

SIMULATION STUDY FOR
INTEGRATING GPS-CONTROL AND INFRARED PHOTOGRAPHY
IN AEROTRIANGULATION FOR SHORELINE MAPPING

Dr. Roop C. Malhotra
Nautical Charting Research and Development Laboratory
Nautical Charting Division, Coast and Geodetic Survey
National Ocean Service, NOAA
Rockville, MD 20852

ABSTRACT

The National Ocean Service (NOS) is primarily responsible for the shoreline mapping of the United States of America. The usual source for photogrammetric compilation of shoreline maps is 1:50,000 scale color photography taken with 60 percent longitudinal and 30 percent lateral overlap. Further, there is an increasing demand for using infrared photography in precision shoreline delineation to supplement shoreline obtained from color photography. Also, with the advent of the Global Positioning System (GPS), it is now possible to carry out aerotriangulation with minimum ground control. Economical and efficient procedures are being sought at NOS for the acquisition of color and infrared photography, and for the utilization of GPS and ground control in precision aerotriangulation for shoreline mapping. Recommendations on these aspects are being made, based on an aerotriangulation simulation study. National Map Accuracy Standards (NMAS), as well as the map accuracy requirements set for shoreline mapping by the Coast and Geodetic Survey (C&GS) of NOS, are considered.

Key Words: Aerotriangulation, Shoreline Mapping, Simulation Study, Global Positioning System, Color Photography, Infrared Photography, Map Accuracy Standards.

INTRODUCTION

Shoreline represents the line of contact between the land and a selected water elevation. In areas affected by tidal fluctuations, the mean high water line is the shoreline, shown on U.S. Geological Survey (USGS) topographic maps and NOS nautical charts. In confined coastal waters of diminished tidal influence, the mean water level line may be used. In areas of marsh grass, cypress or other similar marine vegetation, the shoreline is often obscured and cannot be mapped. In these areas, an apparent shoreline is mapped at the point where the line of vegetation is a definite line above mean high water. Sections of shoreline, which cannot be delineated with reasonable accuracy, are approximately delineated as unsurveyed shoreline.

The shoreline of the United States stretches 95,000 miles. It is composed of an outer coast, offshore islands, sounds, bays, rivers of navigable water areas, and Great Lakes. Of this total, 27,000 miles have never been surveyed photogrammetrically. Coastal maps and nautical charts contain graphic representation of shoreline, alongshore natural and man-made features, and a narrow zone of natural and man-made features inland from the shore.

Early shoreline maps were based on topographic surveys performed with a plane table and alidade. Now, aerial photographs and photogrammetric techniques are used almost exclusively to survey the shoreline and topographic details. All registered maps compiled digitally will have the prefix "DM," representing a digital data set as well as a graphic stable base reproduction of the digital data set. In all mapping projects, photography must be acquired at scales appropriate to satisfy aerotriangulation and feature delineation requirements. In shoreline mapping projects, the spectral reflectance characteristics of water, land, and the sea or lake bed must also be considered and used to advantage. Different film emulsions are sensitive to different ranges of the light spectrum. Infrared light, for example, is reflected by dry land and almost completely absorbed by water. For this reason, tide-coordinated infrared photography is used where distinct definition of low and high water lines are

required. The majority of NOS shoreline or coastal maps are at 1:20,000 scale which are derived from 1:50,000 scale aero-color photography. Black and white infrared photography is now being used more and more to supplement shoreline delineation obtained from color photography.

ACCURACY CONSIDERATIONS

Aerotriangulation, densification and extension of ground control from photographs, is a necessary step in photogrammetric compilation of shoreline maps. It is accomplished by fully analytical methods and first-order stereoinstruments. The planimetric accuracy of nonelevated photo-control or discrete points, established by analytical methods, is estimated to be one part in 10,000 of the photographic flight height. The vertical accuracy results are closer to one part in 5,000 of the flight altitude (American Society of Photogrammetry 1980: 396). In aerotriangulation, photo-controls are established relative to the National Geodetic Reference System datums and local tide or water level datums.

