Airborne Lidar Report

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NE Eastern Nebraska UA Lidar 2016 B16

Contract Number: G16PC00022
Task Number: G16PD01160

Contractor: Woolpert, Inc.
Woolpert Project # 77026

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Section 1: Overview

TASK ORDER NAME: NE Eastern Nebraska UA Lidar 2016 B16

Project: # 77026

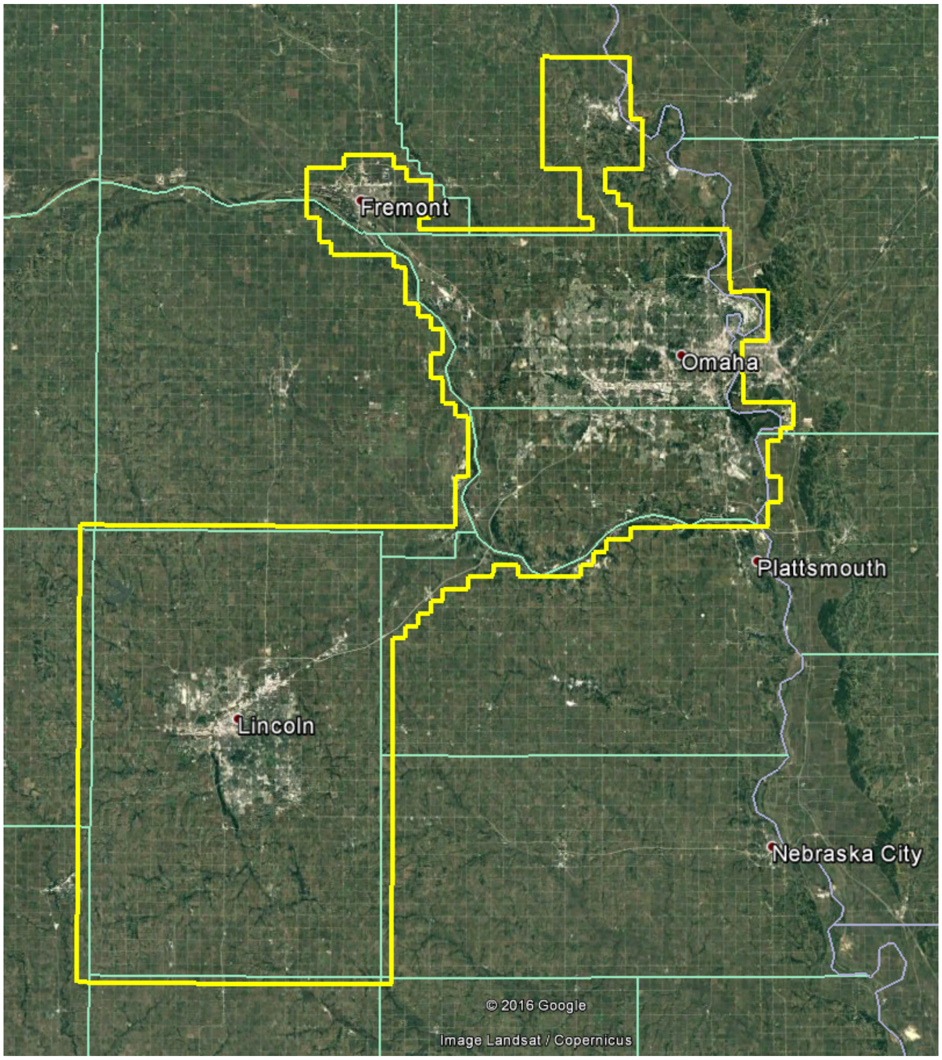
This report contains a comprehensive outline of the NE Eastern Nebraska UA Lidar 2016 B16 task order. Processing task order for the United States Geological Survey (USGS). This task is issued under USGS Contract No. G16PC00022, Task Order No. G16PD01160. This task order requires lidar data to be acquired over 1,789 square miles of V.1.2 lidar, for the area of interest (located in Eastern Nebraska and includes the cities of Lincoln and Omaha) collected at a nominal pulse spacing (NPS) of 0.7 meters. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.

The data was collected using Leica ALS70 500 kHz Multiple Pulses in Air (MPiA) lidar sensor. The ALS70 sensor collects up to four returns per pulse, as well as intensity data, for the first three returns. If a fourth return was captured, the system does not record an associated intensity value. The aerial lidar was collected at the following sensor specifications:

Table 1.1: ALS70 Specifications - ASI	
Post Spacing	0.70 m
AGL (Above Ground Level) average flying height	1,500 m
Average Ground Speed:	150 knots
Field of View (full)	50 degrees
Pulse Rate	177.4 kHz
Scan Rate	25.8 Hz

The horizontal datum used for the task order was referenced to NAD 1983 2011 Nebraska State Plane (FIPS 2600), U.S. Survey Feet. The vertical datum used for the task order was referenced to NAVD 1988 (GEOID12B), U.S. Survey Feet.

Figure 1.1: NE Eastern Nebraska UA Lidar 2016 B16 Task Order AOI



Section 2: Acquisition

The lidar data was acquired with Leica ALS70 500 kHz Multiple Pulses in Air (MPiA) lidar sensors system. The ALS70 lidar system, developed by Leica Geosystems of Heerbrugg, Switzerland, includes the simultaneous first, intermediate and last pulse data capture module, the extended altitude range module, and the target signal intensity capture module.

The ALS70 500 kHz Multiple Pulses in Air (MPiA) Lidar System has the following specifications:

Table 2.1: ALS Lidar System Specifications	
Operating Altitude	200 – 3,500 meters
Scan Angle	0 to 75° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 200 Hz (variable based on scan angle)
Maximum Pulse Rate	500 kHz (Effective)
Range Resolution	Better than 1 cm
Elevation Accuracy	7 - 16 cm single shot (one standard deviation)
Horizontal Accuracy	5 – 38 cm (one standard deviation)
Number of Returns per Pulse	7 (infinite)
Number of Intensities	3 (first, second, third)
Intensity Digitization	8 bit intensity + 8 bit AGC (Automatic Gain Control) level
MPiA (Multiple Pulses in Air)	8 bits @ 1nsec interval @ 50kHz
Laser Beam Divergence	0.22 mrad @ $1/e^2$ (~0.15 mrad @ 1/e)
Laser Classification	Class IV laser product (FDA CFR 21)
Eye Safe Range	400m single shot depending on laser repetition rate
Roll Stabilization	Automatic adaptive, range = 75 degrees minus current FOV
Power Requirements	28 VDC @ 25A
Operating Temperature	0-40°C
Humidity	0-95% non-condensing
Supported GNSS Receivers	Ashtech Z12, Trimble 7400, Novatel Millenium

Prior to mobilizing to the project site, flight crews coordinated with the necessary Air Traffic Control personnel to ensure airspace access.

Crews were onsite, operating a Base Station for the airborne GPS support.

