AN ACCURACY STUDY ON A LARGE AIRBORNE GPS AERO TRIANGULATION BLOCK

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ABSTRACT

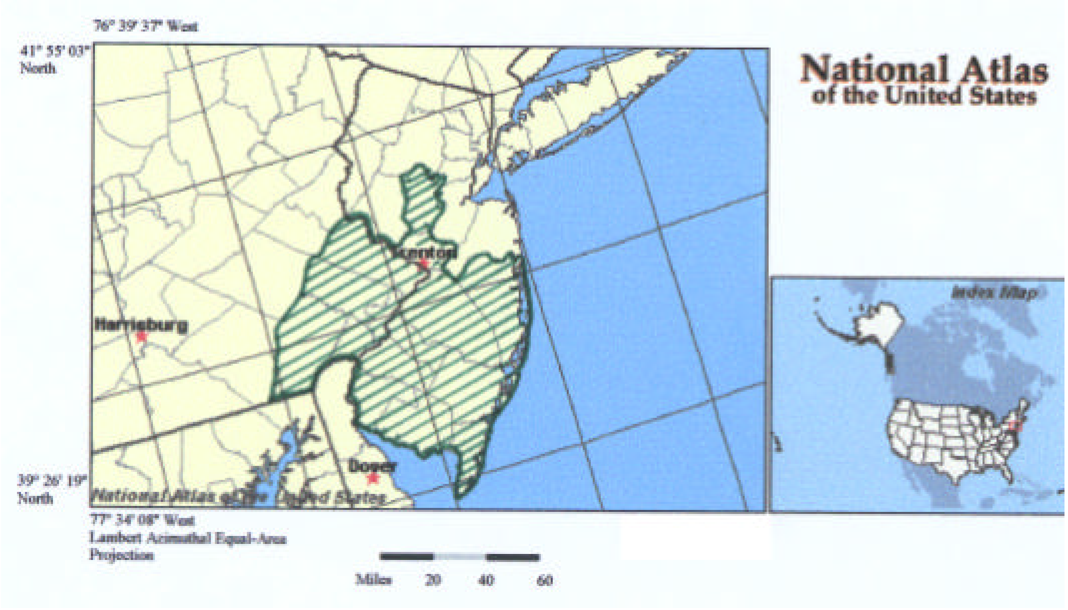
A large irregular shaped aero triangulation block containing 5,101 images, for which the projection centers have been determined by relative kinematics GPS-positioning, with 175 ground control points distributed over 112 flight strips including 18 cross strips, 81 check points evenly distributed over the entire covered area of approximately 20,500 km^2, and 15,455 tie points, was flown at a scale 1:19,200 (1"=1600'), observed and adjusted for the Delaware Valley Regional Planning Commission (DVRPC) in the United States of America. The objective was to gather up-to-date information in terms of digital orthophotographs and digital maps for the regular activities of the Commission. The approach being followed for planning, flight execution, observations, combined simultaneous rigorous adjustment, the obtained results (i.e., internal and external accuracy), the statistical analysis of the results for different control patterns, covariance analysis, elimination of systematic effects, will be described.

1. INTRODUCTION

In November 1999, the Delaware Valley Regional Planning Commission (DVRPC) commissioned BAE SYSTEMS ADR the realization of an aerial Survey Project with the objective of gathering new up-to-date topographic information for its daily activities. The aerial photography covering an area of approximately 20,500 Km^2 (Fig.1) at scale 1”=1600’ (1:19,200) took place during March 2000. The aerial photography was subcontracted with Key Stone Aerial Surveys that carried out the photography mission using Airborne GPS (ABGPS) data acquisition. The project area was covered using four airplanes equipped with Wide Angle Photogrammetric Cameras (Leica RC30) and real time kinematic (RTK) Airborne GPS equipment (Trimble SST4000). Due to several reasons the aerial photography was done on February 29, March 4, 5, 6, 27 and April 1, 2000, in a total of 50.013 hours between the four airplanes, in 12 AGPS Sessions, with a Mean Session Time of 4.168 hours. Two fixed based stations with known coordinates were used. The distance among them was such that to assure an optimal solution for all instantaneous GPS 3D vectors between the base-fixed station and the rover (GPS antenna in the airplane), that means less than 100 Km. One fix station was located in the North

Philadelphia Airport and the second station, depending on the area been flown in the southern tip of Cape May or in the northern zone of Somerset County (New Jersey).

