Freshwater Creek Watershed and Elk River Watershed Tributaries of Humbolt Bay, California

March 2005

LIDAR Campaign Final Report

Prepared by:

SANBORN

EXECUTIVE SUMMARY

In March of 2005, Sanborn was contracted by Space Imaging to execute a LIDAR (Light Detection and Ranging) survey campaign in the Humbolt Bay Area, in Northern California. LIDAR data in the form of 3-dimensional positions of a dense set of masspoints was collected of the Freshwater Creek and Elk River Watersheds. These data will be used for the development of a digital elevation model (DEM).

The Optech ALTM (Airborne Laser Terrain Mapping) LIDAR system is calibrated by conducting flight passes over a known ground surface before and after each LIDAR mission. During final data processing, the calibration parameters are inserted into post-processing software.

Two airborne GPS (Global Positioning System) base stations were used in this project. An existing National Geodetic Survey (NGS) point was used at Murray Field Airport and a point was set at Kneeland Airport. These two stations were tied to two additional NGS markers to create a GPS survey network. The network observations and adjustment were completed on the GRS80 ellipsoid.

The acquired LIDAR data was processed to obtain first and last return point data. The last return data was further filtered to yield a LIDAR surface representing the bare earth.

The filtered bare earth last return data was used to make a point shapefile of elevation values. This in turn served as the input to the interpolation process that created a regularly spaced grid of elevation values, the actual DEM.

The contents of this report summarize the methods used to establish the base station network, preform the LIDAR data collection and post-processing as well as the results of these methods.

TABLE OF CONTENTS

1. INTRODUCTION 1

1.1 DURATION/TIME PERIOD 1
1.2 CONTACT 1
1.3 PURPOSE OF THE LIDAR ACQUISITION 1
1.4 PROJECT LOCATION 1
1.5 PROJECT SCOPE 1
1.6 DATUM ISSUES 1
1.6.1 Horizontal Datum 2
1.6.2 Vertical Datum 2

2. LIDAR CALIBRATION 2

2.1 INTRODUCTION 2
2.2 CALIBRATION PROCEDURES 2
2.2.1 Building Calibration 2
2.2.2 Runway Calibration, System Performance Validation 3
2.3 CALIBRATION RESULTS 3

3. GEODETIC BASE NETWORK 5

3.1 NETWORK SCOPE 5
3.2 DATA PROCESSING AND NETWORK ADJUSTMENT 5

4. LIDAR DATA CAPTURE 8

4.1 FIELD WORK / PROCEDURES 8
4.2 FINAL LIDAR PROCESSING 8
4.3 PROBLEMS AND DELAYS 9
4.4 DAILY RUNWAY PERFORMANCE/DATA VALIDATION TESTS 9

5. DEM PRODUCTION 9

5.1 CONVERSION TO VECTOR FORMAT 9
5.2 DEM GENERATION 9
5.3 MOSAICING OF DEM TILE UNITS 9

LIST OF FIGURES

FIGURE 1. CALIBRATION PASS 1. 3
FIGURE 2. CALIBRATION PASS 2. 3
FIGURE 3. RUNWAY CALIBRATION 3
FIGURE 4. RUNWAY CALIBRATION RESULTS 4
FIGURE 5. SURVEY NETWORK DIAGRAM 5
FIGURE 6. MOVEMENT IN EDGEMATCHED PIXELS 11

LIST OF TABLES

TABLE 1. SURVEY LOOP CLOSURE SUMMARY 6
TABLE 2. ADJUSTMENT CONSTRAINTS 7
TABLE 3. LIDAR ACQUISITION PARAMETERS 8
TABLE 4. RUNWAY VALIDATION RESULTS 10

APPENDIX A - FULLY CONSTRAINED LEAST SQUARES ADJUSTMENT

1. INTRODUCTION

This report contains the technical write-up of the Freshwater Creek and Elk River Watersheds LIDAR campaign, including system calibration techniques, the establishment of base stations by a differential GPS network survey, and the collection and post-processing of the LIDAR data.

1.1 Duration/Time Period

The LIDAR aircraft arrived on site March 5th, 2005 and the LIDAR data collection was accomplished between March 6th and March 14th, 2005. Murray Field Airport was used as the airfield of operation.

1.2 Contact

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

Sanborn
1935 Jamboree Drive
Colorado Springs, CO 80920

Attention: ----------- Andy Lucero (Project Manager)
Telephone: --------- 1–719-593-0093
FAX: ---------------- 1–719-528-5093
email: --------------- alucero@sanborn.com

1.3 Purpose of the LIDAR Acquisition

This LIDAR operation was designed to develop an elevation database to aid in “improved Total Maximum Daily Load (TMDL)” sediment estimates, (per the Work Order Statement issued by Space Imaging).

1.4 Project Location

The project location is defined as Project Area 1: Freshwater Creek watershed, encompassing 37,018 acres and as Project Area 2: Elk River watershed, encompassing 37,270 acres, located in Humbolt county, California.

1.5 Project Scope

The Freshwater Creek and Elk River watersheds campaign was designed to collect LIDAR derived masspoints at a point density of 4.5 points per square meter within the project area. The data were processed to facilitate the generation of an appropriate DEM for topographic mapping.

1.6 Datum Issues

Two stations were used as Airborne GPS base stations for this project. In order to obtain accurate horizontal and vertical coordinates for these stations a ground control network was surveyed using GPS to tie the newly set station to existing

NGS control monuments. A fully constrained adjustment was run on the network defining the horizontal and vertical datums through the published coordinates and heights of NGS monuments.

1.6.1 Horizontal Datum

The horizontal datum associated with the LIDAR data is NAD83, as realized by the physical control monuments used to constrain the survey control network.

1.6.2 Vertical Datum

The vertical datum associated with the LIDAR data is the NAVD88, as realized by the physical benchmarks used to constrain the survey control network.

2. LIDAR CALIBRATION

2.1 Introduction

LIDAR calibrations are performed to determine and therefore eliminate systematic bias' that occur within the hardware of the ALTM system. Once the biases are determined they can be modeled out. The systematic bias' that are corrected for include scale, roll, and pitch.