Certain standards of map accuracy have been established for maps published by Federal Government agencies. In addition to the NMAS (American Society of Photogrammetry 1980: 372), the C&GS of NOS has established its own requirements (Superintendent of Documents 1949) for the horizontal accuracy of shoreline surveys of alongshore features. All shoreline surveys produced by it must meet these requirements.

National Map Accuracy Standards

The NMAS for shoreline maps at scales 1:20,000 or smaller implies (American Society of Photogrammetry 1980: 372):

No more than 10 percent of points tested shall be in error by more than 0.5 mm. These limits of accuracy apply in all cases to positions of well-defined points only. Well-defined points are those that are easily visible or recoverable on the ground, such as, monuments or markers, intersection of roads, corners of larger buildings or structures, and so forth.

Coast and Geodetic Survey Map Accuracy

According to C&GS accuracy requirements (Superintendent of Documents 1949):

"All photo (topo) stations, including landmarks, fixed aids to navigation, etc., shall be located within 0.3 mm (0.01 inch) of the correct geographic position as measured on the manuscript. All photo-hydro stations and well-defined points of detail shall be located within 0.5 mm (0.02 inch) of the correct geographic position as measured on the manuscript."

The statement that "All photo (topo) stations....," and "All photo-hydro stations and well-defined points..." necessarily enforces a higher level of confidence than the 90 percent used in NMAS. Evidently, from the above accuracy statements, the C&GS accuracy requirements are more stringent than the NMAS for shoreline maps.

The Largest Map Scale and the Aerotriangulated Ground Control

The largest map scale, which fulfills the C&GS horizontal accuracy requirement, may be computed by the following empirical rule:

A value of twice the computed circular accuracy (at 95 percent confidence level) of aerotriangulated ground points shall be used for computing the largest map scale that meets the C&GS horizontal accuracy requirements.

The largest map scale so determined will also meet NMAS for shoreline maps. The limiting factor for compiling a map at that large scale will be the ability of the photogrammetric system (including photography and human factors) to compile the required level of details for a shoreline map.

GPS IN AEROTRIANGULATION

Optimum accuracy in conventional aerotriangulation requires photo-identifiable ground control around the perimeter of the area at intervals of about seven air bases or photographs, and precise survey elevation control in the center of the area. The task of establishing photo-identifiable ground control points is less labor and time intensive than ever before using GPS technology. Prior to the availability of GPS, flight-line paths and photographic coverage were often compromised to accommodate existing ground control. With GPS receivers, ground control can now be placed wherever needed for maximum photographic coverage and mapping accuracy. New ground control can be placed in areas previously considered too remote for cost-effective ground survey.

Another application of GPS technology in aerotriangulation is the use of GPS-controlled photography. Camera exposure stations have been determined with a submeter accuracy by keeping one GPS receiver on board the aircraft and another one on a known ground point during a photographic flight mission (Lucas 1989). The information of GPS-determined antenna position at the instant of photographic exposure is utilized in the aerotriangulation data reduction. It has been demonstrated that in a block of aerial photographs, taken from an altitude of 6000 ft above the ground at a speed of 200 mph, GPS-controlled photography can yield aerotriangulation points to an accuracy of 5 cm (Lapine 1991).

In shoreline mapping, usually single strips of photographs are flown along the shoreline. As it would be evident, a single strip of photographs, controlled only by the GPS-determined exposure station positions, cannot be used for aerotriangulation for the simple reason that the entire system of intersecting collinear rays can be rotated on an axis formed by the GPS-determined exposure stations. A minimum of two ground control points per strip will be required unless block photography is acquired. Some field work will be required to provide GPS-determined ground control points in projects using single strips of GPS-controlled photography. As an alternative, it may be logical to fly a block of at least two strips of GPS-controlled photographs to save on time and money spent in providing even the minimal of two ground control points per strip, required in single strips of photographs. Significant savings can be realized due to the elimination of field work involved for provision of minimal ground control points in GPS-controlled aerotriangulation. Also, such an aerotriangulation can be carried out in remote areas previously avoided due to lack of ground control, and for large mapping projects in which the cost of provision of ground control points made the operation too costly (Lapine 1991).

