Nome Creek LiDAR Processing Report

USGS CONTRACT: G10PC00026

CONTRACTOR: Aero-Metric, Inc.

TASK ORDER NUMBER: G10PD01407

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1 INTRODUCTION

This report contains a summary of the LiDAR data acquisition and processing for the **NOME CREEK LiDAR TASK ORDER**.

1.1 Contact Info

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

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1.2 Purpose

The United State Geological Survey contracted AERO-METRIC, INC. to acquire Light Detection and Ranging (LiDAR) data suitable for high resolution digital elevation models and for mapping canopy heights over an area of approximately 90 square miles. AERO-METRIC's Optech Gemini LiDAR system was used in the collection of data for this project.

1.3 Project Location

The project area is located over Nome Creek. This area is about 40 miles North of Fairbanks, Alaska. The project area of interest was defined and supplied by USGS in May of 2010.

1.4 Project Spatial Reference System

All products for this project are delivered in: UTM, NAD 83, Meters; NAVD88, Meters

All data and products reference GEOID06 (Alaska). No direct ties to published monuments were completed for this project.

1.5 Time Period

LiDAR data acquisition, control and QC surveys were completed between October 5th, 2010 and November 15th, 2010. The project was flown in one flight mission on October 5, 2010. See Section 3 for a sketch of the acquisition mission and Section 7 of the report for the flight log. QC surveys were completed on November 15, 2010.

1.6 Project Scope

This project involves new LiDAR data acquisition at a nominal pulse spacing of 2.095 meters. As documented in our proposal dated May 11, 2010 we were to achieve a RMSE vertical accuracy of 30cm. The accuracy as tested and published in this report has met vertical accuracy requirements specified by the client.

2 GEODETIC CONTROL

2.1 Control Scope

Geodetic control for this project was based on a 2 Hz GPS base station operated by PDC Engineers, INC. The location of this base station (CP-3603) was approximately 35 miles northeast of Fairbanks and approximately 5 miles south of the southern most flight line.

The NAD83 (CORS96) position of AM03’s Antenna Reference Point (ARP) is as follows:

- Latitude: 65° 13’ 18.21998” N
- Longitude: 147° 5’ 11.78625” W
- Ellipsoid Height: 314.901 meters

3 LIDAR ACQUISITION & PROCEDURES

3.1 Acquisition Time Period

LiDAR data acquisition and Airborne GPS control surveys were completed on October 5th, 2010.

3.2 LiDAR Planning

The LiDAR data for this project was collected with Aero-Metric's Optech Gemini Airborne LiDAR system (Serial Number 03SEN145). All flight planning and acquisition was completed using Optech's ALTM-Nav, version 2.1.25b (flight planning and LiDAR control software).

The following are the acquisition settings:

- Flying Height (Above Ground): 3800 meters
- Laser Pulse Rate: 33 kHz
- Mirror Scan Frequency: 29 Hz
- Scan Angle (+/-): 14°
- Side Lap: 50 %
- Ground Speed: 150 kts
- Nominal Point Spacing: 2.095 meters

