STARR
Strategic Alliance for Risk Reduction

Kittitas

Post-Flight Aerial Acquisition

Report

August 2011

Post-Flight Aerial Acquisition and Calibration Report

FEMA REGION 10

Kittitas County, WA

August 2011

Contents

1.0 Overview

1.1. Contact Information:

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

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1.2. Purpose and Location

AeroMetric, Inc acquired highly accurate Light Detection and Ranging (LiDAR) data for an area that comprised of approximately 185 square miles of Kittitas County, Washington for STARR as a part of FEMAs RiskMAP program. A graphic of the location is provided in Figure 1.1.

Figure 1.1 Project Area - Kittitas County, WA

2.0 LiDAR Acquisition

2.1 System Parameters

LiDAR was collected to the 'Highest' FEMA specification which is equivalent to the 2 foot contour equivalency accuracy requirement. This requires a nominal post spacing of 1 meter. The LiDAR system parameters to meet this requirement are found in Table 2.1.

Table 2.1 LiDAR System Specifications

Flying Height	1500 meters
Laser Pulse Rate	70 kHz
Mirror Scan Frequency	41 Hz
Scan Angle	(+/-) 16°
Side Lap	50%
Ground Speed	160 knots
Nominal Point Spacing	1 meter

2.2 Base Station Information:

All missions originated and terminated at Bowers Airport in Ellensburg, WA. A GPS base station was operating at the airport during every lift. Table 2.1 is the Base Station information for the project area. Figure 2.1 provides a graphic representation of the Base Station locations. In the figure the Green Stick Pin represents Base Station 39471080.t01. The maximum extent of the collection area was approximately 22 km from Base Station 39471080.t01. The Yellow Stick Pin represents Base Station 82571071. The maximum extent of the collection area was approximately 20 km from Base Station 82571071. Shapefiles of the Base Stations can be found in the Control.zip file attached to this report.

Table 2.2 Base Station Locations

POINT ID	LAT	LONG	HEIGHT (M)
39471080.t01	47 11 39.9373	120 56 33.6098	584.027
82571071	47 01 51.11424	120 31 14.92835	513.293

Figure 2.1 Base Station Location Map

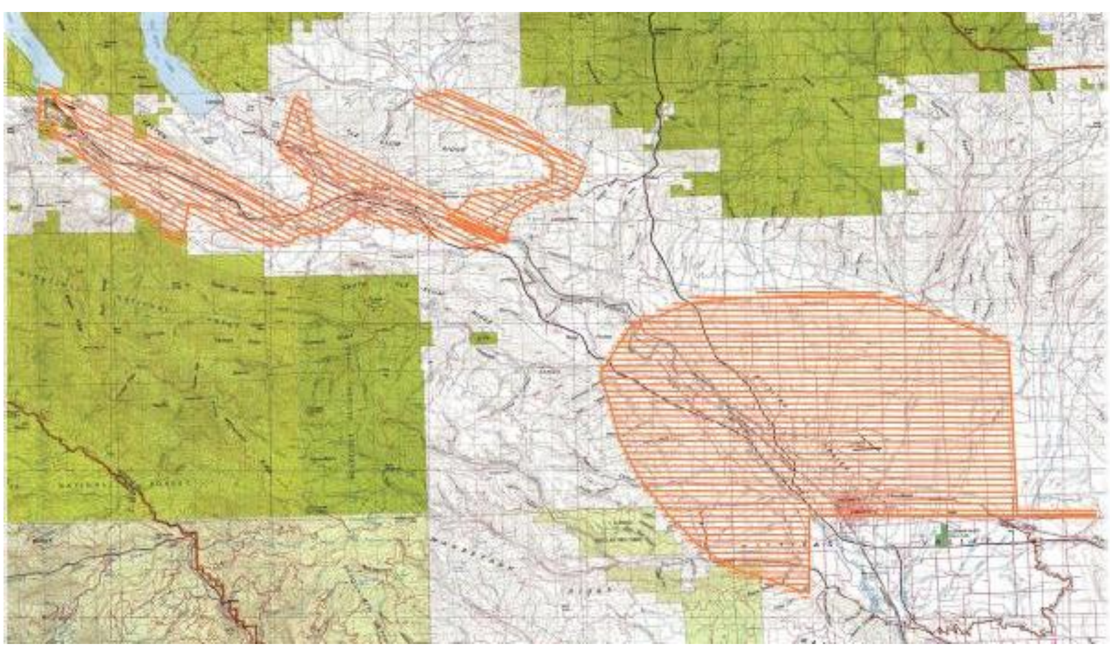
2.3 Time Period:

LiDAR data acquisition was completed between April 17, 2011 and April 19, 2011. A total of 4 flight missions were required to cover the project area. Table 2.3 provides the acquisition parameters. Figure 2.2 depicts the flightlines over the project area. Shapefiles of the flightline swath can be found in the Coverage.zip file attached to this report.

Table 2.3 LiDAR Acquisition Flight Summary

Acquisition Date, Mission, and Time	20110417 107B 12:15-17:00 PDT 20110418 108A 09:15-12:15 PDT 20110419 109A/109B 07:55-17:00 PDT
Area of Acquisition	185 square miles
Aircraft	PA 31 Navajo N59984
Planned Altitude	1,500 meters AGL
Planned Airspeed	160 knots
Planned Number of Flight Lines	Block 1 - 49 lines; Block 2 - 20 lines; Block 3 – 30 Lines
Flight Line Spacing	430 meters
Flight Line Coverage	860 meters
Sidelap	50%
System PRF	70 kHz
Mirror Scan Half Angle	16 degrees
Mirror Scan Rate	42 Hz
Nominal Point Density	0.7 points per square meter per pass
Datum	NAD83(NSRS2007) Epoch of 2007.0
	NAVD88 via Geoid09
Projection and Units	U.S. State Plane WA North Zone, U.S. Survey Foot

Figure 2.2 Flight Line Map



2.4 PDOP

The maximum planned PDOP for the LiDAR collection was set at ≤ 3.0. The PDOP plots are provided in Figures 2.3-2.6

