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Airborne GPS Survey Report For

Illinois Department of Transportation

Aerial Survey Section

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Aerometric Project No. 1110814

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Illinois Department of Transportation

Aerial Survey Section

District 7 of Illinois

Lidar Task Order P-99-005-10

Aerometric Project No. 1101107.01

1 INTRODUCTION

This report contains a summary of the LiDAR data acquisition and processing for **The Illinois Department of Transportation, District 7, LiDAR TASK ORDER P-99-005-10.** District 7 includes Clay, Clark, Coles, Crawford, Cumberland, Edwards, Effingham, Fayette, Jasper, Lawrence, Macon, Moultrie, Richland, Shelby, Wabash and Wayne counties.

1.1 Contact Info

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

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1.2 Purpose

Aerometric, Inc. acquired highly accurate Light Detection and Ranging (LiDAR) data in the District 7 of Illinois for the Illinois Department of Transportation in accordance with requirements specified to produce a dataset as outlined in Task Order P-99-005-10 and as defined by USGS National Geospatial Program Base LiDAR Specification, Version 13(ILMF).

1.3 Project Locations

The project area covers part of the southern region of Illinois, District 7, which includes sixteen counties; Clay, Clark, Coles, Crawford, Cumberland, Edwards, Effingham, Fayette, Jasper, Lawrence, Macon, Moultrie, Richland, Shelby, Wabash and Wayne. The area was defined and by Illinois Department of Transportation, Aerial Survey Section.

1.4 Time Period

LiDAR data acquisition was completed December 7 to December 10, 2010, and March 16 through April 14, 2011. Sixty-eight (68) flight missions totaling 370 flight lines were required to cover the project area. See Item 3.3 for a graphic of the acquisition missions and Section 7 for District 7 Flight Log sheets.