INFRARED PHOTOGRAPHY

For a distinct definition of low and high water lines, tide-coordinated infrared photography may be used to advantage to supplement shoreline information from color photography, commonly used in shoreline mapping. As a standard procedure, infrared photography may be obtained simultaneously along with color photography in a photographic mission. Two aerial photographic cameras, mounted side by side in an aircraft, may be used to obtain desired photography in two different emulsions, color and infrared. Due to two different emulsions, there are difficulties viewing a stereomodel formed from a stereopair of color and infrared photographs during compilation. On the other hand, stereoscopic viewing of color or infrared stereopairs is relatively easy.

SIMULATION STUDY

The objective of the simulation study is to determine a practical procedure for acquiring infrared and color photography for a shoreline mapping project. The effect of GPS technology on shoreline mapping, especially on the photographic mission and aerotriangulation, is also investigated.

In this study, the simulation cases of aerotriangulation cover:

- o Two extreme scales of photography, 1:50,000 and 1:12,000;
- o Two procedures of photography, tandem and staggered, for obtaining color and infrared photography in a single mission; and
- o Two procedures of aerotriangulation, one based on only the ground control and the other based on the GPS-controlled photography with minimum ground control points.

The effect of additional vertical control points (available along shoreline) on the results of aerotriangulation of GPS-controlled photography is also studied as a special case in shoreline mapping. (See table 1.)

The General Integrated ANalytical Triangulation (GIANT) program (Elassal and Malhotra 1991) is used for the data reduction purposes.

Photography

The two procedures of photographic missions with two cameras (one for color and the other for infrared photography) are: (1) the tandem photographic procedure (fig. 1) in which synchronous exposures are taken from the two cameras, and (2) the staggered photographic procedure (fig. 2) in which photographs are taken alternately with the two cameras. Photographs in a block are taken with 60 percent longitudinal overlap and 30 percent side overlap. In the case of staggered photography, 60 percent longitudinal overlap between two successive color or two successive infrared photographs results in 80 percent overlap between a color and adjacent infrared photographs (fig. 2).

In the simulation study, the photographic mission for the GPS-controlled photography is flown over a known ground control point, at or near the airport. This results in a patch of stereocoverage of the ground control point by a photo-block of two strips with at least two photographs per strip in both infrared and color photography. This patch of stereocoverage helps in the solution of the three components of the distance between the camera and the GPS antenna. In addition to this patch, the remote area of interest is then photographed by either a single strip or a block of two strips of photographs. (See sketches in table 1.)

Simulation Data and Data Reduction

Simulation data for each case of aerotriangulation (table 1) is obtained by a specially written software, giving three out of four data files required by the GIANT program used for data reduction. These files are the ground control data file, image coordinates measurement data file, and a data file for the GPS-determined antenna positions at the instant of photographic exposures. The fourth data file required by the GIANT program is interactively created while executing GIANT. This file contains all of the control parameters for an aerotriangulation solution by the GIANT program.

Table 1 shows some of the control parameters in the top part of the table. It may be observed that the precision of GPS-determined positions is based on poor GPS satellite geometry and use of the carrier phase. Higher precisions are, of course, possible. The number and distribution of ground control points used in each case are also shown in the table. The aerotriangulation results for each case give the standard deviation values of longitude, latitude, and elevation averaged over all the ground triangulated points. The three components, ΔX , ΔY , and ΔZ (in the plate coordinate system), of the distance between the antenna and the camera node or exposure station are also obtained in study cases where GPS-controlled photographs are used. Their values and the standard deviation of determination are also shown in the table.

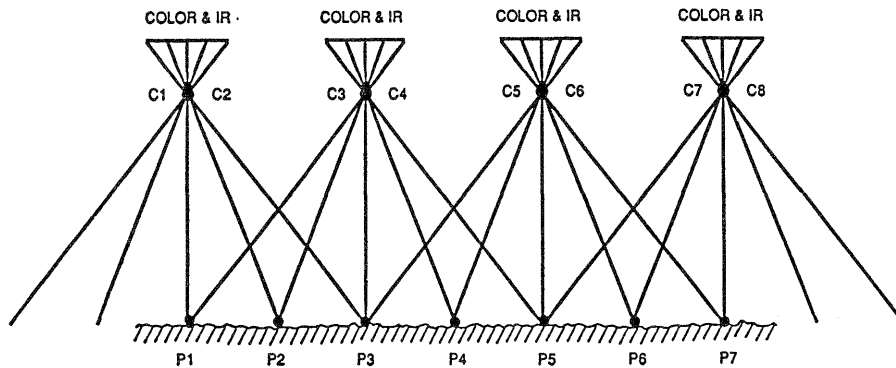


Figure 1.--Tandem photography for aerotriangulation.

