERS	5·93	6·33	6·77	7·75	9·34	
(AVG. OVER 96 POINTS)							
SYSTEM PRECISION:							
NORMALIZED *SF/+M PLAN.	FACTOR	216,332.	197,128.	175,581.	135,305.	97,798.	
ELEV.	FACTOR	127,319.	119,273.	111,521.	97,419.	89,835.	
PHOTO-ACCURACY M/SF PLAN.	MICRONS	4·6	5·1	5·7	7·4	10·2	
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: BLOCK TRIANGULATION: 22 LFC FRAMES
COMPUTER PROGRAM USED: "GIANT"

ERROR PROPAGATION STUDY

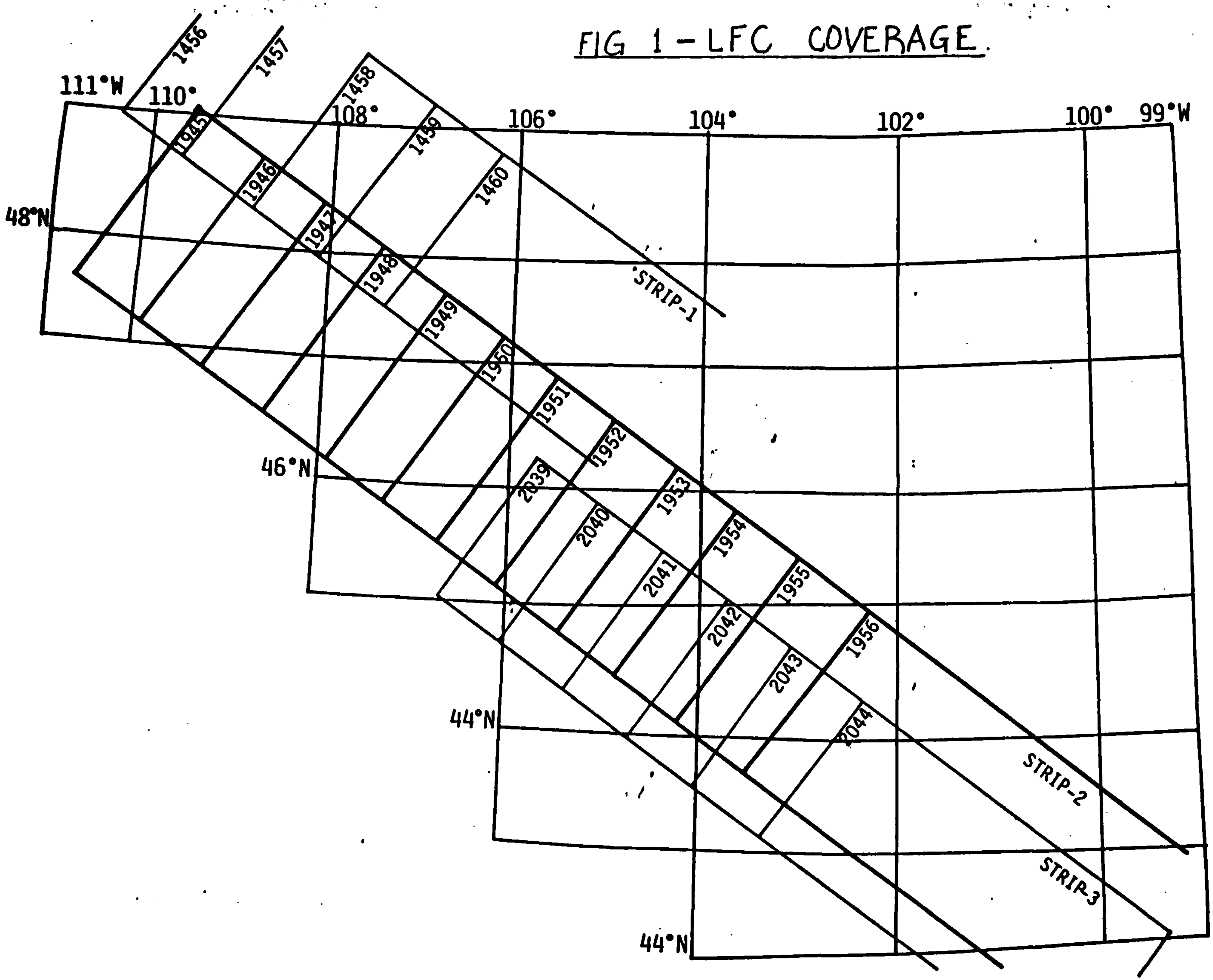
TABLE # 9 - STUDY OF THE EFFECT OF CONSTRAINTS ON CAMERA POSITION (GPS) & GROUND CONTROL (MINM. & ±0·1 m) ON THE DETERMINATION OF TRIANGULATED GROUND POINTS CURVE # 7

SYSTEM CONSTRAINTS RESULTS & ANALYSIS		CASE #					
CONSTRAINTS	UNITS	1	2	3	4	5	6
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 (W)	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 (0)	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 (k)	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 (MINIMUM)	NUMBER MINM.	— MINM.	— MINM.	— MINM.	— MINM.	— MINM.	— MINM.
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							

