Fully Analytical Aerial Triangulation Report
Kanawha County, WV
November 2008

DMC Color Aerial Photography at 5000' AGL

Surdex Corporation - Project Number 1800301

1 INTRODUCTION

This document contains a summary of the triangulation process that was performed for Kanawha County using the aerial photography acquired during March & April of 2008. The triangulation was performed as part of a project designed to produce a set of digital orthophotos, update 2' contours & planimetric data. The final products generated as a result of this project are summarized in Table 1.

Table 1
Product Summary

Orthophoto Scale	Ground Pixel Resolution (GPR)
1 in. = 100 ft.	0.5 ft.

1.1 ***Project Coordinate System and Units***

Horizontal coordinates for all final products for this project are to be referenced to the NAD 83 State Plane Coordinate system, West Virginia South zone, and expressed in U.S. survey feet.

Vertical coordinates for all final products are to be referenced to the NAVD 88 and expressed in U.S. survey feet.

2 GENERAL DESCRIPTION

The purpose of Aerial Triangulation (AT) in the photogrammetric production process is to establish the geometric relationship between the image exposed within the aerial sensor, i.e. each photograph, and a ground coordinate system. This relationship is composed of two primary mathematical components, traditionally referred to as Interior Orientation (IO) and Exterior Orientation (EO). The IO parameters define the mathematical relationship between coordinates on an individual exposed photograph and the sensor coordinate system. The EO parameters define the mathematical relationship between the camera coordinate system and the ground coordinate system.

When the source data for the photogrammetric production is digital imagery scanned from a film-based camera system, the interior orientation is established by taking precise measurements on the digital imagery using a series of fiducial marks. The coordinates of these fiducial marks in the camera coordinate system are typically established via a calibration procedure performed by the U.S.G.S. and documented in a camera calibration report. In softcopy photogrammetric production, the measurement process that supports interior orientation computations can be automated. This automated procedure requires only a small amount of manual operation, specifically to "train" the software as to the appearance of the fiducial marks on the digital image. Once the software has been trained, the only manual task involves initiating/monitoring the automated process.

When the source data for the photogrammetric production is digital imagery from a USGS type certified digital camera system, the interior orientation is completely defined by the camera calibration report provided by the camera vendor. In softcopy photogrammetric production based on a calibrated digital camera, no measurement process in support of interior orientation is required.

Exterior orientation is established by taking precise measurements on multiple images and using a series of ground control points. The coordinates of these ground control points are typically established by ground survey methods. The ground control point data, combined with the film/image measurement data, provide sufficient information to compute the position and attitude of the camera at the instant that each individual photograph was exposed. This computed position and attitude is expressed in the ground coordinate system.

In the simplest case, the determination of the exterior orientation parameters of a single photograph whose exterior orientation is initially unknown requires the measurement of at least three points with known ground coordinates. Additional measurements provide the redundancy necessary for error checking capabilities. The modern photogrammetric process very rarely deals with a single photograph, but more frequently with a "block" of overlapping photographs. In this case, it is neither efficient nor necessary that three ground control points per photograph be measured. By introducing additional measurements that tie adjacent photographs to one another, i.e. "tie points", the number of ground control points can be minimized.

The number of surveyed ground control points can be further decreased if the position of the camera at the instant of image exposure can be measured directly, treated as an additional observation, and only "adjusted" in the course of the photogrammetric process. The Global Positioning System (GPS) can be employed onboard the aircraft to provide these additional observations to a high degree of accuracy. These observations, in effect, lend additional control to the final solution.

In softcopy photogrammetric production, the task of measuring tie points can also be automated. Only a small amount of manual operation is required to initiate/monitor the automated process and check on the quality of the automatically measured points.

The modern photogrammetric production process requires precise measurements that must be taken with specialized instrumentation and processed through specialized algorithms. These algorithms are designed to detect and eliminate blunders and minimize random errors within the project. In recent years, AT software solutions have been designed to detect or eliminate systematic errors in an efficient manner. .

The end result of the triangulation is the final exterior orientation parameters of each photograph, as well as the adjusted ground coordinates of all ground control points. In addition, the computed ground coordinates of all measured points, i.e. the tie points, provide a high density set of ground point coordinates that are used to control the remainder of the mapping process.

As a gross simplification, the aerial triangulation process can be thought of as a densification process where a sparse pattern of surveyed ground control points are used along with aerial imagery to densify the positions of a larger pattern of ground points. The AT software itself serves as the precise algorithm that is used to solve for these previously unknown control point locations.

