Sedgwick County
Kansas
LiDAR Mapping Report

To: **John Rogers, GIS Manager, Sedgwick County Division of Information & Operations, Sedgwick County, Kansas**

Re: **Certification of Aerial Mapping Data for the area designated as the "Sedgwick County" portion of Merrick's Wichita/Sedgwick LiDAR project 02015796.**

This is to certify that the aerial mapping contained in the Hard Drive Disk labeled City of Wichita/Sedgwick County Job No. 02015796, dated April 8, 2009, was done under my direct supervision and checking. The data has been tested to meet the client specified 0.61 ft RMSE ($Accuracy_z$ = 1.19 ft) in accordance with National Standard for Spatial Data Accuracy (FGDC-STD-007.3) of the Geospatial Positioning Accuracy Standards published by the FGDC in 1998 and has met this criterion based on the Ground Truthing surveyed check points provided by Savoy Company, P.A. located at 433 S. Hydraulic, Wichita, KS 67211-1911 under their project No. 08BB09149S signed and sealed n March 31, 2009 by Mark A. Savoy, Kansas LS# 788.

The LiDAR survey was completed between March 9, 2008 and April 5, 2008 under my direct supervision and checking. The portion of the aerial LiDAR survey not certified to above by Mark A. Savoy was performed under my direct supervision and checking and is true and correct, all to the best of my knowledge and belief.

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Doyle G. Abrahamson
Date: April 6, 2009
Registration No.: LS-1293
Merrick Job No.: 02015796
For and on behalf of
Merrick & Company
Prepared by:

Prepared by:

Merrick & Company
2450 South Peoria Street
Aurora, CO 80014
Phone: (303) 751-0741
Fax: (303) 745-0964

To: Scott Lindebak, Civil Engineer, Public Works, City of Wichita, Kansas:

Re: Certification of Aerial Mapping Data for the area designated as the "City of Wichita" portion of Merrick's City of Wichita / Sedgwick County LiDAR project 02015796.

This is to certify that the aerial mapping contained on the Hard Drive Disk labeled City of Wichita/Sedgwick County Job No. 02015796 was done under my direct supervision. The data has been tested to meet the client-specified 0.3 ft RMSE ($Accuracy_z$ = 0.6 ft) on flat, bare-ground in accordance with National Standard for Spatial Data Accuracy (FGDC-STD-007.3) of the Geospatial Positioning Accuracy Standards published by the FGDC in 1998 and has met this criterion based on the Ground Truthing surveyed check points provided by Savoy Company, P.A., located at 433 S. Hydraulic, Wichita, KS 67211-1911 under their project No. 08BB09149S.

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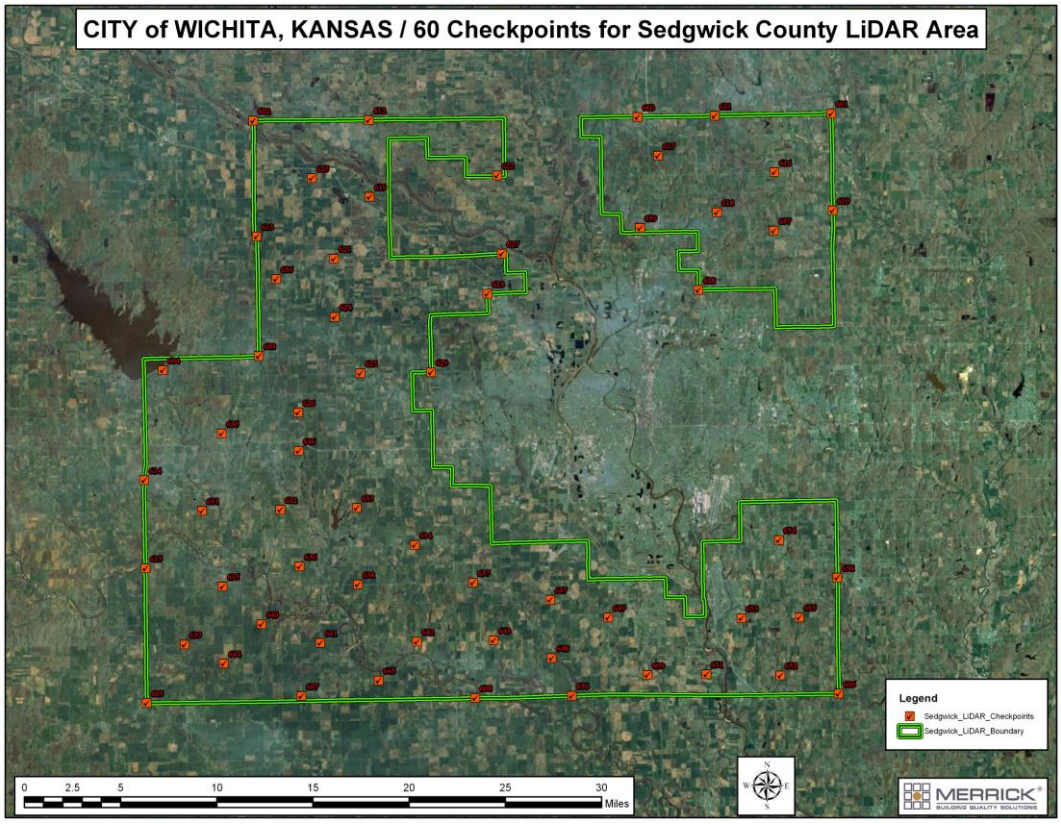
Roger Hanson, CP, GISP
Date: April 8, 2009

ASPRS Certification No.: R1014
ASPRS Certification Expiration Date: August 14, 2013
For and on behalf of
Merrick & Company

EXECUTIVE SUMMARY

In the early part of year 2008, Merrick & Company was contracted by the City of Wichita and the County of Sedgwick, located in the State of Kansas, to execute a LiDAR (Light Detection and Ranging) survey. The purpose of the project is to produce accurate three-dimensional, high-resolution LiDAR image data for planning, analysis, and for use with other data sets. Merrick & Company obtained LiDAR data over approximately 660 square miles for the County of Sedgwick. The LiDAR data has been collected at a Ground Sample Distance (GSD) of 5 feet to meet vertical National Standard for Spatial Data Accuracy (NSSDA) accuracy for 2 foot contours (Accuracy $z \leq 1.2$ feet) and to meet horizontal National Standard for Spatial Data Accuracy (NSSDA) accuracy for 1:2,400 scale mapping (RMSEr ≤ 4.4 feet).



CONTRACT INFORMATION

Questions regarding this report should be addressed to:

Kenny Legleiter / Project Manager
Merrick & Company
GeoSpatial Solutions
2450 South Peoria Street
Aurora, CO 80014
303-353-3837
303-751-0741 (Merrick)

Project Completion Report for the County of Sedgwick, Kansas.

The contents of this report summarize the methods used to establish the GPS base station network, perform the LiDAR data collection and post-processing as well as the results of these methods for the County of Sedgwick, Kansas.

LiDAR FLIGHT and SYSTEM REPORT

Project Location
The project boundary for Sedgwick County Kansas is defined by the client provided shapefile "Sedgwick_LiDAR_Boundary.shp".

Duration/Time Period
The LiDAR aircraft, a Cessna 402C, arrived on site on March 08, 2008 and the LiDAR data collection was accomplished on March 09, 2008 thru April 1, 2008. The Wichita Mid-Continent Airport (FAA Identifier ICT), located in Wichita Kansas, was used as the airfield of operations.

Flight Diagram
See Below.

Mission Parameters

LiDAR Sensor	Leica Geosystems ALS50 Phase 2
Nominal Ground Sample Distance	1.24 meters
Average Altitude	11,500 Feet AMSL
Average Airspeed	~160 Knots
Scan Rate	28.1 Hertz
Scan FOV (scan angle)	30˚
Pulse Rate	78,500 Hertz

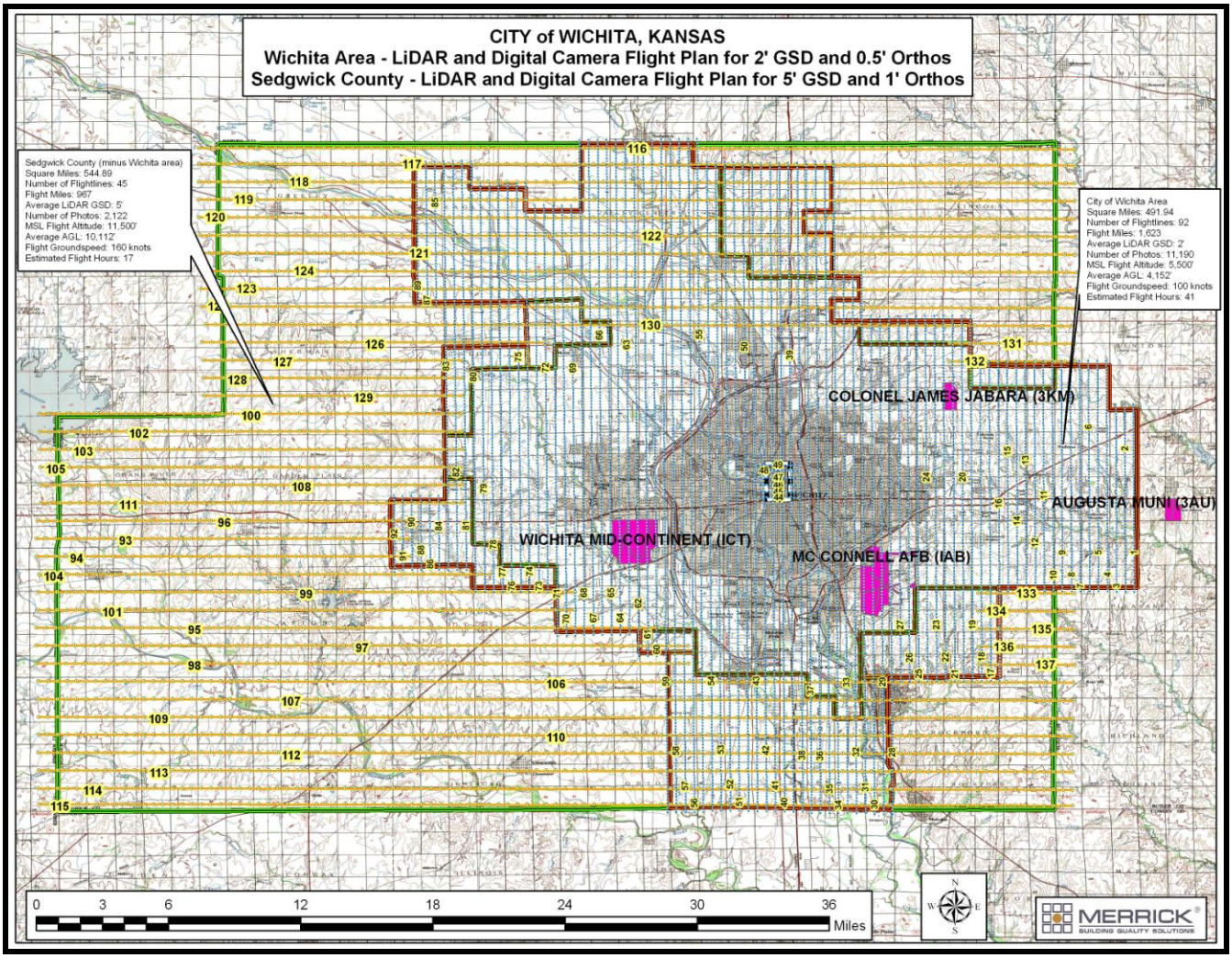
Mission	Date	Start Time	End Time	Length Time
080309A	March 09, 2008	60069 GPS sec. 16:41:09 GMT	75232 GPS sec. 20:53:52 GMT	15163 sec. 04:12:43
080310A	March 10, 2008	142442 GPS sec. 15:34:02 GMT	157577 GPS sec. 19:46:17 GMT	15135 sec. 04:12:15
080311A	March 11, 2008	228688 GPS sec. 15:31:28 GMT	251250 GPS sec. 21:47:30 GMT	22562 sec. 06:16:02
080312A	March 12, 2008	315739 GPS sec. 15:42:19 GMT	323431 GPS sec. 17:50:31 GMT	7692 sec. 02:08:12
080319A	March 19, 2008	313047 GPS sec. 14:57:27 GMT	336581 GPS sec. 21:29:41 GMT	23534 sec. 06:32:14
080320A	March 20, 2008	404647 GPS sec. 16:24:07 GMT	423718 GPS sec. 21:41:58 GMT	19071 sec. 05:17:51
080321A	March 21, 2008	492486 GPS sec. 16:48:06 GMT	512973 GPS sec. 22:29:33 GMT	20487sec. 05:41:27