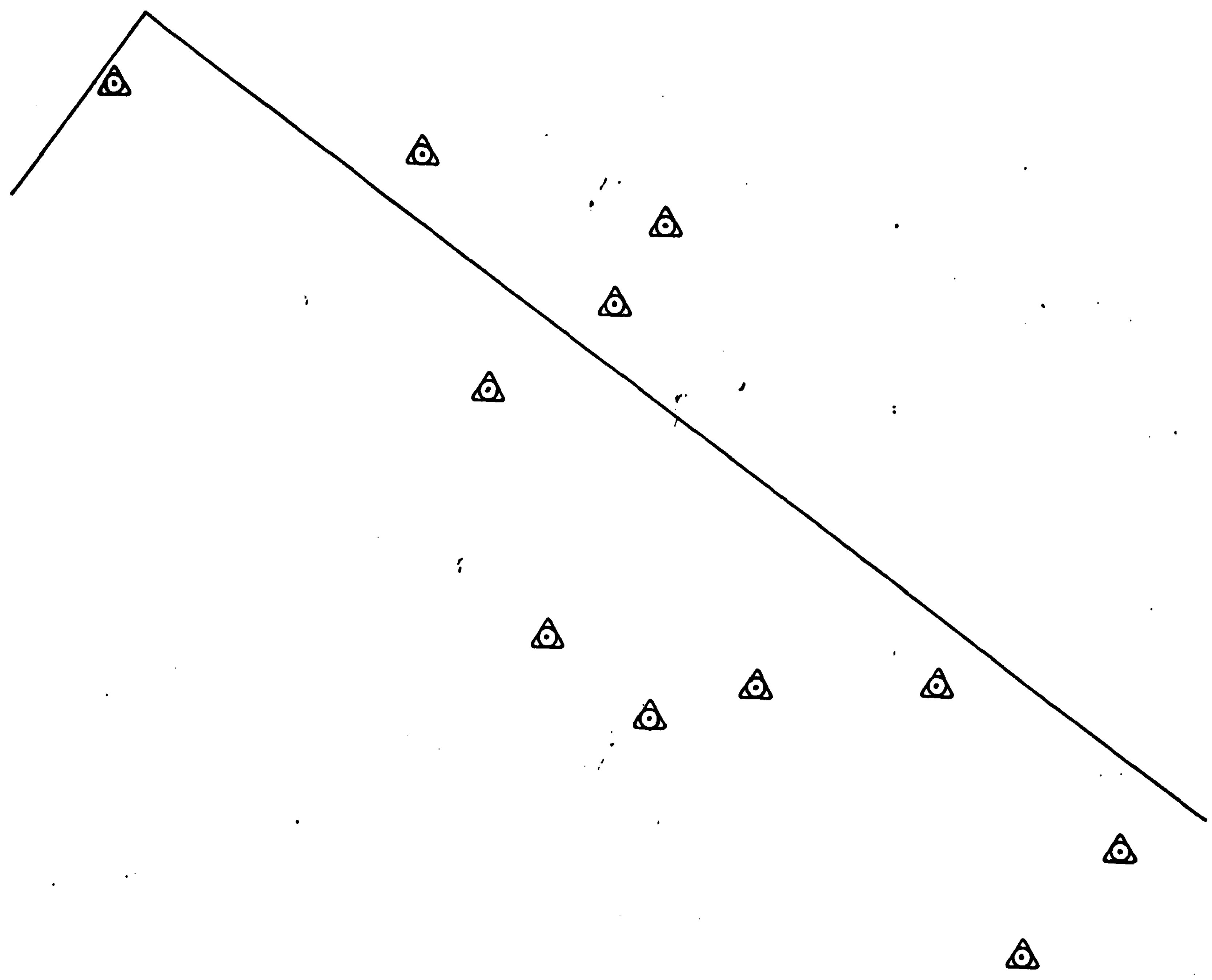
*SF - SCALE FACTOR = 755,000
+M - AVG. S.D. (ELEV. OR PLAN.)
**S.D. - STANDARD DEVIATION

NOTE: BLOCK TRIANGULATION: 22 LFC FRAMES
COMPUTER PROGRAM USED: "GIANT"

FIG 1 - LFC COVERAGE.