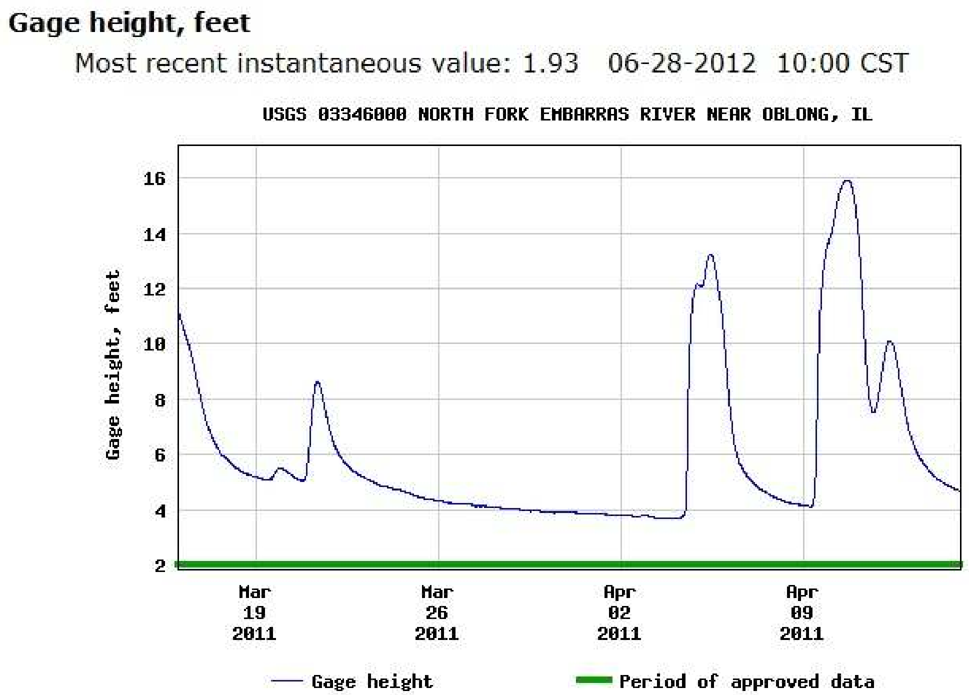
1.5 Project Scope

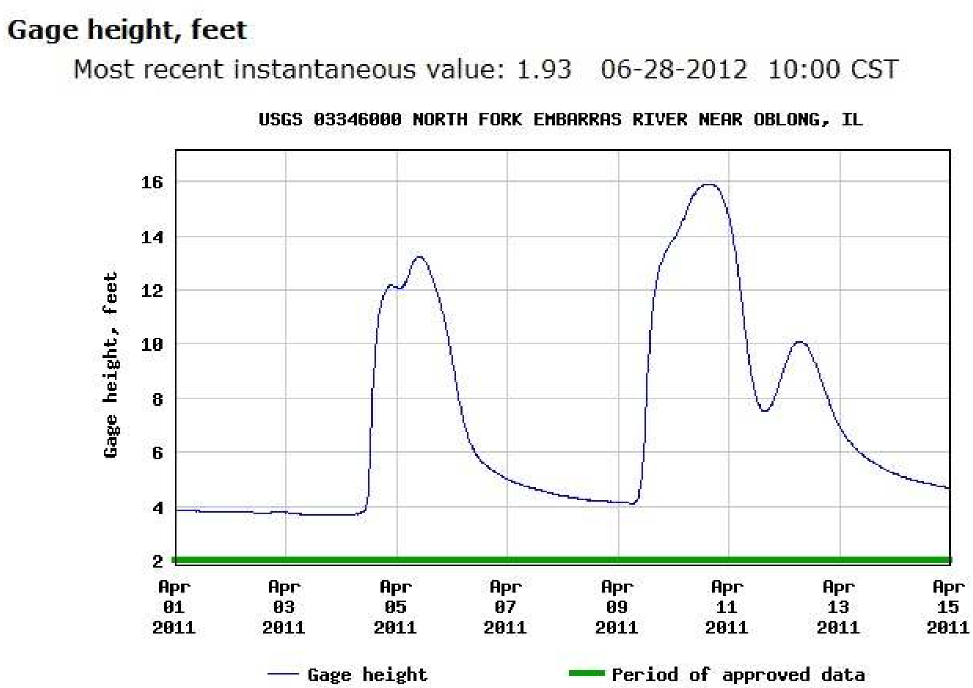
To collect data over the approximately 7760 square miles of the project, two aircraft were operated by Aerometric Inc. using Optech Gemini II airborne LiDAR systems. Data was collected at altitudes of approximately 1600 meters above average terrain to provide optimal data collection of the project area’s surface features.

As documented in our proposal, we were to achieve a TIN accuracy of 0.6 ft for all areas. The accuracy as tested, and included with delivery of this report as “District 7 QC_Control_points.xls”, has met the vertical accuracy requirements. Also, Vertical Accuracy assessment reports per county are included with this report as file ”Dristrict 7_all counties_VARt.pdf”.

1.6 Conditions Affecting Progress

There were seasonal changes and rapidly fluctuating water drainage during the time of collection. Some neighboring flight lines depict this change in water height and drainage width. Item 1.6 is USGS gauging data from the Embarras River in Crawford County Illinois showing water depth measurements during the time when acquisition flights were made.





Item 1.6 Indicates examples of water height changes during data collection period.

2 GEODETIC CONTROL

See file provided by American Surveying and Engineering for survey control information.

3 LiDAR ACQUISITION AND PROCEDURES

3.1 Acquisition Time Period

LiDAR data acquisition and Airborne GPS control surveys were completed between December 7th, 2010 and April 14th, 2011. Sixty-eight missions acquiring 370 flight lines were flown to cover the project areas.

3.2 LiDAR Planning

The LiDAR data for this project was collected with aircraft operated by Aerometric Inc. using Optech Gemini LiDAR systems. All flight planning and acquisition was completed using Optech ALTM-Nav, version 2.1.25b (flight planning and LiDAR control software). Plan version 5.97 in .pln files.

The following are acquisition details for the project areas.

Flying Height (Above Mean Terrain)	1600 meters
Laser Pulse Rate (kHz)	70 kHz
Mirror Scan Rate Frequency(Hz)	35 Hz
Scan Angle (degrees)	22
Side Lap (percent)	50%
Ground Speed (knots)	160 knts
Nominal Point Spacing	1.0 /m^2
Flight lines	370 passes

