MINIMUM TECHNICAL STANDARDS, VOL. 2
FINAL REPORT OF LIDAR MAPPING

PROJECT AREA E

STATE OF FLORIDA
DIVISION OF EMERGENCY MANAGEMENT

TASK ORDER NO. 20070525-492720
CONTRACT NO. 07-HS-34-14-00-22-469

JANUARY 20, 2009
REVISED

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PREPARED BY:
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MINIMUM TECHNICAL STANDARDS REPORT
REPORT OF TOPOGRAPHIC SURVEY

Task Order No. 20070525-492720
Contract No. 07-HS-34-14-00-22-469

PROJECT AREA E

For:
State of Florida, Division of Emergency Management
"State Emergency Response Team"
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REPORT OF TOPOGRAPHIC SURVEY
AREA E: LIDAR TOPOGRAPHIC MAPPING
FOR THE
FLORIDA DIVISION OF EMERGENCY MANAGEMENT

Purpose

This data set is one component of a digital terrain model (DTM) for the Florida Division of Emergency Management's (FDEM) Project Management and Technical Services for Mapping within Coastal Florida (Contract 07-HS-34-14-00-22-469), encompassing the entire coastline of Florida.

This survey was performed according to Baseline Specifications v 1.2. These specifications were developed by a coalition of GIS practitioners, including the Florida Division of Emergency Management, Florida Water Management Districts, Florida Fish and Wildlife Conservation Commission, Florida Department of Environmental Protection, Army Corp of Engineers Jacksonville District, and other state and federal agencies as the model requirements for orthophotography and LiDAR data collection for publicly funded projects within Florida.

The LiDAR topographic mapping survey is to support the Florida Division of Emergency Management (FDEM) development and maintenance of Regional Evacuation Studies (Study), which include vulnerability assessments and assist disaster response personnel in understanding threats to Florida's citizens and visitors. Additionally-intended uses for this survey are growth management, map modernization/floodplain mapping, natural lands stewardship, and homeland security planning.

Type of Survey

Topographic Survey – Line-Drawn (Vector) Topographic Features by LiDAR and Photogrammetric Methods.

Sensor Description

All data was acquired using Leica ALS50-II LiDAR sensor numbers 19, 59, and 62. The ALS50 has a laser pulse rate of up to 150 kilohertz, records up to 4 returns per pulse, and records return intensities for 3 laser returns per pulse. The Area E LiDAR data was collected at 4,000' above ground level, at an average airspeed of 110 knots. Sensor Field of View was set to 29 degrees. Bore-sight calibration was performed at the beginning and at the end of the overall project. A description of that calibration may be found in Appendix D.

Dates of Survey

The LiDAR data was acquired July 17 – August 8, 2007. A map of the LiDAR flight lines and the dates of those flights may be found in Appendix E. The GPS ground control and QA/QC observations occurred from December 4-11, 2007.

Survey Area

The survey encompassed approximately +/-517 square miles within Charlotte and Lee Counties, Florida.

Map Reference

There are no printed maps for this survey. All map data was delivered to the Florida Division of Emergency Management in digital form only.

Name of Responsible Surveyor

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Name of Company

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Abbreviations

2D – Two-Dimensional
3D – Three-Dimensional
ABGPS – Airborne GPS
AGL – Above Ground Level
AT – Aerial Triangulation
CI – Confidence Interval
DEM – Digital Elevation Model
DTM – Digital Terrain Model
FDEM – Florida Division or Emergency Management
FGCC – Federal Geodetic Control Committee
GeoTIFF – Georeferenced Tag(ged) Image File Format
GPS – Global Positioning System
GSD – Ground Sample Distance
ID – Identification
IMU – Inertial Measurement Unit
Inc. – Incorporated
IPAS – Inertial Positioning and Attitude System

LAS – LASer File Format Exchange
LiDAR – Light Detection And Ranging
NAD 83-HARN – North American Datum 1983 High Accuracy Reference Network adjustment
NAVD 88 – North American Vertical Datum of 1988
NGS – National Geodetic Survey
NMAS – National Map Accuracy Standards
NOAA – National Oceanic and Atmospheric Administration
NSSDA – National Standards for Spatial Data Accuracy
PSM – Professional Surveyor and Mapper
QA/QC – Quality Assurance/Quality Control
RGB – Red, Green and Blue Bands
RMSE – Root Mean Square Error
RTK – Real Time Kinematic
STD – Standard
TIFF – Tag(ged) Image File Format
TIN – Triangulated Irregular Network
USGS – United States Geological Survey
Vx – Residual Horizontal Error in the X Direction
Vy – Residual Horizontal Error in the Y Direction
Vxy – Residual Horizontal Error in the XY Direction (Resultant)
XYZ – Easting, Northing and elevation grid coordinates (ASCII format)

Definitions

Orthophoto: A digital image (raster) map produced from a series of aerial photographs and/or image strips that have been rectified to correct for aircraft tilt, terrain relief, and camera lens distortion. The resulting image has a consistent scale throughout, allowing the user to take direct measurements such as distances, angles, positions, and areas. The digital raster image is comprised of a digital grid of pixels, or picture elements. Each pixel has a row and column "address" (an X,Y coordinate) and an intensity value ranging from 0 to 255. Each pixel within an RGB image, will have an intensity value for the red, green, and blue bands. Orthophotos may be produced as a natural color image using natural color bands (red, green, blue) or as a false-color infrared image using the red, green, near-infrared bands.

Map Data Accuracy

Horizontal Feature Accuracy: Per contract specifications, the horizontal accuracy requirement is to meet or exceed a 3.8-foot horizontal accuracy at the 95% confidence level using RMSE(r) x 1.7308 as defined by the FGDC Geospatial Positioning Accuracy Standards, Part 3: NSSDA.

Vertical Feature Accuracy: Per contract specifications, the vertical accuracy requirement of the digital terrain model (DTM) is 0.6 foot at 95% confidence level using RMSE(z) x 1.9600 as defined by the National Standard for Spatial Data Accuracy (NSSDA).

For the following landcover point classifications,

1. Bare-earth and low grass
2. Brush lands and low trees
3. Forested areas fully covered by trees
4. Urban areas

Vertical accuracy guidelines are as follows from FEMA's Appendix A:

In category 1, the RMSEz must be < .30 ft ($Accuracy_z$ < .60 feet)
In category 2, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)
In category 3, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)
In category 4, the RMSEz should be < .61 ft ($Accuracy_z$< 1.19 feet)
In all categories combined, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)

Additionally, two-foot contours in unobscured areas are certified to meet or exceed National Map Accuracy Standards (NMAS). These standards state that not more than 10 percent of the elevations tested shall be in error by more than one-half the contour interval, and none will be in error by more than the full contour interval. Therefore, for a 2-foot contour interval, not more than 10 percent of the elevations tested shall be in error of more than 1 foot, and none will be in error by more that 2 feet. Two-foot contours within low confidence (obscured) areas are attributed as such and are not required to meet NMAS. Additionally, 1-foot contours are delivered for graphical purposes, and are not required to meet these accuracy standards.