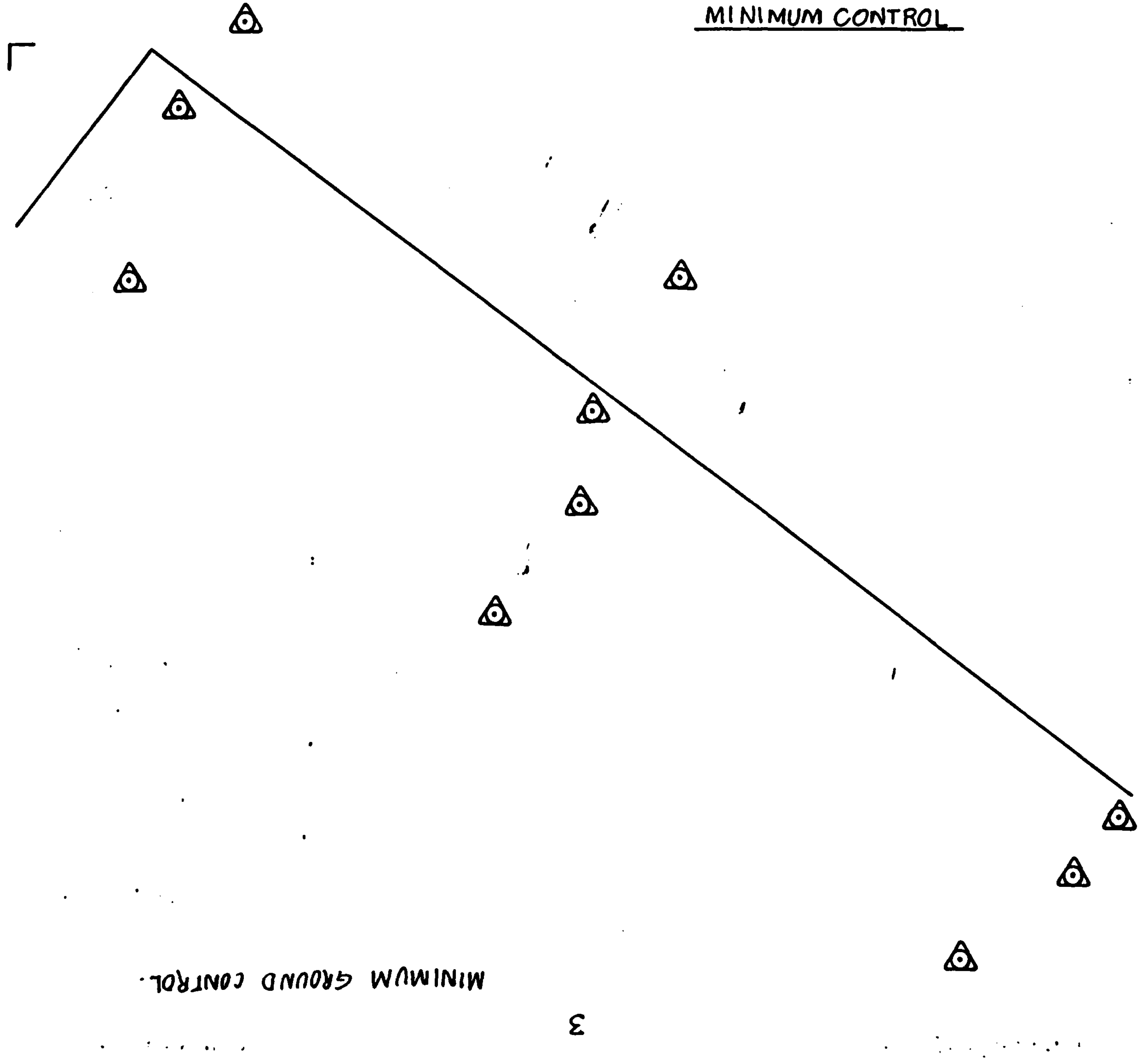


2. EXISTING CONTROL



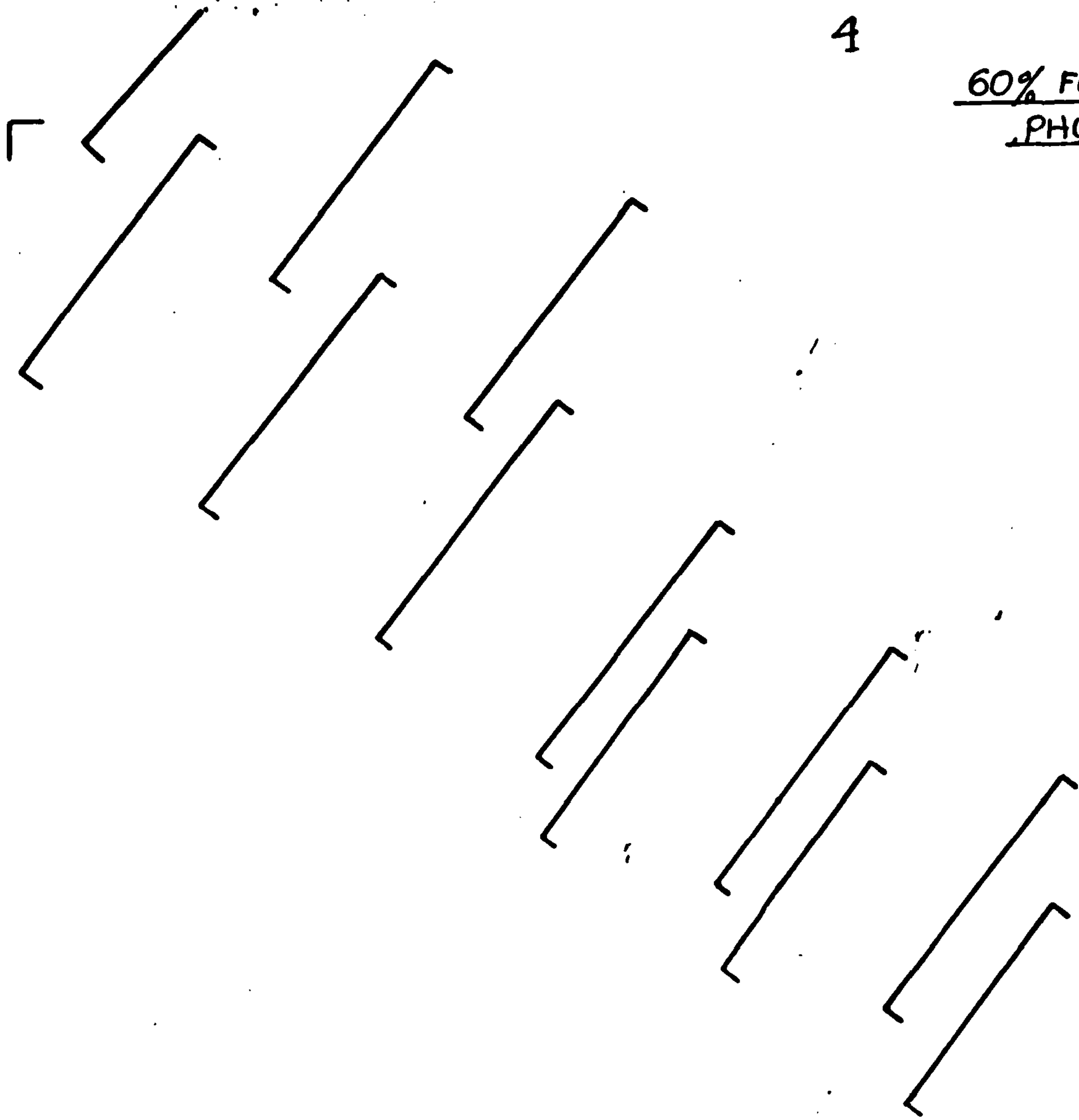
3

