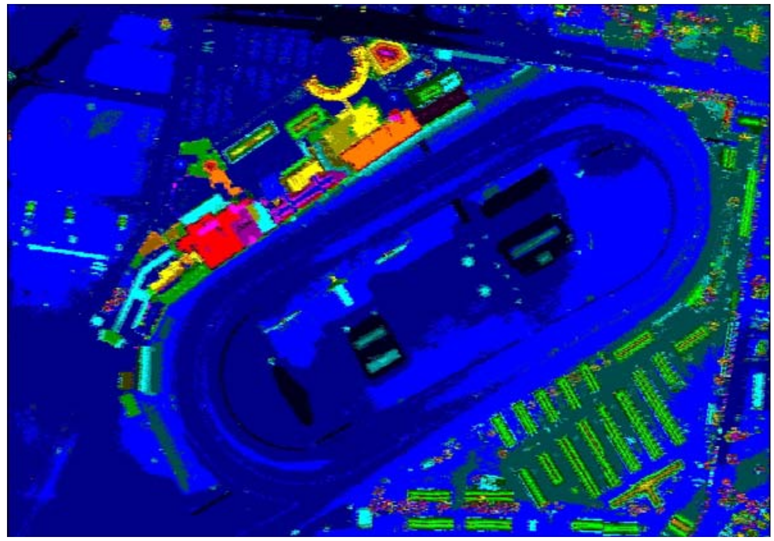
AERIAL LIDAR ACQUISITION AND PROCESSING REPORT



2009 LOUISVILLE JEFFERSON COUNTY KY AERIAL IMAGERY AND PHOTOGRAMMETRIC UPDATE PROJECT

LOUISVILLE JEFFERSON COUNTY KY METROPOLITAN SEWER DISTRICT

WOOLPERT PROJECT #69395

June 2009

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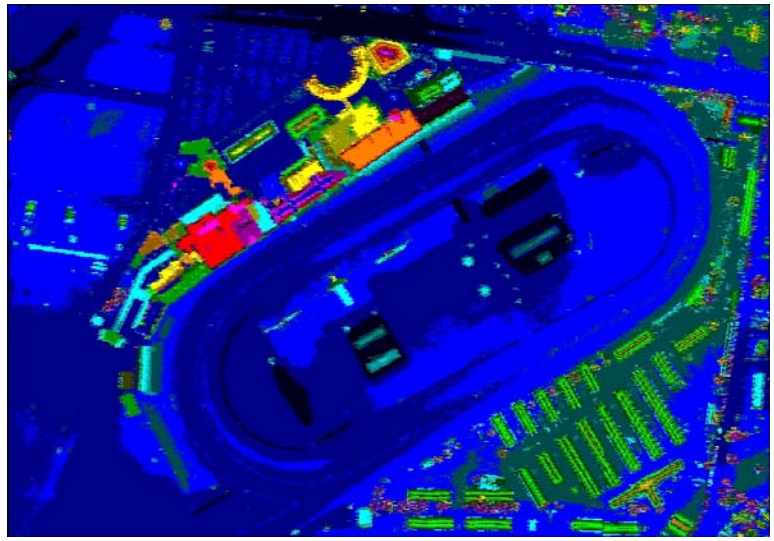

2009 LOUISVILLE JEFFERSON COUNTY KY AERIAL IMAGERY AND PHOTOGRAMMETRIC UPDATE PROJECT

LOUISVILLE JEFFERSON COUNTY KY METROPOLITAN SEWER DISTRICT WOOLPERT PROJECT #69395 JUNE 2009

PREPARED BY:

WOOLPERT
4454 Idea Center Boulevard
Dayton, Ohio 45430-1500

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SECTION 1: OVERVIEW

Project Name: 2009 Louisville Jefferson County, Kentucky, Aerial Imagery and Photogrammetric Update Project

Woolpert Project #69395

Woolpert was contracted by the Metropolitan Sewer District of Louisville, Kentucky to perform an aerial acquisition survey of a three-county area of Jefferson (±390 square miles), Oldham (±185 square miles), and Bullitt (±300 square miles). The LiDAR acquisition was acquired for DEM orthophoto and DTM update support. The LiDAR area encompassed ±875 square miles including a dual pass over the downtown Louisville area.

LiDAR data was collected by the Leica ALS50-II 150kHz Multi-Pulse enabled LiDAR system in Leica roll-stabilizing mounts. The ALS type-II 150kHZ LiDAR sensor collects up to four returns per pulse, as well as intensity data. The aerial LiDAR was collected at the following sensor specifications:

Post Spacing (Average):	3.3 ft / 1.0 m
AGL (Above Ground Level) average flying height:	6,000 ft / 1,829 m
MSL (Mean Sea Level) flying height:	6,300 ft / 1,920 m
Average Ground Speed:	130 kts / 150 mph
Field of View (full):	43 degrees
Pulse Rate:	121.500 kHz
Scan Rate:	34 Hz
Ground Footprint:	1.38 ft / 0.42 m
Side Lap (Average):	30%

Sixty-five (65) flight lines and 1,570 line miles were collected on four (4) days between March 20, 2009 and March 30, 2009.

Flight line acquisition was performed in as few missions as possible, as close together as possible, to ensure consistency across the project area.

The data collected on was flown back to the Woolpert Dayton, Ohio office, processed and quality controlled immediately such that re-flights for GNSS and coverage were determined and relayed to the flight crew the following morning.

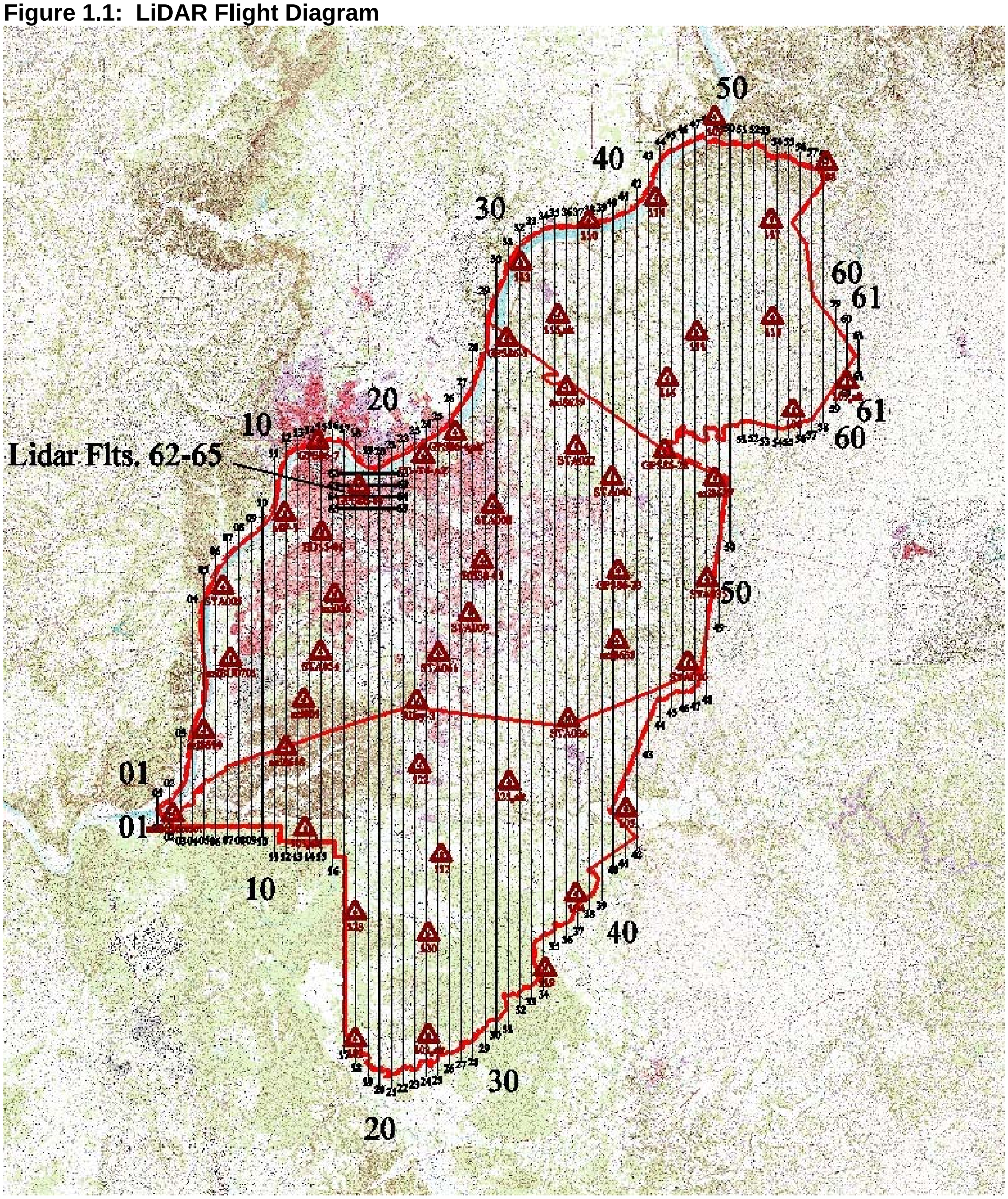
Woolpert's Aerial Acquisition Team coordinated with the necessary Air Traffic Control and Restricted Airspace personnel prior to flying to ensure access. In particular, with proper procedures and advanced notice, Fort Knox was very helpful in assisting Woolpert with acquiring data in their airspace.