080324A	March 24, 2008	141494 GPS sec. 15:18:14 GMT	154379 GPS sec. 18:52:59 GMT	12885 sec. 03:34:45:
080401A	April 01, 2008	235165 GPS sec. 17:19:25 GMT	246724 GPS sec. 20:32:04 GMT	11559 sec. 03:12:39

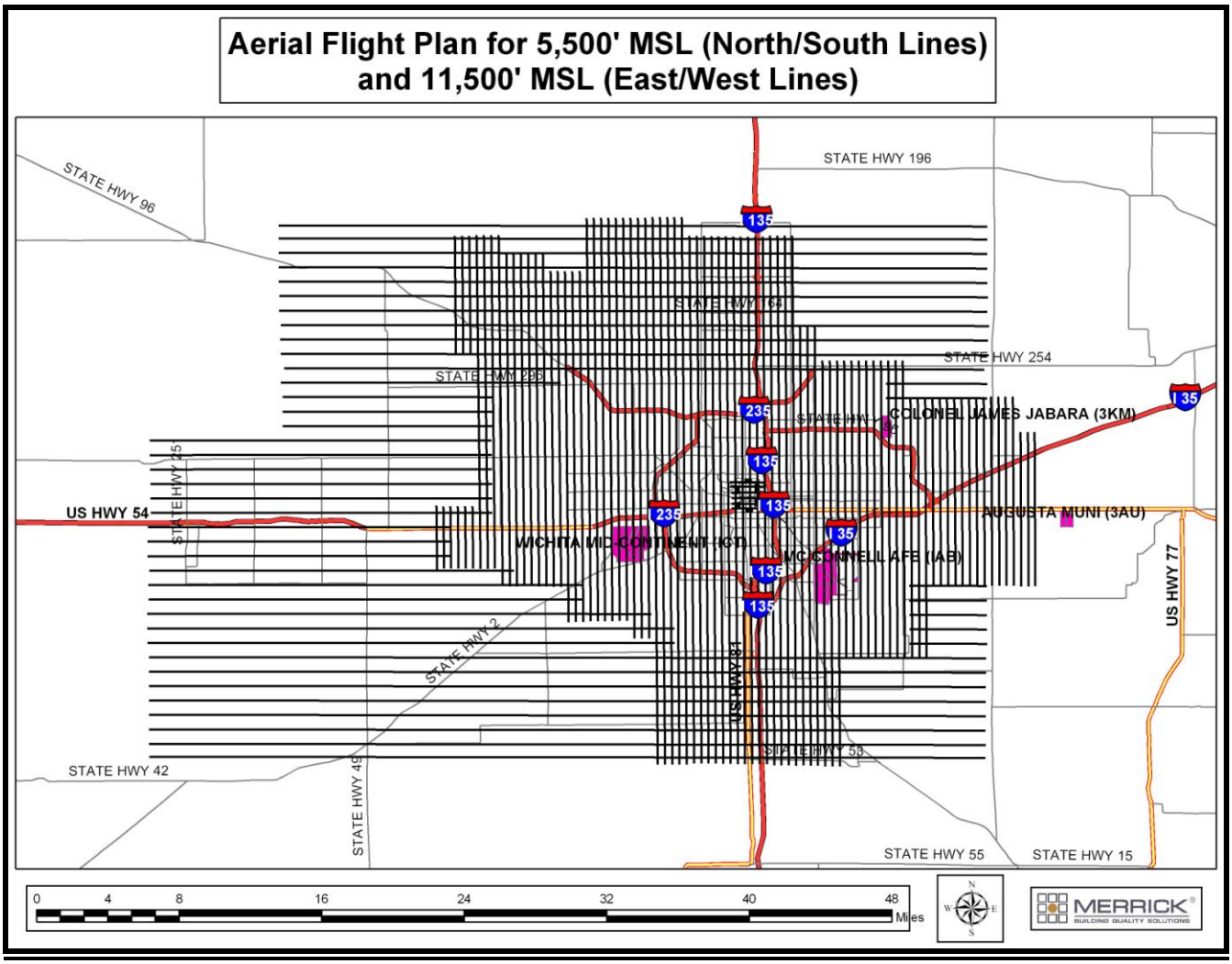
Field Work / Procedures

Two ground airborne GPS Base Stations, for the LiDAR data collection, were set up every mission, one main GPS receiver (Base) located at the Airport and one auxiliary airborne GPS receiver (Aux) also located at the airport. The City of Wichita also supplied 5 GPS ground base stations for the airborne GPS missions.
Pre-flight checks such as cleaning the sensor head glass are performed. A five minute INS initialization is conducted on the ground, with the engines running, prior to flight, to establish fine-alignment of the INS. GPS ambiguities are resolved by flying within ten kilometers of the base station. During the data collection, the operator recorded information on log sheets which includes weather conditions, LiDAR operation parameters, and flight line statistics. Near the end of the mission, GPS ambiguities were again resolved by flying within ten kilometers of the base stations to aid in post-processing. Data was sent back to the main office and preliminary data processing was performed for quality control of GPS data and to ensure sufficient overlap between flight lines. Any problematic data could then be reflown immediately as required. Final data processing was completed in the Aurora, Colorado office.

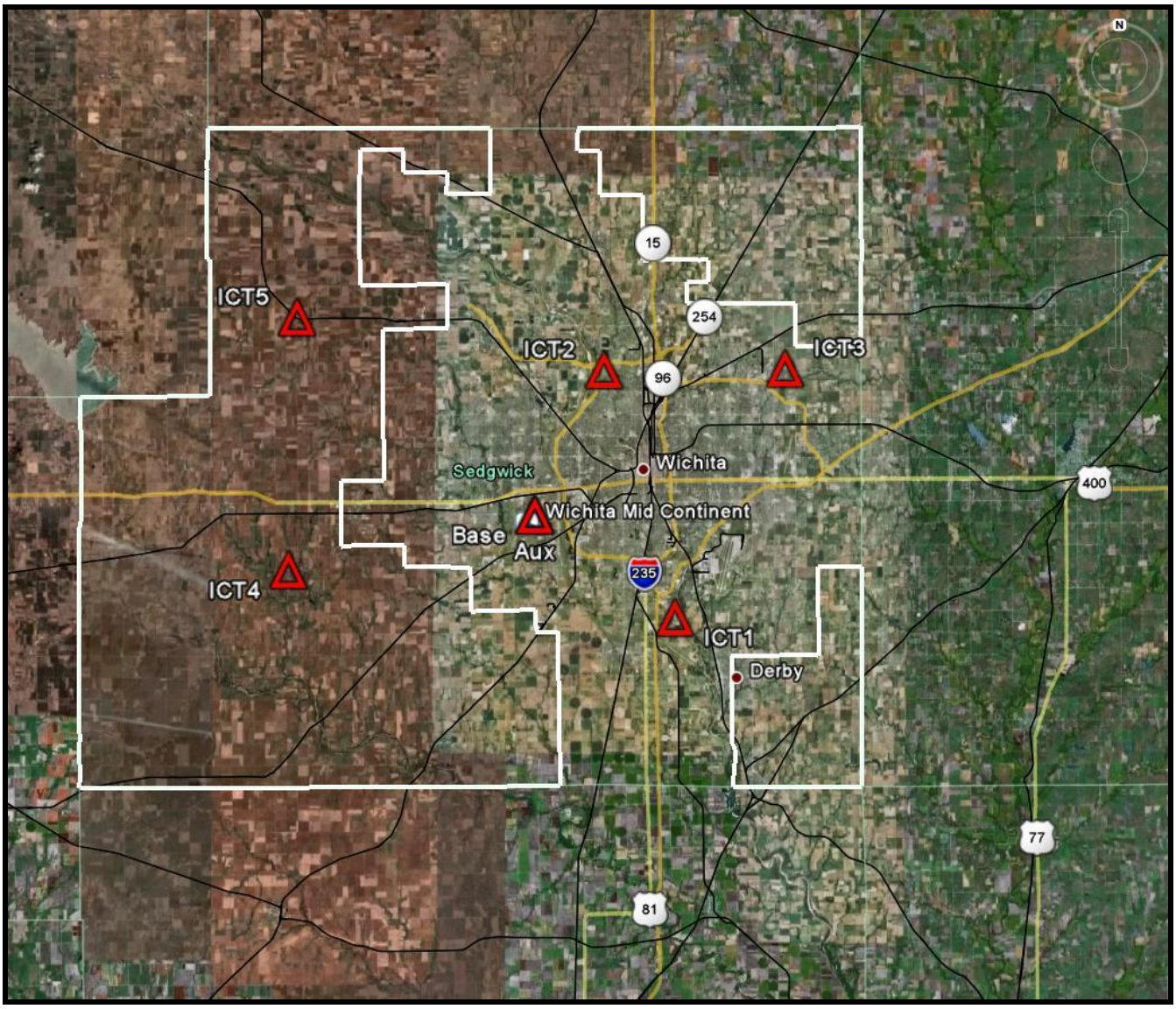
Proposed Flight Diagram 1 for Sedgwick County (East-West Lines). Also shows flight lines for City of Wichita Kansas (North South Lines).



