City of Lubbock TX
2010 Orthoimagery Project

Aerial Triangulation Report

April 16, 2010

EXECUTIVE SUMMARY

Sanborn has successfully completed the aerial triangulation (AT) task for the aerial photography acquired in January thru March of 2010 for the Planimetric, Digital Orthophotography and DTM project for the City Lubbock Texas.

Using fully analytical aerial triangulation (FAAT) methods incorporating automatic analytical aerial triangulation (AAAT) procedures, Sanborn determined ground coordinates for each exposure by flying at an altitude to provide images at a 6" and a 3" ground sampling distance (GSD) covering the project areas.

The results of the final adjustment are sufficient to enable Sanborn to photogrammetrically compile digital terrain model (DTM) data to support the production of orthophoto imagery that meets project accuracy requirements.

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1.   INTRODUCTION

This report contains a technical overview and a summary of the results of the Aerial Triangulation (AT) adjustments associated with the City of Lubbock, Texas to produce planimetric data, and Digital Orthophotography.

This phase of the project included detailed flight planning, the design, reconnaissance, monumentation and the survey of an appropriate ground control layout, the technical design and implementation of the GPS-assisted aerial survey, airborne-GPS data processing, and aerial triangulation (AT).

The AT results provide the framework of control necessary to support the production of digital photogrammetric mapping.

1.1   Project Team

The primary points-of-contact for this Project are summarized below:

Table 1. The Project Team

Contractor	Role	Contact	Position
Sanborn	Prime Contractor	Karen Adkins	Project Manager
		Doug Zehr	AT Manager
		Gary VanderWeide	Senior AT Technician

Questions regarding the technical aspects of this report should be addressed to:

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FAX   (719) 528 – 5093

Sanborn was responsible for the overall technical management of the project, and undertook the initial project design. Sanborn provided the flight layout, and was responsible for examination of the acquired photography for the coverage of the project area, clarity and compliance with specifications.

1.2   Duration

The basic ground control, photography and airborne GPS data acquisition were conducted between January, and March 2010. The photo measurements and the aerial triangulation adjustments were performed in February and March of 2010. This report completes the aerial triangulation phase.

2.   PROJECT LOCATION AND SCOPE

2.1   Project Area

Project Area 1 encompassed approximately 419 sq. miles of the City of Lubbock, Texas. This area was covered by 3" ground sampling distance (GSD) photography.

Project Area 2 encompassed approximately 1088 sq. miles of Lubbock County, Texas. This area was covered by 6" ground sampling distance (GSD) photography.

Project Area 3 encompassed approximately 124 sq. miles within the City of Lubbock, Texas. This is an area of 1"=50' plan capture included in the Project Area 1 3" ground sampling distance (GSD) photography.

Project Area 4 encompassed approximately 16 sq. miles of Lake Allen Henry in Garza, and Kent Counties. This area was covered by 6" ground sampling distance (GSD) photography.

2.2   Accuracy Requirements

2.2.1 Aerial Triangulation

The results of the AT are required to meet project requirements which will enable Sanborn to photogrammetrically compile digital terrain model (DTM) data to support the generation of contours at a 1' interval and to produce planimetric data and orthophoto imagery at a 1"=50' and 1"=100' map scale.

2.2.2 Ground Control Survey

Horizontal ground control was designed to meet the accuracy standards and specifications for *First Order* GPS surveys (10 mm + 10 ppm), as defined by the Federal Geodetic Control Subcommittee (FGCS). This level of accuracy is economically attainable, and is more than adequate to support ground control for the AT. All horizontal ground control coordinates were required to be furnished in the Texas North Central (zone 4202) State Plane Coordinate system, and relative to the North American Datum of 1983 (NAD83).

2.3   Ground Control

The ground control network was designed to provide a geometrically strong horizontal and vertical control system.

2.4   Aerial Triangulation

The aerial triangulation was to be undertaken utilizing GPS-assisted techniques. This approach allows a substantial reduction in the amount of ground control required for the AT solutions.   The ground control layout is therefore designed primarily to provide quality control on the GPS-assisted solutions.

AGPS data is captured during the acquisition of the aerial photography.   An appropriate GPS antenna is mounted on each aircraft used on the project, and the relationship between the antenna phase center and the camera perspective center are determined through a close-range survey.   Dual frequency, geodetic quality receivers were to be utilized for the data collection.   The on-board receiver collects data at a 1 second interval and is electronically connected to the aerial camera.   All exposure events are time-tagged and stored in the GPS receiver.