Fig. 1. DVRPC – PROJECT AREA



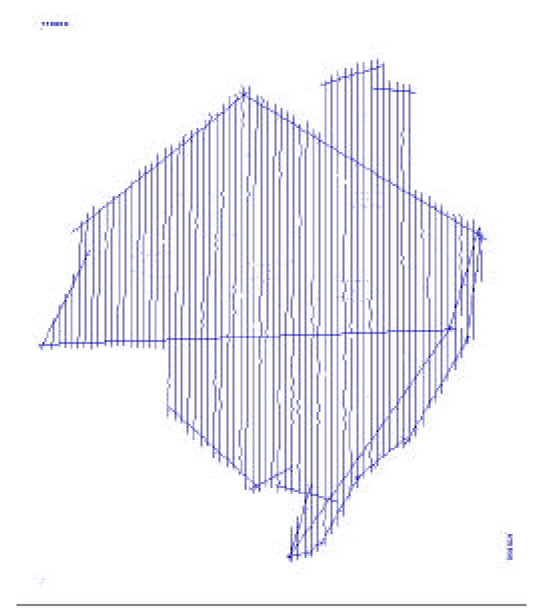


Fig. 2 configuration of flight lines

The area was covered with a total of 5,501 images, flown with 60% longitudinal and 30% lateral overlap, distributed in 112 North-South flight strips and 18 cross strips (Fig. 2). A total of 175 targeted Ground Control Points (GCPs) and 81-targeted randomly distributed checkpoints were GPS Ground Surveyed with computed final coordinates in the New Jersey State Plane Coordinates over NAD83 and orthometric heights NAVD88.

The original developed negatives were scanned with 15 microns pixel size on the LH Systems DSW 500 scanner. The Photogrammetric Observations were done using BAE SYSTEMS Socet Set™. The Simultaneous Combined Bundle Block Adjustment was done using the Program System BLUH of the University of Hannover of Germany. This included Gross Error Detection and Elimination strategies such as Baarda's Data Snooping and during adjustment Robust Estimators. Further, Systematic Effects on the ABGPS data were analyzed, modeled and filtered before and during the adjustment process through self-calibration procedures.

Systematic errors in the image coordinate data were also eliminated with the use of additional parameters. The Reliability, Geometrical Stability and Statistical Significance of the Additional Parameters have been tested and accordingly the additional parameters automatically selected by the same program systems BLUH. This was done based on the outcomes of a t-test on correlation and cross-correlation coefficients. The adjusted results (i.e., exterior orientation parameters, adjusted tie points and up-dated Socet Set Support Files) were imported back to Socet Set for further photogrammetric operations.

In addition to the actual photogrammetric project, the ABGPS Aerial Triangulation Combined Bundle Block was used for research purposes in order to study the effect of several combinations of geometric parameters on the final accuracy of the adjusted block, while using real data on a very large irregular shaped block. In this sense the effect of different Ground Control Pattern / Distribution on the Internal and Absolute Accuracy of the Block, on the ability to detect and eliminate systematic effects (Shift & Drift) on the Airborne GPS data, on the overall deformation of the block due to the remaining systematic effects, on the statistical distribution of residuals, etc. have been investigated and reported herein. Further, the effects on the use (or not) of central block cross strips, the tie points pattern between adjacent models, the number and distribution of tie points between cross strips and block strips have been also investigated.

2. EXPERIMENTAL TEST AND RESULTS

The effects of different patterns of Ground Control distribution over the final accuracy and over the ability of the mathematical model to correctly handle the different types of observations (i.e., image data, AGPS data and Ground Control data) were investigated. Thus, the following cases were studied:

CASE FULL: All available GCPs (175) located on the cross strips and inside the block were used
CASE II: Only GCPs located in the cross strips. Total Number of GCPs=113
CASE III: Only pairs (One in front of the other) of GCPs located in the cross strips. Total Number of GCPs=85
CASE IV: Staged GCPs along the cross strips. Total Number of GCPs=65
CASE V: Only 2 GCPs at each end of cross strips. Total Number of GCPs=46
CASE VI: Only one GCP at each end of cross strip. Total Number of GCPs=22

Tables 1 and 2 below report the arrived accuracy results in terms of Standard Deviation, RMSE over GCPs, Checkpoints, and ABGPS adjusted coordinates of Projection Centers (PCs).