The Lidar data was collected in twelve (12) missions, flown as close together as the weather permitted, to ensure consistent ground conditions across the project area. An initial quality control process was performed immediately on the Lidar data to review the data coverage, airborne GPS data, and trajectory solution. Collection of lidar data took place from December 8, 2017 through February 3, 2017.

Figure 2.1: Lidar Flight Layout, NE Eastern Nebraska UA Lidar 2016 B16

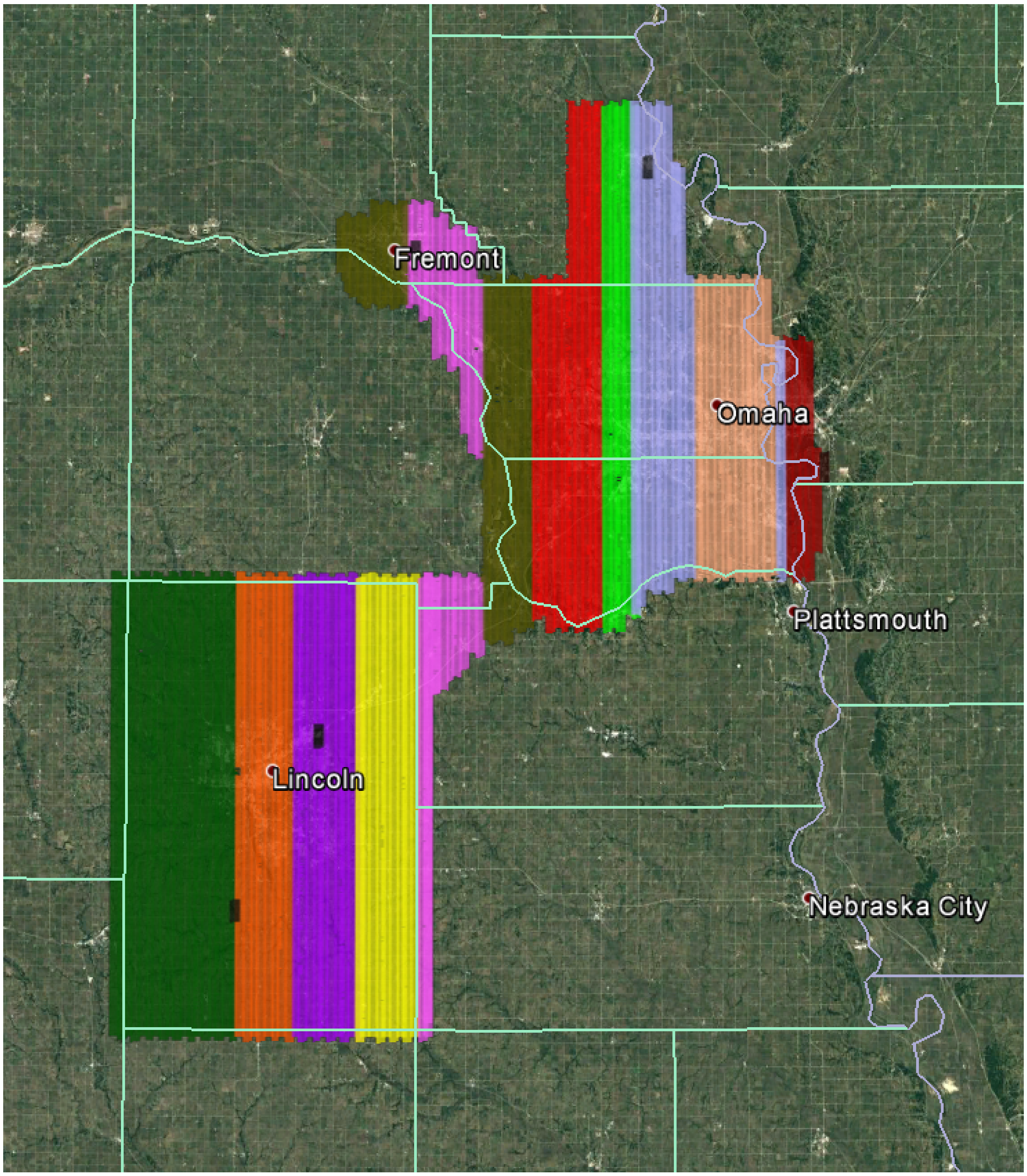


Table 2.3: Airborne Lidar Acquisition Flight Summary	
Date of Mission	Lines Flown
December 8, 2016_A	**97-102**
December 8, 2016_B	**1-19**
December 8, 2016_C	**19-26**
December 9, 2016_A	**27-36**
December 9, 2016_B	**36-44**
December 12, 2016_A	**45-53, 106-109, 117-123**
December 12, 2016_B	**55-60, 103-105, 110-116**
December 12, 2016_C	**61-70**
December 13, 2016_A	**71-75**
December 13, 2016_B	**83-95**
December 13, 2016_C	**75-82, 96**
February 3, 2017	**18R, 30R, 77R, 102R, 118R**

Section 3: LiDAR Data Processing

Applications and Work Flow Overview

With the data in office, the aircraft GPS, IMU, and reference station data was processed using Waypoint Inertial Explorer. Once the reference station data was imported into the program, the lever arm offsets between the aircraft's GPS and the IMU were applied, and the tightly coupled processing ran. Once completed, the quality of the airborne solution was analyzed. The PDOP during each data collection was verified to be ≤3.0, and the combined vertical separation <10 cm. Other graphs, including Positional Accuracy, Quality Factor, and Distance to Base, were also analyzed to ensure a good solution. Finally, the data was smoothed and the final solution file was output for use in the LiDAR data processing.

In Leica's CloudPro software, the raw LiDAR data was processed and output into a usable format for calibration and editing. It began by applying the calculated boresight angles to each of the sensor's 2 channels, and then the intensity scale factors, as determined based on the flight height, were applied. At that point, the proper LAS file format and projection information was set for the data output. In the final data output process, the airborne solution file and IMU lever arm adjustments were applied to the raw data to create the processed LAS and trajectory files.

Once the LAS and trajectory files had been generated, they were imported into the Terrasolid program to begin calibration QC and adjustment. The first step was to review the overlapping swaths at random spots to determine the amount of mismatch. A relative adjustment was then calculated to adjust the data to ensure that the RMSDz was not above 8 cm, and that no observations of mismatch greater than 16 cm were observed. The final adjustment was then calculated by measuring the mismatch between the surveyed ground control and the LiDAR data.

Once the data had been processed the technician reviewed the data for, coverage, point density, and projection. Coverage check was preformed to ensure the area of interest was fully covered by the LiDAR data. The LiDAR was checked to safeguard that both density and distribution within the data was achieved.

Global Navigation Satellite System (GNSS)–Inertial Measurement Unit (IMU) Trajectory Processing

Equipment

The pilots are skilled at maintaining their planned trajectory, while holding the aircraft steady and level. If atmospheric conditions are such that the trajectory, ground speed, roll, pitch and/or heading cannot be properly maintained, the mission is aborted until suitable conditions occur.

