# Post-Flight Aerial Acquisition and Calibration Report

FEMA REGION 5
Racine County, WI

FEDERAL EMERGENCY MANAGEMENT AGENCY
Racine County, Wisconsin LIDAR Project Number: 400000096
December 2013

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**Section 1** <u>**Overview**</u>

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**Purpose:** Quantum Spatial, Inc. acquired highly accurate Light Detection and Ranging (LiDAR) data for an area that consisted of approximately 332 square miles of Racine County, Wisconsin.

**Location:** The project area includes approximately 332 square miles of Racine County, Wisconsin. This project area was defined and supplied by STARR on October 1, 2013.

(Figure 1.1 – Project Area – Racine County, Wisconsin)
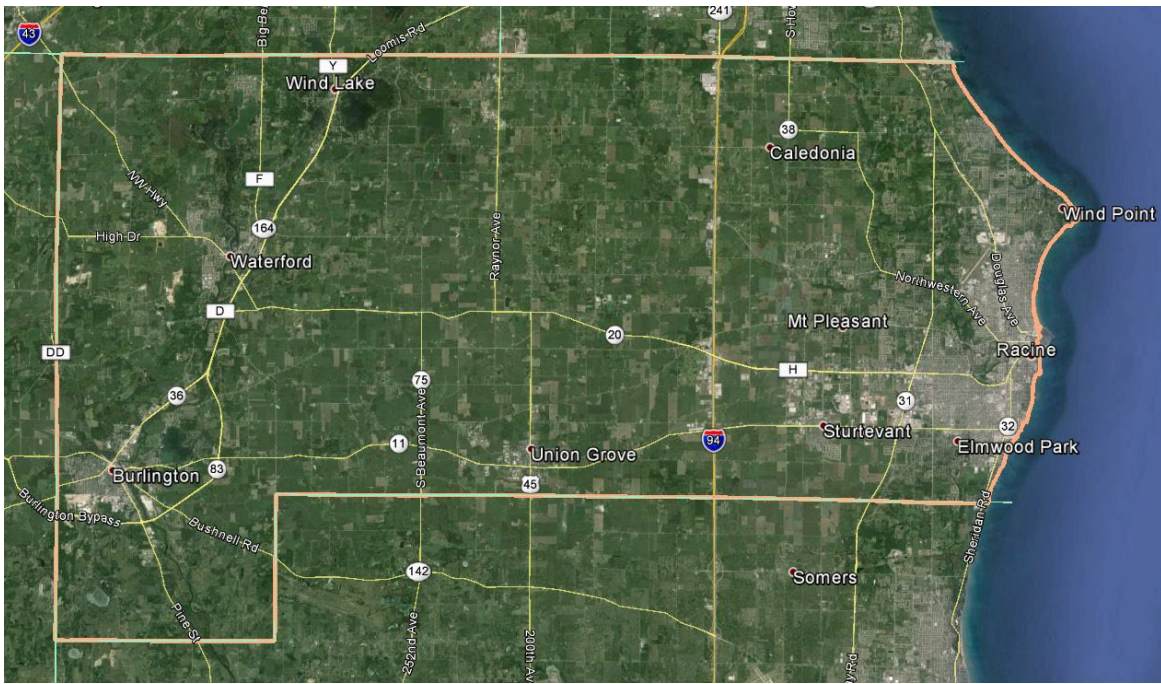


| Project extents of Racine County, Wisconsin acquisition area | | |
|---|---|---|
| North | 42° 50'36'' N | 088° 04'12'' W |
| East | 42° 46'52'' N | 087° 45'26'' W |
| South | 42° 36'39'' N | 088° 14'30'' W |
| West | 42° 43'37'' N | 088° 18'26'' W |

**Section 2**                                        **Acquisition**

(LiDAR System Specification Table 2.1)

| Flying Height | 1700 meters |
|---|---|
| Laser Pulse Rate | 70kHz |
| Mirror Scan Frequency | 32 Hz |
| Scan Angle | (+/-) 22° |
| Side Lap | 55% |
| Ground Speed | 160 knots |
| Nominal Point Spacing | 1.3 meter |

**Base Station Information:** All missions were processed using Wisconsin CORS base stations. The Racine Area 2 utilized *KEHA* (Kenosha, WI), SIWI (Milwaukee, WI), and SHAN (Sheboygan, WI).  The following is the base station information as it relates to the project areas.  The maximum extent of the baseline collection area was approximately 50 km from a base.   The maximum PDOP for bases was 3.6 as shown in the PDOP graphs (see Section 3).

(Base Station Location Table 2.2)

| POINT | LAT (N) | LONG (W) | HEIGHT (Ellipsoid) |
|---|---|---|---|
| *KEHA* | 42°33'32.29917" | 87°55'09.15144" | 204.203m |
| *SHAN* | 43°44'51.46198" | 87°44'05.22551" | 152.946m |
| *SIWI* | 42°52'04.53392" | 87°58'58.56228" | 190.721m |

(Figure 2.1 - Base Station Locations Racine County, Wisconsin)

**Time Period:** The Racine County Area 2 was collected between March 18th, 2010 and March 29th, 2010 with a total of three (3) flight missions. There were no conditions affecting flight.

(Airborne LiDAR Acquisition Flight Summary Table 2.3)

| | |
|---|---|
| Acquisition Date, Mission, and Time | L031810A  19:22 – 22:29CDT<br>M031810A  21:39 – 01:49CDT<br>M031810B  03:12 –04:53CDT |
| Area of Acquisition | Racine County area 332 square miles |
| Aircrafts | Cessna C320E N3443Q; Aero Commander 500 N280MB |
| Planned Altitude | 1,700 meters AGL |
| Planned Airspeed | 160 knots |
| Planned Number of Flight Lines | L031810A    14 passes 03.18.2010  31-44<br>M031810A    17 passes 03.19.2010  14-30<br>M031810B    13 passes 03.19.2010  1-13 |
| Flight Line Spacing | 618 meters |
| Flight Line Coverage | 960 sq. kilometers |
| Sidelap | 55% |
| System PRF | 70 kHz |
| Mirror Scan Half Angle | 22 degrees |
| Mirror Scan Rate | 32 Hz |
| Nominal Point Density | 1.3 points per square meter per pass |
| Datum | NAD83 |
| | NAVD88 via Geoid09 in Feet |
| Projection and Units | Universal Transverse Mercator (UTM) 16N meters |

(Figure 2.2 LiDAR Flight Line Layout Map– Racine County, Wisconsin)
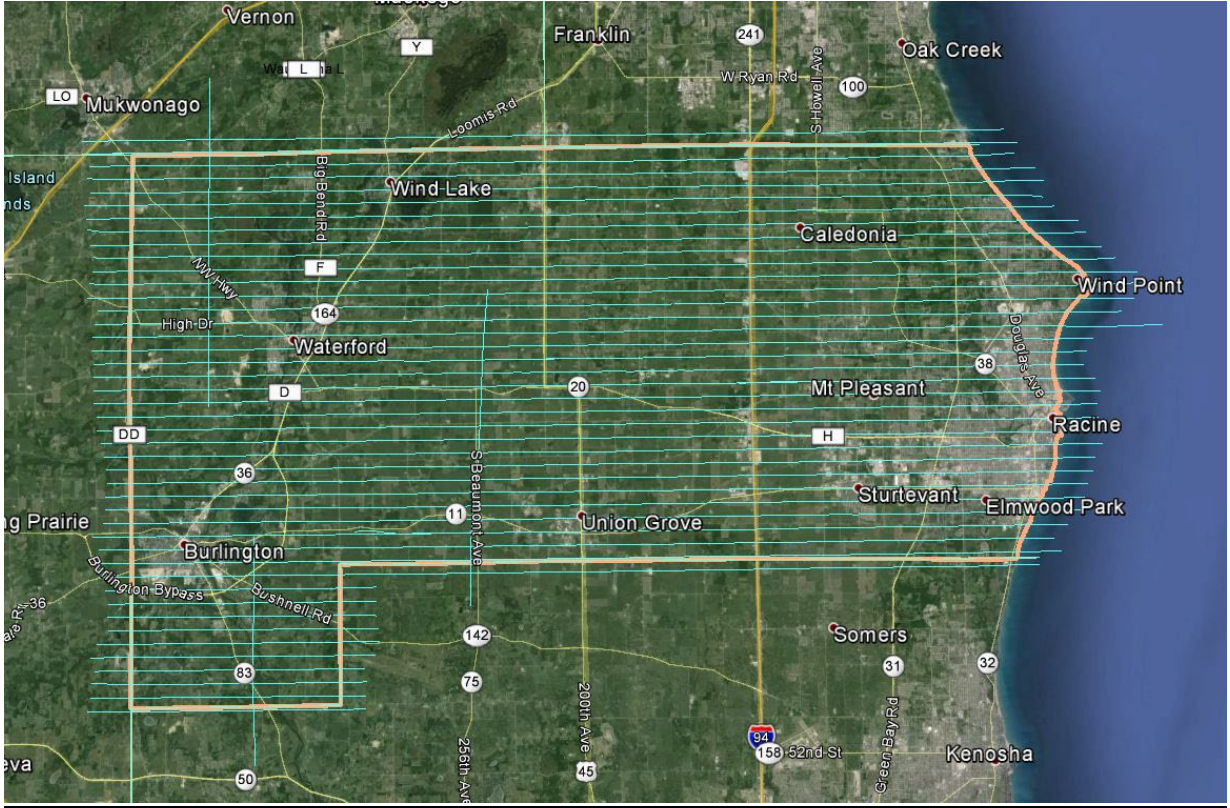


