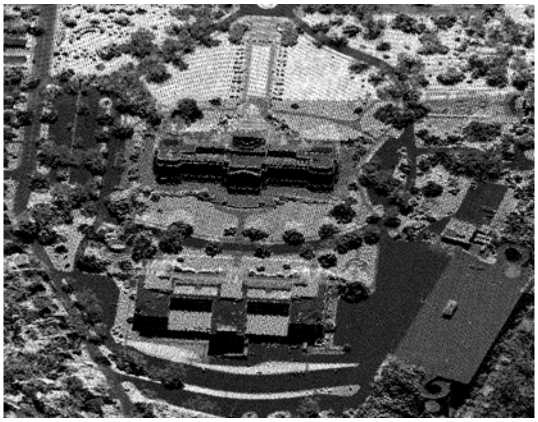
AIRBORNE LIDAR PROJECT REPORT



SAIC LIDAR
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION (SAIC)

CONTRACT NUMBER: PO10020755_R13

Woolpert Project Number: 66566
July 2011

WOOLPERT
DESIGN | GEOSPATIAL | INFRASTRUCTURE

AIRBORNE LIDAR PROJECT REPORT

SAIC LIDAR

CONTRACT: #66566

For:

Science Applications International Corporation
(SAIC)
14668 Lee Road
Chantilly, VA 20151
Tel 703.676.9315

By:

Woolpert
4454 Idea Center Boulevard
Dayton, OH 45430-1500
Tel 937.461.5660

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SECTION 1: OVERVIEW

TASK ORDER NAME: SAIC LIDAR

WOOLPERT PROJECT #66566

This report contains a comprehensive outline of the airborne LiDAR data acquisition for Louisville, KY, for Science Applications International Corporation (SAIC). The project area was approximately 462 square kilometers. The LiDAR was collected and processed to meet the Nominal Post Spacing (NPS) requirement of 1.0 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 a Leica ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR sensor installed in a Leica gyro-stabilized PAV30 mount. The ALS50-II 150 kHz 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:

Post Spacing (Minimum):	3.2 ft / 1.0 m
AGL (Above Ground Level) average flying height:	6500 ft / 1981 m
MSL (Mean Sea Level) average flying height:	6850 ft / 2088 m
Average Ground Speed:	130 knots / 150 mph
Field of View (full):	40 degrees
Pulse Rate:	115.6 kHz
Scan Rate:	41.8 Hz
Side Lap (Minimum):	25.1%

LiDAR data was produced in Universal Transverse Mercator (UTM) Zone 16N, North American Datum of 1983 (NAD83) for insert site here Coordinate positions were specified in units of meters. The vertical datum used for the project was referenced to NAVD 1988, meters, Geoid09.

SECTION 2: ACQUISITION

The LiDAR data was acquired with a Leica ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR sensor system, on board a Cessna 404. The ALS50-II 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 system software is operated on an OC50 Operation Controller aboard the aircraft.

The ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR System has the following specifications:

Table 2.1 ALS50-II LiDAR System Specifications

Specification	
Operating Altitude	200 - 6,000 meters
Scan Angle	0 to 75° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 90 Hz (variable based on scan angle)
Maximum Pulse Rate	150 kHz
Range Resolution	Better than 1 cm
Elevation Accuracy	8 – 24 cm single shot (one standard deviation)
Horizontal Accuracy	7 – 64 cm (one standard deviation)
Number of Returns per Pulse	4 (first, second, third, last)
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, Woolpert flight crews coordinated with the necessary Air Traffic Control personnel to ensure airspace access.

Woolpert survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station at the DK3320 NGS point for the airborne GPS support.

The LiDAR data was collected in three missions, 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. Any gaps found in the LiDAR data were relayed to the flight crew, and the area was re-flown.

Table 2.2 Airborne LiDAR Acquisition Flight Summary

Airborne LiDAR Acquisition Flight Summary			
Date of Mission	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down	Mission Time (Local = EDT) Wheels Up/ Wheels Down
June 16, 2011	13-22	13:39 – 19:13	9:39AM – 3:13PM
June 30, 2011	1-12, 23-23, (RF) 9-11, 14, 16, 18	12:57 - 17:17	8:57AM - 01:17PM
July 6, 2011	(RF) 12	12:54 - 15:03	8:54AM - 11:03AM

SECTION 3: LIDAR DATA PROCESSING

APPLICATIONS AND WORK FLOW OVERVIEW

1. Resolved kinematic corrections for three subsystems: inertial measurement unit (IMU), sensor orientation information and airborne GPS data. Developed a blending post-processed aircraft position with attitude data using Kalman filtering technology or the smoothed best estimate trajectory (SBET).
   Software: POSPac Software v. 5.3, IPAS Pro v.1.3.