Base stations were set by acquisition staff and were used to support the Lidar data acquisition. The base station operated during the Lidar acquisition missions is listed below:

Table 3.1: Base Station

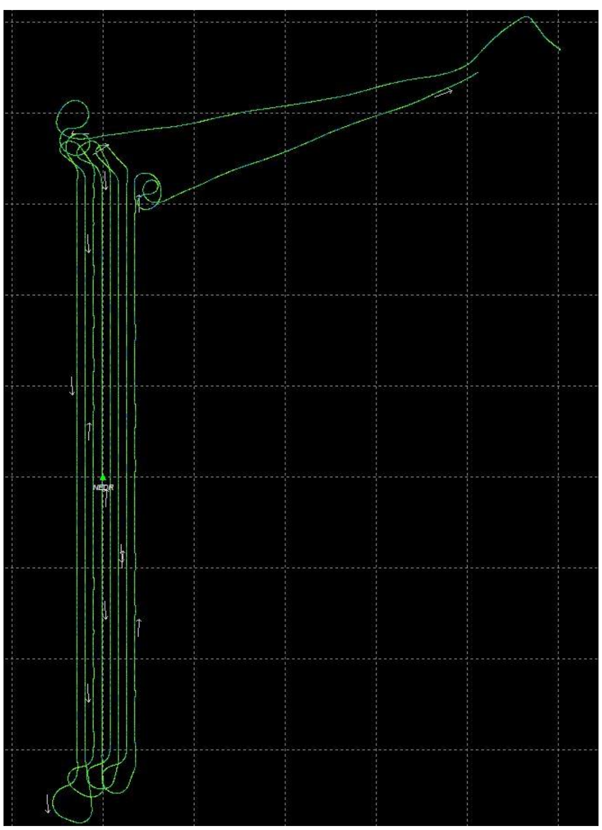
Station (Name)	Latitude (DMS)	Longitude (DMS)	Ellipsoid Height (L1 Phase center) (Meters)
IACB	41°13'26.40834"	95°51'11.63598"	276.893

NEDR	40°46'21.31567"	96°42'01.18714"	348.307
NEOM	41°12'56.04907"	96°04'49.45298"	350.484

Trajectory Quality

The GNSS Trajectory, along with high quality IMU data are key factors in determining the overall positional accuracy of the final sensor data. Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the combined separation, the estimated positional accuracy, and the Positional Dilution of Precision (PDOP).

Figure 3.1: Trajectory, Day34316

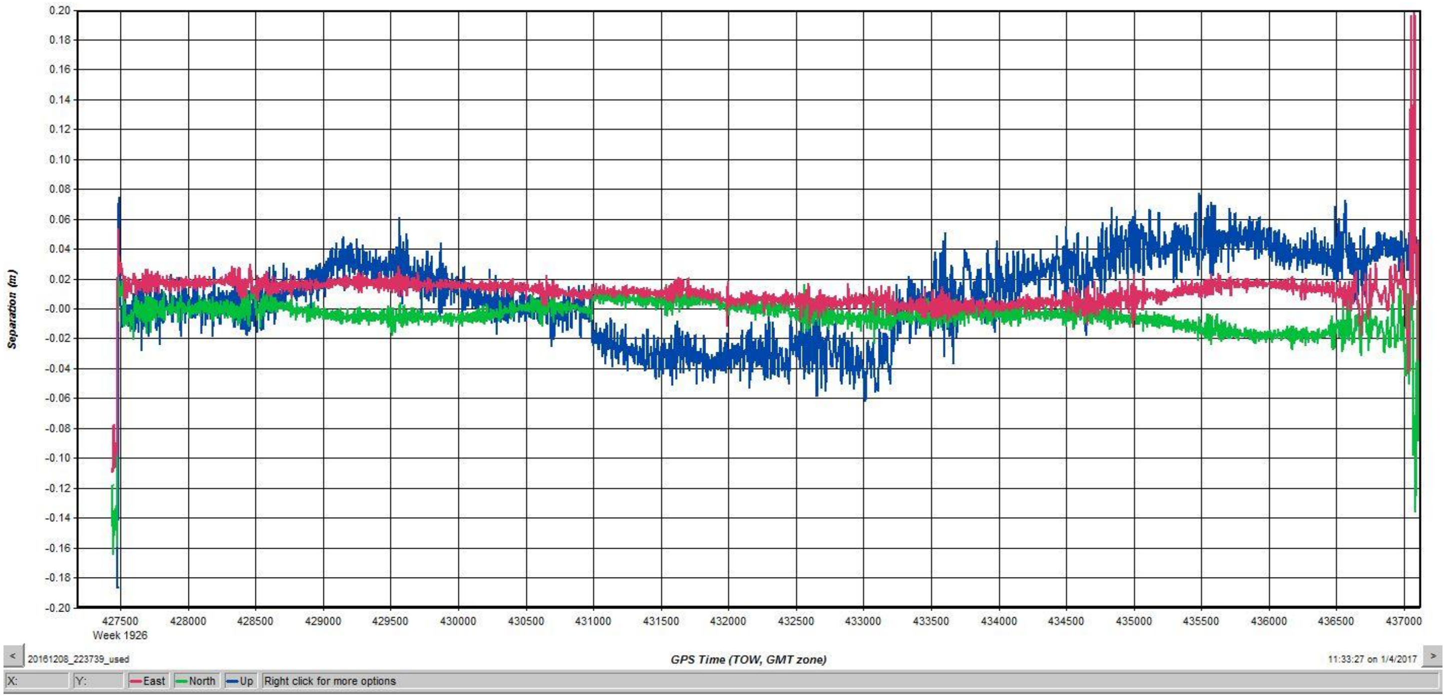


Combination Separation

The Combined Separation is a measure of the difference between the forward run and the backward run solution of the trajectory. The Kalman filter is processed in both directions to remove the combined directional anomalies. In general, when these two solutions match closely, an optimally accurate reliable solution is achieved.

Woolpert's goal is to maintain a Combined Separation Difference of less than ten (10) centimeters. In most cases we achieve results below this threshold.

