City of Wichita
Kansas
LiDAR Mapping Report

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 Wichita/Sedgwick LiDAR project 02015796.**

This is to certify that the aerial mapping contained in the Hard Drive Disk labeled City of Wichita 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 0.3 ft RMSE ($Accuracy_z$ = 0.6 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:

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.

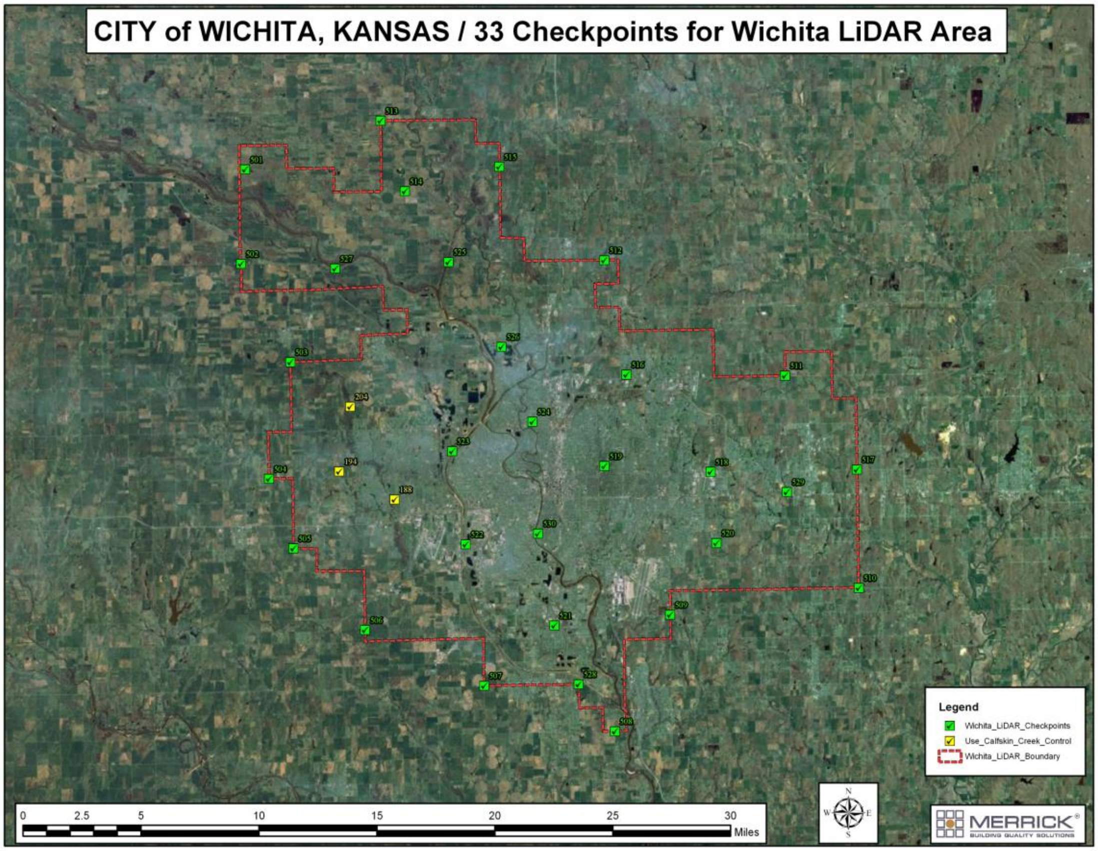
This is to certify that the aerial mapping contained on the Hard Drive Disk labeled City of Wichita/Sedgwick County Job No. 02015796 was done under my direct supervision. The data has been tested to meet the client-specified 0.3 ft RMSE ($Accuracy_z$ = 0.6 ft) on flat, bare-ground in accordance with 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.

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. For the first part, Merrick & Company obtained LiDAR data over approximately 422 square miles for the City of Wichita. The LiDAR data has been collected at a Ground Sample Distance (GSD) of 2 foot to meet accuracy for 1-foot contour interval. The City of Wichita boundary is shown with the red line in the graphic below.



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 City of Wichita, and Sedgwick County 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 City of Wichita and Sedgwick County Kansas.

LiDAR FLIGHT and SYSTEM REPORT

Project Location
The project location for the City of Wichita is defined by the client provided shapefile “Wichita_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 March 20, 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