3 PROJECT ACCURACY REQUIREMENTS

3.1 *Horizontal Accuracy*

The photogrammetric mapping products generated for this project shall meet National Map Accuracy Standards (NMAS). NMAS states that:

"For maps on publication scales larger that 1:20,000, not more than 10 percent of the points tested shall be in error by more that 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch. These limits of accuracy shall apply in all cases to positions of well-defined points only."

The horizontal accuracy requirements for the products generated for this project are tabulated in Table 3.1a.

Table 3.1a
NMAS – Planimetric Accuracy

Target Map Scale	Map/Orthophoto Accuracy
1 in. = 100 ft.	3.33 ft.

3.2 *Vertical Accuracy*

The vertical accuracy requirements for the products generated on this project are tabulated in Table 3.2a.

Table 3.2a
NMAS – Topographic Elevation Accuracy

Target Contour Interval (ft.)	Accuracy (90% of tested points)
2	1.00 ft

4 AEROTRIANGULATION ACCURACY

While the product accuracy values stated in Section 3 specify the overall final product accuracy requirements for each mapping product, it is necessary to divide these errors into components that are assigned to each of the photogrammetric production steps. This can be accomplished statistically by the equation presented below:

$$\sigma_{total} = (\sigma_{control} + \sigma_{aerial\ triangulation} + \sigma_{orthorectification})^{1/2}$$

This equation can be described as the error budget for the product. By assigning values to each of the components in the equation and monitoring them during the production process, compliance with the final product accuracy requirements can be assured.

A simplistic way to think of this equation is to visualize it in a fashion similar to that of a home budget for expenses. If one category exceeds its limit, then the remaining budget items must be reduced so that the total income/expense budget is not exceeded. In a similar fashion, excessive errors in one area of production can be compensated for by reducing errors in production steps elsewhere in the production process, provided none of the errors in any of the steps exceeds the overall budget.

For the purposes of this report, it is convenient to derive the component of the overall product accuracy that can be allocated to the AT production step. Based on experience with the fully analytical equipment and processes that have been employed at Surdex Corporation on similar projects, and following the guidance in the US Army Corps of Engineers EM 1110-1-1000, it is possible to define a requirement on ground points such that the RMSE of the AT residuals on all control in the adjustment not exceed the values in the following table.

Table 4a
AT Accuracy Criteria

	Horizontal residuals		Vertical residuals	
Map Class	RMSE (ft.)	Max. (ft.)	RMSE (ft.)	Max. (ft.)
NMAS	H/10000	3 * RMSE	H/9000	3 * RMSE

The derived AT accuracy requirements for the photographic scales in this project are tabulated in Table 4b.

Table 4b
Limiting Error Sources in Adjustment Results

	Horizontal residuals		Vertical residuals	
Map Class	RMSE (ft.)	Max. (ft.)	RMSE (ft.)	Max. (ft.)
NMAS	0.5	1.5	0.55	1.67

It is these values that will be used to evaluate the quality of the final aerial triangulation adjustment.

5 AERIAL IMAGERY

Color aerial imagery was acquired for this project during March & April 2008. The imagery was collected with nominal 60% forward overlap and 30% sidelap. The acquisition is summarized in Table 5 and depicted graphically in Figure 5.

Table 5
Aerial Imagery Acquisition Summary

Photo Scale	Date of Photography	Film Type	Camera/Lens Serial Number	Flight Lines	Exposures
5000’ AGL	Mar 21 April 8, 15, 24	DMC	DMC01-0029 DMC01-0105	50	6010