MINIMUM CONTROL

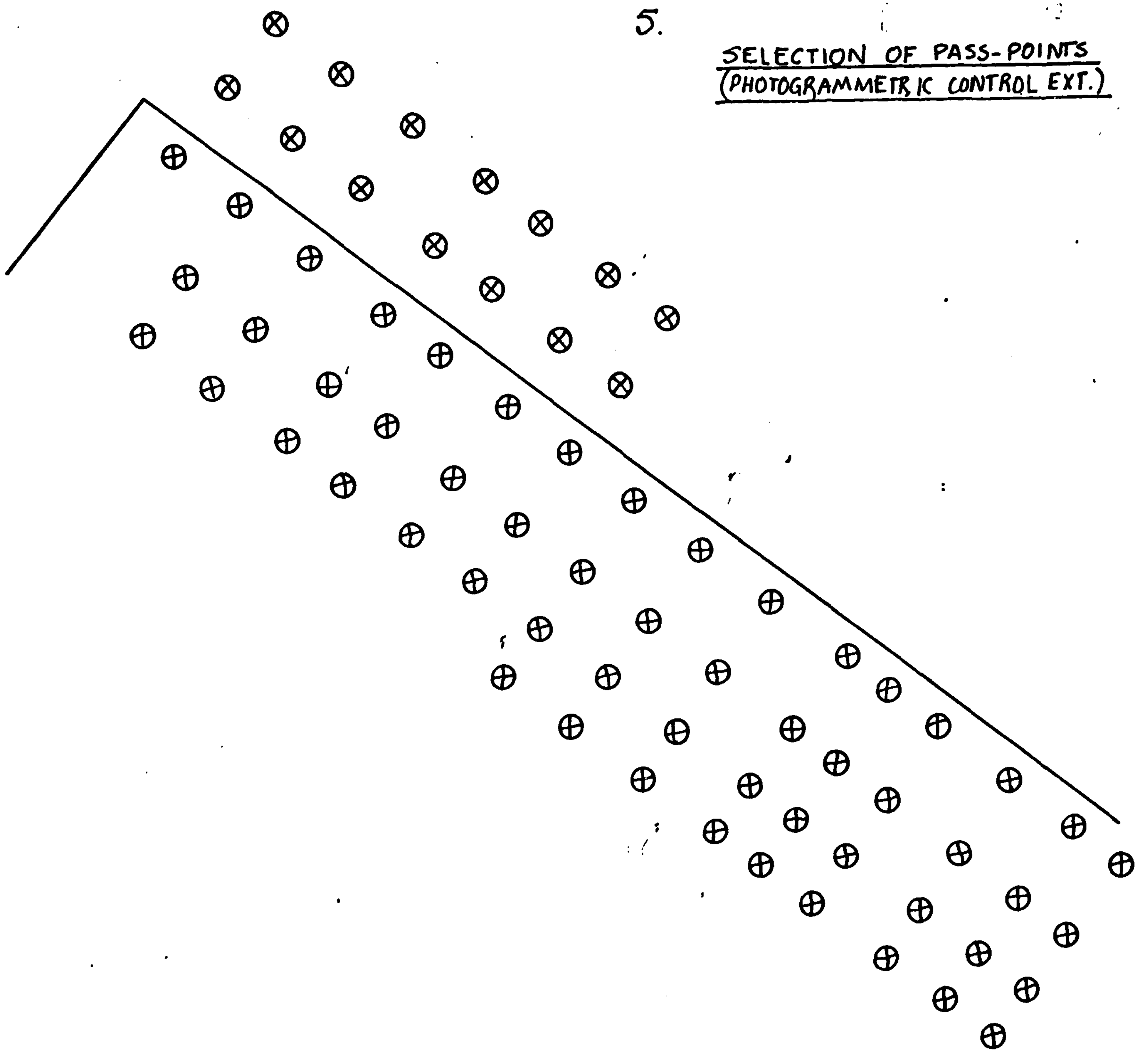


4

60% FORWARD OVERLAP PHOTOGRAPHY