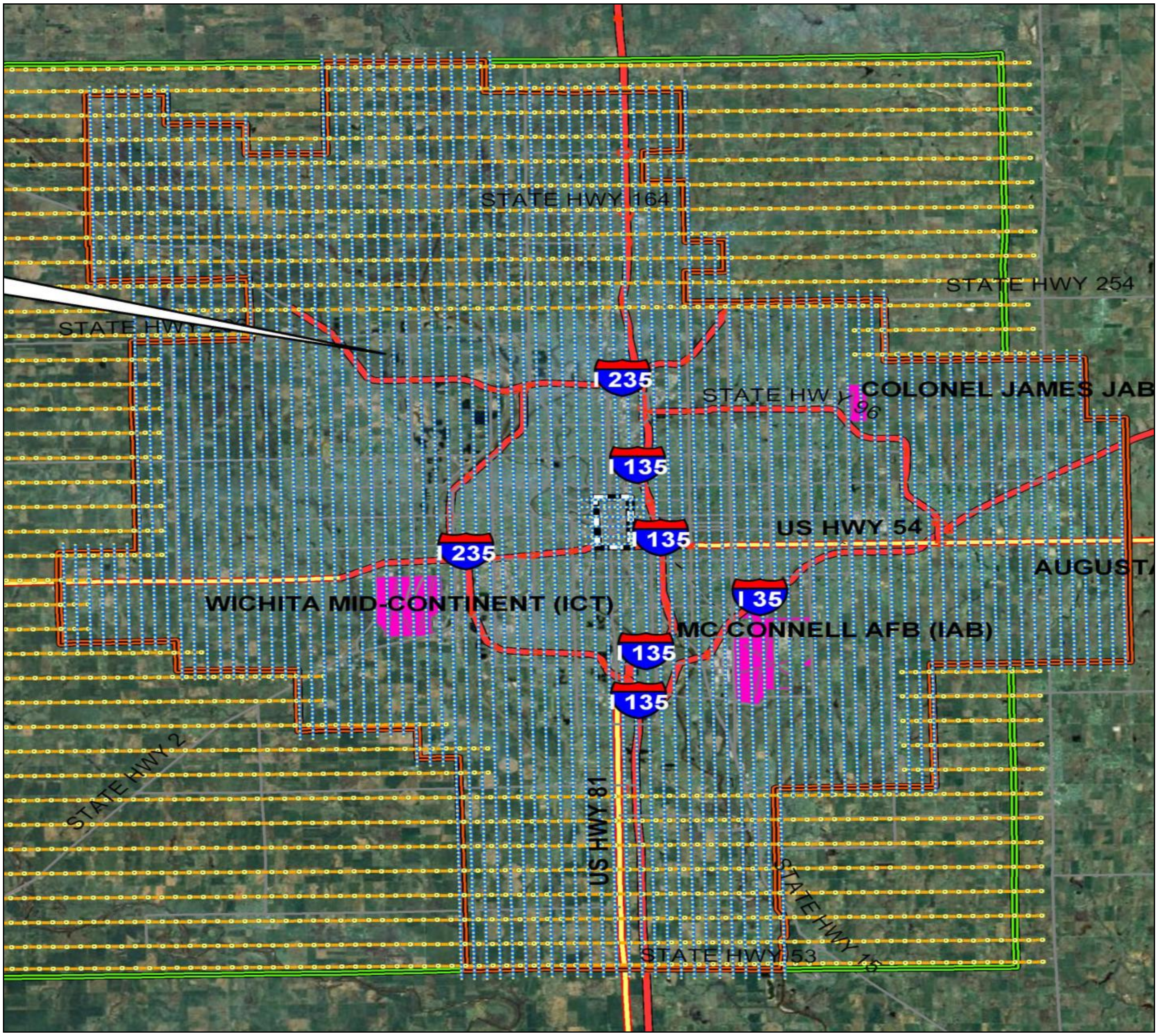
LiDAR Sensor	Leica Geosystems ALS50 Phase 2
Nominal Ground Sample Distance	0.45 meters
Average Altitude	5,500 Feet AMSL
Average Airspeed	~100 Knots
Scan Rate	47.2 Hertz
Scan FOV (scan angle)	30˚
Pulse Rate	150,000 Hertz

Mission	Date	Start Time	End Time	Length Time
080309A	March 09, 2008	60069 sec. 16:41:09 GMT	75232 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

