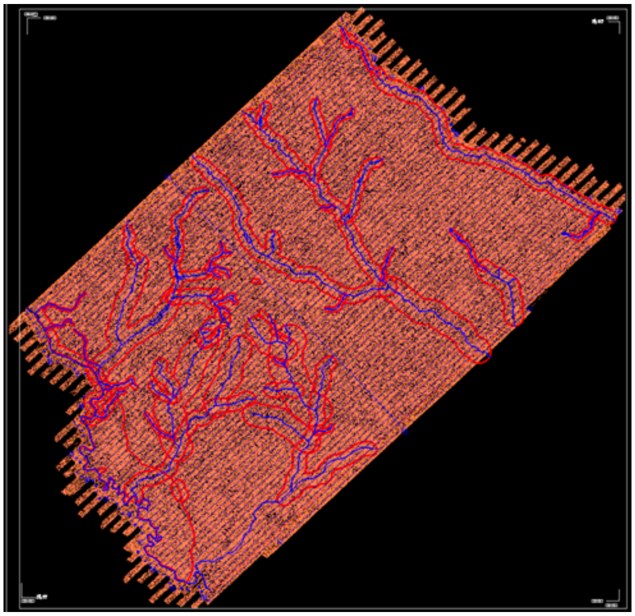
LIDAR REPORT



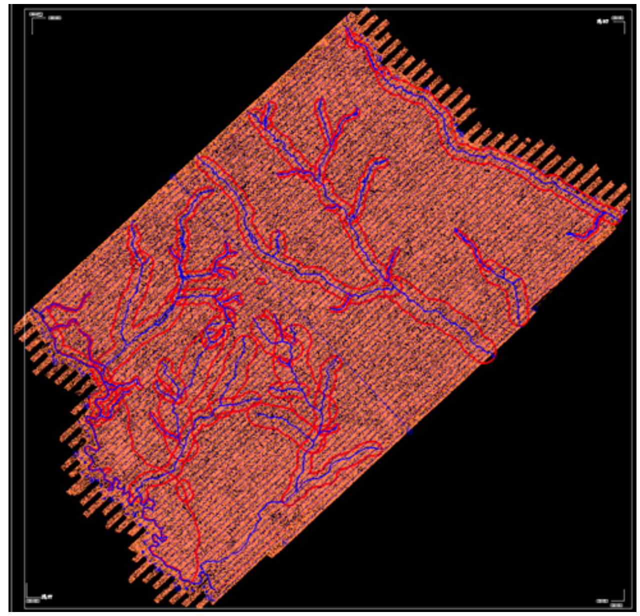
AIKEN COUNTY, SC, LIDAR

SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES

WOOLPERT # 65185

2006

LIDAR REPORT



AIKEN COUNTY, SOUTH CAROLINA 2006
LIDAR PROJECT
SOUTH CAROLINA DEPARTMENT OF
NATURAL RESOURCES
WOOLPERT PROJECT #65185
2006

PREPARED BY:

WOOLPERT INC.

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Dayton, Ohio 45402-1261

SECTION 1: OVERVIEW

The Aiken County, South Carolina Department of Natural Resources 2006 LiDAR Project calls for the following:

- ✓ 1038 sq. miles of LiDAR acquisition and processing
- ✓ Up to 430 sq. miles of 2-D breakline compilation and hydro cleaning in the detailed study area
- ✓ SCDNR will provide the mapping boundary for the detailed study area

This report contains a review of the project requirements and detailed information for LiDAR data acquisition and quality control (QC) including:

- ✓ Documentation specifying altitude, airspeed, scan angle, scan rate, LiDAR pulse rates, and other flight and equipment information deemed appropriate
- ✓ A chart of position dilution of precision (PDOP)
- ✓ A LiDAR System Data Report
- ✓ A LiDAR Data Acquisition report
- ✓ A ground control report for the airborne global positioning system (ABGPS) survey performed during the LiDAR mission
- ✓ A system calibration report

Project Requirements

General standards for the LiDAR mission include:

- ✓ High density LiDAR data acquisition within the project limits (see Figure A, Project Boundary/LiDAR Coverage) at a sufficient altitude and density to support digital terrain model (DTM) development capable of generating 2-foot contours with a vertical accuracy of 1.2-feet RMSE at the 90% confidence level.
- ✓ Avoid inclement weather for flight missions.
- ✓ Choose a flight path that provides satisfactory coverage of the study area, including both parallel and enough cross flight lines to allow for proper quality control.
- ✓ Document flight mission date, time, flight altitude, airspeed, scan angle, scan rate, laser pulse rates and other information deemed pertinent.

SECTION 2: LIDAR DATA ACQUISITION

This section provides an overview of the LiDAR acquisition methodology employed by Woolpert LLP on the Aiken County, South Carolina 2006 LiDAR Project. Typical LiDAR system parameters include:

- ✓ Altitude
- ✓ Airspeed
- ✓ Scan angle
- ✓ Scan rate
- ✓ Laser pulse repetition rate

Flight and equipment information is also included.

LiDAR Overview

Woolpert Inc. conducted a topographic LiDAR survey to support the South Carolina FEMA Map Modernization Program and the generation of 2-foot contours with a vertical accuracy of 1.2-feet at the 90% confidence level. The LiDAR data was acquired across the project limits (see Figure A, Project Boundary/LiDAR Coverage) only.

LiDAR Mission

The LiDAR data acquisition was executed in five sessions, on March 15, 16 & 17, 2006, using a Leica ALS50 LiDAR System. Specific details about the ALS50 system are included in Section 4 of this report.

The three airborne GPS (ABGPS) base stations supporting the LiDAR acquisition were located on 1) a NGS SAC monumented control point inside Bush Field Airport (AGS), point AA2799, 2) a point inside the county “RS_0001” and 3) a another point nearby “RS_0002”. Dual Frequency data was logged continuously for the duration of each LiDAR flight mission at a one-second sampling rate. A table of control points for the LiDAR survey is included in Section 5 of this report.

The flight plan for LiDAR consisted of parallel flights in a north-east/south-west extent across the site (see Figure B, LiDAR Flight Layout). Sixty-three (63) flight lines of LiDAR data were acquired in 5 sessions along with 1 cross flight across the County.

No significant problems were encountered during the LiDAR data acquisition phase of the project.

LiDAR Statistical Data

The LiDAR parameters are as follows:

Aircraft Speed .... 130 knots indicated air speed
Flying Height .... 6,500 feet above ground level
Scanner Field of View .... 30 degrees
Scan Frequency .... 28 Hertz
Pulse Repetition Rate .... 38,700 Hertz

Data Acquisition Summary

Table 2.1 LiDAR Acquisition Log, Aiken County, South Carolina 2006 LiDAR Project.

Date	Day	Lines	Base 1
3-15-06	07406	1-14	FAA AGS ARP 2
3-15-06	07406	30-39	FAA AGS ARP 2
3-16-06	07506	15-29, 63	FAA AGS ARP 2
3-16-06	07506	40-57	FAA AGS ARP 2
3-17-06	07606	58-62	FAA AGS ARP 2

SECTION 3: PDOP INFORMATION

PDOP, the Positional Dilution of Precision, is a factor that describes the effects of satellite geometry on the accuracy of the airborne GPS solution. The geometric distribution of the satellites is measured relative to the locations of the receivers on the ground and in the aircraft. PDOP can be computed in advance, based on the approximate receiver locations and the predicted location of the satellite, which is called the satellite ephemeris.

Low PDOP numbers are preferable; the higher the PDOP number, the weaker the geometric quality of solution between the satellite, aircraft and reference receivers.

Woolpert's goal is to maintain a final PDOP of 3.0 or less during all LiDAR acquisition missions. Satellite geometry and the resultant PDOP levels are dynamic, changing with the position of the aircraft. Occasionally, one satellite in the network will drop below the horizon, breaking its connection to the receiver, and the PDOP level will spike above 3.0 momentarily. Small deviations of this type are accounted for during post-processing of the data through the use of Kalman filtering. If PDOP in the aircraft rises above 3.0 for a significant time period, the survey is usually stopped until the geometry improves.

The following table contains the average PDOP and distance separation between the aircraft and base station for each LiDAR acquisition mission.