DVRPC. GCPs PATTERNS AND ACCURACY RESULTS								
GCPs Pattern	No. of GCPs	GCPs [ft]		ABGPS [ft]		AGPS/Rel. Diff.[ft]		σ_o
		RMSP	RMSEZ	RMSEP	RMSEZ	RMSEP	RMSEZ	μm
FULL	175	0.35	0.36	1.23	0.40	0.80	0.37	7.39
CASE II	113	0.30	0.37	1.23	0.40	0.81	0.38	7.35
CASEIII	85	0.27	0.36	1.22	0.40	0.81	0.37	7.33
CASE IV	65	0.30	0.37	1.22	0.42	0.82	0.39	7.32
CASE V	46	0.31	0.34	1.23	0.43	0.83	0.4	7.33
CASE VI	22	0.26	0.38	1.24	0.45	0.84	0.41	7.33

RMSP = root mean square of RMSX and RMSY

Table 1

DVRPC. GCPs PATTERNS AND ACCURACY RESULTS				
GCPs Pattern	RMSE on CHKPTs [ft]		MAX. ERRORS on CHKPTs	
	RMSEP	RMSEZ	MAX ΔP	MAX ΔZ
FULL	1.01	0.75	1.80	1.12
CASE II	1.02	0.75	1.83	1.15
CASEIII	1.01	0.83	1.84	1.38
CASE IV	1.03	0.83	2.03	1.61
CASE V	1.04	0.80	2.21	1.68
CASE VI	0.99	0.80	2.28	1.71

Table 2

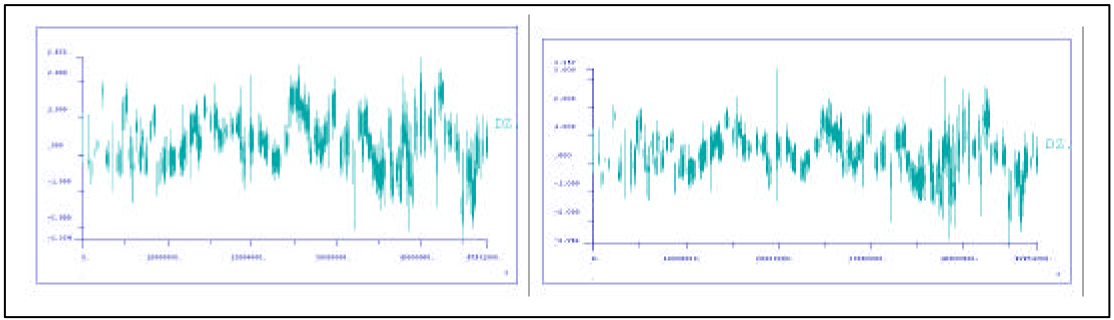
Table 1 and 2 clearly shows that in an ABGPS simultaneous combined Bundle Block adjustment the effect of the number and distribution of GCPs plays no significant roll in the final accuracy of the aerial triangulation. One clearly sees that GCPs located inside the block do not contribute significantly to the achievable accuracy (i.e., results of CASE=FULL versus others). The internal accuracy of the block remains almost constant, i.e., no apparent change of the standard deviation. The largest significant variation of the RMSE over GCPs is less than 20% for Planimetry and 10% for height. The ABGPS data after adjustment are also quite stable both in absolute and relative discrepancies. The absolute accuracy measured in terms of discrepancies at checkpoints it is not significantly affected by the number and distribution of GCPs, especially for the presence of GCPs inside the block (i.e., CASE=FULL versus others). The largest variations of the maximum errors on checkpoints are less than 0.5’ for Planimetry and 0.59’ for height.

It is also known that due to system errors the RTK ABGPS data do have systematic errors that their effects should be eliminated (or minimized) during block adjustment. This depends among others, on the comprehensiveness of the mathematical model of the block adjustment program and on the number and distribution of GCPs. Program Systems BLUH is one of the most comprehensive and advanced Simultaneous Bundle Adjustment Systems. Table 3 Shows for different control pattern, the difference of adjusted coordinates of the projection centers versus the given ABGPS data. Also after shift and drift corrections and polynomial filtering.