The following procedures are intended to eliminate blunders in the field and office work, and are designed to detect inconsistencies. The emphasis is not only on the quality control (QC) aspects, but also on the documentation, i.e., on the quality assurance (QA).

2.2 Calibration Procedures

Sanborn performs two types of calibrations on its LIDAR system. The first is a building calibration, done any time the LIDAR system has been moved from one plane to another. New calibration parameters are computed and compared with previous calibration runs. If there is any change, the new values are updated internally or during the LIDAR post-processing. These values are applied to all data collected with this plane/ALTM system configuration.

Once final processing calibration parameters are established from the building data, a precisely-surveyed surface is observed with the LIDAR system to check for stability in the system. This is done several times during each mission. An average of the systematic bias' are applied on a per mission basis.

2.2.1 Building Calibration

Whenever the ALTM is moved to a new aircraft, a building calibration is performed. The rooftop of a large, flat, rectangular building is surveyed on the ground using conventional survey methods, and used as the LIDAR calibration target. The aircraft flies several specified passes over the building with the ATLM system set first in scan and then in profile modes, with the scan angle set to zero degrees.

Figure 1 shows a pass over the center of the building. The purpose of this pass is to identify a systematic bias in the scale of the system.

Figure 2 demonstrates a pass along a distinct edge of the building to verify the roll compensation performed by the INS.

Additionally, a pass is made in profile mode across the middle of the building to compensate for any bias in pitch.

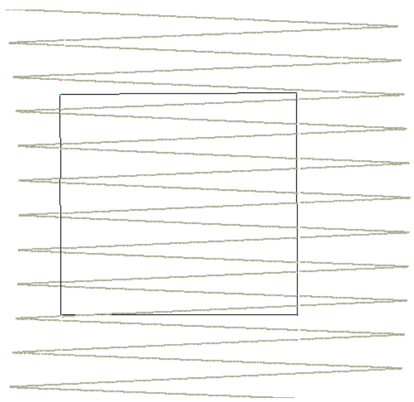

Figure 1: Calibration Pass 1

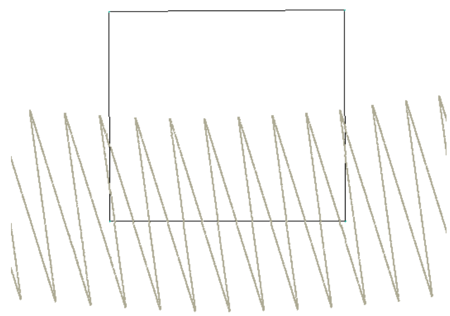

Figure 2: Calibration Pass 2

2.2.2 Runway Calibration, System Performance Validation

An active asphalt runway was precisely-surveyed at the Murray Field airport using kinematic GPS survey techniques (accuracy: ±3cm at 1σ, along each coordinate axis) to establish an accurate digital terrain model of the runway surface. The LIDAR system is flown at right angles over the runway several times and residuals are generated from the processed data. Figure 3 shows a typical pass over the runway surface.

Approximately 25,000 LIDAR points are observed with each pass. These points are “draped” over the runway surface TIN (Triangular Irregular Network) to compute vertical residuals for every data point. The residuals are analyzed with respect to the location *along* the runway to identify the level of noise and system biases.

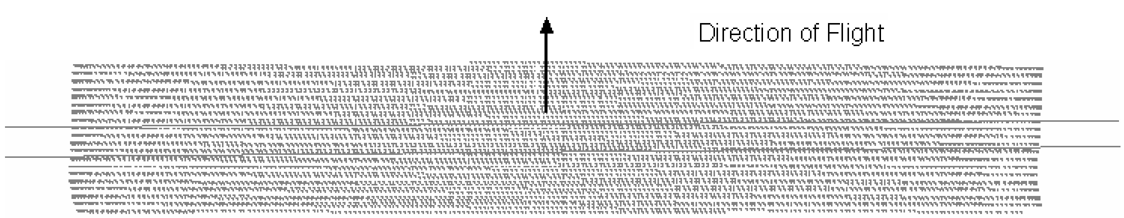

Figure 3: Runway Calibration

2.3 Calibration Results

The LIDAR data captured over the building are used to determine whether there have been any changes to the alignment of the IMU with respect to the laser system. The parameters are designed to eliminate systematic biases within certain system parameters.

The runway over-flights are intended to be a quality check on the calibration and to identify any system irregularities and overall noise. IMU misalignments and internal system calibration parameters are verified by comparing the collected LIDAR points with the runway surface.

Figure 4, on page 4, shows the typical results of a runway over-flight analysis. The X-axis represents the position *along* the runway. The overall statistics from this analysis provides evidence of the overall random noise in the data (typically, 7cm standard deviation – an unbiased estimator, and 8cm RMS which includes any biases) and indicate that the system is performing within specifications. As described in later sections of this report, this analysis will identify any peculiarities within the data along with mirror-angle scale errors (identified as a "smile" or "frown" in the data band) or roll biases.