Figure 3.2: Combined Separation, Day34316

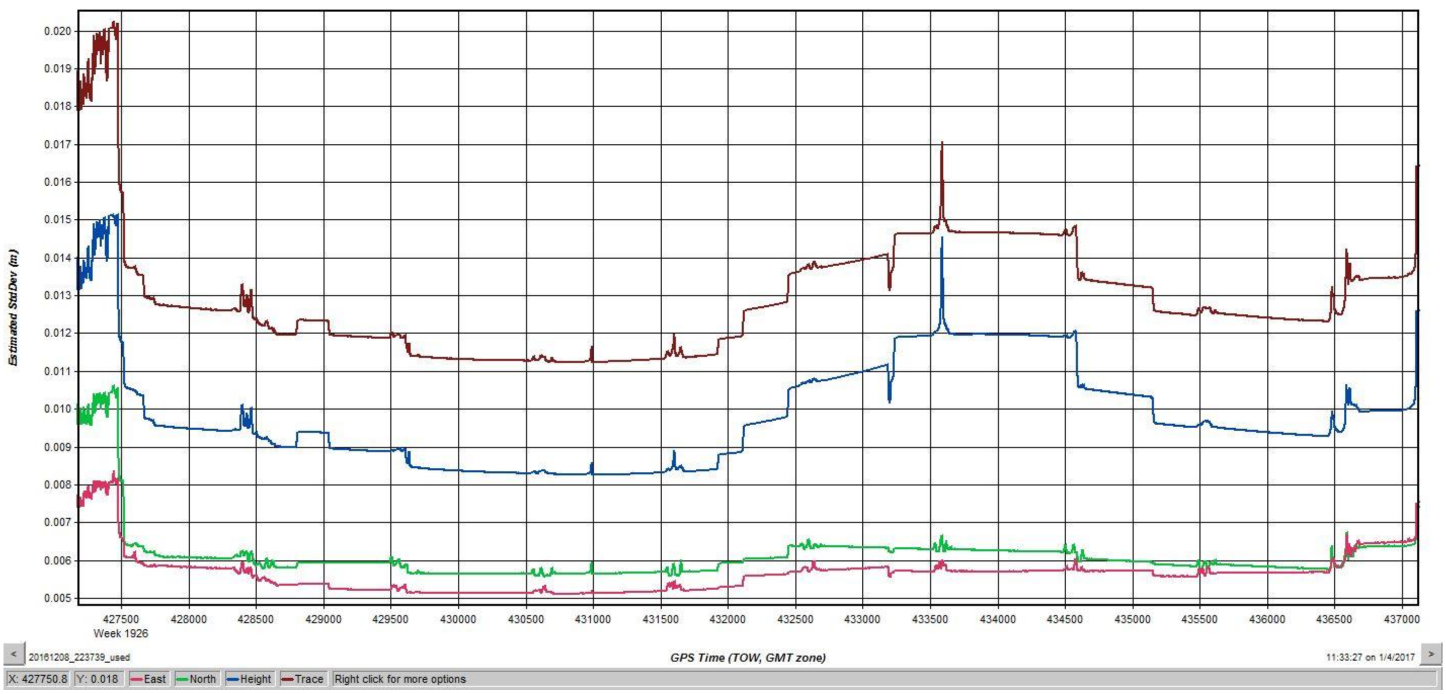


Estimated Positional Accuracy

The Estimated Positional Accuracy plots the standard deviations of the east, north, and vertical directions along a time scale of the trajectory. It illustrates loss of satellite lock issues, as well as issues arising from long baselines, noise, and/or other atmospheric interference.

Woolpert's goal is to maintain an Estimated Positional Accuracy of less than ten (10) centimeters, often achieving results well below this threshold.

Figure 3.3: Estimated Positional Accuracy, Day34316

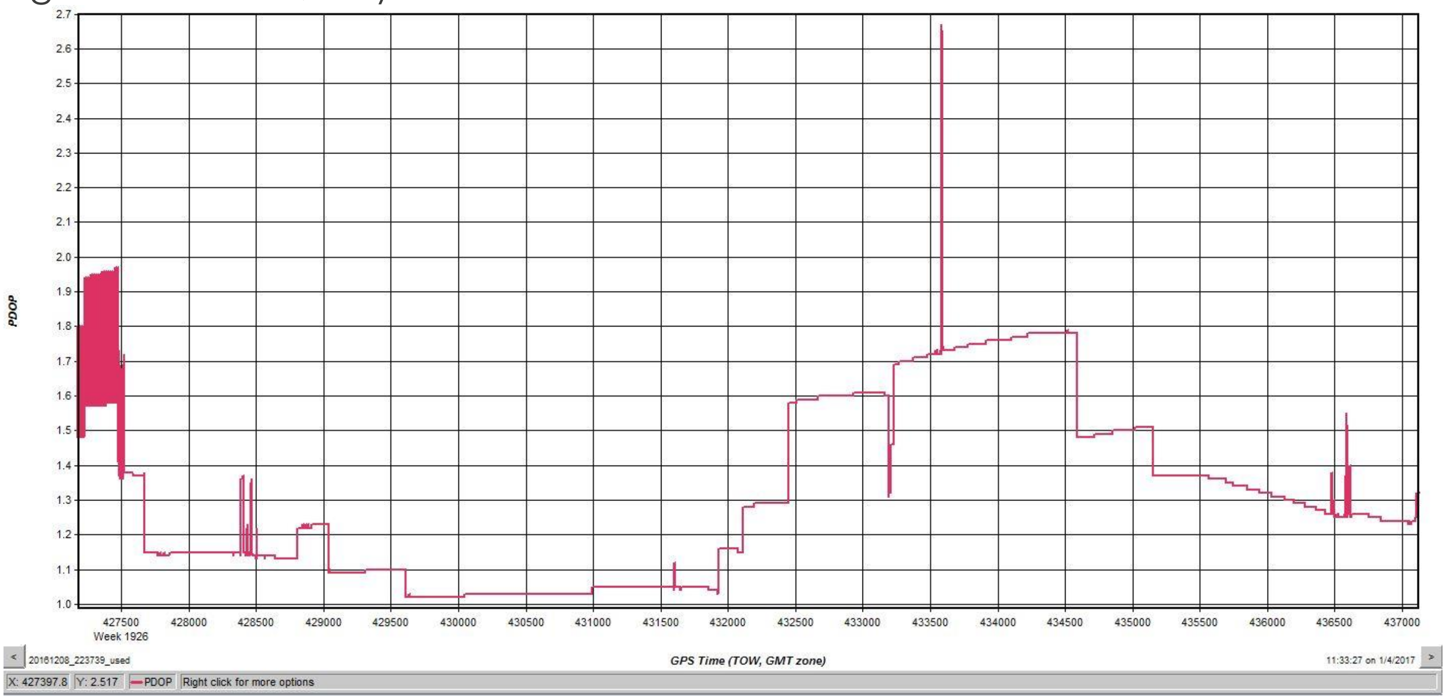


PDOP

The PDOP measures the precision of the GPS solution in regards to the geometry of the satellites acquired and used for the solution.

Woolpert's goal is to maintain an average PDOP value below 3.0. Brief periods of PDOP over 3.0 are acceptable due to the calibration and control process if other metrics are within specification.