The GPS data is post-processed, and the appropriate interpolations, transformations and reductions applied to derive the camera's spatial position referenced to the World Geodetic System of 1984 (WGS84) at each instant of exposure.   These data are then introduced along with the reduced image coordinates, as observations, into a combined three dimensional simultaneous least squares adjustment by bundles.
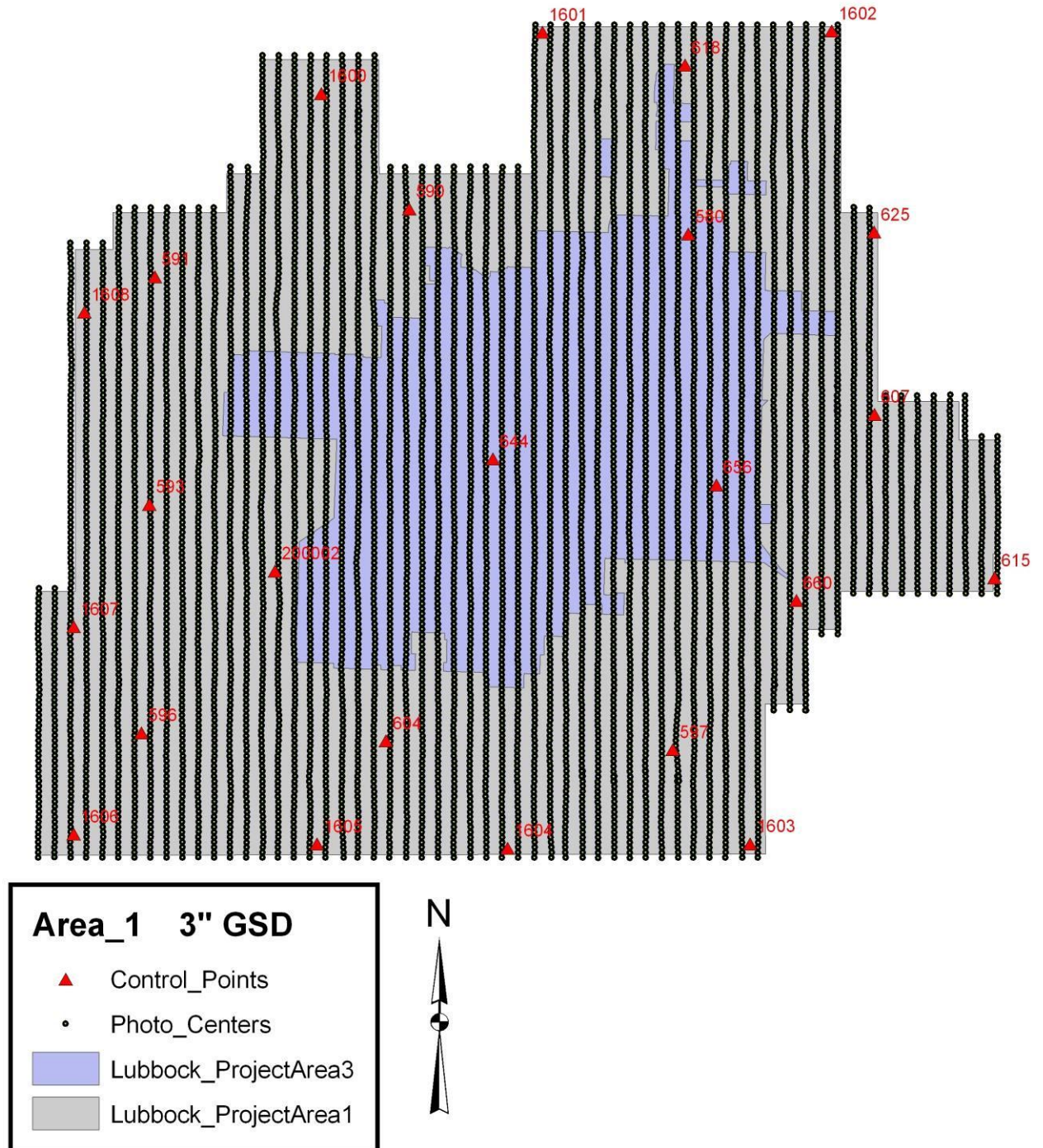
3.   GROUND CONTROL SURVEY

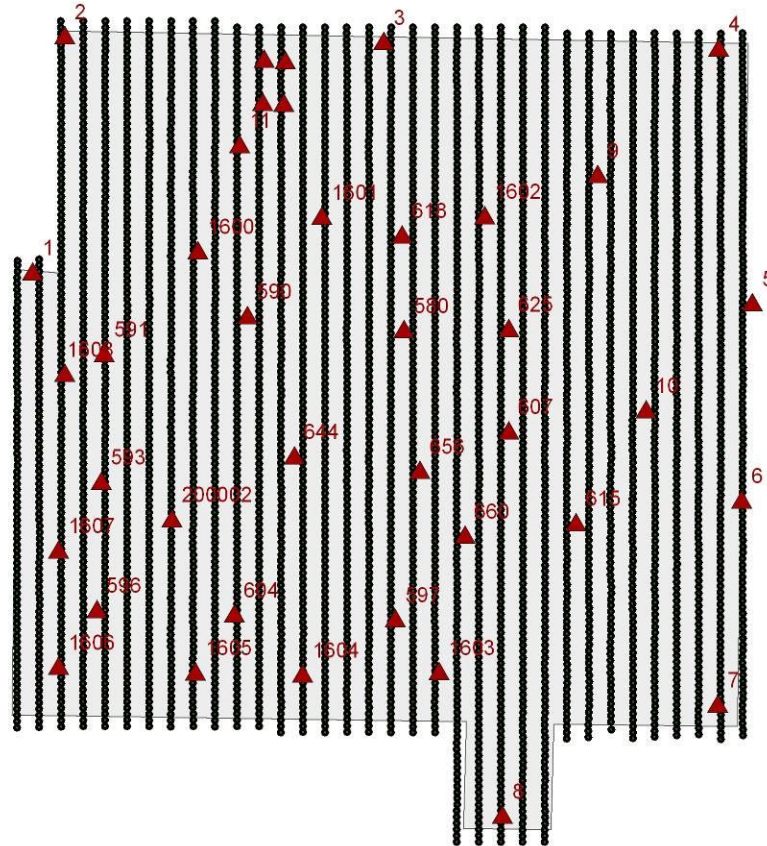The ground control network was performed in accordance with the current FGCS accuracy standards for *first order* surveys.