2. Calculated laser point position by associating the SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in .LAS format. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift.
   Software: ALS Post Processing Software v.2.70, Proprietary Software, TerraMatch v. 10.04.

3. Imported processed .LAS point cloud data into project tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet the project classification specifications. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the LiDAR data was then adjusted in relation to the survey ground control.
   Software: TerraScan v.10.018.

4. The .LAS files were evaluated through a series of QA/QC steps to eliminate remaining artifacts and small undulations from the ground class.
   Software: TerraScan v.10.018.

GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)-INERTIAL MEASUREMENT UNIT (IMU) TRAJECTORY PROCESSING

EQUIPMENT

Flight navigation during the LiDAR data acquisition mission is performed using IGI CCNS (Computer Controlled Navigation System). The pilots are highly 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.

The aircraft are all configured with a NovAtel Millennium 12-channel, L1/L2 dual frequency Global Navigation Satellite System (GNSS) receivers collecting at 2 Hz.

All Woolpert aerial sensors are equipped with a Litton LN200 series Inertial Measurement Unit (IMU) operating at 200 Hz.

A base-station unit was mobilized for each acquisition mission, and was operated by a member of the Woolpert survey crew. Each base-station setup consisted of one Trimble 4000 – 5000 series dual frequency receiver, one Trimble Compact L1/L2 dual frequency antenna, one 2-meter fixed-height tripod, and essential battery power and cabling. Ground planes were used on the base-station antennas. Data was collected at 1 or 2 Hz.

Woolpert survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station at the DK3320 NGS Point for the airborne GPS support. The GNSS base station operated during the LiDAR acquisition missions is listed below:

Table 3.1: GNSS Base Stations

Station	Latitude	Longitude	Ellipsoid Height (L1 Phase Center)
Name	(DMS)	(DMS)	(Meters)
KYTE CORS	N 38° 16' 35.93986"	W 85° 35' 54.20083"	157.915

DATA PROCESSING

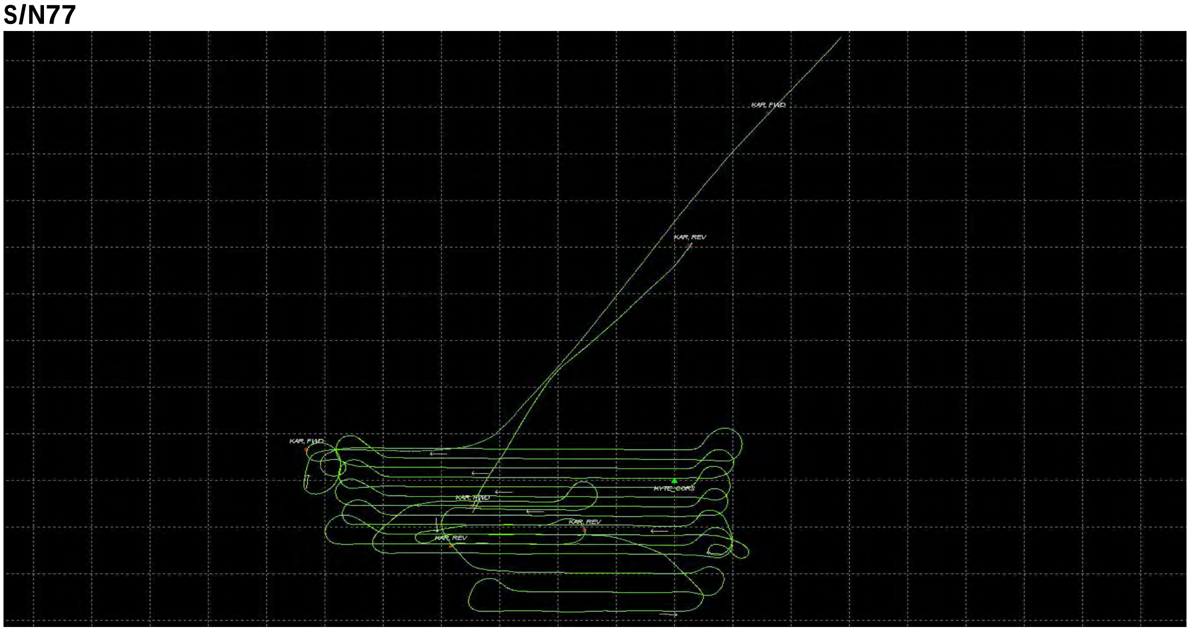
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

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. See **Figure 3.1** for the flight trajectory.