3.3 LiDAR Acquisition

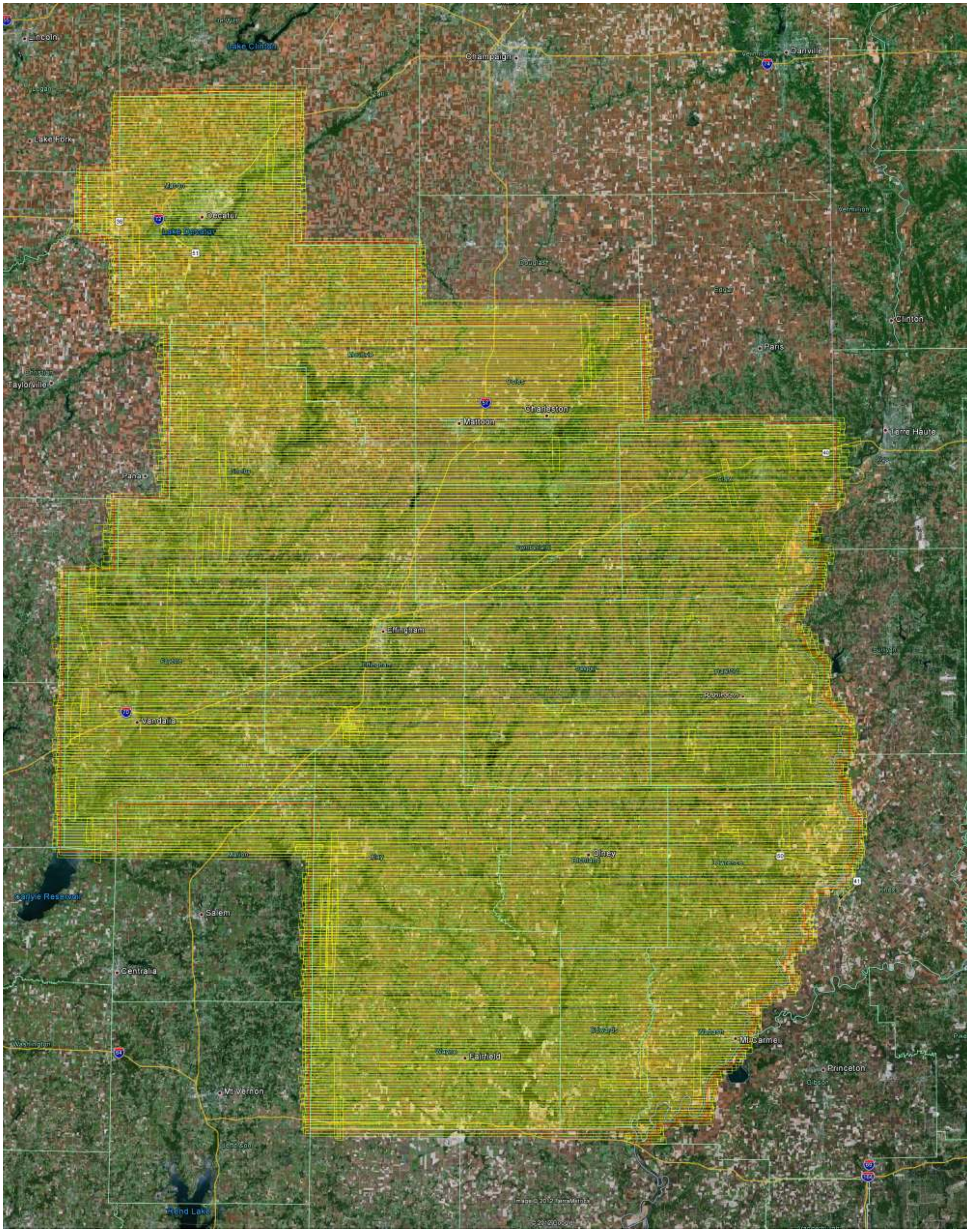
A total of 370 flight missions were required to cover the project area. The missions were flown using the above planned values. See item 3.3 for a graphic of acquisition flight lines or flight swaths relative to the project area and Section 7 of the report for individual mission flight logs.