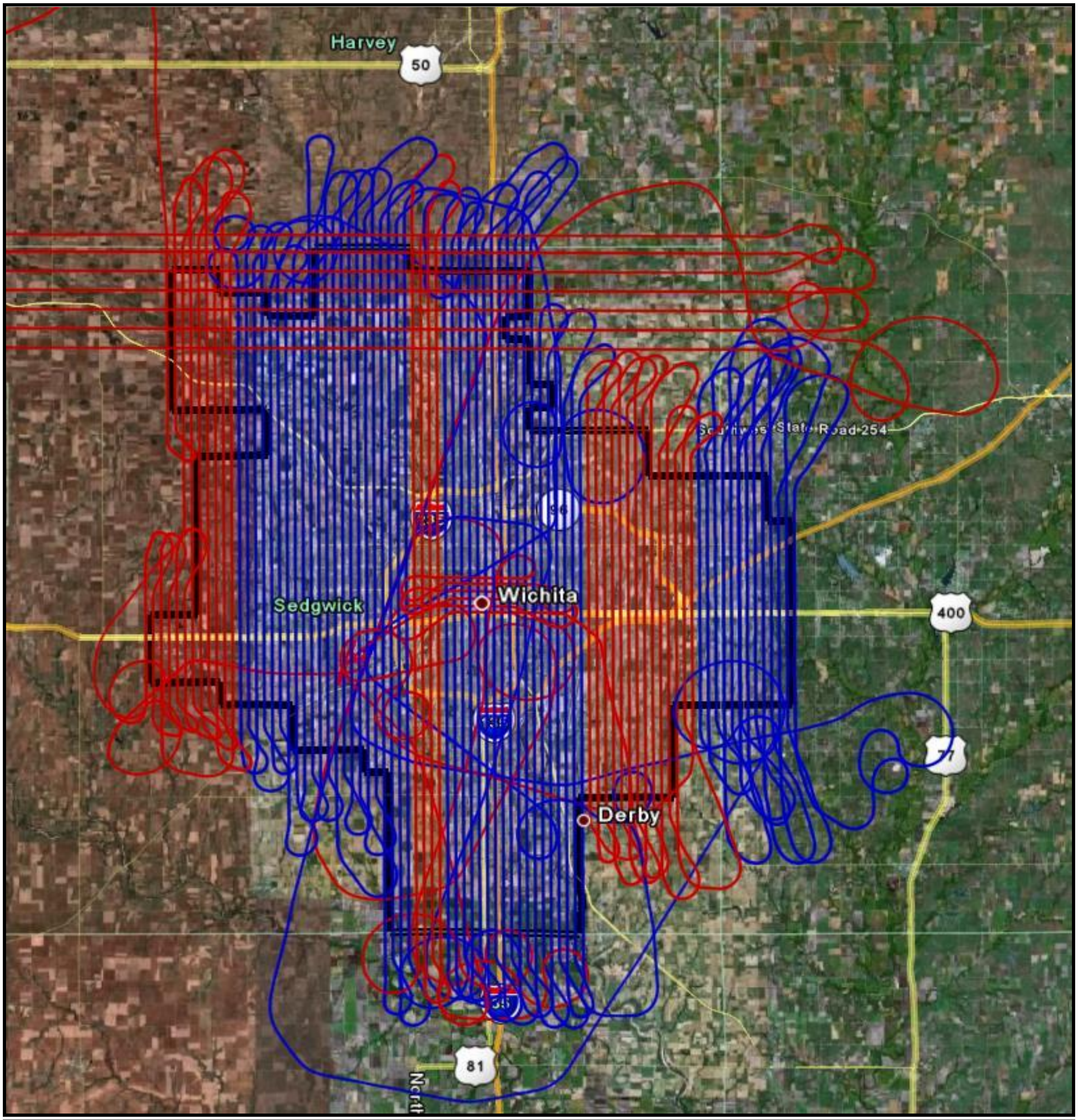
Field Work / Procedures

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.
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.