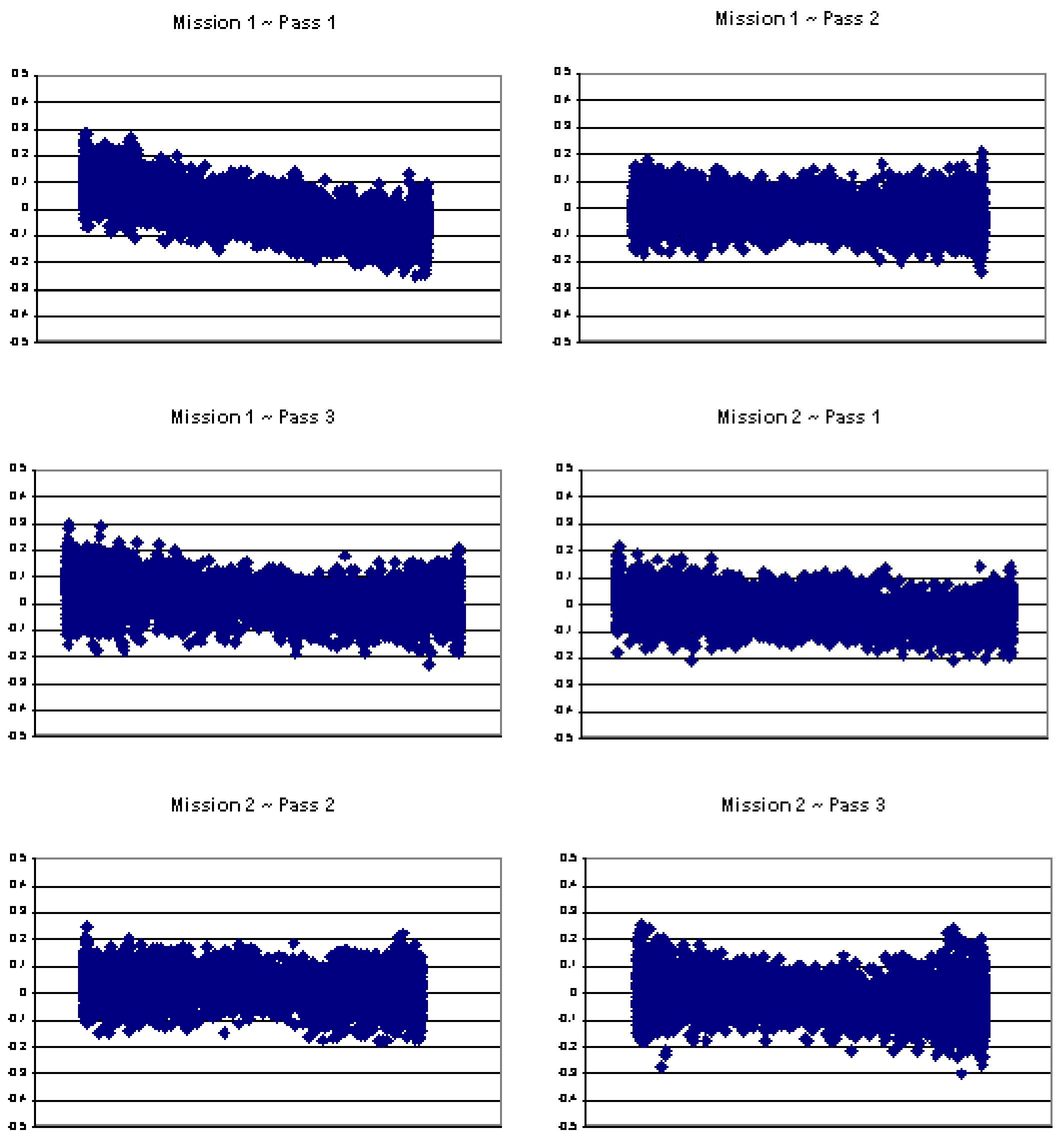

FIGURE 4: RUNWAY CALIBRATION RESULTS

3. Geodetic Base Network

3.1 Network Scope

One new point was set to be used as an Airborne GPS base station. A new point is a twelve inch spike nailed to be flush with the ground level in an open and secure area, where a GPS receiver can be set up and left to log data for the duration of the LIDAR flight mission.

During the LIDAR campaign, the Sanborn field crew conducted a GPS field survey to establish a survey network (figure 5) containing the GPS base stations used to support the campaign. Point 901, an NGS point located at Murray Field airport, and point 501 a new point established at the Kneeland airport were used as base stations for every mission. Point 601 and 801 are also NGS monuments that were used to tie in the network. See table 2 for station names, orders and constraints.

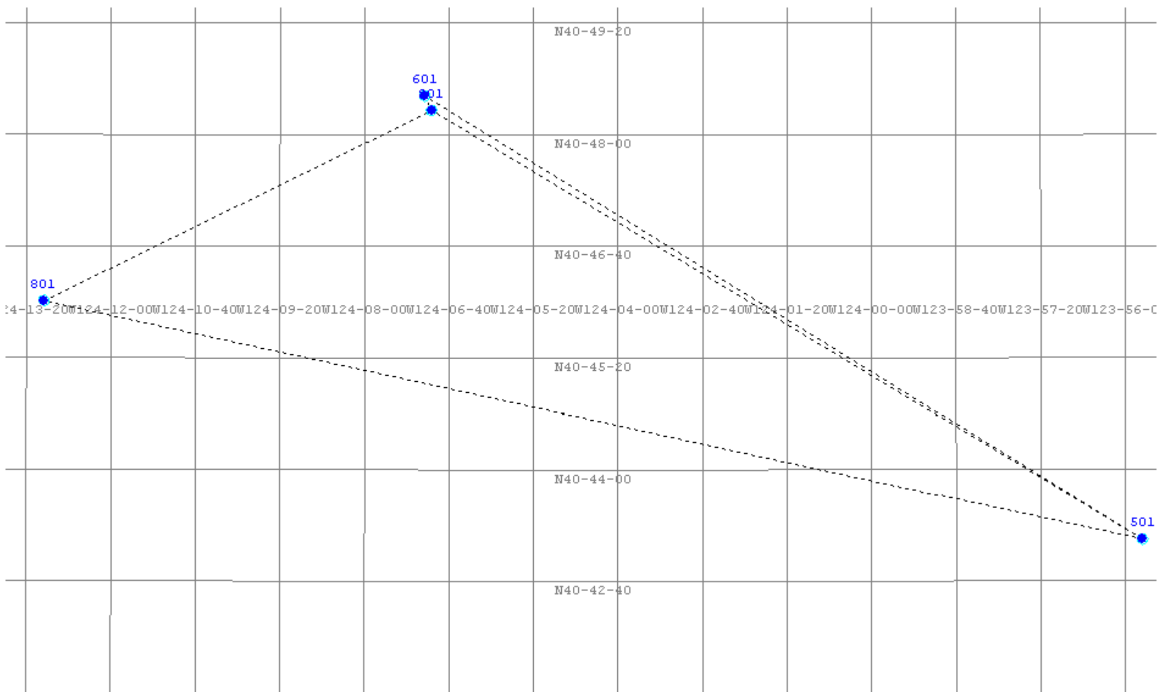

Figure 5: Survey Network Diagram

3.2 Data Processing and Network Adjustment

All static baseline vectors were processed using Trimble Navigation's GPSurvey™ (Ver. 2.35a) software. Fixed bias solutions were obtained for all baselines. The broadcast ephemeris was used, since the accuracy and extent of the network does not warrant the use of the precise ephemeris.