Camera calibration data are provided in Appendix

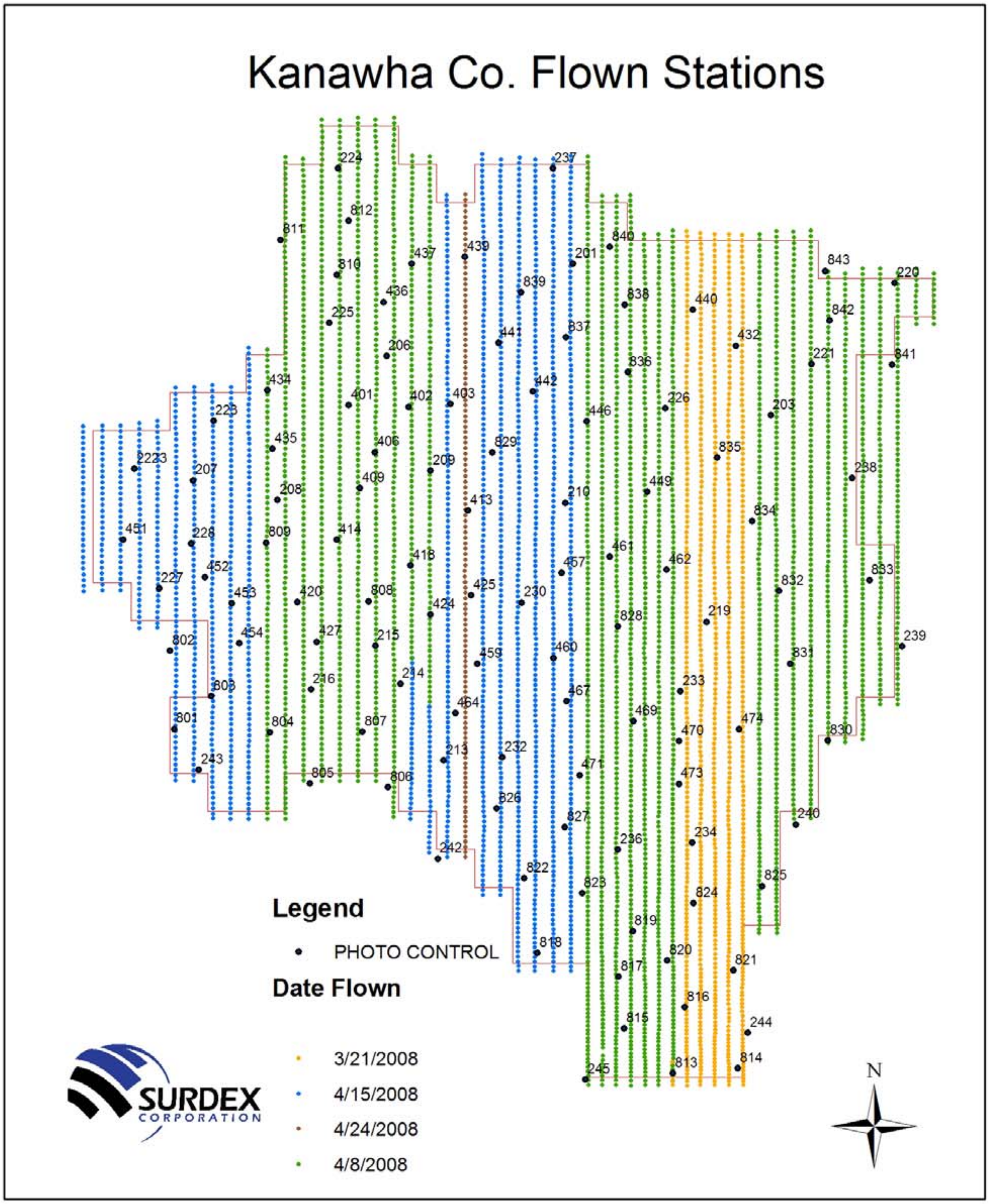
Kanawha Co. Flown Stations
Legend
PHOTO CONTROL
Date Flown
3/21/2008
4/15/2008
4/24/2008
4/8/2008
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Figure 5a

6 GROUND CONTROL

The ground control for this project was provided by Kanawha County. Aerial targets were placed on existing control monuments provided by the county (and/or) new locations, as specified during March 2008. The existing points were recovered and targeted using the values supplied by the county. Targets were white plastic or paint in the shape of a +. All measurements were performed using static GPS procedures.

Horizontal coordinates for this project are referenced to the NAD83 State Plane Coordinate System, West Virginia South, in U.S. Survey feet. Vertical control is referenced to the NAVD88.

7 AIRBORNE GPS CONTROL

Differential Airborne GPS (ABGPS) positions were collected and used in this mapping project. DMC flights & base stations were setup at Leesburg Municipal Airport in Virginia.

The ABGPS data was acquired through the use of geodetic grade GPS receivers. One receiver was leveled and positioned over a recoverable base point, whose coordinates had been established by ground survey, during photographic acquisition. This receiver functioned as the base station collecting GPS signals during the entire photo acquisition time period. The second receiver was placed in the aircraft and continuously recorded the position of the aircraft-mounted GPS antenna. The GPS time of the center of the shutter opening event for each photograph was also collected.