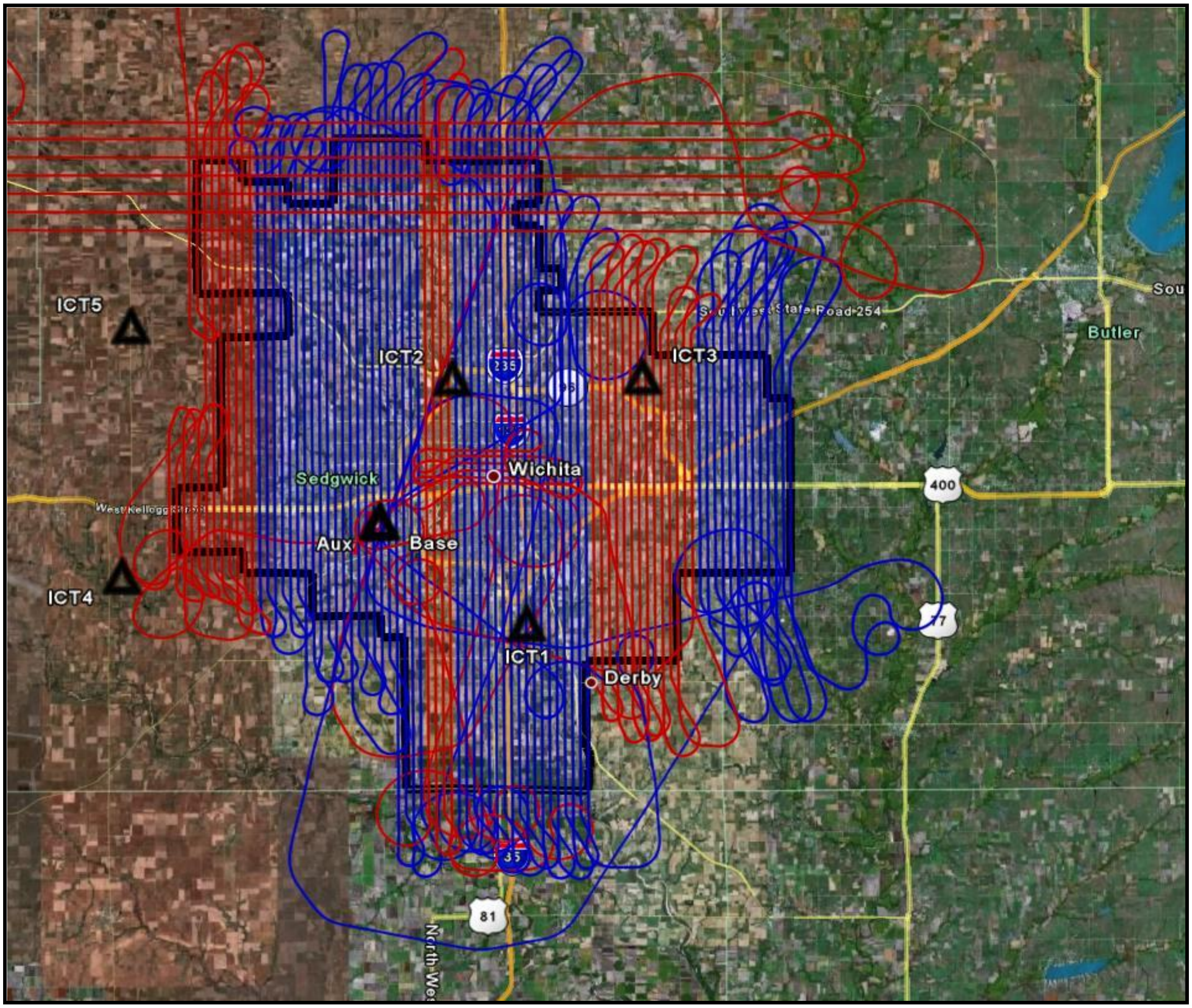
Flight Diagram for Wichita Kansas (North South Lines) also shows part of flight lines for Sedgwick County (East-West Lines).