PDOP Plots

Figure 2.3

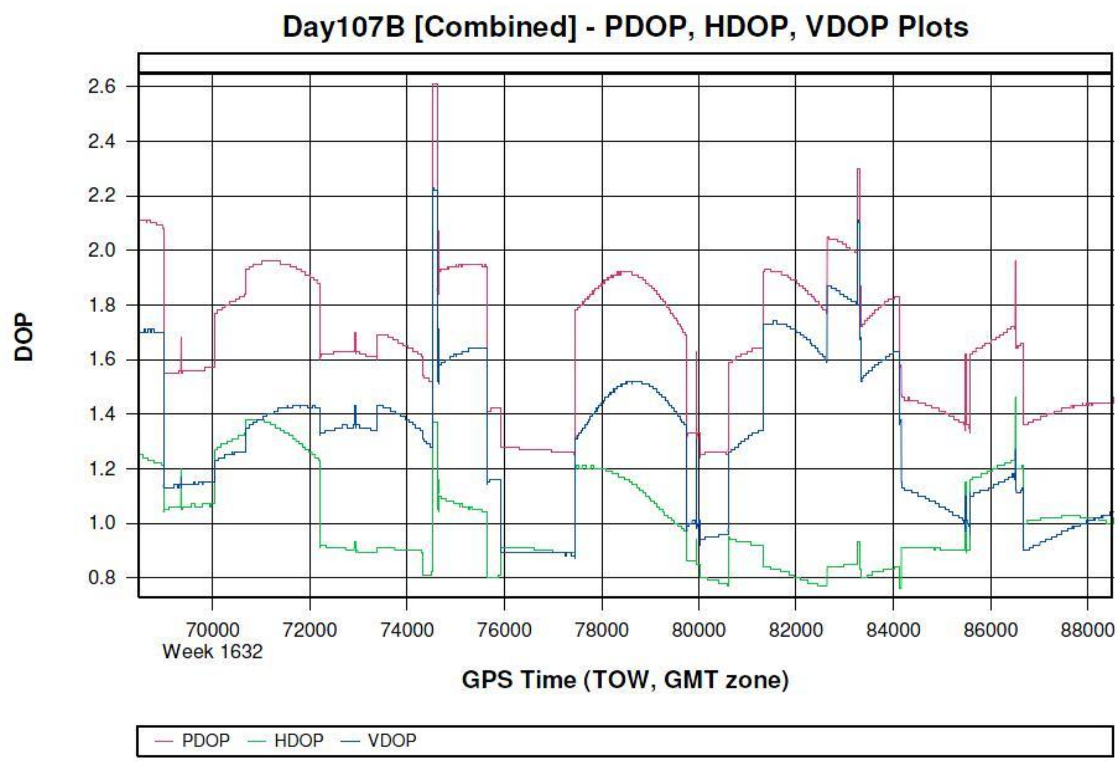


Figure 2.4

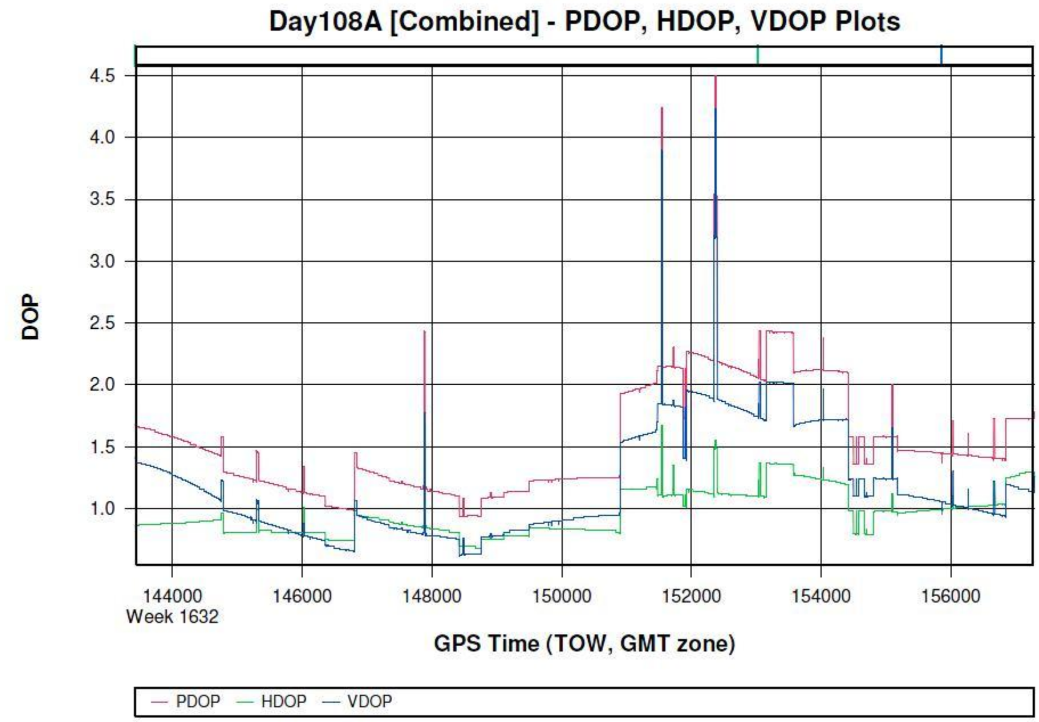


Figure 2.5

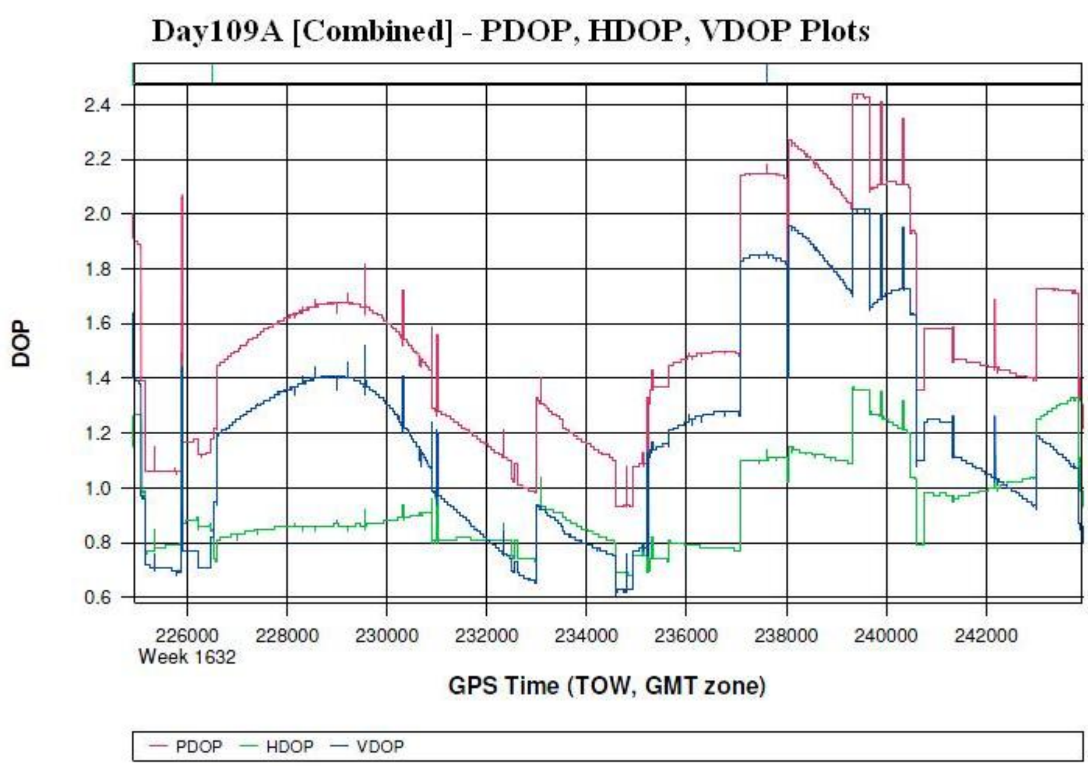
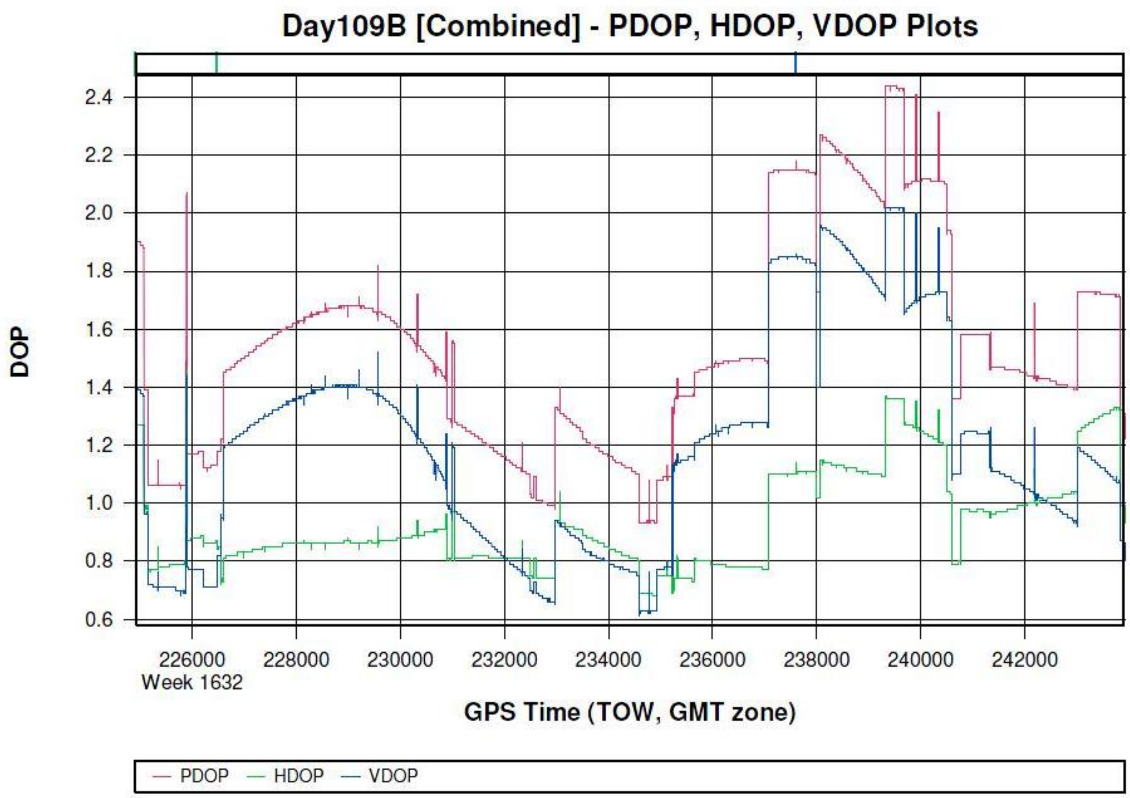


Figure 2.6



3.0Processing Summary

3.1 Airborne GPS

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 (Figures 3.1-3.4)between any two solutions, which will ultimately determine the acceptance of the airborne GPS post processing.