(Mission Flightline Summary Racine County, Wisconsin - Table 2.4)

Flown from Ontario, Oregon over five missions December 1 thru 5, 2011

| Mission | Time of acquisition | Block flown | Lines acquired |
|---------|---------------------|-------------|----------------|
| L031810A | 19:22-22:29 | Area 1 | Lines 31-44 |
| M031810A | 21:41-1:49 | Area 2 | Lines 14-30 |
| M031810B | 03:16-04:53 | Area 3 | Lines 1-13 |

**Section 3**                                    **LiDAR Data Processing**

ABGPS and IMU Processing

    Applanix - POSGPS

    Utilizing carrier phase ambiguity resolution on the fly (i.e., without initialization),  the solution to sub-decimeter kinematic positioning without the operational constraint of static initialization as used in semi-kinematic or stop-and-go positioning was utilized for the airborne GPS post-processing.

    The processing technique used by Applanix, Inc. for achieving the desired accuracy is Kinematic Ambiguity Resolution (KAR).  KAR searches for ambiguities and uses a special method to evaluate the relative quality of each intersection (RMS).  The quality indicator is used to evaluate the accuracy of the solution for each processing computation.  In addition to the quality indicator, the software will compute separation plots between any two solutions, which will ultimately determine the acceptance of the airborne GPS post processing.

    Inertial Data

    The post-processing of inertial and aiding sensor data (i.e. airborne GPS post processed data) is to compute an optimally blended navigation solution. The Kalman filter-based aided inertial navigation algorithm generates an accurate (in the sense of least-square error) navigation solution that will retain the best characteristics of the processed input data.  An example of inertial/GPS sensor blending is the following: inertial data is smooth in the short term.  However, a free-inertial navigation solution has errors that grow without bound with time.  A GPS navigation solution exhibits short-term noise but has errors that are bounded.  This optimally blended navigation solution will retain the best features of both, i.e. the blended navigation solution has errors that are smooth and bounded.

    The resultant processing generates the following data:

-     Position:        Latitude, Longitude, Altitude
-     Velocity:        North, East, and Down components
-     3-axis attitude:   roll, pitch, true heading
-     Acceleration:    x, y, z components
-     Angular rates:    x, y, z components

    The airborne GPS and blending of inertial and GPS post-processing were completed in multiple steps.

1. The collected data was transferred from the field data collectors to the main computer.  Data was saved under the project number and separated between LiDAR mission dates.  Inside each mission date, a sub-directory was created with the aircraft's tail number and an A or B suffix was attached to record which mission of the day the data is associated with.  Inside the tail number sub-directory, five sub-directories were also created: EO, GPS, IMU, PROC, and RAW.

2. The aircraft raw data (IMU and GPS data combined) was run through a data extractor program.  This separated the IMU and GPS data.  In addition to the extraction of data, it provided the analyst

the first statistics on the overall flight. The program was POSPac (POS post-processing PACkage).

3. Executing POSGPS program to derive accurate GPS positions for all flights:

Applanix POSGPS

The software utilized for the data collected was PosGPS, a kinematic on-the-fly (OTF) processing software package. Post processing of the data is computed from each base station (Note: only base stations within the flying area were used) in both a forward and backward direction. This provides the analyst the ability to Quality Check (QC) the post processing, since different ambiguities are determined from different base stations and also with the same data from different directions.

The trajectory separation program is designed to display the time of week that the airborne or roving antenna traveled, and compute the differences found between processing runs. Processed data can be compared between a forward/reverse solution from one base station, a reverse solution from one base station and a forward solution from the second base station, etc. For the Applanix POSGPS processing, this is considered the final QC check for the given mission. If wrong ambiguities were found with one or both runs, the analyst would see disagreements from the trajectory plot, and re-processing would continue until an agreement was determined.

Once the analyst accepts a forward and reverse processing solution, the trajectory plot is analyzed and the combined solution is stored in a file format acceptable for the IMU post processor.

4. When the processed trajectory (either through POSGPS) data was accepted after quality control analysis, the combined solution is stored in a file format acceptable for the IMU post processor (i.e. POSProc).

5. Execute POSProc.

POSProc comprises a set of individual processing interface tools that execute and provide the following functions:

This diagram shows the organization of these tools, and is a function of the POSProc processing components.
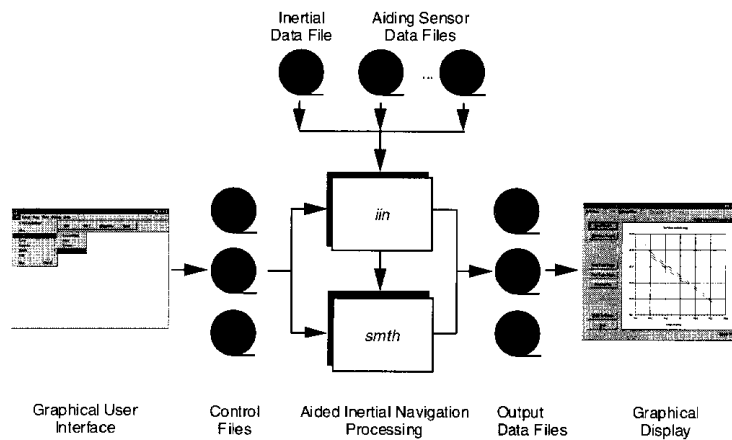
Integrated Inertial Navigation (*iin*) Module.

The name *iin* is a contraction of Integrated Inertial Navigation. *iin* reads inertial data and aiding data from data files specified in a processing environment file and computes the aided inertial navigation solution. The inertial data comes from a strapdown IMU. *iin* outputs the navigation data between start and end times at a data rate as specified in the environment file. *iin* also outputs Kalman filter data for analysis of estimation error statistics and smoother data that the smoothing program *smth* uses to improve the navigation solution accuracy.

*iin* implements a full strapdown inertial navigator that solves Newton's equation of motion on the earth using inertial data from a strapdown IMU. The inertial navigator implements coning and sculling compensation to handle potential problems caused by vibration of the IMU.

Smoother Module (*smth*)

*smth* is a companion processing module to *iin*. *smth* is comprised of two individual functions that run in sequence. *smth* first runs the *smoother function* and then runs the *navigation correction function*.

The *smth* smoother function performs backwards-in-time processing of the forwards-in-time blended navigation solution and Kalman filter data generated by *iin* to compute smoothed error estimates. *smth* implements a modified Bryson-Frazier smoothing algorithm specifically designed for use with the *iin* Kalman filter. The resulting smoothed strapdown navigator error estimates at a given time point are the optimal estimates based on all input data before and after the given time point. In this sense, *smth* makes use of all available information in the input data. *smth* writes the smoothed error estimates and their RMS estimation errors to output data files.

The *smth* navigation correction function implements a feedforward error correction mechanism similar to that in the *iin* strapdown navigation solution using the smoothed strapdown navigation errors. s*mth* reads in the smoothed error estimates and with these, corrects the strapdown navigation data. The resulting navigation solution is called a Best Estimate of Trajectory (BET), and is the best obtainable estimate of vehicle trajectory with the available inertial and aiding sensor data.

The above mentioned modules provide the analyst the following statistics to ensure that the most optimal solution was achieved: a log of the *iin* processing, the Kalman filter Measurement Residuals, Smoothed RMS Estimation Errors, and Smoothed Sensor Errors and RMS.

LIDAR Calibration

The purpose of the LiDAR system calibration is to refine the system parameters in order for the post-processing software to produce a "point cloud" that best fits the actual ground.

For each mission, LiDAR data for at least one cross flight is acquired over the mission's acquisition site. The processed data of the cross flight is compared to the perpendicular flight lines using either the Optech proprietary software or TerraSolid's TerraMatch software to determine if

any systematic errors are present.  In this calibration, the data of individual flight lines are compared against each other and their systematic errors are corrected in the final processed data.