Woolpert flight crews coordinated with Dunaway Engineering, Inc. to provide ABGNSS support. All GNSS base station data and point locations were tied together, along with the ground control. ADS digital imagery flown on this project also utilized the same GNSS base stations (see Aerial Digital Imagery Acquisition Report).

Table 1.2: Aerial Digital Imagery Flight Summary

Date of Flying	Lines Flown	Time On/Off Line (UTC)	Time On/Off Line (Local = EDT)
March 20, 2009 – Sensor 46	08-29	14:53 - 21:35	10:53AM - 5:35PM
March 21, 2009 – Sensor 46	01-07, 30-36, 62-65	16:16 – 20:15	12:16PM - 4:15PM
March 22, 2009 – Sensor 46	37-61	00:58 – 06:10	8:58PM - 2:10AM
March 30, 2009 – Sensor 46	*Reflights 27-29*	15:24 - 19:04	11:24AM - 3:04PM

Figure 1.1: LiDAR Flight Diagram



SECTION 2: GNSS-IMU TRAJECTORY INFORMATION

Equipment

Woolpert owns all the equipment used for the ground control and ABGNSS missions with the exception of CORS stations.

Flight navigation is performed using IGI CCNS (Computer Controlled Navigation System). The pilots are thoroughly trained and 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 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 GNSS receivers collecting at 2 Hz.

All Woolpert aerial sensors are equipped with Litton LN200 series IMU’s operating at 200 Hz.

A base-station unit was mobilized for each acquisition mission, and was operated by a member of the Woolpert survey and/or flight crew. Each base-station setup consisted of one (1) Trimble 4000 – 5000 series dual frequency receiver, one (1) Trimble Compact L1/L2 dual frequency antenna, one (1) 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.

GNSS Base Stations operated during the acquisition missions, including nearby CORS stations, are listed below.

ADS digital imagery flown on this project also utilized the same GNSS base stations (see Aerial Digital Imagery Acquisition Report).

JVY B: Woolpert flight crews set up one GNSS base station at Clark Regional Airport.

DE LOU: A second Woolpert flight crew met with Dunaway Engineering, Inc.’s, Alex Donenberg, before and after missions. Mr. Donenberg is an experienced surveyor who established this point for ease of use and who ran a Woolpert provided GNSS base station at Bowman Field (LOU).

KYTE: CORS operated by Kentucky DOT – 1 second epochs

Table 2.1: GNSS Base Stations

Station Name	Latitude (DMS)	Longitude (DMS)	Ellipsoid Height (L1 Phase center) (Meters)
JVY B	N 38° 22' 03.18043"	W 85° 44' 26.64652"	106.217
DE LOU	N 38° 13' 30.38242"	W 85° 39' 33.11022"	413.598
KYTE	N 38° 16' 35.93986"	W 85° 35' 54.20083"	157.915

Data Processing

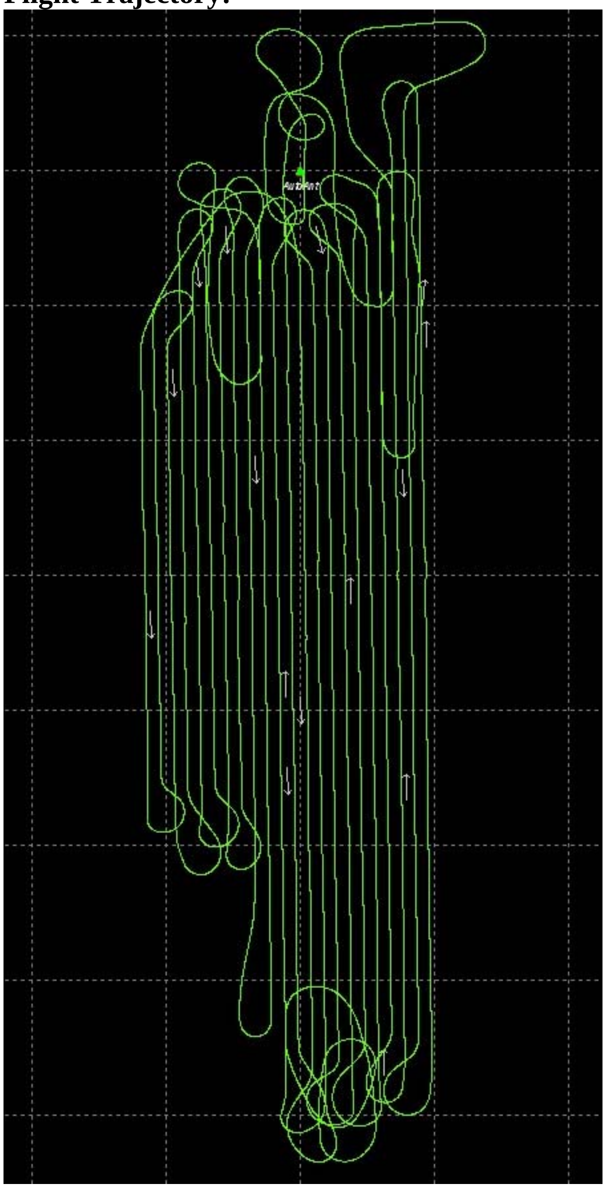
All airborne GNSS and IMU data was post-processed and quality controlled using Grafnav Waypoint software and either Applanix POSPac or Leica IPAS software. GNSS data was processed at a 1 or 2 Hz data capture rate and IMU data was processed at 200 Hz.

Trajectory Quality

Example graphs from: **Day079, N7079F & ALS LiDAR S/N 46:**

The GNSS Trajectory, along with high quality IMU data, is a key factor in determining the overall positional accuracy of the final sensor data.

Flight Trajectory:



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 PDOP.

The following table lists the Base Station(s), the average Combined Separation, Estimated Position Accuracy and PDOP for each acquisition mission.