The loop misclosures are summarized in Table 1 below.

The misclosures in each component (X, Y and Z) are given in millimeters and parts per million (ppm) in an ECEF Cartesian coordinate system. The spatial misclosure in ppm is also provided. All loops comprise of quasi–independent baselines from at least two different sessions. Every station in the network appears at least once in a loop. All loops, in fact, satisfy GPS guidelines for first order work, namely:

- in any component (X, Y, Z), the maximum misclosure does not exceed 250 mm , the worst case of this network is 57.2 mm.
- in any component (X, Y, Z), the maximum misclosure in terms of the loop length does not exceed 12.5 ppm, the worst case of this network is 1.53 ppm.
- in any component (X, Y, Z), the average misclosure in terms of the loop length does not exceed 8 ppm, the worst case of this network is 1.68 ppm.

Table 1. Survey Loop Closure Summary

LOOP	**δX [mm]**	**δX [ppm]**	**δY [mm]**	**δY [ppm]**	**δZ [mm]**	**δZ [ppm]**	**LENGTH [m]**	**δS [ppm]**
901-601-501-901	5.4	0.14	25.5	0.68	57.2	1.53	37506.7	1.68
901-501-801-901	15.0	0.28	2.9	0.05	20.6	0.39	52978.4	0.48

A 3-dimensional network adjustment was carried out using GeoLab™ (version 3.61) 3-D adjustment software. The network is displayed in Figure 5.

Initially, a minimally constrained adjustment was performed to examine the internal accuracy of the network. The geodetic latitude, longitude of one existing control point were held fixed and the elevation of another existing control point was held fixed. The adjustment comprises 4 stations and 15 baseline vector components (5 baselines). *A priori* weights for the observations were based on the scaled variance-covariance sub-matrices from the GPSurvey™ solutions.

No standardized residual were flagged for possible rejection under the Tau_{max}–test (τ_{MAX}–test), at the 0.05 level of significance. The histogram of standardized residuals indicates that the observations are well distributed. The *a posteriori* variance factor (σ_o^2= 1.0600) indicates that the scaled *a priori* standard deviations of the vector components are realistic. The absolute and relative confidence regions were not scaled by the *a posteriori* variance factor.

All station pairings with the exception of one (901 to 601) meet the horizontal positioning standard for *first order* surveys, i.e., the relative horizontal precision between each pair of points does not exceed 10 mm + 10 ppm of their horizontal separation, at the 95 percent level of confidence. Baseline 901 to 601 does not meet first order due to being a short baseline, it does however meet second order standards. Despite one second order baseline the network is classified as *first order* in terms of its *internal* accuracy.

To complete a fully constrained adjustment, the network was horizontally constrained to control points 901 and 801, and vertically constrained by orthometric elevation to 901 and 801, see Table 2 for associated orders and assigned standard deviations.

TABLE 2. ADJUSTMENT CONSTRAINTS
(standard deviations in meters)

Horizontal

Code	NGS Station Name	Order	ϕ	λ
901	ARP 1967	1	0.047	0.047
801	941 8767 TIDAL 11	A	0.047	0.047

Vertical

Code	NGS Station Name	Order	Ht
901	ARP 1967	3	0.017
801	941 8767 TIDAL 11	1 – II	0.017
601	H 75 RESET	1 – II	0.021

A full listing of the constrained adjustment is contained in Appendix A. The residuals and the standardized residuals are listed on page 6 of the adjustment results. One of the 15 vector components was flagged for possible rejection under the τMAX - test at the 0.05 level of significance. The slight increase in the a posteriori variance factor (σ_o^2= 1.0938) from the minimally constrained adjustment indicates that the network is not being unduly distorted by the imposition of the constraints. The absolute and relative confidence regions were not scaled by the a posteriori variance factor. The relative horizontal confidence ellipses appear on page 10 of Appendix A. Examination of the relative precision reveals that the network has maintained its high internal accuracy, with the exception of baseline 901 to 601, being a short baseline.

4. LIDAR DATA CAPTURE

4.1 Field Work / Procedures

Data capture began March 6th and was completed March 14th, 2005. Two GPS base stations were set up during each mission.

Pre-flight checks such as cleaning the sensor head glass are performed. A four minute INS initilization is conducted on the ground, with the engines running, prior to flight, to establish fine-alignment of the INS. GPS ambiguities are resolved by flying within ten kilometers of the base stations.

The flight missions were typically between three and five hours in duration including runway calibration flights flown at the beginning and the end of each mission. Some missions were reduced to between one and two hours due to rapid influx of fog. During the data collection, the operator recorded information on logsheets which includes weather conditions, LIDAR operation parameters, and flight line statistics. Near the end of the mission GPS abiguities are again resolved by flying within ten kilometers of the base stations, to aid in post-processing.

Table 3 shows the planned LIDAR acquisition parameters with a flying height of 1,000 meters above gound level (agl) on a mission to mission basis.

Table 3. LIDAR Acquisition Parameters

Average Altitude	1,000 Meters Above Ground Level
Airspeed	~100 Knots
Scan Frequency	40 Hertz
Scan Width Half Angle	16 Degrees
Pulse Rate	50000 Hertz

Preliminary data processing was performed in the field immediately following the missions for quality control of GPS data and to ensure sufficient overlap between flight lines. Any problematic data could then be reflown immediately as required. Final data processing was completed in the Colorado Springs office.