Table 3.1. Aiken County, South Carolina 2006 LiDAR Project **LiDAR Report, PDOP**

Date	Base Station	PDOP	Dist. Separation, KM
March 15, 2006	FAA AGS ARP 2	< 2.6	45
March 15, 2006	FAA AGS ARP 2	< 3.0	40
March 16, 2006	FAA AGS ARP 2	< 3.0, spike 4.5	40
March 16, 2006	FAA AGS ARP 2	< 3.0, spike 3.8	50
March 17, 2006	FAA AGS ARP 2	< 2.2	55

SECTION 4: LIDAR SYSTEM DATA REPORT

The LiDAR data was acquired using 2 ALS50's onboard 2 Cessna T404's. The ALS50 LiDAR system, developed by Leica Geosystems of Boston, Massachusetts, 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 a P-400 Diagnostic System Laptop Computer aboard the aircraft.

The ALS50 LiDAR System has the following specifications:

Nominal	
Operating Altitude	400 – 3,000 meters
Elevation accuracy	15cm single shot
Range Resolution	1 cm
Scan angle	Variable from 0 to 75°
Swath width	Variable from 0 to 1.5 X altitude
Angle resolution	0.01°
Scan frequency	Variable based on scan angle
Horizontal Accuracy	Better than 1/2000 X altitude
Supported GPS receivers	Ashtech Z12, Trimble 7400, Novatel Millenium
Laser repetition rate	58 kHz
Beam divergence	0.3 mrads
Laser classification	Class IV laser product (FDA CFR 21)
Eye safe range	400m single shot depending on laser repetition rate
Power requirements	28 VDC @ 25A
Operating temperature	10-35°C
Humidity	0-95% non-condensing

Figures C-1 through C-5 contain images of the LiDAR flight logs.

SECTION 5: GROUND CONTROL REPORT FOR AIRBORNE GPS SURVEY DURING LIDAR MISSION

Introduction

Woolpert performed ABGPS surveying during the LiDAR mission to derive the flight trajectory at a half-second interval. ABGPS is a critical factor in LiDAR data collection. As such, we spent considerable time developing flight windows around the satellite constellation. We also developed multiple base stations to provide redundancy and to reduce ionospheric and atmospheric errors due to distance separation between the aircraft and the base stations.

At a minimum, two base stations were in operation for every LiDAR acquisition session, operating at a half-second sampling rate. Final adjusted control point values were used to process the LiDAR data. The survey report includes extensive data about the procedures and results for the ground control survey.

As a continuing quality control measure, data was downloaded each evening in the field to verify a strong GPS solution and then refined in-house to determine final trajectories.

A base-station control survey was performed to provide uniformity and to ensure consistency between the ground control and Airborne GPS. All ground control surveys were performed to achieve accuracies consistent with a second-order, class I horizontal (meets or exceeds 1:50,000) and third-order vertical survey as outlined in *Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques*, Version 5.0, of August 1, 1989, published by the Federal Geodetic Control Committee (FGCC).

Project Team

Woolpert LLP survey and flight crews were responsible for the successful completion of this LiDAR project. The airborne GPS survey was conducted with exceptional coordination between the Woolpert survey crews and the flight crews.

Weather

LiDAR acquisition occurred when the cloud ceiling was at least 7,500 feet above ground level (AGL) and there was no rain or thick haze (visibility less than 4 miles).

Datum Reference

The datums used for this project include the following:

- South Carolina State Plane
- Horizontal NAD 83 – International Feet
- Vertical NAVD 88 - U.S. Survey feet
- HARN 2001
- 2 decimal places for vertical and horizontal

Field Work

The Woolpert flight and survey crews coordinated twice daily to review weather, flight schedules and GPS base station locations. Flights were generally performed in sequence, except when outside factors interfered, such as controlled burns or localized clouds. Once the day's schedule was determined, field crews set receivers in relation to the appropriate base stations. Flight and ground crews were in constant communication during data acquisition sessions through air-to-ground radios; if ground crews saw developing problems, such as high PDOP levels, they would alert the flight crew.

At the close of each day's data acquisition session, the flight and ground crews would meet to download data from receivers, recharge batteries, process and quality check the data, and prepare data backups. By the end of each day, the field crews were ready for the next day and the first-level quality control was complete. LiDAR data was also downloaded and initial processing steps were completed to check for any voids in the data. For example, if the plane encounters windy conditions, gaps in data between flight lines may result.

Airborne Control Stations

A NGS SAC point at Bush Field Airport, as well as 2 additional points set in the North East part of the county, were established as ABGPS base station location points. NOTE: Only the FAA AGS ARP 2 SAC Point at Bush Field Airport actually ended up being used as it yielded the best solutions.

Station	Ellipsoid Height(ft)	Latitude (deg min sec)	Longitude (Deg min sec)
FAA AGS ARP 2	35.43	33 22 11.72864 (N)	081 57 54.24887 (W)
RS_0001	233.86	33 34 57.19045 (N)	081 29 46.20709 (W)
RS_0002	227.486	33 34 58.15458 (N)	081 29 56.57877 (W)

Equipment

Woolpert owns all the equipment used for the ground control and ABGPS missions. Two base-station units were mobilized every day during the LiDAR mission, and were operated by a member of the Woolpert survey crew. Each base-station setup consisted of one Trimble 4000 SSI or 4700 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. The aircraft is configured with a Novatel Millennium 12-channel, dual frequency GPS receiver to support LiDAR acquisition missions.

Data Processing

All initial airborne data was processed using the Waypoint Consulting, Inc. GrafNav™ software. Data was gathered and processed at a one-second data capture rate. All data was recorded at an elevation mask of 10 degrees.

SECTION 6: DATA PROCESSING AND QUALITY CONTROL

LiDAR Data Processing

In this process, Woolpert employed GPS differential processing and Kalman filtering techniques to derive an aircraft trajectory solution at 1-second intervals for each base station within the project limits. Statistics for each solution (base station) were generated and studied for quality. The goal for each solution is to have:

- maintained satellite lock throughout the session
- position standard deviation of less than 5 centimeters
- low ionospheric noise
- few or no cycle slips
- a fixed integer ambiguity solution throughout the trajectory
- a maximum number of satellites for a given constellation
- a low (3.0 or less) Position Dilution of Precision (PDOP)

Often times a solution for a given base station will meet all of the above parameters in certain portions of the trajectory while the other base station might meet the above conditions in different portions of the trajectory solution. In this case, further processing was done to form different combinations of base station solutions and/or satellites to arrive at the optimal trajectory.

When the calibration, data acquisition, and GPS processing phases were complete, the formal data reduction process began. Woolpert LiDAR specialists:

- ✓ Studied individual flight lines and how these lines match adjacent flight lines to ensure the accuracy meets expectations.

- ✓ Identified and removed systematic error locally (by flight) which is not possible if the lines are combined into a block. This is sometimes the case when a satellite loss of lock occurs during a flight and the GPS solution fixes on the wrong integer ambiguity.

- ✓ Adjusted any small residual error (due to system noise) between flight lines and across all flight lines to survey ground control (or existing mapping if available).

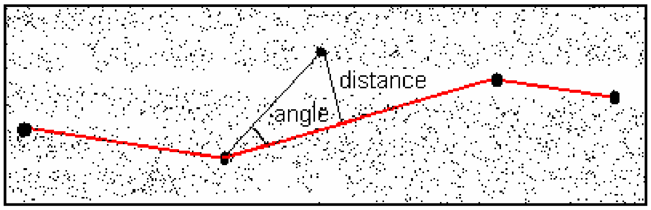
- ✓ Clipped the overlap region of each flight line to obtain a single homogenous coverage across the project area. This eliminated redundant, overlapping point data that could overwhelm terrain modeling software packages.

- ✓ Processed individual flight lines to derive “Point Cloud.”

  Given the airborne GPS aircraft trajectory and the raw LiDAR data subdivided by flight lines, we used manufacturer software to reduce raw information to a LiDAR point cloud on the ground. Woolpert has developed proprietary software to generate parameter files, allowing the manufacturer’s software to process a block; this allows us to batch process any number of flight lines. As part of this process, outliers in the data are removed. Typical outlying data points are a result of returns from clouds.

- ✓ Classified the point cloud data into ground and non-ground points

The classification algorithm classifies ground points by iteratively building a triangulated surface model. The routine starts by selecting some local low points as sure hits on the ground then builds an initial Triangulated Irregular Network (TIN) from selected low points. The routine then starts developing the ground model upward by iteratively adding new laser points to it. Each added point makes the model follow the ground surface more closely. Two iteration parameters, iteration angle and iteration distance, determine how close a point must be to a triangle plane so that the point can be accepted to the ground model. **Iteration angle** is the maximum angle between points, its projection on triangle plane and closest triangle vertex. **Iteration distance** parameter makes sure that the iteration does not make big jumps upwards when triangles are large. This helps to keep low buildings out of the ground model.