3.3 LiDAR Acquisition

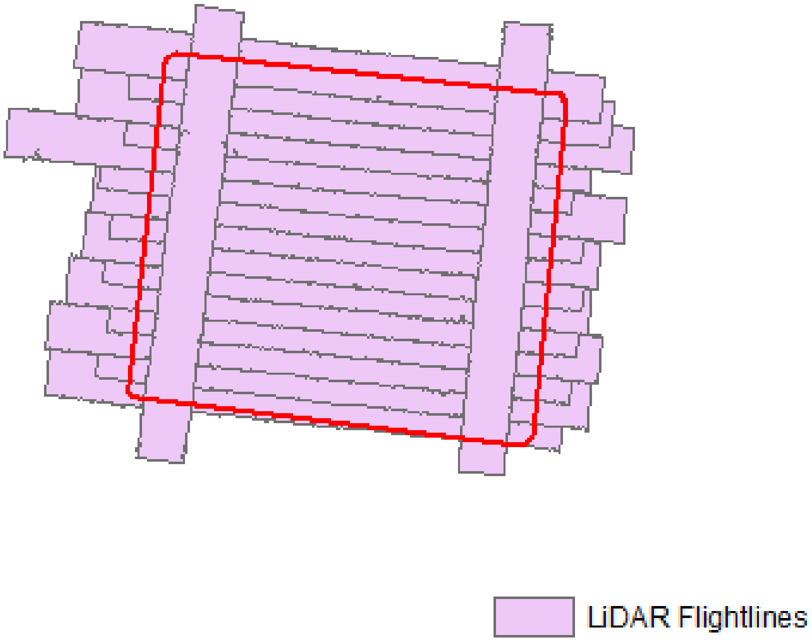
Only 1 flight mission was required to cover the project area. The mission was flown using the above planned values. See below for a sketch of the acquisition missions and Appendix A of the report for the flight log.

Airborne GPS and IMU trajectories for the LiDAR sensor where also acquired during the time of flight.

The mission was approximately 1.5 hours long. Before take-off, the LiDAR system and the Airborne GPS and IMU system were initiated for a period of five minutes and then again after landing for another five minutes. The missions acquired data according to the planned flight lines and included cross flights. The cross flights were flown perpendicular to the planned flight lines and their data used in the in-situ calibration of the sensor.

3.3 LiDAR Trajectory Processing

The airborne positioning of all missions was based on control station CP-3603. The red polygon indicates the extents of the project boundary.



4 QC SURVEY

Design Alaska, INC. performed a QC survey on November 15th over open, identifiable surfaces to determine the presence of any vertical bias within the LiDAR data set. Real Time Kinematic GPS methods were utilized to perform this survey. The results of the analysis that followed led to a vertical bias adjustment of -0.176 meters being applied to the LiDAR data. These points were collected to assess Fundamental Vertical Accuracy. Additional information regarding the QC control survey can be found in the control survey report

5 FINAL LIDAR PROCESSING

5.1 ABGPS and IMU Processing

The Applanix POSPac software, version 4.4, was used to determine both the ABGPS trajectory and the blending of inertial data.

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 between any two solutions, which will ultimately determine the acceptance of the airborne GPS post processing.

Inertial Data

Applanix - POSProc
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 the field data collectors to the main computer. Data was saved under the project number and separated between LiDAR missions.

2. The aircraft raw data (IMU and GPS data combined) was run through Applanix POSPac's extractor program. This separated the IMU and GPS data. In addition to the extracting of data, it provided the analyst the first statistics on the overall flight.

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.

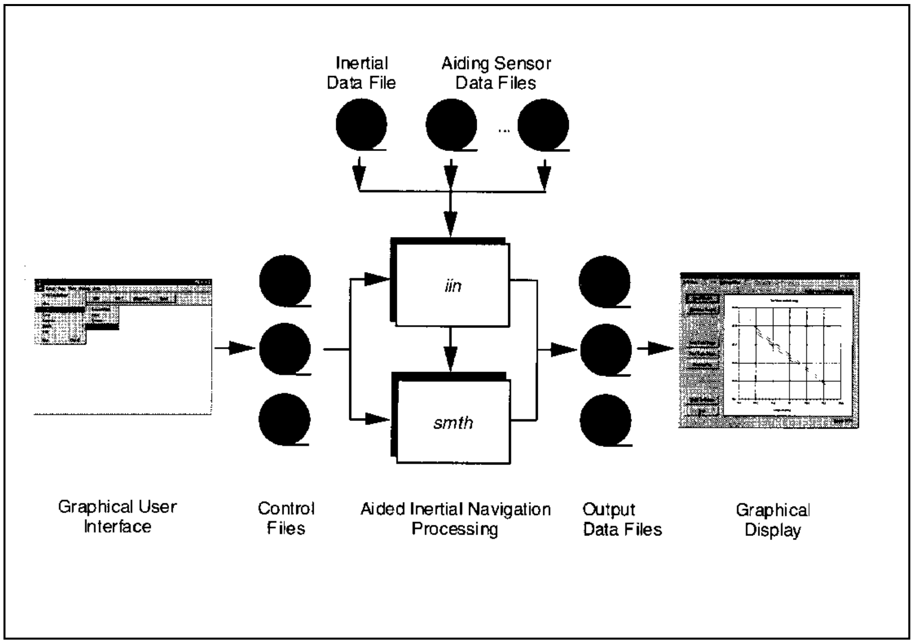
   Once the analyst accepts a forward and reverse processing solution, the trajectory plot is analyzed and the combined solution is stored in a file format acceptable for the IMU post processor.