LIDAR Processing

The LAS files were then imported, verified, and parsed into manageable, tiled grids using GeoCue.

After the data has been processed and calibrated a relative accuracy assessment is performed comparing flightline to flightline for proper position between flightlines. A data density test is also performed to ensure proper coverage. Quantum Spatial uses GeoCue to create ortho images by elevation differences.  The generated orthos have assigned elevation ranges that allow the technician to evaluate if the data passes the accuracy assessment and determine if additional calibration efforts are needed based on the bias trends.  In Section 4, Figures 4-2 and 4-3 represent the elevation orthos comparing  neighboring flightline vertical positions. Green indicates a difference of less than 7cm; yellow is 7cm to 14cm; orange is 14cm to 21cm; red is 21cm to 28cm and magenta is greater than 28cm.

Summary

The GPS quality for the collection was very good as represented in the plots in this section.  The maximum horizontal variance for the project during collection of mission lines was 12 cm.  The maximum vertical variance for the project collection was 15 cm.  These values are reflected in the separation plots below. (Figures 3.01-3.09)

Flight Log Overview

-Post Spacing – 1.3 meter
-AGL (Above Ground Level) average flying height – 1700 meters
-MSL (Mean Sea Level) average flying height – 1900 meters
-Average Ground Speed – 160 knots
-Pulse Rate – 70 kHz
-Scan Rate – 32 Hz
-Side Lap (Average) – 55%

GPS/IMU Processing Summary Plots (Figures 3.01-3.24)