The accuracy assessment was performed using a standard method to compute the root mean square error (RMSE) based on a comparison of ground control points and filtered LiDAR data points. Filtered LiDAR data has had vegetation and cultural features removed and by analysis represents bare earth elevations. The RMSE figure was used to compute the vertical National Standard for Spatial Data Accuracy (NSSDA).

The results of Woolpert's accuracy analysis are included in Appendix B, LiDAR Accuracy Checks.

Datums/Coordinate Systems

The LiDAR data and breaklines are in reference to the State Plane Coordinate System, Florida West Zone (0902), in units of US Survey Feet. The horizontal datum is NAD83-HARN, and the vertical datum is NAVD88.

Data Sources

Original Control Point Coordinates:	NGS Information Services NOAA, N/NGS12 National Geodetic Survey SSMC-3, #9202 1315 East-West Highway Silver Spring, Maryland 20910-3282 Phone: (301) 713-3242 Fax: (301) 713-4172 Email: info_center@ngs.noaa.gov http://www.ngs.noaa.gov/

Methodology

A digital terrain model (DTM) was developed from a combination of newly-flown LiDAR point data and existing orthophoto imagery. Stereo imagery was created from the LiDAR surface and

orthophoto imagery using GeoCue software, generating the stereo view from the 3D LiDAR data. Terrain breakline data was photogrammetrically collected to improve the digital elevation model within this stereo view.

Area E encompasses approximately 517 square miles within Charlotte and Lee Counties, Florida (see Appendix A: Mapping Area and QC Checkpoint Locations). The LiDAR data was collected at a maximum post spacing of 4 feet in unobscured areas for random point data. The end product complies with the Florida Administrative Code 61G17, Minimum Technical Standards for Surveying and Mapping.

A minimum of one hundred and twenty (120) ground survey quality control (QC) checkpoints are required for per 500 square miles of project area. These were surveyed by Woolpert throughout the project area and were used to confirm the accuracy of the LiDAR data. The accuracy analysis was based on methods outlined in the Geospatial Positioning Accuracy Standards, Part 3: National Standards for Spatial Data Accuracy (NSSDA) developed by the Federal Geodetic Data Committee (FGDC-STD-007.3-1998).

LiDAR Ground Control Survey

The ground control network to support the LiDAR survey was comprised of 29 control points located by rapid static GPS methods to second-order horizontal and third-order vertical accuracies in Area E. For a detailed overview of the ground control survey, refer to Volume 1 of this report.

QA/QC Checkpoint Survey

To support the accuracy analysis of the topographic mapping, Woolpert acquired 125 new field-surveyed QC checkpoints using rapid static GPS ground surveys, along with conventional surveying methods to locate points within dense tree cover. Again, a detailed overview of the QA/QC checkpoint survey may be found in Volume 1 of this report. ***Note that two of these points were later found to be under water at the time the LiDAR mission was flown – BARE EARTH AND LOW GRASS Point LEE5055 and BRUSH LANDS AND LOW TREES Point LEE5056. So while 125 points were collected, these two points were removed and only 123 points were considered in the accuracy calculations.***

LiDAR Acquisition and Processing

The LiDAR data was acquired using Leica ALS50-II LiDAR sensors, on July 17 – August 8, 2007. The LiDAR data was collected at a maximum post spacing of 4 feet in unobscured areas for random point data. ABGPS base stations used during acquisition were VENICE CBL 800, VENICE CBL 800, 3 08 44 22, PUNT 75063, and W 247.

The ABGPS data was reduced using the GrafNav software package by Waypoint Consulting, Incorporated.

The IMU data for Sensor 19 was reduced using the PosProc software package by Applanix Corporation. The IMU data for Sensors 59 and 62 was reduced using Leica's IPAS Pro software to process the IMU data, with Leica's IPAS sensor embedded.

The initial LiDAR "point cloud" was derived through the ALS Post Processor software package by Leica Geosystems. The ground base stations were placed at no more than a 20-mile radius

from the flight survey area.

Once the initial LiDAR "point cloud" was derived, the data was reviewed to look for any systematic error within the LiDAR flights using proprietary software. After systematic error was identified and removed, above-ground features were classified and removed using proprietary software to produce the bare-earth coverage. The overlap area between flight lines was maintained in order that potentially usable data is available.

LiDAR QC/Photogrammetric Compilation

To collect the breaklines, the LiDAR data was used as the main source data set in addition to orthophotography. Orthophoto imagery for the area within Lee County was from new imagery collected and developed by the Woolpert Team. All imagery for Lee County is dated 2007 with a 0.5-foot pixel resolution. Orthophoto imagery for the areas within Charlotte County was provided by FDEM, and was provided at 1.0-foot pixel resolution and dated 2006.

Stereo imagery was created from the LiDAR surface and orthophoto imagery using GeoCue software. From these stereo images, or LiDARgrammetry, breakline features were collected along linear topographic features as required. Breakline elevations were linearly ramped between identified critical elevation points.

In accordance with the Baseline Specifications v 1.2, the following breakline features were collected:

- Closed water bodies (lakes, reservoirs, etc) as 2-D or 3-D polygons
- Linear hydrographic features (streams, shorelines, canals, swales, embankments, etc) as 3-D breaklines
- Coastal shorelines as 2-D or 3-D linear features
- Edge of pavement road features as 3-D breaklines
- Soft features (ridges, valleys, etc.) as 3-D breaklines
- Low confidence areas as 2-D polygons; island features as 2-D or 2D polygons
- Overpasses and bridges as 3-D breaklines

The Coastal Shoreline breaklines were collected at the shoreline water elevation at the land-water interface. Breakline features were captured to develop a hydrologically correct DTM.

Automated QC processes were run on the breaklines and LiDAR elevation points to check for outlying elevations not probable within the mapping area. Additional visual QC was performed to verify the automated processes.

Breakline features were compiled in the softcopy environment using ImageStation SSK software on Pentium IV, quad processor, 3GHz photogrammetric workstations. Intergraph Corporation of Huntsville, Alabama, distributes the ImageStation SSK software.

The DTM was delivered as LiDAR mass points in LAS version 1.1 and the breaklines were delivered as an ArcGIS geodatabase. A list of the 576 LAS files delivered for Area E may be found in Appendix C.

Contours were generated from a 30-foot gridded DEM: 2-foot contours meet NMAS, with 1-foot contours for visualization purposes. The LiDAR masspoints are delivered in the LAS 1.1 file

format based on FDEM's 5,000' by 5,000' grid. Contours were generated using TerraScan software, distributed by TerraScan, Inc., of Lincoln, Nebraska.

The dataset is comprised of an ESRI ArcGIS geodatabase containing the mass points (ground only), 2-D and 3-D breakline features, 1-foot and 2-foot contours, ground control, vertical test points, and a footprint of the data set; and LAS 1.1 binary files of the classified LiDAR points.

The LiDAR point classification codes for LAS 1.1 files are as follows:

- Class 1 = Unclassified
- Class 2 = Ground
- Class 7 = Noise
- Class 9 = Water
- Class 12 = Overlap

Classes 1, 2, 7, and 9 include LiDAR points in the overlap area between flight lines.

Class 1 is used for all features that do not fit into the Classes 2, 7, 9, or 12, including vegetation, buildings, etc.

Class 7 represents artifacts not representing the earth's surface (cell towers, birds, etc.) – Noise as defined above.