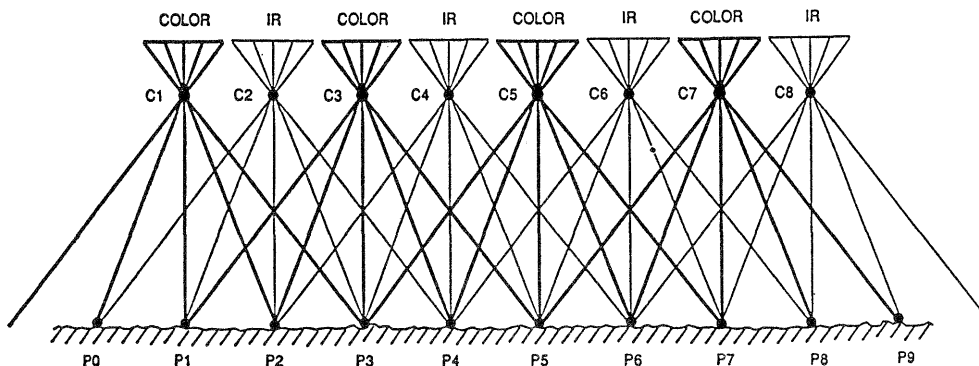


Figure 2.--Staggered photography for aerotriangulation.

CONCLUSIONS BASED ON THE RESULTS OF THE SIMULATION STUDY

The following are some of the generalizations and conclusions from the results of the simulation study shown in table 1:

Accuracies Achieved, Compilation Scales, and the Effect of Forward Motion Compensation (FMC) Device in a Camera

The best aerotriangulation accuracies are achieved by the conventional aerotriangulation with sufficient ground control. In the study cases, provision is made for one horizontal control point every fifth photograph and one vertical control point every other photograph in a strip of photographs. However, the results obtained by the GPS-controlled photographs in a strip or a block were found accurate enough to meet the C&GS horizontal accuracy standard of 0.3 mm at manuscript scales of 1:20,000 or smaller.

The above statement can be substantiated by the following computations. Standard deviations in longitude and latitude of ± 0.02 second of arc (approximately ± 0.6 m) or better were achieved in all cases (cases 1 to 10 in table 1) of aerotriangulation with 1:50,000 scale photography at the location of the test area. The circular accuracy at 95 percent confidence level works out to be ± 1.5 m (Harter 1960). As per the procedure described above, the largest scale of the map with discrete points within twice the circular error (± 3.0 m on the ground or ± 0.3 mm at map scale) is 1:10,000 to meet the C&GS map accuracy requirements. The corresponding map scale, which will meet the NMAS, is 1:8,000. Thus, the C&GS map accuracy requirement is more stringent than the NMAS. Also, depending on the ability of the photogrammetric system to compile the level of details required by the scale of the map, 1:50,000 scale photography will be able to support map scales 1:10,000 or smaller.

Standard deviations in longitude and latitude of ± 0.01 second of arc (approximately ± 0.3 m) or better were achieved in all cases (cases 11 to 16 in table 1) of aerotriangulation with 1:12,000 scale photography at the location of the test area. The circular error at 95 percent confidence level works out to be ± 0.7 m and the largest scale of the map with discrete points within twice the circular error (± 1.5 m on the ground or ± 0.3 mm at map scale) is 1:5,000 to meet the C&GS map accuracy requirements. The corresponding map scale which will meet the NMAS is 1:4,000. Thus, 1:12,000 scale photography will support map scales 1:4000 or smaller which will meet the C&GS requirements as well as NMAS, provided the photogrammetric system has the ability to compile the level of details required by the scale of the map.