4.2 Final LIDAR Processing

Final post-processing of LIDAR data involves several steps. The airborne GPS data were post-processed using Waypoint's GravNAV™ software (version 6.03). A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. Whenever practicle, LIDAR acquisition was limited to periods when the PDOP was less than 4.0.

The GPS trajectory was combined with the raw IMU data and post-processed using Applanix Inc.'s POSPROC Kalman Filtering software. This results in a two-fold improvement in the attitude accuracies over the real-time INS data. The best estimated trajectory (BET) and refined attitude data are then re-introduced into the Optech REALM software to compute the laser point-positions – the trajectory is combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points.

First and last return values are produced within REALM software. The first return information provides a useful depiction of the “canopy” within the project area. The last return is further processed to obtain ground-filtered data with a corresponding regular grid DEM.

Laser point filtering was accomplished using TerraScan LIDAR processing and modeling software. The bare earth surface generated by TerraScan is used to produce regular grid DEMs.

4.3 Problems and Delays

Fog over the airport and caused one pre-mission calibration and four post-mission calibrations to be missed. Without much warning the fog would roll in and cover the calibration site, which was the runway at Murray Field airport, on multiple occasions the aircraft was required to land at Arcata and Rohnerville airports.

Data collection was not inturupted by fog and no major delays occurred. Higher ground within the project area was flown when lower elevations were fogged in.

4.4 Daily Runway Performance/Data Validation Tests

Performance flights over the runway test field were performed before and after each mission. Table 4 shows the standard deviation and RMS values of the residuals between the test flights and the known surface of the test ranges for each pass. The maximum RMS value is 0.128. The average RMS among all test flights is 0.052 meters. Figure 4, above, provides a graphical representation of the runway results.

Rigorous quality assurance procedures were followed to ensure that the appropriate data accuracy was achieved.

Table 4. Runway Validation Results (meters)

Mission	RMS
065a	0.020
066a	0.025
066b	0.016
067a	0.037
068a	0.128
069a	0.062
069b	0.046
071a	0.086
072a	0.048
073a	0.054

5. DEM Production

5.1 Convertion to vector format

The filtered bare earth last return data was created in a tabular format. This tabular data existed as 1291 separate text files. Each of these contained the filtered points (consisting of x and y coordinates and an elevation value) for a 0.5 km square (2.5 km^2) tile unit of the project area. Because the interpolation program requires a vector input, these data were first made into a point shapefiles. This was carried out in ESRI ArcGIS. A script was writen that read in the coordinates and placed the elevation value in the shapefile’s “Z” attribute for every point in the unit. This script was batched and run to create 1291 point shapefiles.

5.2 DEM Generation

The kriging algorithm was chosen to convert the data from an irregularly spaced cloud of points to the regularly spaced grid of values that makes up a DEM. This algorithm is available in either the Spatial Analyst or 3D Analyst extention of ArcGIS. A number of parameters have to be provided to the kriging algorothm to instruct it exactly how to use the avaiable elevation data. Experimantation determined that the folowing parameters provided the most pleasing result with a minimal impact on processing time:

Semivariogram model: Spherical

Points: 16

Search Radius: 20 meters

Cell size: 1 meter

Lag: 5 meters

As for shapefile generation, a script was writen that batched the kriging of the individual units. This was key as kriging is a very computationally intensive process. Most units require between 30 minuites and 10 hours to complete the kriging process. The end result was 1291 DEMs, in GRID format, 0.5 km square.

5.3 Mosaicing of DEM tile units

In order to provide a more easily interpreted model of the complete project area, the 1291 tiles were mosaiced. One mosaic was generated for the Freshwater Creek watershed and one for the Elk River watershed. These steps were carried out in ArcGIS Workstation’s GRID module and ArcMap.

Before the mosaicing could start, each tile was resampled (snapped) so that its cell corner coordinates would be the same as every other tile unit. (These corners varied from unit to unit because the kriging process gets this value from the bounding box of the points that make up the tile. As mentioned above, these points are irregularly spaced, thus each kriged tile doesn't fall on the exact same snap grid). This initial resampling was necessary because of the subsequent resamplings that would occur as part of the mosaicing process (see below). If not done, multiple small hoizontal shifts would have occured instead of one single predictable shift. Thus, each tile was resampled so that it's cell corners fell on a coordinate that was a multiple of the cell size. As the DEMs have a resolution of 1 meter, this simply meant the corner coordinates had to be a whole number. The maximum possible shift was 0.5 meters in the x and y. Because all subsequent processing would occur on this common grid, no (further) horizontal shift occured.

The actual mosaicing process consisted of two steps. This stems from the fact that a certain amount of edgematching had to be done between tiles. This was the case because the elevation values are not as well constrained at the tile edges (as there are no available points past the tile edge). Thus, the elevation made small but abrupt changes at the tile edge, resulting in scarp-like artefacts along the tile boundaries. While this effect is fairly modest when looking at the DEM, it becomes very pronounced when dealing with DEM derivatives such as slope or aspect. Different programs were used for the two mosaic steps because each program does its edgematch in a slightly different way. Which one is better depends on the nature of the inputs. The first mosaic step was done in GRID. GRID has a limit of 50 datasets per command (49 inputs and the output), thus, the first mosaic resulted in 7 by 7 blocks of tiles. These composite blocks were then mosaiced again, this time in ArcMap, up to the level of the watershed, once for Freshwater Creek, once for Elk River.

The amount of elevation change that resulted from the above edgematching is described in Figure 6.