GPS Separation Plots

Figure 3.1

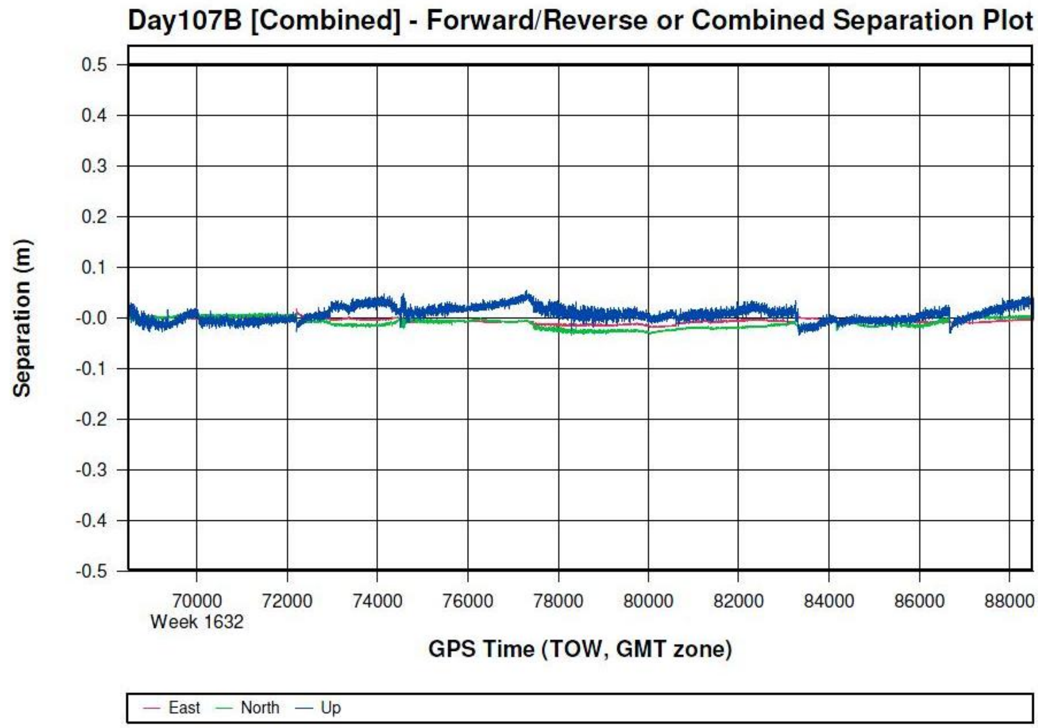


Figure 3.2

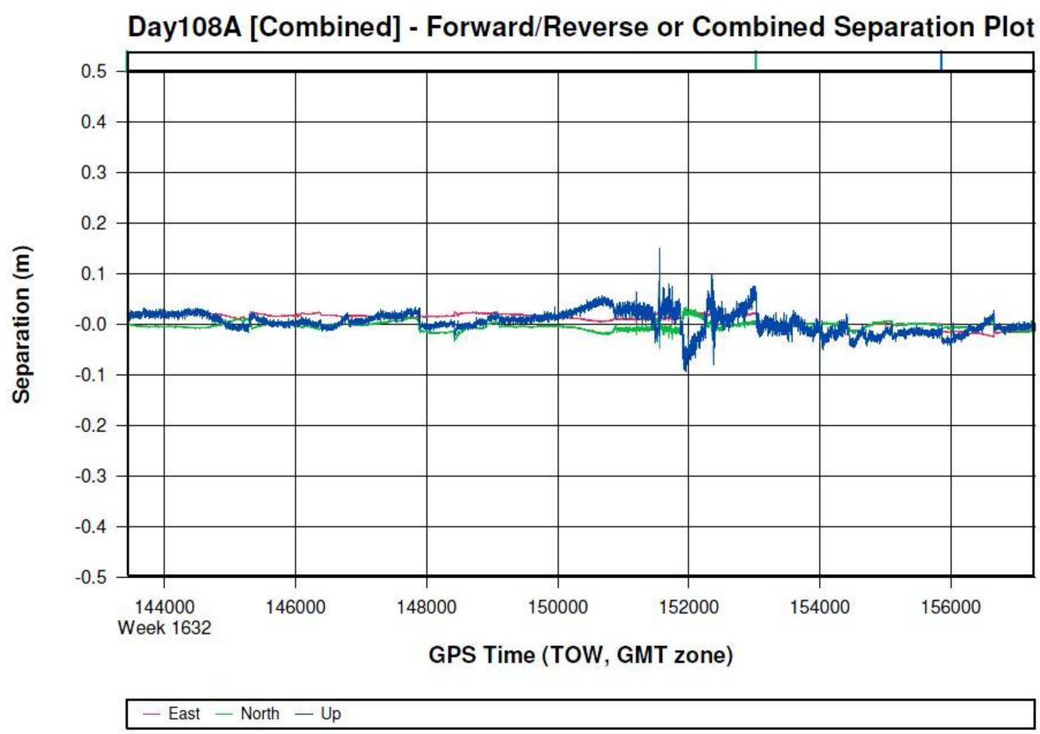


Figure 3.3

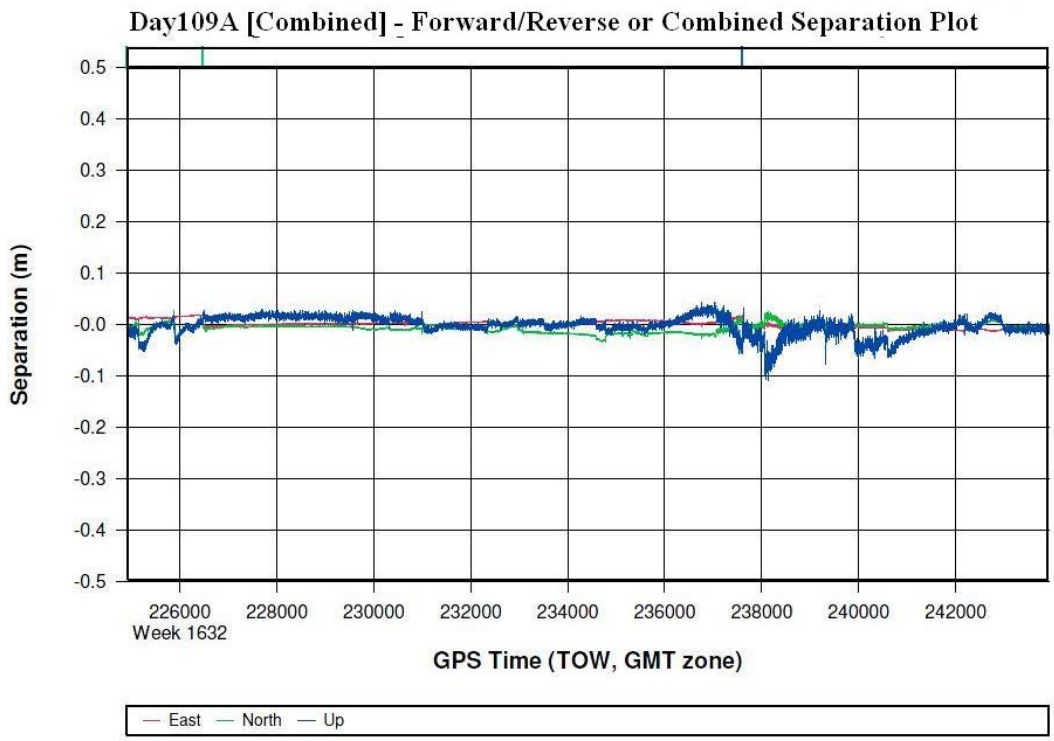