All of the collected ABGPS data was post processed using Trimble's GrafNav static/kinematic GPS processing software. This software uses the difference between the recorded signals from the base and remote receivers, along with the position of the base station, to determine a precise position of the mobile GPS antenna at the time of the camera shutter events. The offset from the aircraft-mounted GPS antenna and the perspective center of the camera system is then applied. The final step in ABGPS processing is to convert the camera positions to the project coordinate system.

8 TRIANGULATION

The ImageStation Automatic Triangulation (ISAT) software package, developed by Z/I Imaging, was used to perform digital image mensuration, and bundle block adjustment for all the imagery associated with this project.

8.1 Project Setup

The first ISAT function performed by the operator is to set up the project parameters. This involves selecting the appropriate project units, coordinate system, camera calibration parameters, and error tolerances. The location on disk (or network) of the digital image files is then specified to the ISAT package. ABGPS-derived camera positions are also imported into the ISAT project during this production step.

This project involved the adjustment of two sets of aerial imagery, flown on different dates, at different altitudes. Some phases of the processing on this set of imagery were performed on separate ISAT "sub-projects" or "sub-blocks". Sub-blocks are utilized within ISAT on projects containing a large number of images. By subdividing the project into sub-blocks a more efficient image measurement and error detection process can be performed. Once all sub-blocks are approved, they are tied together into a master block to assure the final overall block accuracy.

8.2 Softcopy Mensuration

The softcopy mensuration process entails the measurement of all the necessary image points to complete the triangulation. This includes all tie, pass and control point locations in the images. This process is initially performed automatically. Once the automated process is completed, however, a technician is presented with a graphical representation of the digital images with the measured points overlaid. The technician then interactively measures any additional points to obtain the required tie point density. As part of this same step, the operator interactively measures the ground control point locations. The outcome of this process is a set of image coordinates for each ground control point and for a large number of tie points.

In addition to the tie and ground control points, Quality Control (QC) points are also collected throughout the project area. The computed ground coordinates of the QC points are later compared against measured/computed coordinates at various subsequent processing phases and ultimately against measured/computed coordinates on the final digital orthophotos. These QC points are typically photo identifiable points such as manhole covers, bases of telephone poles, and the like. In this way, the data integrity at any point in the photogrammetric production process or in the finished digital orthophoto product can be monitored and evaluated.

8.3 Analytical Processing

After all data have been entered/imported, and all measurements have been taken and merged, the analytical phase of the AT begins. The first step performed in the analytical phase of AT processing is to run an initial bundle block adjustment on the accumulated measurement data. The built-in bundle adjustment capability of ISAT (PhotoT) is used for this process.

The main purpose of the initial AT run is to evaluate the quality of the measurement data and isolate and remove any measurement errors. This initial run includes the measurements from all the ground control point measurements, but uses them only as checkpoints. This run provides a check on the integrity of the ABGPS control data and the ground control data. PhotoT incorporates a robust set of data analysis, snooping (blunder detection), and corrective functions that can be used to arrive at the optimum set of measurement data. The output of this process is a final set of image coordinates that will be used as input to the final processing of the fully analytical aerial triangulation.

The final AT solution is also performed by the PhotoT package. The final run incorporates all the ground control points into the solution, using appropriate statistical weights. The PhotoT software is an advanced bundle adjustment package that also provides options that allow for rigorous modeling of the effects of atmospheric refraction and earth curvature, camera self-calibration, and GPS shift and/or drift computations. PhotoT can also perform the data snooping functions at this stage in the solution.

The data snooping functions uses statistical techniques to automatically locate and withhold from the solution any image, ground control point coordinates, and/or ABGPS coordinates that are determined to be blunders. These points are identified in the adjustment report and are provided with suggested standard errors that permit them to remain in the adjustment.

Throughout the bundle adjustment process the production photogrammetrist continuously checks the quality of observed data. As blunders are detected in the automatically or manually measured points, they are either corrected or removed from the block. By correcting or removing these blunders from the solution, the operator can arrive at an optimal AT solution.

Appendix B presents a link to the full listing of the final AT results for the GSD050 block.

8.3.1 Processing the "GSD050" Blocks

8.3.1.1 Initial Adjustment

An initial adjustment, in which ground control points are treated only as check points, was performed on each of the sub-blocks. This adjustment primarily checks the overall fit of the image measurements. This adjustment secondarily provides a measure of the agreement between the ABGPS control data and the ground control point data. Airborne GPS positions used a-priori weights (in U.S. Survey Feet) of (0.2, 0.2, 0.2).