Figure 3.4: PDOP, Day34316



LiDAR Data Processing

When the sensor calibration, data acquisition, and GPS processing phases were complete, the formal data reduction processes by lidar specialists included:

- Processed individual flight lines to derive a raw “Point Cloud” LAS file. Matched overlapping flight lines, generated statistics for evaluation comparisons, and made the necessary adjustments to remove any residual systematic error.
- Calibrated LAS files were imported into the task order tiles and initially filtered to create a ground and non-ground class. Then additional classes were filtered as necessary to meet client specified classes.
- Once all project data was imported and classified, survey ground control data was imported and calculated for an accuracy assessment. As a QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparisons against the TIN and the DEM using surveyed ground control of higher accuracy. The lidar is adjusted accordingly to meet or exceed the vertical accuracy requirements.
- The lidar tiles were reviewed using a series of proprietary QA/QC procedures to ensure it fulfills the task order requirements. A portion of this requires a manual step to ensure anomalies have been removed from the ground class.
- The lidar LAS files are classified into the Processed but not classified (Class 1), Ground or Bare earth ground (Class 2), Low Noise (Class 7), Water (Class 9), Ignored ground (Class10), Bridge Decks (Class 17), High Noise (Class 18) classifications.
- FGDC Compliant metadata was developed for the task order in .xml format per product.
- The horizontal datum used for the task order was referenced to Nebraska State Plane FIPS 2600, NAD83 (2011), US Survey Feet. The vertical datum used for the task order was referenced to NAVD 1988 (GEOID12B), U.S. Survey Feet,

GDSection 4: Hydrologic Flattening

HYDROLOGIC FLATTENING OF LIDAR DEM DATA

NE Eastern Nebraska UA Lidar 2016 B16 processing task order required the compilation of breaklines defining water bodies and rivers. The breaklines were used to perform the hydrologic flattening of water bodies, and gradient hydrologic flattening of double line streams and rivers. Lakes, reservoirs and ponds, at a minimum size of 2-acre or greater, were compiled as closed polygons. The closed water bodies were collected at a constant elevation. Rivers and streams, at a nominal minimum width of 30 meters (100 feet), were compiled in the direction of flow with both sides of the stream maintaining an equal gradient elevation.

LIDAR DATA REVIEW AND PROCESSING

Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing lidar data.

1. Woolpert used the newly acquired lidar data to manually draw the hydrologic features in a 2D environment using the lidar intensity and bare earth surface. Open Source imagery was used as reference when necessary.
2. Woolpert utilizes an integrated software approach to combine the lidar data and 2D breaklines. This process “drapes” the 2D breaklines onto the 3D lidar surface model to assign an elevation. A monotonic process is performed to ensure the streams are consistently flowing in a gradient manner. A secondary step within the program verifies an equally matching elevation of both stream edges. The breaklines that characterize the closed water bodies are draped onto the 3D lidar surface and assigned a constant elevation at or just below ground elevation.
3. The lakes, reservoirs and ponds, at a minimum size of 2-acre or greater and streams at a minimum size of 30 meters (100 feet) nominal width, were compiled to meet task order requirements. **Figure 4.1** illustrates an example of 30 meters (100 feet) nominal streams identified and defined with hydrologic breaklines. The breaklines defining rivers and streams, at a nominal minimum width of 30 meters (100 feet), were draped with both sides of the stream maintaining an equal gradient elevation.
4. All ground points were reclassified from inside the hydrologic feature polygons to water, class nine (9).
5. All ground points were reclassified from within a buffer along the hydrologic feature breaklines to buffered ground, class ten (10).
6. The lidar ground points and hydrologic feature breaklines were used to generate a new digital elevation model (DEM).

Figure 4.1: Example Hydrologic Breaklines

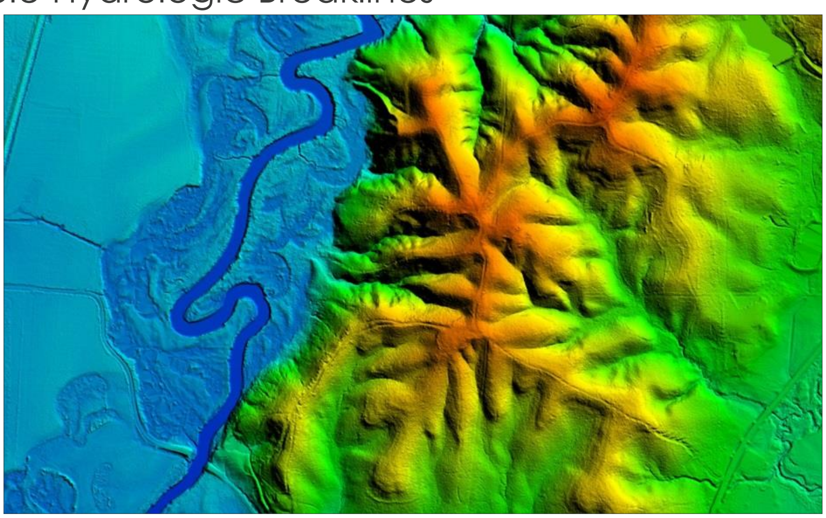


Figure 4.2 reflects a DEM generated from original lidar bare earth point data prior to the hydrologic flattening process. Note the “tinning” across the lake surface.

Figure 4.3 reflects a DEM generated from lidar with breaklines compiled to define the hydrologic features. This figure illustrates the results of adding the breaklines to hydrologically flatten the DEM data. Note the smooth appearance of the lake surface in the DEM.

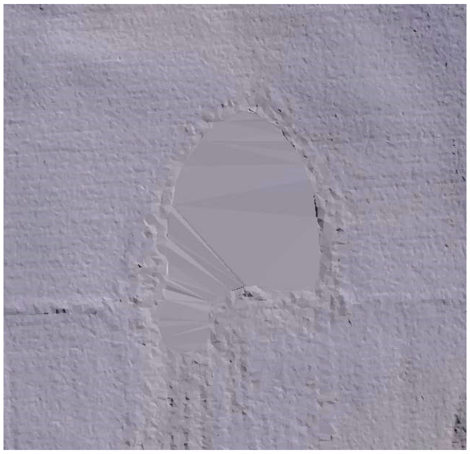


Figure 4.2

Figure 4.3

Terrascan was used to add the hydrologic breakline vertices and export the lattice models. The hydrologically flattened DEM data was provided to USGS in ERDAS .IMG format.

The hydrologic breaklines compiled as part of the flattening process were provided to the USGS in ESRI GDB format. The breaklines defining the water bodies greater than 2-acre and for the gradient flattening of all rivers and streams at a nominal minimum width of 30 meters (100 feet) were provided in geodatabase as a Polygon-Z and Polyline-Z shape file, respectively.

DATA QA/QC

Initial QA/QC for this task order was performed in Global Mapper v17, by reviewing the grids and hydrologic breakline features. Additionally, ESRI software and proprietary methods were used to review the overall connectivity of the hydrologic breaklines.

Edits and corrections were addressed individually by tile. If a water body breakline needed to be adjusted to improve the flattening of the DEM data, the area was cross referenced by tile number, corrected accordingly, a new DEM file was regenerated and reviewed.

Section 5: ACCURACY ASSESSMENT

Accuracy Assessment

The vertical accuracy statistics were calculated by comparison of all lidar points to the ground surveyed QC points.