4.   AERIAL SURVEY

4.1   Flight Plans

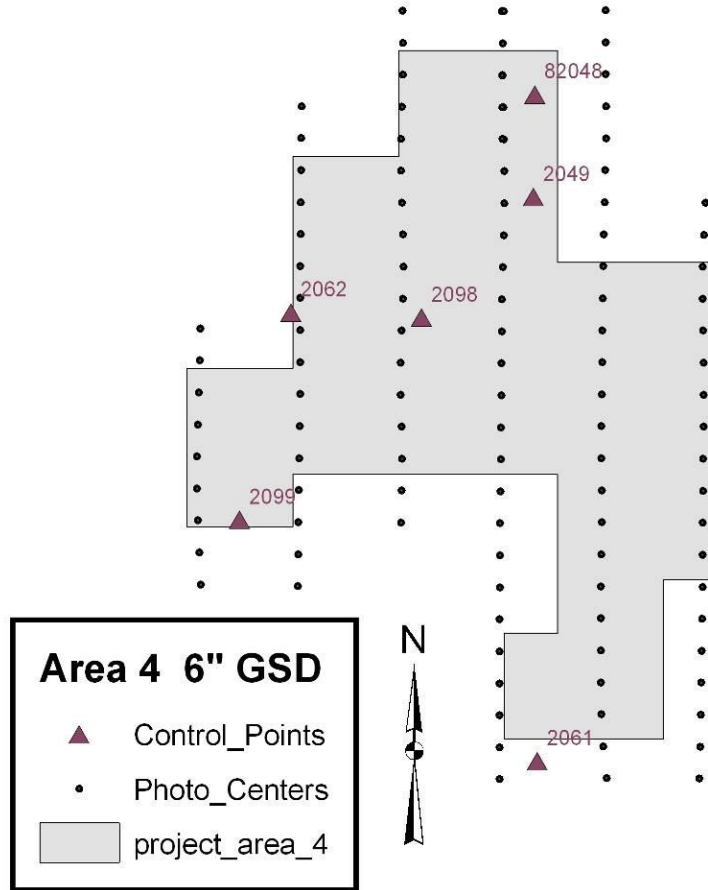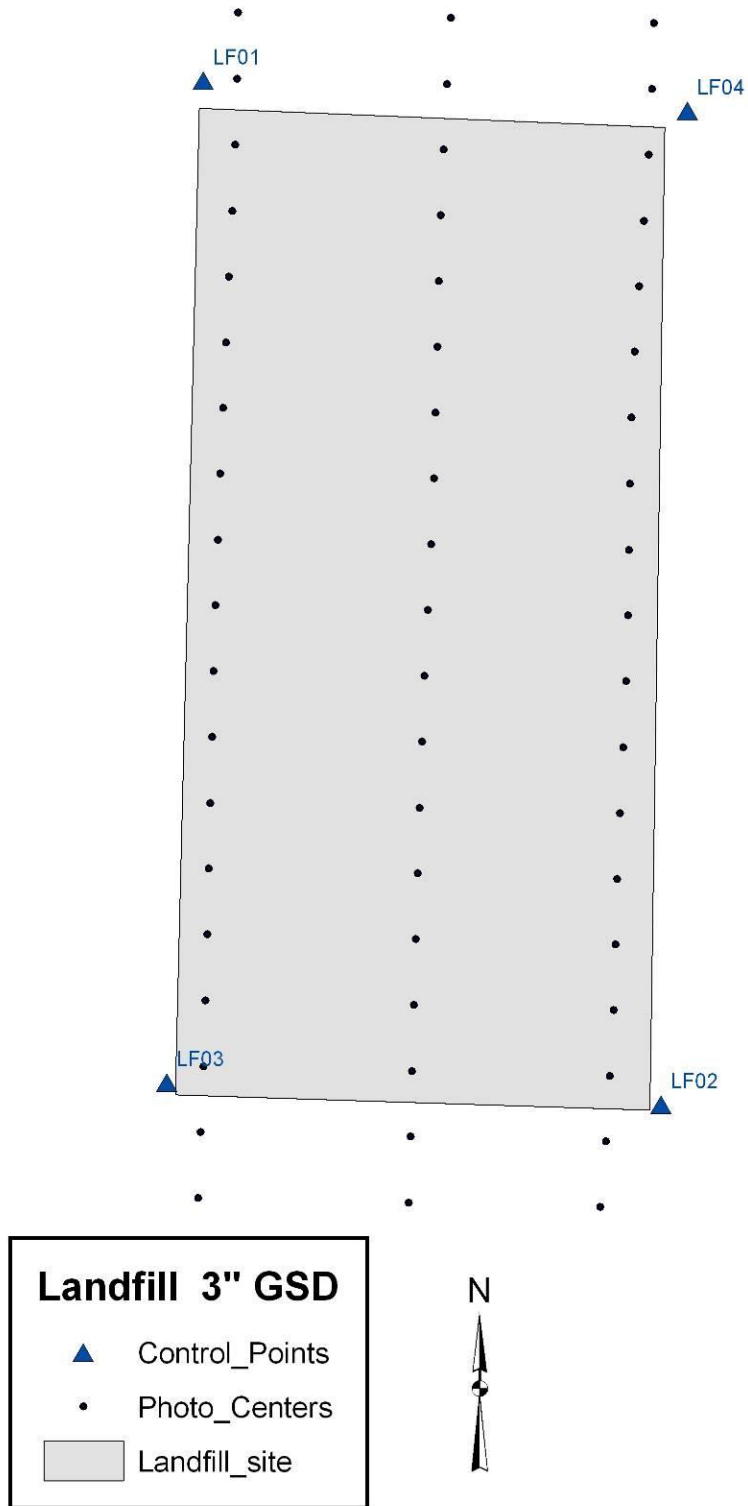Area 4 6" GSD
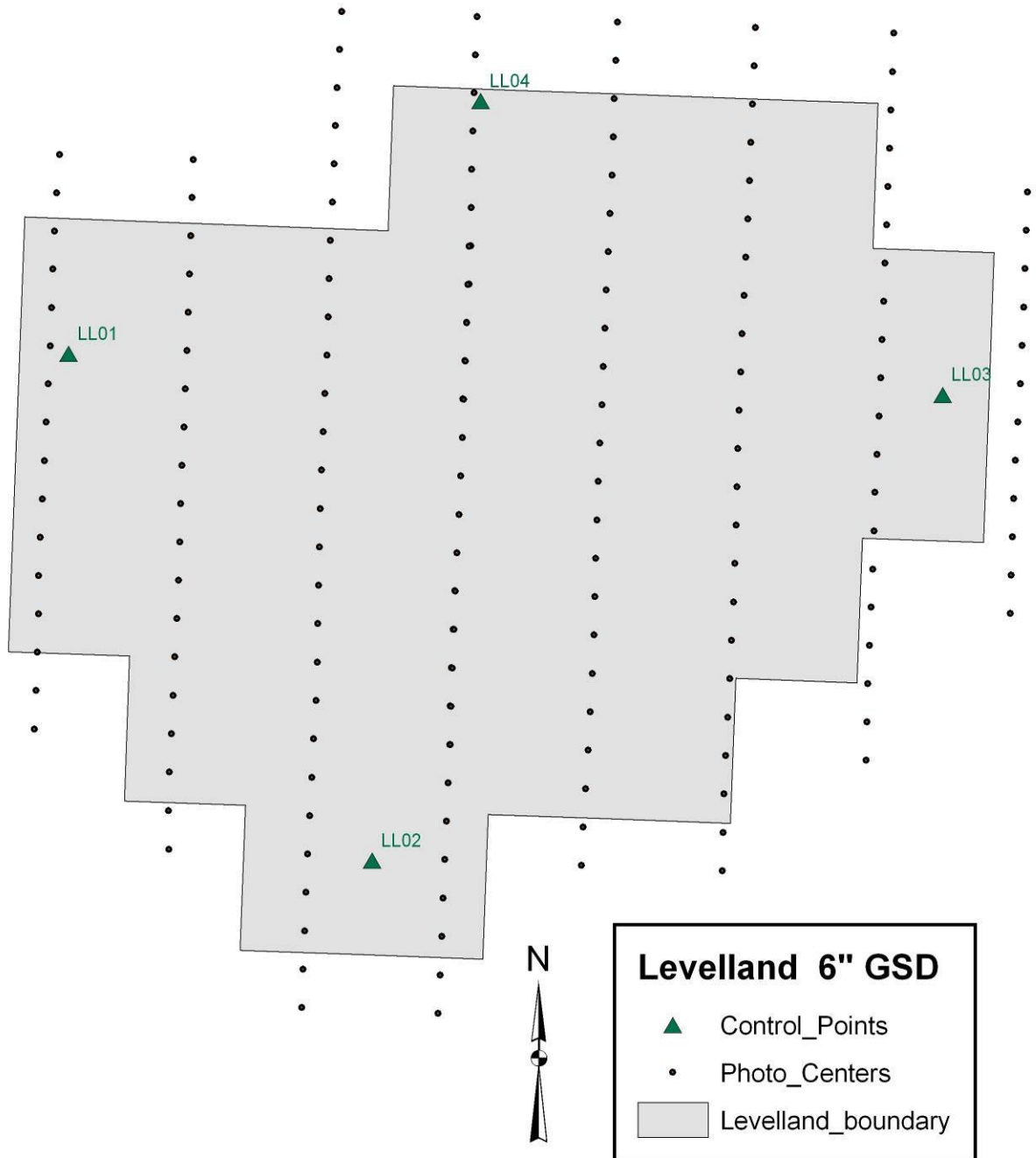
▲   Control_Points