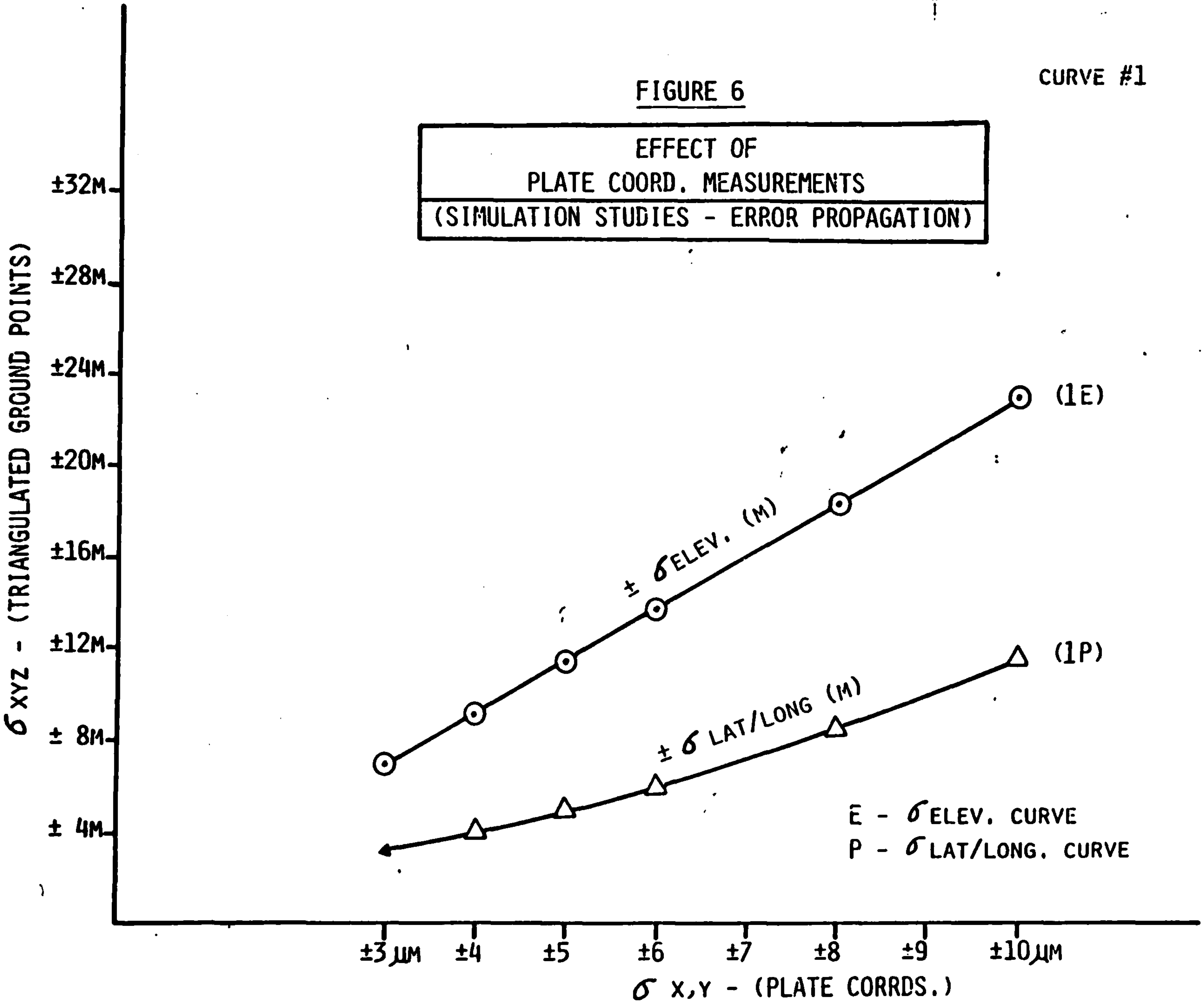
5. SELECTION OF PASS-POINTS (PHOTOGRAMMETRIC CONTROL EXT.)



CURVE #1

FIGURE 6