8.3.1.2 Final Adjustment

The final adjustment used the 116 available ground control points, treated as fully constrained observations.

Appendix B presents a complete listing of the results from the final adjustment for each of the sub-blocks. The listing includes the basic parameters of the adjustment as well as all details of the final run. For this adjustment the measurement standard errors and ABGPS standard errors were left unchanged from the initial run.

Table 8.3.1.4a summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4a
Final "GSD050A" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
207	1726196	506973	607.211	0.386	0.08	-0.007
208	1748278	501850	594.273	-0.497	-0.023	0.013
223	1731461	522585.5	626.309	-0.212	0.36	0.009
227	1717249	478601.6	724.338	0.268	0.166	-0.002
228	1725605	490368.6	602.398	-0.08	0.164	-0.002
243	1727648	430899.7	666.479	0.028	-0.107	0.009
420	1753501	475033.4	1151.307	-0.3	-0.124	-0.053
434	1745589	530682.6	605.755	-0.084	-0.046	0.005
435	1747002	515303.9	678.816	-0.625	0.009	0.046
451	1707798	491419.3	728.649	-0.083	-0.199	-0.041
452	1729212	481554.3	631.564	-0.12	0.185	0.144
453	1736350	474610.9	619.81	-0.474	0.003	-0.02
454	1738180	464136	606.48	-0.728	-0.053	0.16
801	1721146	441650.4	684.14	0.535	0.148	-0.015
802	1720147	462249.4	1114.57	0.539	0.085	-0.047
803	1730869	450212.2	981.292	0.011	0.026	-0.009
804	1746241	440712.6	694.364	-0.467	0.013	-0.015
809	1745350	490605.4	1141.127	-0.384	-0.061	-0.006
2223	1710823	510021.3	934.154	0.176	0.063	-0.035
COUNT				19	19	19
RMSE				0.381	0.133	0.055
MEAN				-0.111	0.036	0.007
MIN. RESID.				-0.728	-0.199	-0.053
MAX. RESID.				0.539	0.36	0.16

Table 8.3.1.4b presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4b
Aerial Triangulation Accuracy Evaluation of "GSD050A" Block

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.381 X 0.133 Y 0.055 Z	-0.728 X 0.360 Y 0.160 Z

Table 8.3.1.4c summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4c
Final "GSD050B" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
206	1776851	539596.8	797.814	-0.163	-0.094	0.074
209	1788344	509569.6	789.188	0.065	0.325	-0.008
224	1764191	588956.9	1055.213	-0.208	0.047	0.003
225	1761898	548359.7	625.834	-0.953	0.228	-0.146
401	1766899	526665.3	661.739	0.099	0.445	0.119
402	1782580	526307.1	771.048	0.351	0.055	0.122
406	1773862	514355.7	613.89	-0.229	0.429	-0.04
409	1769883	504997.4	1073.911	-0.244	0.322	-0.029
434	1745589	530682.6	605.748	-0.87	-0.028	-0.002
435	1747002	515303.7	678.842	-0.686	-0.125	0.072
436	1776130	553807.1	627.741	0.464	-0.239	0.035
437	1783451	563859	646.656	-0.584	-0.024	0.006
810	1763736	560865.1	628.676	0.001	0.149	-0.01
811	1749069	570191.2	937.068	-0.874	0.508	0.078
812	1766834	575160.1	995.591	-0.161	0.051	0.031
COUNT				15	15	15
RMSE				0.50	0.26	0.069
MEAN				-0.266	0.137	0.02
MIN. RESID.				-0.953	-0.239	-0.146
MAX. RESID.				0.464	0.508	0.122

Table 8.3.1.4d presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4d
Aerial Triangulation Accuracy Evaluation of "GSD050B" Blocks

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.50 X 0.260 Y 0.069 Z	-0.953 X 0.508 Y -0.146 Z