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:

Diagram 3 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.[3]
  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. [3]

- 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*. [3]

  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. [3]

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. [3]

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.

5.2 LiDAR "Point Cloud" Processing

The ABGPS/IMU post processed data along with the LiDAR raw measurements were processed using Optech Incorporated's LiDAR Mapping Suite software (LMS). This software was used to match the raw LiDAR measurements with the computed ABGPS/IMU positions and attitudes of the LiDAR sensor. The result was a "point cloud" of LiDAR measured points referenced to the ground control system.

5.3 LIDAR CALIBRATION

Introduction

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.

The following report outlines the calibration techniques employed for this project.

Calibration Procedures

AERO-METRIC routinely performs two types of calibrations on its Optech Gemini LiDAR system. The first calibration, system calibration, is performed whenever the LiDAR system is installed in the aircraft. This calibration is performed to define the system parameters affected by the physical misalignment of the system versus aircraft. The second calibration, in-situ calibration, is performed for each mission using that missions data. This calibration is performed to refine the system parameters that are affected by the on site conditions as needed.

System Calibration and Correction Software

Optech has developed a proprietary calibration software in December of 2009 that performs system calibration. The results from this new software achieved excellent results and an accuracy that meets the project requirements.

This new calibration tool incorporates Optech’s proprietary optical sensor models to compute laser point positions and provide laser point calibration improvements on a per flightline basis for the entire project area. It furthermore calculates planar surfaces at different angles from each flight line and then uses a robust least squares solution to compute the orientation parameters at the optical level instead of the traditional methods relating to the ground points. Determining and correcting at the optical level is critical when correcting the data especially when working in terrain and aggressive design parameters as found in this project. Each flight line was computed individually and output in LAS 1.2 format.

In-situ Calibration

The in-situ calibration is performed as needed using the mission’s data. This calibration is performed to refine the system parameters that are affected by the on site conditions.

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 (or a combination of both) 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.

5.4 LiDAR Processing

LAS files were imported, verified, and parsed into manageable, tiled grids using GeoCue version 7.0.34.0. GeoCue allows for ease of data management and process tracking.

The first step after the data has been processed and calibrated is to perform a relative accuracy assessment of the flightlines in relation to each other. To perform this assessment, Aero-Metric uses GeoCue to create Orthophotos colored by elevation differences. These images provide a visual interpretation of how well flightlines match, and are a useful tool and determining either the success or need to re-evaluate the in-situ calibration procedure.

Once the accuracy between swaths is accepted, an automated classification algorithm is performed using TerraSolid’s TerraScan, version 10.011. This will produce the majority of the bare-earth datasets.

The remainder of the data was classified using manual classification techniques. The majority of the manual edit removed points misclassified as ground (class 2) to unclassified (class 1). Erroneous low points and high point are classified to class 7. Data from overlapping flight lines that were not used for DEM generation were classified as class 1 using the withheld flag (bit 7 of the classification word).