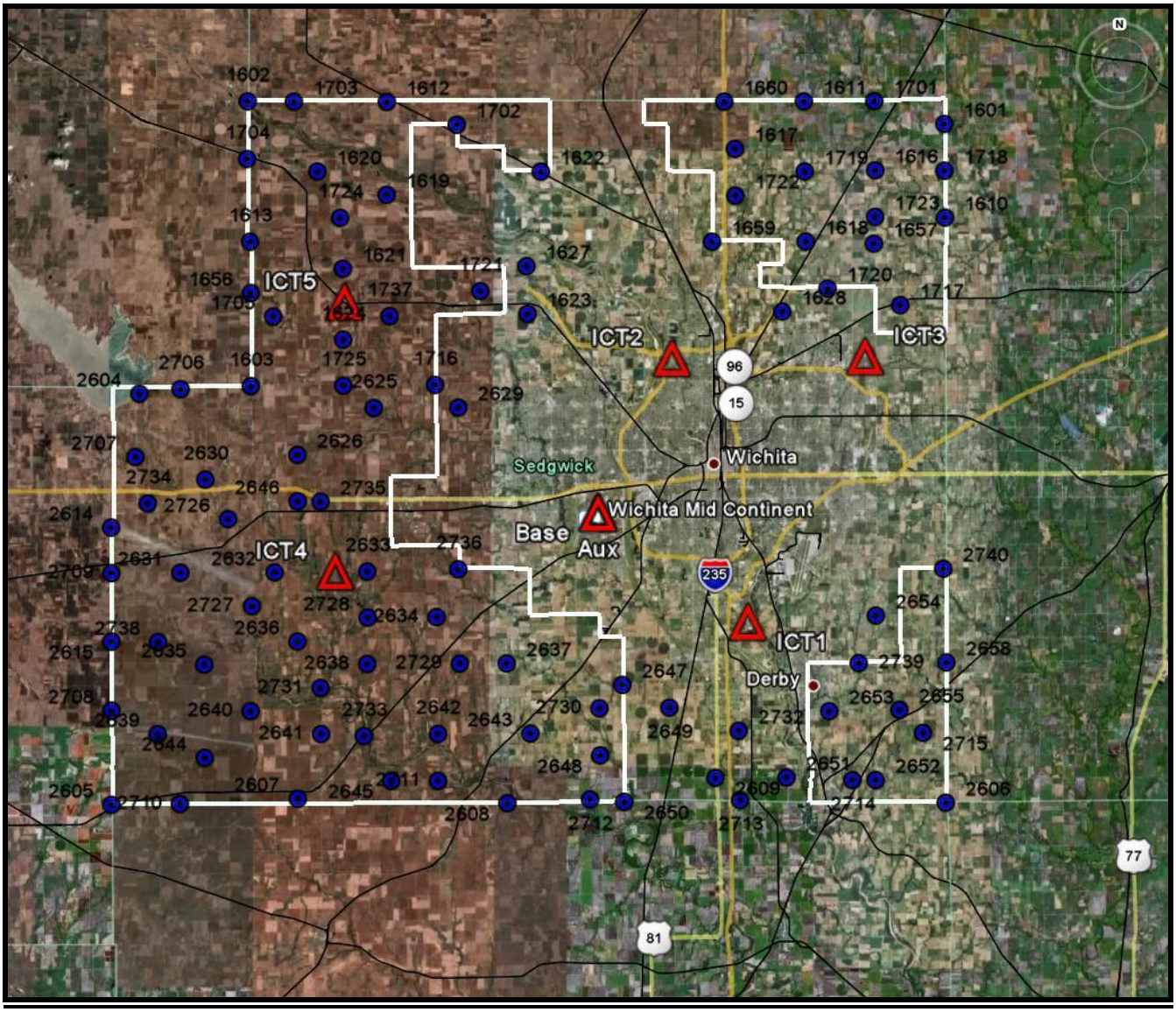
Proposed Flight Diagram 2 for Sedgwick County (East-West Lines). Also shows flight lines for City of Wichita Kansas (North South Lines).



Base Station Location for Sedgwick County



Base Station and Ground Control for Sedgwick County



LiDAR Data Processing

The airborne GPS data was post-processed using Waypoint's GravNAV software version 7.8. A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. Whenever practical, LiDAR acquisition was limited to periods when the PDOP (Positional Dilution of Precision) was less than 4.0.
PDOP (Positional Dilution of Precision) indicates satellite geometry relating to position. Generally PDOP's of 4.0 or less result in a good solution, however PDOP's between 4.0 and 5.0 can still yield good results most of the time. PDOP's over 6.0 are of questionable results and PDOP's of over 7.0 usually result in a poor solution. Other quality control checks used for the GPS include analyzing the combined separation of the forward and reverse GPS processing from one base station and the results of the combined separation when processed from two different base stations. Basically this is difference between the two trajectories. Also analysis of the number of satellites present during the flight and data collection times. The number of satellites, at time of LiDAR data collection, should always be 5 or more.
The GPS trajectory was combined with the raw IMU data and post-processed using IPAS Pro GPS/INS Processor Version 1.15. The smoothed best estimated trajectory (SBET) and refined attitude data are then utilized in the ALS Post Processor to compute the laser point-positions – the trajectory is combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points. Up to four return values are produced within the ALS Post Processor software for each pulse which ensures the greatest chance of ground returns in a heavily forested area.
Laser point classification was completed using Merrick Advanced Remote Sensing (MARS®) LiDAR processing and modeling software. Several algorithms are used when comparing points to determine the best automatic ground solution. Each filter is built based on the projects terrain and land cover to provide a surface that is 90% free of anomalies and artifacts. After the auto filter has been completed the data is then reviewed by an operator utilizing MARS® to remove any other anomalies or artifacts not resolved by the automated filter process. During these final steps the operator also verifies that the data set is consistent and complete with no data voids.

GROUND CONTROL REPORT / CHECKPOINT SURVEY RESULTS

GPS Controls

Two GPS ground base stations were set up at the airport, for the LiDAR data collection. The City of Wichita also supplied 5 GPS ground base stations for the airborne GPS missions.
Base stations set up at the airport are named Base and Aux, the bases supplied by the City are named ICT(1-5). The GPS base stations at the airport (Base and Aux) and all of the LiDAR ground control and ground cover points were tied directly to the City of Wichita control point values.
See spreadsheet below.

Project: Sedgwick County Kansas and Wichita Kansas
Job#: 02015796
Date: March 2008

Coordinate System: US State Plane NAD83
Zone: Kansas South 1502
Project Datum: NAD 1983 (Conus)
Vertical Datum: NAVD88 (GEOID2003)
Units: US survey feet

Pt#	Geodetic NAD83		Ellipsoid	DESCRIPTION
Name	Latitude	Longitude	Height	
	North	West	Geoid2003	
	Deg Min Sec	Deg Min Sec	US Feet	
ICT1	37°35'15.77374"N	97°18'31.95961"W	1196.01	At Antenna Phase Center (0.00 Antenna Height)
ICT2	37°45'06.45827"N	97°22'05.23222"W	1257.00	At Antenna Phase Center (0.00 Antenna Height)
ICT3	37°45'09.31254"N	97°12'58.38149"W	1320.47	At Antenna Phase Center (0.00 Antenna Height)
ICT4	37°37'08.55538"N	97°37'56.95883"W	1290.42	At Antenna Phase Center (0.00 Antenna Height)
ICT5	37°47'12.02002"N	97°37'32.69188"W	1352.68	At Antenna Phase Center (0.00 Antenna Height)
Base	37°39'21.19346"N	97°25'35.21903"W	1224.44	Base Point Set
Aux	37°39'19.26167"N	97°25'34.05927"W	1227.64	Aux Point Set

Pt#	SP NAD83 Kansas South		NAVD88	DESCRIPTION
Name	NORTHING	EASTING	ELEVATION	
	Y	X	Z	
	US Feet	US Feet	US Feet	
ICT1	1649911.77	1657458.38	1290.39	At Antenna Phase Center (0.00 Antenna Height)
ICT2	1709438.09	1639568.59	1351.44	At Antenna Phase Center (0.00 Antenna Height)
ICT3	1710295.72	1683478.32	1415.09	At Antenna Phase Center (0.00 Antenna Height)
ICT4	1660283.30	1563589.91	1384.47	At Antenna Phase Center (0.00 Antenna Height)
ICT5	1721336.23	1564969.84	1446.50	At Antenna Phase Center (0.00 Antenna Height)
Base	1674319.17	1623107.91	1318.80	Base Point Set at Airport
Aux	1674124.87	1623203.42	1322.00	Aux Point Set at Airport

Ground Control Parameters

Horizontal Datum: The horizontal datum for the project is NAD83 (North American Datum of 1983.
Coordinate System: Kansas State Plane South Zone (1502).
Vertical Datum: The vertical datum for the project is NAVD88 (North American Vertical Datum of 1988).
Geoid Model: Geoid03 (Geoid 03 will be used to convert ellipsoid heights to orthometric heights).
Units: Horizontal units and Vertical units are in USFeet.

Ground Survey Control Report

The following spreadsheet shows the GPS ground control collected for LiDAR check points and Photo check points. The ground control survey (LiDAR check points) was performed by Savoy Company P.A.

Project: Sedgwick County Kansas
Job#: 02015796
Date: April 9,2008

Coordinate System: US State Plane NAD83(Conus)
Zone: Kansas South 1502
Project Datum: NAD 1983 (Conus)
Vertical Datum: NAVD88 (GEOID2003)
Units: US Survey Feet

Pt#	SP NAD83 Zone Kansas South		NAVD88	DESCRIPTION
Name	NORTHING	EASTING	Elevation	
	Y	X	Z	
	US Feet	US Feet	US Feet	
1601	1763546.299	1701157.206	1355.72	INTERSEC 2RDS
1602	1766937.819	1542558.609	1440.777	CTR RD
1603	1702351.083	1544052.923	1533.889	INTERSEC 2 RDS
1610	1742296.738	1701495.573	1357.475	INTERSEC 2 RDS
1611	1768265.502	1669122.719	1470.576	INTERSEC 2 RDS
1612	1767113.953	1574252.259	1413.95	NE COR RD STRIPE
1613	1735076.928	1543487.873	1513.869	CTR ROAD
1616	1752839.411	1685503.788	1401.917	SE COR RD STRIPE
1617	1757312.271	1653548.754	1456.697	INTERSEC 2 RDS
1618	1736484.689	1669870.609	1430.161	INTERSEC 2 RDS
1619	1746039.573	1574454.656	1398.411	INTERSEC 2 RDS
1620	1751157.396	1558619.685	1429.025	NW COR RD STRIPE
1621	1729148.731	1564666.783	1421.638	SE COR RD STRIPE
1622	1751654.475	1609445.557	1375.122	INTERSEC 2 RDS