Shorelines of water bodies are captured as breaklines and LiDAR points inside of water bodies are classified as Class 9 = Water in the LAS deliverable.

Class 12 LiDAR points are in areas of overlapping flight lines, which have been deliberately deleted and removed from all other classes because of their reduced accuracy, for example, due to their off-nadir position.

Accuracy Checks

The vertical accuracy of the final LiDAR DTM/Mass-Point Data mapping was verified using the field-surveyed QC checkpoints. Results of those field verifications are included in Appendix B.

References

Florida GIS
Baseline Specifications for Orthophotography and LiDAR, v 1.2
http://www.floridadisaster.org/GIS/specifications/Documents/BaselineSpecifications_1.2.pdf

UGSG Internet Site for National Map Accuracy Standards.
http://erg.usgs.gov/isb/pubs/factsheets/fs17199.html#Map%20Accuracy

General Notes

1. THIS REPORT IS NOT COMPLETE WITHOUT THE PORTABLE HARD DRIVE OF THE DIGITAL MAPPING, AND VICE VERSA.

2. **INTENDED DISPLAY SCALE – THIS MAPPING IS INTENDED TO BE DISPLAYED AT A SCALE OF 1:1,200 (1"=100') OR SMALLER.**

3. **THIS MAP COMPLIES WITH NATIONAL STANDARDS FOR SPATIAL DATA ACCURACY.**

4. **THIS MAP COMPLIES WITH THE FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA) "GUIDELINES AND SPECIFICATIONS FOR FLOOD HAZARD MAPPING PARTNERS, APPENDIX A: GUIDANCE FOR AERIAL MAPPING AND SURVEYING."**

THIS REPORT IS NOT VALID WITHOUT THE SIGNATURE AND RAISED SEAL OF A FLORIDA LICENSED SURVEYOR AND MAPPER IN RESPONSIBLE CHARGE.

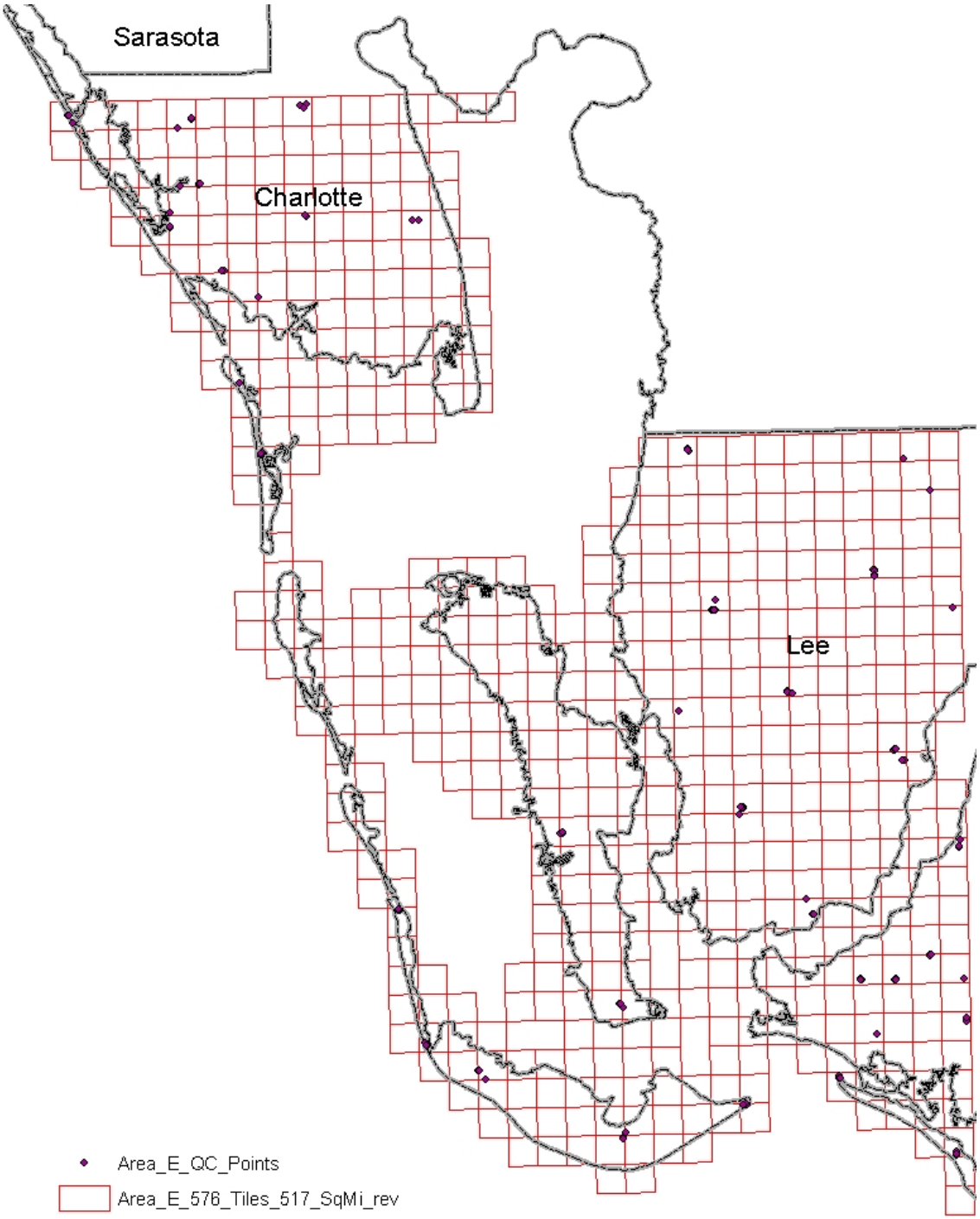
Surveyor and Mapper in Responsible Charge
Richard R. Hudson, PE, PSM
Professional Surveyor and Mapper
License Number: PSM 5473

Signed: Richard R Hudson 1-20-09
Date

Seal:

RICHARD R. HUDSON
CERTIFICATE
No. 5473
STATE OF
FLORIDA
Registered Surveyor & Mapper

APPENDIX A: MAPPING AREA AND QC CHECKPOINT LOCATIONS



APPENDIX B: LIDAR ACCURACY CHECKS

The vertical accuracy of the LiDAR DTM was verified by comparison of the DTM/TIN against the field-surveyed QC checkpoints. The requirements are to acquire a minimum of one-hundred twenty (120) three-dimensional LiDAR QA/QC checkpoints per 500 square miles of project area. To the extent allowed by the terrain, the LiDAR control points and checkpoints are distributed so that points were spaced at intervals of at least 10% of the diagonal distance across the dataset and at least 20% of the points were located in each quadrant of the project area.

For this 517 square-mile area, 124 checkpoints are required – a total of 125 checkpoints were captured across the delivery area. ***However two of these points were later found to be under water at the time the LiDAR mission was flown – BARE EARTH AND LOW GRASS Point LEE5055 and BRUSH LANDS AND LOW TREES Point LEE5056. So while 125 points were collected, these two points were removed and only 123 points were considered in the accuracy calculations.*** Woolpert field crews observed and established 3-dimensional coordinates on four different types of landcover:

1. Bare-earth and low grass
2. Brush lands and low trees
3. Forested areas fully covered by trees
4. Urban areas

Woolpert acquired the QC checkpoints using rapid static GPS ground surveys, along with conventional surveying methods to locate points within dense tree cover. A detailed overview of the QA/QC checkpoint survey may be found in Volume 1 of this report.