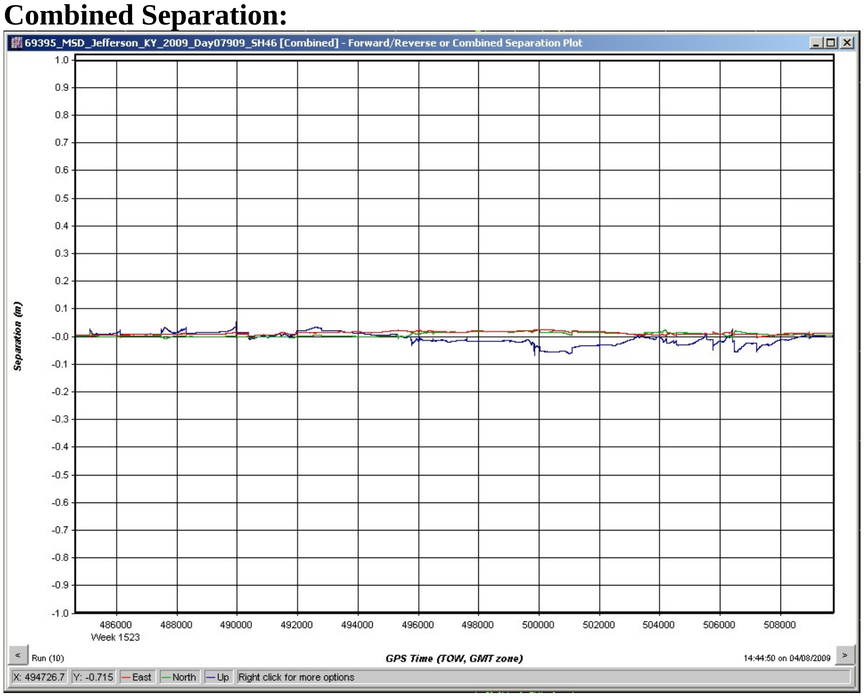
Table 2.2:
Mission Specific Base Stations, Combined Separation, Estimated Positional Accuracy and PDOP

Date Sensor Head	Base Station(s)	Combined Separation: Average Difference (meters)	PDOP: Average	Horizontal Estimated Positional Accuracy: (meters)	Vertical Estimated Positional Accuracy: (meters)
Mar-20-2009 Sensor 46	JVY B	0.03	2.0	0.020	0.050
Mar-21-2009 Sensor 46	KYTE	0.04	2.0	0.015	0.035
Mar-22-2009 Sensor 46	KYTE	0.03	2.0	0.025	0.065
Mar-30-2009 Sensor 46	JVY B	0.02	1.9	0.025	0.055

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 run in both directions to remove directional specific anomalies. The closer these two solutions match; in general, the better is the overall reliability of the solution.

Woolpert's goal is to maintain a Combined Separation Difference of < 10cm, often achieving results well below this cap.

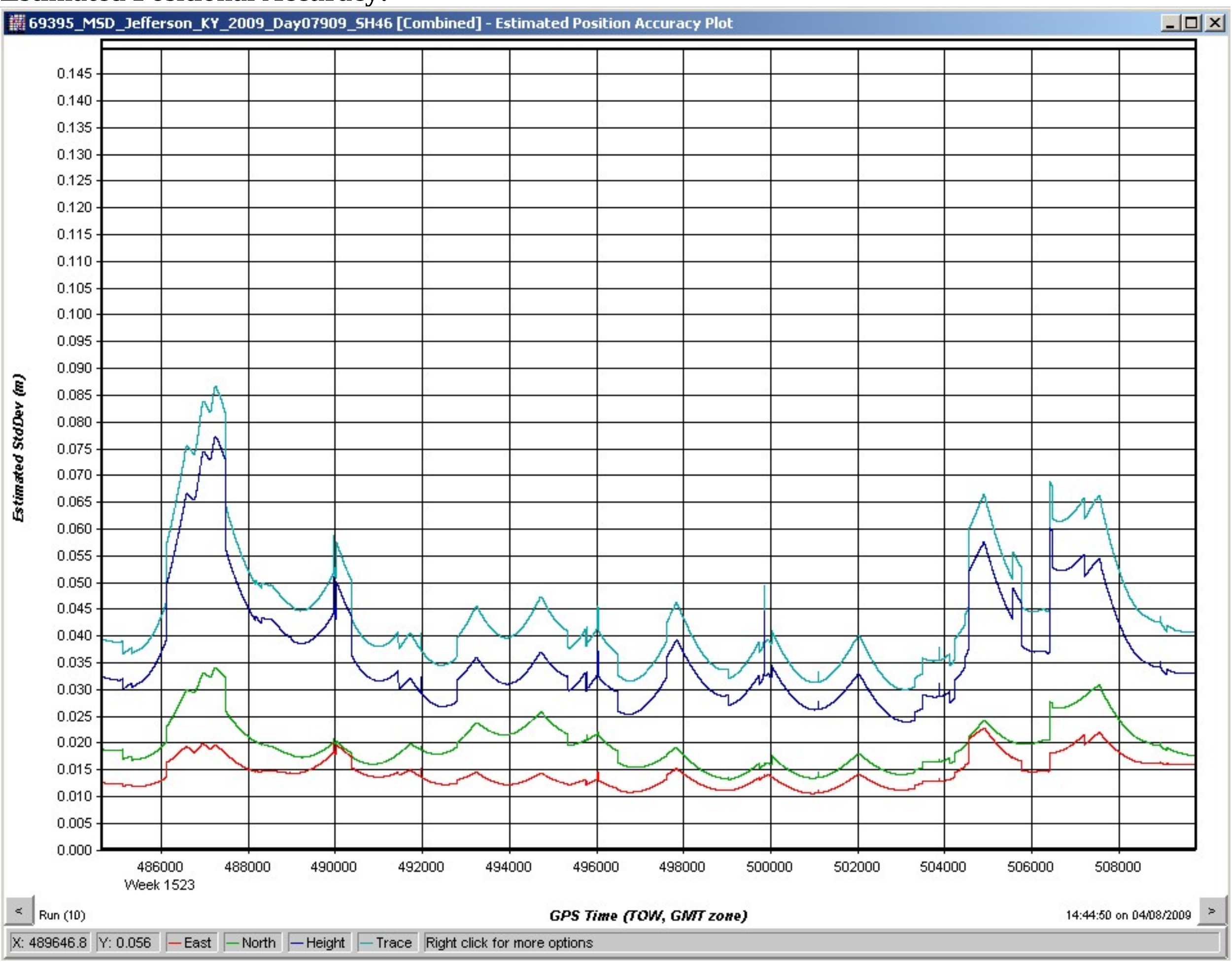
Combined Separation:



The Estimated Positional Accuracy plots the standard deviations of the east, north, and vertical directions along a time scale of the trajectory. It shows loss of lock issues as well as issues arising from long baselines and noise or other interference.

Woolpert's goal is to maintain an Estimated Positional Accuracy of < 10 cm, often achieving results well below this cap.

Estimated Positional Accuracy:

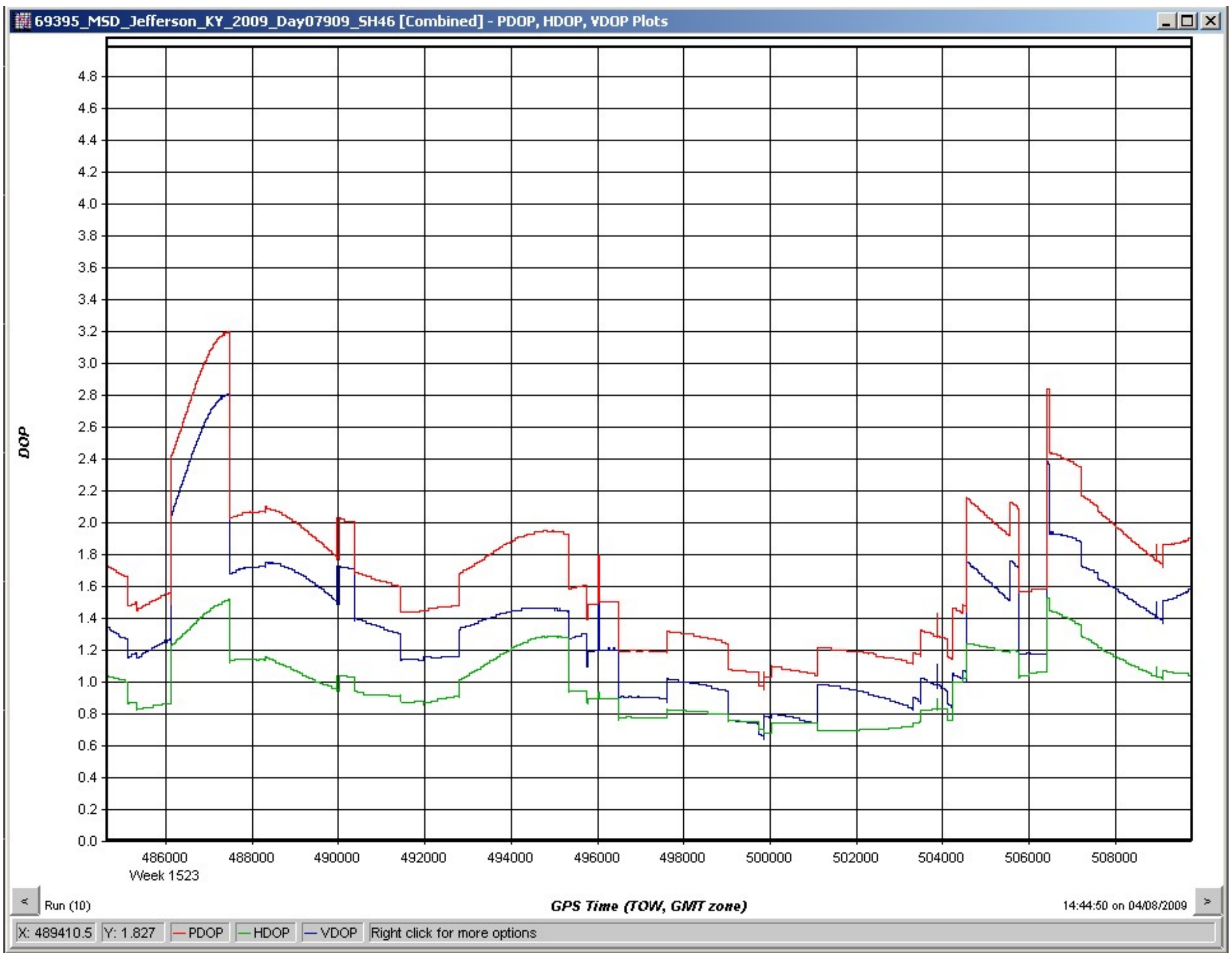


PDOP, the Positional Dilution of Precision, is a factor that describes the effects of satellite geometry on the accuracy of the airborne GNSS solution. The geometric distribution of the satellites is measured relative to the locations of the receivers on the ground and in the aircraft. PDOP can be computed 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 during 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 or flight is marked for a re-flight if post processing signifies a significant loss of accuracy due to the PDOP.

PDOP:



SECTION 3: FLIGHT LOG(S)

This section contains the Flight Log(s) covering the project. Flight Logs list mission specific details such as crew members, airports, weather conditions, real time DOP values and document any issues encountered during the mission. Flight Logs are filled out by the sensor operator during the acquisition flight.

Page 1 of

LIDAR LOG SHEET	Date: 20/03/09 DD / MM / YY	Julian Date: 79	Mission Name: MSD LOJIC		
Operator: Smith	Aircraft: ☑ N7079F ☐ N404CP ☐ N475RC	Hobbs Start 812.7	Local Start Time (Wheels Up) 10:46 AM	Zulu Start 14:46	
Pilot: Rader	Sensor: ☑ SH46 ☐ SH77	Hobbs End 819.5	Local End Time (Wheels Down) 5:31 PM	Zulu End Time 21:31	
Passengers:					

Wind Direction/Sp	Visibility	Cloud ceiling (ft):	Cloud Cover %:	Departing Airport	Arriving
040/5	10	clr blw 12000		JVY	JVY
Temp: 3.0 ° C	Dew Point: 3.0 ° C	Pressure: 3046.00	Wind/Haze/Cloud/Fire?	Applanix GPS Began Logging at: 14:36 10:36 am	

Base Station #	Operator: Smith	JVY B	Using or Relying on CORS
Base Station #	Operator:		☐ YES ☐ NO

"Laser Specifications "

Scan Angle (FOV): 43	Scan Frequency (Hz): 34	Pulse Rate(kHz): 121.5	Mode	Attenuator	Air Speed	
			☐ 2+2	☐ 0.0	130	AGL: 6000 ft
			☑ 4+3	☐ 0.3		MSL: 6300 ft
			☐ Single	☐ 0.7	Laser Power %	Max Range:
			☑ Multi		78%	Avg. Elev.: 300
						Adj. AGL:

Flt Line	Mission ID#	Heading	HDOP	VDOP	SVs	Course	Fine	AGC	Line Notes
TEST	090320-145324		-----------	-----------	-----------	----	-----------	-----------	ok
▲ Times entered are Zulu / GMT ▼				Verify S-Turns Before Mission				☑ Yes ☐ No	
19	90320-145324	S	0.968	1.701	10	6	7		
18	"" 151108	N			9	6	7		PDOP 3.4-STOP, CIRCLE
18	"" 152246	N	1.156	2.031	10	6	7		
17	"" 153918	S	1.149	1.897	10	6	7		TOP "LASER DEATH, CIRCLE, REBOOT SYSTEI
17	"" 155108	S	1.133	1.844	8	6	7		
16	"" 160952	N	1.055	1.467	9	6	7		
15	"" 162324	S	1.109	1.465	8	6	7		
14	"" 163617	N	1.108	1.238	9	6	7		
13	"" 164914	S	1.159	1.248	9	6	7		
12	"" 170122	N	1.278	1.522	8	6	7		
11	"" 171345	S	1.361	1.624	8	6	7		
10	"" 172632	N	1.399	1.687	8	6	7		
9	"" 173724	S	1.023	1.187	10	6	7		
8	"" 174723	N	1	1.245	10	6	7		
20	"" 180037	S	0.829	1.124	11	6	7		
21	"" 181844	N	0.884	1.51	10	6	7		
22	"" 183617	S	0.815	1.367	11	6	7		
23	"" 185321	N	0.737	1.266	12	6	7		
24	"" 191030	S	0.807	1.404	11	6	7		
25	"" 192801	N	0.81	1.302	11	6	7		
26	"" 194558	S	0.797	1.129	11	6	7		STOP "LASER DEAT, CIRCLE ,REBOOT
26	"" 194558	S	0.851	1.097	10	6	7		
27	"" 201552	N	1.383	1.986	7	6	7		END? LASER DEATH, CIRCLE, REBOOT
28	"" 204035	S	1.128	1.242	8	6	7		
29	"" 210028	N	1.472	2.215	9	6	7		
27	"" 211946	S	1.29	1.898	9	6	7		REFLT WP 1-3

Verify S-Turns After Mission ☑ Yes ☐ No

Supplemental Note

Page 1 of

LIDAR LOG SHEET

Date: 21/03/09 DD / MM / YY	**Julian Date:** 80	**Mission Name:** MSD LOJIC	
Operator: Smith	**Aircraft:** ☑ N7079F ☐ N404CP ☐ N475RC	**Hobbs Start** 821.1	**Local Start Time (Wheels Up)** 12:05 PM
Pilot: Albers			**Zulu Start** 16:05
Passengers:	**Sensor:** ☑ SH46 ☐ SH77	**Hobbs End** 825.6	**Local End Time (Wheels Down)** 4:35 PM
			Zulu End Time 20:35

Wind Direction/Sp	Visibility	Cloud ceiling (ft):	Cloud Cover %:	Departing Airport	Arriving
varies/3	10	ovrcst 3000		LOU	LOU
Temp: 8.0 ° C	**Dew Point:** -4.0 ° C	**Pressure:** 30.45	**Wind/Haze/Clouds/Fire?**	**Applanix GPS Began Logging at: 15:34 11:54 am**	