In conclusion, the GPS-controlled 1:50,000 scale photography will be able to support map scales of 1:10,000 or smaller, and the GPS-controlled 1:12,000 scale photography will be able to support map scales of 1:5,000 or smaller from the point of view of C&GS requirements as well as NMAS for shoreline mapping. Clearly, the GPS-controlled 1:50,000 scale photography is amply adequate to map 1:20,000 scale shoreline maps.

The FMC device in a camera will be a major contributor in improving the image definition. This will enhance the ability to give higher pointing precision, as well as enable compilation of a higher

level of detail from the same scale of photography. This will result in planning for yet a smaller scale photography than required for photography without the FMC device in the camera. The number of photographs required to cover a project will reduce, thereby further economizing the mapping process.

Conventional Versus GPS-Controlled Aerotriangulation

Under the constraints of the simulation study, the precision of ground triangulated points determined by the conventional aerotriangulation method is definitely higher than the precision obtained in the corresponding cases of GPS-controlled aerotriangulation. This is substantiated by the comparison of case 1 versus case 2; case 3 versus 4; case 5 versus case 6; case 8 versus case 9; case 11 versus case 12; and case 14 versus case 15 (table 1).

Tandem Versus Staggered Photographic Mission

Tandem photography gives higher precision compared to staggered photography in all three coordinates, especially in the vertical coordinate, in both the conventional and GPS-controlled aerotriangulation cases. This is substantiated by the comparison of 1:50,000 scale photography cases: case 3 versus case 1; case 4 versus case 2; case 8 versus case 5; case 9 versus case 6; case 10 versus case 7 (table 1); and similarly by comparison of 1:12,000 scale photography cases (table 1).

Effect of Additional Vertical Control Points

In all GPS-controlled cases, it is also observed that additional vertical ground control increases the accuracy appreciably in the elevation of aerotriangulation points. This is substantiated by the comparison of the following cases: case 7 versus case 6; case 10 versus case 9; case 13 versus case 12; case 16 versus case 15 (table 1).

Single Strip of GPS-Controlled Photography

It may be also be noted that a single strip of GPS-controlled aerotriangulation is possible only with some ground control, which can be well distributed vertical ground control points, separated as much as possible in a lateral direction to the flight line of photography (Lapine 1991). This is demonstrated by cases 2 and 4 (table 1).

RECOMMENDATIONS

From the simulation cases studied, certain recommendations are being made to optimally obtain infrared and color photographs in a single mission for an efficient and economical aerotriangulation to support compilation of shoreline maps.

The GPS-controlled tandem color and infrared vertical photography, with a patch of stereophoto coverage of at least one known ground control point (which may also be used by the ground based GPS receiver), is a desirable photographic acquisition procedure. This will also photographically cover all the ground control points required in the GPS-controlled aerotriangulation. However, in case of a single strip of vertical photographs, there is an additional requirement of vertical control points along the strip so positioned as to be far removed from the nadir points of the photographs. As a general recommendation, whenever possible, additional vertical ground control points must be

included in any aerotriangulation process. In shoreline mapping, it may be easily possible to locate vertical ground control points along a well-defined shoreline.

In the simulation study, the usual aerotriangulation, based on ground control, yields higher precision than from the aerotriangulation of GPS-controlled photography. However, it has been amply shown in the study that the GPS-controlled 1:50,000 scale photography will support shoreline mapping at 1:20,000 scale to meet the horizontal accuracy requirements set by C&GS as well as those of NMAS.

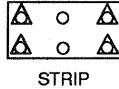
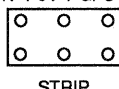

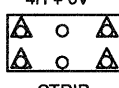
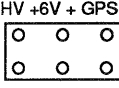

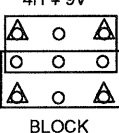
It is recommended that the tandem procedure of photographic acquisition be adopted if for any reason infrared and color photographs are used in a stereopair during compilation of shoreline maps. The reason being it results in a higher aerotriangulation precision than that obtained from the corresponding cases of staggered photography. The obvious explanation for this is the stronger geometry due to higher base:height ratio in the tandem case (60 percent) than in the staggered case (80 percent). One can also take advantage of the fact that the positions of both cameras are associated with a single GPS antenna observation in the tandem case.