GPS Separation Plots

Figure 3.01

Separation Plot L031810A
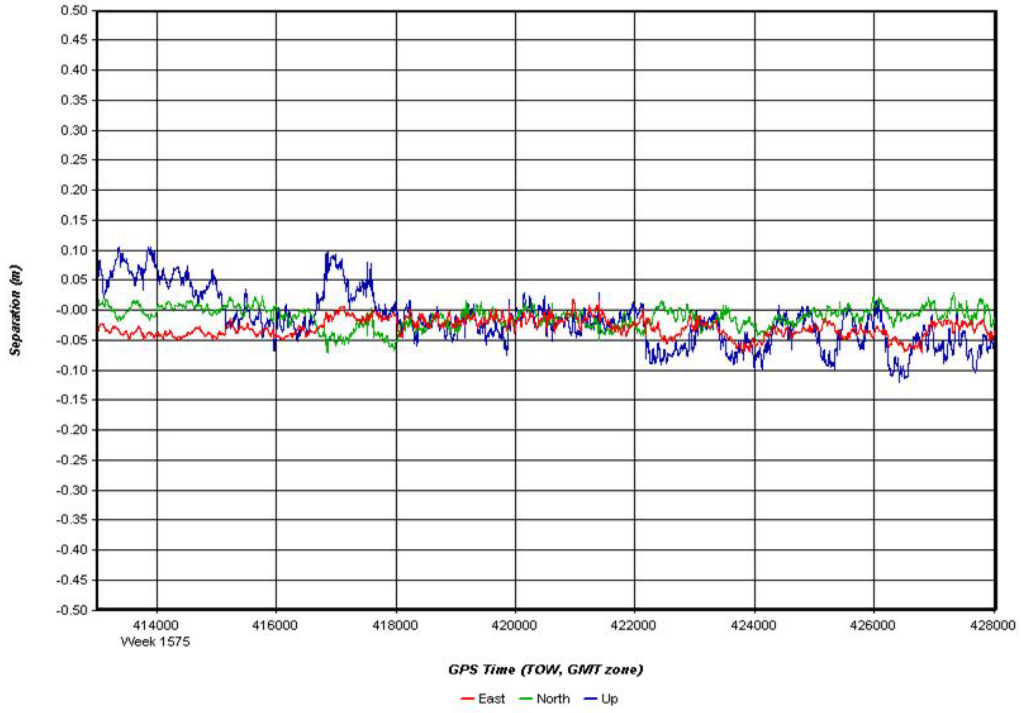


L031810A_SEP_KEHA-SIWI-Cmb_SHAN-Fwd.doc

Figure 3.02

## Separation Plot M120311A
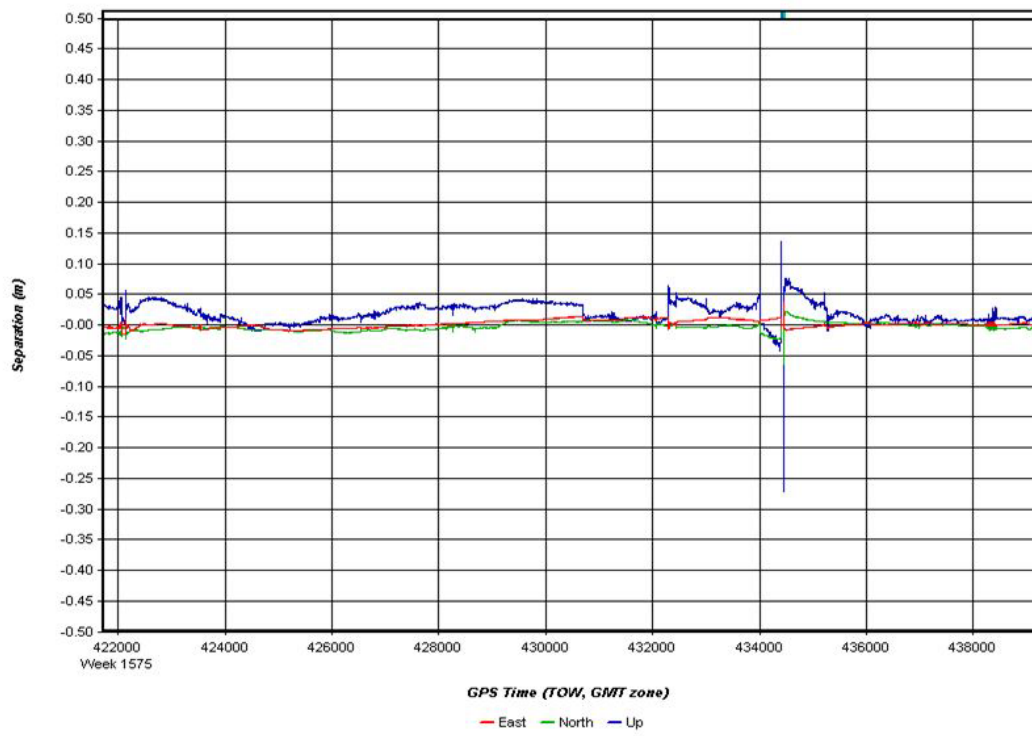


M031810A_SEP_KEHA_SIWI_SHAN-Cmb.doc

Figure 3.03

## Separation Plot M031810B
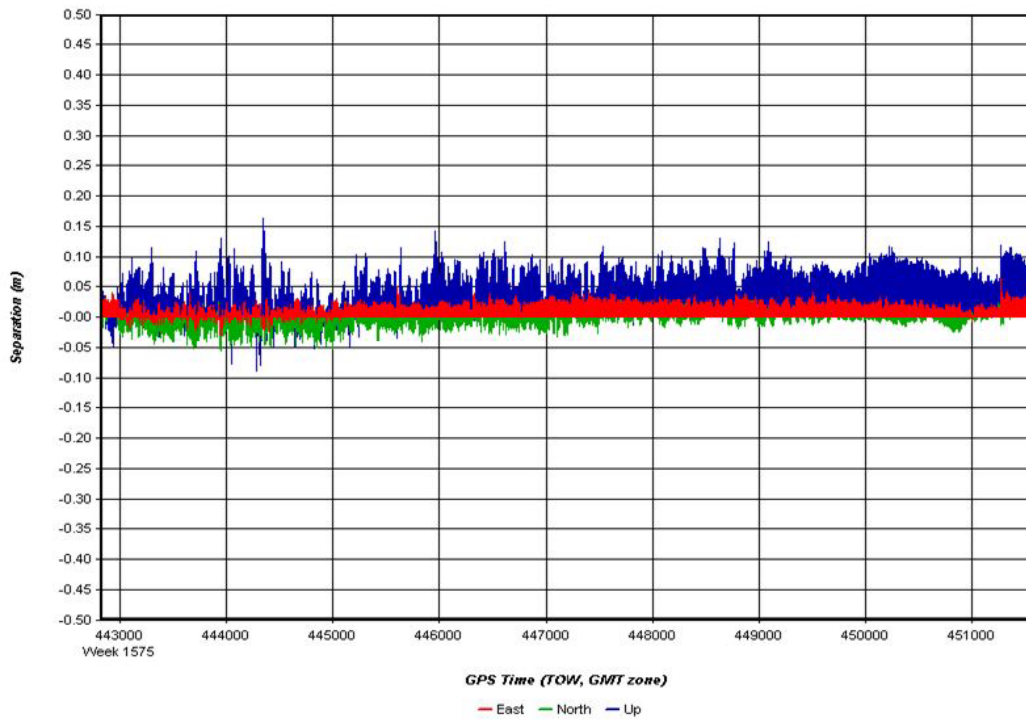


M031810B_SEP_KEHA_SIWI_SHAN-Rev_TP.doc

GPS Altitude Plots

Figure 3.04

## Altitude Plot L031810A



Figure 3.05
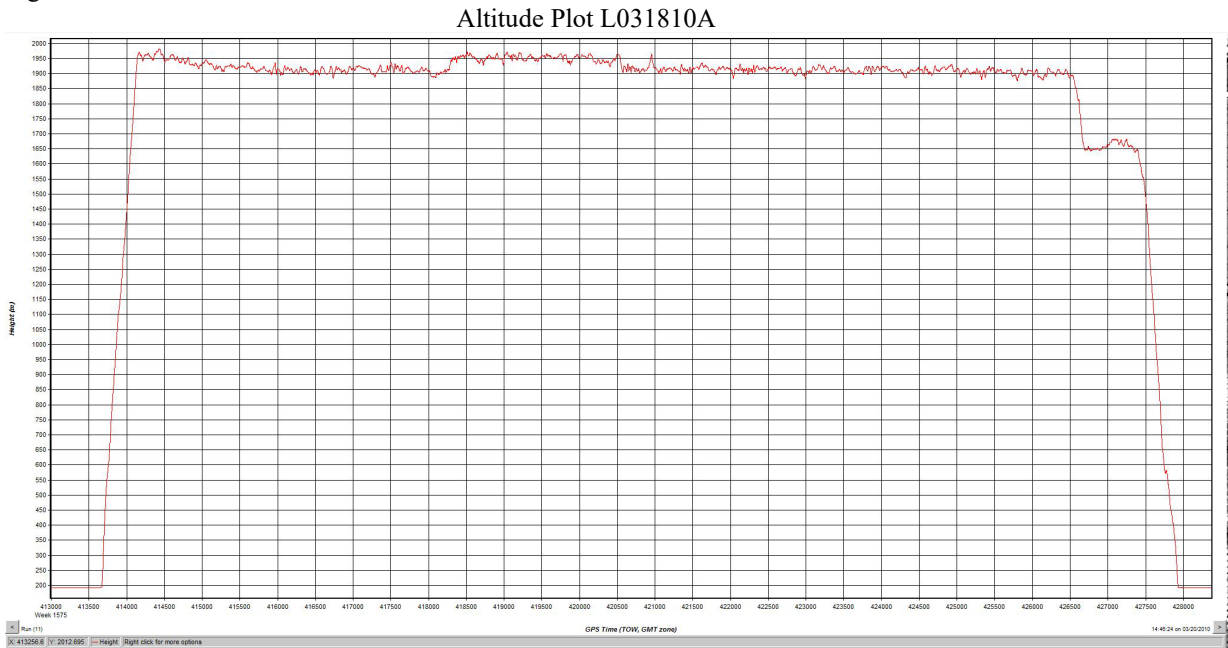
## Altitude Plot M031810A
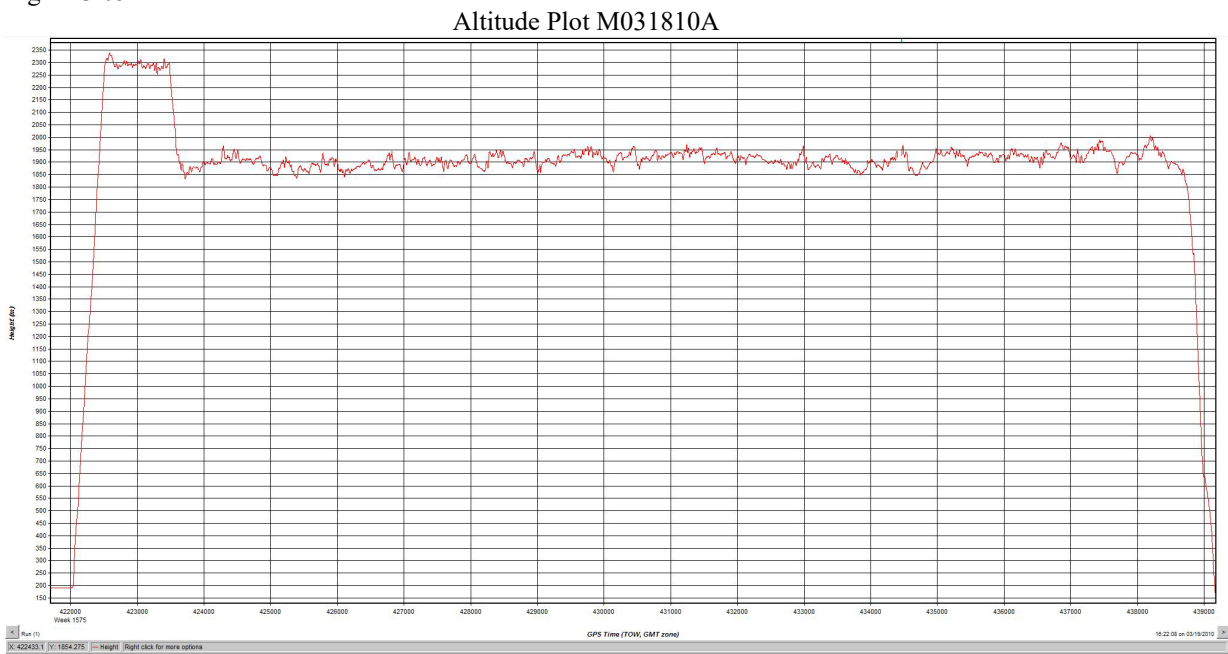
Figure 3.06