The vegetation and buildings are removed to obtain bare-earth. Even in areas covered by dense vegetation, ground points are correctly classified.

✓ Filtered the bare-earth data to remove small undulations.

Small random errors exist in the data due to electronic noise within the system. These errors manifest themselves as small undulations in the data. Woolpert developed a software application based on a Laplacian of Gaussian (LOG) operator modified to fit LiDAR data and remove small undulations. The filter controls accuracy by an elevation tolerance setting to meet a given accuracy threshold. The tolerance determines the maximum allowable elevation change of laser points. We developed a data structure suitable for LiDAR so that the searching routine is very fast [O(1)] computational complexity] making this algorithm quite efficient.

✓ Edge matched individual flight lines, generated statistics on the fit, and clipped the flight lines to butt match each other.

The next step in our process is to clip individual flight lines such that adjacent flight lines butt match and a homogenous LiDAR coverage is provided across the entire mapping limit, without overlap. A software routine was developed to follow the overlap region between two adjacent flight lines and place a "cut line" in the middle of the overlap region. The software will also generate statistics along each seamline as to how well each flight matches with its neighbor in flight.

If all flights are consistent within the mapping specifications, cross flight and ground control data is imported and studied for fit. As a QC measure, Woolpert has developed software to generate accuracy statistical reports by comparison among LiDAR points, ground control, and TINs generated by LiDAR points. The absolute accuracy is determined by comparison with ground control. Statistical analysis is then performed on the fit between the LiDAR data and the ground control. Based on the statistical analysis, the LiDAR data is then adjusted in relation to the ground control.

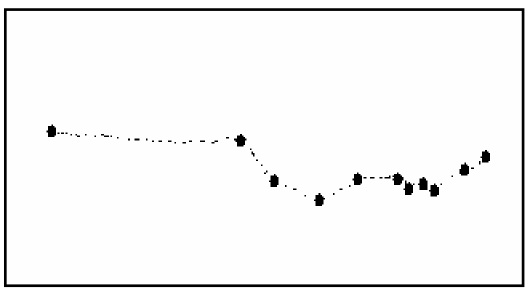
✓ Smoothed edges along flight lines if necessary.

Note, this is rarely required but in some instances the portions of opposing flight lines will not edge match exactly due to terrain features. For example, on the side of a very steep hill the opposing flight lines will have a slightly different elevation when ranged from an uphill direction as opposed to a downhill direction. The accuracy is controlled by an elevation tolerance setting.

✓ Determined key points for the DTM. Used the key points to reduce the overall number of points within the DTM.

Because LiDAR produces extremely dense data that requires a tremendous amount of storage and processing power, Woolpert has developed software to reduce the amount of data while preserving the integrity and accuracy of the terrain model.

The algorithm selects key points from points classified as ground by iteratively building a triangulated surface model. The accuracy is controlled by an elevation tolerance setting. This determines the maximum allowable elevation difference from a ground laser point to a triangulated model. The application will try to find a relatively small set of points (=keypoints) which would create a triangulated model of given accuracy. The point density is also ensured by a grid size setting.



✓ Translated the Bare-Earth Data Into the Appropriate Map Projection

Once all of the data has been reduced and quality controlled, the bare-earth data is translated into the final map projection. Note that the airborne GPS aircraft trajectory is processed in the target datums in relation to the orthometric height. Woolpert used National Geodetic Survey's GEOID99 software to derive the orthometric height.

As a quality control step, the orthometric heights are compared against ground survey results. In our experience, GEOID's are sometimes inaccurate in certain areas of the country. If a problem is detected, we will have to acquire additional ground control that will allow us to calculate our own transformation by determining the rotation matrix.

3D Compilation Breaklines using LiDAR Intensity images & supplementing with Orthophotography Images:

Woolpert produced intensity stereo images covering just the 430 sq. miles of detailed study area. SCDNR provided a boundary map of the detailed study area.

The compilation team will stereoscopically compile break lines in the detailed study area and remove LiDAR data from the large streams. The breaklines will be stereoscopically compiled.

Woolpert provided QA/QC of the data and delivered in the following format.

- Breaklines - .SHP
- Mass points and TINs – ASCII x/y/z
- DEM – ASCII x/y/z
- Tile size – 10,000 ft by 10,000 ft

LiDAR QA/QC Verification

LiDAR QA/QC verification will be provided by SCDNR through their contractor URS Corporation.

The complete LiDAR data set for the entire project area was delivered to URS on July 19, 2006. URS conducted a data assessment and provided comments and examples to Woolpert for delivery on August 4, 2006.URS indicated the LiDAR data met the vertical and horizontal accuracy requirements for each of the land use categories.

Vertical Accuracy - 1.2 feet RMSE
Horizontal Accuracy -11 feet RMSE

They next performed a review of LiDAR data artifacts URS summarized the errors into the five following categories. The following are URS's comments and Woolpert's responses.

1. Points on bridges that were not removed from the bare-earth file

Woolpert was able to identify these areas and re-classified any points that were determined to be on elevated bridges as non-ground features. On bridges determined to be earthen Woolpert verified that any earthen bridges were correctly modeled and included breaklines were necessary.

2. "Shaved surface" areas, where ground points were mistakenly removed from the bare-earth file.

Woolpert reviewed the "shaved surface" areas and reinserted available ground LiDAR points which may have been removed by the filter where needed. Smaller areas were also reviewed and corrected where necessary. There were several areas that appeared to have been covered by breaklines not available during the cleanliness assessment which were left unchanged.

3. Low vegetation points, some in the range of 4-6 feet above ground that were not removed from the bare-earth file.

Woolpert located a number of areas were LiDAR points were classified as ground, but could have possibly been reflecting off of low vegetation or tree trunks. We were able to correct these through further filtering or left unchanged based on further analysis.

4. Ground points that were classified as water and removed from the bare-earth file in areas that are obscured by vegetation.

The area in the southeastern portion of the project is characterized by a number of large oxbow areas where the LiDAR data indicates shallow, marshy water with heavy vegetation. Because this area is so flat the LiDAR filtering process is unable to distinguish between flat ground and water. After reviewing both the stereo LiDAR data and the 3D points our conclusion was that many of these areas could have LiDAR data reinserted but there was little or no impact on the vertical surface when doing so. Even though the revisions were not required, we did go ahead and modify many of these areas for consistency.

5. The overlap area between some flight lines, where it appears that the processing "thinned" the bare-earth points to post spacing greater than the non-overlap area.

As noted above, there are several locations in the southeastern project area characterized by dense vegetation and low lying marsh. This had the greatest impact on small portions of 6 LiDAR flights and the data between them. We have concluded that beyond an angle of around 13 degrees the LiDAR points were unable to both penetrate the vegetations and reflect from the marshy surface. In order to provide a more consistent dataset we took those points that did return from ground level in these areas and interpolated additional, random points in the sparse area based on their elevation. The LiDAR strips in this area had sufficient overlap and were collected within specifications.

URS provided Woolpert 843 polygons indicating areas to be corrected. In response, Woolpert provided an ESRI shapefile that identifies 3 categories: CORRECTED, EDIT-UNNEEDED and SWAMP_TREE_AREA. Of the 843 edit areas provided by URS, Woolpert corrected 683 and left 160 unchanged based on review and/or inclusion of breaklines.

Woolpert resubmitted the LiDAR data to URS on Sept 14, 2006. On October 4, 2006 Woolpert received comments from URS that additional editing was still required. Woolpert agreed to review all the bridge locations within the detailed study area and make the appropriate corrections. Woolpert than resubmitted the LiDAR data on November 4, 2006 and it was accepted on **November 29, 2006.**

SECTION 7: ALS50 SYSTEM CALIBRATION REPORT

Introduction

This Woolpert ALS50 LiDAR System Calibration Report shall be used to represent confirmation of the LiDAR system specifications, performance, and requirements. The system functionality, elevation, and horizontal accuracy performance shall be demonstrated for calibration purposes.

This report contains various test results and information pertaining to the system. It should be noted that all numbers shown in this report are in **meters** unless otherwise stated. All coordinates stated in the report are in the WGS84 coordinate system with ellipsoidal elevation.