ABGPS SYSTEMATIC EFFECTS AND GCPs DISTRIBUTION [feet]										
GCPs Pattern	RMSD (RMS Diff)		RMSD-SHIFT		RMSD –(SH+DRFT)		POLYNOMIAL FILTER			
							T*T		T*T*T	
	sp	sz	sp	sz	sp	sz	sp	sz	sp	sz
FULL	1.67	0.79	1.27	0.27	1.27	0.28	1.11	0.28	1.12	0.28
CASE II	1.59	0.81	1.27	0.28	1.26	0.27	1.11	0.29	1.12	0.28
CASE III	1.70	0.85	1.57	0.41	1.55	0.41	1.63	0.35	1.60	0.35
CASE IV	1.68	0.86	1.64	0.49	1.66	0.51	1.58	0.49	1.59	0.50
CASE V	1.68	0.87	1.66	0.57	1.65	0.60	1.59	0.58	1.60	0.59
CASE VI	1.69	0.81	1.66	0.67	1.67	0.67	1.62	0.65	1.62	0.65

Table 3

Table 3 shows that if the ABGPS systematic effects are precisely modeled in the Bundle Block Adjustment (i.e., self calibration through additional parameters), the effect of the control pattern plays not a significant role. It is only necessary that the minimum number and distribution of the GCPs (i.e., one point on each extreme of cross strips) be assured and the systematic effects of the ABGPS data can be efficiently removed (or minimized). In case of the DVRPC block, table 3 shows also that there is no linear time depending drift among the ABGPS data (i.e., compare columns RMSD-SHIFT and RMSD –(SH+DRFT)). The filtering effect of higher order polynomial is not significant also in this case (Compare columns T*T and T*T*T of table 3 above). Figures 3 shows also that the removal of the ABGPS systematic is not mainly dependent on the control distribution pattern.



(a) (b)

Figure 3 discrepancies at projection centers Z as function of flight time

Figure 3 (a) represents the CASE=FULL (i.e., all GCPs in the cross strips and inside the block, 175 GCPs) and Figure 3 (b) corresponds to the minimum number and distribution of GCPs (i.e., only one point on each cross strip end, 22 GCPs). In both cases (Figure 3a and 3b) the discrepancies DZ between adjusted vertical coordinates of the Projection Centers and the raw ABGPS data follows the same pattern. The same can be shown in relation with the planimetric discrepancies.

One of the frequently asked questions is whether accuracy results are different if for the cross strips ABGPS are not acquired. Table 4 shows the answer.

GCPS & ABGPS	GCPs [ft]		AGPS [ft]		AGPS Rel. Diff		St. Dev.
	RMSP	RMSZ	RMSP	RMSZ	RMSP	RMSZ	σo
(1)	0.35	0.36	1.23	0.40	0.80	0.37	7.39
(2)	0.32	0.31	1.19	0.38	0.80	0.35	7.21

Table 4
influence of ABGPS in cross strips (1)=with (2)=without

(1) Means CASE FULL and all cross strips with ABGPS data. (2) is CASEFULL but all cross strips without ABGPS data. One can clearly see that that there is no apparent difference between both solutions, i.e., as long as the cross strips are well controlled, the contribution of their ABGPS data to the final accuracy is not relevant. On the contrary without ABGPS data on the cross strips results are slightly better. This is because the system has less constraint to get accommodated to the reference frame.

CASE	RMS [ft]			max.diff. at check points [ft]			σo
	RMSE	RMSN	RMSZ	DE	DN	DZ	μm
(1)	0.26	0.23	0.36	1.28	1.27	1.12	7.4
(2)	0.26	0.23	0.35	1.35	1.41	1.58	8.0
(3)	0.33	0.35	0.46	2.12	2.42	3.01	8.3

Table 5 (Results at Control and Checkpoints)

Another question is in relation to the use of the center block cross strip and the final accuracy. Tables 5 and 6 include statistics from different adjustment scenarios.
(1) Represents CASE FULL
(2) is no ABGPS data in center block cross strip and (3) no center block cross strip at all