Table 8.3.1.4e summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4e
Final "GSD050C" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
208	1748277	501849.9	594.331	-0.799	-0.126	0.071
214	1780465	453553.5	951.473	0.607	-0.743	0.053
215	1773910	463573.9	1176.916	0.382	-0.778	-0.014
216	1757046	452080.5	677.087	-0.638	-0.159	0.117
409	1769883	504996.8	1073.909	-0.602	-0.256	-0.031
414	1763803	491348.5	786.211	0.075	0.181	-0.015
418	1783180	484694.3	1043.008	-0.37	-0.068	0.028
420	1753501	475033.5	1151.263	-0.556	-0.01	-0.097
424	1788363	471759.8	755.883	-0.357	0.007	0.003
427	1758528	464570	1092.11	-0.168	0.19	-0.004
804	1746241	440712.6	694.358	-0.751	0.053	-0.021
805	1756677	427374.6	773.253	-0.03	0.044	0.003
806	1777276	426376.9	899.594	0.177	0.159	0.022
807	1770592	440918.7	842.826	0.056	-0.227	-0.004
808	1772189	475218	1097.85	0.188	0.314	-0.183
809	1745350	490605.7	1141.122	-0.639	0.171	-0.011
COUNT				16	16	16
RMSE				0.473	0.311	0.065
MEAN				-0.214	-0.078	-0.005
MIN. RESID.				-0.799	-0.778	-0.183
MAX. RESID.				0.607	0.314	0.117

Table 8.3.1.4f presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4f
Aerial Triangulation Accuracy Evaluation of "GSD050C" Blocks

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.473 X 0.311 Y 0.065 Z	-0.799 X -0.778 Y -0.183 Z

Table 8.3.1.4g summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4g
Final "GSD050D" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
201	1825672	563901.3	1295.338	-0.701	0.069	-0.012
209	1788344	509569.3	789.186	0.088	0.014	-0.01
210	1823757	501091.8	754.959	-1.082	-0.313	-0.001
237	1820390	588926.8	661.42	-0.353	0.396	0.03
402	1782580	526307	770.927	0.068	-0.033	0.001
403	1793631	527074	754.356	0.293	0.202	0.016
413	1798190	499045.6	847.558	0.603	-0.301	0.008
418	1783180	484694.3	1043.004	0.012	-0.113	0.024
437	1783451	563859.3	646.63	-0.024	0.226	-0.02
439	1797385	565664.9	624.388	0.859	0.104	0.008
441	1806157	543080.3	781.378	0.36	-0.028	-0.022
442	1815187	530252.8	694.951	-0.073	-0.16	0.001
829	1804586	514266.2	819.888	0.009	0.015	-0.012
839	1812097	556367.5	1141.47	-0.06	-0.08	-0.01
COUNT				14	14	14
RMSE				0.473	0.189	0.015
MEAN				0	0	0
MIN. RESID.				-1.082	-0.313	-0.022
MAX. RESID.				0.859	0.396	0.03

Table 8.3.1.4h presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4h
Aerial Triangulation Accuracy Evaluation of "GSD050D" Blocks

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.473 X 0.189 Y 0.015 Z	-1.082 X 0.396 Y 0.030 Z

Table 8.3.1.4i summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4i
Final "GSD050E" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
213	1791829	433364.1	1749.362	0.924	0.534	0.002
214	1780464	453554.5	951.427	-0.063	0.235	0.007
232	1807219	434220.3	721.238	0.112	-0.345	-0.012
242	1790277	407587.6	693.395	-0.081	-0.027	-0.005
418	1783180	484694.4	1042.96	-0.054	0.021	-0.02
424	1788363	471759.8	755.88	-0.193	0.047	0
457	1822702	482645.2	627.479	-0.338	0.257	0.019
459	1800608	458743.4	641.429	0.483	-0.045	0.008
464	1794840	445878.7	677.63	0.03	-0.154	-0.01
467	1823995	448960.6	628.291	-0.237	0.012	0.021
471	1827453	429520.2	666.229	-0.403	0.057	-0.015
818	1816376	382799.7	899.748	0.011	-0.306	0.018
822	1812967	402419.6	1083.947	-0.166	-0.144	-0.033
823	1828109	398445.7	893.308	-0.026	0.191	-0.002
826	1805768	420731.4	1094.479	0.356	-0.31	-0.001
827	1823634	415880.9	1160.152	-0.4	-0.059	-0.008
COUNT				16	16	16
RMSE				0.335	0.225	0.014
MEAN				-0.003	-0.002	-0.002
MIN. RESID.				-0.403	-0.345	-0.033
MAX. RESID.				0.924	0.534	0.021

Table 8.3.1.4j presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4j
Aerial Triangulation Accuracy Evaluation of "GSD050E" Blocks

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.335 X 0.225 Y 0.014 Z	0.924 X 0.534 Y -0.033 Z