System Model Number: ALS50

Client Name: South Carolina Department of Natural Resources

Project Name: Aiken County, SC 2006 LiDAR Project

Calibration Date: January 7, 2006
February 13, 2006

Report Prepared By: Qian Xiao

System Specifications and Requirements

The ALS50 LiDAR system, built by Leica Geosystems for Woolpert, has the following specifications:

Nominal	
Operating Altitude	400 – 3,000 meters
Elevation accuracy	15cm single shot
Range Resolution	1 cm
Scan angle	Variable from 0 to 75°
Swath width	Variable from 0 to 1.5 X altitude
Angle resolution	0.01°
Scan frequency	Variable based on scan angle
Horizontal Accuracy	Better than 1/2000 X altitude
Supported GPS receivers	Ashtech Z12, Trimble 7400, Novatel Millenium
Laser repetition rate	58 kHz
Beam divergence	0.3 mrads
Laser classification	Class IV laser product (FDA CFR 21)
Eye safe range	400m single shot depending on laser repetition rate
Power requirements	28 VDC @ 25A
Operating temperature	10-35°C
Humidity	0-95% non-condensing

On Site Antenna Offsets and Location

Aircraft GPS Antenna

The following measurements were calculated for Woolpert's aircraft Cessna 310 and 404 N404CP equipped with LiDAR. The POS/AV and ALS50 processing numbers were calculated from internal measurements completed in Leica's lab, and the positioning of the GPS antenna on the aircraft was field surveyed by Woolpert using a total station.

N7079F: Cessna 404 (Woolpert)

Reference Point to GPS Antenna	
X	**0.742 m**
Y	**-0.011 m**
Z	**-1.344 m**

N404CP: Cessna 404 (Woolpert)

Reference Point to GPS Antenna	
X	**0.646 m**
Y	**0.014 m**
Z	**-1.304 m**

The following measurements were calculated in the lab at Leica and will remain constant.

User to IMU Lever Arm (POS/AV) for AIMU	
X	**-0.269 m**
Y	**0.139 m**
Z	**-0.017 m**

User to IMU Lever Arm (POS/AV) for LN200	
X	**-0.273 m**
Y	**0.161 m**
Z	**-0.017 m**

Aircraft N7079F (Woolpert) is equipped with AIMU, Aircraft N404CP (Woolpert) is equipped with LN200.

Base Station GPS Antenna

Monument Description:	
GPS Receiver Type: Trimble 5700 Antenna Type: Trimble	Epoch Interval: 1/2 sec Elevation Mask: 10 degrees Observation Type: Static
Station Names used in processing the acceptance data: #1: Woolpert N 39 45 56.36709 Lat. W 84 11 12.26236 Long. 194.775 Ellipsoidal. HI.	

Flight Calibration Methodology

Data Collection

To accomplish the formal calibration, Woolpert has established a calibration range consisting of an airport runway. The calibration range has been ground surveyed to an accuracy of better than 1 cm. Four flight lines with two different altitude and opposing headings (see Figure 7-3) are required in order to capture pitch, roll, heading (see Figure 7-1) and torsion errors (see Figure 7-2).

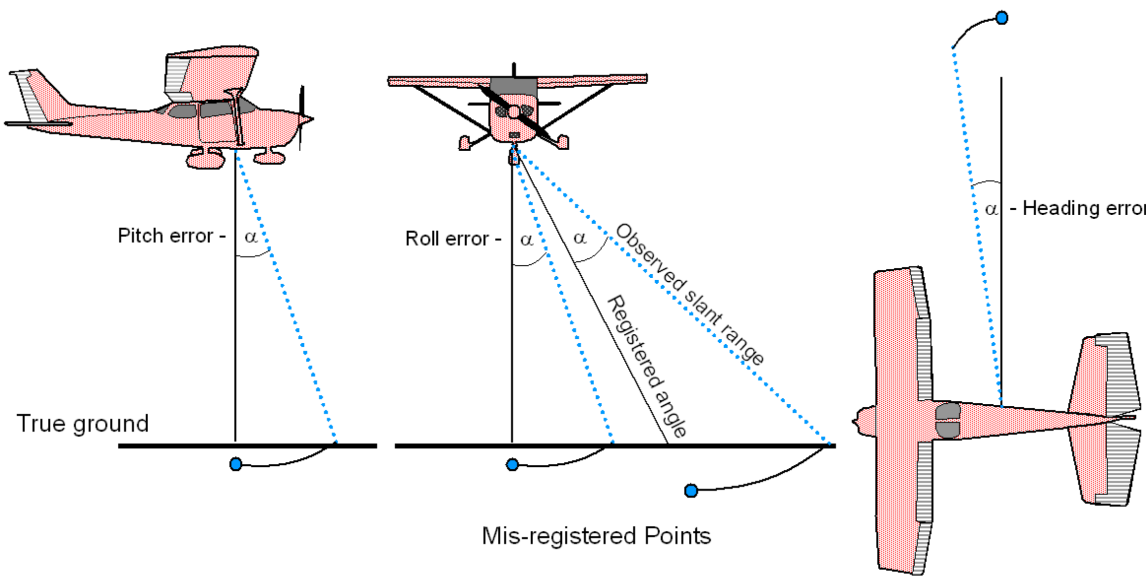


Figure 7-1: Misalignment Errors.

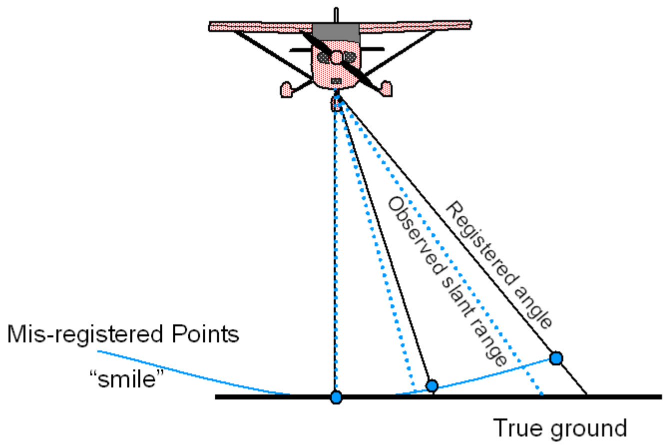


Figure 7-2: Torsion Error

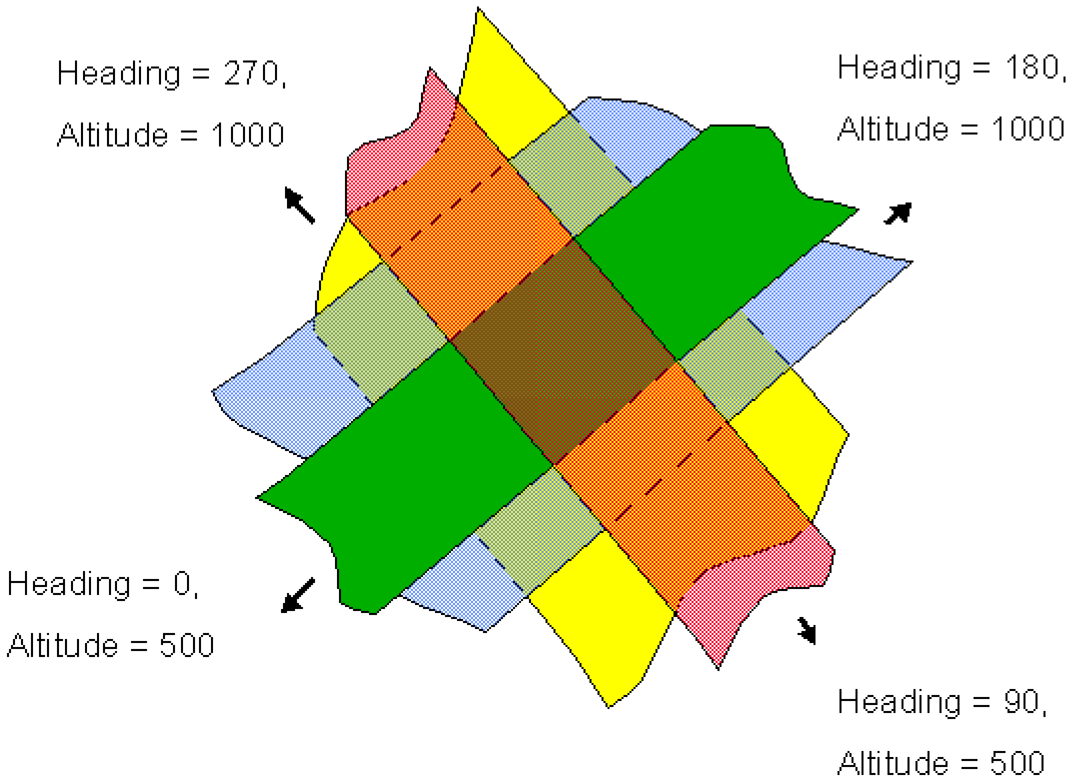


Figure 7-3: Optimal Flight Pattern for Calibration

Intensity Images

Four images from LiDAR intensity reflectance are generated in order to pick up tie points (see Figure 7-4). A least square adjustment (LSA) is performed using AutoBoresighting software provided by system manufacturer. Pitch, roll, heading, and torsion errors are calculated by LSA.