Solution Diff.	RMSE [ft]		Max Diff [ft]		Sys Diff [ft]		No Sys Dif	
	RMSP	RMSZ	DXY	DZ	SYSP	SYSZ	RMSP	RMSZ
(1)-(2)	0.11	0.19	1.3	1.86	0.015	0.004	0.11	0.196
(1)-(3)	0.15	0.32	1.71	2.71	0.016	0.005	0.15	0.32

Table 6
differences of adjusted tie points

. Table 5 shows that the absence of ABGPS data in central block cross strip do not degrade the arrived accuracy, both in terms of internal and absolute accuracy (i.e., compare statistics at GCPs, at check points and standard deviation). But the total absence of control (i.e., no central cross strip at all and corresponding GCPs) in the center part across of the block degrade the accuracy of up to 80% in Planimetry and 168% in height (see maximal differences at check points), whereas the accuracy lost at GCPs is 37% in Planimetry and 27% in height. The internal accuracy is kept stable with no apparent variation of the standard deviation. Table 6 shows the statistics related with the difference of the 3 sets of adjusted tie points according to the 3 different solutions. The quoted statistics shows the same trend. This means that even the ABGPS data have systematic effects such as shift and linear time dependent drifts, those are not totally systematic or better say, they do not follow the same pattern or sign along a very lengthily strip. So there is a need of ground control or a cross strip to break the line and to control better in such a way the ABGPS systematic errors. Such a problem can be caused by a not optimal ambiguity solution of the GPS computation.

Another factor that can affect the arrived accuracy is the number and distribution of tie points between block strips and cross strips. With modern digital matching this should not be a problem, but the rate of success of matching tie points between bundle of rays belonging to different photo strips depends of many factors, being one of the most critical is the presence of vegetation as it is the case of the wooded area of the DVRPC project. Failure of matching requires to resort to manual operation with a considerably increase of production time and hence a lost of efficiency.

To assess the above mentioned possible lost of accuracy, 4 different cases (TP1, TP2, TP3 and TP4) of number of tie points between end model strip block and the corresponding cross strip model, have been investigated, i.e.:
TP1=All tie points of the cross strip are transfer to the block strip and vice versa.
TP2=only four common tie points, TP3=only two common tie points, TP4=one new common tie point per model. Tables 7 and 8 shows the effects on the accuracy results.

DVRPC. Cross and Block Strips Common Tie Points and Block Adjustment Results										
Tie Pts. Pattern	σ_o	RMS @ GCPs [ft]			RMS @ ABGPS [ft]			ABGPS Rel. Diff [ft]		
	µm	RMSE	RMSN	RMSZ	RMSE	RMSN	RMSZ	RMSE	RMSN	RMSZ
TP1	7.35	0.26	0.23	0.36	0.78	0.94	0.40	0.52	0.64	0.37
TP2	7.35	0.23	0.23	0.36	0.78	0.94	0.41	0.53	0.65	0.38
TP3	7.35	0.24	0.21	0.37	0.77	0.95	0.42	0.52	0.65	0.39
TP4	7.35	0.25	0.20	0.38	0.78	0.93	0.41	0.53	0.64	0.39

Table 7 effect of tie point distribution

Cross and Block Strips Common Tie Points and Block Adjustment Accuracy Results at Checkpoints							
Tie Point Pattern	σ_o	RMS @ check points [ft]			MAX. ERR. @ check points [ft]		
	µm	RMSE	RMSN	RMSZ	ΔX	ΔY	ΔZ
TP1	7.35	0.70	0.73	0.75	1.28	1.27	1.12
TP2	7.35	0.71	0.73	0.75	1.28	1.28	1.12
TP3	7.35	0.72	0.73	0.77	1.29	1.30	1.13
TP4	7.35	0.71	0.72	0.75	1.30	1.31	1.12

Table 8 effect of tie point distribution

Tables 7 and 8 shows that there is no degradation of the accuracy by using less number of tie points between block strip models and the corresponding model in the cross strip. As long as there are enough tie points between adjacent strips of the block only one good tie point between each last model block strip and the corresponding cross strip model is enough to provide control to be able to model and remove the systematic effects of the ABGPS data.