1623	1719385.311	1606775.235	1358.245	NE COR RD STRIPE
1624	1713081.958	1564922.966	1494.823	NE COR RD STRIPE
1627	1730192.766	1606429.955	1362.676	INTERSEC 2 RDS
1628	1720545.534	1664677.885	1398.578	NE COR RD STRIPE
1656	1723445.025	1543790.013	1522.703	NE COR RD STRIPE
1657	1736193.698	1685375.554	1391.085	SW COR RD STRIPE
1659	1736174.721	1648546.643	1380.542	NE COR RD STRIPE
1660	1768011.606	1651004.008	1417.012	NE COR RD STRIPE
1701	1768550.56	1685158.149	1381.949	NE COR RD STRIPE
1702	1762091.004	1590219.786	1397.564	NE COR RD STRIPE
1703	1766967.504	1553088.689	1431.086	NE COR RD STRIPE
1704	1753854.213	1542561.821	1449.888	SE COR RD STRIPE
1705	1718165.586	1548953.897	1510.325	NE COR RD STRIPE
1716	1703068.523	1585941.586	1403.09	NE COR RD STRIPE
1717	1722318.005	1691527.351	1416.153	CTR SO. END DR
1718	1752929.778	1701286.344	1350.987	NE COR RD STRIPE
1719	1752364.739	1669486.972	1413.885	NW COR RD STRIPE
1720	1725900.066	1674928.117	1423.172	NW COR STRIPE
1721	1724433.838	1595992.248	1381.872	NE COR RD STRIPE
1722	1746702.757	1653738.955	1419.007	NE COR RD STRIPE
1723	1742264.21	1685592.417	1404.717	SE COR RD STRIPE
1724	1740699.323	1563937.243	1416.163	NE COR RD STRIPE
1725	1702676.772	1565085.814	1484.049	NE COR RD STRIPE
1737	1718541.019	1575443.862	1405.793	SW COR RD STRIPE
2604	1700350.32	1518687.57	1416.37	MAG
2605	1607117.35	1513299.31	1438.33	60D
2606	1609688.67	1703111.16	1310.04	END STRIPE
2607	1609008.57	1555754.00	1353.78	MAG
2608	1608536.61	1603432.17	1258.58	60D
2609	1614823.12	1650663.37	1255.16	MAG
2614	1669962.37	1512578.67	1426.26	60D
2615	1644116.12	1512926.09	1366.01	60D
2625	1697690.86	1572057.85	1443.28	MAG
2626	1686876.80	1554849.31	1492.23	60D
2629	1697991.63	1591271.73	1379.77	SAV TRAV PT
2630	1681063.97	1533919.25	1455.35	MAG
2631	1659918.38	1528470.45	1343.69	MAG
2632	1660212.73	1549980.32	1435.19	MAG
2633	1660644.25	1570987.02	1415.32	MAG
2634	1650520.79	1586870.42	1403.65	SCC
2635	1639150.49	1534129.06	1332.65	SM 1/2R
2636	1644619.82	1555315.52	1354.54	
2637	1640188.60	1602936.49	1341.34	MAG
2638	1639702.85	1571219.57	1342.89	END STRIPE
2639	1623263.18	1523679.48	1390.32	MAG
2640	1628740.63	1544803.71	1326.02	SAV TRAV PT
2641	1623718.66	1560910.01	1315.87	MAG
2642	1624049.95	1587477.88	1290.93	MAG

2643	1624381.25	1608496.60	1295.79	60D
2644	1618018.51	1534448.87	1344.04	60D
2645	1613339.76	1576959.56	1312.79	MAG
2646	1676356.20	1554992.65	1446.96	MAG
2647	1635620.78	1629262.89	1295.70	60D
2648	1619597.72	1624407.16	1265.53	MAG
2649	1630565.80	1639998.78	1283.62	SAV TRAV PT
2650	1609138.97	1629983.14	1243.49	MAG
2651	1615061.53	1666818.26	1231.51	60D
2652	1614699.32	1687097.62	1269.45	END STRIPE
2653	1630173.95	1676360.79	1328.66	MAG
2654	1651932.34	1686724.42	1342.64	END PAINT STRIPE
2655	1630654.82	1692320.52	1318.71	60D
2658	1641507.37	1702874.39	1337.40	SAV TRAV PT
2706	1701503.29	1528047.65	1476.67	EC
2707	1686022.21	1517912.77	1399.88	MAG
2708	1628486.94	1513128.31	1405.62	60D W/TARGET
2709	1659652.94	1512758.88	1391.96	MAG
2710	1607489.49	1528918.22	1417.45	EC
2711	1613421.63	1587606.52	1276.42	END STRIPE
2712	1609592.72	1622220.92	1246.22	END STRIPE
2713	1609843.56	1656321.59	1235.71	END STRIPE
2714	1614620.92	1681798.35	1288.13	WLK
2715	1625475.30	1697744.53	1344.51	END STRIPE
2726	1672168.14	1539208.27	1419.35	EC
2727	1652503.29	1544880.00	1368.18	EC
2728	1650212.56	1571206.86	1409.66	MAG
2729	1640044.01	1592287.84	1385.36	MAG
2730	1630257.10	1624099.14	1278.97	END STRIPE
2731	1634157.51	1560658.29	1300.30	END STRIPE
2732	1625507.17	1655795.39	1244.86	END STRIPE
2733	1623356.52	1570644.18	1298.06	MAG
2734	1675502.41	1520877.03	1388.82	MAG
2735	1676337.53	1560218.20	1456.68	MAG
2736	1661383.56	1591677.78	1387.60	END STRIPE
2738	1644152.37	1523576.50	1349.28	MAG
2739	1641134.15	1682934.36	1288.11	END PAINT STRIPE
2740	1662713.89	1701929.37	1334.46	EC

Ground Survey Cover (Ground Truth) Report

LiDAR Accuracy / Validation Results

The following listing shows the results of the LiDAR data compared to the GPS ground control survey data. The listing is sorted by the **Z Error** column showing, in ascending order, the vertical difference between the surveyed ground control points and the LiDAR points.

Post-Filter Control Report for Sedgwick County Kansas

Project File: MARSProject Sedgwick County
Date: August 03: 2008
Vertical Accuracy Objective
Requirement Type: Accuracy(z)
Accuracy(z) Objective: 1.20
Confidence Level: 95%
Control Points in Report: 156
Elevation Calculation Method: Interpolated from TIN
Control Points with LiDAR Coverage: 100
Control Points with Required Accuracy (+/- 1.20): 100
Percent of Control Points with Required Accuracy (+/- 1.20): 100.00
Average Control Error Reported: -0.04
Maximum (highest) Control Error Reported: 0.73
Median Control Error Reported: -0.03
Minimum (lowest) Control Error Reported: -0.45
Standard deviation (sigma) of Z for sample: 0.20
RMSE of Z for sample (RMSE(z)): 0.20: PASS
FGDC/NSSDA Vertical Accuracy (Accuracy(z)): 0.40: PASS
NSSDA Achievable Contour Interval: 0.7
ASPRS Class 1 Achievable Contour Interval: 0.7
NMAS Achievable Contour Interval: 0.7

Control	Control Pt	Control Pt	Coverage	Control Pt	Z from	**Z Error**	Min.	Median	Max.
Point Id	X (East)	Y (North)		Z (Elev)	LiDAR		Z	Z	Z
	USFeet	USFeet		USFeet	USFeet	**USFeet**	USFeet	USFeet	USFeet
2727	1544880.00	1652503.29	Yes	1368.18	1367.73	**-0.45**	1367.56	1367.58	1368.08
2642	1587477.88	1624049.95	Yes	1290.93	1290.53	**-0.40**	1290.46	1290.55	1290.64
2605	1513299.31	1607117.35	Yes	1438.33	1437.96	**-0.37**	1437.93	1438.06	1438.27
2639	1523679.48	1623263.18	Yes	1390.32	1389.96	**-0.36**	1389.91	1389.97	1389.99
2641	1560910.01	1623718.66	Yes	1315.87	1315.51	**-0.36**	1315.48	1315.50	1315.54
2709	1512758.88	1659652.94	Yes	1391.96	1391.60	**-0.36**	1391.49	1391.66	1391.66
1725	1565085.81	1702676.77	Yes	1484.05	1483.70	**-0.35**	1483.64	1483.69	1483.82
1613	1543487.87	1735076.93	Yes	1513.87	1513.53	**-0.34**	1513.49	1513.58	1513.58
2632	1549980.32	1660212.73	Yes	1435.19	1434.85	**-0.34**	1434.67	1434.69	1434.86

2643	1608496.60	1624381.25	Yes	1295.79	1295.46	**-0.33**	1295.39	1295.48	1295.49
1616	1685503.79	1752839.41	Yes	1401.92	1401.60	**-0.32**	1401.55	1401.61	1401.73
2736	1591677.78	1661383.56	Yes	1387.60	1387.28	**-0.32**	1387.21	1387.33	1387.49
2715	1697744.53	1625475.30	Yes	1344.51	1344.24	**-0.27**	1344.14	1344.27	1344.34
1660	1651004.01	1768011.61	Yes	1417.01	1416.76	**-0.25**	1416.68	1416.77	1416.80
2633	1570987.02	1660644.25	Yes	1415.32	1415.07	**-0.25**	1415.05	1415.05	1415.14
2710	1528918.22	1607489.49	Yes	1417.45	1417.20	**-0.25**	1417.10	1417.15	1417.27
2734	1520877.03	1675502.41	Yes	1388.82	1388.58	**-0.24**	1388.51	1388.59	1388.60
1716	1585941.59	1703068.52	Yes	1403.09	1402.86	**-0.23**	1402.80	1402.86	1402.87
1723	1685592.42	1742264.21	Yes	1404.72	1404.50	**-0.22**	1404.47	1404.52	1404.58
2615	1512926.09	1644116.12	Yes	1366.01	1365.80	**-0.21**	1365.75	1365.76	1365.85
1720	1674928.12	1725900.07	Yes	1423.17	1422.97	**-0.20**	1422.93	1422.98	1423.01
2631	1528470.45	1659918.38	Yes	1343.69	1343.49	**-0.20**	1343.39	1343.56	1343.72
1701	1685158.15	1768550.56	Yes	1381.95	1381.76	**-0.19**	1381.68	1381.82	1381.87
2626	1554849.31	1686876.80	Yes	1492.23	1492.04	**-0.19**	1492.00	1492.03	1492.19
2738	1523576.50	1644152.37	Yes	1349.28	1349.10	**-0.18**	1348.66	1349.00	1349.17
2707	1517912.77	1686022.21	Yes	1399.88	1399.71	**-0.17**	1399.51	1399.53	1399.82
1719	1669486.97	1752364.74	Yes	1413.89	1413.73	**-0.16**	1413.61	1413.80	1413.93
2630	1533919.25	1681063.97	Yes	1455.35	1455.19	**-0.16**	1455.05	1455.16	1455.23
2404	1575991.67	1681987.18	Yes	1450.67	1450.52	**-0.15**	1450.52	1450.53	1450.59
1620	1558619.69	1751157.40	Yes	1429.03	1428.88	**-0.15**	1428.79	1428.95	1428.97
1656	1543790.01	1723445.03	Yes	1522.70	1522.56	**-0.14**	1522.50	1522.62	1522.67
1657	1685375.55	1736193.70	Yes	1391.09	1390.95	**-0.14**	1390.80	1390.85	1391.03
1724	1563937.24	1740699.32	Yes	1416.16	1416.02	**-0.14**	1415.72	1415.97	1416.37
2607	1555754.00	1609008.57	Yes	1353.78	1353.64	**-0.14**	1353.42	1353.70	1353.83
2735	1560218.20	1676337.53	Yes	1456.68	1456.54	**-0.14**	1456.39	1456.51	1456.64
1622	1609445.56	1751654.48	Yes	1375.12	1374.99	**-0.13**	1374.87	1374.93	1375.05
1722	1653738.96	1746702.76	Yes	1419.01	1418.88	**-0.13**	1418.73	1418.87	1418.95
2604	1518687.57	1700350.32	Yes	1416.37	1416.25	**-0.12**	1416.08	1416.22	1416.29
2636	1555315.52	1644619.82	Yes	1354.54	1354.43	**-0.11**	1354.22	1354.34	1354.55
2706	1528047.65	1701503.29	Yes	1476.67	1476.57	**-0.10**	1476.54	1476.64	1476.89
2733	1570644.18	1623356.52	Yes	1298.06	1297.96	**-0.10**	1297.81	1298.02	1298.05
2634	1586870.42	1650520.79	Yes	1403.65	1403.56	**-0.09**	1403.46	1403.58	1403.61
2646	1554992.65	1676356.20	Yes	1446.96	1446.87	**-0.09**	1446.63	1446.83	1446.95
1611	1669122.72	1768265.50	Yes	1470.58	1470.51	**-0.07**	1470.47	1470.52	1470.54
1718	1701286.34	1752929.78	Yes	1350.99	1350.93	**-0.06**	1350.80	1350.86	1351.19
2648	1624407.16	1619597.72	Yes	1265.53	1265.47	**-0.06**	1265.41	1265.50	1265.53
1737	1575443.86	1718541.02	Yes	1405.79	1405.74	**-0.05**	1405.64	1405.72	1405.80
1512	1661281.66	1736370.23	Yes	1384.11	1384.07	**-0.04**	1384.00	1384.31	1384.41
1621	1564666.78	1729148.73	Yes	1421.64	1421.60	**-0.04**	1421.58	1421.61	1421.70
2606	1703111.16	1609688.67	Yes	1310.04	1310.01	**-0.03**	1309.97	1310.01	1310.06