Figure 7-4: Ortho photo generated from LiDAR intensity reflectance.

Ground Control Points

Ground control points were collected along and across an airport runway. A total of 116 runway points were surveyed. The LiDAR collects scan data over the control points and the data is then used to determine the absolute Z accuracy of the system. The distribution of the runway points can be found in Figure 7.5.

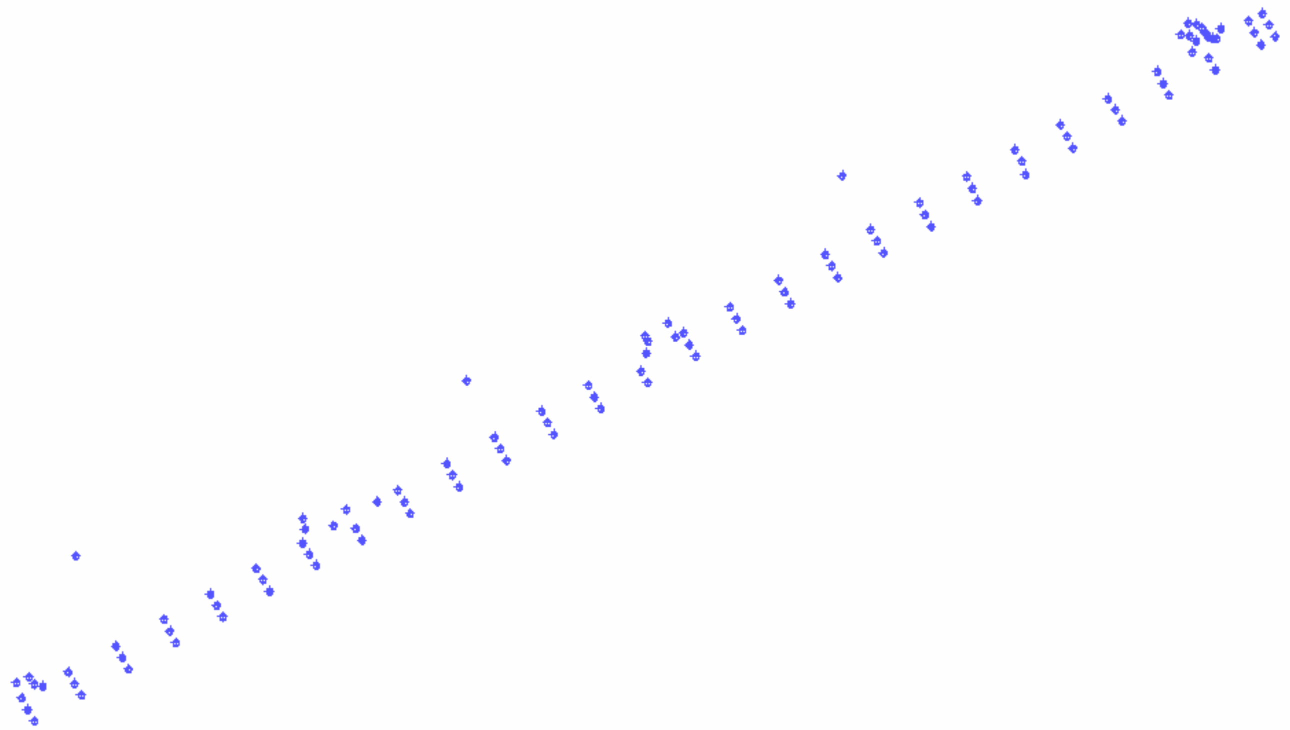


Figure 7-5: Ground control points on the runway

Flight over Ground Control Points

Flight lines, flown parallel and perpendicular to the runway control points, were used to determine the elevation (Z) error of the LiDAR data as well as pitch, roll, heading, and torsion can be seen in Figure 7-6. Each day the runway was flown, multiple overlapping strips were performed to assure that most control points were covered and to increase the likelihood that a laser point would strike within 0.5 meters of a control point.

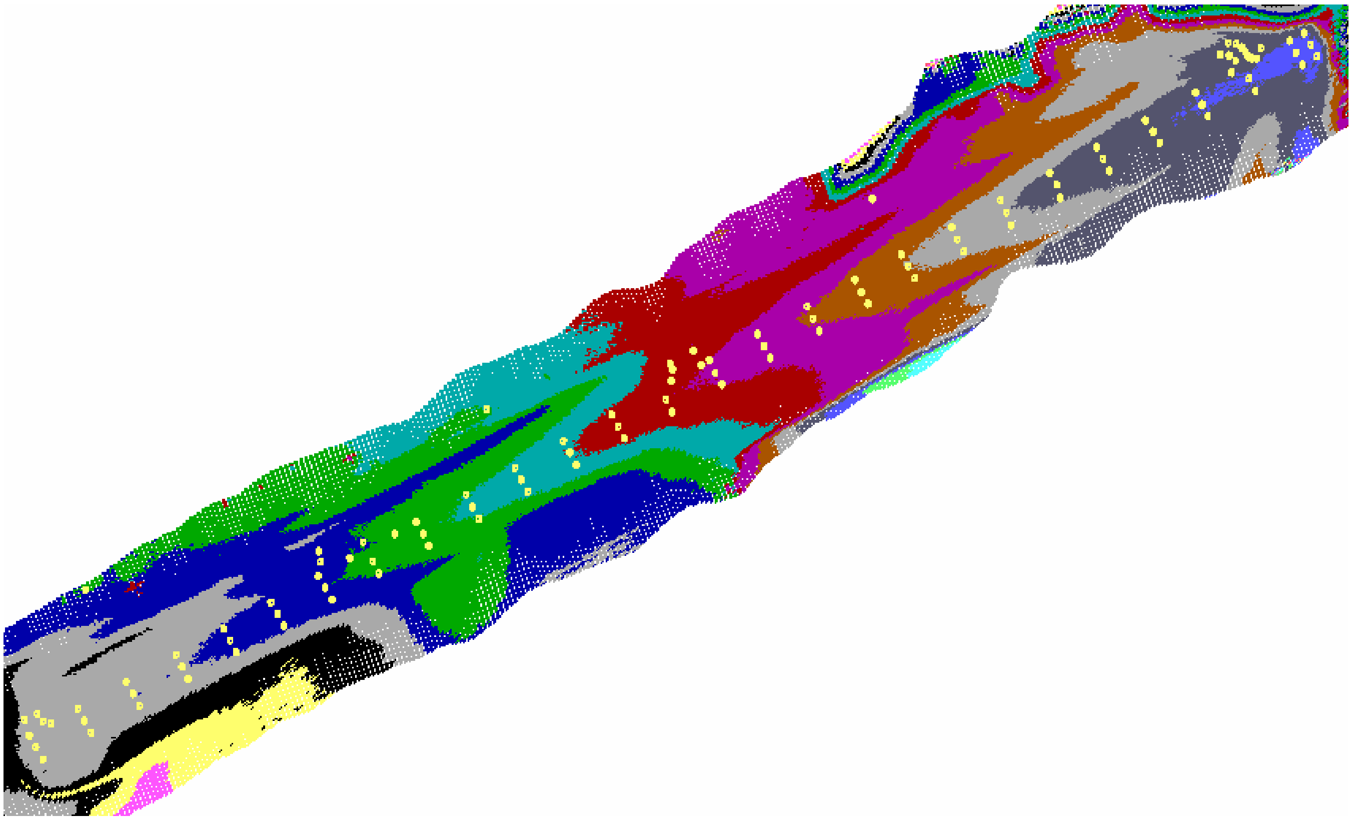


Figure 7-6: One flight line parallel to the runway ground control points. The flight line is color coded at one-meter elevation intervals. The LiDAR data was collected at about 500 meters AGL.