Another degrading factor of the accuracy of a Bundle Block is the number and distribution of tie points between models of adjacent strips. Their reduction in number degrades also the internal reliability and in the case of the ABGPS Bundle Blocks it can even more let systematic effects non-modeled and not removed. To study their effect on the arrived Bundle Block accuracy and on the ABGPS systematic effects the following cases have been investigated:

TPA0=general case, i.e., all models from adjacent strips are completely tighten
TPA1=each alternated model of two adjacent strips has at least one tie point
TPA2=each two alternated model of two adjacent strips have at least one tie point

TPA3=each three alternated model of two adjacent strips have at least one tie point
TPA4=each four alternated model of two adjacent strips have at least one tie point

Tables 9 and 10 show the arrived results:

tie point case	GCPs [ft]		ABGPS [ft]		σo
	RPSEP	RMSEZ	RPSEP	RMSEZ	µm
TPA0	0.35	0.36	1.23	0.40	7.39
TPA1	0.32	0.31	1.18	0.38	7.01
TPA2	0.29	0.28	0.94	0.35	6.44
TPA3	0.21	0.28	0.88	0.29	6.01
TPA4	0.18	0.17	0.69	0.28	5.88

Table 9
influence of number and distribution of tie points at control points and airborne GPS-values

In all studied cases the all-available (175) GCPs have been used. Table 10 shows an increase in the accuracy in terms of smaller RMSE both in GCPs and on the ABGPS adjusted data. Improvements in the range of 50% are gained between the general TPA0 and TPA4 case both for the GCPs and ABGPS adjusted data. The internal accuracy of the Block measured in terms of the a posteriori standard deviation (σo) shows better results. Improvements in the range of 22.5% are reported between the general case and case TPA4.

tie point case	RMS @ check points			max. diff. @ check points		
	RMSE	RMSN	RMSZ	DE	DN	DZ
TPA0	0.70	0.73	0.75	1.28	1.27	1.12
TPA1	0.81	0.77	0.90	1.41	1.33	1.35
TPA2	0.88	0.80	1.36	1.58	1.45	2.54
TPA3	0.93	0.88	1.58	1.72	1.63	2.88
TPA4	1.01	0.97	1.61	2.01	1.91	3.44

Table 10
influence of number and distribution of tie points at independent check points

Table 10 shows the actual reality, i.e., the external accuracy of the block gets degraded with a smaller number of tie points. The block gets deformed. In terms of RMS differences on check points there is a degradation of approximately 40% in plan and nearly 115% in height (see RMS at check points), with maximum degradations exceeding 90% for plan and almost three times for height when considering maximal differences at check points between tie points cases TPA0 and TPA4 (i.e., all possible tie points and each four alternated model of two adjacent strips have at least one tie point). The absence of tie points between corresponding models of adjacent strips contributes to the degradation of the absolute accuracy of the block. The block looses integrity, geometric strength and as a consequence systematic errors and blunders cannot be controlled any longer. The degradation is larger in height because the lack of controllability of the lateral tilt between neighboring adjacent models. Due to the decrease of constrains among data and their associated a priori standard deviation (or weight) the observations have more flexibility to get accommodated among themselves and into the model, rendering smaller residuals and apparently better accuracy. But the reality is that due to a relaxation on constrains, the mathematical model looses efficiency and effectiveness in the detection and elimination of systematic effects, the bundle block gets deformed.

differences of tie point cases	RMS of differences			maximal differences		
	RMSE	RMSN	RMSZ	DX	DY	DZ
TPA0-TPA1	0.12	0.15	0.32	0.51	0.46	1.21
TPA0-TPA2	0.33	0.25	0.65	1.27	1.15	1.88
TPA0-TPA3	0.47	0.42	0.88	1.39	1.33	2.45
TPA0-TPA4	0.51	0.48	1.01	1.59	1.48	3.12

Table 11 differences of the tie point cases at ground points

Table 11 shows the block deformations in terms of differences between coordinates of adjusted common points between the above different (PTAi) solutions. From Table 11 we can clearly see that the deformations of the blocks are more noticeable in height, with a maximum of more than 3 feet for bridging 4 or more consecutive models in adjacent strips without a single tie points.

Although the aerial photography block includes areas of Pennsylvania (see fig. 1) the simultaneous combined bundle block adjustments were carried out in the New Jersey State Plane Coordinate System. Moreover, as the block covers 20,500 km^2 it is necessary to take into consideration cartographic deformations due to extend of the covered area. Although the program systems BLUH has provisions to take this effect into consideration, it is advisable to perform the bundle block adjustment in a local coordinate system and to transform the resulting coordinates to the final cartographic systems to be used in the project. Table 12 and 13 reports the results of block adjustments of table 1. A GCP (196) located near the center of the block was the origin of the new coordinates system. Regarding the height coordinates of the GCPs, the same orthometric heights were used.