5.4 Check Point Validation

The data was verified using 3082 ground control check points collected by Design Alaska, Inc. TerraScan then computes the vertical differences between the surveyed elevation and the LiDAR derived elevation for each point. The RMSE (95th Confidence Interval as defined by the NSSDA) of the lidar dataset is 0.067 meters.

A report listing the differences and common statistics was created and can be found in Appendix B of this report.

5.5 LiDAR Data Delivery

Classified Point Cloud Data:

- 1000m x 1000m tiles
- 200 * NPS (418m) buffered extents
- LAS, version 1.2
- GPS times recorded as Adjusted GPS Time
- Classification schemed:
  - Code 1 – Processed, but unclassified
  - Code 2 – Bare-Earth Ground
  - Code 7 – Noise

2.5 Meter Bare-Earth DEMs:

- 1000m x 1000m tiles
- 200 * NPS (418m) buffered extents
- ESRI Float/Grid format

2.5 Meter First-Return DEMs:

- 1000m x 1000m tiles
- 200 * NPS (418m) buffered extents
- ESRI Float/Grid format

The DEMs were created in the following manner. First, 32-bit binary float raster files were exported from QCoherent's LP360. The raster files were then converted into ESRI grid format using ArcGIS.

6 CONCLUSION

Because of the rigorous procedures and use of new technology, this project will serve the USGS and all users requiring the provided LiDAR derivative products for the Nome Creek project area well into the future.

APPENDIX A – FLIGHT LOGS

```
          Flight Log
------------------------------
Project Number: 6100601
S/N          : 03SEN145
Operator      : Croffut
Pilot(s)      : Czechowicz
Aircraft      : 6GR
Airport       : FAI
Mission       : 6GR27810A

          Weather
------------------------------
Date         : October 05, 2010
Julian Day    : 278
Temperature   : 27° F
Visibility    : 10 miles
Clouds        : Partly Cloudy
Precipitation : None
Wind Dir      : Calm
Wind Speed    : Calm
Pressure      : 29.35 in
          Statistics
------------------------------
Laser Time    : 00:58:03
```

START	STOP	LINE#	ALT	PRF	FREQ	ANGLE	MP	DIV	RC	HDG
18:03:14.14	18:06:44.44	2	4452	33	19	14	OFF	NAR	ON	276
18:10:12.12	18:14:16.16	3	4450	33	19	14	OFF	NAR	ON	276
18:18:18.18	18:21:47.47	4	4396	33	19	14	OFF	NAR	ON	96
18:25:26.26	18:29:21.21	5	4378	33	19	14	OFF	NAR	ON	96
18:33:18.18	18:36:45.45	6	4378	33	19	14	OFF	NAR	ON	96
18:40:33.33	18:44:22.22	7	4391	33	19	14	OFF	NAR	ON	276
18:48:07.7	18:51:34.34	8	4379	33	19	14	OFF	NAR	ON	96
18:55:09.9	18:58:52.52	9	4393	33	19	14	OFF	NAR	ON	276
19:02:28.28	19:06:12.12	10	4383	33	19	14	OFF	NAR	ON	96
19:09:18.18	19:13:39.39	11	4375	33	19	14	OFF	NAR	ON	96
19:18:15.15	19:21:36.36	12	4379	33	19	14	OFF	NAR	ON	96
19:24:58.58	19:29:10.10	13	4402	33	19	14	OFF	NAR	ON	276
19:33:06.6	19:36:32.32	14	4386	33	19	14	OFF	NAR	ON	96
19:39:58.58	19:43:58.58	15	4381	33	19	14	OFF	NAR	ON	7.41
19:47:10.10	19:50:23.23	18	4458	33	19	14	OFF	NAR	ON	7.41
19:53:48.48	19:57:05.5	19	4472	33	19	14	OFF	NAR	ON	7.41

```
======================================
18:03:18.156 GMT : Comment

computer shut off so we lost swath of first line

18:09:43.15 GMT : Comment

2 west good

18:14:24.945 GMT : Comment

3 east good

18:23:11.336 GMT : Comment

4west good

18:29:39.83 GMT : Comment

5 east good

18:36:47.923 GMT : Comment

6 west good

18:44:36.515 GMT : Comment

7 east good

18:53:19.807 GMT : Comment

8 west good

18:58:58.902 GMT : Comment

9 east good

19:07:22.894 GMT : Comment

10 west had cloud at very east end. hopefully not in project area.

19:18:27.184 GMT : Comment

11 east clouds on east 2 miles

19:21:37.581 GMT : Comment

12 west maybe good

19:29:18.274 GMT : Comment
```