From the discussion on the accuracy requirements, it is recommended that for shoreline maps at 1:20,000 or smaller scales, photography may be flown at a higher altitude than required to obtain 1:50,000 scale photography, provided the level of detail for the map being compiled is supported by the photography.

The limiting factors for the selection of the scale of photography are the accuracy standards and the level of detail supported by the photography for the compilation of the desired map. The FMC device in a camera further improves the pointing accuracy as well as the ability to capture a higher level of detail from a certain scale of photography. This encourages reducing the scale of photography further, so as to economize on a project, due to a lesser number of stereomodels to be processed for the same area coverage and map scale.

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PHOTOGRAPHY					OBSERVATIONS & ADJUSTMENT PARAMETERS								
CAMERA F.L. = 6" (152.4 mm) SCALE = 1:50,000 FLYING HT. = 7,720 m GD. ELEV. = 100 m EMULSION = IR & COLOR OVERLAP (LONG.) = STAGGERED 80% / TANDEM 60% (SIDE) = STAGGERED 30% / TANDEM 30%					GPS-ASSISTED AEROTRIANGULATION							IMAGE $\sigma_x, \sigma_y = \pm 5$ microns GROUND $\sigma_x, \sigma_y = \pm 0.01$ sec (LAT, LONG) $\sigma_z = \pm 0.30$ m (ELEV) GPS $\sigma_x, \sigma_y = \pm 0.01$ sec (LAT, LONG) $\sigma_z = \pm 0.30$ m (ELEV)	
CASE NO.	BLOCK TYPE	PHOTOS PER STRIP	TOTAL PHOTOS	GROUND CONTROL HOR. VERT. Δ \circ	GPS CONTROL (Y/N)	TRIANGULATION RESULTS (GROUND POINTS)						CAMERA NODE* TO ANTENNA $\Delta X, \Delta Y, \Delta Z$ (METERS)	
						RMS #pts	LONG \pm sec	RMS #pts	LAT \pm sec	RMS #pts	ELEV \pm m		
1.	STAGGERED STRIP	6 (I-RED) 6 (COLOR)	12	4H + 6V  STRIP	NO	37	0.01	37	0.01	33	0.60	-	
2.	STAGGERED STRIP	6 (I-RED) 6 (COLOR)	12	1HV + 6V + GPS  STRIP	YES	62	0.02	62	0.02	57	0.75	$\frac{\Delta X}{0.7 \pm .2}$	
	PATCH	2x2 (I-RED) 2x2 (COLOR)	8	 PATCH								$\frac{\Delta Y}{1.7 \pm .6}$ $\frac{\Delta Z}{-1.4 \pm .2}$	
3.	TANDEM STRIP	6 (I-RED) 6 (COLOR)	12	4H + 6V  STRIP	NO	30	0.01	30	0.01	26	0.48	-	
4.	TANDEM STRIP	6 (I-RED) 6 (COLOR)	12	1HV + 6V + GPS  STRIP	YES	47	0.02	47	0.02	42	0.59	$\frac{\Delta X}{0.7 \pm .2}$	
	PATCH	2x2 (I-RED) 2x2 (COLOR)	8	 PATCH								$\frac{\Delta Y}{1.2 \pm .7}$ $\frac{\Delta Z}{-1.3 \pm .2}$	
5.	STAGGERED BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	4H + 9V  BLOCK	NO	56	0.02	56	0.02	53	0.74	-	

(*NOTE: Camera nodes of IR and color photography coincide in the simulation. In reality, they are two separate nodes.)