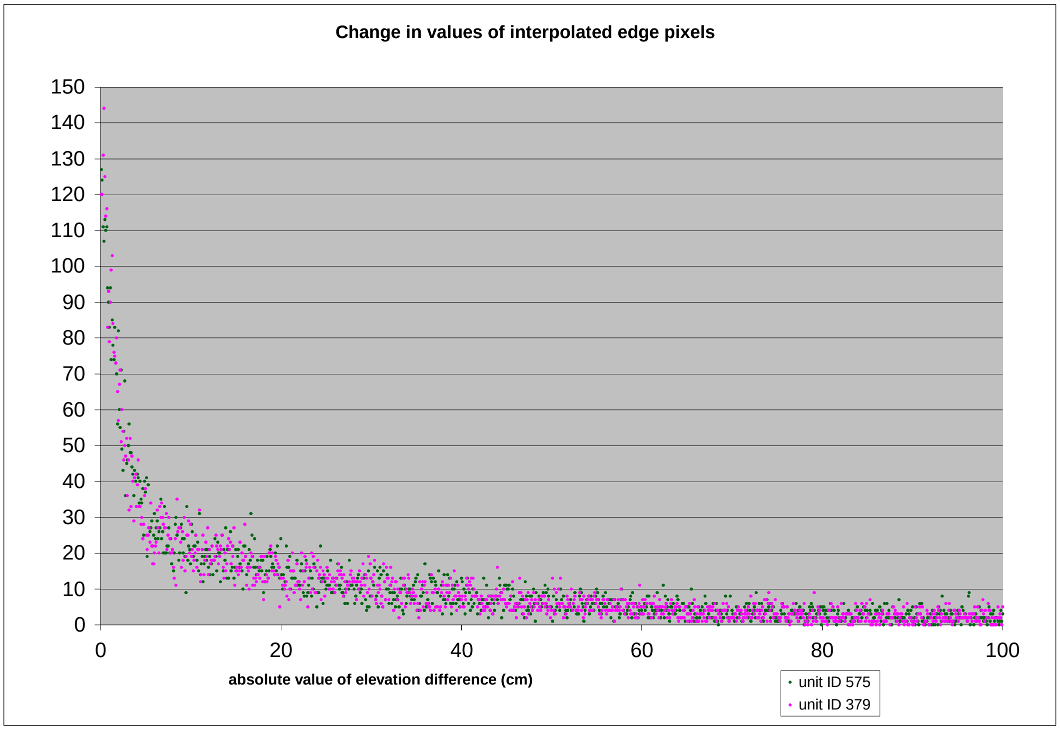

Figure 6: Movement in edgematched pixels

This figure plots absolute value of elevation change in the interpolated edge pixels versus number of pixels for two sample tile units, 575 and 379. It can be seen that the majority of the shifted pixels were moved by less than 20 centimeters (50% of edge pixels are shifted less than 18.5 and 18.7 cm in units 575 and 379 respectively). As the amount of overlap between tiles was about 5 pixels (5 meters), the vast majority of the pixels are not altered at all. The standard deviation for the elevation change for the whole tile was 0.127 and 0.121 for units 575 and 379 respectively.