•   Photo_Centers

    project_area_4

LF01

LF04

Landfill 3" GSD

▲   Control_Points

•   Photo_Centers

☐   Landfill_site

LF03

LF02

N

Levelland 6" GSD

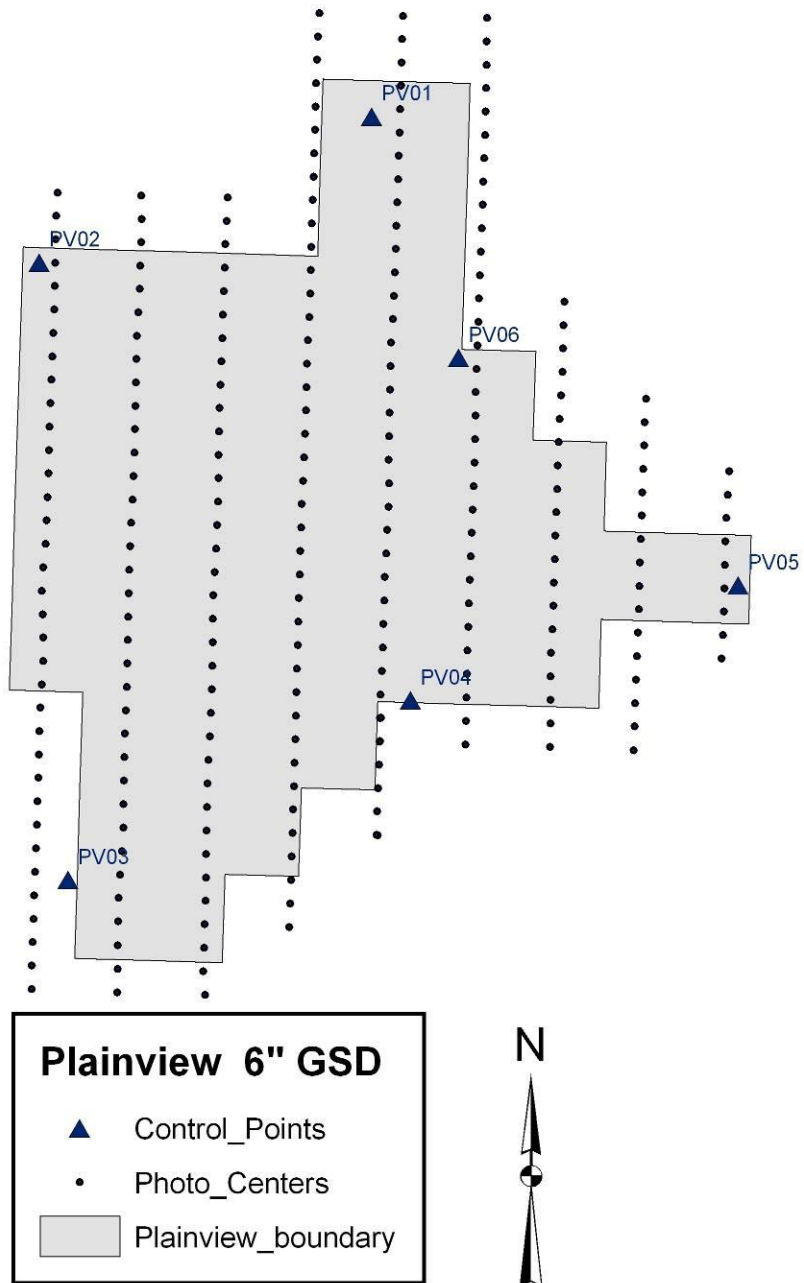▲ Control_Points

• Photo_Centers

   Levelland_boundary

4.2   Instrumentation

Three fully equipped aircraft were employed for the photographic missions. In the aircraft, the instrumentation utilized in the acquisition of aerial photography and AGPS data comprised of a Z/I DMC (Digital Mapping Camera) featuring forward motion compensation, a Novatel Millenium dual frequency GPS receiver, and a high precision aircraft antenna. A camera file is contained in Appendix A.

4.3   Mounting of GPS Antenna

The GPS antenna is mounted on the aircraft roof. The plane and the camera were leveled to simulate in-flight conditions. In order to derive the accurate positions of the front lens node required for the aerial triangulation solution, detailed knowledge of the relationship between the antenna phase center and the lens node is required. The offset vector was determined through close-range survey which was conducted using precise, conventional surveying equipment, and which involved angle and distance measurements between the camera, and the antenna location. Additional measurements were undertaken to the nose, tail and wing tips in order to properly determine the offset vector in relation to the aircraft. Rigorous 3-dimensional least squares adjustments were performed to derive the offset between the antenna base and the camera.

4.4   Photo Missions

The photo missions were conducted between January 21st and March 13th 2010. The photo mission procedures are outlined below.

The aircraft GPS receiver was connected to the antenna mounted on the aircraft, and to the Vexcel Ultracam. The receiver recorded data at a sampling rate of 1 second. Before take-off, the aerial camera was switched on to verify communications between the camera and the GPS receiver.

During the flight, every exposure triggered by the camera was recorded in the GPS data file as an external event. A time-tag attached to each event later allowed the interpolation of the camera position at each instant or exposure.