Table 5.1: Overall Vertical Accuracy Statistics		
Average error	+0.012	U.S. Sv Feet
Minimum error	-0.494	U.S. Sv Feet
Maximum error	+0.728	U.S. Sv Feet
Average magnitude	0.197	U.S. Sv Feet
Root mean square	0.261	U.S. Sv Feet
Standard deviation	0.262	U.S. Sv Feet

Table 5.2: RAW Swath Quality Check Point Analysis NVA

Point ID	Easting (U.S. Sv Feet)	Northing (U.S. Sv Feet)	Elevation (U.S. Sv Feet)	TIN Elevation (U.S. Sv Feet)	Dz (U.S. Sv Feet)
2001	2496248.379	314438.308	1441.568	1441.750	0.182
2002	2533738.019	278413.524	1461.691	1461.240	-0.451
2003	2555629.606	266740.877	1438.200	1438.000	-0.200
2004	2575971.105	283403.412	1398.491	1398.470	-0.021
2005	2574140.526	304133.246	1240.579	1240.730	0.151
2006	2567239.625	350341.668	1290.037	1289.960	-0.077
2007	2552276.053	349209.226	1228.142	1228.060	-0.082
2008	2559509.559	394249.159	1159.270	1159.200	-0.070
2009	2598308.722	416430.531	1117.311	1117.800	0.489
2010	2642866.648	461880.089	1068.149	1068.210	0.061
2011	2676670.544	498725.957	1284.355	1284.300	-0.055
2012	2771728.973	489179.623	963.866	963.830	-0.036
2013	2746857.903	516704.218	1084.286	1084.170	-0.116
2014	2739579.873	528950.248	1091.135	1090.920	-0.215
2015	2732290.996	549214.374	1165.804	1165.680	-0.124
2016	2726390.330	563630.601	1089.862	1089.780	-0.082
2017	2692019.562	581910.113	1092.799	1093.040	0.241
2018	2676514.246	547557.615	1244.139	1244.240	0.101
2019	2641663.744	559720.048	1140.835	1140.770	-0.065
2020	2592436.700	607180.716	1203.980	1204.010	0.030
2021	2609008.922	606708.122	1183.240	1183.240	0.000
2022	2698631.345	643818.467	1083.965	1083.910	-0.055

2023	2692959.464	648317.519	1090.811	1091.150	0.339
2024	2510029.864	432261.909	1318.387	1318.750	0.363
2025	2567242.421	443400.740	1269.380	1269.480	0.100
2026	2743319.358	496742.395	1126.662	1126.340	-0.322
2027	2707065.657	479039.267	1140.738	1140.620	-0.118
2028	2672520.382	456927.016	1073.840	1073.640	-0.200
2029	2504407.063	388901.225	1284.953	1285.450	0.497
2030	2498374.244	266769.338	1433.730	1433.650	-0.080
2031	2533403.734	331524.625	1323.814	1323.320	-0.494
2032	2513229.464	359811.666	1316.654	1317.360	0.706
2033	2535664.756	416290.565	1224.342	1224.060	-0.282
2034	2624233.010	276629.623	1368.943	1369.110	0.167
2035	2609049.571	300105.837	1423.834	1424.420	0.586
2036	2609136.384	328221.847	1281.790	1282.400	0.610
2037	2635655.440	437362.707	1134.590	1134.490	-0.100
2038	2584370.430	604135.594	1210.977	1210.820	-0.157
2039	2588146.904	587169.729	1354.801	1354.820	0.019
2040	2625529.103	599215.087	1162.121	1162.060	-0.061
2041	2613059.514	590575.745	1177.306	1177.210	-0.096
2042	2679737.933	621131.232	1187.176	1187.110	-0.066
2043	2708021.865	661979.064	1009.000	1009.130	0.130
2044	2712780.621	626806.438	1261.346	1261.100	-0.246
2045	2703239.881	610883.302	1229.242	1229.020	-0.222
2046	2743837.901	593869.103	1310.710	1310.420	-0.290
2047	2522517.566	315044.031	1416.017	1415.940	-0.077
2048	2543600.151	305710.032	1280.353	1280.230	-0.123
2050	2585231.615	333270.498	1399.387	1399.360	-0.027
2051	2604069.201	376306.618	1312.063	1312.510	0.447
2052	2604970.920	455591.173	1195.608	1196.120	0.512
2053	2672624.250	480298.284	1265.947	1265.910	-0.037
2054	2699436.172	518416.019	1136.344	1136.630	0.286
2055	2703718.751	553120.946	1183.474	1183.390	-0.084
2056	2668518.782	570327.121	1306.455	1306.380	-0.075
2057	2646782.062	584368.040	1142.358	1142.210	-0.148
2058	2679289.054	638511.170	1278.778	1278.690	-0.088
2059	2684282.525	666654.606	1078.177	1078.220	0.043
2060	2695400.431	633897.530	1282.730	1283.120	0.390
2061	2710786.525	592348.119	1307.677	1307.370	-0.307
2062	2731108.712	582812.580	1294.842	1294.770	-0.072
2063	2750924.297	571482.333	1023.131	1022.910	-0.221
2064	2771300.190	551004.892	986.214	986.200	-0.014

2065	2754587.625	540511.756	1099.257	1098.910	-0.347
2066	2753306.463	476194.117	994.781	994.650	-0.131
2067	2694015.779	464753.876	1146.408	1146.420	0.012
2068	2718179.478	504214.641	1105.243	1105.060	-0.183
2069	2529606.200	459596.368	1438.151	1437.880	-0.271
2070	2567113.847	422434.721	1281.137	1281.210	0.073
2071	2517860.071	299076.131	1415.910	1416.230	0.320
2072	2593046.090	360019.066	1242.240	1242.330	0.090
2073	2617890.429	397938.620	1167.855	1168.130	0.275
2074	2605597.894	439774.434	1173.712	1174.440	0.728
2075	2648309.401	547332.180	1134.019	1133.820	-0.199
2076	2649207.404	530904.417	1116.434	1116.320	-0.114
2077	2659793.048	515259.858	1105.496	1105.390	-0.106

VERTICAL ACCURACY CONCLUSIONS

Raw Swath Non-Vegetated Vertical Accuracy (NVA) Tested 0.157 Meters Non vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using all lidar points against 76 NVA points.

LAS Swath Non-Vegetated Vertical Accuracy (NVA) Tested 0.153 Meters Non vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using lidar ground points against 76 NVA points.