Table 8.3.1.4k summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4k
Final "GSD050F" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
201	1825672	563901.2	1295.336	-0.369	-0.082	-0.014
210	1823758	501092.1	754.973	-0.18	-0.002	0.013
226	1850004	525905.5	785.141	0.109	0.008	0.05
237	1820391	588926.5	661.385	-0.014	0.027	-0.005
446	1829356	522450.8	618.349	-0.151	0.054	0.006
449	1845175	503980.3	1026.157	0.337	0.005	-0.013
457	1822702	482644.9	627.485	0.01	-0.127	0.025
461	1835344	486959.2	703.403	-0.182	-0.082	-0.027
462	1850335	483420.1	881.483	0.583	0.051	-0.027
828	1837530	468616.4	1031.892	-0.58	0.212	-0.008
836	1840030	535381.1	646.299	0.173	0.294	0.029
838	1839324	553067.9	682.09	0.4	0.017	-0.01
840	1835384	568241.1	1036.23	-0.137	-0.374	-0.02
COUNT				13	13	13
RMSE				0.308	0.154	0.023
MEAN				0	0	0
MIN. RESID.				-0.58	-0.374	-0.027
MAX. RESID.				0.583	0.294	0.05

Table 8.3.1.4l presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4l
Aerial Triangulation Accuracy Evaluation of "GSD050F" Blocks

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.308 X 0.154 Y 0.023 Z	0.583 X -0.374 Y 0.050 Z

Table 8.3.1.4m summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4m
Final "GSD050G" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
233	1853849	451557.9	678.943	0.235	-0.122	0.023
236	1837555	409983.9	728.687	-1.015	-0.384	0.017
245	1828934	349480.3	936.903	-0.241	0.354	0.013
467	1823996	448960.6	628.227	0.259	0.015	-0.043
469	1841525	443644.3	631.541	-0.483	-0.202	-0.019
470	1853521	438436.7	624.598	0.741	-0.079	0.058
471	1827453	429520.2	666.247	-0.329	0.023	0.003
473	1853454	427241.1	643.062	-0.264	-0.009	-0.038
813	1851920	351202.8	2394.852	0.095	-0.597	0.008
815	1839153	362907.7	1526.002	0.091	0.06	0.018
816	1854990	368490.3	1341.079	0.254	0.114	0.009
817	1837699	376508.7	1115.081	-0.038	0.476	-0.039
819	1841330	388529.7	897.676	-0.053	0.168	-0.034
820	1850391	380788.1	2134.941	0.89	0.039	-0.019
823	1828109	398445.4	893.306	-0.097	-0.065	-0.004
827	1823634	415881.2	1160.207	-0.046	0.209	0.047
COUNT				16	16	16
RMSE				0.437	0.252	0.029
MEAN				0	0	0
MIN. RESID.				-1.015	-0.597	-0.043
MAX. RESID.				0.89	0.476	0.058

Table 8.3.1.4n presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4n
Aerial Triangulation Accuracy Evaluation of "GSD050G" Blocks

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.437 X 0.252 Y 0.029 Z	-1.015 X -0.597 Y 0.058 Z

Table 8.3.1.4o summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4o
Final "GSD050H" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
203	1877555	524109.6	1368.486	0.045	0.031	0.016
219	1860659	469801.1	1631.134	-0.144	0.022	-0.046
226	1850004	525905.4	785.034	0.475	-0.054	-0.057
233	1853849	451557.7	678.957	0.411	-0.269	0.037
432	1868357	542359.3	619.066	0.247	-0.333	0.016
440	1857204	551772.8	772.484	-0.13	0.08	0.044
449	1845175	503980.5	1026.184	-0.101	0.235	0.014
462	1850334	483419.8	881.544	-0.14	-0.216	0.034
834	1872635	496268.5	762.401	-0.503	0.298	0.001
835	1863473	512963.9	1185.07	-0.16	0.206	-0.06
COUNT				10	10	10
RMSE				0.283	0.207	0.038
MEAN				0	0	0
MIN. RESID.				-0.503	-0.333	-0.06
MAX. RESID.				0.475	0.298	0.044

Table 8.3.1.4p presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4p
Aerial Triangulation Accuracy Evaluation of "GSD050H" Blocks

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.283 X 0.207 Y 0.038 Z	-0.503 X -0.333 Y -0.060 Z