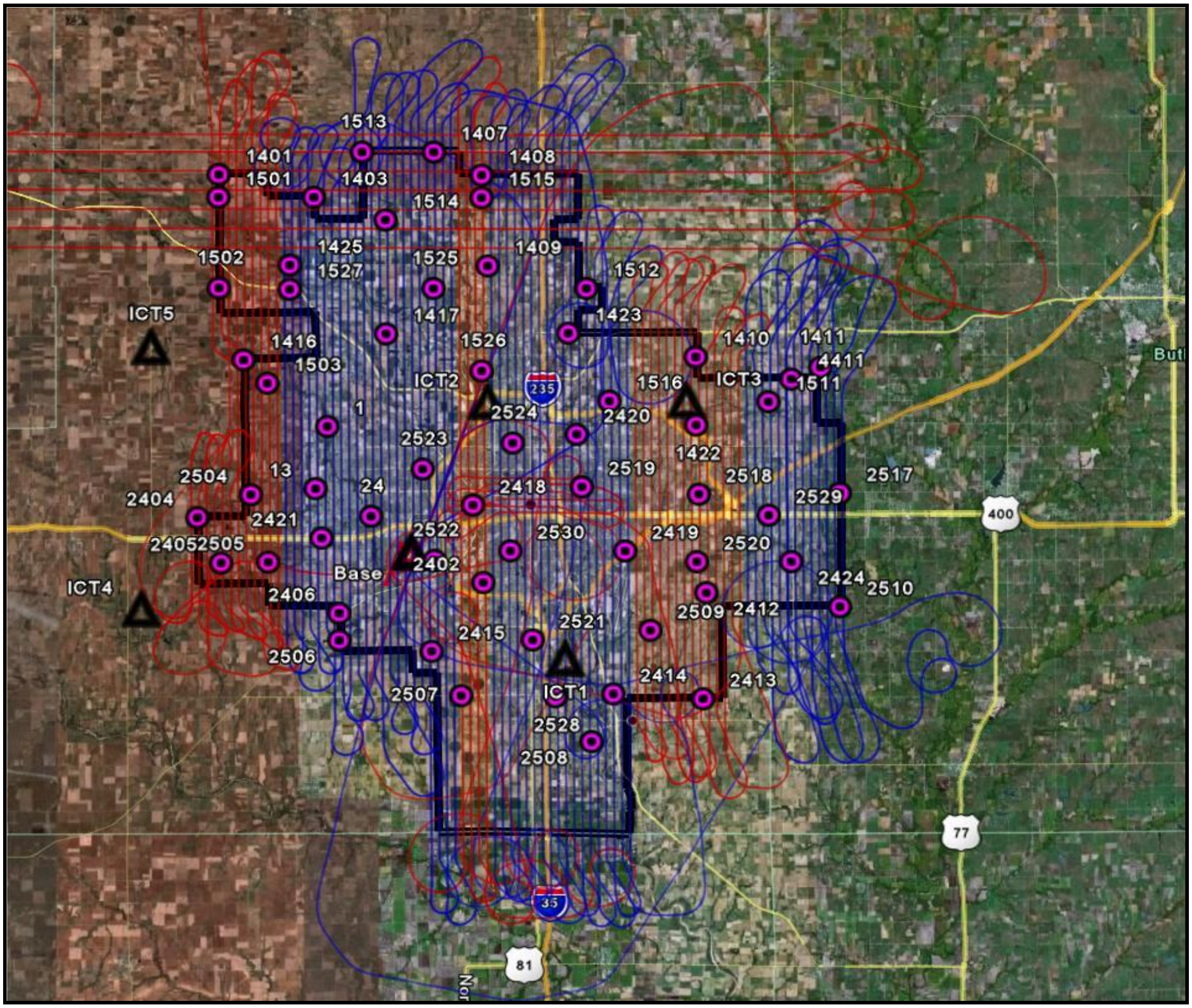
Actual Flight Lines for Wichita Kansas



Actual Flight Lines for Wichita Kansas with Base Stations

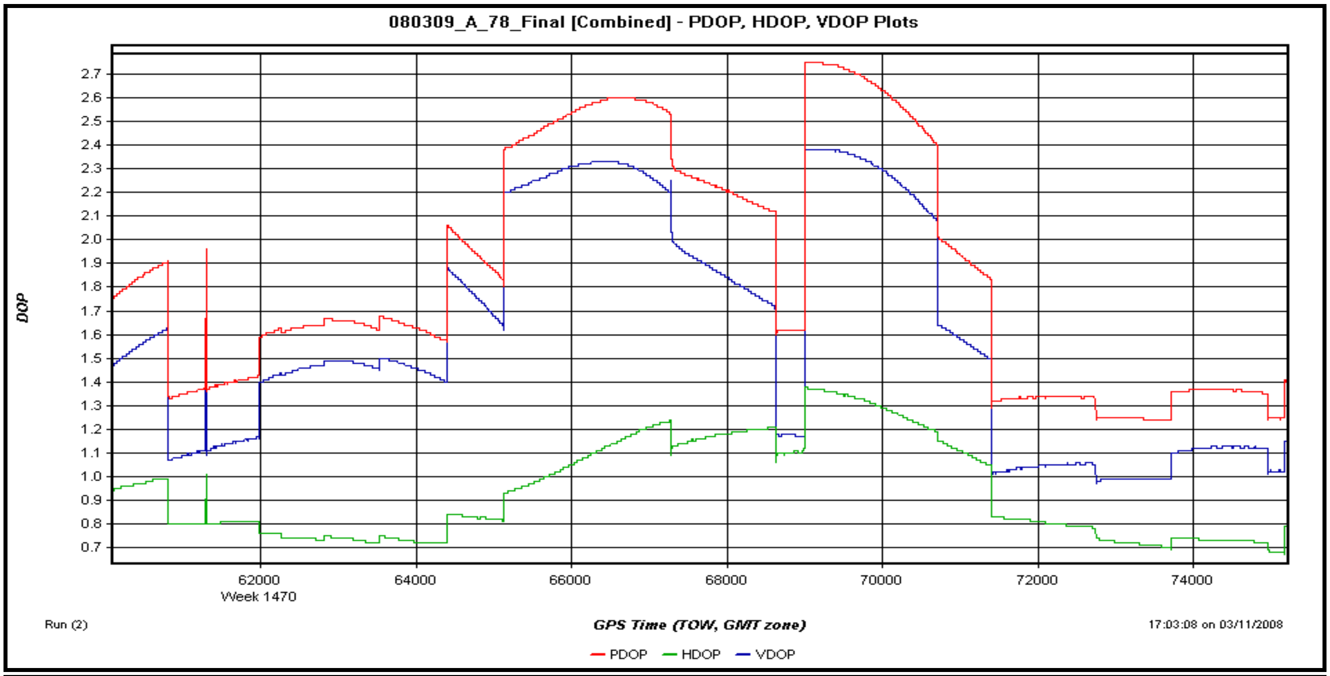


<u>Actual Flight Lines for Wichita Kansas with Base Stations and Ground Control</u>