5.   AERIAL TRIANGULATION

5.1   Overview

Aerial triangulation is the simultaneous space resection of image rays projected and recorded at one source, the perspective center of the aerial camera. These image rays projected from two or more overlapping images, stereo-models, intersect at the corresponding ground location to determine the three-dimensional coordinates of each point measured. This collection of image rays is fit to known ground survey control in a simultaneous 3-dimensional least squares adjustment.   After the completion of this adjustment, coordinates of the 'unknown' ground points are derived by the intersection of the adjusted image points.

The purpose of aerial triangulation is to densify horizontal and vertical control from relatively few ground control points (GCPs). Since obtaining GCPs is a relatively significant expense in any mapping project, AT procedures are used to reduce the amount of field survey required by extending control to all stereo-models.

This method is essentially a mathematical tool, capable of extending control to areas between ground survey points using several contiguous uncontrolled stereo-models.

5.2   SoftCopy Measurements

All photo measurements were directly observed in a digital 'softcopy' environment. Z/I Imaging, an Intergraph – Carl Zeiss joint venture, software and hardware were used to perform the photo measurements.

In order to perform measurements of digital images in softcopy, images must be processed to a panchromatic .tif format using Vexcel Ultacam Office Processing Center (OPC) Version 1.3.2.

5.2.1 Photo Measurements

AT requires that a series of photographs be situated with one another in a continuous strip configuration.   The orientation of any photograph that does not contain sufficient number of ground control points is determined by the orientation of the adjacent photographs. In a strip formation, each photograph aids in the exterior orientation of the adjacent photography through the pass points located in the triple overlap areas.   This tri–lap area refers to the common ground area shared by two stereo-models (three consecutive photographs) along the strip.

As mentioned above, a pass point is an image point that is common to two or more consecutive photographs along that strip.   As the pass point is prepared and measured in a stereo-model, it can be used as control to orient the adjacent stereo-model.   Thus, the point "passes" control down the strip.   A pass point that is common to adjacent strips of photographs is called a tie point. Tie points hold two adjacent strips together similar to a pass point holding or tying together adjacent

photos along a strip. The location of the tie and pass points are in areas which allow geometrically stability in strips and the blocks. These locations are known as the Von Gruber points.

The automatic Point measurement feature of the ZI software was used to measure the pass points in this project. This feature automatically records the image coordinates of up to 7 matched points in each Von Gruber area. All ground control points were manually measured.

Internal software checks were performed to detect gross errors in the photo measurements.

5.3   Simultaneous Adjustment by Bundles

The surveyed control, along with the reduced image coordinates, served as input into the 'combined' block adjustment. Three–dimensional, simultaneous least squares adjustments by bundles, commonly referred to as "bundle" adjustments, were undertaken using Photo-T GPS adjustment software. This particular bundle method is very sensitive to systematic errors of the photo measurements and provides the correction of constant and regular errors through self-calibration. This concept regards these types of errors to be common to all photographs or to be present in sub-sets of the photographs. This bundle block adjustment software has proven to be a very rigorous and stable platform.

A series of aerial triangulation solutions were completed. The adjustment strategy was devised to provide the optimal solution for the subsequent mapping, while providing comprehensive quality control to detect errors, omissions and spurious data.

5.3.1 Fully Constrained Adjustment

The final adjustment, and the optimal solution to be used for mapping, included all control points as constraints and block–wise self–calibration parameters. All image points were assigned standard deviations of $4\mu m$.

5.3.2 'CheckPoint' Adjustment

As a standard procedure at Sanborn, an AT solution is executed withholding certain well distributed GCPs as 'checkpoints'. This procedure is a quality control check to verify the accuracy of the fully constrained AT solution.

The suggested industry standard Root Mean Square "checkpoint error" is 2 pixels. For this project it would be 1.0 feet for the 6" gsd blocks, and 0.5 feet for the 3" block.

The results of the checkpoint adjustment are contained in table 2 of this report.

5.4   Anomalies and Misfits

The elevation of control point LL03 in the Levelland block did not fit in the adjustment. This point was used as a horizontal-only control point.

Due to the large number of images block 1 was adjusted in 2 overlapping "sub blocks".

Area_1_West consisted of flight lines 1 thru 33, and Area_1_East consisted of flight lines 29 thru 61. After the 2 blocks were adjusted the final coordinate files were merged and a "bulk orientation" was run on the entire block.

5.5   Final Coordinates and Elevations

The final horizontal coordinates are *Texas North Central (zone 4202)* state plane coordinates.

The final AT solution was found to be of a very high quality and will meet or exceed the NMAS accuracy standards for 1"=100' scale orthophoto production.

5.6   Summary of AT Results

Table 2.a - Summary of AT Results
3" gsd Area 1 East Block

Parameters	Statistics
No. of photos	4063
No. of Image points	191144
No. of GCP	13 HV
No. of GCP Check Point Run	9 HV
Standard deviation (image points)	4 μm
Standard deviation (control xyz)	0.10 ft
Standard deviation (AGPS xyz)	0.35 ft
Standard deviation (IMU ω,φ,κ)	0.05, 0.05, 0.10
RMS GCP x/y/z	0.204ft / 0.125ft / 0.137ft
RMS GCP Check Point Run x/y/z	0.242ft / 0.130ft / 0.121ft
RMS AGPS x/y/z	0.305ft / 0.389ft / 0.720ft
RMS AGPS Check Point Run x/y/z	0.305ft / 0.389ft / 0.720ft
RMS IMU	0.008° / 0.013° / 0.010°
RMS IMU Check Point Run	0.008° / 0.013° / 0.010°
Sigma	2.861 μm
RMS image cords x/y	2.162 / 1.287 μm
RMS Checkpoints x/y/z	**0.095ft / 0.176ft / 0.448ft**

Table 2.b - Summary of AT Results
3" gsd Area 1 West Block

Parameters	Statistics
No. of photos	4496
No. of Image points	202403
No. of GCP	14 HV
No. of GCP Check Point Run	10 HV
Standard deviation (image points)	4 μm
Standard deviation (control xyz)	0.10 ft
Standard deviation (AGPS xyz)	0.35 ft
Standard deviation (IMU ω,φ,κ)	0.05, 0.05, 0.10
RMS GCP x/y/z	0.142ft / 0.150ft / 0.099ft
RMS GCP Check Point Run x/y/z	0.153ft / 0.147ft / 0.106ft
RMS AGPS x/y/z	0.204ft / 0.326ft / 0.174ft
RMS AGPS Check Point Run x/y/z	0.303ft / 0.326ft / 0.174ft
RMS IMU	0.009° / 0.006° / 0.009°
RMS IMU Check Point Run	0.009° / 0.006° / 0.009°
Sigma	2.259 μm
RMS image cords x/y	1.842 / 1.384 μm
RMS Checkpoints x/y/z	**0.141ft / 0.242ft / 0.320ft**