CALIBRATION RESULTS

The following numbers were derived by Leica through lab calibration and also by Woolpert using data acquired on Woolpert's LiDAR calibration sites. These parameters might have been refined using data collected for the project.

N7079F: Cessna 404 (Woolpert)

Parameter	Value	Format
Lab fixed parameters		
Range 1 Correction	2.400 m	0.000
Range 2 Correction	2.400 m	0.000
Range 3 Correction	2.400 m	0.000
Encoder Latency	0.00 mcr sec	0.00
Ticks Per Revolution	8401818 ticks	0000000
Attitude		
*Roll (radian)	0.040857800	0.000000000
*Pitch (radian)	-0.002981712	0.000000000
*Heading (radian)	0.001416112	0.000000000
*Scan angle correct	-12613 ticks	00000
Mechanic		
*Torsion (no unit)	-85000	00000

N404CP: Cessna 404 (Woolpert)

Parameter	Value	Format
Lab fixed parameters		
Range 1 Correction	2.446 m	0.000
Range 2 Correction	2.446 m	0.000
Range 3 Correction	2.446 m	0.000
Encoder Latency	0.00 mcr sec	0.00
Ticks Per Revolution	8389996 ticks	0000000
Attitude		
*Roll (radian)	0.002224375	0.000000000
*Pitch (radian)	0.014947456	0.000000000
*Heading (radian)	0.000319404	0.000000000
*Scan angle correct	17500 ticks	00000

Mechanic		
*Torsion (no unit)	23000	00000

Final Calibration Parameters

The following numbers were derived by Leica through lab calibration, and from data acquired on Woolpert's LiDAR calibration site as well as from data for the project.

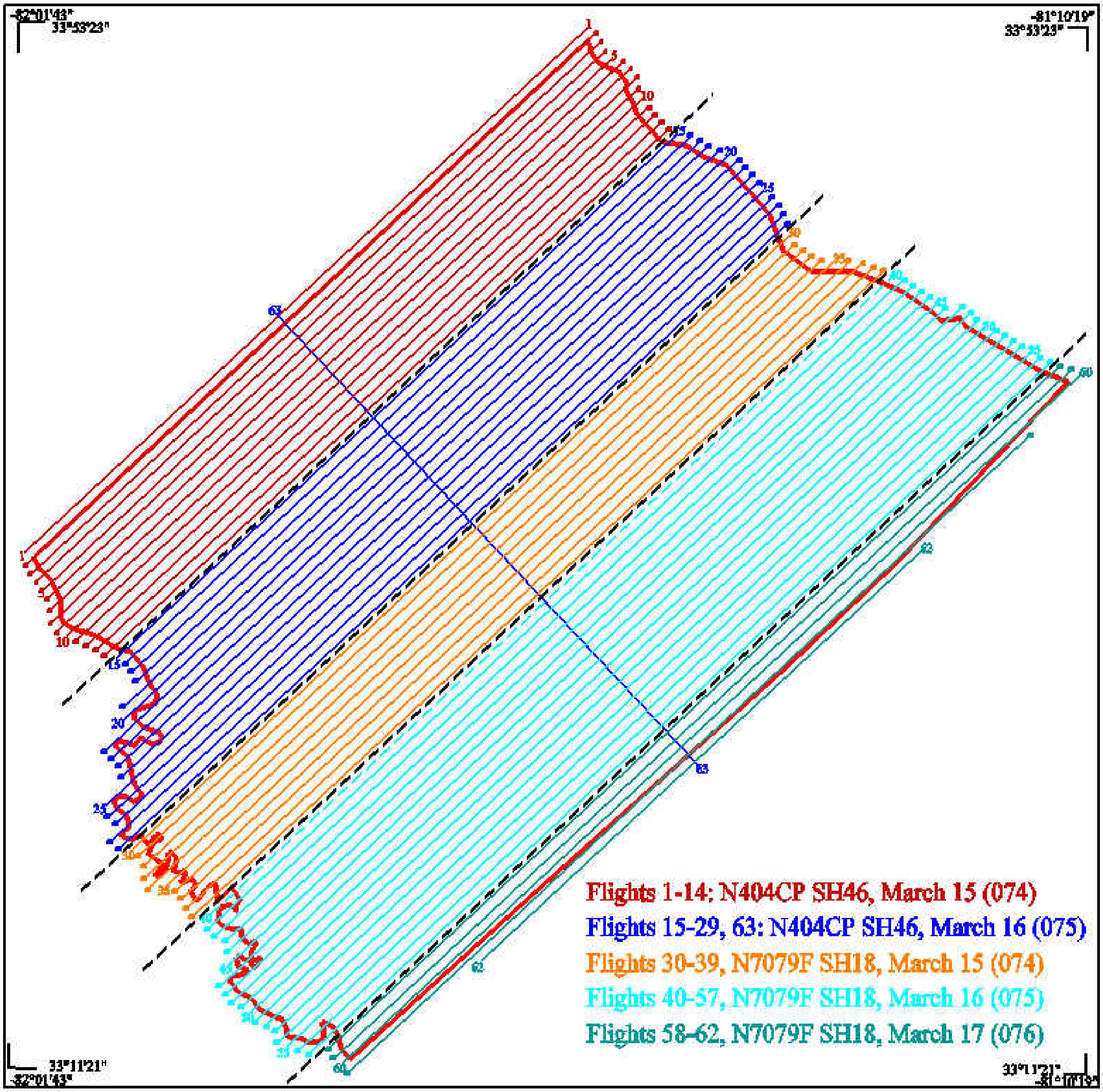
Parameter	Value	Format
Lab fixed parameters		
Range 1 Correction	2.400 m	0.000
Range 2 Correction	2.400 m	0.000
Encoder Latency	0.00 mcr sec	0.00
Ticks Per Revolution	8401818 ticks	0000000
Attitude		
*Roll (radian)	0.040857800	0.000000000
*Pitch (radian)	-0.002981712	0.000000000
*Heading (radian)	0.001416112	0.000000000
*Scan angle correct	-12613 ticks	00000
Mechanic		
*Torsion (no unit)	-85000	00000

*Value calibrated on site from calibration data

Based on the analysis of the LiDAR data the accuracy of the system meets the required specifications.

Approved By:			
Title	**Name**	**Signature**	**Date**
LiDAR Specialist Certified Phohogrammetrist	**Qian Xiao**		**February 20, 2006**

Figure A – Project Boundary/LiDAR Coverage



AIKEN COUNTY, SOUTH CAROLINA
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Figure B–LiDAR Coverage