Base Station #	**Operator:**		**Using or Relying on CORS**
Base Station #	**Operator:**		☐ YES ☐ NO

"Laser Specifications "

Scan Angle (FOV): 43	Scan Frequency (Hz): 34	Pulse Rate(kHz): 121.5	Mode	Attenuator	Air Speed	
			☐ 2+2 ☑ 4+3 ☐ Single ☑ Multi	☐ 0.0 ☐ 0.3 ☐ 0.7	130	**AGL: 6000 ft** **MSL: 6300 ft** **Max Range:**
					Laser Power % 78%	**Avg. Elev.: 300** **Adj. AGL:**

Flt Line	Mission ID#	Heading	HDOP	VDOP	SVs	Course	Fine	AGC	Line Notes
TEST	090321-155552		----------	----------	----------	----	----------	----------	ok

▲ Times entered are Zulu / GMT ▼ Verify S-Turns Before Mission ☑ Yes ☐ No

Flt Line	Mission ID#	Heading	HDOP	VDOP	SVs	Course	Fine	AGC	Line Notes
30	90321-161630	S	1.103	1.481	8	6	7		
31	"" 163735	N	1.128	1.243	9	6	7		
32	"" 165824	S	1.277	1.537	8	6	7		
7	"" 172445	N	1.397	1.689	8	6	7		
6	"" 173527	S	1.02	1.198	10	6	7		
5	"" 174557	.N	0.836	1.066	11	6	7		
4	"" 175553	S	0.83	1.123	11	6	7		
3	"" 180513	N	0.823	1.166	11	6	7		
2	"" 181158	S	0.817	1.187	11	6	7		
1	"" 181746	N	0.882	1.53	10	6	7		
65	"" 182655	E	0.826	1.361	11	6	7		
64	"" 183252	W	0.818	1.37	11	6	7		
63	"" 183911	E	0.804	1.363	11	6	7		laser shutdown, reboot, failed in turn
62	"" 185111	W	0.735	1.263	12	6	7		
33	"" 190337	S	0.807	1.415	11	6	7		
34	"" 192438	N	0.809	1.305	11	6	7		
35	"" 194610	S	0.754	1.063	12	6	7		
36	"" 200530	N	1.092	1.233	9	6	7		

Verify S-Turns After Mission ☑ Yes ☐ No

Supplemental Notes:

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LIDAR LOG SHEET

Date: 21/03/09 DD / MM / YY	Julian Date: 81	Mission Name: MSD LOJIC	
Operator: Schneider	Aircraft: ☑ N7079F ☐ N404CP ☐ N475RC	Hobbs Start: 827.3	Local Start Time (Wheels Up): 8:28 PM
Pilot: Probert	Sensor: ☑ SH46 ☐ SH77	Hobbs End: 833.3	Local End Time (Wheels Down): 2:27 AM
Passengers:			

Zulu Start: 0:28

Zulu End Time: 6:27

Wind Direction/Sp	Visibility	Cloud ceiling (ft):	Cloud Cover %:	Departing Airport	Arriving
calm	10	clr below 12000		Clark (JVY)	JVY

Temp:	Dew Point:	Pressure:	Wind/Haze/Cloud/Fire?	Applanix GPS Began Logging at:
12.0 ˚C	10.0 ˚C	30.37		00:19

Base Station #:	Operator:	JVY B	Using or Relying on CORS
Base Station #:	Operator:		☐ YES ☐ NO

"Laser Specifications"

Scan Angle (FOV): 43	Scan Frequency (Hz): 34	Pulse Rate(kHz): 121.5	Mode	Attenuator	Air Speed	
			☐ 2+2	☐ 0.0	130	AGL: 6000 ft
			☑ 4+3	☐ 0.3		MSL: 6300 ft
			☐ Single	☐ 0.7	Laser Power %	Max Range: 4679-6614
			☑ Multi		78%	Avg. Elev.: 300
						Adj. AGL:

Flt Line	Mission ID#	Heading	HDOP	VDOP	SVs	Course	Fine	AGC	Line Notes
TEST	090322-002038		-----------	-----------	-----------	----	-----------	-----------	ok

▲ Times entered are Zulu / GMT ▼ Verify S-Turns Before Mission ☑ Yes ☐ No

Flt Line	Mission ID#	Heading	HDOP	VDOP	SVs	Course	Fine	AGC	Line Notes
61	90322- 005847	S	1.214	1.936	8	6	7		
60	"" 010326	N	1.286	2.067	7	6	7		
59	"" 010827	S	1.286	2.13	7	6	7		
58	"" 011408	N	1.279	2.159	7	6	7		
57	"" 012237	S	1.236	2.127	7	6	7		
56	"" 013129	N	1.016	1.649	8	6	7		
55	"" 014028	S	1.041	1.718	8	6	7		
54	"" 014941	N	0.77	1.148	10	6	7		
53	"" 015916	S	0.77	1.245	10	6	7		
52	"" 020837	N	0.773	1.326	10	6	7		
51	"" 021803	S	0.902	1.658	9	6	7		
50	"" 022931	N	0.901	1.77	9	6	7		
49	"" 024134	S	0.881	1.502	10	6	7		
48	"" 025655	N	0.885	1.389	11	6	7		
47	"" 031217	S	0.865	1.334	11	6	7		
46	"" 032720	N	1.267	2.084	9	6	7		
45	"" 034219	S	1.141	1.799	9	6	7		
44	"" 035738	N	1.204	2.784	8	6	7		
43	"" 041240	S	1.26	3.171	8	6	7		
42	"" 042959	N	1.31	2.98	8	6	7		
41	""044646	S	1.082	1.561	9	6	7		
40	"" 050322	N	1.034	1.423	9	6	7		
39	"" 052031	S	0.818	1.047	11	6	7		
38	"" 053656	N	0.897	1.331	10	6	7		
37	"" 055403	S	0.879	1.271	10	6	7		

Verify S-Turns After Mission ☑ Yes ☐ No

Supplemental Notes: Still receiving gps errors after shutting down as if switching off DL. Conducted full air restart. GPS log 00:48 system seems ok. POS/AV data gap error initially after takeoff. POS/AV position, velocity, heading errors not w/in user specified bound

Page 1 of 2

LIDAR LOG SHEET	Date: 30/03/09 DD / MM / YY	Julian Date: 89	Mission Name: MSD LOJIC		
Operator: Smith	Aircraft: ☑ N7079F ☐ N404CP ☐ N475RC	Hobbs Start 869.8	Local Start Time (Wheels Up) 11:14 AM		Zulu Start 15:14
Pilot: Rader	Sensor: ☑ SH46 ☐ SH77	Hobbs End 873.8	Local End Time (Wheels Down) 3:15 PM		Zulu End Time 19:15
Passengers:					

Wind Direction/Sp	Visibility	Cloud ceiling (ft):	Cloud Cover %:	Departing Airport	Arriving
calm	10	clr below 12000		Clark (JVY)	JVY
Temp: 7.0 ° C	Dew Point: 1.0 ° C	Pressure: 30.11	Wind/Haze/Cloud Fire?	Applanix GPS Began Logging at: 15:04 11:04am	

Base Station #	Operator:	JVY B	Using or Relying on CORS
Base Station #	Operator:		☐ YES ☐ NO

Laser Specifications

Scan Angle (FOV): 43	Scan Frequency (Hz): 34	Pulse Rate(kHz): 121.5	Mode	Attenuator	Air Speed: 130	AGL: 6000 ft
			☐ 2+2	☐ 0.0		MSL: 6300 ft
			☑ 4+3	☐ 0.3		Max Range: 4679-6614
			☐ Single	☐ 0.7	Laser Power %: 78%	Avg. Elev.: 300
			☑ Multi			Adj. AGL:

Flt Line	Mission ID#	Heading	HDOP	VDOP	SVs	Course	Fine	AGC	Line Notes
TEST	090330-150536		-----------	-----------	-----------	----	-----------	-----------	ok
▲ Times entered are Zulu / GMT ▼				Verify S-Turns Before Mission				☑ Yes ☐ No	
27	"" 152446	S	1.078	1.642	8	6	7		REFLT 1-18
29	"" 153707	S	1.081	1.495	8	6	7		REFLT
28	"" 155546	N	1.028	1.24	9	6	7		REFLT 37-46

Verify S-Turns After Mission ☑ Yes ☐ No

Supplemental Notes:

SECTION 4: LIDAR SYSTEM SPECIFICATIONS

The LiDAR data was acquired using two ALS50-II 150kHz Multi-Pulse enabled LiDAR systems, both which are on board Cessna 404 Titans. 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 LiDAR System has the following specifications:

Nominal	
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

SECTION 5: LIDAR SYSTEM CALIBRATION AND ACCURACY ASSESSMENT

Introduction

This Woolpert Leica ALS50-II 150kHz Multi-Pulse enabled LiDAR system Calibration and Accuracy Assessment 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.

On Site Antenna Offsets and Location

Aircraft GPS Antenna

The following measurements were calculated for Woolpert's aircraft Cessna 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 with ALS50-II S/N 46 installed

Reference Point to GPS Antenna	
X	0.608 m
Y	0.050 m
Z	-1.341 m

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

ALS50-II S/N 46

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

Base Station GPS Antenna

Monument Description:	
GPS Receiver Type: Trimble 4700 Antenna Type: Trimble	Epoch Interval: 1 sec Elevation Mask: 10 degrees Observation Type: Static
Station Names used in processing the acceptance data: #1: ASI N 39 53 57.97634 Lat. W 84 12 01.41721 Long. 277.671 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 5-3) are required in order to capture pitch, roll, heading (see Figure 5-1) and torsion errors (see Figure 5-2).

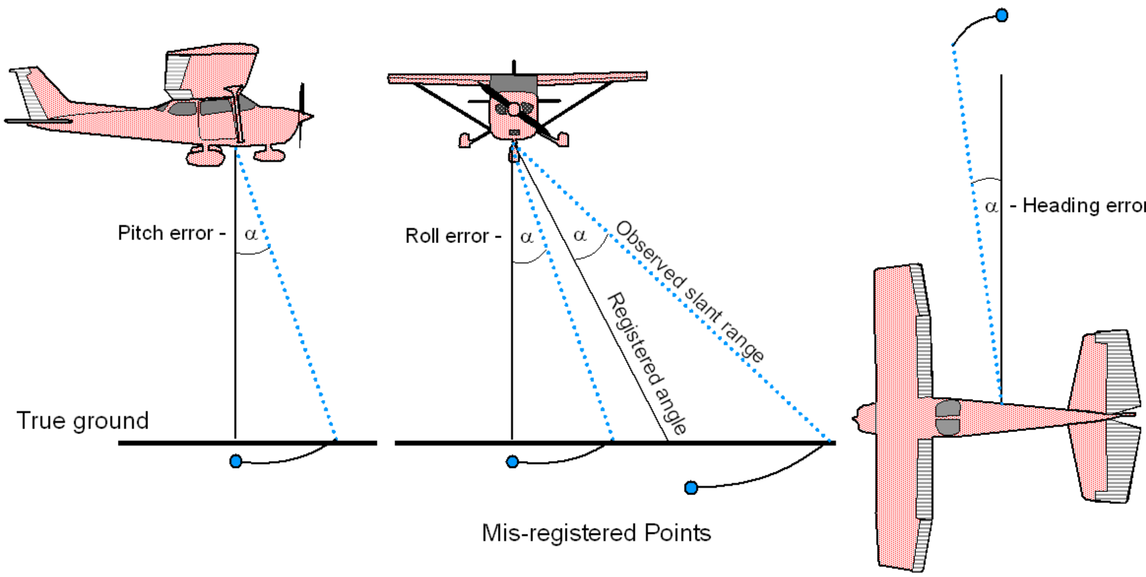

Figure 5-1: Misalignment Errors.

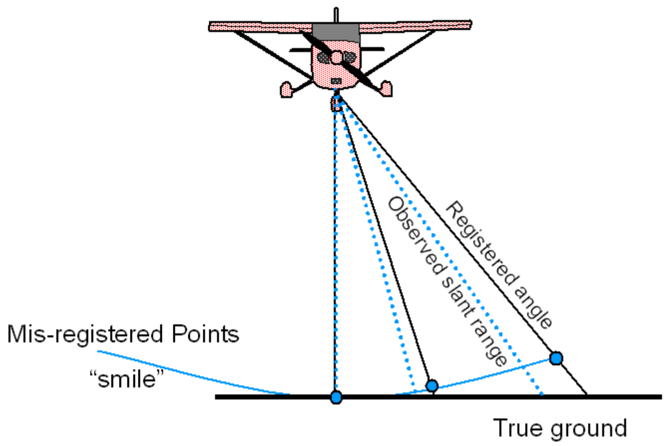

Figure 5-2: Torsion Error

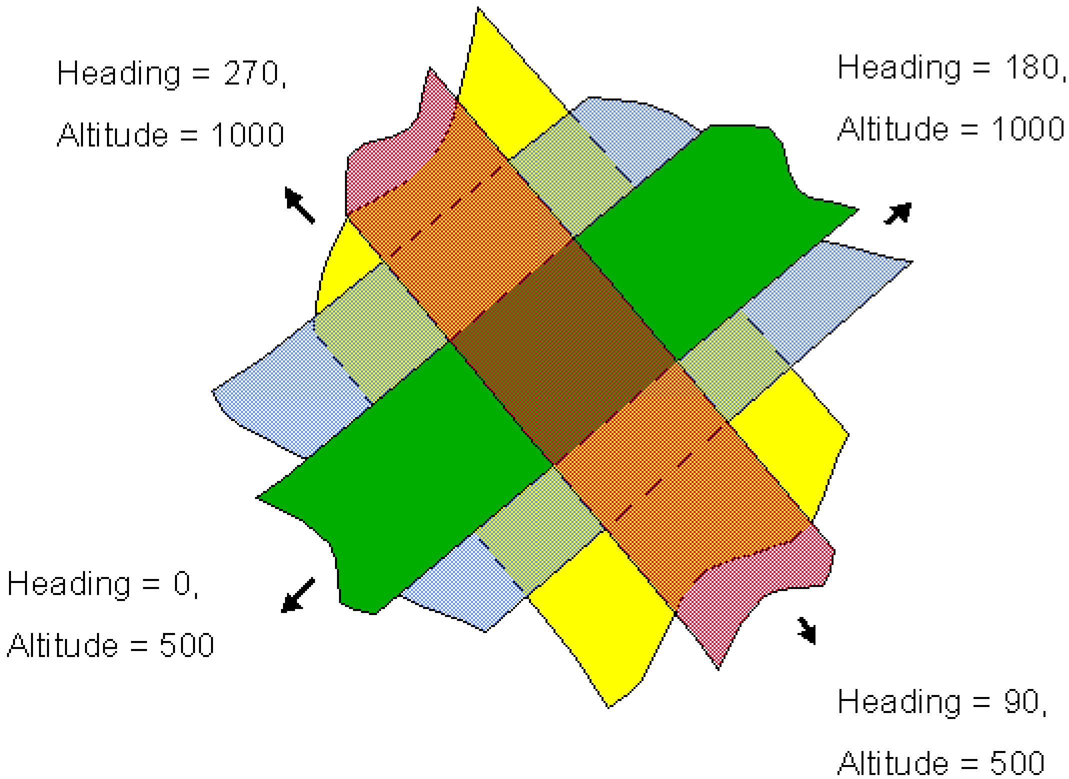

Figure 5-3: Optimal Flight Pattern for Calibration

Intensity Images

Four images from LiDAR intensity reflectance are generated in order to pick up tie points (see Figure 5-4). 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 5-4: 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 5.5.