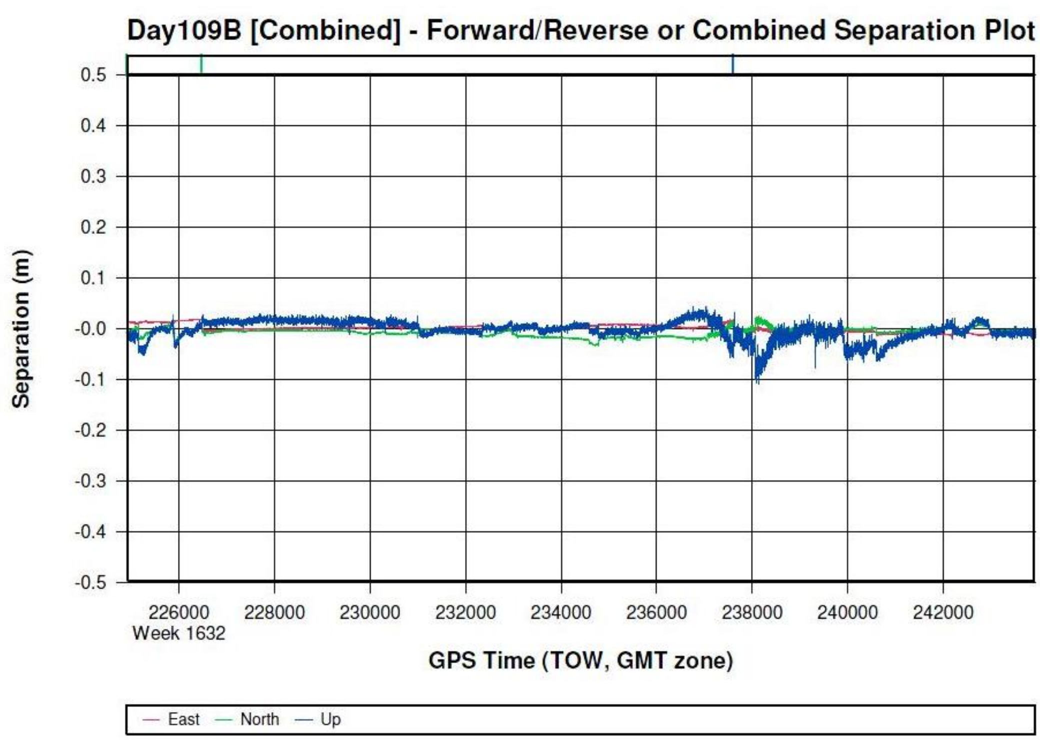


Figure 3.4



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 GPS Altitude Plots are presented in Figures 3.5 – 3.8.