The accuracy analysis was based on methods outlined in the Geospatial Positioning Accuracy Standards, Part 3: National Standards for Spatial Data Accuracy (NSSDA) developed by the Federal Geodetic Data Committee (FGDC-STD-007.3-1998). The first step was to generate a TIN from the DTM. Each QC checkpoint was then compared against its corresponding TIN elevation. The difference between field-surveyed QC checkpoint and DTM/TIN elevation represents the residual error (Vz) at that point. A statistical analysis was then performed on the residual errors.

Per contract specifications, the vertical accuracy requirement of the digital terrain model (DTM) is 0.6 foot at 95% confidence level using RMSE(z) x 1.9600 as defined by the National Standard for Spatial Data Accuracy (NSSDA).

Vertical accuracy guidelines are as follows from FEMA's Appendix A:

In category 1, the RMSEz must be < .30 ft ($Accuracy_z$ < .60 feet)
In category 2, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)
In category 3, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)
In category 4, the RMSEz should be < .61 ft ($Accuracy_z$< 1.19 feet)
In all categories combined, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)

Additionally, two-foot contours in unobscured areas are certified to meet or exceed National Map Accuracy Standards (NMAS). These standards state that not more than 10 percent of the elevations tested shall be in error by more than one-half the contour interval, and none will be in error by more than the full contour interval. Therefore, for a 2-foot contour interval, not more than 10 percent of the elevations tested shall be in error of more than 1 foot, and none will be in error by more that 2 feet.

Two-foot contours within low confidence (obscured) areas are attributed as such and are not required to meet NMAS. Additionally, 1-foot contours are delivered for graphical purposes, and are not required to meet these accuracy standards.

The following table summarizes the statistical tests for the four landcover classifications, for the overall accuracy at all checkpoints, and NMAS within unobscured areas:

Statistical Summary By LANDCOVER					
Bare Earth and Low Grass			**Brush Lands and Low Trees**		
Calculated RMSEz	0.29	ft	Calculated RMSEz	0.53	ft
Target RMSEz	0.30	ft	Target RMSEz	0.61	ft
Calculated 95% CI	0.57	ft	Calculated 95% CI	1.03	ft
Target 95% CI	0.60		Target 95% CI	1.19	
Min	0.00	ft	Min	0.01	ft
Max	0.69	ft	Max	1.92	ft
Average	0.22	ft	Average	0.37	ft
Count	27		Count	30	
Forested Areas Fully Covered by Trees			**Urban Areas**		
Calculated RMSEz	0.49	ft	Calculated RMSEz	0.23	ft
Target RMSEz	0.61	ft	Target RMSEz	0.61	ft
Calculated 95% CI	0.96	ft	Calculated 95% CI	0.44	ft
Target 95% CI	1.19		Target 95% CI	1.19	
Min	0.01	ft	Min	0.00	ft
Max	1.27	ft	Max	0.50	ft
Average	0.36	ft	Average	0.19	ft
Count	36		Count	30	
Overall at All Checkpoints			**Unobscured LANDCOVER NMAS**		
Calculated RMSEz	0.41	ft	Calculated 90th Percentile	0.40	ft
Target RMSEz	0.61	ft	Target 90th Percentile	1.0	ft
Calculated 95% CI	0.80	ft	Calculated Max	0.69	ft
Target 95% CI	1.19		Target Max	2.0	ft
Min	0.00	ft	Count	58	ft
Max	1.92	ft			
Average	0.29	ft			
Count	123				

The calculated RMSEz and 95% confidence interval (CI) are shown for each of the four landcover types, and for all landcover types combined. To calculate the correlation to NMAS, only the Bare Earth and Low Grass, and the Urban Areas landcover types were considered, because these are the only "unobscured" landcover types. To calculate "not more than 10 percent" of the values, the 90th Percentile was determined for the combined Bare Earth and Low Grass, and the Urban Areas landcover measurements.

The Brush Lands and Low Trees Landcover type does exceed the recommended maximum values for RMSEz and 95% CI by 0.02 foot and 0.04 foot, respectively. This indicates that there is a greater degree of misclassification of LiDAR points within this Landcover type than within the other three Landcover types, though if the one Residual Error of 1.95 feet were omitted, the Landcover type would have fallen within the desired range. The LiDAR DTM does meet the accuracy requirements of the Baseline Specifications (RMSEz *should* be < .61 ft ($Accuracy_z$< 1.19 feet), but it's important that users of the data be aware of the potential accuracy limitations within areas of Brush Lands and Low Trees Landcover.

The following table lists the test results for all checkpoints:

Accuracy Analysis
Area E
Map Projection: State Plane Coordinate System, Florida West Zone
Horizontal Datum: NAD 83/HARN
Vertical Datum: NAVD 88
Units: U.S. Survey Feet
Date: November, 2008

Image Tile	QC Point	Field Truth (US SV FT)			DTM Measurement (US SV FT)	Residual Error (US SV FT)	LANDCOVER
CELLNUM	ID	Northing	Easting	Elevation	Elevation	Vz	
093412_W	5148	941501.96	559388.80	12.80	12.75	-0.051	BARE EARTH AND LOW GRASS
102437_W	LEE5003	794760.02	683405.30	4.60	4.77	0.164	BARE EARTH AND LOW GRASS
102435_W	LEE5011	791104.99	671279.46	9.04	9.39	0.345	BARE EARTH AND LOW GRASS
101238_W	LEE5028	813318.00	688658.40	5.55	5.70	0.149	BARE EARTH AND LOW GRASS
103038_W	LEE5035	783285.18	689297.66	3.91	4.13	0.219	BARE EARTH AND LOW GRASS
103634_W	LEE5040	773843.75	667208.67	3.73	4.42	0.691	BARE EARTH AND LOW GRASS
104238_W	LEE5044	760264.09	687159.39	2.57	2.58	0.016	BARE EARTH AND LOW GRASS
101819_W	LEE5050	804526.86	592066.11	6.61	6.92	0.31	BARE EARTH AND LOW GRASS
103322_W	LEE5058	775012.17	606272.85	3.10	3.10	0.003	BARE EARTH AND LOW