## Altitude Plot M120311B
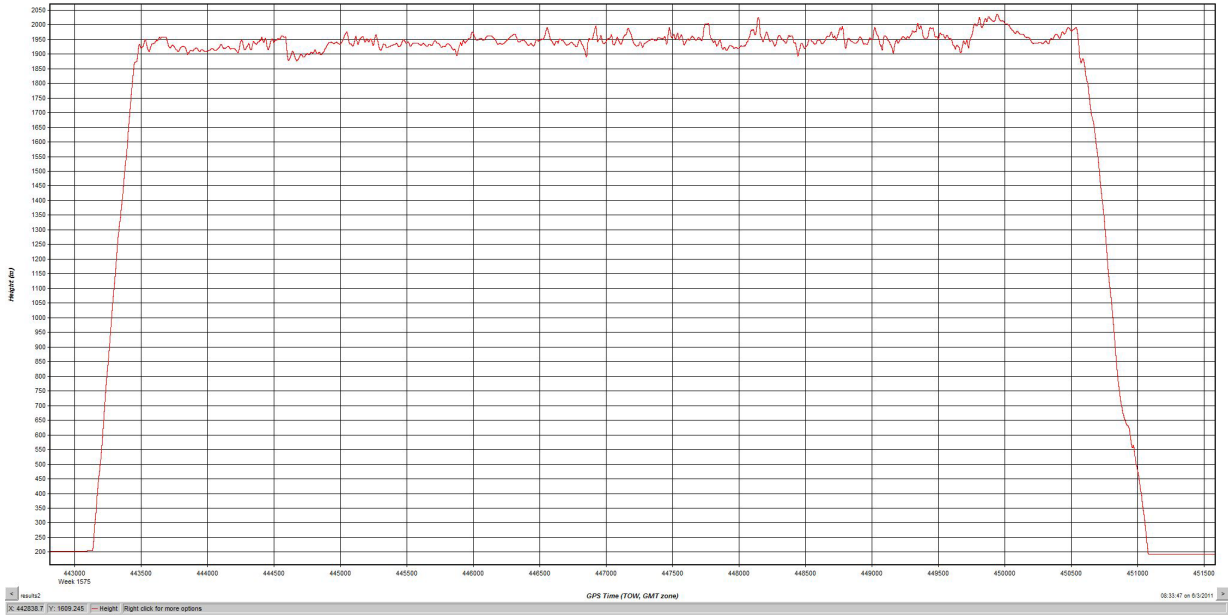
GPS PDOP Plots

Figure 3.07

PDOP Plot L031810A
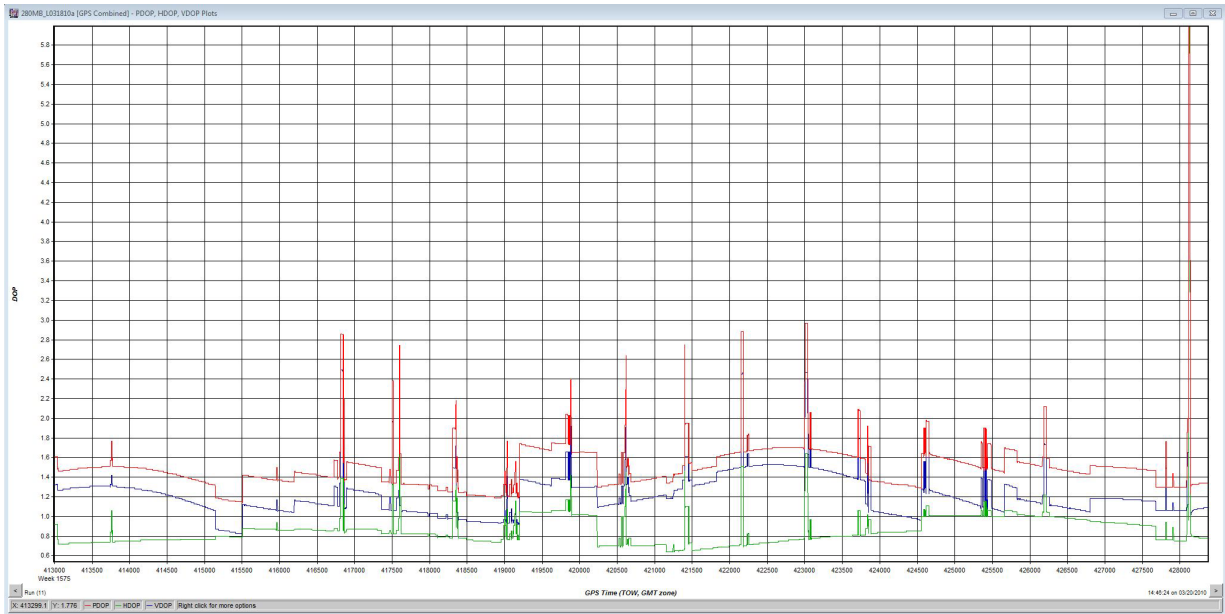


Figure 3.08

PDOP Plot M031810A
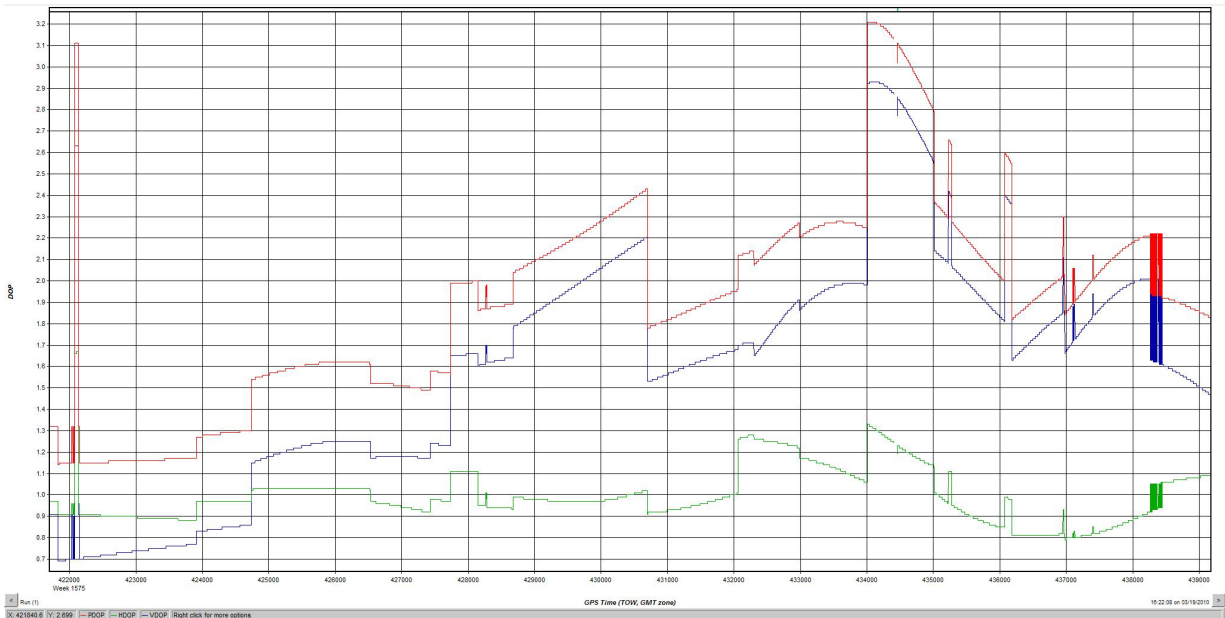
Figure 3.09

PDOP Plot M031810B
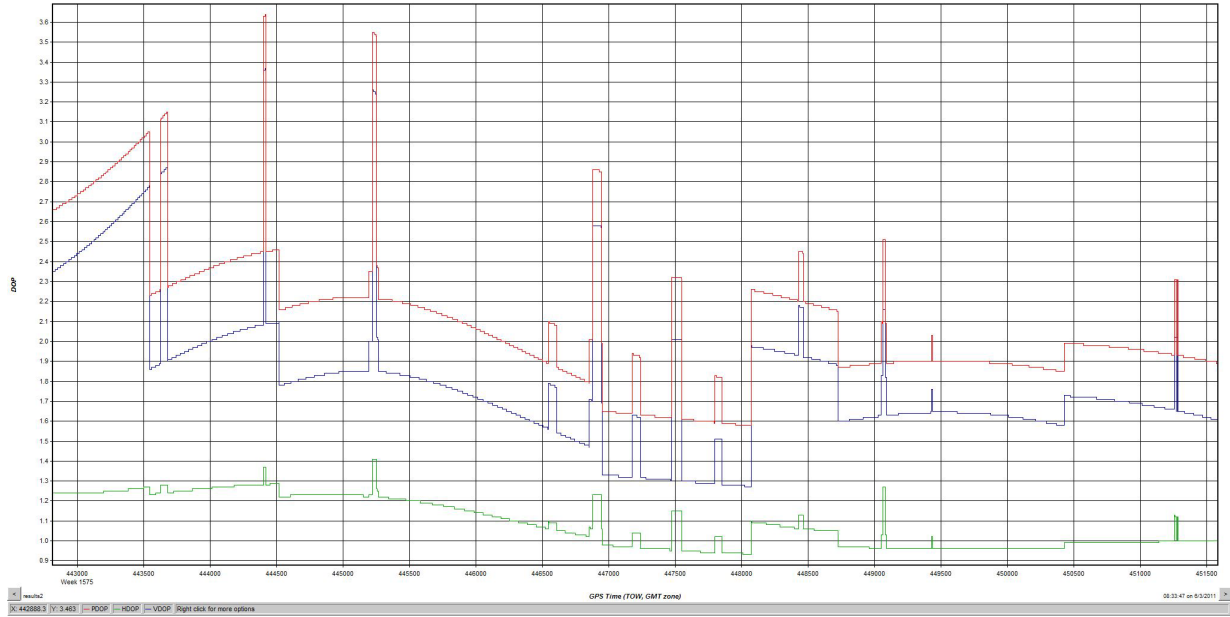
**Section 4**                                    **Final Accuracy Assessment**

Data Verification:

The data was verified using the ground control data collected by Quantum Spatial. 223 points were distributed throughout the project area and the points were compared to the LIDAR data using TerraScan. TerraScan computes the vertical differences between the surveyed elevation and the LiDAR derived elevation for each point.

The Fundamental Vertical Accuracy (FVA) was tested by Quantum Spatial. The FVA of the classified bare earth achieved 0.980 ft (at the 95% confidence level) in the "Open Terrain" land cover category.  This test consisted of 46 vertical checkpoints across Racine County.

The Supplemental Vertical Accuracy (SVA) was tested by Quantum Spatial as follows:
The SVA results for Hard Surface/Urban achieved 0.936 ft at the 95th Percentile using 46 points.
The SVA results for Short Grass achieved 0.751 ft at the 95th Percentile using 44 points.
The SVA results for Long Grass achieved 0.977 ft at the 95th Percentile using 45 points.
The SVA results for Brush achieved 0748ft at the 95th Percentile using 43 points.
The SVA results for Forest achieved 0.862ft at the 95th Percentile using 45 points.

The Consolidated Vertical Accuracy (CVA) results for all Land Cover Classes combined achieved 0.920 ft at the 95th Percentile using 223 Points.

Overall vertical accuracy statistics are in Table 4-1.