APPENDIX A

FULLY CONSTRAINED LEAST SQUARES ADJUSTMENT

```
================================================================================
                          humboldt_c  fully constrained
GeoLab V3.65                  GRS 80             UNITS: m,DMS           Page
0001
==============================================================================
===
14:45:46, Fri Mar 25, 2005

Input file:  J:\Survey\Humbolt_LIDAR\adjustment\humboldt_c.iob
Output file: J:\Survey\Humbolt_LIDAR\adjustment\humboldt_c.lst
Options file: C:\glab32v3\default.cfg

Geoid File:  c:\glab32v3\geoid03\g2003u05pc.gsp
 -----------------------------------------------------------------------------
-
|             PARAMETERS                 |            OBSERVATIONS
|
|-----------------------------------------------------------------------------
-|
|   Description    |      Number       |   Description     |      Number
|
|-----------------------------------------------------------------------------
-|
| No. of Stations  |           4       | Directions        |           0
|
| Coord Parameters |          12       | Distances         |           0
|
| Free Latitudes   |           4       | Azimuths          |           0
|
| Free Longitudes  |           4       | Vertical Angles   |           0
|
| Free Heights     |           4       | Zenithal Angles   |           0
|
| Fixed Coordinates|           0       | Angles            |           0
|
| Astro. Latitudes |           0       | Heights           |           2
|
| Astro. Longitudes|           0       | Height Differences|           0
|
| Geoid Records    |           0       | Auxiliary Params. |           0
|
| All Aux. Pars.   |           0       | 2-D Coords.       |           4
|
| Direction Pars.  |           0       | 2-D Coord. Diffs. |           0
|
| Scale Parameters |           0       | 3-D Coords.       |           0
|
| Constant Pars.   |           0       | 3-D Coord. Diffs. |          15
|
| Rotation Pars.   |           0       |                   |
|
| Translation Pars.|           0       |                   |
|
|                  |                   |                   |
|
|                  |    --------       |                   |    --------
|
| Total Parameters |          12       | Total Observations|          21
|
|-----------------------------------------------------------------------------
-|
|                      Degrees of Freedom =         9
|
 -----------------------------------------------------------------------------
-
```

```
--------------------------------------------------------------------------
--
                        SUMMARY OF SELECTED OPTIONS
--------------------------------------------------------------------------
--
    OPTION                              |   SELECTION
--------------------------------------------------------------------------
--
    Computation Mode                    |   Adjustment
    Maximum Iterations                  |   5
    Convergence Criterion               |   0.00100
    Residual Rejection Criterion        |   Tau Max
    Confidence Region Types             |   1D 2D Station Relative
    Relative Confidence Regions         |   Connected Only
    Variance Factor (VF) Known          |   Yes
    Scale Covariance Matrix With VF     |   No
    Scale Residual Variances With VF    |   No
    Force Convergence in Max Iters      |   No
    Distances Contribute To Heights     |   No
    Compute Full Inverse                |   Yes
    Optimize Band Width                 |   Yes
    Generate Initial Coordinates        |   Yes
    Re-Transform Obs After 1st Pass     |   Yes
    Geoid Interpolation Method          |   Bi-Quadratic
--------------------------------------------------------------------------
--
```

```
==========================================================================
===
                         humboldt_c  fully constrained
GeoLab V3.65                 GRS 80             UNITS: m,DMS           Page
0002
==========================================================================
===
Input Station Data:
FFF STATION      ELIP-LATITUDE     ELIP-LONGITUDE    ELIP-HEIGHT
                 ASTRO-LATITUDE    ASTRO-LONGITUDE   ORTHO-HEIGHT
                 N/S DEFLECTION    N/S DEFLECTION    GEOID-HEIGHT
                 NORTHING          EASTING           PROJECTION
--- ------------ ----------------- ----------------- ------------
000 501          N 40 43   9.75397 W123 55  43.85199      811.203
                 N 40 43   9.75397 W123 55  43.85199      811.203
                 -  0  0      1.68 -  0  0     10.24      -29.369
                       4508020.747       421551.582 UTM 10
000 601          N 40 48  27.53196 W124  7   3.04762      -27.382
                 N 40 48  27.53196 W124  7   3.04762      -27.382
                 -  0  0      1.95 -  0  0     11.19      -30.300
                       4518005.267       405741.844 UTM 10
000 801          N 40 46   0.90245 W124 13   3.45797      -25.235
                 N 40 46   0.90245 W124 13   3.45797        4.155
                 -  0  0      2.95 -  0  0      9.34      -30.778
                       4513596.294       397234.635 UTM 10
000 901          N 40 48  17.34986 W124  6  56.72986      -27.046
                 N 40 48  17.34986 W124  6  56.72986        1.860
                 -  0  0      1.92 -  0  0     11.35      -30.294
                       4517689.408       405885.873 UTM 10
```

```
================================================================================
===
                         humboldt_c  fully constrained
GeoLab V3.65                 GRS 80             UNITS: m,DMS           Page
0003
================================================================================
===
Adjusted NEO Coordinates:
                                NORTHING         EASTING   O-HEIGHT
 CODE FFF STATION                STD DEV         STD DEV    STD DEV MAPPROJ
 ---- --- ------------ ---------------- ---------------- ---------- -------
 NEO  000 501              4508019.218       421552.505    839.167 UTM 10  m
0
                                 0.045            0.045      0.022
 NEO  000 601              4518003.743       405742.784      1.474 UTM 10  m
0
                                 0.045            0.045      0.020
 NEO  000 801              4513596.242       397234.639      4.156 UTM 10  m
0
                                 0.045            0.045      0.017
 NEO  000 901              4517685.416       405888.630      1.859 UTM 10  m
0
                                 0.045            0.045      0.017
```

```
================================================================================
===
                         humboldt_c  fully constrained
GeoLab V3.65                 GRS 80             UNITS: m,DMS            Page
0004
================================================================================
===
Adjusted PLH Coordinates:
                                  LATITUDE          LONGITUDE  ELIP-HEIGHT
 CODE FFF STATION                  STD DEV            STD DEV      STD DEV
 ---- --- ------------ ----------------- ----------------- ------------
 PLH  000 501          N 40 43   9.70469 W123 55  43.81197      809.798 m
0
                                     0.045              0.045        0.022
 PLH  000 601          N 40 48  27.48292 W124  7   3.00667      -28.825 m
0
                                     0.045              0.045        0.020
 PLH  000 801          N 40 46   0.90077 W124 13   3.45780      -26.623 m
0
                                     0.045              0.045        0.017
 PLH  000 901          N 40 48  17.22154 W124  6  56.61003      -28.434 m
0
                                     0.045              0.045        0.017
```

```
==============================================================================
===
                         humboldt_c  fully constrained
GeoLab V3.65                 GRS 80            UNITS: m,DMS           Page
0005
==============================================================================
===
Geoid Values:
 CODE     STATION         N/S DEFLECTION    E/W DEFLECTION   UNDULATION
 ----     ------------ ----------------- ----------------- ------------
 GEOI     501          -  0  0      1.68 -  0  0     10.24      -29.369 m
 GEOI     601          -  0  0      1.95 -  0  0     11.19      -30.300 m
 GEOI     801          -  0  0      2.95 -  0  0      9.34      -30.778 m
 GEOI     901          -  0  0      1.92 -  0  0     11.35      -30.294 m
```

```
================================================================================
===
                         humboldt_c  fully constrained
GeoLab V3.65                 GRS 80            UNITS: m,DMS           Page
0006
================================================================================
===
Residuals (critical value = 2.599):
NOTE: Observation values shown are reduced to mark-to-mark.
                                                  OBSERVATION RESIDUAL  STD
RES
TYPE AT           FROM         TO                     STD DEV  STD DEV
PPM
---- ------------ ------------ ------------ ---------------- -------- ------
--
ELAT 801                                    N 40 46   0.90245   -0.052   -
1.164
                                                        0.063    0.045
ELON 801                                    W124 13   3.45797    0.004
0.090
                                                        0.063    0.045
ELAT 901                                    N 40 48  17.21986    0.052