							GRASS
104226_W	LEE5063	764573.03	629864.20	2.35	2.46	0.106	BARE EARTH AND LOW GRASS
103931_W	LEE5068	769853.53	651098.61	3.54	3.52	-0.022	BARE EARTH AND LOW GRASS
102726_W	LEE5091	787535.89	629756.54	3.53	3.61	0.087	BARE EARTH AND LOW GRASS
100336_W	LEE5099	828505.56	679767.39	3.82	3.87	0.051	BARE EARTH AND LOW GRASS
101833_W	LEE5104	802260.29	663330.41	4.92	5.33	0.413	BARE EARTH AND LOW GRASS
100631_W	LEE5108	820824.23	651516.74	8.77	8.61	-0.165	BARE EARTH AND LOW GRASS
099433_W	LEE5113	840415.13	660565.59	9.93	10.16	0.238	BARE EARTH AND LOW GRASS
098838_W	LEE5121	854511.75	688537.86	11.02	10.79	-0.227	BARE EARTH AND LOW GRASS
098236_W	LEE5126	860390.30	675220.37	18.55	18.67	0.12	BARE EARTH AND LOW GRASS
098830_W	LEE5130	854942.88	647376.96	6.94	6.89	-0.05	BARE EARTH AND LOW GRASS
097029_W	LEE5135	882812.56	643565.12	11.06	11.71	0.647	BARE EARTH AND LOW GRASS
097037_W	LEE5138	880321.05	680517.34	19.62	19.64	0.023	BARE EARTH AND LOW GRASS
093416_W	LEE5144	943661.89	579159.85	6.89	7.07	0.183	BARE EARTH AND LOW GRASS
093408_W	LEE5152	942665.82	538133.67	5.88	5.51	-0.367	BARE EARTH AND LOW GRASS
094013_W	LEE5155	930268.68	560466.14	5.06	5.39	0.327	BARE EARTH AND LOW GRASS
097015_W	LEE5172	883337.76	570000.37	3.92	3.58	-0.343	BARE EARTH AND LOW GRASS
094620_W	LEE5174	923253.88	598004.17	5.03	4.78	-0.256	BARE EARTH AND LOW GRASS
094616_W	LEE5179	924479.88	578536.09	5.49	5.97	0.483	BARE EARTH AND LOW GRASS
093412_W	5147	941723.07	559448.12	10.71	10.44	-0.267	URBAN AREAS
102437_W	LEE5001	794831.11	683412.40	5.32	5.51	0.19	URBAN AREAS
102435_W	LEE5009	790883.07	671344.78	8.88	9.14	0.264	URBAN AREAS

101238_W	LEE5027	813381.09	688673.48	7.07	7.43	0.354	URBAN AREAS
103038_W	LEE5034	783787.96	689287.29	4.54	4.55	0.002	URBAN AREAS
103634_W	LEE5039	773840.37	667340.56	4.16	4.34	0.18	URBAN AREAS
104238_W	LEE5043	760559.85	687113.95	3.78	3.81	0.03	URBAN AREAS
101819_W	LEE5048	804787.40	591977.25	4.68	4.83	0.152	URBAN AREAS
103322_W	LEE5057	776557.10	605275.51	6.68	6.95	0.263	URBAN AREAS
104226_W	LEE5062	764381.40	629833.24	4.18	4.37	0.191	URBAN AREAS
103931_W	LEE5067	769759.72	650586.85	3.58	3.87	0.289	URBAN AREAS
100925_W	LEE5085	817238.03	620556.57	7.70	7.96	0.258	URBAN AREAS
102726_W	LEE5090	787532.27	629892.45	2.38	2.44	0.061	URBAN AREAS
100336_W	LEE5098	828408.36	679280.05	4.29	4.30	0.01	URBAN AREAS
101833_W	LEE5103	802327.94	663431.35	4.14	4.41	0.268	URBAN AREAS
100631_W	LEE5107	820903.41	651253.83	6.87	6.72	-0.153	URBAN AREAS
098838_W	LEE5120	854478.49	688457.57	12.14	11.93	-0.21	URBAN AREAS
098236_W	LEE5125	860334.35	675125.25	16.62	16.68	0.058	URBAN AREAS
098530_W	LEE5129	855075.35	647399.93	7.31	7.21	-0.099	URBAN AREAS
097029_W	LEE5134	882656.29	643577.32	12.24	12.73	0.496	URBAN AREAS
097637_W	LEE5137	874897.26	684971.76	20.57	20.51	-0.057	URBAN AREAS
093416_W	LEE5143	943083.29	578642.40	6.54	6.33	-0.205	URBAN AREAS
093408_W	LEE5151	942598.56	538312.59	4.78	4.51	-0.27	URBAN AREAS
094013_W	LEE5156	930271.14	560564.03	5.26	5.20	-0.067	URBAN AREAS
094913_W	LEE5166	915324.10	563903.08	4.57	4.54	-0.037	URBAN AREAS
097014_W	LEE5169	883664.03	569985.89	4.60	4.21	-0.394	URBAN AREAS
094620_W	LEE5173	923245.12	597070.50	6.40	6.51	0.105	URBAN AREAS
094616_W	LEE5178	924563.11	578650.31	5.12	5.44	0.324	URBAN AREAS
095215_W	LEE5184	910680.31	570222.19	7.93	7.71	-0.224	URBAN AREAS
096114_W	LEE5185	895863.95	566673.12	4.19	3.94	-0.249	URBAN AREAS
093412_W	5149	940037.07	556948.44	13.86	13.87	0.015	BRUSH LANDS AND LOW TREES
101819_W	LEE1051	804473.29	592231.98	4.28	4.34	0.067	BRUSH LANDS AND LOW TREES
102437_W	LEE5005	794839.43	683319.75	4.20	4.55	0.358	BRUSH

							LANDS AND LOW TREES
102435_W	LEE5007	790791.68	671482.14	5.19	6.05	0.862	BRUSH LANDS AND LOW TREES
103035_W	LEE5017	781395.80	673855.67	3.69	3.98	0.29	BRUSH LANDS AND LOW TREES
102438_W	LEE5023	790528.31	689116.13	2.93	3.44	0.509	BRUSH LANDS AND LOW TREES
101238_W	LEE5026	814457.15	689029.70	6.17	6.53	0.36	BRUSH LANDS AND LOW TREES
102436_W	LEE5032	790754.59	677122.42	5.71	5.70	-0.012	BRUSH LANDS AND LOW TREES
103634_W	LEE5041	774259.19	667173.32	9.59	10.11	0.521	BRUSH LANDS AND LOW TREES
104238_W	LEE5045	760806.98	687087.97	2.81	2.84	0.036	BRUSH LANDS AND LOW TREES
103322_W	LEE5059	776526.37	605155.53	6.66	7.12	0.462	BRUSH LANDS AND LOW TREES
103927_W	LEE5064	765291.88	630289.28	4.94	5.22	0.279	BRUSH LANDS AND LOW TREES
103931_W	LEE5069	769820.46	651199.38	3.56	4.07	0.51	BRUSH LANDS AND LOW TREES
102727_W	LEE5092	786934.30	630366.62	2.94	3.40	0.456	BRUSH LANDS AND LOW TREES
099729_W	LEE5095	837803.61	641076.10	4.81	5.21	0.396	BRUSH LANDS AND LOW TREES
099729_W	LEE5096	837739.77	641023.40	4.71	5.34	0.631	BRUSH LANDS AND LOW TREES
100036_W	LEE5100	830233.45	678000.12	4.10	4.23	0.135	BRUSH LANDS AND LOW TREES
101833_W	LEE5105	804986.42	662206.34	8.19	8.82	0.632	BRUSH LANDS AND LOW TREES
100931_W	LEE5109	819768.89	651091.76	7.36	7.59	0.234	BRUSH LANDS AND LOW TREES
098838_W	LEE5122	854567.39	688521.94	11.71	11.52	-0.185	BRUSH LANDS AND LOW TREES
098530_W	LEE5131	856777.56	647645.70	7.25	7.35	0.101	BRUSH LANDS AND LOW TREES
097029_W	LEE5136	882425.35	643684.67	8.79	9.29	0.498	BRUSH LANDS AND LOW TREES
093416_W	LEE5145	943382.88	578112.95	6.95	6.99	0.037	BRUSH LANDS AND