Table 8.3.1.4q summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4q
Final "GSD050I" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
233	1853849	451557.9	678.87	-0.009	-0.072	-0.05
234	1856990	411784	743.789	-0.945	-0.07	0.039
244	1871512	361853.8	1099.841	-0.063	-0.262	-0.029
470	1853521	438436.7	624.564	0.474	-0.056	0.024
473	1853453	427240.8	643.101	-0.679	-0.251	0.001
474	1869243	441499.6	705.692	0.376	-0.065	0.021
813	1851920	351203.2	2394.833	0.218	-0.188	-0.011
814	1868960	352519.8	2715.602	-0.041	-0.061	0
816	1854989	368490	1341.103	-0.134	-0.193	0.033
820	1850391	380789.2	2134.954	0.426	1.044	-0.006
821	1867718	378206.1	2157.18	0.107	-0.043	0.02
824	1857341	395858.7	787.454	-0.09	0.105	-0.046
825	1875334	400394.3	835.004	0.36	0.112	0.004
COUNT				13	13	13
RMSE				0.404	0.321	0.027
MEAN				0	0	0
MIN. RESID.				-0.945	-0.262	-0.05
MAX. RESID.				0.474	1.044	0.039

Table 8.3.1.4r presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4r
Aerial Triangulation Accuracy Evaluation of "GSD050I" Blocks

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.404 X 0.321 Y 0.027 Z	-0.945 X 1.044 Y -0.050 Z

Table 8.3.1.4s summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4s
Final "GSD050J" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
203	1877554	524109.8	1368.44	-1.072	0.241	-0.03
220	1910069	558753.6	853.486	0.111	-0.289	0.016
221	1888159	537494.8	637.673	-0.075	0.108	0.033
238	1898887	507559.1	1012.599	0.741	0.871	-0.021
432	1868357	542359	619.033	0.232	-0.666	-0.017
834	1872635	496268.2	762.435	-0.584	-0.038	0.035
841	1909436	537413.4	658.272	0.81	0.178	-0.018
842	1893058	548947.6	1138.986	-0.064	-0.337	0.001
843	1891856	562008.5	662.539	-0.099	-0.069	0.002
COUNT				9	9	9
RMSE				0.556	0.409	0.022
MEAN				0	0	0
MIN. RESID.				-1.072	-0.666	-0.03
MAX. RESID.				0.81	0.871	0.035

Table 8.3.1.4t presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4t
Aerial Triangulation Accuracy Evaluation of "GSD050J" Blocks

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.556 X 0.409 Y 0.022 Z	-1.072 X 0.871 Y 0.035 Z

Table 8.3.1.4u summarizes the ground control point residuals from the listings in Appendix B.

Table 8.3.1.4u
Final "GSD050K" Adjustment Residuals (at control points)

Point ID	Easting(X)	Northing(Y)	Elevation(Z)	VX	VY	VZ
239	1911921	463299.1	832.408	0.468	-0.054	-0.012
474	1869243	441499.4	705.663	-0.316	-0.167	-0.008
825	1875334	400394.6	835.009	0.072	0.43	0.009
830	1892514	438561.3	841.567	0.276	0.07	-0.013
831	1882655	458839.5	1348.918	-0.198	0.04	0.018
832	1879742	477942.2	988.224	-0.753	-0.06	-0.016
833	1903413	480762	1260.322	0.451	-0.259	0.022
COUNT				7	7	7
RMSE				0.416	0.205	0.015
MEAN				0	0	0
MIN. RESID.				-0.753	-0.259	-0.016
MAX. RESID.				0.468	0.43	0.022

Table 8.3.1.4v presents a comparison of the final adjustment values against the project triangulation requirements discussed in Section 4.

Table 8.3.1.4v
Aerial Triangulation Accuracy Evaluation of "GSD050K" Blocks

Allowable Limits Of Error in Final Block Adjustment		
Type	**RMSE**	**Maximum Error**
Specification	0.50 X 0.50 Y 0.50 Z	1.5 X 1.5 Y 1.6 Z
AT Output (control pts)	0.416 X 0.205 Y 0.015 Z	-0.753 X 0.430 Y 0.022 Z

Appendix A - Camera Calibration Data

See Calibration Certificate_DMC#29_CBU#29.pdf
See Calibration Certificate_DMC01-0105_CBU#60.pdf

Appendix B – ISAT Final AT Report (GSD050)

See attached AT-report-gsd050a.txt
See attached AT-report-gsd050b.txt
See attached AT-report-gsd050c.txt
See attached AT-report-gsd050d.txt
See attached AT-report-gsd050e.txt
See attached AT-report-gsd050f.txt
See attached AT-report-gsd050g.txt
See attached AT-report-gsd050h.txt
See attached AT-report-gsd050i.txt
See attached AT-report-gsd050j.txt
See attached AT-report-gsd050k.txt