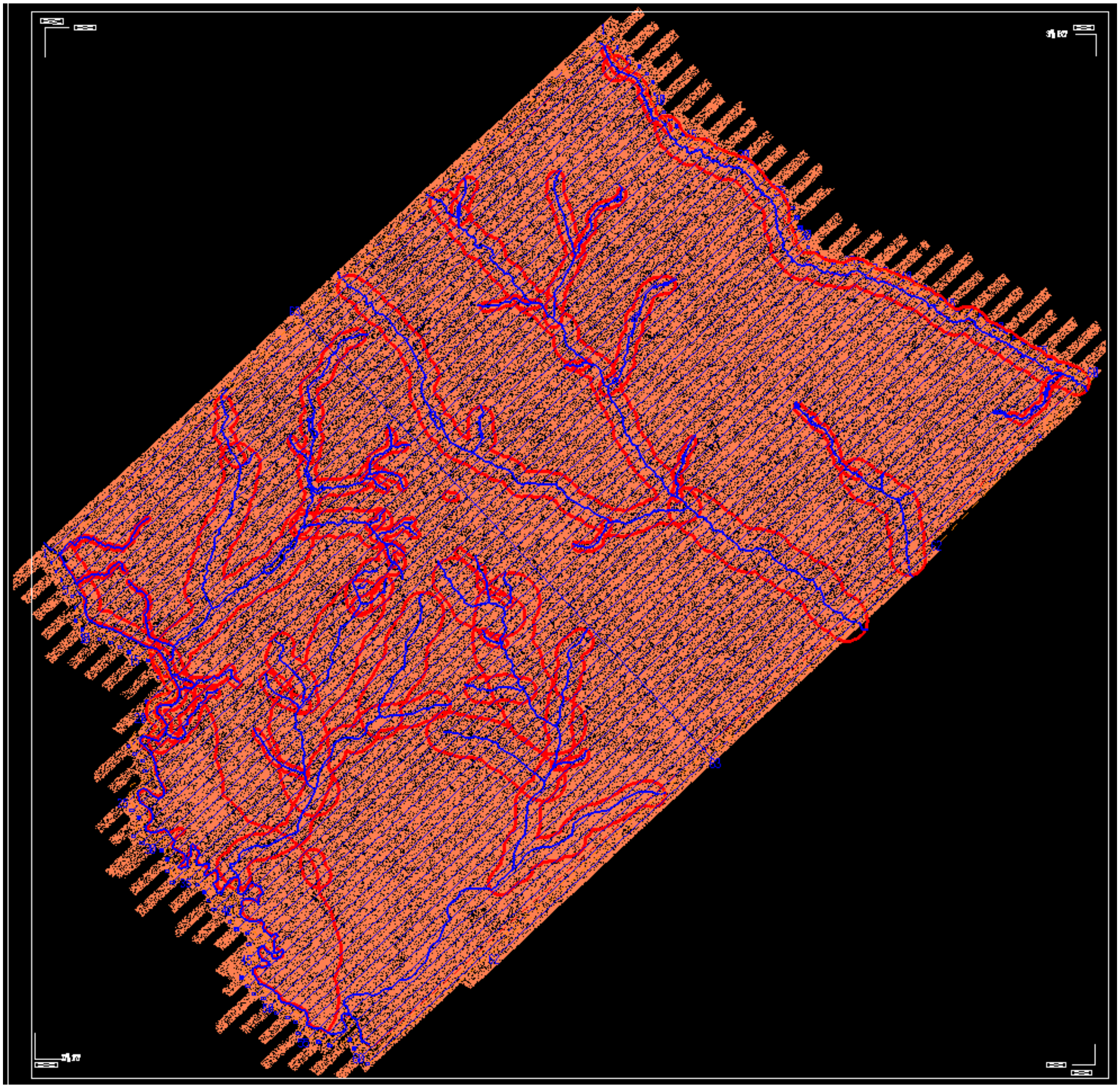

Figure C.1 – LiDAR Flight Log

LiDAR Data Aquisition Log
(for use with Leica ASL50 unit)

Date: 15/03/06 dd/mm/yy
Julian Day: 74
Client/Mission Name/Project Number: Aiken

Operator: ☐ Morgan ☑ Smith ☐ Maloney ☐ Kibler ☐ Other
Aircraft: ☑ N404CP ☐ N7079F
Survey Type: ☐ Wires ☑ Terrain ☐ Calibration
Applanix GPS began logging at: 7:36pm

Pilot: ☑ Gebhart ☐ Rader ☐ Tocknell ☐ Probert
ALS50 Unit: ☐ SH18 ☑ SH46
Mission Start Time (Wheels Up): 7:47pm

Tempurature (C): 12
Dew Point: -2
Pressure: 30.16
Mission End Time (Wheels Down): 12:35am

Horizontal Visibility: 10
Wind Direction: 280
Wind Speed: 5
From: AWG **To:** AWG

Cloud Cover: clear BLW 120w
Sfc Conditions: ☐ Wet ☑ Dry ☐ Snow
Precipitation: ○ Y **No** ○ N
Using Digital Camera Images? NO ○ Yes ◉ No

Base Station #1:
Operator:
CORS ☐

------------ LASER SPECIFICATIONS -------------

Scan Angle (FOV):	Scan Frequency (Hz)	Pulse Rate (kHz):	RNG/INT	Attentuator Setting	Approx. Air Speed (knots)	
30	28	38, 7	☐ 1+1 ☐ 2+2 ☐ 3+3 ☑ 4+3	☑ 0 (0.0) ☐ 1 (0.5) ☐ 2 (1.0)	130	**Specified AGL:** 6500 **MSL:** 7000 **Range Gate:** -- **Max Range Values:** - - **Adjusted AGL:**

Flt Line	Mission ID#	Heading	HDOP	VDOP	SV's	Course Setting	Fine Setting	Line Notes
TEST	060316_004150	-	-	-	-			OK 113 AGC
1	060316_005848	NE	0.948	1.632	8	9	3	
2	060316_011758	SW	0.939	1.443	8	9	3	
3	060316_013716	NE	0.946	1.408	8	9	3	
4	060316_015617	SW	1.075	1.536	7	9	3	
5	060316_021517	NE	1.038	1.393	7	9	3	
6	060316_023429	SW	0.916	1.218	8	9	3	
7	060316_025411	NE	0.897	1.244	8	9	3	
8	060316_031358	SW	1.091	1.590	7	9	3	
9	060316_033327	NE	1.085	1.591	8	9	3	
10	060316_035237	SW	1.190	1.309	8	9	3	
11	060316_041215	NE	1.301	1.527	8	9	3	
12	060316_043137	SW	1.295	1.658	8	9	3	
13	060316_045110	NE	0.921	1.254	9	9	3	
14	060316_051045	SW	0.949	1.312	9	9	3	
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Figure C.2 – LiDAR Flight Log

LiDAR Data Aquisition Log (for use with Leica ASL50 unit)	Date: 15/03/06 dd/mm/yy	Julian Day: 74	Client/Mission Name/Project Number: Aiken County 065185
Operator: ☐ Morgan ☐ Smith ☑ Maloney ☐ Kibler ☐ Other	Aircraft: ☐ N404CP ☑ N7079F	Survey Type: ☐ Wires ☑ Terrain ☐ Calibration	Applanix GPS began logging at: 7:45pm
Pilot: ☐ Gebhart ☐ Rader ☑ Tocknell ☐ Probert	ALS50 Unit: ☑ SH18 ☐ SH46		Mission Start Time (Wheels Up): 7:54pm
Tempurature (C): 12	Dew Point: -2	Pressure: 30.16	Mission End Time (Wheels Down): 1:02am
Horizontal Visibility: 10	Wind Direction: 280	Wind Speed: 5	From: Bush To: Bush
Cloud Cover: Clear Below 12,000	Sfc Conditions: ☐ Wet ☑ Dry ☐ Snow	Precipitation: ◯ Y **No** ◯ N	Using Digital Camera Images? No ◯ Yes ◉ No
Base Station #1:	Operator:	CORS ☐	

------------ *LASER SPECIFICATIONS* -------------

Scan Angle (FOV):	Scan Frequency (Hz)	Pulse Rate (kHz):	RNG/INT	Attentuator Setting	Approx. Air Speed (knots)	Specified AGL: 6500 MSL: 7000 Range Gate: 6929 -- Max Range Values: - -
30	28	38.7	☐ 1+1 ☑ 2+2 ☐ 3+3 ☐ 4+3	☑ 0 (0.0) ☐ 1 (0.5) ☐ 2 (1.0)	130	Adjusted AGL:

Flt Line	Mission ID#	Heading	HDOP	VDOP	SV's	Course Setting	Fine Setting	Line Notes
TEST	251030_004717	-	-	-	-			Lasen Test
30	251030_011006	NE	0.939	1.546	8	9	14	AGC = 118 Par / AV Error W.P. 28
31	251030_013332	SW	0.949	1.415	8	9	14	Start Over - Wrong Alt. - 6000ft
30	251030_015759	NE	1.073	1.518	7	9	14	AGC = 118
31	251030_022048	SW	1.028	1.351	7	9	14	
32	251030_024422	NE	0.905	1.244	8	9	14	
33	251030_030738	SW	1.478	2.188	6	9	14	
34	251030_033148	NE	1.079	1.589	8	9	14	
35	251030_035504	SW	1.205	1.335	8	9	14	
36	251030_041955	NE	1.322	1.596	8	9	14	
37	251030_044306	SW	1.238	1.639	8	9	14	
38	251030_050801	NE	0.949	1.308	9	9	14	
39	251030_053146	SW	1.129	1.871	7	9	14	
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Figure C.3 – LiDAR Flight Log

LiDAR Data Aquisition Log
(for use with Leica ASL50 unit)