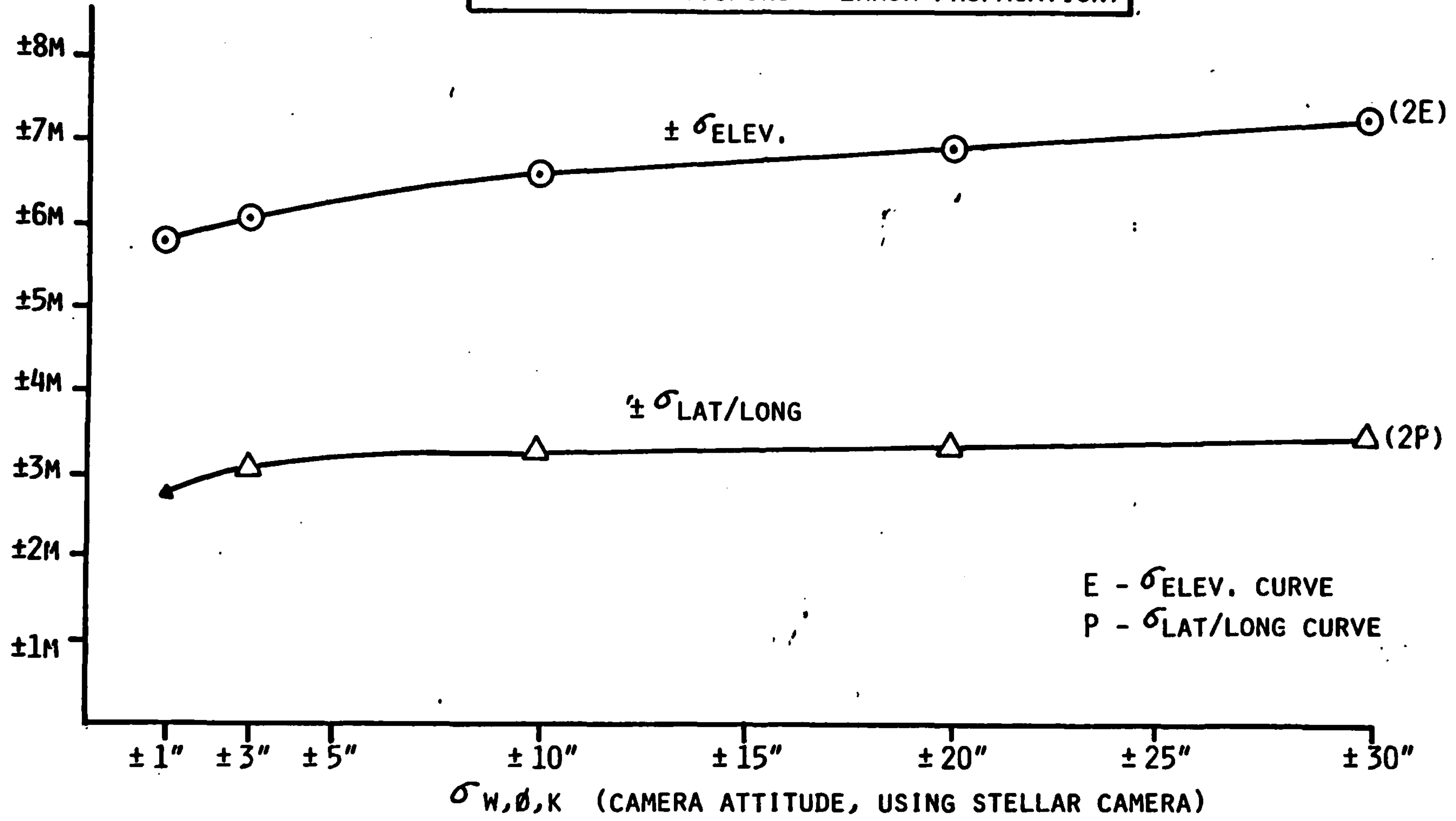
EFFECT OF
PLATE COORD. MEASUREMENTS
(SIMULATION STUDIES - ERROR PROPAGATION)