GPS Altitude Plots

Figure 3.5 107B GPS Altitude Plot

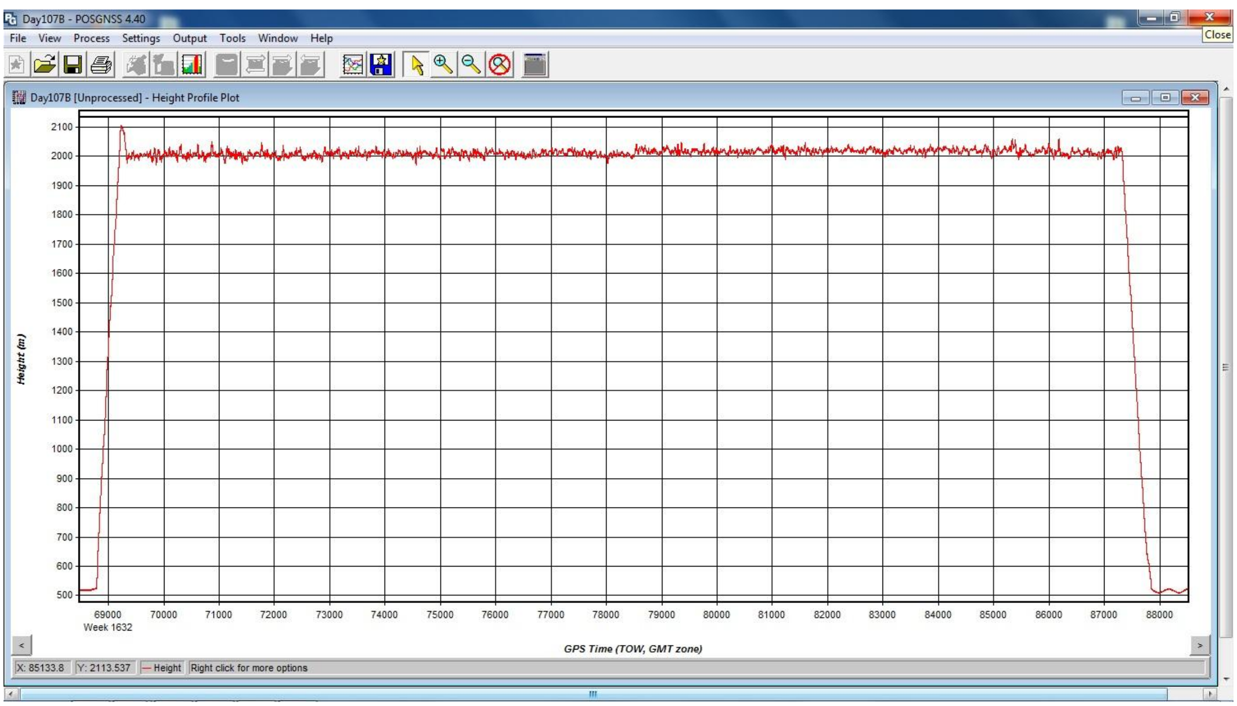


Figure 3.6 108A GPS Altitude Plot

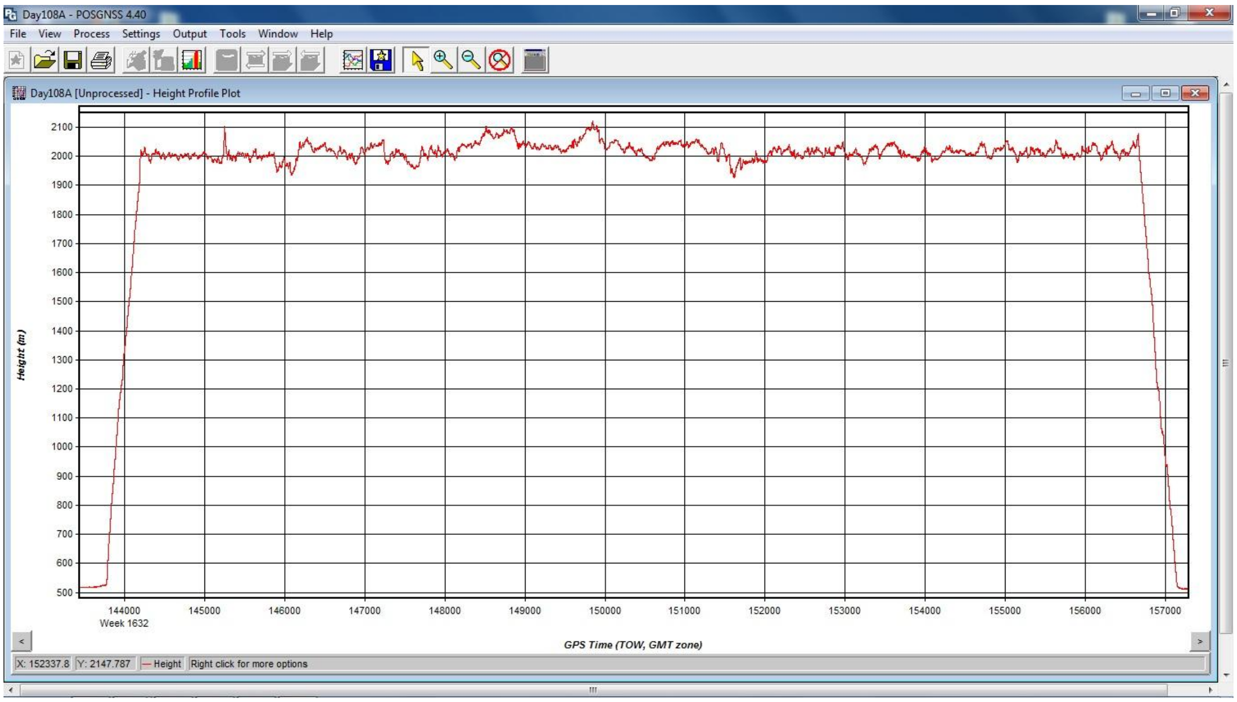


Figure 3.7 109A GPS Altitude Plot

Figure 3.8 109B GPS Altitude Plot

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.

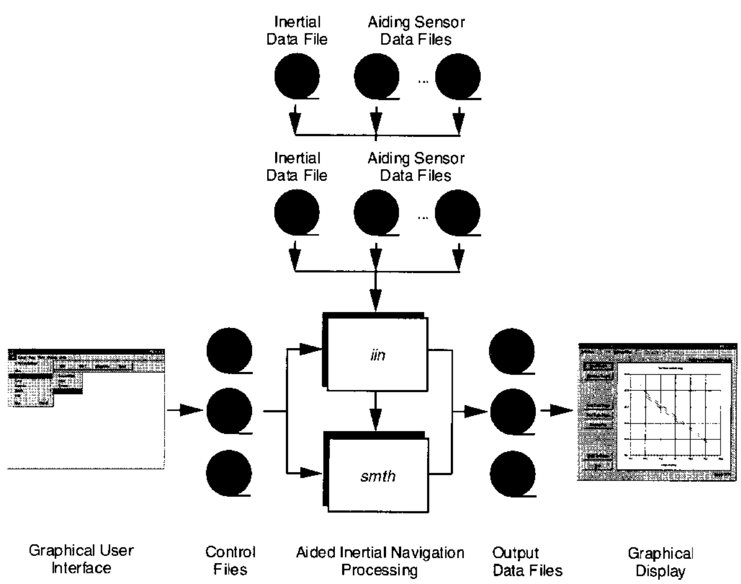
4. When the processed trajectory (either through POSGPS) data was accepted after quality control analysis, the combined solution is stored in a file format acceptable for the IMU post processor (i.e. POSProc). Shapefiles of the trajectories are found in the Coverage.zip attachment to this document.

5. Execute POSProc.

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

Figure 3.9 shows the organization of these tools, and the function of the POSProc processing components.

Figure 3.9 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.

3.2 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.

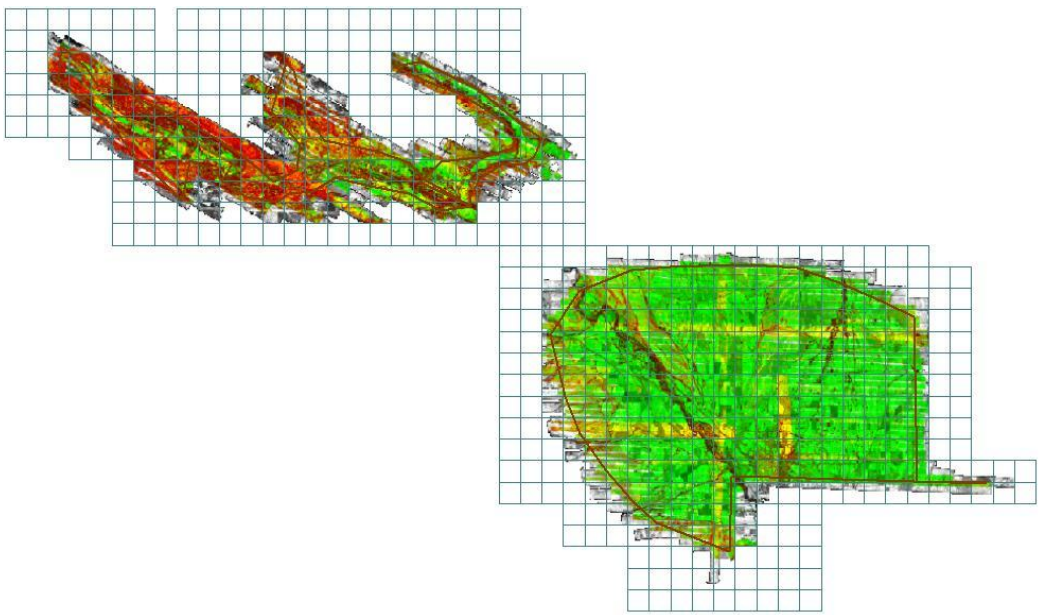
For each mission, LiDAR data for at least one cross flight is acquired over the mission's acquisition site. The processed data of the cross flight is compared to the perpendicular flight lines using either the Optech proprietary software or TerraSolid's TerraMatch software to determine if any systematic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