Table 2.c - Summary of AT Results
6" gsd Area 2

Parameters	Statistics
No. of photos	4005
No. of Image points	192670
No. of GCP	39 HV
No. of GCP Check Point Run	30 HV
Standard deviation (image points)	4 μm
Standard deviation (control xyz)	0.15 ft
Standard deviation (AGPS xyz)	0.35 ft
Standard deviation (IMU ω,φ,κ)	0.05, 0.05, 0.10
RMS GCP x/y/z	0.292ft / 0.303ft / 0.197ft
RMS GCP Check Point Run x/y/z	0.292ft / 0.295ft / 0.211ft
RMS AGPS x/y/z	0.312ft / 0.417ft / 0.309ft
RMS AGPS Check Point Run x/y/z	0.313ft / 0.418ft / 0.309ft
RMS IMU	0.006° / 0.006° / 0.012°
RMS IMU Check Point Run	0.006° / 0.006° / 0.012°
Sigma	2.466 μm
RMS image cords x/y	1.943 / 1.575 μm
RMS Checkpoints x/y/z	**0.533ft / 0.560ft / 0.551ft**

Table 2.d - Summary of AT Results
6" gsd Area 4

Parameters	Statistics
No. of photos	115
No. of Image points	5224
No. of GCP	6 HV
No. of GCP Check Point Run	N/A
Standard deviation (image points)	4 μm
Standard deviation (control xyz)	0.15 ft
Standard deviation (AGPS xyz)	0.35 ft
Standard deviation (IMU ω,φ,κ)	0.05, 0.05, 0.10
RMS GCP x/y/z	0.152ft / 0.192ft / 0.102ft
RMS GCP Check Point Run x/y/z	N/A
RMS AGPS x/y/z	0.286ft / 0.291ft / 0.324ft
RMS AGPS Check Point Run x/y/z	N/A
RMS IMU	0.006° / 0.007° / 0.016°
RMS IMU Check Point Run	N/A
Sigma	2.608 μm
RMS image cords x/y	1.892 / 1.951 μm
RMS Checkpoints x/y/z	**N/A**

Table 2.e - Summary of AT Results
3" gsd Landfill Area

Parameters	Statistics
No. of photos	57
No. of Image points	2443
No. of GCP	4 HV
No. of GCP Check Point Run	N/A
Standard deviation (image points)	4 μm
Standard deviation (control xyz)	0.10 ft
Standard deviation (AGPS xyz)	0.35 ft
Standard deviation (IMU ω,φ,κ)	0.05, 0.05, 0.10
RMS GCP x/y/z	0.154ft / 0.133ft / 0.041ft
RMS GCP Check Point Run x/y/z	N/A
RMS AGPS x/y/z	0.137ft / 0.303ft / 0.127ft
RMS AGPS Check Point Run x/y/z	N/A
RMS IMU	0.004° / 0.008° / 0.017°
RMS IMU Check Point Run	N/A
Sigma	1.906 μm
RMS image cords x/y	1.328 / 1.300 μm
RMS Checkpoints x/y/z	**N/A**

Table 2.f - Summary of AT Results
3" gsd Levelland Area

Parameters	Statistics
No. of photos	177
No. of Image points	7450
No. of GCP	3 HV 1 H-only
No. of GCP Check Point Run	N/A
Standard deviation (image points)	4 μm
Standard deviation (control xyz)	0.15 ft
Standard deviation (AGPS xyz)	0.35 ft
Standard deviation (IMU ω,φ,κ)	0.05, 0.05, 0.10
RMS GCP x/y/z	0.316ft / 0.297ft / 0.108ft
RMS GCP Check Point Run x/y/z	N/A
RMS AGPS x/y/z	0.236ft / 0.234ft / 0.348ft
RMS AGPS Check Point Run x/y/z	N/A
RMS IMU	0.007° / 0.007° / 0.006°
RMS IMU Check Point Run	N/A
Sigma	2.040 μm
RMS image cords x/y	1.498 / 1.265 μm
RMS Checkpoints x/y/z	**N/A**

Table 2.g - Summary of AT Results
3" gsd Plainview Area

Parameters	Statistics
No. of photos	260
No. of Image points	10846
No. of GCP	6 HV
No. of GCP Check Point Run	N/A
Standard deviation (image points)	4 μm
Standard deviation (control xyz)	0.15 ft
Standard deviation (AGPS xyz)	0.35 ft
Standard deviation (IMU ω,φ,κ)	0.05, 0.05, 0.10
RMS GCP x/y/z	0.140ft / 0.154ft / 0.037ft
RMS GCP Check Point Run x/y/z	N/A
RMS AGPS x/y/z	0.147ft / 0.292ft / 0.214ft
RMS AGPS Check Point Run x/y/z	N/A
RMS IMU	0.004° / 0.006° / 0.009°
RMS IMU Check Point Run	N/A
Sigma	1.862 μm
RMS image cords x/y	1.362 / 1.273 μm
RMS Checkpoints x/y/z	**N/A**

APPENDIX A – CAMERA FILES

ZI IMAGING   Calibration Protocol   INTERGRAPH
                  DMC01 - 0044

Calibration Certificate

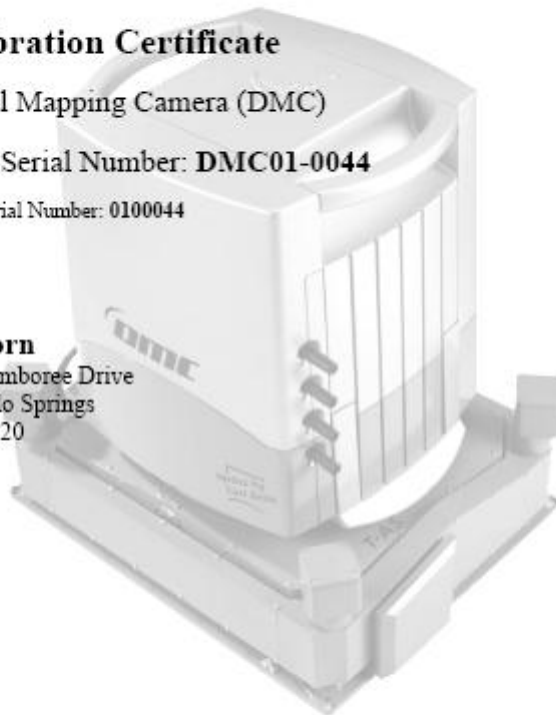Digital Mapping Camera (DMC)