Block Adjustments Accuracy Results in a Local Coordinates System								
GCPs Pattern	No. of GCPs	GCPs		ABGPS		AGPS/Rel. Diff.		σ_o
		RMSP	RMSEZ	RMSEP	RMSEZ	RMSEP	RMSEZ	μm
FULL	175	0.31	0.36	1.08	0.40	0.73	0.37	7.39
CASE II	113	0.27	0.37	1.09	0.40	0.75	0.38	7.35
CASEIII	85	0.25	0.36	1.09	0.40	0.75	0.37	7.29
CASE IV	65	0.27	0.37	1.10	0.42	0.77	0.39	7.32
CASE V	46	0.28	0.34	1.08	0.43	0.75	0.4	7.38
CASE VI	22	0.25	0.38	1.09	0.45	0.75	0.41	7.33

Table 12 block adjustment in tangential coordinate system

Block Adjustments Accuracy Results in a Local Coordinates System				
GCPs Pattern	RMSE on check points [ft]		max. discrepancies on check points	
	RMSEP	RMSEZ	MAX ΔP	MAX ΔZ
FULL	0.89	0.74	1.63	1.12
CASE II	0.89	0.75	1.63	1.18
CASEIII	0.90	0.84	1.67	1.41
CASE IV	0.92	0.83	1.87	1.61
CASE V	0.93	0.85	1.97	1.71
CASE VI	0.89	0.81	2.03	1.70

Table 13 block adjustment in tangential coordinate system – results at check points

Table 12 and 13 shows an improvement in the planimetric accuracy. In general planimetric accuracy improvements between 10 to 12% can be verified from both

Tables. As expected, the internal accuracy measured in terms of the computed standard deviation do not show major significant variations. The use of a tangential local system, corresponding to the mathematical model of orthogonal coordinates, is to the purposes of a better fit to a reference frame; hence the internal relationship of image data should and has been respected.

One of the often asked question is in relation with the ability of the systems to detect and eliminate blunders and systematic errors when constrains and GCPs are eased. In our particular case when the number and distribution of GCPs within the block and on the cross strips are diminished or when no center block cross strip is used. Assuming a basic field of adjusted points with absence of gross and systematic errors, i.e., the above Case=FULL, it is important to compare this field of adjusted points versus other fields of points coming from bundle blocks adjustments where GCPs (or center block cross strip) have been reduced (or not used). The null hypothesis would be: *"No Errors (Gross and Systematic) are present in the observations"*. Then the differences of coordinates between the above basic FULL solution and each of the eased GCPs cases (or no center block cross strip) should fulfill the following conditions:

C1: all residuals should be distributed according to normal distribution $(0,\sigma_o)$
C2: residuals should be also distributed according to:

$C2\_1 = [-1.645\sigma_x < x-\mu_x < +1.645\sigma_x] = 90\%$
$C2\_2 = [-1.960\sigma_x < x-\mu_x < +1.960\sigma_x] = 95\%$
$C2\_3 = [-2.576\sigma_x < x-\mu_x < +2.576\sigma_x] = 99\%$ or:

$C2\_1' = [-\sigma_x < x-\mu_x < +\sigma_x] = 68.27\%$
$C2\_2' = [-2\sigma_x < x-\mu_x < +2\sigma_x] = 95.45\%$
$C2\_3' = [-3\sigma_x < x-\mu_x < +3\sigma_x] = 99.73\%$

With σ_x: standard deviation of the unit weight, and $(x-\mu_x)$ associated residuals, i.e., adjusted coordinates according eased GCPs case minus the adjusted coordinates from the FULL Case.

Intensive computations have been conducted to verify the above conditions; some are presented in Table 14.