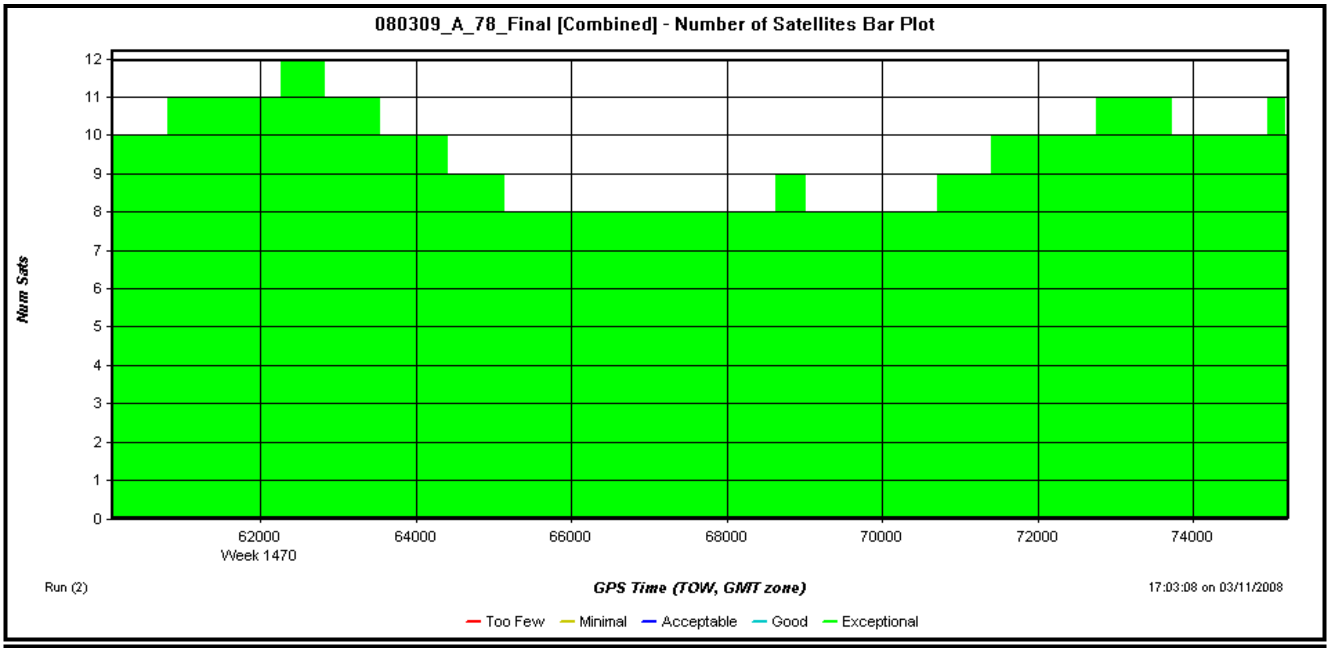


The following Graphs Show the mission by mission PDOP (Positional Dilution Of Precision) Plots and the Number of Satellites Plots.

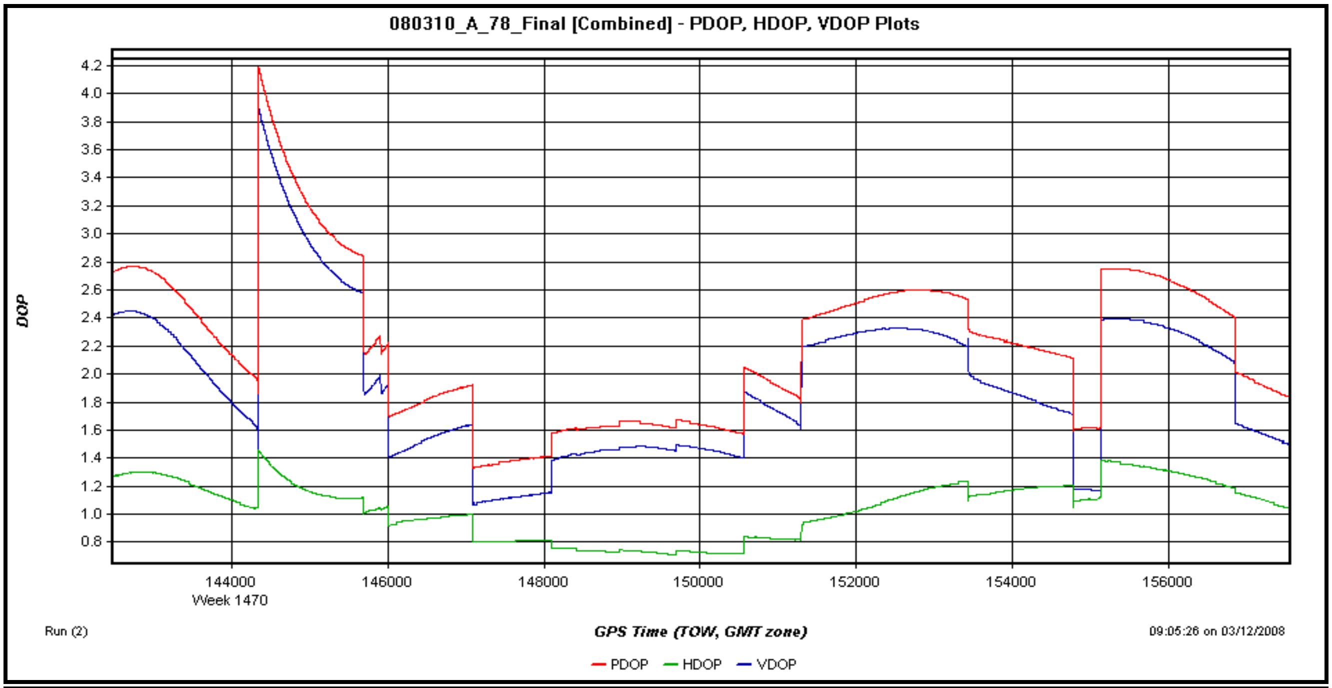
PDOP (Positional Dilution of Precision) Plot for mission 080309