TABLE 1

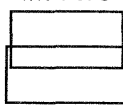

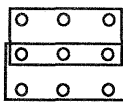

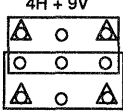


PHOTOGRAPHY

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 SCALE = 1:50,000
 FLYING HT. = 7,720 m
 GD. ELEV. = 100 m
 EMULSION = IR & COLOR
 OVERLAP (LONG.) = STAGGERED 80% / TANDEM 60%
 (SIDE) = STAGGERED 30% / TANDEM 30%

GPS-ASSISTED AEROTRIANGULATION

OBSERVATIONS & ADJUSTMENT
PARAMETERS

IMAGE $\sigma_x, \sigma_y = \pm 5$ microns
 GROUND $\sigma_x, \sigma_y = \pm 0.01$ sec (LAT, LONG)
 $\sigma_z = \pm 0.30$ m (ELEV)
 GPS $\sigma_x, \sigma_y = \pm 0.01$ sec (LAT, LONG)
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						RMS	LONG	RMS	LAT	RMS	ELEV	
						#pts	\pm sec	#pts	\pm sec	#pts	\pm m	
6.	STAGGERED BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	1HV + GPS 	YES	85	0.02	85	0.02	85	0.84	ΔX 0.9 \pm .5
	PATCH	2x2 (I-RED) 2x2 (COLOR)	8									ΔY 1.2 \pm .4 ΔZ -1.3 \pm .3
7.	STAGGERED BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	1 HV + 9V + GPS 	YES	85	0.02	85	0.02	78	0.74	ΔX 1.7 \pm .5
	PATCH	2x2 (I-RED) 2x2 (COLOR)	8									ΔY 1.2 \pm .5 ΔZ -1.3 \pm .2
8.	TANDEM BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	4H + 9V 	NO	48	0.01	48	0.01	45	0.40	-
9.	TANDEM BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	1HV + GPS 	YES	70	0.02	70	0.02	70	0.75	ΔX 0.8 \pm .5
	PATCH	2x2 (I-RED) 2x2 (COLOR)	8									ΔY 1.2 \pm .5 ΔZ -1.4 \pm .3

(*NOTE: Camera nodes of IR and color photography coincide in the simulation. In reality, they are two separate nodes.)

TABLE 1 (cont.)

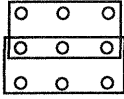

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GPS-ASSISTED AEROTRIANGULATION

**OBSERVATIONS & ADJUSTMENT
PARAMETERS**

IMAGE $\sigma_x, \sigma_y = \pm 5$ microns
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CASE NO.	BLOCK TYPE	PHOTOS PER STRIP	TOTAL PHOTOS	GROUND CONTROL HOR. Δ VERT. \circ	GPS CONTROL (Y/N)	TRIANGULATION RESULTS (GROUND POINTS)						CAMERA NODE* TO ANTENNA $\Delta X, \Delta Y, \Delta Z$ (METERS)
						RMS	LONG	RMS	LAT	RMS	ELEV	
						#pts	\pm sec	#pts	\pm sec	#pts	\pm m	
10.	TANDEM BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	1 HV + 9V + GPS 	YES	70	0.02	70	0.01	61	0.57	ΔX .7 \pm .5
	PATCH	2x2 (I-RED) 2x2 (COLOR)	8	 PATCH								ΔY 1.2 \pm .5 ΔZ -1.3 \pm .2

(*NOTE: Camera nodes of IR and color photography coincide in the simulation. In reality, they are two separate nodes.)

TABLE 1 (cont.)

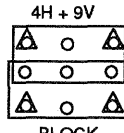
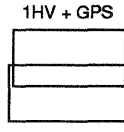

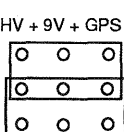

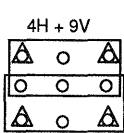
PHOTOGRAPHY

CAMERA F.L. = 6" (152.4 mm)
 SCALE = 1:12,000
 FLYING HT. = 1,928 m
 GD. ELEV. = 100 m
 EMULSION = IR & COLOR
 OVERLAP (LONG.) = STAGGERED 80% / TANDEM 60%
 (SIDE) = STAGGERED 30% / TANDEM 30%