							LOW TREES
093408_W	LEE5153	941329.43	538816.00	7.49	7.41	-0.083	BRUSH LANDS AND LOW TREES
094012_W	LEE5157	930088.53	557102.40	5.43	5.57	0.135	BRUSH LANDS AND LOW TREES
094312_W	LEE5163	925466.56	555395.78	2.21	2.27	0.061	BRUSH LANDS AND LOW TREES
094913_W	LEE5168	915307.92	564390.92	4.16	4.94	0.78	BRUSH LANDS AND LOW TREES
097015_W	LEE5171	883851.05	570273.03	1.34	1.88	0.543	BRUSH LANDS AND LOW TREES
094620_W	LEE5175	923257.42	598108.80	5.96	5.91	-0.05	BRUSH LANDS AND LOW TREES
094616_W	LEE5180	924341.65	578696.27	4.97	6.89	1.919	BRUSH LANDS AND LOW TREES
094013_W	5710	930343.14	560469.73	5.67	5.73	0.064	FORESTED AREAS FULLY COVERED BY TREES
094013_W	5711	930189.73	560404.85	5.69	5.74	0.047	FORESTED AREAS FULLY COVERED BY TREES
094612_W	5712	922921.56	555232.40	3.89	4.18	0.291	FORESTED AREAS FULLY COVERED BY TREES
094612_W	5713	923041.20	555231.25	4.58	5.63	1.055	FORESTED AREAS FULLY COVERED BY TREES
094913_W	5714	915327.58	564104.55	3.40	3.31	-0.087	FORESTED AREAS FULLY COVERED BY TREES
094913_W	5715	915331.11	564012.55	3.61	3.53	-0.073	FORESTED AREAS FULLY COVERED BY TREES
099432_W	5716	840847.35	659791.49	10.02	10.30	0.274	FORESTED AREAS FULLY COVERED BY TREES
099432_W	5717	840678.78	659874.09	10.00	10.46	0.46	FORESTED AREAS FULLY COVERED BY TREES
099432_W	5718	840544.48	659682.98	10.68	10.94	0.265	FORESTED AREAS FULLY COVERED BY TREES
103038_W	5719	783382.78	689415.43	2.71	3.13	0.42	FORESTED AREAS FULLY COVERED BY

							TREES
103038_W	5720	783401.79	689386.18	2.78	3.16	0.375	FORESTED AREAS FULLY COVERED BY TREES
103038_W	5721	783474.38	689379.87	3.41	4.57	1.163	FORESTED AREAS FULLY COVERED BY TREES
102436_W	5722	790778.86	677355.44	5.22	5.84	0.629	FORESTED AREAS FULLY COVERED BY TREES
102436_W	5723	790765.11	677325.82	5.87	5.81	-0.059	FORESTED AREAS FULLY COVERED BY TREES
102436_W	5724	790760.25	677289.06	6.31	6.31	-0.005	FORESTED AREAS FULLY COVERED BY TREES
103020_W	5728	781268.24	596203.09	5.38	6.12	0.739	FORESTED AREAS FULLY COVERED BY TREES
103020_W	5729	781369.46	596257.35	2.23	2.96	0.725	FORESTED AREAS FULLY COVERED BY TREES
103020_W	5730	781567.75	596106.99	6.54	7.81	1.274	FORESTED AREAS FULLY COVERED BY TREES
103931_W	5731	769649.72	650616.91	5.19	5.10	-0.09	FORESTED AREAS FULLY COVERED BY TREES
103931_W	5732	769772.56	650691.30	3.61	3.89	0.281	FORESTED AREAS FULLY COVERED BY TREES
103931_W	5733	769749.68	650764.45	6.03	5.41	-0.617	FORESTED AREAS FULLY COVERED BY TREES
100036_W	5850	830282.98	677747.63	4.70	4.53	-0.164	FORESTED AREAS FULLY COVERED BY TREES
100036_W	5851	830416.83	678042.16	4.26	4.22	-0.036	FORESTED AREAS FULLY COVERED BY TREES
100036_W	5852	830304.40	678114.04	4.01	4.35	0.342	FORESTED AREAS FULLY COVERED BY TREES
100631_W	5854	820945.93	651635.12	5.75	6.02	0.272	FORESTED AREAS FULLY COVERED BY TREES

100631_W	5855	820839.42	651637.57	5.62	5.33	-0.29	FORESTED AREAS FULLY COVERED BY TREES
100631_W	5856	820710.38	651631.96	5.94	5.79	-0.155	FORESTED AREAS FULLY COVERED BY TREES
100925_W	5857	817172.96	620513.64	7.04	7.83	0.79	FORESTED AREAS FULLY COVERED BY TREES
100925_W	5858	817123.73	620395.02	6.67	6.86	0.184	FORESTED AREAS FULLY COVERED BY TREES
100925_W	5859	817200.18	620092.59	5.82	6.60	0.776	FORESTED AREAS FULLY COVERED BY TREES
098830_W	5863	854952.82	647039.73	6.34	6.56	0.225	FORESTED AREAS FULLY COVERED BY TREES
098830_W	5864	854949.43	647202.98	6.43	6.45	0.012	FORESTED AREAS FULLY COVERED BY TREES
098830_W	5865	854985.82	647574.16	6.11	6.06	-0.056	FORESTED AREAS FULLY COVERED BY TREES
098236_W	5866	861322.68	675117.20	14.05	14.29	0.241	FORESTED AREAS FULLY COVERED BY TREES
098236_W	5867	861248.72	675064.32	14.10	14.31	0.213	FORESTED AREAS FULLY COVERED BY TREES
098236_W	5868	861149.37	675096.98	13.94	14.22	0.285	FORESTED AREAS FULLY COVERED BY TREES

APPENDIX C: LAS FILES DELIVERED

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APPENDIX D: LIDAR CALIBRATION

Photo Science ALS50 LiDAR Calibrations

Introduction

Woolpert Team member Photo Science, Inc., performed all LiDAR acquisition and post processing. The following is the LiDAR system calibration report from Photo Science.