13 east good

19:36:34.067 GMT : Comment

14 west good

19:48:19.856 GMT : Comment

15 east good

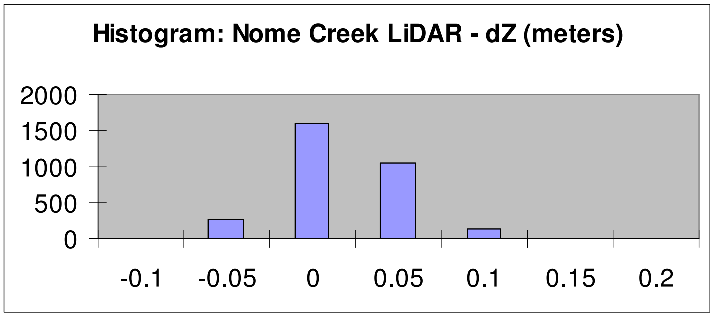
19:50:39.854 GMT : Comment

cross flight 18 south good

19:57:39.248 GMT : Comment

19 north good

APPENDIX B – CHECK POINT RESULTS



Statistical Summary:
Mean : -0.007 meters
Mode : -0.009 meters
Kurtosis : 0.705
Skew : 0.355
Minimum dz : -0.105 meters
Maximum dz : 0.169 meters
DZ Range : 0.274 meters
Count : 3082
RMSE : 0.034 meters
RMSE*1.96 (95% CI – NSSDA) : 0.067 meters

Number	Easting	Northing	Known Z	Laser Z	Dz	Dz^2
4295	498979.9	7248845	545.665	545.56	-0.105	0.011025
2679	500372.4	7248059	580.025	579.92	-0.105	0.011025
4034	501345.6	7247351	592.884	592.78	-0.104	0.010816
2333	496544.7	7249663	510.652	510.55	-0.102	0.010404
1737	500707.5	7247828	589.657	589.56	-0.097	0.009409
2721	500797	7247824	593.866	593.77	-0.096	0.009216
2562	499081.1	7248772	547.773	547.68	-0.093	0.008649
2559	499054.2	7248793	547.012	546.92	-0.092	0.008464
2427	497542.2	7249348	526.371	526.28	-0.091	0.008281
1637	501332	7247381	593.921	593.83	-0.091	0.008281
2726	500856.4	7247829	596.591	596.5	-0.091	0.008281
2221	495869.7	7249508	505.179	505.09	-0.089	0.007921
2560	499063.4	7248786	547.408	547.32	-0.088	0.007744
3058	504023.6	7246416	571.268	571.18	-0.088	0.007744
…	…	…	…	…	…	…

…3061 more…full results in a separate document…

…	…	…	…	…	…	…
1382	503924.6	7246453	569.632	569.75	0.118	0.013924
3050	503947.9	7246461	568.281	568.4	0.119	0.014161
1379	503947.6	7246461	568.288	568.41	0.122	0.014884
1296	504646.8	7246499	577.539	577.67	0.131	0.017161
1385	503905	7246436	569.918	570.05	0.132	0.017424
3044	503896.3	7246425	569.94	570.1	0.16	0.0256
3046	503906.5	7246438	569.961	570.13	0.169	0.028561