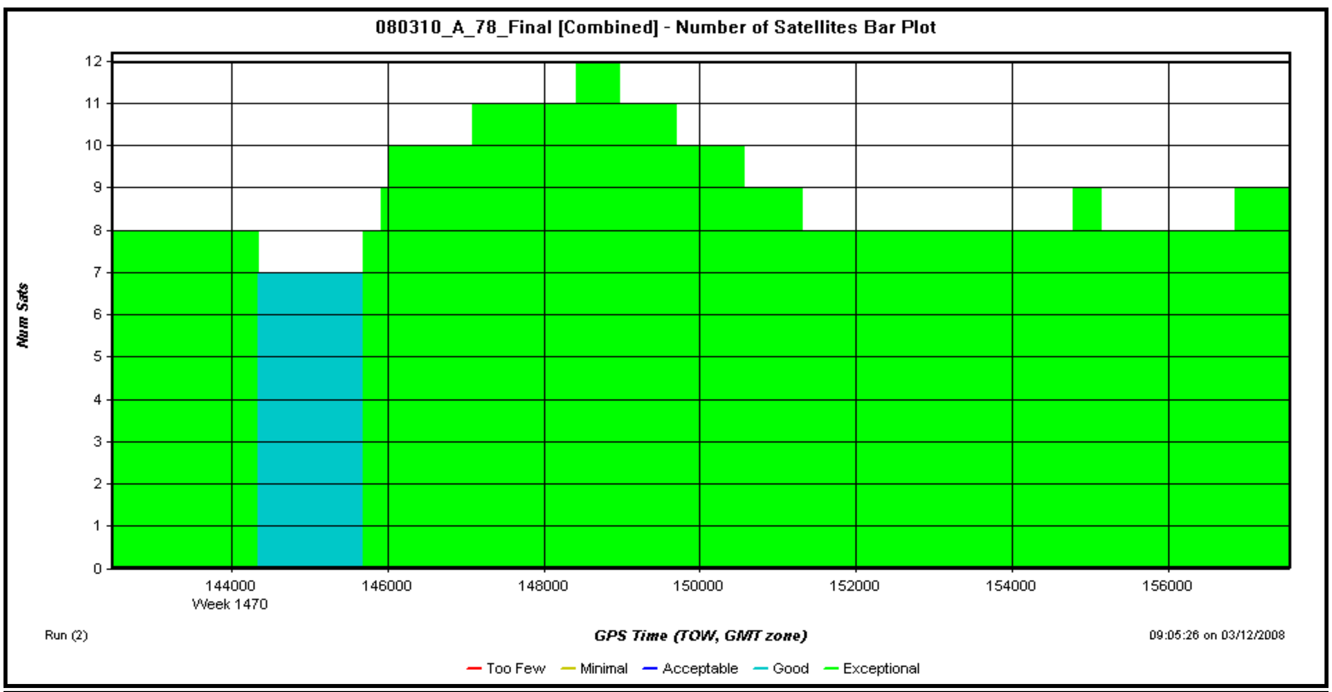
Number of Satellites for mission 080309



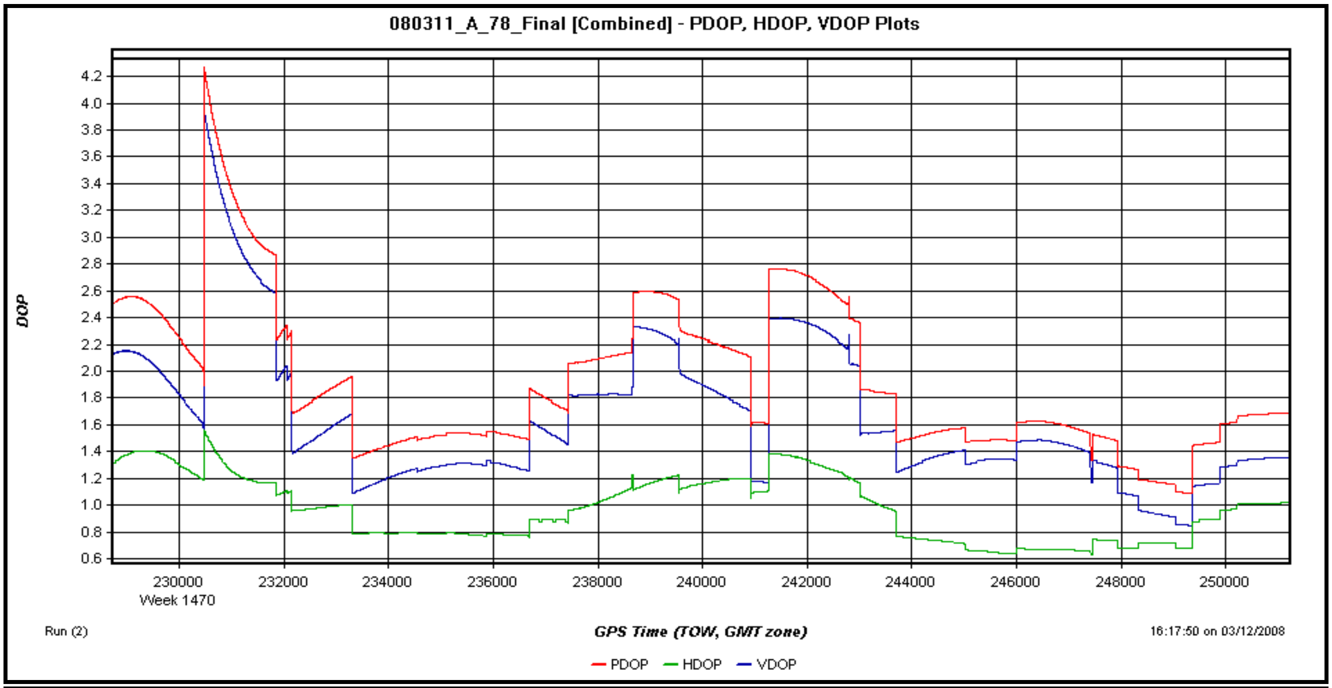