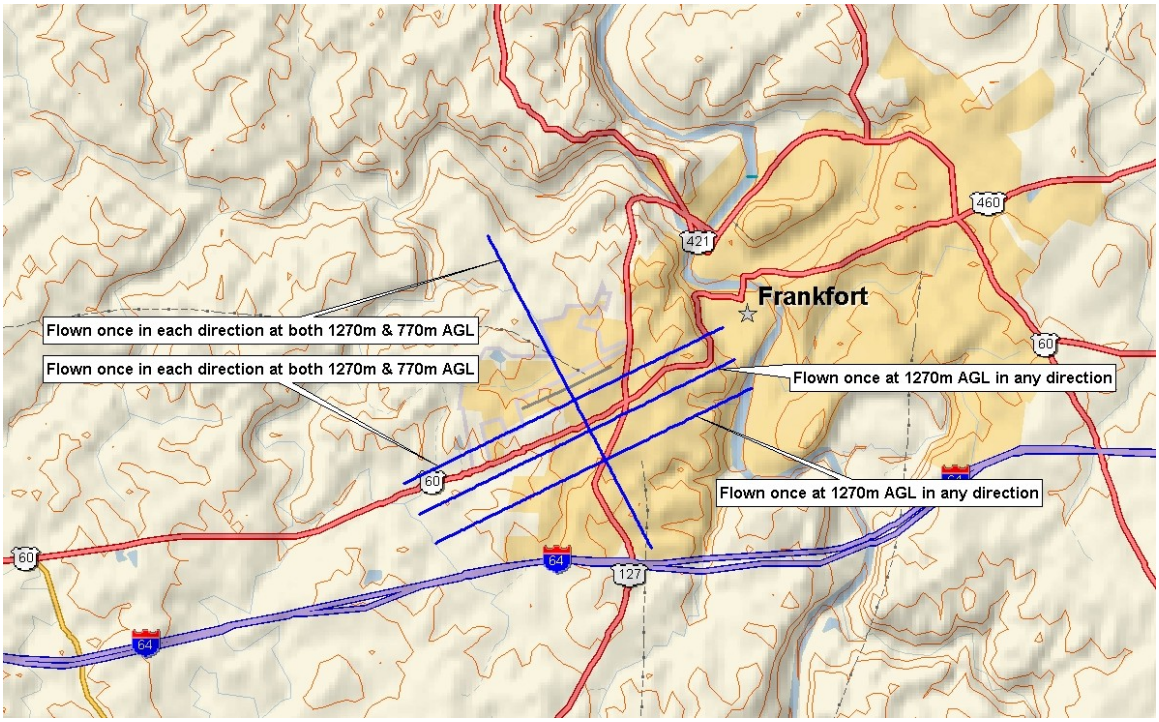
Overview

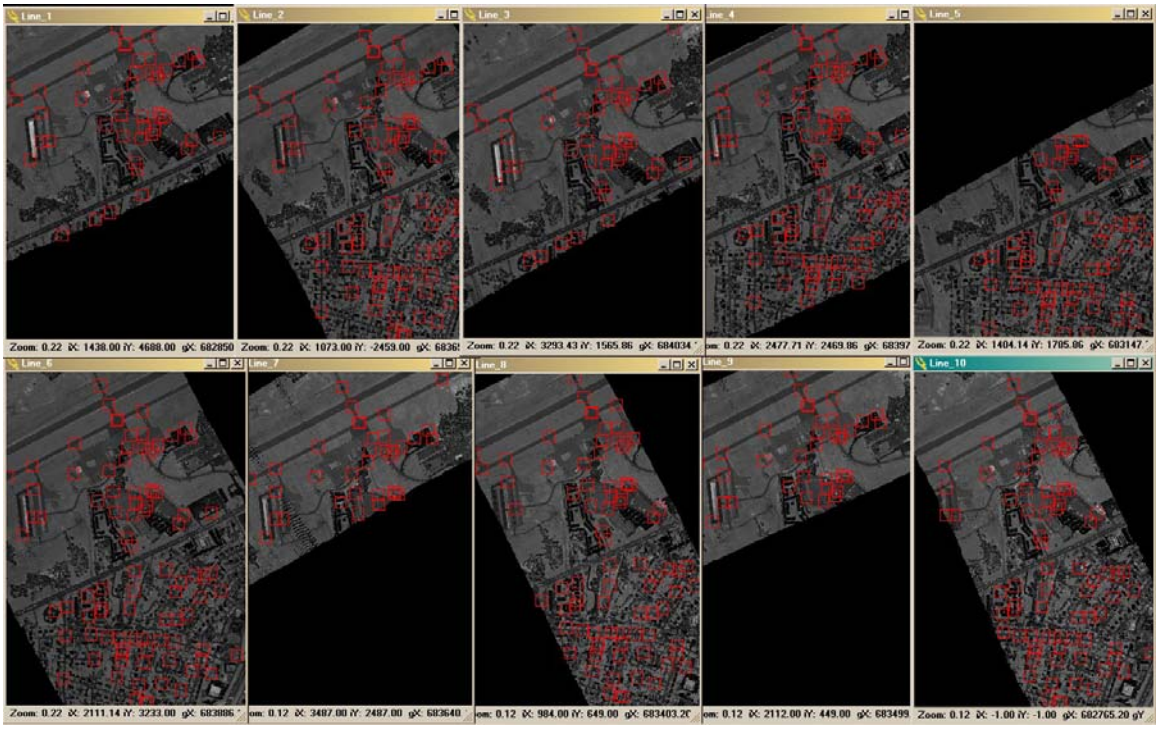
This Calibration Report shall be used to confirm LiDAR system specifications, performance, and requirements. The system functionality, elevation, and horizontal accuracy performance shall be demonstrated for calibration purposes. Photo Science completes calibration flights at regular intervals for ongoing monitoring of correction values, both at our home airport as well as in the field.

Once computed, the various derived values for correcting the inherent errors in the system should remain fairly constant, monitoring to ensure that no value starts to change more than expected. The sensors come from the factory with a set of values provided, measured by Leica, many of which will not change over the life of the system. Even moving a sensor in to and out of an aircraft should not appreciably change the correction values unless it experiences a hard bump or other trauma; the calibrated values are internal to the sensor.

Our main source of calibration data is collected in the form of Leica's prescribed Attune method. This involves collecting opposing passes at right angles to one another at 1270m above ground, and again at 770m above ground, centered over the same ground features, and using their proprietary calibration software for picking common tiepoints to determine roll, pitch, and heading correction values. They normally require 4 total passes at a minimum (2 high, 2 low) and have strong suggestions about types of features to use as tie-points.

We have slightly modified Leica's Attune flight procedure, with their guidance, wherein we fly 10 passes (4 high crisscross, 2 high offset, and 4 low crisscross) as seen below. This terrain includes not only the flat pavement of the airport and its surroundings, but a large amount of residential and commercial features in a gently rolling setting.





Periodically, roughly twice a year, we collect calibration data at 11000 feet above our home airport and have it analyzed by Leica with their higher-level calibration regimen. The increased flying height exaggerates the internal misalignments and makes them easier to measure, serving as tighter comparison benchmarks for the previous and subsequent Attune flights.

For this entire project we used the following sensors and aircraft:
Leica ALS50 Phase II Capable: serial number 019, mounted in N7320G
Leica ALS50 Phase II : serial number 059, mounted in N9471R and N2448G
Leica ALS50 Phase II : serial number 062, mounted in N2448G

Antenna Offsets

We mount our LiDAR systems exclusively in our fleet of Cessna 206 aircraft, removing them as little as possible to help maintain consistent system integrity. As such, our GPS antennas and the mounting plates for the sensor heads remain constant per plane. Once a new plane or sensor is incorporated in to our fleet and the initial sensor installation is completed, we have our ground survey team derive the offsets with a total station. That antenna offset value will not change unless the placement of a sensor's head within the aircraft changes.