2506	1607740.75	1653813.43	Yes	1335.02	1335.00	**-0.02**	1334.97	1335.03	1335.11
2625	1572057.85	1697690.86	Yes	1443.28	1443.26	**-0.02**	1442.99	1443.26	1443.31
2638	1571219.57	1639702.85	Yes	1342.89	1342.87	**-0.02**	1342.81	1342.84	1342.90
1601	1701157.21	1763546.30	Yes	1355.72	1355.71	**-0.01**	1355.68	1355.69	1355.79
1612	1574252.26	1767113.95	Yes	1413.95	1413.94	**-0.01**	1413.89	1413.90	1414.00
2645	1576959.56	1613339.76	Yes	1312.79	1312.78	**-0.01**	1312.68	1312.77	1312.93
2635	1534129.06	1639150.49	Yes	1332.65	1332.65	**0.00**	1332.57	1332.65	1332.82
2653	1676360.79	1630173.95	Yes	1328.66	1328.66	**0.00**	1328.65	1328.67	1328.75
1603	1544052.92	1702351.08	Yes	1533.89	1533.90	**0.01**	1533.83	1533.84	1533.96
2644	1534448.87	1618018.51	Yes	1344.04	1344.05	**0.01**	1344.02	1344.05	1344.07
2655	1692320.52	1630654.82	Yes	1318.71	1318.73	**0.02**	1318.70	1318.79	1318.89
1513	1611260.30	1767562.21	Yes	1376.16	1376.19	**0.03**	1376.13	1376.18	1376.30
2413	1688239.19	1641246.74	Yes	1315.26	1315.29	**0.03**	1315.28	1315.30	1315.34
1618	1669870.61	1736484.69	Yes	1430.16	1430.19	**0.03**	1430.10	1430.30	1430.38
1705	1548953.90	1718165.59	Yes	1510.33	1510.36	**0.03**	1510.21	1510.35	1510.62
2650	1629983.14	1609138.97	Yes	1243.49	1243.52	**0.03**	1243.43	1243.57	1243.65
1416	1585734.64	1718819.62	Yes	1380.60	1380.65	**0.05**	1380.48	1380.65	1380.93
2726	1539208.27	1672168.14	Yes	1419.35	1419.40	**0.05**	1419.28	1419.42	1419.54
2728	1571206.86	1650212.56	Yes	1409.66	1409.71	**0.05**	1409.67	1409.76	1409.77
1411	1713212.99	1718666.88	Yes	1348.59	1348.65	**0.06**	1348.40	1348.64	1348.71
2406	1607632.03	1660119.43	Yes	1338.46	1338.52	**0.06**	1338.45	1338.55	1338.57
2637	1602936.49	1640188.60	Yes	1341.34	1341.40	**0.06**	1341.32	1341.40	1341.52
1619	1574454.66	1746039.57	Yes	1398.41	1398.48	**0.07**	1398.22	1398.51	1398.51
1624	1564922.97	1713081.96	Yes	1494.82	1494.89	**0.07**	1494.50	1494.84	1495.00
2729	1592287.84	1640044.01	Yes	1385.36	1385.44	**0.08**	1385.07	1385.33	1385.46
1702	1590219.79	1762091.00	Yes	1397.56	1397.65	**0.09**	1397.57	1397.65	1397.71
1703	1553088.69	1766967.50	Yes	1431.09	1431.18	**0.09**	1431.02	1431.18	1431.21
2711	1587606.52	1613421.63	Yes	1276.42	1276.51	**0.09**	1276.36	1276.58	1276.73
1401	1579649.02	1761976.26	Yes	1405.06	1405.17	**0.11**	1404.89	1404.91	1405.19
1502	1580042.13	1735512.17	Yes	1410.39	1410.50	**0.11**	1410.21	1410.48	1410.54
1721	1595992.25	1724433.84	Yes	1381.87	1381.98	**0.11**	1381.82	1381.92	1382.00
2608	1603432.17	1608536.61	Yes	1258.58	1258.69	**0.11**	1258.66	1258.67	1258.76
2658	1702874.39	1641507.37	Yes	1337.40	1337.52	**0.12**	1337.36	1337.72	1337.73
2731	1560658.29	1634157.51	Yes	1300.30	1300.42	**0.12**	1300.11	1300.28	1300.48
2712	1622220.92	1609592.72	Yes	1246.22	1246.35	**0.13**	1246.26	1246.29	1246.47
1410	1685619.02	1720718.69	Yes	1406.82	1406.96	**0.14**	1406.87	1407.01	1407.07
1602	1542558.61	1766937.82	Yes	1440.78	1440.94	**0.16**	1440.94	1440.94	1441.09
1610	1701495.57	1742296.74	Yes	1357.48	1357.64	**0.16**	1357.62	1357.64	1357.75
2714	1681798.35	1614620.92	Yes	1288.13	1288.29	**0.16**	1288.22	1288.59	1288.67
2730	1624099.14	1630257.10	Yes	1278.97	1279.13	**0.16**	1279.08	1279.08	1279.18
2652	1687097.62	1614699.32	Yes	1269.45	1269.64	**0.19**	1269.39	1269.62	1269.68

1403	1600748.75	1756886.15	Yes	1387.18	1387.38	**0.20**	1387.35	1387.43	1387.44
1717	1691527.35	1722318.01	Yes	1416.15	1416.39	**0.24**	1416.33	1416.38	1416.41
1704	1542561.82	1753854.21	Yes	1449.89	1450.14	**0.25**	1449.84	1450.13	1450.20
2614	1512578.67	1669962.37	Yes	1426.26	1426.52	**0.26**	1426.19	1426.48	1426.60
2640	1544803.71	1628740.63	Yes	1326.02	1326.29	**0.27**	1326.14	1326.26	1326.46
2708	1513128.31	1628486.94	Yes	1405.62	1405.93	**0.31**	1405.75	1405.92	1406.07
2739	1682934.36	1641134.15	Yes	1288.11	1288.49	**0.38**	1287.86	1288.54	1288.69
1501	1579646.26	1756670.89	Yes	1404.59	1404.98	**0.39**	1404.92	1404.98	1404.98
2740	1701929.37	1662713.89	Yes	1334.46	1335.19	**0.73**	1335.03	1335.21	1335.21
1407	1627140.56	1767722.67	No	1385.01					
1408	1637793.83	1762465.88	No	1390.17					
1409	1639410.27	1741332.55	No	1346.73					
1417	1617169.30	1725262.92	No	1350.35					
1422	1685917.26	1704883.02	No	1389.06					
1423	1657417.04	1725898.37	No	1401.22					
1425	1595659.13	1741020.82	No	1385.03					
1503	1591066.09	1713473.05	No	1368.32					
1511	1701789.52	1710503.01	No	1345.43					
1514	1616684.93	1751779.66	No	1364.62					
1515	1637853.19	1757212.79	No	1378.84					
1516	1666692.93	1710201.18	No	1384.82					
1525	1627516.15	1735947.49	No	1352.73					
1526	1638396.59	1716876.83	No	1328.82					
1527	1595728.81	1735384.92	No	1378.52					
2402	1639376.53	1667662.48	No	1285.76					
2405	1581365.11	1671503.61	No	1460.14					
2412	1688653.16	1665913.28	No	1363.79					
2414	1668420.03	1642132.35	No	1316.46					
2415	1628169.07	1651529.03	No	1299.89					
2418	1636875.88	1685653.79	No	1307.67					
2419	1670607.75	1675390.79	No	1327.90					
2420	1659584.34	1702397.54	No	1362.33					
2421	1603535.56	1677575.17	No	1333.99					
2424	1707322.14	1673389.89	No	1320.32					
2504	1587762.61	1687466.45	No	1408.81					
2505	1591769.90	1671825.48	No	1432.18					
2507	1634829.25	1641308.35	No	1296.31					
2508	1663743.28	1630978.44	No	1245.10					
2509	1676418.07	1657017.10	No	1372.68					
2510	1718201.33	1663026.31	No	1337.35					
2517	1717823.85	1689456.05	No	1343.78					

2518	1686714.63	1688801.12	No	1374.80					
2519	1660870.29	1690187.76	No	1355.70					
2520	1686473.09	1673108.84	No	1353.00					
2521	1650456.82	1654454.80	No	1276.21					
2522	1628565.80	1672695.27	No	1296.14					
2523	1625670.24	1693906.94	No	1317.78					
2524	1645474.03	1700202.61	No	1310.95					
2528	1655649.55	1641326.24	No	1257.09					
2529	1702195.76	1684110.22	No	1302.76					
2530	1645273.30	1675113.40	No	1288.51					
4411	1706785.01	1715822.40	No	1351.67					
1617	1653548.75	1757312.27	No	1456.70					
1623	1606775.24	1719385.31	No	1358.25					
1627	1606429.96	1730192.77	No	1362.68					
1628	1664677.89	1720545.53	No	1398.58					
1659	1648546.64	1736174.72	No	1380.54					
2609	1650663.37	1614823.12	No	1255.16					
2629	1591271.73	1697991.63	No	1379.77					
2647	1629262.89	1635620.78	No	1295.70					
2649	1639998.78	1630565.80	No	1283.62					
2651	1666818.26	1615061.53	No	1231.51					
2654	1686724.42	1651932.34	No	1342.64					
2713	1656321.59	1609843.56	No	1235.71					
2732	1655795.39	1625507.17	No	1244.86					

Vertical Accuracy / Ground Cover Classification (Ground Truth Survey)

The following spreadsheet shows the GPS ground cover points (Ground Truth Survey) collected for the following three categories:
Bare_Ground-Short_Grass
Shrub-Short_Trees-Tall_Trees
Woodland
The ground cover survey (Ground Truth) was performed by Savoy Company P.A.