1.164
                                                        0.063    0.045
ELON 901                                    W124 06  56.60986   -0.004   -
0.088
                                                        0.063    0.045
OHGT 901                                              1.86000   -0.001   -
0.046
                                                        0.020    0.011
OHGT 801                                              4.15500    0.001
0.046
                                                        0.020    0.011
GROUP: 00000061.SSF,obs#:    1 day  71  OPT                     71    15:
DXCT              501          601                 -9266.94070    0.033
2.616
                                                        0.015    0.012
1.74

^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
DYCT              501          601                 14745.32060    0.011
0.825
                                                        0.018    0.014
0.60
DZCT              501          601                  6877.44110   -0.019   -
0.904
                                                        0.026    0.021
1.02
GROUP: 00000065.SSF,obs#:    2 day  69  OPT                     69    17:
DXCT              501          801                -17919.09550   -0.012   -
1.072
                                                        0.016    0.012
0.50
DYCT              501          801                 17046.27100   -0.020   -
1.348
                                                        0.020    0.015
0.80
DZCT              501          801                  3455.35070    0.007
0.548
                                                        0.019    0.012
0.27
GROUP: 00000053.SSF,obs#:    3 day  65  OPT                     65    20:
DXCT              501          901                 -9258.95540   -0.012   -
0.944
                                                        0.015    0.013
0.65
```

```
DYCT              501          901                    14489.75010   -0.012   -
0.673
                                                            0.022    0.018
0.67
DZCT              501          901                     6638.07210    0.013
0.706
                                                            0.023    0.019
0.72
GROUP: 00000057.SSF,obs#:    4 day  68  OPT                         68    15:
DXCT              901          601                       -7.93780   -0.003   -
2.294
                                                            0.005    0.001
8.22
DYCT              901          601                      255.59500   -0.001   -
0.443
                                                            0.007    0.002
2.79
DZCT              901          601                      239.33570    0.001
0.229
                                                            0.011    0.004
2.72
GROUP: 00000069.SSF,obs#:    5 day  72  OPT                         72 1  16:
DXCT              901          801                    -8660.15190    0.011
0.769
                                                            0.018    0.015
1.18
DYCT              901          801                     2556.49830    0.015
1.215
                                                            0.017    0.012
1.56
DZCT              901          801                    -3182.71940   -0.008   -
0.480
                                                            0.022    0.017
0.87
```

```
=============================================================================
===
                        humboldt_c  fully constrained
GeoLab V3.65                GRS 80              UNITS: m,DMS           Page
0007
=============================================================================
===
```

```
   0.4 -                              ***
                                     *   *
                                    *--   * ---
                                   *:::|   *:::|
R                                  |:::|   |:::|
e                                 *|:::|   |*::|
l                                  |:::|   |:::|
a                                  |:::|   |:::|
t  0.3 -                         * |:::|   |:*:|
i                                  |:::|   |:::|
v                           --- *--|:::|---|::*|
e                          |:::|:::|:::|:::|:::|
                           |:::|:::|:::|:::|:::|
F                          |:::*:::|:::|:::|:::*
r                          |:::|:::|:::|:::|:::|
e                          |::*|:::|:::|:::|:::|*
q  0.2 -                   |:::|:::|:::|:::|:::|
u                          |:*:|:::|:::|:::|:::| *
e                          |:::|:::|:::|:::|:::|---
n                          |:::|:::|:::|:::|:::|:::|
c                          |*::|:::|:::|:::|:::|::*|
y                          |:::|:::|:::|:::|:::|:::|
                           *:::|:::|:::|:::|:::|:::*
                           |:::|:::|:::|:::|:::|:::|
   0.1 -                  *|:::|:::|:::|:::|:::|:::|*
                         * |:::|:::|:::|:::|:::|:::| *
                    ---    |:::|:::|:::|:::|:::|:::|        ---
                   |:::|*  |:::|:::|:::|:::|:::|:::|  *    |:::|
                   |:::*   |:::|:::|:::|:::|:::|:::|   *   |:::|
                   |::*|   |:::|:::|:::|:::|:::|:::|    *  |:::|
                   |:*:|   |:::|:::|:::|:::|:::|:::|     * |:::|
                  ***::|   |:::|:::|:::|:::|:::|:::|      ***::|
   +---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
      -4      -3      -2      -1       0       1       2       3       4
                          ALL RESIDUALS (21 residuals)
```

```
================================================================================
===
                         humboldt_c  fully constrained
GeoLab V3.65                 GRS 80             UNITS: m,DMS           Page
0008
================================================================================
===

 -----------------------------------------------------------------------------
-
|
|
|                    S T A T I S T I C S     S U M M A R Y
|
|
|
 -----------------------------------------------------------------------------
-
|                                      |
|
|     Residual Critical Value Type     |                Tau Max
|
|     Residual Critical Value          |                 2.5985
|
|     Number of Flagged Residuals      |                      1
|
|     Convergence Criterion            |                 0.0010
|
|     Final Iteration Counter Value    |                      2
|
|     Confidence Level Used            |                95.0000
|
|     Estimated Variance Factor        |                 1.0938
|
|     Number of Degrees of Freedom     |                      9
|
|                                      |
|
 -----------------------------------------------------------------------------
-
|
|
|                   Chi-Square Test on the Variance Factor:
|
|
|
|                    5.1749e-01  <  1.0000  <  3.6454e+00  ?
|
|
|
|                               THE TEST PASSES
|
|
|
 -----------------------------------------------------------------------------
-


 -----------------------------------------------------------------------------
-
|
|
| NOTE:  All confidence regions were computed using the following factors:
|
|       ----------------------------------------------------------------
|
```

```
|        Variance factor used      =          1.0000
|
|        1-D expansion factor      =          1.9600
|
|        2-D expansion factor      =          2.4477
|
|
|
|        Note that, for relative confidence regions, precisions are
|
|        computed from the ratio of the major semi-axis and the spatial
|
|        distance between the two stations.
|
|
|
 ---------------------------------------------------------------------------
-
```

```
================================================================================
===
                         humboldt_c  fully constrained
GeoLab V3.65                 GRS 80             UNITS: m,DMS           Page
0009
================================================================================
===
2-D and 1-D Station Confidence Regions (95.000 and 95.000 percent):
STATION            MAJOR SEMI-AXIS  AZ     MINOR SEMI-AXIS
VERTICAL
------------ -------------------- --- ------------------- ------------------
--
501                          0.110   1              0.110
0.044
601                          0.111 177              0.110
0.039
801                          0.110 163              0.110
0.032
901                          0.110 162              0.110
0.032
```

```
================================================================================
===
                         humboldt_c  fully constrained
GeoLab V3.65                 GRS 80              UNITS: m,DMS           Page
0010
================================================================================
===
2-D and 1-D Relative Station Confidence Regions (95.000 and 95.000 percent):
FROM         TO           MAJ-SEMI  AZ MIN-SEMI  VERTICAL     DISTANCE
PPM
------------ ------------ -------- --- -------- --------- ------------ ------
--
501          601              0.017 177    0.012     0.039    18724.298
0.90
501          801              0.022 177    0.020     0.039    24972.157
0.89
501          901              0.012 175    0.009     0.037    18432.177
0.66
601          901              0.013 180    0.008     0.023      350.248
37.57
801          901              0.022 162    0.019     0.034     9574.108
2.25

14:45:46, Fri Mar 25, 2005
```