GPS-ASSISTED AEROTRIANGULATION

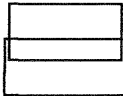

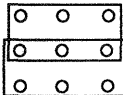

OBSERVATIONS & ADJUSTMENT
PARAMETERS

IMAGE $\sigma_x, \sigma_y = \pm 5$ microns
 GROUND $\sigma_x, \sigma_y = \pm 0.01$ sec (LAT, LONG)
 $\sigma_z = \pm 0.30$ m (ELEV)
 GPS $\sigma_x, \sigma_y = \pm 0.01$ sec (LAT, LONG)
 $\sigma_z = \pm 0.30$ m (ELEV)

CASE NO.	BLOCK TYPE	PHOTOS PER STRIP	TOTAL PHOTOS	GROUND CONTROL HOR. Δ VERT. \circ	GPS CONTROL (Y/N)	TRIANGULATION RESULTS (GROUND POINTS)						CAMERA NODE* TO ANTENNA $\Delta X, \Delta Y, \Delta Z$ (METERS)
						RMS	LONG	RMS	LAT	RMS	ELEV	
						#pts	\pm sec	#pts	\pm sec	#pts	\pm m	
11.	STAGGERED BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	 BLOCK	NO	62	0.01	62	0.01	57	0.25	-
12.	STAGGERED BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	 BLOCK	YES	91	0.01	91	0.01	91	0.32	$\frac{\Delta X}{0.7 \pm .42}$
	PATCH	2x2 (I-RED) 2x2 (COLOR)	8	 PATCH								$\frac{\Delta Y}{1.2 \pm .39}$
13.	STAGGERED BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	 BLOCK	YES	91	0.01	91	0.01	82	0.29	$\frac{\Delta X}{0.7 \pm .42}$
	PATCH	2x2 (I-RED) 2x2 (COLOR)	8	 PATCH								$\frac{\Delta Y}{1.2 \pm .39}$
14.	TANDEM BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	 BLOCK	NO	54	0.01	54	0.01	49	0.23	-

(*NOTE: Camera nodes of IR and color photography coincide in the simulation. In reality, they are two separate nodes.)

TABLE 1 (cont.)

PHOTOGRAPHY						OBSERVATIONS & ADJUSTMENT PARAMETERS											
CAMERA F.L. = 6" (152.4 mm) SCALE = 1:12,000 FLYING HT. = 1,928 m GD. ELEV. = 100 m EMULSION = IR & COLOR OVERLAP (LONG.) = STAGGERED 80% / TANDEM 60% (SIDE) = STAGGERED 30% / TANDEM 30%						GPS-ASSISTED AEROTRIANGULATION						IMAGE $\sigma_x, \sigma_y = \pm 5$ microns GROUND $\sigma_x, \sigma_y = \pm 0.01$ sec (LAT, LONG) $\sigma_z = \pm 0.30$ m (ELEV) GPS $\sigma_x, \sigma_y = \pm 0.01$ sec (LAT, LONG) $\sigma_z = \pm 0.30$ m (ELEV)					
CASE NO.	BLOCK TYPE	PHOTOS PER STRIP	TOTAL PHOTOS	GROUND CONTROL		GPS CONTROL (Y/N)	TRIANGULATION RESULTS (GROUND POINTS)						CAMERA NODE* TO ANTENNA $\Delta X, \Delta Y, \Delta Z$ (METERS)				
				HOR. Δ	VERT. \circ		RMS #pts	LONG \pm sec	RMS #pts	LAT \pm sec	RMS #pts	ELEV \pm m					
15.	TANDEM BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	1HV + GPS 		YES	75	0.01	75	0.01	75	0.29	ΔX 0.7 \pm .46				
	PATCH	2x2 (I-RED) 2x2 (COLOR)	8	 BLOCK PATCH									ΔY 1.2 \pm .39 ΔZ -0.6 \pm .61				
16.	TANDEM BLOCK	2x6 (I-RED) 2x6 (COLOR)	24	1 HV + 9V + GPS 		YES	75	0.01	75	0.01	66	0.24	ΔX 0.7 \pm .46				
	PATCH	2x2 (I-RED) 2x2 (COLOR)	8	 BLOCK PATCH									ΔY 1.2 \pm .39 ΔZ -0.7 \pm .16				

(*NOTE: Camera nodes of IR and color photography coincide in the simulation. In reality, they are two separate nodes.)

TABLE 1 (cont.)