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

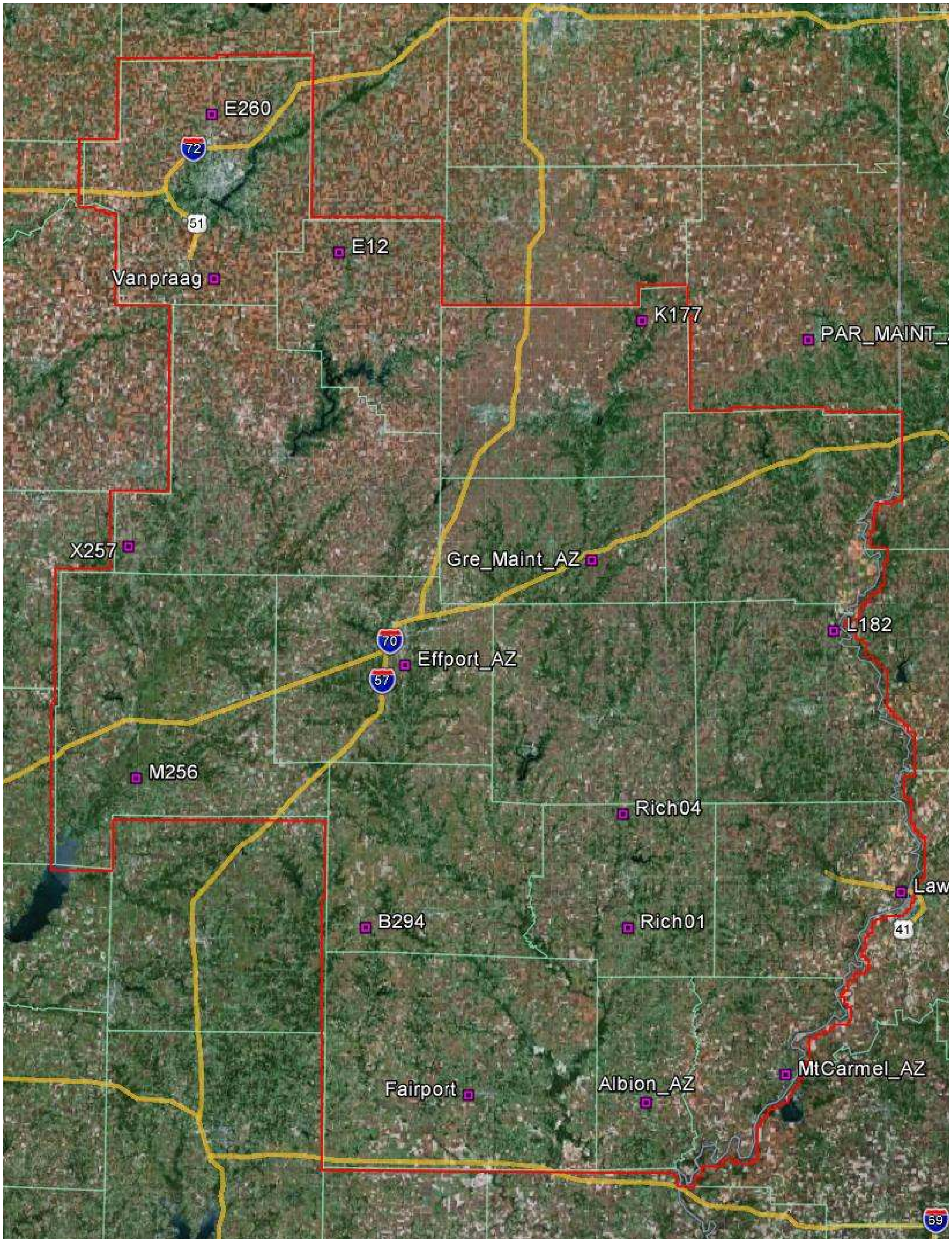
Each mission was typically four to five hours long. Before take-off, the LiDAR system and the Airborne GPS and IMU system were initialized for a period of five minutes and then again after landing for another five minutes. The missions acquired data according to the planned flight lines and included a minimum of one (usually two) cross flights. The cross flights were flown perpendicular to the planned flight lines and their data was used in the in-situ calibration of the sensor.

3.4 LiDAR Trajectory Processing

The airborne positioning was based on the following control stations: Par Maint A, E260, Rich01, Rich04, B294, E12, Effport_AZ, Gre_Maint A, K177, L182, Lawrence, M256, Vanpraag, X257, Albion AZ, Fairport, MtCarmel AZ. See item 3.4 for a graphic of locations.



Item 3.3 District 7, southern Illinois. Indicates area of acquisition missions and flight swaths



Item 3.4 District 7, southern Illinois base station locations and project boundary

4 QC SURVEYS

Ground survey to collect control data for assessment of Fundamental Vertical Accuracy analysis was performed by American Surveying and Engineering from June 2011 to June 2012. Using Rapid Static GPS techniques American Survey collected a total of 7016 check points in open terrain or hard surface areas throughout the District 7 project area. See accompanying survey control report for a complete listing of points, locations and further details.

5 FINAL LiDAR PROCESSING

5.1 ABGPS and IMU Processing

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

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 for the time of when the data was collected. 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 extracting 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.