Bare_Ground-Short_Grass

Project File: Bare Ground Short Grass

Date: March 20: 2009

Vertical Accuracy Objective

Requirement Type: Accuracy(z)

Accuracy(z) Objective: 1.20

Confidence Level: 95%

Control Points in Report: 20

Elevation Calculation Method: Interpolated from TIN

Control Points with LiDAR Coverage: 20
Control Points with Required Accuracy (+/- 1.20): 20
Percent of Control Points with Required Accuracy (+/- 1.20): 100.00
Average Control Error Reported: 0.15
Maximum (highest) Control Error Reported: 0.62
Median Control Error Reported: 0.12
Minimum (lowest) Control Error Reported: -0.15
Standard deviation (sigma) of Z for sample: 0.19
RMSE of Z for sample (RMSE(z)): 0.24: PASS
FGDC/NSSDA Vertical Accuracy (Accuracy(z)): 0.47: PASS
NSSDA Achievable Contour Interval: 0.8
ASPRS Class 1 Achievable Contour Interval: 0.8
NMAS Achievable Contour Interval: 0.8

Control Point Id	Control Pt X (East) USFeet	Control Pt Y (North) USFeet	Coverage	Control Pt Z (Elev) USFeet	Z from LiDAR USFeet	**Z Error USFeet**	Min. Z USFeet	Median Z USFeet	Max. Z USFeet
2863	1613109.35	1645782.72	Yes	1325.07	1324.92	-0.15	1324.90	1324.91	1325.08
2860	1539178.89	1654846.02	Yes	1342.83	1342.71	-0.12	1342.53	1342.60	1342.82
2855	1520668.41	1663375.64	Yes	1385.11	1385.05	-0.06	1385.01	1385.02	1385.07
2854	1549607.23	1676349.05	Yes	1463.02	1463.01	-0.01	1462.98	1462.99	1463.02
2857	1539804.61	1612768.95	Yes	1381.62	1381.65	0.03	1381.58	1381.62	1381.67
2858	1566318.92	1613041.37	Yes	1317.36	1317.40	0.04	1317.32	1317.41	1317.42
2869	1653701.32	1740551.49	Yes	1393.05	1393.10	0.05	1393.08	1393.10	1393.12
2868	1649839.62	1751934.33	Yes	1420.25	1420.33	0.07	1420.27	1420.29	1420.37
2859	1555421.61	1649809.27	Yes	1384.41	1384.51	0.10	1384.19	1384.52	1384.59
2861	1603456.39	1619194.68	Yes	1276.61	1276.71	0.11	1276.65	1276.70	1276.87
2867	1690690.99	1758124.67	Yes	1380.87	1381.01	0.14	1380.96	1381.09	1381.17
2851	1553343.61	1750863.36	Yes	1442.40	1442.61	0.21	1442.47	1442.67	1442.69
2856	1518195.25	1649251.44	Yes	1359.31	1359.55	0.24	1359.39	1359.69	1359.71
2852	1564740.70	1723838.37	Yes	1425.98	1426.25	0.27	1426.21	1426.25	1426.27
2870	1664247.05	1754060.71	Yes	1446.60	1446.87	0.27	1446.71	1446.94	1446.96
2853	1601133.36	1728912.25	Yes	1368.50	1368.79	0.29	1368.64	1368.77	1368.83
2865	1677056.71	1635405.73	Yes	1288.05	1288.37	0.32	1288.28	1288.33	1288.51
2862	1603135.40	1634848.83	Yes	1348.74	1349.06	0.33	1348.84	1348.84	1349.10
2864	1678310.66	1615515.26	Yes	1301.10	1301.44	0.34	1301.42	1301.44	1301.49
2866	1664382.09	1731101.10	Yes	1410.41	1411.03	0.62	1411.00	1411.01	1411.12

Shrub-Short_Trees-Tall_Trees

Project File: Shrub Short Trees Tall Trees
Date: March 20: 2009
Vertical Accuracy Objective

Requirement Type: Accuracy(z)
Accuracy(z) Objective: 1.20
Confidence Level: 95%
Control Points in Report: 20
Elevation Calculation Method: Interpolated from TIN
Control Points with LiDAR Coverage: 20
Control Points with Required Accuracy (+/- 1.20): 20
Percent of Control Points with Required Accuracy (+/- 1.20): 100.00
Average Control Error Reported: 0.19
Maximum (highest) Control Error Reported: 0.43
Median Control Error Reported: 0.20
Minimum (lowest) Control Error Reported: -0.19
Standard deviation (sigma) of Z for sample: 0.17
RMSE of Z for sample (RMSE(z)): 0.25: PASS
FGDC/NSSDA Vertical Accuracy (Accuracy(z)): 0.49: PASS
NSSDA Achievable Contour Interval: 0.9
ASPRS Class 1 Achievable Contour Interval: 0.8
NMAS Achievable Contour Interval: 0.9

Control	Control Pt	Control Pt	Coverage	Control Pt	Z from	**Z Error**	Min.	Median	Max.
Point Id	X (East)	Y (North)		Z (Elev)	LiDAR		Z	Z	Z
	USFeet	USFeet		USFeet	USFeet	**USFeet**	USFeet	USFeet	USFeet
2820	1554713.68	1692174.06	Yes	1503.34	1503.15	-0.19	1502.98	1503.13	1503.24
2813	1512802.32	1659727.08	Yes	1390.19	1390.19	0.01	1390.19	1390.19	1390.22
2801	1665039.98	1768169.89	Yes	1465.21	1465.23	0.02	1465.15	1465.24	1465.25
2807	1613858.93	1619195.07	Yes	1257.61	1257.66	0.05	1257.63	1257.66	1257.71
2806	1634496.02	1635856.83	Yes	1289.18	1289.23	0.06	1289.21	1289.24	1289.24
2814	1532578.46	1691690.39	Yes	1464.66	1464.72	0.06	1464.66	1464.83	1464.87
2816	1581067.18	1687325.87	Yes	1440.34	1440.41	0.07	1440.06	1440.27	1440.51
2809	1586342.08	1661231.01	Yes	1407.32	1407.43	0.11	1407.32	1407.40	1407.47
2811	1534259.74	1628629.89	Yes	1349.09	1349.22	0.13	1349.19	1349.23	1349.24
2808	1592361.33	1640106.60	Yes	1386.17	1386.36	0.19	1386.21	1386.49	1386.60
2805	1661264.62	1614972.08	Yes	1232.90	1233.11	0.21	1233.07	1233.10	1233.12
2817	1580538.78	1713354.45	Yes	1397.59	1397.87	0.27	1397.72	1397.79	1397.93
2804	1697247.77	1657437.29	Yes	1352.60	1352.88	0.28	1352.61	1352.94	1352.99
2812	1515662.19	1628479.55	Yes	1404.46	1404.74	0.28	1404.58	1404.73	1404.81
2815	1565497.66	1681767.04	Yes	1488.73	1489.02	0.29	1488.87	1488.90	1489.11
2802	1696096.19	1747612.09	Yes	1331.88	1332.23	0.36	1332.18	1332.28	1332.34
2803	1691020.09	1715688.94	Yes	1388.18	1388.55	0.36	1388.52	1388.55	1388.56
2818	1569213.21	1743436.32	Yes	1410.77	1411.16	0.40	1410.78	1411.20	1411.34
2810	1571413.72	1629050.85	Yes	1294.85	1295.25	0.41	1295.14	1295.31	1295.58

2819	1563705.39	1761835.83	Yes	1422.33	1422.77	0.43	1422.57	1422.77	1422.90

Woodlands

Project File: Woodlands
Date: March 20: 2009
Vertical Accuracy Objective
Requirement Type: Accuracy(z)
Accuracy(z) Objective: 1.20
Confidence Level: 95%
Control Points in Report: 20
Elevation Calculation Method: Interpolated from TIN
Control Points with LiDAR Coverage: 20
Control Points with Required Accuracy (+/- 1.20): 20
Percent of Control Points with Required Accuracy (+/- 1.20): 100.00
Average Control Error Reported: 0.24
Maximum (highest) Control Error Reported: 0.91
Median Control Error Reported: 0.33
Minimum (lowest) Control Error Reported: -0.44
Standard deviation (sigma) of Z for sample: 0.41
RMSE of Z for sample (RMSE(z)): 0.46: PASS
FGDC/NSSDA Vertical Accuracy (Accuracy(z)): 0.91: PASS
NSSDA Achievable Contour Interval: 2.0
ASPRS Class 1 Achievable Contour Interval: 2.0
NMAS Achievable Contour Interval: 2.0

Control Point Id	Control Pt X (East)	Control Pt Y (North)	Coverage	Control Pt Z (Elev)	Z from LiDAR	**Z Error**	Min. Z	Median Z	Max. Z
	USFeet	USFeet		USFeet	USFeet	**USFeet**	USFeet	USFeet	USFeet
2911	1686944.00	1626544.96	Yes	1326.29	1325.86	-0.44	1325.74	1325.78	1326.10
2910	1637408.08	1619884.62	Yes	1265.75	1265.40	-0.35	1265.36	1265.36	1265.53
2918	1695174.75	1763407.31	Yes	1343.23	1342.88	-0.35	1342.71	1343.12	1343.12
2905	1533792.92	1643915.94	Yes	1319.65	1319.36	-0.28	1318.88	1319.76	1320.27
2906	1518552.85	1615209.42	Yes	1405.36	1405.27	-0.09	1404.24	1405.21	1405.80
2915	1680499.56	1742127.45	Yes	1391.88	1391.86	-0.03	1391.24	1391.86	1392.06
2917	1635904.71	1757321.16	Yes	1371.90	1371.92	0.03	1371.63	1371.96	1371.97
2916	1679932.74	1767573.44	Yes	1414.94	1415.03	0.09	1414.65	1415.12	1415.32
2920	1554091.58	1728989.95	Yes	1457.23	1457.37	0.14	1457.22	1457.54	1457.59
2908	1575492.67	1645266.40	Yes	1395.35	1395.66	0.31	1395.65	1395.66	1395.73
2909	1582524.58	1618435.09	Yes	1270.22	1270.57	0.34	1270.36	1270.53	1270.70
2904	1517576.87	1691282.41	Yes	1369.35	1369.73	0.38	1369.23	1369.76	1370.07
2907	1550635.94	1618196.80	Yes	1350.50	1350.93	0.43	1350.75	1350.96	1350.97
2912	1697419.48	1614957.36	Yes	1326.58	1327.04	0.46	1326.73	1327.21	1327.80

2901	1547930.29	1760380.35	Yes	1433.03	1433.56	0.53	1432.66	1433.30	1433.65
2914	1698304.68	1731552.77	Yes	1322.21	1322.78	0.58	1322.63	1322.67	1322.96
2903	1565015.92	1707993.46	Yes	1456.92	1457.53	0.62	1457.00	1457.60	1457.82
2919	1605924.68	1765197.48	Yes	1381.52	1382.21	0.70	1382.07	1382.16	1382.24
2902	1545321.83	1740597.86	Yes	1465.71	1466.53	0.82	1466.41	1466.63	1467.08
2913	1694795.56	1646977.09	Yes	1348.29	1349.20	0.91	1348.91	1349.12	1349.50

LiDAR CALIBRATION

Introduction

A LiDAR calibration or 'boresight' is performed on every mission to determine and eliminate systemic biases that occur within the hardware of the Leica ALS50 laser scanning system, the inertial measurement unit (IMU), and because of environmental conditions which affect the refraction of light. The systemic biases that are corrected for include roll, pitch, and heading.