Table 5.3: NVA Check Point Analysis DEM

Point ID	Easting (U.S. Sv Feet)	Northing (U.S. Sv Feet)	Elevation (U.S. Sv Feet)	DEM Elevation (U.S. Sv Feet)	Dz (U.S. Sv Feet)
2001	2496248.379	314438.308	1441.568	1441.753	0.185
2002	2533738.019	278413.524	1461.691	1461.193	-0.498
2003	2555629.606	266740.877	1438.200	1438.183	-0.017
2004	2575971.105	283403.412	1398.491	1398.353	-0.138
2005	2574140.526	304133.246	1240.579	1240.712	0.133
2006	2567239.625	350341.668	1290.037	1289.843	-0.194
2007	2552276.053	349209.226	1228.142	1228.032	-0.110
2008	2559509.559	394249.159	1159.270	1159.162	-0.108
2009	2598308.722	416430.531	1117.311	1117.812	0.501
2010	2642866.648	461880.089	1068.149	1068.232	0.083

2011	2676670.544	498725.957	1284.355	1284.293	-0.062
2012	2771728.973	489179.623	963.866	963.712	-0.154
2013	2746857.903	516704.218	1084.286	1084.202	-0.084
2014	2739579.873	528950.248	1091.135	1090.882	-0.253
2015	2732290.996	549214.374	1165.804	1165.662	-0.142
2016	2726390.330	563630.601	1089.862	1089.812	-0.050
2017	2692019.562	581910.113	1092.799	1092.972	0.173
2018	2676514.246	547557.615	1244.139	1244.162	0.023
2019	2641663.744	559720.048	1140.835	1140.792	-0.043
2020	2592436.700	607180.716	1203.980	1204.012	0.032
2021	2609008.922	606708.122	1183.240	1183.192	-0.048
2022	2698631.345	643818.467	1083.965	1084.252	0.287
2023	2692959.464	648317.519	1090.811	1091.062	0.251
2024	2510029.864	432261.909	1318.387	1318.593	0.206
2025	2567242.421	443400.740	1269.380	1269.493	0.113
2026	2743319.358	496742.395	1126.662	1126.342	-0.320
2027	2707065.657	479039.267	1140.738	1140.642	-0.096
2028	2672520.382	456927.016	1073.840	1073.502	-0.338
2029	2504407.063	388901.225	1284.953	1285.273	0.320
2030	2498374.244	266769.338	1433.730	1433.703	-0.027
2031	2533403.734	331524.625	1323.814	1323.353	-0.461
2032	2513229.464	359811.666	1316.654	1317.103	0.449
2033	2535664.756	416290.565	1224.342	1224.002	-0.340
2034	2624233.010	276629.623	1368.943	1369.083	0.140
2035	2609049.571	300105.837	1423.834	1424.403	0.569
2036	2609136.384	328221.847	1281.790	1282.383	0.593
2037	2635655.440	437362.707	1134.590	1134.652	0.062
2038	2584370.430	604135.594	1210.977	1210.842	-0.135
2039	2588146.904	587169.729	1354.801	1354.733	-0.068
2040	2625529.103	599215.087	1162.121	1162.072	-0.049
2041	2613059.514	590575.745	1177.306	1177.122	-0.184
2042	2679737.933	621131.232	1187.176	1187.142	-0.034
2043	2708021.865	661979.064	1009.000	1009.092	0.092
2044	2712780.621	626806.438	1261.346	1261.063	-0.283
2045	2703239.881	610883.302	1229.242	1229.002	-0.240
2046	2743837.901	593869.103	1310.710	1310.433	-0.277
2047	2522517.566	315044.031	1416.017	1415.873	-0.144
2048	2543600.151	305710.032	1280.353	1280.153	-0.200
2050	2585231.615	333270.498	1399.387	1399.273	-0.114
2051	2604069.201	376306.618	1312.063	1312.483	0.420
2052	2604970.920	455591.173	1195.608	1196.302	0.694

2053	2672624.250	480298.284	1265.947	1265.853	-0.094
2054	2699436.172	518416.019	1136.344	1136.602	0.258
2055	2703718.751	553120.946	1183.474	1183.392	-0.082
2056	2668518.782	570327.121	1306.455	1306.403	-0.052
2057	2646782.062	584368.040	1142.358	1142.162	-0.196
2058	2679289.054	638511.170	1278.778	1278.703	-0.075
2059	2684282.525	666654.606	1078.177	1078.212	0.035
2060	2695400.431	633897.530	1282.730	1282.983	0.253
2061	2710786.525	592348.119	1307.677	1307.363	-0.314
2062	2731108.712	582812.580	1294.842	1294.693	-0.149
2063	2750924.297	571482.333	1023.131	1022.842	-0.289
2064	2771300.190	551004.892	986.214	986.302	0.088
2065	2754587.625	540511.756	1099.257	1098.952	-0.305
2066	2753306.463	476194.117	994.781	994.582	-0.199
2067	2694015.779	464753.876	1146.408	1146.422	0.014
2068	2718179.478	504214.641	1105.243	1105.172	-0.071
2069	2529606.200	459596.368	1438.151	1437.853	-0.298
2070	2567113.847	422434.721	1281.137	1281.113	-0.024
2071	2517860.071	299076.131	1415.910	1416.203	0.293
2072	2593046.090	360019.066	1242.240	1242.352	0.112
2073	2617890.429	397938.620	1167.855	1168.122	0.267
2074	2605597.894	439774.434	1173.712	1174.452	0.740
2075	2648309.401	547332.180	1134.019	1133.822	-0.197
2076	2649207.404	530904.417	1116.434	1116.322	-0.112
2077	2659793.048	515259.858	1105.496	1105.282	-0.214

VERTICAL ACCURACY CONCLUSIONS

Bare-Earth DEM Non-Vegetated Vertical Accuracy (NVA) Tested 0.153 Meters Non-Vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM against 76 NVA points.