CURVE #2

FIGURE 7

EFFECT OF
CONSTRAINTS ON CAMERA ATTITUDE
(USING STELLAR CAMERA)
(SIMULATION STUDIES - ERROR PROPAGATION)



CURVES #3 & 4

FIG #8

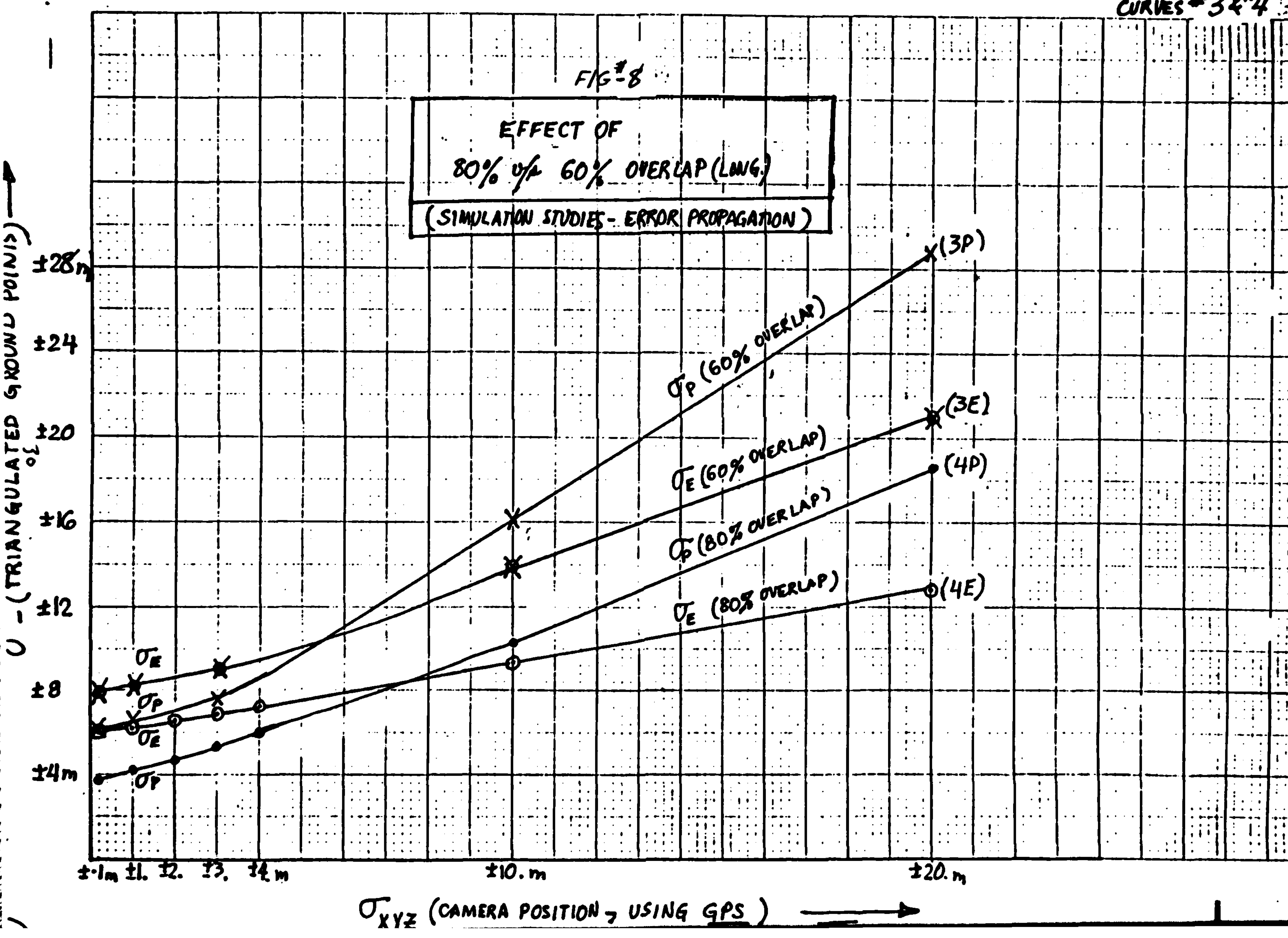
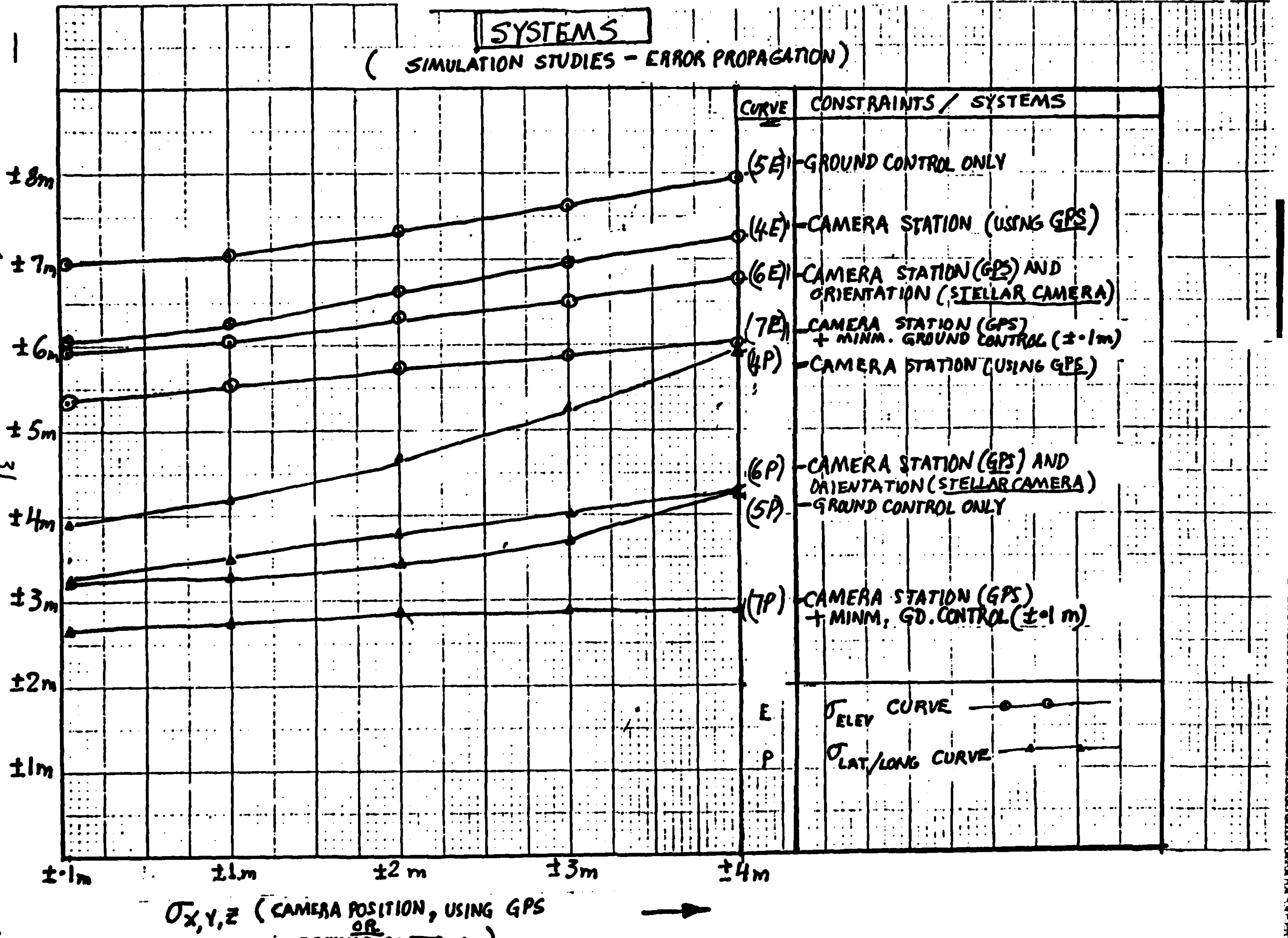