Sol.Diff.	Statistic	$[-\sigma_x<x-\mu_x<+\sigma_x]$	$[-2\sigma_x<x-\mu_x<+2\sigma_x]$	$[-3\sigma_x<x-\mu_x<+3\sigma_x]$
FULL-CIII	$\sigma_x=0.274$	74.01%	95.75%	99.53%
	$\sigma_y=0.174$	74.37%	95.90%	99.62%
	$\sigma_z=0.327$	75.65%	95.77%	99.67%
FULL-CVI	$\sigma_x=0.372$	70.42%	95.51%	99.13%
	$\sigma_y=0.308$	68.91%	95.61%	99.17%
	$\sigma_z=0.346$	73.92%	95.58%	98.89%
No ABGPS in all cross strips	$\sigma_x=0.151$	83.22%	95.51%	99.01%
	$\sigma_y=0.131$	91.93%	95.55%	98.88%
	$\sigma_z=0.456$	90.33%	95.49%	98.41%
No center block cross strip & GCPs	$\sigma_x=0.157$	79.78%	94.45%	98.01%
	$\sigma_y=0.124$	86.22%	95.01%	98.11%
	$\sigma_z=0.271$	78.53%	93.89%	97.03%

Table 14 check for normal distribution

Table 14 clearly shows that in the majority of the cases the above conditions are fulfilled. Only in the case of no center block cross strip & GCPs the condition $[-3\sigma_x<x-\mu_x<+3\sigma_x] = 99.73\%$ is only marginally fulfilled, but still acceptable for the purposes of the block. This implies the presence of at least some systematic effects left in the observations, mainly in the ABGPS data. Several strip flight ended in the center cross strip and were continued in another GPS session. In those cases, in order to fully control, model and eliminate the ABGPS systematic errors it is necessary to have at least one control point at the end/beginning of each ABGPS Session (Model of the strip). This is provided by the center block cross strip. Its absence it is only partially substituted by tie points to other adjacent strips.

3. CONCLUSSIONS

Based on the above experimental test the following conclusions can be extracted:

1 Aerial triangulation bundle blocks supported with airborne real time kinematic GPS data requires GCPs located only on the cross strips. GCPs located inside the block do not substantially contribute to the accuracy of the bundle block

2 In general only two control points per cross strip located one on each strip end are enough for good stabilization and bundle block adjustment.

3 Large scale airborne GPS aero triangulation blocks for large-scale topographic mapping and / or engineering works may require additional control. Staged GCPs along the cross strips with a separation of no less than 10 models is sufficient.

4 Cross strips do not require to be supplemented with airborne GPS data. They fulfill their purpose (i.e., to provide control to each block strip end) even without ABGPS data. Results are totally comparable to the cases where cross strips are flown with ABGPS.

5 In general the systematic effects of ABGPS data (i.e., shifts, linear time dependent drifts) are better controlled, modeled and filtered with large number of GCPs, but

with the minimum number and distribution of GCPs in the cross strips, the filters render quite acceptable results (i.e., T*T & T*T*T polynomial fitting after shift + drift removal).

6 In large bundle blocks the central cross strips can be used without ABGPS data. The accuracy results of such a solution is fully comparable as if the block would have been adjusted including ABGPS data of the central block cross strip.

7 In large bundle blocks (DVRPC) depending upon the application and ABGPS flight strip session (See 8 bellow), the central block cross strip can be fully ignored, including the use of its GCPs in the adjustment. Nevertheless it is preferably its use to allow partial releases for production purposes.

8 Having the minimum configuration of GCPs (one GCP on each strip end) and the appropriate model for filtering, gross and systematic errors in the observations can be modeled and removed. Regarding the center block cross strips, its use is essential when ABGPS block strips ends over it and the strips is continued on another ABGPS Session. Through its use (or GCPs located at each end of each block strip) in a combined bundle block adjustment, the modeling and full elimination of systematic effects are guaranteed.

9 In relation with the number of tie points between end models of the block strips and the corresponding model in the cross strip, only one tie point is required to provide control for the removal of the ABGPS systematic effects.

10 Regarding tie points between neighbor block strips, it is convenient not to bridge more than one (maximum two) consecutive model without a tie point. Undesirable height differences can be found. Moreover, the easy on constrains may provoke the filter (lack of removal) of ABGPS systematic effects.

11 Substantial (10% or more) increase in the accuracy of a ABGPS bundle block can be accomplished by performing the adjustment in a local (tangential) coordinate system. This avoids the considerably cartographic projection effect that cannot be totally removed by the additional parameters.

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