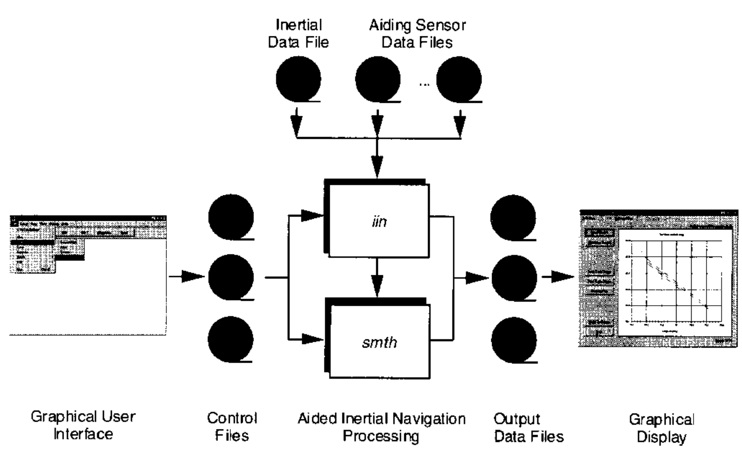
Once the analyst accepts a forward and reverse processing solution, the trajectory plot is analyzed and the combined solution is stored in a file format acceptable for the IMU post processor.

Please see Section 7 of the control report for the final accepted trajectory plots.

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

The diagram below 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.

5.2 LiDAR "Point Cloud" Processing

The ABGPS/IMU post processed data along with the LiDAR raw measurements were processed using Optech Incorporated's ASDA software. 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

All Companies involved in collection routinely performs two types of calibrations on its airborne 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 developed 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 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

The LAS files were then imported, verified, and parsed into manageable, tiled grids using GeoCue version 2011.1.20.1. 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 on the flightline to flightline comparisons and also a data density test prior any further processing.

In addition to the relative accuracy assessment, Aerometric also reviews a few tiles to ensure that the desired density has been met. Aerometric utilizes an in- house proprietary software to complete this task. Initially a grid was placed according to the version 13 specification that is based on the USGS specification, version 13 allowing doubling the nominal post spacing. Of the sample tiles tested 96% of the data met or exceeded this specified density criteria.

Once both the accuracy between swaths and data density is accepted, an automated classification algorithm is performed using TerraSolid's TerraScan, version 012.005. This will establish the initial bare-earth (class 2) dataset. Points outside the bare earth classification will be set to unclassified (class 1) or low points (class 7). Misclassified points are then manually set to an appropriate classification.

5.5 Check Point Validation

The data was then verified using the ground control data collected by American Surveying and Engineering. TerraScan then computes the vertical differences between the surveyed elevation and the LiDAR derived elevation for each survey point.

A report listing the differences and common statistics was created "District 7 QC_Control_points.xls", and included with delivery of this report.

5.6 LiDAR Data Delivery

Raw point cloud data supplied is in the following format:

- LAS, version 1.2
- GPS times adjusted to GPS Absolute
- Full swaths and delivered as 1 file per swath which did not exceed 2gb.

Classified point cloud data is also being supplied using the following criteria.

- LAS, version 1.2
- GPS times adjusted to GPS Absolute
- Classification scheme:
  - Code 1 Processed, but unclassified
  - Code 2 Ground
  - Code 7 Noise
  - Code 9 Water
  - Code 10 Ignored Ground (Breakline proximity)
- Breakline data
- Tile layout in 2000 foot client format and naming convention

Data is orientated into a grid system for production control and management. Collection of breaklines and manual editing is performed in Microstation environment using the base specifications and client preferences. Upon acceptance by in-house quality control the breaklines, either polygons or lines, are translated into ARC and imported to the final geodatabase as separate features and provided as .dgn breakline files.

The classed LAS data representing bare earth, combined with any needed breaklines, are processed through a series of steps within MicroStation and GeoPak that converts the data into x,y,z points as a Triangulated Integrated Network file or TIN. Tiled data is supplied as DAT and TIN files in a grid layout per client request and to client's preferred naming and organizing sequence.

6 CONCLUSION

Utilization of accurate procedures and new technologies provide that this project data will serve the Illinois Department of Transportation and subsequent users requiring the provided LiDAR data or derivative products well into the future. District 7 covers over 7500 square miles. Although acquisition of a project of this size presents challenges the resulting data and model derivatives are accurate and reliable.

7 FLIGHT LOGS

8 SEPARATION PLOTS