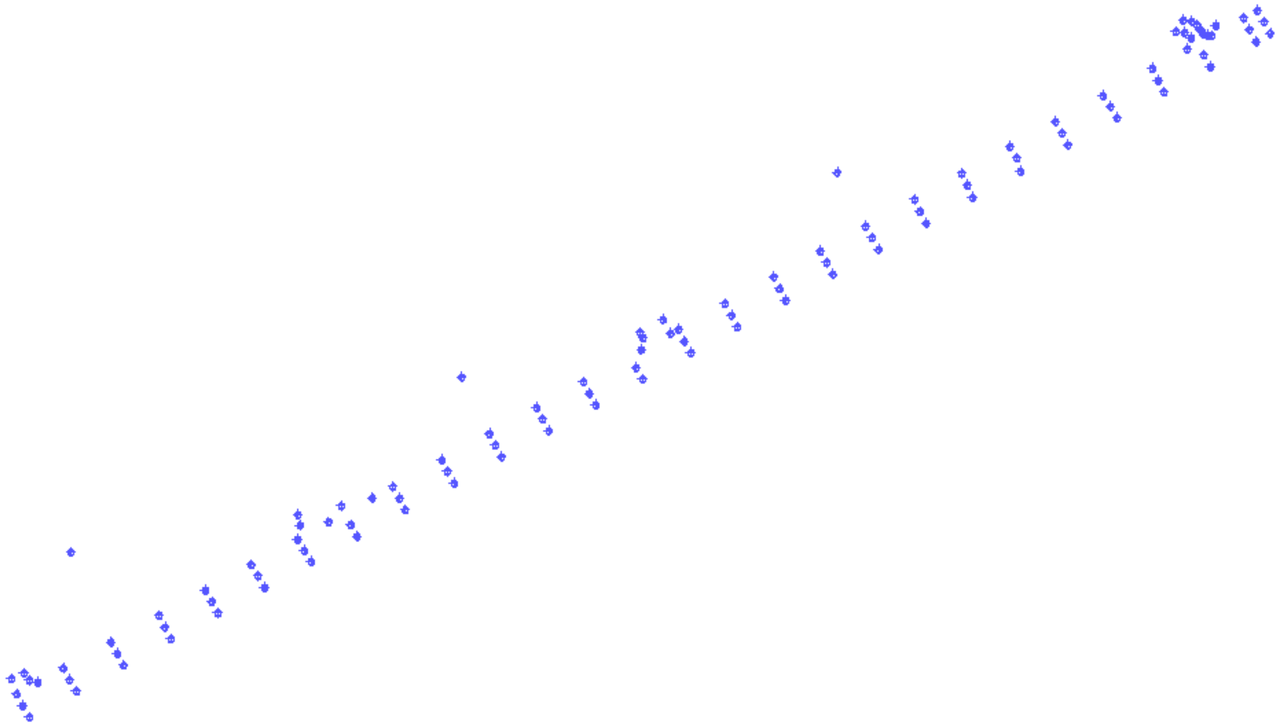

Figure 5-5: Ground control points on the runway

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 5-6. 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.

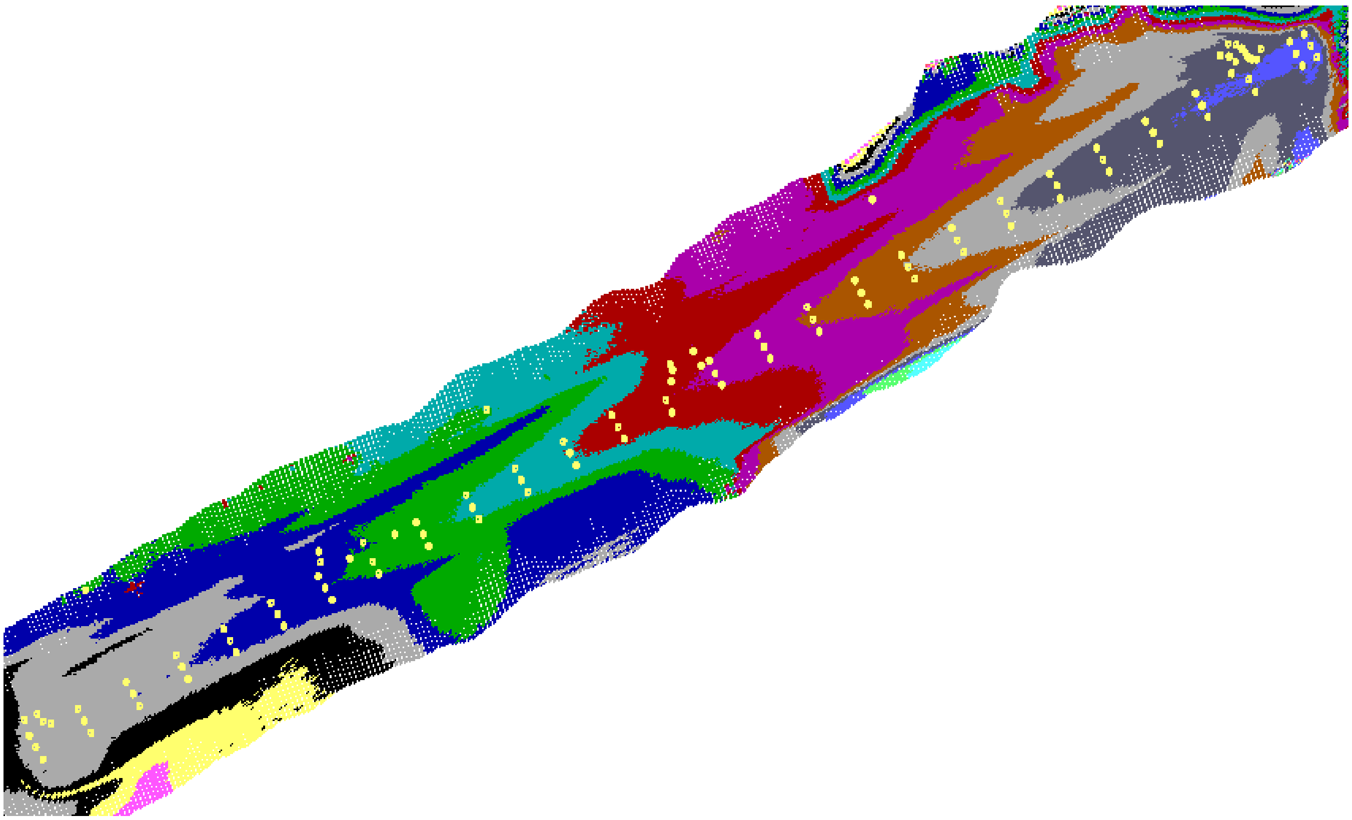

Figure 5-6: One flight line parallel to the runway ground control points. The flight line is color coded by elevations. The LiDAR data was collected at about 2.500 meters AGL.

Calibration Results and Accuracy Assessment

Final Calibration Parameters

The following numbers were derived by Leica through lab calibration, and/or from data acquired on Woolpert's LiDAR calibration site as well as from data acquired over the project site. These are the latest pertinent values for each respective sensor and project.

ALS50-II S/N 46

Parameter	Value	Format
Lab fixed parameters		
Range 1 Correction	1.000/1.000 m	0.000
Range 2 Correction	1.002/1.026 m	0.000
Range 3 Correction	1.018/0.975 m	0.000
Range 4 Correction	0.979/1.006 m	0.000
Encoder Latency	0.00 mcr sec	0.00
Ticks Per Revolution	8388608 ticks	0000000
Attitude		
*Roll (radian)	-0.021955901	0.000000000
*Pitch (radian)	0.016556528	0.000000000
*Heading (radian)	-0.000551812	0.000000000
*Scan angle correct	35600 ticks	00000
Mechanic		
*Torsion (no unit)	500000	00000

*Value calibrated on site from calibration data

Accuracy Assessment

Vertical accuracy statistics was calculated by comparing LiDAR bare earth to existing control points as following.