Table 5.4: VVA Quality Check Point Analysis DEM

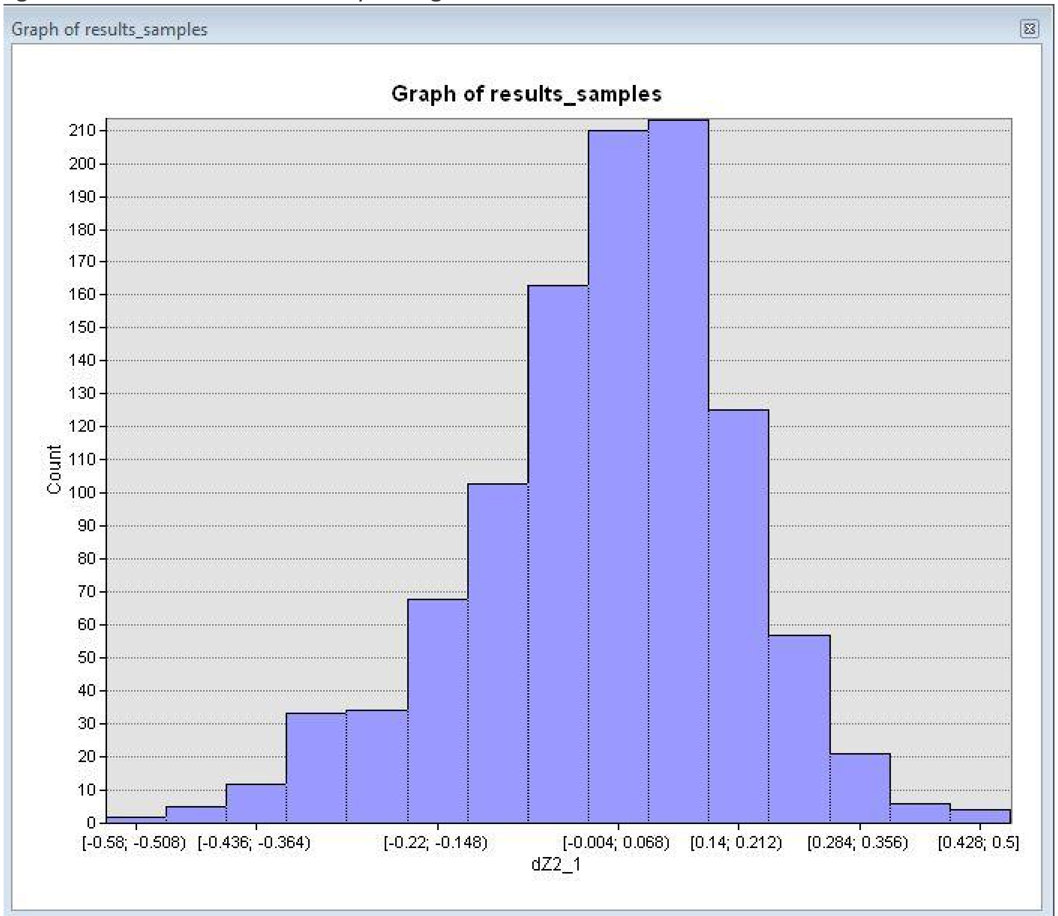
Point ID	Easting (U.S. Sv Feet)	Northing (U.S. Sv Feet)	Elevation (U.S. Sv Feet)	DEM Elevation (U.S. Sv Feet)	Dz (U.S. Sv Feet)
3001	2494998.548	312951.977	1402.446	1402.923	0.477
3002	2532311.260	278457.526	1397.385	1397.423	0.038
3003	2555703.968	266856.238	1434.566	1434.873	0.307
3004	2574552.647	285318.817	1403.277	1403.843	0.566
3006	2569850.570	351025.265	1257.872	1257.993	0.121
3007	2551501.384	349743.438	1206.908	1206.902	-0.006
3008	2559101.649	393785.950	1171.361	1171.342	-0.019
3010	2641664.079	462946.954	1062.050	1063.172	1.122
3011	2675491.184	502075.548	1280.935	1281.463	0.528
3012	2772352.791	489780.178	960.132	961.162	1.030
3013	2746328.291	518125.308	1081.674	1081.492	-0.182
3014	2739851.774	528946.549	1093.980	1094.362	0.382
3015	2730831.027	549252.469	1093.585	1093.302	-0.283
3016	2726643.377	562294.722	1124.084	1124.092	0.008
3017	2691695.663	582238.237	1092.011	1092.722	0.711
3018	2677580.325	545847.097	1191.951	1191.922	-0.029
3019	2641116.228	560333.793	1140.236	1140.722	0.486
3020	2591620.927	605912.811	1211.232	1211.622	0.390
3021	2610474.023	608556.800	1178.387	1178.502	0.115
3022	2699783.738	643300.339	1084.943	1085.232	0.289
3023	2692689.819	648384.428	1118.322	1119.072	0.750
3024	2509841.506	432999.411	1306.898	1307.343	0.445
3026	2743171.176	496909.542	1099.366	1098.992	-0.374
3027	2709534.904	478696.735	1113.385	1113.292	-0.093
3028	2672471.017	455976.722	1048.560	1048.732	0.172
3029	2505207.702	390650.805	1260.611	1261.333	0.722
3030	2499185.653	266857.703	1407.124	1407.573	0.449
3031	2536641.201	331517.809	1326.441	1326.923	0.482
3032	2510773.553	357794.899	1239.975	1240.542	0.567
3033	2538525.374	416464.908	1304.774	1305.013	0.239
3034	2624827.590	276612.073	1338.465	1339.203	0.738
3035	2608679.152	300701.953	1407.352	1408.273	0.921
3036	2608959.667	326942.602	1240.225	1240.912	0.687
3037	2637255.966	437190.325	1171.210	1171.252	0.042
3038	2584779.688	604156.765	1210.897	1210.932	0.035
3039	2588901.952	587285.875	1337.492	1337.573	0.081
3041	2613246.765	590126.365	1174.457	1174.952	0.495

3042	2681428.274	620257.606	1144.503	1144.922	0.419
3043	2707282.782	662223.594	1012.161	1011.802	-0.359
3044	2714167.088	626521.154	1240.029	1240.012	-0.017
3045	2703637.659	612479.955	1311.998	1312.833	0.835
3046	2743804.974	593856.248	1309.576	1309.663	0.087
3047	2522862.229	308979.606	1318.967	1319.473	0.506
3048	2543940.642	305309.249	1254.883	1254.423	-0.460
3049	2553684.061	329928.212	1219.238	1219.552	0.314
3050	2585195.249	332493.042	1376.893	1377.313	0.420
3052	2600332.841	455221.394	1168.719	1169.572	0.853
3053	2672346.952	480174.443	1280.662	1280.763	0.101
3054	2702402.122	517213.689	1103.190	1103.672	0.482
3055	2703819.245	553037.120	1186.399	1186.192	-0.207
3056	2668576.034	568561.727	1300.397	1300.353	-0.044
3057	2647408.243	584470.161	1137.660	1138.072	0.412
3058	2676810.024	638444.653	1173.052	1173.052	0.000
3059	2685560.282	665271.838	1064.936	1065.662	0.726
3060	2706067.905	634350.734	1276.308	1275.853	-0.455

VERTICAL ACCURACY CONCLUSIONS

Vegetated Vertical Accuracy (VVA) Tested 0.287 Meters at the 95th percentile reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM against 55 VVA points. VVA Errors larger than 95th percentile include:
Point 3010, Easting 2641664.079, Northing 462946.954, Z-Error 0.342 Meters
Point 3012, Easting 2772352.791, Northing 489780.178, Z-Error 0.314 Meters

Figure 5.1: Lidar Relative Accuracy Histogram



RELATIVE ACCURACY ASSESSMENT AND CONCLUSION

Relative accuracy also known as "between swath" accuracy was tested through a series of well distributed flight line overlap locations. The relative accuracy for the NE Eastern Nebraska UA Lidar 2016 B16 measured at 0.159 U.S. Sv Feet RMSDz.

Approved by:	Name	Signature	Date
Associate Member, Lidar Specialist Certified Photogrammetrist #1381	Qian Xiao		September 2017

Section 6: Final Deliverables

The final lidar deliverables are listed below.

- LAS v1.4 classified point cloud
- LAS v1.4 raw unclassified point cloud flight line strips.
- Hydro breaklines in ESRI GDB
- Bridge breaklines in ESRI GDB
- Digital Elevation Model in ERDAS GeoTIFF format
- Digital Surface Models in ERDAS GeoTIFF format
- 8-bit gray scale intensity images in .TIF format
- 1 foot contours in ESRI GDB
- Tile layout provided as ESRI shapefile
- Control points provided as ESRI shapefile
- Flight lines provided as ESRI shapefile
- FGDC compliant metadata per product in XML format
- Lidar processing report in pdf format
- Survey report in pdf format