Flight Trajectory

Figure 3.1: Representative Graph from Day18111: N475RC and ALS LiDAR S/N77



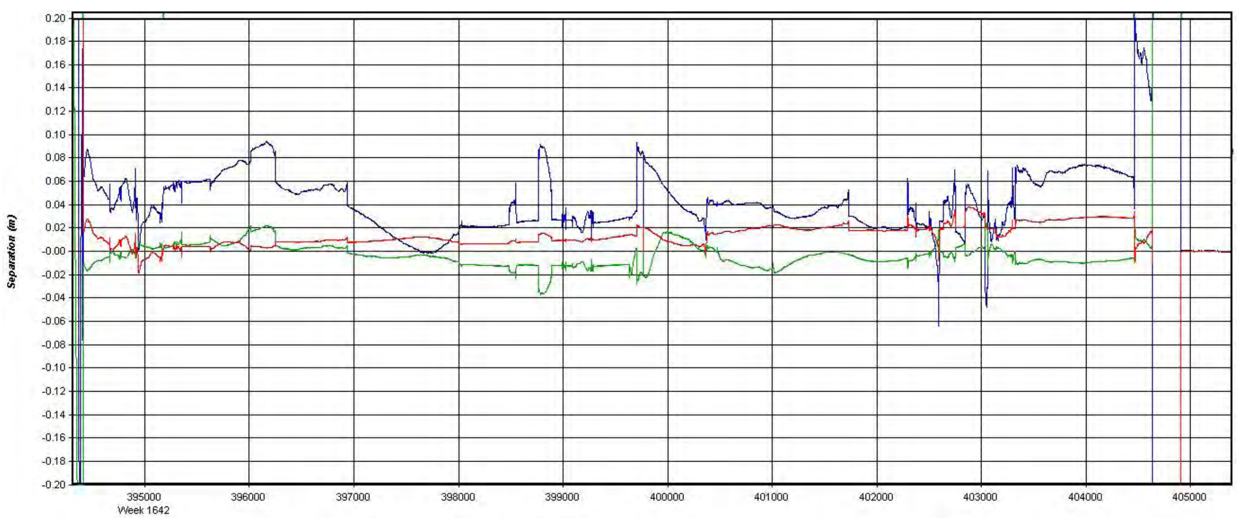
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

Combined 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. See **Figure 3.2** for the combined separation graph.

Figure 3.2: Representative Graph from Day18111 of Combined Separation

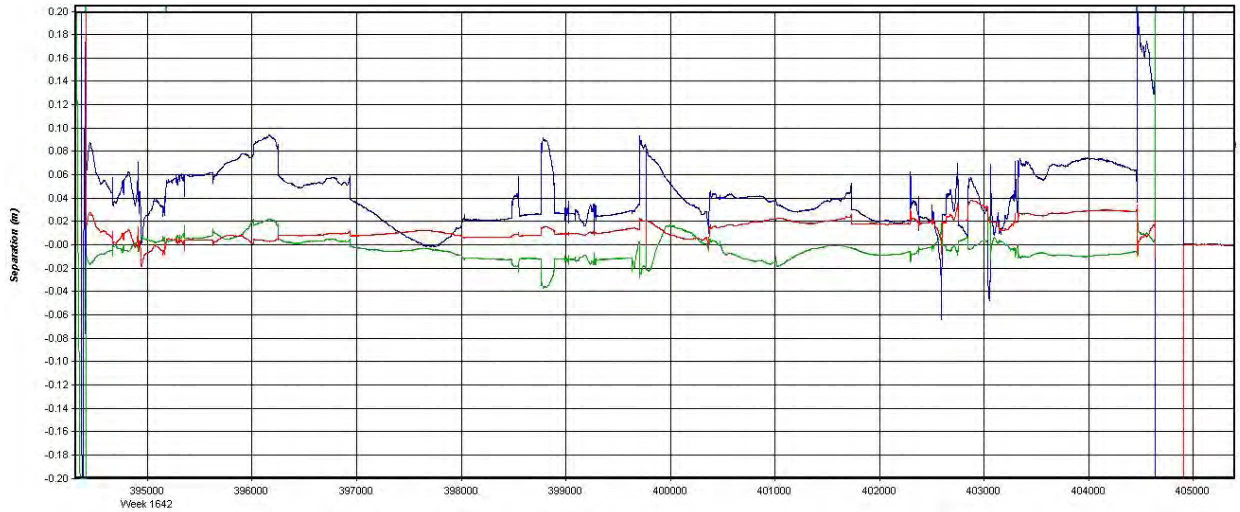


Estimated Positional Accuracy

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: Representative Graph from Day18111 of Positional Accuracy