Average error	0.00	feet
Minimum error	-0.48	feet
Maximum error	0.74	feet
Average magnitude	0.22	feet
Root mean square	0.29	feet
Standard deviation	0.29	feet

Point ID	Easting (feet)	Northing (feet)	Elevation (feet)	Laser Elevation (feet)	Dz (feet)	Intensity	Line
101	1191941.87	184237.39	817.45	817.41	-0.04	10.5	14
102	1205583.99	125055.07	447.89	447.78	-0.11	15.6	18
103	1226337.31	123398.09	480.99	481.03	0.04	15.8	24
104	1266880.58	165233.74	645.67	645.63	-0.04	16.8	37
105	1280762.14	188849.92	473.77	473.51	-0.26	14.5	41
106	1327059.86	299212.73	681.03	681.10	0.07	12.9	55
107	1348516.45	323108.32	823.43	outside	*	*	*
108	1336457.17	367710.36	873.92	873.91	-0.01	14.2	58
109	1305236.77	380192.81	468.28	outside	*	*	*
110	1270417.21	351524.25	445.86	445.42	-0.44	23.1	38
111	1300330.89	320686.18	713.55	713.40	-0.15	20.6	47
112	1229609.24	176113.58	489.69	489.63	-0.06	19.2	25
113	1251717.37	339903.67	451.06	450.63	-0.43	19.9	32
114	1289035.74	357894.11	472.33	472.08	-0.25	16.9	44
115	1262049.68	325522.52	665.58	665.10	-0.48	13.2	35
116	1292064.19	307858.89	783.91	783.79	-0.12	18.6	45
117	1321093.01	351833.58	724.42	724.24	-0.18	13.6	54
118	1321326.09	324834.40	880.94	880.81	-0.13	14.8	54
119	1258499.13	144704.87	605.13	604.72	-0.41	13.6	34
120	1225882.96	154095.39	498.54	498.61	0.07	13.0	24
121	1248370.68	196562.45	630.66	630.75	0.09	11.4	31
122	1223703.42	200852.62	475.14	475.29	0.15	14.2	23
123	1205587.35	160125.54	460.22	460.25	0.03	11.9	18
azi001	1191630.43	219059.49	487.66	488.09	0.43	16.3	14
azi006	1200138.98	248268.94	483.79	483.75	-0.04	19.8	16
azi8614	1163843.55	210504.87	435.75	435.75	0.00	24.2	5
azi8616reset	1155323.29	187413.61	428.74	428.60	-0.14	24.5	2
azi8618	1186673.32	205707.63	530.09	530.49	0.40	14.9	12
azi8627	1305411.35	280136.01	710.91	710.55	-0.36	8.9	49
azi8629	1264289.94	305329.30	690.56	690.44	-0.12	14.2	36
azi8635	1278289.20	235414.99	563.15	562.67	-0.48	10.1	40
aziBU0701	1171200.01	230350.46	436.11	436.17	0.06	14.2	7
BD15-01	1196639.89	265288.85	465.95	466.34	0.39	23.1	15
BH30-01	1240831.37	257363.60	515.68	515.58	-0.10	21.6	29
GPS86-1	1247688.11	318872.18	458.06	458.66	0.60	17.0	31
GPS86-4	1235133.61	295419.65	450.61	451.35	0.74	23.0	127
GPS86-7	1195432.25	290629.97	463.95	464.36	0.41	24.4	15
GPS86-28	1291452.71	287897.58	663.48	664.16	0.68	12.6	44
GPS86-33	1278637.01	254717.15	726.67	727.06	0.39	14.9	40
GPS86-43	1206849.46	278083.40	460.50	460.61	0.11	22.3	18
I71-T4-AZ	1224483.83	286449.76	433.08	433.51	0.43	12.9	24
MF-1	1186137.98	270537.87	437.62	437.65	0.03	13.9	12
Riley-3	1222970.93	218580.89	542.52	slope	*	*	*
STA005	1169036.56	250221.33	445.74	445.89	0.15	20.6	7

Point ID	Easting (feet)	Northing (feet)	Elevation (feet)	Laser Elevation (feet)	Dz (feet)	Intensity	Line
STA008	1243753.06	272736.41	513.04	512.85	-0.19	23.6	30
STA009	1237384.05	242934.17	508.56	508.32	-0.24	13.3	28
STA022	1266941.75	289226.58	713.17	713.17	0.00	23.3	37
STA030	1297942.85	229186.27	748.13	747.95	-0.18	20.3	46
STA035	1303406.05	252303.91	654.76	654.51	-0.25	19.0	48
STA036	1264842.45	213739.32	515.34	515.47	0.13	16.7	36
STA040	1276926.11	280459.25	707.18	707.22	0.04	18.3	40
STA054	1195973.40	232192.26	479.53	479.51	-0.02	16.3	15
STA061	1228797.38	231790.62	490.52	490.40	-0.12	23.3	25
101	1191941.87	184237.39	817.45	817.41	-0.04	10.5	14
102	1205583.99	125055.07	447.89	447.78	-0.11	15.6	18
103	1226337.31	123398.09	480.99	481.03	0.04	15.8	24
104	1266880.58	165233.74	645.67	645.63	-0.04	16.8	37
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GPS86-43	1206849.46	278083.40	460.50	460.61	0.11	22.3	18
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MF-1	1186137.98	270537.87	437.62	437.65	0.03	13.9	12
Riley-3	1222970.93	218580.89	542.52	slope	*	*	*
STA005	1169036.56	250221.33	445.74	445.89	0.15	20.6	7
STA008	1243753.06	272736.41	513.04	512.85	-0.19	23.6	30
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STA036	1264842.45	213739.32	515.34	515.47	0.13	16.7	36
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STA054	1195973.40	232192.26	479.53	479.51	-0.02	16.3	15
STA061	1228797.38	231790.62	490.52	490.40	-0.12	23.3	25

The final point density of the project, for all points collected minus the overlap, was determined to be:

$$0.10 \text{ pts} / \text{ft}^2 = 1.07 \text{ pts} / \text{m}^2$$

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

Approved By:			
Title	**Name**	**Signature**	**Date**
Woolpert-Associate Member LiDAR Specialist Certified Photogrammetrist #1281	**Qian Xiao**		**June 4, 2009**

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 one or half-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 10 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 by Woolpert LiDAR specialists:

- ✓ 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.

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

- ✓ Overlap match individual flight lines, generated statistics on the fit, and make the necessary adjustments.

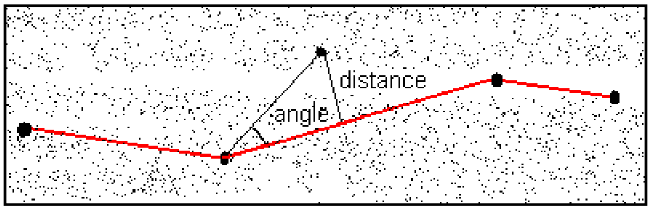
- ✓ Identified and removed systematic error locally (by flight) which is not possible if the lines are combined into a block. This is sometimes the case when a satellite loss of lock occurs during a flight and the GPS solution fixes on the wrong integer ambiguity.

- ✓ 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 outer edges of the swath to remove less accurate points.

- ✓ 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. 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.

- ✓ Adjust for vertical offsets

  If all flights are consistent within the mapping specifications, cross flights and ground control data is imported and studied for fit. As a QC measure, Woolpert has developed a routine 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.

- ✓ All final delivery data was determined to meet and or exceed the project specifications.

- ✓ Reformat data in accordance with final deliverables.