3.3 LIDAR Processing

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

The first step after the data has been processed and calibrated is to perform a relative accuracy assessment on the flightline to flightline comparisons and also a data density test prior any further processing. To determine a proper accuracy assessment between flightlines, Aerometric uses GeoCue to create Orthos by elevation differences. The generated orthos have assigned elevation ranges that allow the technician to evaluate if the data passes the accuracy assessment and also determine if additional calibration efforts are needed based on the bias trends. Figure 3.10 is the screen capture of the elevation orthos where green indicates a flightline comparison of less than 0.2 feet; yellow is 0.2-0.4 feet; orange is 0.4-0.6 feet, and red is greater than 0.6 feet.

Figure 3.10 DZ Raster Image



3.4Flight Log Overview:

-Post Spacing – 1 meter
-AGL (Above Ground Level) average flying height – 1500 meters
-MSL (Mean Sea Level) average flying height – 2100 meters
-Average Ground Speed – 160 knots
-Field of View – 30°
-Pulse Rate – 70 kHz
-Scan Rate – 41 Hz
-Side Lap (Average) – 50%

Flight logs are located at the end of this document.

4.0 Data Verification

The data was verified using the ground control data collected by Compass Data, Inc. 21 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. Table 4.1 provides this vertical accuracy test. RMSE = 0.1feet.

The Fundamental Vertical Accuracy (FVA) was tested by Compass Data, Inc. This test consisted of 20 vertical checkpoints reported at the 95% confidence level RMSE. FVA= 0.117 meters

The Supplemental Vertical Accuracy (SVA) was tested by Compass Data, Inc. This test consisted of 20 vertical checkpoints reported at the 95th Percentile RMSE. CVA= 0.152 meters

Table 4.1 Vertical Accuracy Test Results

Point	**Surveyed Elev.** (U.S. Survey Foot)	**Lidar Elev.** (U.S. Survey Foot)	**Difference** (U.S. Survey Foot)
CP50	1734.91	1734.85	-0.06
CP51	1923.59	1923.64	0.05
CP52	1823.89	1823.87	-0.02
CP53	1678.68	1678.85	0.17
CP54	2078.41	2078.55	0.15
CP55	1714.18	1714.17	-0.01
CP56	2310.98	2311.15	0.17
CP57	1995.45	1995.23	-0.22
CP58	1685.77	1685.75	-0.02
CP59	1540.66	1540.69	0.03
CP70	2303.73	2303.72	-0.01
CP71	2205.49	2205.35	-0.14
CP72	2092.45	2092.39	-0.06
CP73	2038.72	2038.79	0.07
CP74	1841.34	1841.16	-0.18
CP75	1910.75	1910.73	-0.02
CP76	2193.97	2193.99	0.02
CP77	2048.34	2048.29	-0.05
Cleelum	1916.10	1916.18	0.08
SX0873	2076.54	2076.52	-0.02
SX1547	1750.17	1750.25	0.08
Average dz			0.00
Standard deviation			0.10
Root mean square (RMS)			0.10

Original Flight Logs

Flight Log 107B Page 1

TOWILL Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date:	4-17-11
Mission:	107B

Survey Information		Base Station Data	
Project Name:	ELN 13652-101	Station Name:	SX1547
Flight Vendor / Tail No:	Marc Inc. N59984	Receiver Type & SN:	R7 # 8257
METs: temp, press, humid)	9.7° 950 mb 37.5%	Antenna & Measurement Type:	Zephyr Geodetic
Airport Start/End:	KELN	Antenna Height – meters:	1.357
Planned Parameters: (scan angle, freq., height)	16 42 1500	Antenna Height – feet:	4.451 → 1.3566 Checks?

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
Test	1908	1908				
Test	1915	1915				
c1	1916	1917	1500	356		Cal @ KELN
c2	1920	1926	1500	176		
49	1923	1923	1500	272		aborted
49	1927	1928	1500	272		
48	1931	—	1500	92		Error
48	1935	1936	1500	272		
47	1939		1500	92		Error Eye-Safety Alarm
47	1944	1946	1500	272		

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TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-17-11
Mission: 107B

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
46	1947	1950	1500	92		
45	1954	1956	1500	272		
44	1959	2001	1500	92		
43	2005	2007	1500	272		
42	2011	2013	1500	92		
41	2016	2019	1500	272		
40	2023	2025	1500	92		
39	2029	2032	1500	272		
37	2035	2041	1500	92		
36	2045	2052	1500	272		
38	2055	2058	1500	92		
35	2104	2109	1500	272		
34	2113	2118	1500	92		
33	2123	2129	1500	272		
32	2133	2138	1500	92		
31	2143	2149	1500	272		

TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-17-11
Mission: 107B

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
30	2153	2158	1500	92		
29	2263	2209	1500	272		
28	2213	2218	1500	92		
27	2223	2229	1500	272		
26	2233	2239	1500	92		
25	2244	2250	1500	272		
24	2254	2300	1500	92		
23	2305	2312	1500	272		
22	2315	2321	1500	92		
21	2325	2332	1500	272		
20	2335	2341	1500	92		
19	2346	2353	1500	272		
18	2358	0003	1500	92		
c3	0007	0002	1500	176		
c4	0017	0014	1500	356		

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LIDAR FLIGHT LOG

TOWILL | Surveying, Mapping and GIS Services

Date: 4-18-11
Mission: 108A

Survey Information		Base Station Data	
Project Name:	ELN 13652_101	Station Name:	SX 1547
Flight Vendor / Tail No:	Mosc. Inc N59984	Receiver Type & SN:	R7 # 8257
METs: temp, press, humid)	12.5° 950.1 mb 46.2%	Antenna & Measurement Type:	Zephyr Geodetic
Airport Start/End:	KELN	Antenna Height – meters:	1.398
Planned Parameters: (scan angle, freq., height)	16 42 1500	Antenna Height – feet:	4.585 → 13975'

Checks?