(Figure 4.1 – Racine County - DZ Raster Image)
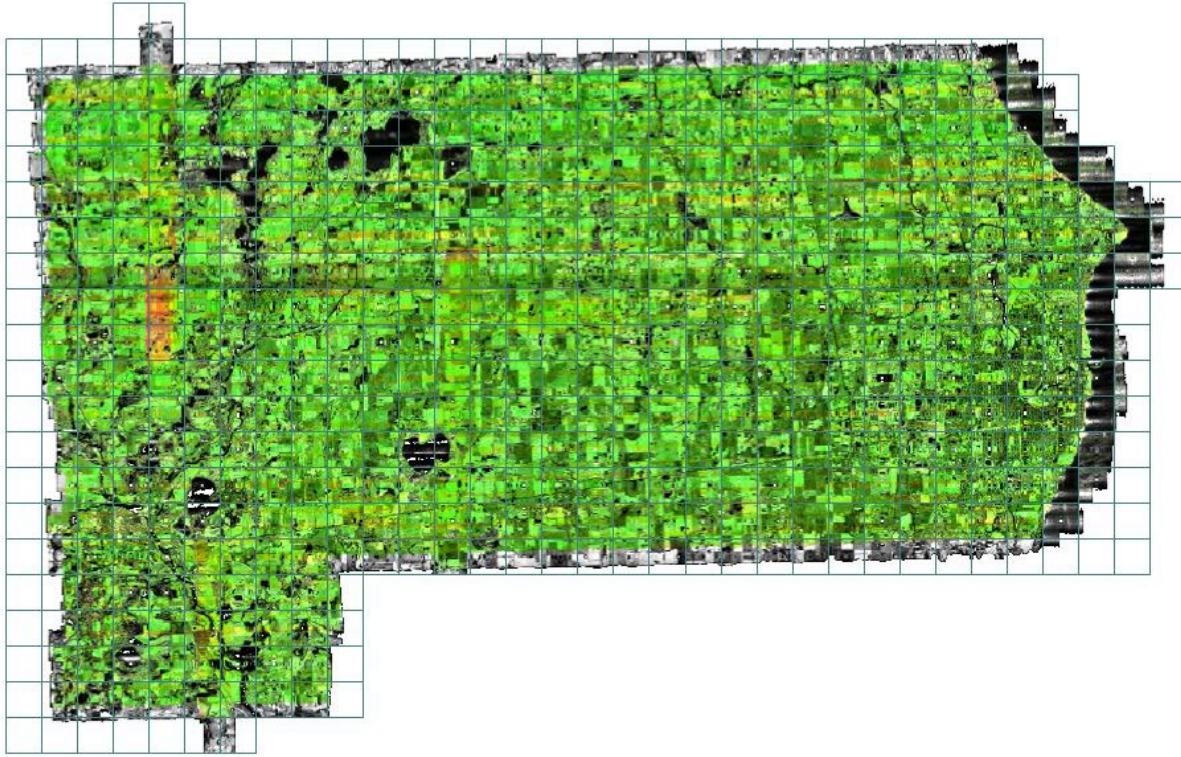
(Table 4-1 Overall Vertical Accuracy Statistics)

Racine County, Wisconsin

**Results of Process**

| Point | Surveyed Elev. | LiDAR Elev. | Difference | Land Category |
|---|---|---|---|---|
| 4 | 770.317 | 769.70 | -0.617 | Hard Surface |
| 10 | 745.497 | 744.83 | -0.667 | Hard Surface |
| 14 | 750.579 | 750.38 | -0.199 | Hard Surface |
| 20 | 822.262 | 822.35 | 0.088 | Hard Surface |
| 25 | 742.63 | 742.64 | 0.01 | Hard Surface |
| 30 | 769.195 | 769.00 | -0.195 | Hard Surface |
| 35 | 727.236 | 727.06 | -0.176 | Hard Surface |
| 40 | 826.888 | 826.03 | -0.858 | Hard Surface |
| 45 | 782.167 | 781.02 | -1.147 | Hard Surface |
| 50 | 794.391 | 793.78 | -0.611 | Hard Surface |
| 55 | 799.998 | 799.72 | -0.278 | Hard Surface |
| 58 | 830.274 | 829.69 | -0.584 | Hard Surface |
| 65 | 752.351 | 752.42 | 0.069 | Hard Surface |
| 75 | 688.253 | 688.34 | 0.087 | Hard Surface |
| 77 | 681.314 | 680.92 | -0.394 | Hard Surface |
| 81 | 782.193 | 782.18 | -0.013 | Hard Surface |
| 83 | 777.915 | 777.24 | -0.675 | Hard Surface |
| 88 | 804.273 | 804.27 | -0.003 | Hard Surface |
| 95 | 826.252 | 826.27 | 0.018 | Hard Surface |
| 101 | 808.381 | 807.92 | -0.461 | Hard Surface |
| 501 | 795.966 | 795.82 | -0.146 | Hard Surface |
| 502 | 814.099 | 814.08 | -0.019 | Hard Surface |
| 503 | 776.107 | 775.01 | -1.097 | Hard Surface |
| 504 | 810.104 | 809.41 | -0.694 | Hard Surface |
| 505 | 829.955 | 829.32 | -0.635 | Hard Surface |
| 506 | 780.652 | 780.12 | -0.532 | Hard Surface |
| 507 | 668.519 | 667.58 | -0.939 | Hard Surface |
| 508 | 720.005 | 719.71 | -0.295 | Hard Surface |
| 509 | 682.095 | 681.59 | -0.505 | Hard Surface |
| 510 | 645.202 | 645.17 | -0.032 | Hard Surface |
| 511 | 655.845 | 655.34 | -0.505 | Hard Surface |
| 512 | 630.586 | 630.23 | -0.356 | Hard Surface |
| 513 | 586.538 | 586.5 | -0.038 | Hard Surface |
| 514 | 696.131 | 696.01 | -0.121 | Hard Surface |
| 515 | 692.263 | 692.19 | -0.073 | Hard Surface |
| 516 | 683.175 | 683.22 | 0.045 | Hard Surface |
| 517 | 742.466 | 742.47 | 0.004 | Hard Surface |

| | | | | |
|---|---|---|---|---|
| 518 | 741.199 | 741.15 | -0.049 | Hard Surface |
| 519 | 719.381 | 718.57 | -0.811 | Hard Surface |
| 520 | 791.721 | 791.06 | -0.661 | Hard Surface |
| 521 | 808.597 | 808.19 | -0.407 | Hard Surface |
| 522 | 814.68 | 813.84 | -0.84 | Hard Surface |
| 523 | 821.976 | 821.05 | -0.926 | Hard Surface |
| 524 | 781.951 | 781.95 | -0.001 | Hard Surface |
| 525 | 821.347 | 821.24 | -0.107 | Hard Surface |
| 526 | 772.532 | 772.40 | -0.132 | Hard Surface |

| | |
|---|---|
| Average Dz | -0.358 |
| Root mean square (RMS) | 0.500 |
| Standard Deviation | 0.353 |

(Table 4.2 QA/QC Analysis)
Internal QC results

**Section 5**                                          <u>**Final Deliverables**</u>
 (To Be Populated By STARR)
          List of Deliverables:
          -LAS v1.2 classified point cloud files in tile format.
          -Project metadata in Microsoft Word format.
          -The project data delivered on (Hard Drive/DVD's).

**Appendix A: Condensed Flight Logs**

Figure 1.01

L031810A

```
          Flight Log
------------------------------
Project Number: 1100319
S/N          : 07SEN201
Operator     : TOM
Pilot(s)     : JOSEY
Aircraft     : N280MB
Airport      : KSBM
Mission      : L031810A
Wheels Up    : 18:52
Flight Length :
HOBBS Start  :
HOBBS End    :


          Weather
------------------------------
Date         : March 18, 2010
Julian Day   : 077
Temperature  : ???
Visibility   : ???
Clouds       : ???
Precipitation : ???
Wind Dir     : ???
Wind Speed   : ???
Pressure     : LOTS
          Statistics
------------------------------
Laser Time   : 02:13:23
```

| START | STOP | LINE# | ALT | PRF | FREQ | ANGLE | MP | DIV | RC | HDG | Plan File |
|-------|------|-------|-----|-----|------|-------|-----|-----|-----|-----|-----------|
| 19:19:46.3 | 19:20:21.3 | 44 | 1923 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 19:21:05 | 19:21:36.9 | 44 | 1915 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 19:22:10 | 19:30:55.803 | 44 | 1908 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 19:36:14.504 | 19:45:06.206 | 43 | 1922 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 19:48:23.707 | 19:57:16.91 | 42 | 1903 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 20:01:05.411 | 20:09:59.313 | 41 | 1905 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 20:13:34.714 | 20:22:44.117 | 40 | 1945 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 20:26:51.418 | 20:35:43.721 | 39 | 1963 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 20:39:09.022 | 20:48:25.224 | 38 | 1961 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 20:52:33.626 | 21:01:50.228 | 37 | 1905 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 21:05:17.829 | 21:14:52.632 | 36 | 1910 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 21:18:53.734 | 21:28:26.737 | 35 | 1910 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 21:31:58.938 | 21:41:38.841 | 34 | 1905 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 21:45:29.642 | 21:55:17.745 | 33 | 1910 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 21:58:48.446 | 22:08:33.649 | 32 | 1891 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 22:12:47.751 | 22:22:26.254 | 31 | 1880 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 22:25:53.455 | 22:29:03.356 | 31 | 1885 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |

Figure 1.02

M120311A

```
              Flight Log
--------------------------------------
Project Number : 1100319
S/N            : Racine
Operator       : Jim
Pilot(s)       : Nick
Aircraft       : N3443Q
Airport        : KSBM
Mission        : M03181OA
Wheels Up      : ???
Flight Length  :
HOBBS Start    : 21:08
HOBBS End      :

              Weather
--------------------------------------
Date           : March 18, 2010
Julian Day     : 077
Temperature    : ???
Visibility     : ???
Clouds         : ???
Precipitation  : ???
Wind Dir       : ???
Wind Speed     : ???
Pressure       : 29.81
              Statistics
--------------------------------------
Laser Time     : 02:29:25
```

| START | STOP | LINE# | ALT | PRF | FREQ | ANGLE | MP | DIV | RC | HDG | Plan File |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21:39:16.615 | 21:39:37.114 | 15 | 1980 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 21:40:04.614 | 21:40:31.613 | 15 | 1891 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 21:40:59.613 | 21:50:42.601 | 15 | 1891 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 21:40:59.613 | 21:50:43.101 | 15 | 1891 | 70 | 32.00 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 21:54:59.596 | 22:04:24.084 | 22 | 1845 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 22:08:06.08 | 22:17:33.569 | 16 | 1883 | 70 | 31.90 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 22:21:29.064 | 22:30:48.053 | 23 | 1865 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 22:34:33.548 | 22:43:46.037 | 17 | 1883 | 70 | 31.90 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 22:47:08.033 | 22:56:32.022 | 24 | 1863 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 22:58:37.519 | 23:07:59.008 | 18 | 1904 | 70 | 31.90 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 23:11:13.504 | 23:20:37.493 | 25 | 1922 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 23:23:52.489 | 23:33:07.478 | 19 | 1935 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 23:36:35.473 | 23:45:44.462 | 26 | 1933 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 23:49:44.957 | 23:59:06.945 | 20 | 1902 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 00:02:24.441 | 00:11:45.93 | 27 | 1886 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:15:38.925 | 00:24:47.913 | 21 | 1926 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 00:15:38.925 | 00:24:48.913 | 21 | 1926 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 00:15:38.925 | 00:24:49.913 | 21 | 1926 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 00:28:11.909 | 00:37:47.897 | 28 | 1890 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:42:09.392 | 00:51:44.88 | 30 | 1923 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 00:56:20.374 | 01:05:05.863 | 29 | 1904 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:06:10.362 | 29 | 1926 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:06:14.862 | 29 | 1927 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:06:19.362 | 29 | 1928 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:06:20.862 | 29 | 1928 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:06:31.861 | 29 | 1929 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:06:40.361 | 29 | 1928 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:06:49.361 | 29 | 1923 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:06:56.861 | 29 | 1911 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:07:45.36 | 29 | 1928 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:07:46.86 | 29 | 1927 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:08:24.359 | 29 | 1949 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:08:25.359 | 29 | 1950 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:08:26.859 | 29 | 1950 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:08:30.859 | 29 | 1950 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:08:37.359 | 29 | 1951 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:09:17.358 | 29 | 1944 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:09:26.858 | 29 | 1950 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:09:28.358 | 29 | 1950 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:09:29.358 | 29 | 1949 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 00:56:20.374 | 01:10:45.356 | 29 | 1932 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |

Figure 1.03

M031810A (Cont)

```
            Flight Log
------------------------------
Project Number: 1100319
S/N           : Racine
Operator      : Jim
Pilot(s)      : Nick
Aircraft      : N3443Q
Airport       : KRAC
Mission       : M031810A
Wheels Up     : ???
Flight Length :
HOBBS Start   :
HOBBS End     : 2:07

            Weather
------------------------------
Date          : March 18, 2010
Julian Day    : 077
Temperature   : ???
Visibility    : ???
Clouds        : ???
Precipitation : ???
Wind Dir      : ???
Wind Speed    : ???
Pressure      : ???
            Statistics
------------------------------
Laser Time    : 00:14:25
```

```
      START        STOP LINE#   ALT  PRF    FREQ  ANGLE   MP  DIV   RC      HDG   Plan File
=========================================
 01:16:57.848  01:19:55.845     30  1936   70   32.40  22.00  NAR  OFF  OFF    90.00 racine_fixline.pln
 01:23:10.341  01:24:17.339     27  1921   70   32.40  22.00  NAR  OFF  OFF    90.00 racine_fixline.pln
 01:25:25.838  01:26:00.837     25  1923   70   32.40  22.00  NAR  OFF  OFF    90.00 racine_fixline.pln
 01:33:40.328  01:40:30.819     14  1909   70   32.40  22.00  NAR  OFF  OFF   270.00 racine_fixline.pln
 01:46:46.312  01:49:55.808     14  1888   70   32.40  22.00  NAR  OFF  OFF    90.00 racine fixline.pln
```

Figure 1.04

M031810B

```
            Flight Log
------------------------------
Project Number: 1100319
S/N            : Racine
Operator       : Jim
Pilot(s)       : Nick
Aircraft       : N3443Q
Airport        : KBUU
Mission        : M031810B
Wheels Up       : ???
Flight Length :
HOBBS Start    : 03:00
HOBBS End      :

            Weather
------------------------------
Date           : March 18, 2010
Julian Day     : 077
Temperature    : ???
Visibility     : ???
Clouds         : ???
Precipitation : ???
Wind Dir       : ???
Wind Speed     : ???
Pressure       : ???
            Statistics
------------------------------
Laser Time    : 00:53:21
```

| START | STOP | LINE# | ALT | PRF | FREQ | ANGLE | MP | DIV | RC | HDG | Plan File |
|-------|------|-------|-----|-----|------|-------|----|----|----|-----|-----------|
| 03:11:59.148 | 03:12:25.147 | 13 | 1921 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 03:12:32.147 | 03:12:53.147 | 13 | 1927 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 03:16:09.643 | 03:25:16.132 | 13 | 1921 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 03:29:32.627 | 03:38:17.116 | 12 | 1930 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 03:42:25.111 | 03:51:27.1 | 11 | 1917 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 03:59:00.091 | 04:01:32.588 | 6 | 1944 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 04:04:27.085 | 04:06:54.582 | 1 | 1934 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 04:09:18.579 | 04:11:48.576 | 7 | 1931 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 04:14:20.073 | 04:16:48.07 | 2 | 1952 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 04:19:21.067 | 04:21:49.564 | 8 | 1948 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 04:24:43.56 | 04:27:06.557 | 3 | 1926 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 04:29:41.554 | 04:32:12.051 | 9 | 1942 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 04:34:55.048 | 04:37:20.045 | 4 | 1938 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 04:40:06.042 | 04:42:30.539 | 10 | 1931 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 270.00 | racine_fixline.pln |
| 04:44:56.536 | 04:47:24.033 | 5 | 1951 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |
| 04:51:52.028 | 04:53:42.525 | 10 | 1916 | 70 | 32.40 | 22.00 | NAR | OFF | OFF | 90.00 | racine_fixline.pln |

**Appendix B: Original Flight Logs**

Figure 2.01

L031810A

## LIDAR FLIGHT LOG

MISSION: L031810A  
PILOT: Josey  
OPERATOR: Tom  
DATE: 3-18-10 THURS.  
AIRCRAFT: GPS 008  280mB

| PROJECT NUMBER | LINE NO. & Hdg | GND SPEED (KTS) | FREQ | SCAN ANGLE | PRF | ALT (m) | COT TIME START | STOP | Tranzpak Drive | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1100319 | | 2 TESTS | 19:19 | → | 19:21 | | | | | |
| | 44 E | ±156 | 32 | 22° | 70 | 1700 | 1:30 | 2:24 | | FERRY: SBM → SITE 9 |
| | 43 W | | | | | | 19:22 | 19:30 | | SOME ICE ON LAKES/PONDS |
| | 42 E | | | | | | 19:36 | 19:45 | | |
| | 41 W | 154-161 | | | | | 19:46 | 19:57 | | |
| | 40 E | 153-160 | | | | | 20:01 | 20:10 | | |
| | 39 W | | | | | | 20:13 | 20:22 | | ATC: 6.5 ASSIGNED 85m Hz E. |
| | 38 E | | | | | | 20:24 | 20:35 | | |
| | 37 W | | | | | | 20:37 | 20:45 | | |
| | 36 E | | | | | | 20:52 | 21:01 | | |
| | 35 N | | | | | | 21:05 | 21:14 | | |
| | 34 E | | | | | | 21:10 | 21:28 | | |
| | 33 W | | | | | | 21:31 | 21:41 | | |
| | 32 E | | | | | | 21:45 | 21:55 | | |
| | 31 W | | | | | | 21:58 | 22:08 | | |
| XFLT | 31 N | | | | | | 22:12 | 22:22 | | |
| | | | | | | | 22:25 | 22:29 | | |
| | | | | | | | 5:30 | 6:04 | | FERRY: SITE → SBM 6 |

| STATUS | TOTAL LINES | FLOWN | LEFT | AIRCRAFT SITE | FERRY | STATIC START | STOP |
|---|---|---|---|---|---|---|---|
| 1100319 | 44 | 14 | 30 | 3.1 | 1.5 | WX | |

NOTES: SOME MINOR FLOODING IN A FEW LOW AREAS IN SOME FIELDS. NO SNOW... GOOD CALL ON BROWN.