DMC Serial Number: **DMC01-0044**

CBU Serial Number: **0100044**

For

Sanborn
1935 Jamboree Drive
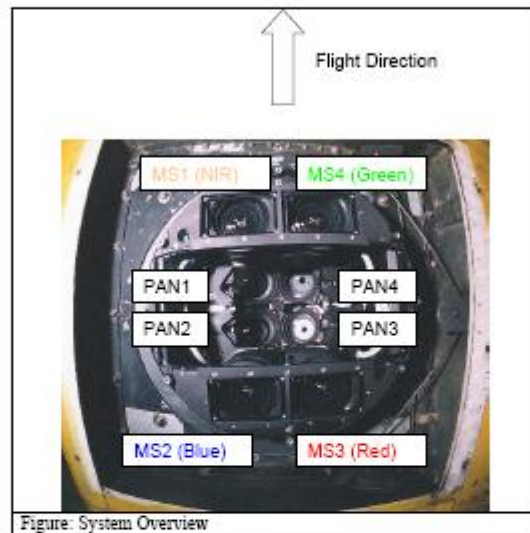Colorado Springs
CO 80920
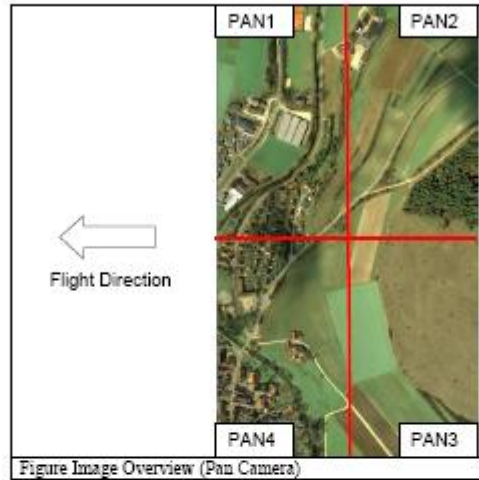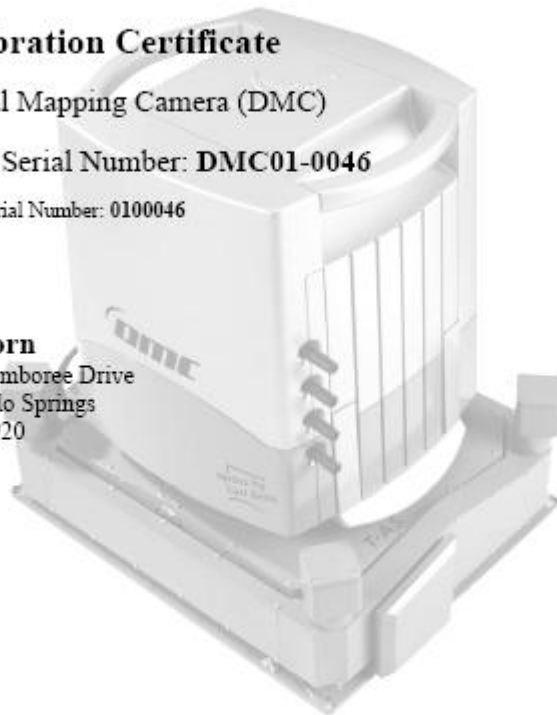
USA

ZI IMAGING

Calibration Protocol
DMC01 - 0044

INTERGRAPH

System Overview

Figure: System Overview

Calibration Protocol
DMC01 - 0044

Figure Image Overview (Pan Camera)

Camera Parameter for Virtual Image (High Resolution)

Virtual Focal Length [m]	0.12
Virtual Sensor Size [Pixel]	13824 x 7680
Virtual Pixel Size [µm]	12
Virtual Principle Point [mm]	X = 0.0 Y = 0.0
Distortion Parameter	Distortion Free

Camera Parameter for Virtual Image (Color Resolution) before Version PPS 5.0.10.3

Virtual Focal Length [m]	0.12 / 4.75
Virtual Sensor Size [Pixel]	3072 x 2048
Virtual Pixel Size [µm]	12
Virtual Principle Point [mm]	X= -0.646 Y=0.646
Distortion Parameter	Distortion Free

Calibration Protocol
DMC01 - 0044

Camera Parameter for Virtual Image (Color Resolution) after Version PPS 5.0.10.3

Virtual Focal Length [m]	0.030
Virtual Sensor Size [Pixel]	3456x1920
Virtual Pixel Size [μm]	12
Virtual Principle Point [mm]	X = 0.0 Y = 0.0
Distortion Parameter	Distortion Free

Calibration Certificate

Digital Mapping Camera (DMC)

DMC Serial Number: **DMC01-0046**

CBU Serial Number: 0100046

For

Sanborn
1935 Jamboree Drive
Colorado Springs
CO 80920

USA

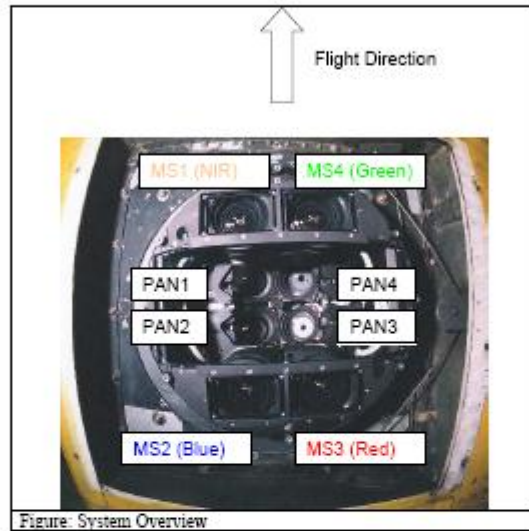ZI IMAGING   Calibration Protocol   INTERGRAPH
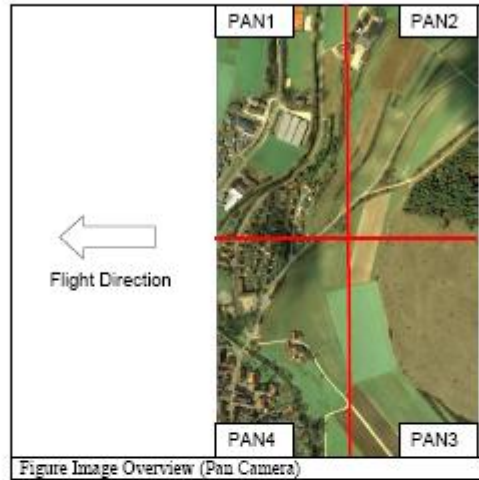   DMC01 - 0046