N7320G, 1977 Cessna 206
X = -0.07
Y = 0.05
Z = -1.10

N9471R, 1985 Cessna 206
X = 0.875
Y = -0.125
Z = 1.012

N2448G, 2001 Cessna 206
X = -0.018
Y = -0.169
Z = -1.057

Leica provides their precisely measured internal IMU offsets, with respect to the focal point of the system's mirror, per each of the 2 types of IMU they use. These are embedded into the sensors' firmware for carrying forward into the subsequent trajectory-generating software, so these are not measured by us.

GPS Base Stationing

Whether calibration flights occur at our home airport (FFT – Capital City Airport in Frankfort, KY) or in the field on a project site, we strive to set up our GPS base station over the Primary Airport Control Station (PACS) as indicated by the National Geodetic Survey. If this is not possible, or the flight is only for purposes of resolving roll, pitch, and heading corrections, we can use almost any point because the software is solving the

corrections for these parameters within the flight's data, not with respect to absolute positions on the ground.

Photo Science uses Trimble 5700 GPS data logging units paired with Trimble Zephyr Geodetic antennas. We log at a 2hz interval (every ½ second) and with a 5 degree elevation mask. We also use variable height tripods, measured and logged at the beginning and end of each session.

Ground Control Points / Vertical Bias

Due to electronic delay within the sensor, there is a constant element of vertical bias which must be corrected. We have surveyed many points along the length and width of the runway and taxiways of our home airport and reference this in to our calibration flights to monitor over time that the pertinent correction value is unchanging. In the case of an upgrade or repair to certain parts of the sensor, we recalculate this value.

Overall Calibration Results

The values below are a combination of constants provided by the manufacturer and variables derived from analysis of data collected over Photo Science's calibration site(s). These were the used throughout the Florida Gulf Coast 2007 project, with minor variations per individual aircraft sortie as needed.

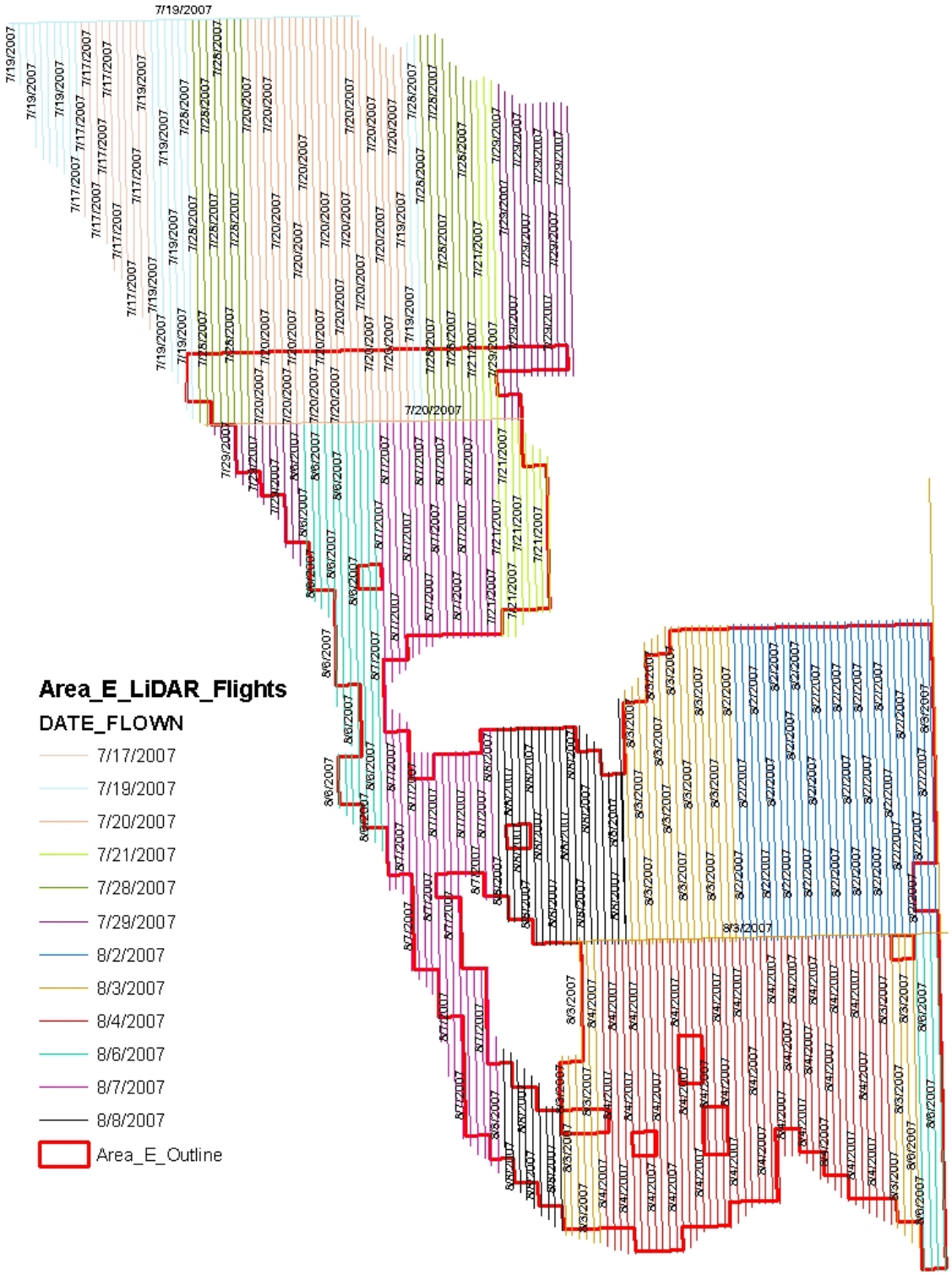
June 23rd, 2007

	Parameter	Value
SN19	**Leica provided**	
	Encoder Latency	0.0 mcr sec
	Ticks Per Revolution	8388608 ticks
	Ranging Correction	-0.48m
	Scan Angle Correction	-19120 ticks
	Pitch Slope	0.0000185 rad/deg
	Attitude	
	Roll	0.00088397 rad
	Pitch	0.00966448 rad
	Heading	-0.00282358 rad
	Mechanical	
	Torsion	-19370 units

June 14th, 2007

	Parameter	Value
SN59	**Leica provided**	
	Encoder Latency	0.5 mcr sec
	Ticks Per Revolution	8388608 ticks
	Ranging Correction	1.258m
	Scan Angle Correction	8000 ticks
	Pitch Slope	0.000058 rad/deg
	Attitude	
	Roll	0.00170705 rad
	Pitch	0.01463471 rad
	Heading	-0.00165231 rad
	Mechanical	
	Torsion	-60000 units

Provided by Leica – their 'loaner' unit

	Parameter	Value
SN62	**Leica provided**	
	Encoder Latency	0.0 mcr sec
	Ticks Per Revolution	8388608 ticks
	Ranging Correction	2.425m
	Scan Angle Correction	23800 ticks
	Pitch Slope	0.00000011 rad/deg
	Attitude	
	Roll	0.004918 rad
	Pitch	0.00956337 rad
	Heading	0.0000545 rad
	Mechanical	
	Torsion	-35000 units

APPENDIX E: LIDAR FLIGHT DATES