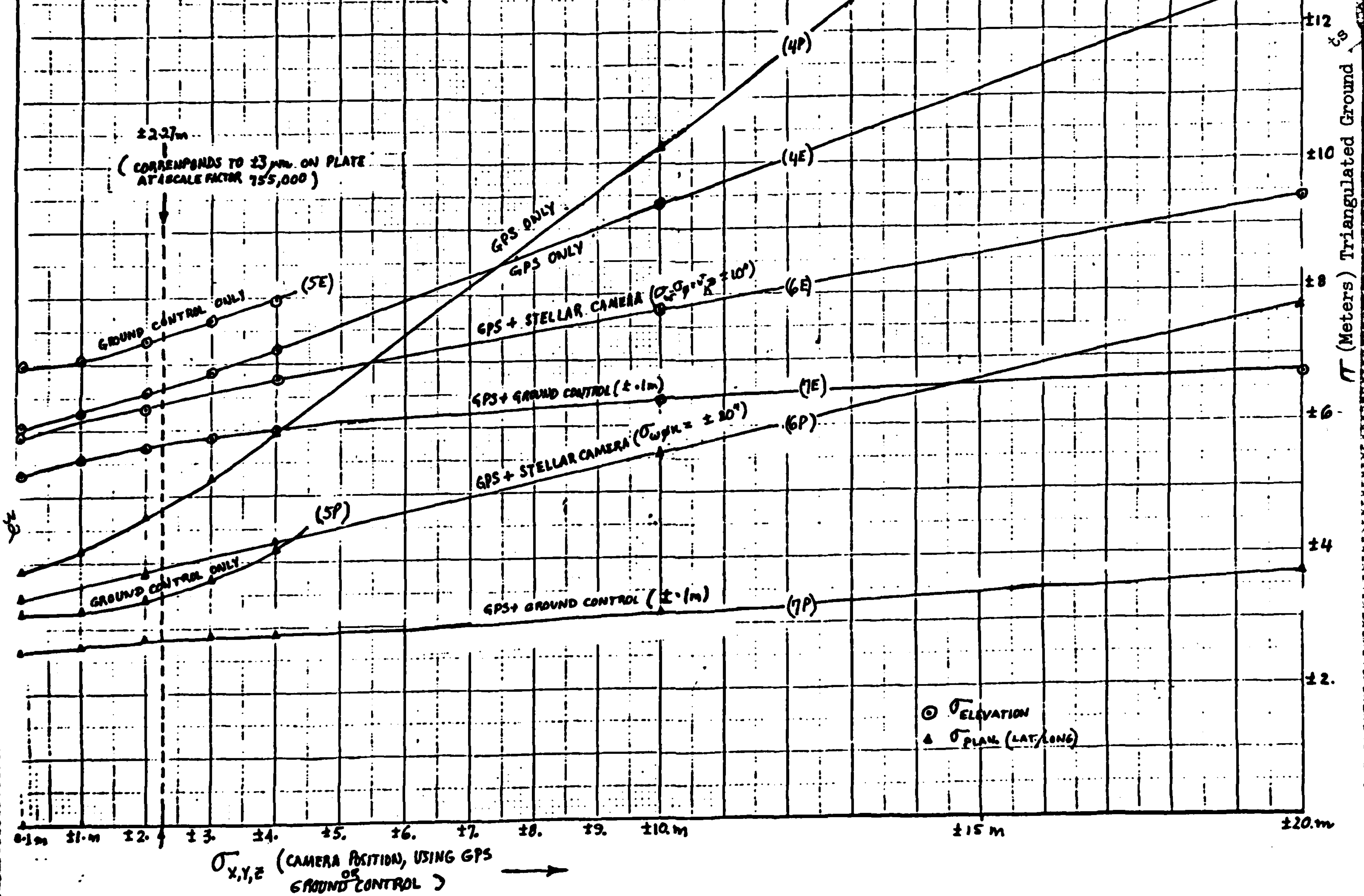
FIG-#9


SYSTEMS
(SIMULATION STUDIES - ERROR PROPAGATION)
CURVE
CONSTRAINTS / SYSTEMS
(5E) - GROUND CONTROL ONLY
(4E) - CAMERA STATION (USING GPS)
(6E) - CAMERA STATION (GPS) AND ORIENTATION (STELLAR CAMERA)
(7E) - CAMERA STATION (GPS) + MINM. GROUND CONTROL (±·1m)
(4P) - CAMERA STATION (USING GPS)
(6P) - CAMERA STATION (GPS) AND ORIENTATION (STELLAR CAMERA)
(5P) - GROUND CONTROL ONLY
(7P) - CAMERA STATION (GPS) + MINM. GD. CONTROL (±·1 m)
E σ ELEV CURVE
P σ LAT/LONG CURVE
±8m
±7m
±6m
±5m
±4m
±3m
±2m
±1m
(TRIANGULATED GROUND POINTS)
±·1m
±1m
±2 m
±3m
±4m
σ X,Y,Z (CAMERA POSITION, USING GPS OR

FIG—#10

SYSTEMS

(SIMULATION STUDIES – ERROR PROPAGATION)



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17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
08	02		photogrammetric triangulation; LFC (Large Format Camera); NOSAP; GIANT; GPS; Stellar Camera

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

In this paper, the potentials of a Large Format Camera (LFC) photography are explored specifically for the putpose of carrying out photogrammetric control extension. This study is based on the error propagation analysis in photogrammetric triangulation of a block of 22 LFC frames, having an approximate scale of 1:755,000 and taken during the October "84 Shuttle Mission 41-G.

A study of error propagation in photogrammetric triangulation of the block of 22 LFC frames was carried out for several simulated cases, representing various present and future systems of data acquisition and reduction. In these simulated cases, the geometric configuration of the block of photographs was obtained from the triangulation solution, using the existing ground control and the plate coordinates, measured on the National Ocean Service Analytical Plotter (NOSAP). Further, the block triangulation

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the parameters; such as, plate coordinated, camera position attitude, and ground control, in order to simulate a certain system. General Integrated Analytical Triangulation (GIANT) program was used for error propagation and block triangulation computations.

The results of the study are shown graphically as error curves for each of the simulated systems. The best results are achievable when the Geodetic Positioning System (GPS), along with minimum ground control, is used in the LFC photography block triangulation. The stellar camera is also useful in conjunction with the Geodetic Positioning System, in areas where the ground control is not available for use in the block triangulation. Average standard deviation of determination of coordinates of triangulated ground points can be as good as $\pm$ 2.7 meters (planimetry) and $\pm$ 5.4 meters (elevation). These correspond to $\pm$ 3.5 micrometers (planimetry) and $\pm$ 7.2 micrometers (elevation) at the photo scale.

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