Date: 16/03/06 dd/mm/yy	**Julian Day:** 75	**Client/Mission Name/Project Number:** Aiken	
Operator: ☐ Morgan ☑ Smith ☐ Maloney ☐ Kibler ☐ Other	**Aircraft:** ☑ N404CP ☐ N7079F	**Survey Type:** ☐ Wires ☑ Terrain ☐ Calibration	**Applanix GPS began logging at:** 11:27am
Pilot: ☑ Gebhart ☐ Rader ☐ Tocknell ☐ Probert	**ALS50 Unit:** ☐ SH18 ☑ SH46		**Mission Start Time (Wheels Up):** 11:38am
Tempurature (C): 8	**Dew Point:** -3	**Pressure:** 30.19	**Mission End Time (Wheels Down):**
Horizontal Visibility: 10	**Wind Direction:** 230	**Wind Speed:** 8	**From:** AWG **To:** AWG
Cloud Cover: Clear	**Sfc Conditions:** ☐ Wet ☑ Dry ☐ Snow	**Precipitation:** ○ Y **NO** ○ N	**Using Digital Camera Images? NO** ○ Yes ◉ No
Base Station #1:	**Operator:**	**CORS** ☐	

------------ LASER SPECIFICATIONS -------------

Scan Angle (FOV):	Scan Frequency (Hz)	Pulse Rate (kHz):	RNG/INT	Attentuator Setting	Approx. Air Speed (knots)	Specified AGL: 6500 MSL: / Range Gate: -- / Max Range Values: - -
30	28	38.7	☐ 1+1 ☐ 2+2 ☐ 3+3 ☑ 4+3	☑ 0 (0.0) ☐ 1 (0.5) ☐ 2 (1.0)	130	Adjusted AGL:

Flt Line	Mission ID#	Heading	HDOP	VDOP	SV's	Course Setting	Fine Setting	Line Notes
TEST	060316_163157	-	-	-	-	9	3	OK AGC
15	060316_164915	NE	1.557	2.582	5	9	3	POS/AV Heading Eror
16	060316_170854	SW	1.843	2.232	6	9	3	
17	060316_172833	NE	0.964	1.359	7	9	3	
18	060316_174831	SW	1.231	1.854	7	9	3	
19	060316_180837	NE	1.298	2.677	7	9	3	
20	060316_182950	SW	1.416	2.817	7	9	3	
21	060316_185031	NE	1.134	1.782	8	9	3	
22	060316_191131	SW	1.146	1.579	8	9	3	
23	060316_193154	NE	1.213	1.531	8	9	3	SXP Possible Rain 20-33
24	060316_195309	SW	1.235	1.509	8	9	3	SXP Possible Rain 48-33
25	060316_201449	NE	1.046	1.265	9	9	3	
26	060316_203638	SW	0.905	1.536	9	9	3	
27	060316_205829	NE	0.837	1.491	10	9	3	
28	060316_212103	SW	0.838	1.614	10	9	3	
29	060316_214316	NE	0.936	1.802	9	9	3	
24	060316_220429	SW	0.803	1.131	11	9	3	Re-Flight
23	060316_221909	NE	1.049	1.232	9	9	3	
63	060316_224326	SE	1.275	1.411	8	9	3	
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Figure C.4 – LiDAR Flight Log

LiDAR Data Aquisition Log (for use with Leica ASL50 unit)	Date: 16/03/06 dd/mm/yy	Julian Day: 75	Client/Mission Name/Project Number: Aiken Co. 065185
Operator: ☐ Morgan ☐ Smith ☑ Maloney ☐ Kibler ☐ Other	Aircraft: ☐ N404CP ☑ N7079F	Survey Type: ☐ Wires ☑ Terrain ☐ Calibration	Applanix GPS began logging at: 11:47am
Pilot: ☐ Gebhart ☐ Rader ☑ Tocknell ☐ Probert	ALS50 Unit: ☑ SH18 ☐ SH46		Mission Start Time (Wheels Up): 11:56am
Tempurature (C): 8	Dew Point: -3	Pressure: 30.19	Mission End Time (Wheels Down): 7:40pm
Horizontal Visibility: 10	Wind Direction: 230	Wind Speed: 8	From: Bush To: Bush
Cloud Cover: Clear	Sfc Conditions: ☐ Wet ☑ Dry ☐ Snow	Precipitation: ○ Y NO ◉ N	Using Digital Camera Images? NO ○ Yes ○ No
Base Station #1:	Operator:	CORS ☐	

------------ LASER SPECIFICATIONS ------------

Scan Angle (FOV):	Scan Frequency (Hz)	Pulse Rate (kHz):	RNG/INT	Attentuator Setting	Approx. Air Speed (knots)	Specified AGL: 6500 MSL: 6900 Range Gate: 6929 -- Max Range Values: - -
30	28	38.7	☐ 1+1 ☑ 2+2 ☐ 3+3 ☐ 4+3	☑ 0 (0.0) ☐ 1 (0.5) ☐ 2 (1.0)	130	Adjusted AGL:

Flt Line	Mission ID#	Heading	HDOP	VDOP	SV's	Course Setting	Fine Setting	Line Notes
TEST	251030_165022	-	-	-	-	9	14	Laser Test
40	251030_171445	NE	0.959	1.254	7	9	14	AGC = 118.4
41	251030_173752	SW	0.968	1.283	8	9	14	
42	251030_180133	NE	1.254	2.342	7	9	14	
43	251030_182614	SW	1.420	3.254	7	9	14	VDOP Spike
44	251030_184903	NE	1.139	1.807	8	9	14	
45	251030_191153	SW	1.148	1.576	8	9	14	
46	251030_193552	NE	1.230	1.526	8	9	14	Rain at W.P. 41?-52 Virga
47	251030_200016	SW	1.212	1.502	8	9	14	Possible Spits of rain down to W.P.50
48	251030_202607	NE	0.915	1.371	9	9	14	
49	251030_205016	SW	0.909	1.843	9	9	14	
50	251030_211452	NE	0.832	1.615	10	9	14	
51	251030_213923	SW	0.949	1.914	9	9	14	
52	251030_220429	NE	0.799	1.131	11	9	14	
53	251030_222914	SW	1.126	1.235	9	9	14	
54	251030_225357	NE	1.329	1.386	8	9	14	
55	251030_231939	SW	1.321	1.904	8	9	14	
56	251030_234340	NE	1.103	1.567	8	9	14	
57	251030_000809	SW	1.023	1.750	8	9	14	
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Figure C.5 – LiDAR Flight Log

LiDAR Data Aquisition Log
(for use with Leica ASL50 unit)

Date: 17/03/06 dd/mm/yy

Julian Day: 76

Client/Mission Name/Project Number: Aiken Co. 065185

Operator: ☐ Morgan ☐ Smith ☑ Maloney ☐ Kibler ☐ Other

Aircraft: ☐ N404CP ☑ N7079F

Survey Type: ☐ Wires ☑ Terrain ☐ Calibration

Applanix GPS began logging at: 8:10am

Pilot: ☐ Gebhart ☐ Rader ☑ Tocknell ☐ Probert

ALS50 Unit: ☑ SH18 ☐ SH46

Mission Start Time (Wheels Up): 8:20am

Tempurature (C): 13

Dew Point: 6

Pressure: 30.03

Mission End Time (Wheels Down): 10:35am

Horizontal Visibility: 10

Wind Direction: 260

Wind Speed: 7

From: Bush **To:** Bush

Cloud Cover: Clear

Sfc Conditions: ☐ Wet ☑ Dry ☐ Snow

Precipitation: ○ Y NO ◉ N

Using Digital Camera Images? NO ○ Yes ○ No

Base Station #1:

Operator:

CORS ☐

------------ ***LASER SPECIFICATIONS*** -------------

Scan Angle (FOV):	Scan Frequency (Hz)	Pulse Rate (kHz):	RNG/INT	Attentuator Setting	Approx. Air Speed (knots)
30	28	38.7	☐ 1+1 ☑ 2+2 ☐ 3+3 ☐ 4+3	☑ 0 (0.0) ☐ 1 (0.5) ☐ 2 (1.0)	130

Specified AGL: 6500 **MSL:** 6900
Range Gate: 6929 --
Max Range Values: - -

Adjusted AGL:

Flt Line	Mission ID#	Heading	HDOP	VDOP	SV's	Course Setting	Fine Setting	Line Notes
TEST	251031_131419	-	-	-	-			Laser Test
58	251031_133045	NE	1.023	1.370	8	9	14	AGC = 117.9 Pos/AV Error W.P. 13 up
59	251031_135403	SW	1.215	1.818	7	9	14	
60	251031_141852	NE	1.154	1.734	7	9	14	
61	251031_144213	SW	0.971	1.386	8	9	14	
62	251031_150527	NE	1.014	1.661	8	9	14	
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