LIDAR DATA PROCESSING

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

- Processed individual flight lines to derive a "Point Cloud". 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 project tiles and initially filtered to create a ground and non-ground class. Then additional classes are filtered as necessary to meet client specified classes.
- Once all project data was imported and classified, cross flights and survey ground control data was imported and calculated for an accuracy assessment. As a QA/QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparison among LiDAR points, ground control, and TINs. The LiDAR is adjusted accordingly to meet or exceed the vertical accuracy requirements.
- The LiDAR data in LAS format was reviewed using a series of proprietary QA/QC procedures to ensure it fulfills the project requirements.
- The LiDAR LAS files for this project have been classified into the Default (Class 1), Ground (Class 2), Noise (Class 7), and Vegetation (Class 5) classifications.
- Final deliverable data was derived from the adjusted classified LiDAR data.

SECTION 4: FINAL ACCURACY ASSESSMENT

FINAL VERTICAL ACCURACY ASSESSMENT

The vertical accuracy statistics were calculated by comparison of the LiDAR bare earth points to the ground surveyed QA/QC points.

Table 4.1: Overall Vertical Accuracy Statistics

Average error	0.001	meters
Minimum error	-0.177	meters
Maximum error	0.112	meters
Average magnitude	0.056	meters
Root mean square	0.073	meters
Standard deviation	0.074	meters

Table 4.2: QA/QC Analysis UTM 16N, NAD83

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1	621318.2	4240257	187.942	187.9	-0.042
2	602452.6	4239166	140.559	140.47	-0.089
3	609582.8	4237963	135.342	135.33	-0.012
4	618651.2	4237006	176.258	176.15	-0.108
5	602574.7	4235582	139.39	139.33	-0.06
6	607359.1	4234897	141.001	141	-0.001
7	609760	4234263	140.625	140.55	-0.075
8	616066.3	4234316	165.477	165.3	-0.177
9	602907.7	4233294	136.601	136.54	-0.061
10	616161.4	4232265	163.431	163.43	-0.001
11	607206.6	4230661	140.693	140.69	-0.003
12	616127.8	4230157	151.956	151.96	0.004
13	604845.4	4228763	139.57	139.68	0.11
14	618488.8	4228001	154.808	154.92	0.112
15	620887.3	4226367	184.119	184.14	0.021
16	602570.6	4224951	137.751	137.8	0.049
17	617664.6	4223901	152.671	152.76	0.089
18	601873.2	4222885	141.942	141.98	0.038
19	612256.9	4221585	139.318	139.41	0.092
20	621514.4	4220890	205.671	205.66	-0.011
21	600425.9	4219737	144.87	144.92	0.05

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
22	614184.8	4225204	141.292	141.38	0.088
23	603184.4	4226884	135.505	135.51	0.005

VERTICAL ACCURACY CONCLUSIONS

- **Data Accuracy** tested 0.073 meters RMSE vertical accuracy at 95% percent confidence level.

Based on the analysis of the LiDAR data, the accuracy of the data meets the task order requirements.

Approved By:			
Title	Name	Signature	Date
Associate Member LiDAR Specialist Certified Photogrammetrist #1281	Qian Xiao		June 20, 2011

SECTION 5: FINAL DELIVERABLES

FINAL DELIVERABLES

The final deliverables are listed below:

- One set of LiDAR data reflective surface tiles in 1 meter ArcGRID format in 2,000 meter x 2,000 meter overlapping tiles.
- One set of LiDAR data bare earth tiles in 1 meter ArcGRID format in 2,000 meter x 2,000 meter overlapping tiles.
- One set of LiDAR data last return tiles in 1 meter ArcGRID format in 2,000 meter x 2,000 meter overlapping tiles.
- One set of LiDAR data intensity tiles in 1 meter ArcGRID format in 2,000 meter x 2,000 meter overlapping tiles.
- LAS v1.1 classified point cloud and bare earth point files in tile format.
- The project data was delivered on DVDR.