Calibration Procedures

In order to correct the error in the data, misalignments of features in the overlap areas of the LiDAR flightlines must be detected and measured. At some point within the mission, a specfic flight pattern must be flown which shows all the misalignments that can be present. Typically, Merrick flies a pattern of at least three opposing direction and overlapping lines, three of which provide all the information required to calibrate the system.

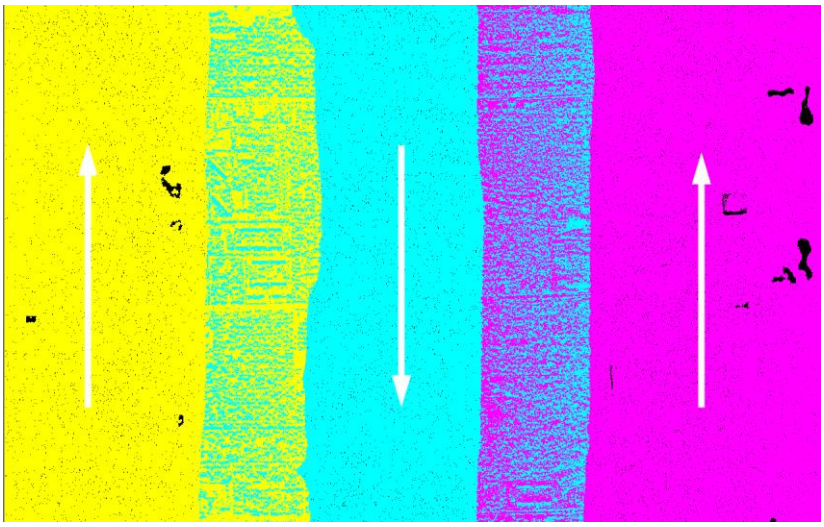


Figure 1: Flight pattern required for calibration

Correcting for Pitch and Heading Biases

There are many settings in the ALS40/50 post processor that can be used to manipulate the data; six are used for boresighting. They are roll, pitch, heading, torsion, range and atmospheric correction. The order in which each is evaluated is not very important and may be left to the discretion of the operator. For this discussion, pitch and heading will be evaluated first. It is important to remember that combinations of error can be very confusing, and this is especially true with pitch and heading. They affect the data in similar ways, so error attributed to pitch may be better blamed on heading and vice versa. To see a pitch/heading error, one must use the profile tool to cut along the flight path at a pitched roof or any elevation feature that is perpendicular to the flight path. View the data by elevation to locate these scenarios.

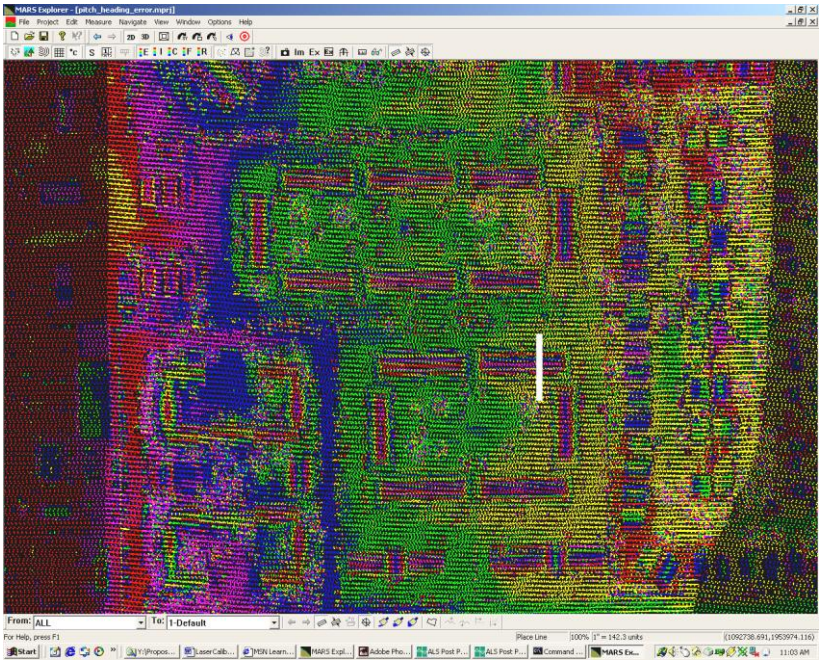


Figure 2: Orthographic view with profile line

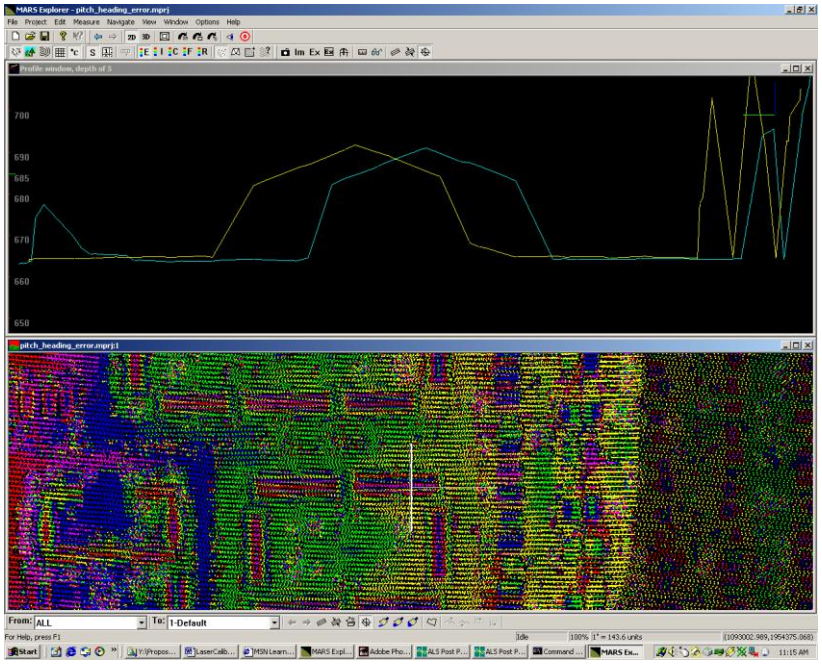


Figure 3: Profile view of misalignment

The profile line in figures 2 and 3 has an additional thin line perpendicular to the cut that shows the direction of the view. In this case, the line is pointing to the right, or east. In the profile window, we are looking through two separate TINs, so there are two lines showing the location of the same building. The yellow line is from the flight line on the left (flown north); the light blue line is from the flight line in the middle (flown south).

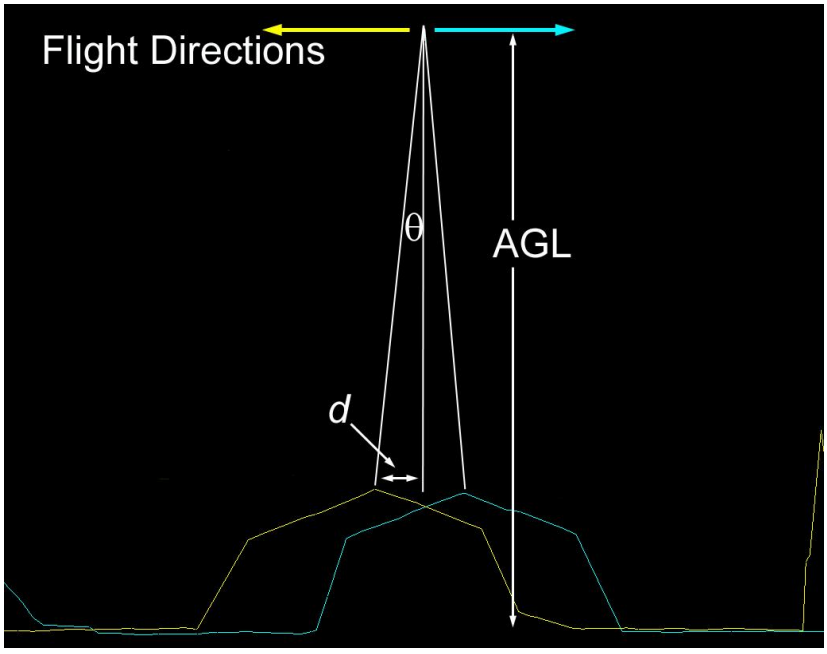


Figure 4: Adjusting pitch

The top arrows represent each respective flight direction. We are looking east, the yellow flight line was flown north, and the blue line is flown south. Adjusting pitch changes the relationship between the pitch from the IMU and the actual pitch of the plane. Increasing pitch sends the nose of the plane up and the data ahead in the flight direction. Lowering pitch does the opposite. In this example, pitch needs to decrease in order to bring these two roof lines together. The angle theta must be expressed in radians. The formula to arrive at this angle is…

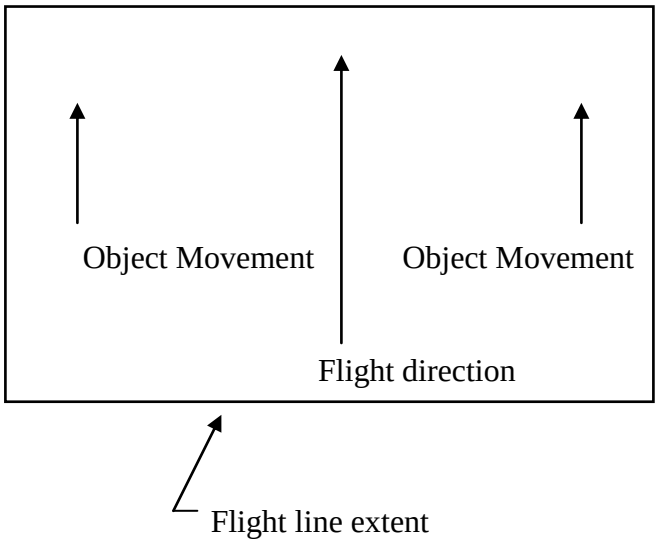
$$\theta = \frac{\arctan\left(\frac{d}{AGL}\right)}{57.2958}$$

where *d* is the distance from nadir (directly under the plane) to the peak of the roof and AGL is the 'above ground level' of the plane. The conversion from degrees to radians is one radian equals 57.2958 degrees. This number is then subtracted from the pitch value that was used to create the data.