System Overview

Figure: System Overview

ZI Imaging

Calibration Protocol
DMC01 - 0046

INTERGRAPH

Figure Image Overview (Pan Camera)

Camera Parameter for Virtual Image (High Resolution)

Virtual Focal Length [m]	0.12
Virtual Sensor Size [Pixel]	13824 x 7680
Virtual Pixel Size [μm]	12
Virtual Principle Point [mm]	X = 0.0 Y = 0.0
Distortion Parameter	Distortion Free

Camera Parameter for Virtual Image (Color Resolution) before Version PPS 5.0.10.3

Virtual Focal Length [m]	0.12 / 4.75
Virtual Sensor Size [Pixel]	3072 x 2048
Virtual Pixel Size [μm]	12
Virtual Principle Point [mm]	X= -0.646 Y=0.646
Distortion Parameter	Distortion Free

Calibration Protocol
DMC01 - 0046

INTERGRAPH

Camera Parameter for Virtual Image (Color Resolution) after
Version PPS 5.0.10.3

Virtual Focal Length [m]	0.030
Virtual Sensor Size [Pixel]	3456x1920
Virtual Pixel Size [µm]	12
Virtual Principle Point [mm]	X = 0.0 Y = 0.0
Distortion Parameter	Distortion Free

ZI IMAGING   Calibration Protocol   INTERGRAPH
                      DMC01-107
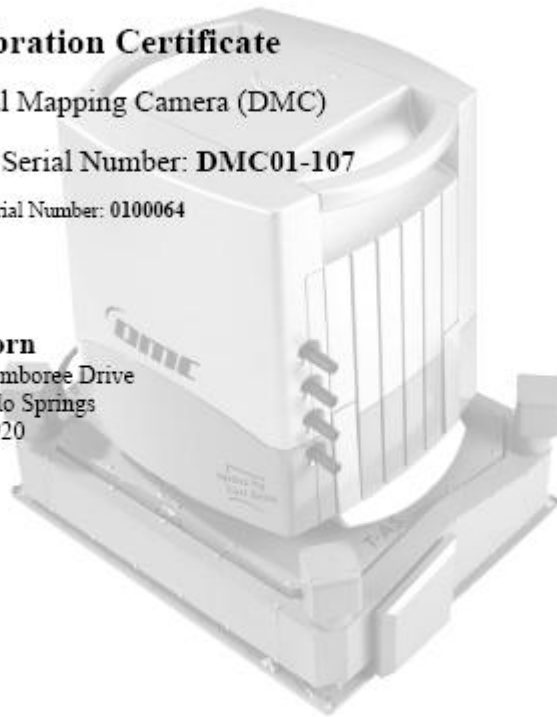
Calibration Certificate

Digital Mapping Camera (DMC)

DMC Serial Number: **DMC01-107**

CBU Serial Number: **0100064**

For

Sanborn
1935 Jamboree Drive
Colorado Springs
CO 80920

USA

Figure: System Overview

Calibration Protocol
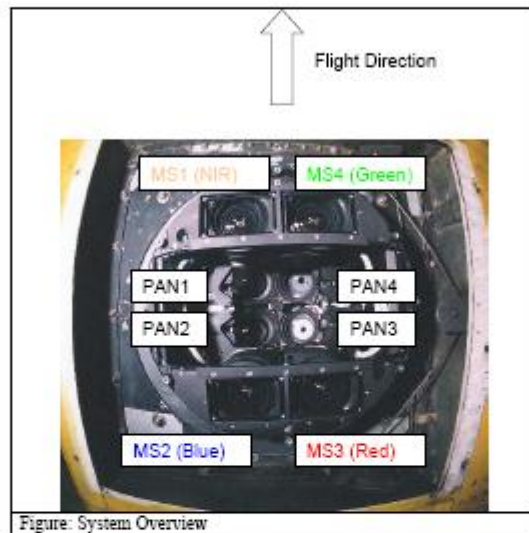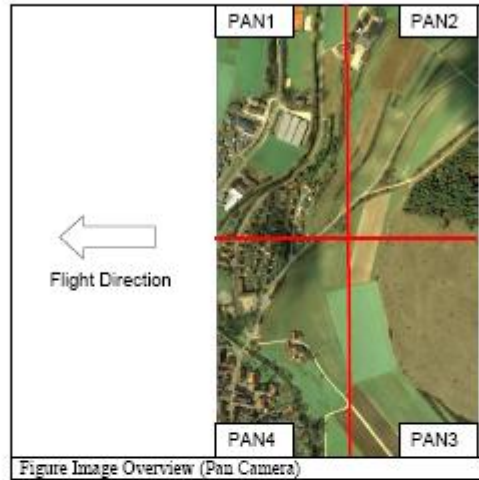DMC01-107

Figure Image Overview (Pan Camera)

Camera Parameter for Virtual Image (High Resolution)

Virtual Focal Length [m]	0.12
Virtual Sensor Size [Pixel]	13824 x 7680
Virtual Pixel Size [µm]	12
Virtual Principle Point [mm]	X = 0.0 Y = 0.0
Distortion Parameter	Distortion Free

Camera Parameter for Virtual Image (Color Resolution) before Version PPS 5.0.10.3

Virtual Focal Length [m]	0.12 / 4.75
Virtual Sensor Size [Pixel]	3072 x 2048
Virtual Pixel Size [µm]	12
Virtual Principle Point [mm]	X= -0.646 Y=0.646
Distortion Parameter	Distortion Free

Calibration Protocol
DMC01-107

INTERGRAPH

Camera Parameter for Virtual Image (Color Resolution) after
Version PPS 5.1.10.3

Virtual Focal Length [m]	0.030
Virtual Sensor Size [Pixel]	3456x1920
Virtual Pixel Size [μm]	12
Virtual Principle Point [mm]	X = 0.0 Y = 0.0
Distortion Parameter	Distortion Free