AERO-METRIC, INC.  N.6216 Resource Drive Sheboygan Falls, WI. 53085  PHONE: 920-467-2855  FAX: 920-457-1451  E-Mail: amephoto@aerometric.com

Figure 2.02
M031810A

# LIDAR FLIGHT LOG

**MISSION:** M031810A    **PILOT:** Nick    **OPERATOR:** Jim    **DATE:** 3-18-10 Thur    **AIRCRAFT:** N3443Q

| PROJECT NUMBER | LINE NO. & Hdg | | GND SPEED (KTS) | SCAN FREQ | SCAN ANGLE | PRF | ALT (m) | TIME START | TIME STOP | Tranzpak Drive | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1100319 | | | | | | | | | | | FERRY, SBM → SITE  AU TIMES GMT |
| RACINE | J TEST | | | | | | | 21:08 | 21:41 | | |
| | 15 | 270 | 155 | 32.0 | 88 | 70 | 1700 | 21:39 | 21:41 0181 | | |
| | 22 | 90 | 160 | 32.4 | | | | 21:41 | 21:50 | | |
| | 16 | 270 | 155 | 31.9 | | | | 21:55 | 22:4 | | |
| | 23 | 90 | 160 | 32.4 | | | | 22:08 | 22:17 | | |
| | 17 | 270 | 155 | 31.9 | | | | 22:21 | 22:30 | | |
| | 24 | 90 | 160 | 32.4 | | | | 22:34 | 22:43 | | |
| | 18 | 270 | 155 | 31.9 | | | | 22:47 | 22:56 | | |
| | 25 | 90 | 160 | 32.4 | | | | 22:58 | 23:08 | | |
| | 19 | 270 | | | | | | 23:11 | 23:20 | | |
| 10 | 26 | 90 | | | | | | 23:23 | 23:33 | | |
| | 20 | 270 | | | | | | 23:36 | 23:45 | | |
| | 27 | 90 | | | | | | 23:49 | 23:59 | | |
| | 21 | 270 | | | | | | 00:02 | 00:11 | | |
| | 28 | 90 | | | | | | 00:15 | 00:24 | | |
| 15 | 30 | 270 | | | | | | 00:28 | 00:37 | | |
| | 29 | 90 | | | | | | 00:42 | 00:51 | | LASM would not start off |
| | CROSS | 2 | | | | | | 00:56 | 01:10 | | PWR Down - LOST APC PWR |
| | | | | | | | | 01:16 | 01:19 | | 4552 |

| STATUS | TOTAL LINES | FLOWN | LEFT | AIRCRAFT SITE | AIRCRAFT FERRY | | STATIC START | STOP |
|---|---|---|---|---|---|---|---|---|
| 1100319 | 44 | 15/31 | 13 | 4.1 | 1.0 | | 21:08 | 02:32 |
| | | | Ø | 1.7 | .7 | | | |
| | | | | 5.6 | 1.8 | | | |

WAX HIGH Scully CLAVUS

**NOTES:**

Figure 2.03
M031810A

# LIDAR FLIGHT LOG

ALTM    JS2

MISSION: M031810A

PILOT: Nick    OPERATOR: Jim    DATE: 3-18-10 THUR    AIRCRAFT: N3443Q

| PROJECT NUMBER | LINE NO. & Hdg | | GND SPEED (KTS) | SCAN FREQ | ANGLE | PRF | ALT (m) | TIME START | STOP | Tranzpak Drive | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1100319 | 27 | 90 | 160 | 324 | 22 | 70 | 1700 | 01:23 | 01:24 | 0181 | GAP AREA |
| RACINE | 25 | 90 | | | | | | 01:25 | 01:26 | | GAP AREA |
| | 14 | 270 | | | | | | 01:33 | 01:40 | | PARTIAL ~ OFF LINE |
| | 14 | 90 | | | | | | 01:46 | 01:49 | | LINE COMPLETE |
| | | | | | | | | | 02:07 | | FERRY: SITE → RAC    .3 |
| | | | | | | | | 2:15 | 08:22 | | FERRY: RAC → BOJ |
| | | | | | | | | | | | → JS3  NEW MISSION    .2 |

| STATUS | TOTAL LINES | FLOWN | LEFT | AIRCRAFT SITE | FERRY | STATIC | START: | STOP: | NOTES: |
|---|---|---|---|---|---|---|---|---|---|
| ○○○ | | | | | | WX | | | |

Figure 2.04
M031810B

Mar 19 10 12:53a    Aero-Metric Hangar                    920-467-1220              p.1

## LIDAR FLIGHT LOG

MISSION: M031810B  
PILOT: NICK  
OPERATOR: JIM  
DATE: 3-18-10 THUR  
AIRCRAFT: N34473A

PROJECT NUMBER: 11003.9  RACINE

| LINE NO. & Hdg | GND SPEED (KTS) | SCAN FREQ | ANGLE | PRF | ALT (m) | TIME START | STOP | Tranzpak Drive | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| 2 TEST | | | | | | 03:00 | 03:12 | | FERRY: Bus → SITE |
| 13 90 | 160 | 32.4 | 22 | 70 | 1760 | 03:12 | 03:12 | | |
| 12 270 | | | | | | 03:16 | 02:35 | 0181 | |
| 11 90 | | | | | | 03:29 | 03:38 | | |
| 6 270 | | | | | | 03:42 | 03:51 | | |
| 1 90 | | | | | | 03:59 | 04:01 | | |
| 7 270 | | | | | | 04:04 | 04:04 | | |
| 2 90 | | | | | | 04:09 | 04:11 | | |
| 8 270 | | | | | | 04:14 | 04:16 | | |
| 3 90 | | | | | | 04:19 | 04:21 | | |
| 9 270 | | | | | | 04:24 | 04:27 | | |
| 4 90 | | | | | | 04:29 | 04:32 | | |
| 10 270 | | | | | | 04:34 | 04:37 | | |
| 5 90 | | | | | | 04:40 | 04:42 | | |
| CROSS N | | | | | | 04:44 | 04:47 | | |
| | | | | | | 04:51 | 04:53 | | |
| | | | | | | | 05:25 | | FERRY: SITE → BASE |

| STATUS | TOTAL LINES | FLOWN | LEFT | AIRCRAFT SITE | FERRY | STATIC START | STOP | NOTES: |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 03:... | | |

AERO-METRIC, INC.   N.8216 Resource Drive Sheboygan Falls, WI. 53085   PHONE: 920-467-2655   FAX: 920-457-1451   E-Mail: amophoto@aerometric.com

# Appendix C: Folder Structure

Appendix\
Control\

- KEHA.shp (Point)

Attributes to be included:
Name - KEHA
Latitude – N42° 33' 32.29917"
Longitude – W087° 55' 09.15144"
Base Station Elevation – 204.203 Meters

- SHAN.shp (Point)

Attributes to be included:
Name - SHAN
Latitude – N43°44'51.46198"
Longitude – W087° 44' 05.22551"
Base Station Elevation – 152.946 Meters

- SIWI.shp (Point)

Attributes to be included:
Name - SIWI
Latitude – N42° 52' 04.53392"
Longitude – W087° 58' 58.56228"
Base Station Elevation – 190.721 Meters

* Control_UTM16 (Point)
Attributes to be included:
Northing –NAD83_UTM_Zone_16N_Meters
Easting – NAD83_UTM_Zone_16N_Meters
Elevation – NAVD 88_Survey_Feet

Coverage\

* Flightline_LIDAR_Swath_SWATH.shp (Line)
Attributes to be included:
- Line Type (Calibration or Flight)
- Flight Line Number (Should correspond to flight logs)
- Date Flown