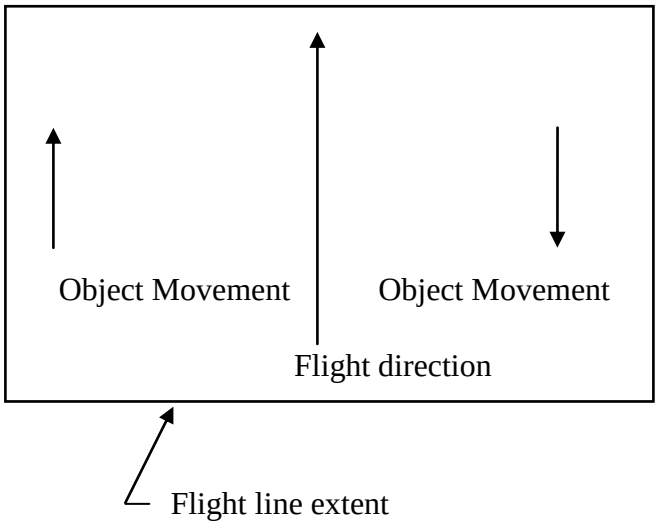
The next issue to resolve, before actually changing the pitch value, is to determine if this shift is at all due to an incorrect heading value, since heading will move data in the direction of flight also. The difference is that heading rotates the data, meaning that when heading is changed, objects on opposite sides of the swath move in opposite directions.

Figures 5 and 6: Pitch and Heading movement

Pitch increases, objects throughout the data move forward.



Heading increases, objects move clockwise.



When heading changes, objects on the sides of the flight line move in opposite directions. If heading is increased, objects in the flight line move in a clockwise direction. If heading is decreased, objects move in a counter-clockwise direction.

To find out if heading is correct, a similar profile line must be made in the overlap area between the middle flight line and the one to the east, or right side. If the distance *d* (see figure 4) is different on the right verses the left, then heading is partially responsible for the error. If the distance *d* is the same on both sides then heading *or* pitch is fully responsible.

Correcting for the Roll Bias

The purpose of a 'truth survey' is to evaluate roll and to ensure that the surface is accurate vertically. This survey is typically done in a localized area and the purpose is to provide a truth reference to every mission and to help in the calibration effort. Since every mission's data must be compared to this survey, it makes sense for this survey to be done at a place where the plane will be for every mission, i.e., the airport. The survey is done along a taxiway or runway, and the calibration flight lines are flown perpendicular to it, which makes it perfect for evaluating roll.

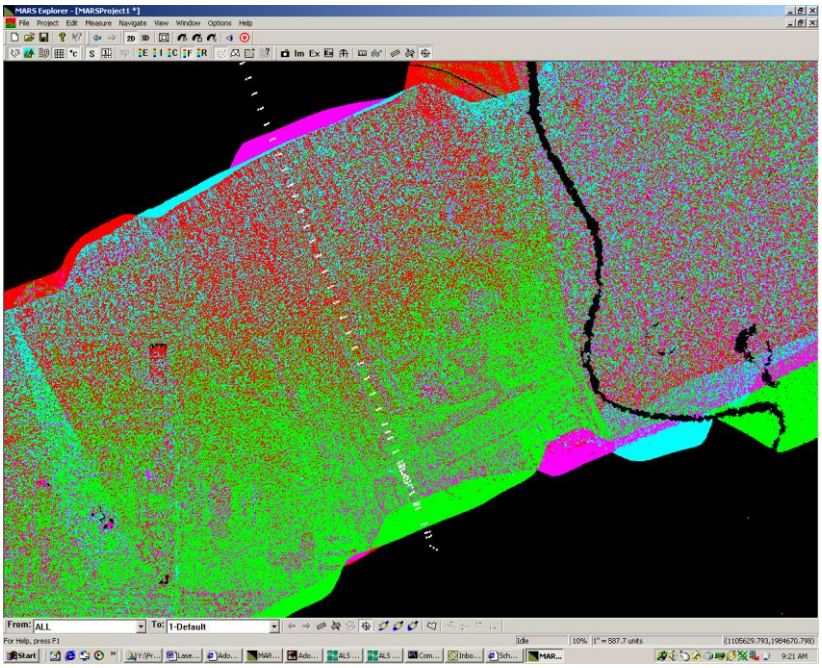


Figure 7: The truth survey

The white dots represent the survey, and four flight lines, two from the beginning of the mission and two from the end, have been flown. Each pair of flight lines was flown in opposite directions, and in this case the red and blue lines were flown east and the green and magenta lines were flown west. The first step is to make a profile line across the survey. It is important to create this cut on one side of the taxiway so as to avoid cutting through and over the crown. Once the profile is created, exaggeration of the elevation by 100 times is necessary to see the pattern. (Figure 8)

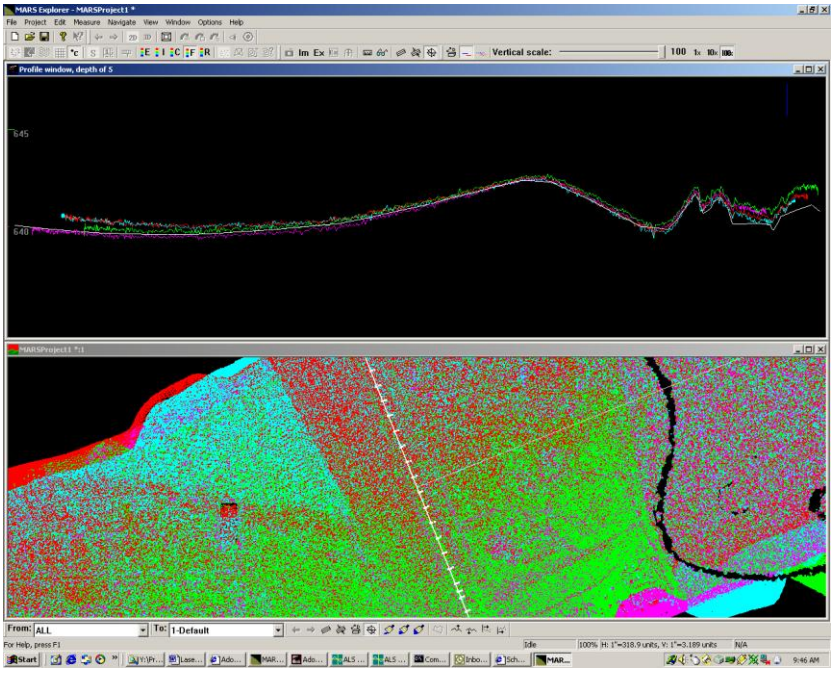


Figure 8: Profile view of calibration flight lines

Even without zooming in, a pattern is already apparent. The two east flown lines, red and blue, are high on the left compared to the west flown lines, and low on the right. Since the profile line was created with the view eastward, it is easiest to think about what the east lines are doing. The east lines are low on the right, which means the relationship between the IMU and the right wing of the plane must be adjusted up. As in heading adjustments, sending the data in a clockwise direction is positive. If the axis of the clock is the tail/nose axis of the plane, then it is obvious this data must go in a counter clock-wise, or negative direction. The method for determining the magnitude of the adjustment is similar to determining the magnitude of the adjustment for the pitch. The only difference is how the triangles are drawn in relationship to the data. (Figures 9 and 10)

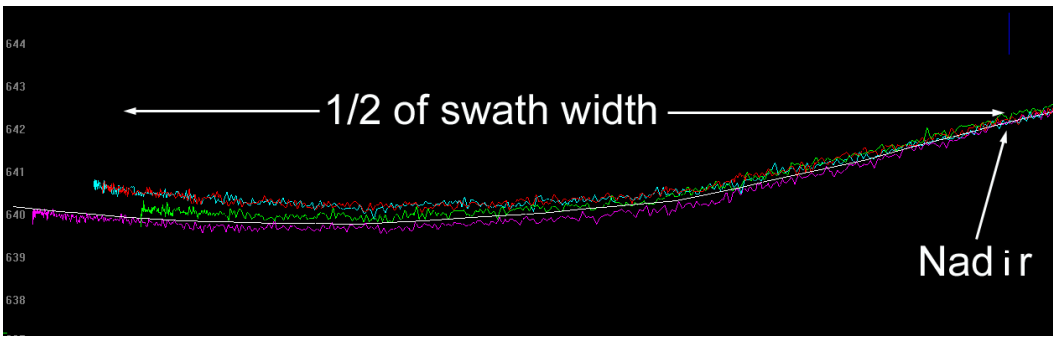


Figure 9: Half of calibration profile

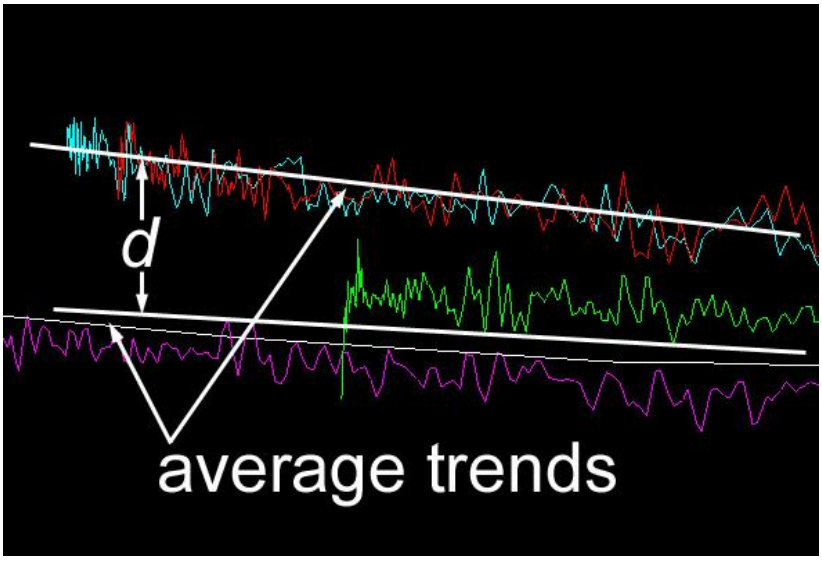


Figure 10: Differences in average roll trends

The important measurements for this formula are the distance from nadir to the edge of the swath, or ½ swath width, and d, the distance from the two average trend lines for each group. Since any adjustments made to roll effect both east and west lines, we are really interested in ½ d; this will give the value that will bring both sets of lines together. The formula is:

$$\theta = \frac{\arctan\left(\frac{d/2}{EdgeToNadir}\right)}{57.2958}$$

Correcting the Final Elevation

The next step is to ensure that all missions have the same vertical offset. Two techniques are used to achieve this. The first is to compare all calibration flight lines and shift the missions appropriately. The second is to fly an extra 'cross flight' which touches all flight lines in the project. Each mission's vertical differences can then be analyzed and corrected. However, the result of this exercise is only proof of a high level of relative accuracy. Since many of the calibration techniques affect elevation, project wide GPS control must be utilized to place the surface in the correct location. This can be achieved by utilizing the elevation offset control in the post processor or by shifting the data appropriately in MARS®. The control network may be pre-existing or collected by a licensed surveyor. This is always the last step and is the only way to achieve the high absolute accuracy that is the overall goal.