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
test	1559	1559				
c1	1603	1604	1500	176		Cal @ KELN
c2	1609	1610	1500	356		" Ellensburg
S0	1616	1619	1400	296		
S1	1622	1625	1400	116		trace amounts of snow
S2	1628	1631	1400	296		
S3	1635	1638	1400	116		
S4	1642	1646	1400	296		cloud - east
S5	1649	1650	1400	116		
S4	1655	1656	1400	296		Reflight ☆

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TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-18-11
Mission: 108A

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
56	1700	1701	1400	116		clouds ☆ Refly
17	1705	1711	1500	92		possible cloud - Big box
16	1715	1721	1500	272		
15	1725	1731	1500	92		
14	1735	1742	1500	272		
13	1746	1752	1500	92		
12	1756	1802	1500	272		
56	1805	1806	1400	296		Reflight
57	1809	1810	1400	116		
58	1815	1816	1400	296		
59	1820	1821	1400	116		
60	1826	1827	1400	296		
61	1831	1832	1400	116		
62	1837	1839	1400	296		possible cloud
63	1842	1844	1400	116		"
64	1849	1850	1400	296		"

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TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-18-11

Mission: 108A

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
65	1854	1855	1500	116		cloud possible
66	1900	1902	1500	296		
67	1906	1907	1500	116		
68	1911	1913	1500	296		
69	1117	1918	1500	116		
11						abort
c3	1924	1925	1500	176		
c4	1929	1930	1500	356		

Flight Log 109A Page 1

TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-19-11
Mission: 109A

Survey Information		Base Station Data	
Project Name:	ELN 13657-101	Station Name:	SX1547
Flight Vendor / Tail No:	Mare Inc N59984	Receiver Type & SN:	R7 #8257
METs: temp, press, humid)	11.5° 956.6 mb 55%	Antenna & Measurement Type:	Zephyr Geodetic
Airport Start/End:	KELN	Antenna Height – meters:	1.334
Planned Parameters: (scan angle, freq., height)	16 42 1500	Antenna Height – feet:	4.378 → 1.3344 Checks?

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
test	1437	1437				
c1	1441	1442	1500	176		Cal @ KELN
c2	1446	1447	1500	356		" Ellensburg
86	1455	1459	1100	300		Snow - abort - clouds
85	1502	1503	1405	120		
84	1507	1508	1400	300		
83	1512	1514	1400	120		
82	1518	1520	1450	300		
81	1523	1526	1400	120		
80	1530	1533	1400	300		possible cloud

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LIDAR FLIGHT LOG

TOWILL | Surveying, Mapping and GIS Services

Date: 4-19-11
Mission: 109A

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
74	1538	1542	1200	120		66 reflight
75	1546	1550	1500	300		
76	1554	1558	1400	120		possible clouds
77	1603	1607	1400	300		
78	1611	1614	1400	120		
79	1619	1623	1400	300		cloud at West ☆
76	1625	1625	1400	120		aborted Snow
61	1628	1629	1500	116		Reflight
57	1632	1635	1500	296		Reflight + 53
64	1637	1638	1500	116		Reflight
90	1642	1643	1500	300		Aborted
12	1649	1655	1500	92		Reflight
1	1658	1701	1500	272		
2	1706	1709	1500	92		
3	1714	1718	1500	272		
4	1722	1726	1500	92		

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TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-19-11
Mission: 109A

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
5	1730	1735	1500	272		
6	1739	1744	1506	92		
7	1749	1754	1500	272		
87	1757	1802	1200	300		1200 meter plan abort
8	1809	1815	1500	92		
9	1819	1825	1500	272		
10	1829	1835	1500	92		
13	1840	1841	1500	271		Reflight
11	1846	1853	1500	272		
20	1856	1857	1500	92		Reflight
21	1904	1905	1500	92		Reflight
29	1910	1913	1500	92		
Cross	1918	1923	1500	2		Crossline
C3	1926	1927	1500	176		
C4	1931		1500	356		

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TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date:	4-19-11
Mission:	109B

Survey Information		Base Station Data	
Project Name:	ELN 13652_101	Station Name:	SX 1547
Flight Vendor / Tail No:	Move Inc N59984	Receiver Type & SN:	R7 # 8257
METs: temp, press, humid)	14° 956 mb 23.2%	Antenna & Measurement Type:	Zephyr Geodetic
Airport Start/End:	KELN	Antenna Height – meters:	1.334
Planned Parameters: (scan angle, freq., height)	19.50 42 1200	Antenna Height – feet:	4.378 → 13344 Checks?

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
test	2110					
87	2117	2125	1200	300		1200m plan
88	2128	2133	1200	170		
89	2134	2141	1200	300		
90	2146	2150	1200	120		
91	2155	2200	1200	300		
92	2204	2208	1200	170		Snow in Air - west
93	2212	2218	1200	300		
94	2220	2224	1200	120		
95	2229	2233	1200	300		

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TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-19-11
Mission: 109B

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
96	2236	2238	1200	120		
97	2242	2244	1200	300		
98	2246	2248	1200	120		
99	2251	2252	1200	300		
100	2256	2257	1200	120		
92	2259	2302	1700	300		Reflight - Bad line
70	2306	2307	1400	120		1500m plan
71	2311	2312	1500	300		
72	2315	2316	1700	120		
73	2319	2321	1700	300		
92	2326	2330	1700	110		Reflight
80	2333	2337	1500	300		Reflight
79	2340	2343	1500	120		Reflight
77	2347	2352	1500	300		Reflight
76	2355	2359	1500	120		Reflight
C3	0005	0005	1500	176		Cal
C4	0008	0009	1500	356		