PDOP (Positional Dilution of Precision) Plot for mission 080310



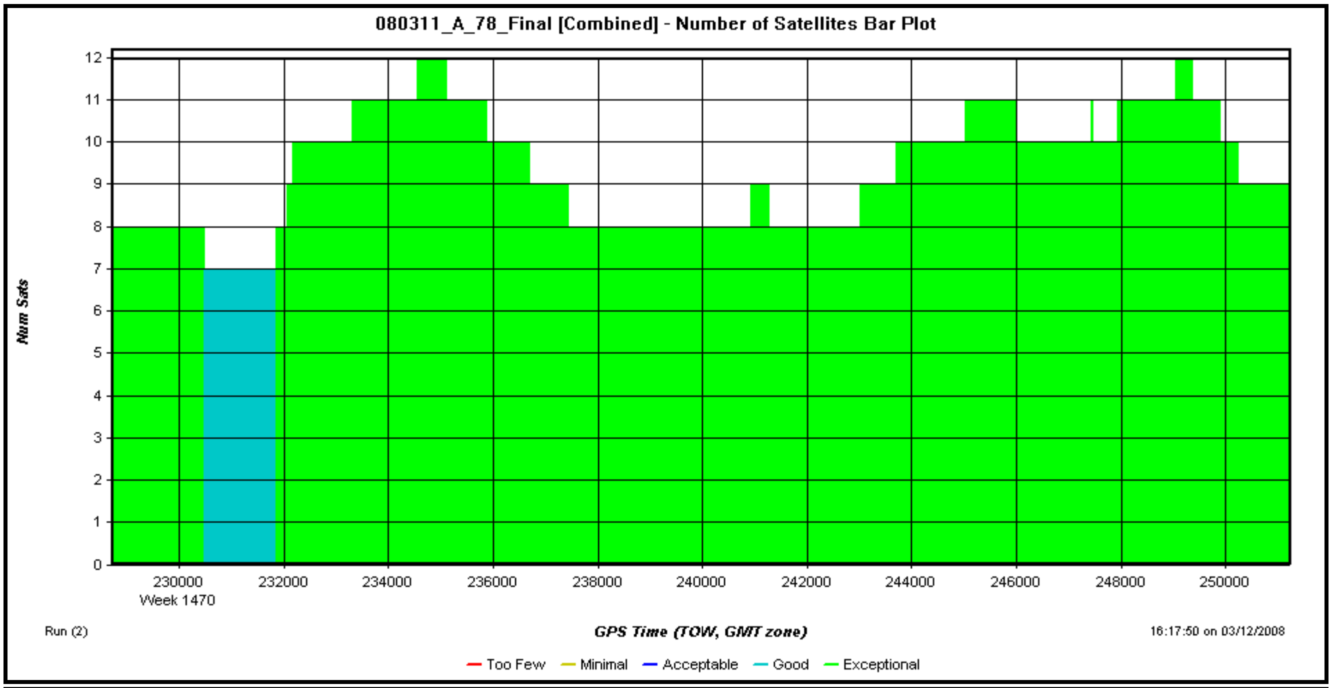
Number of Satellites for mission 080310



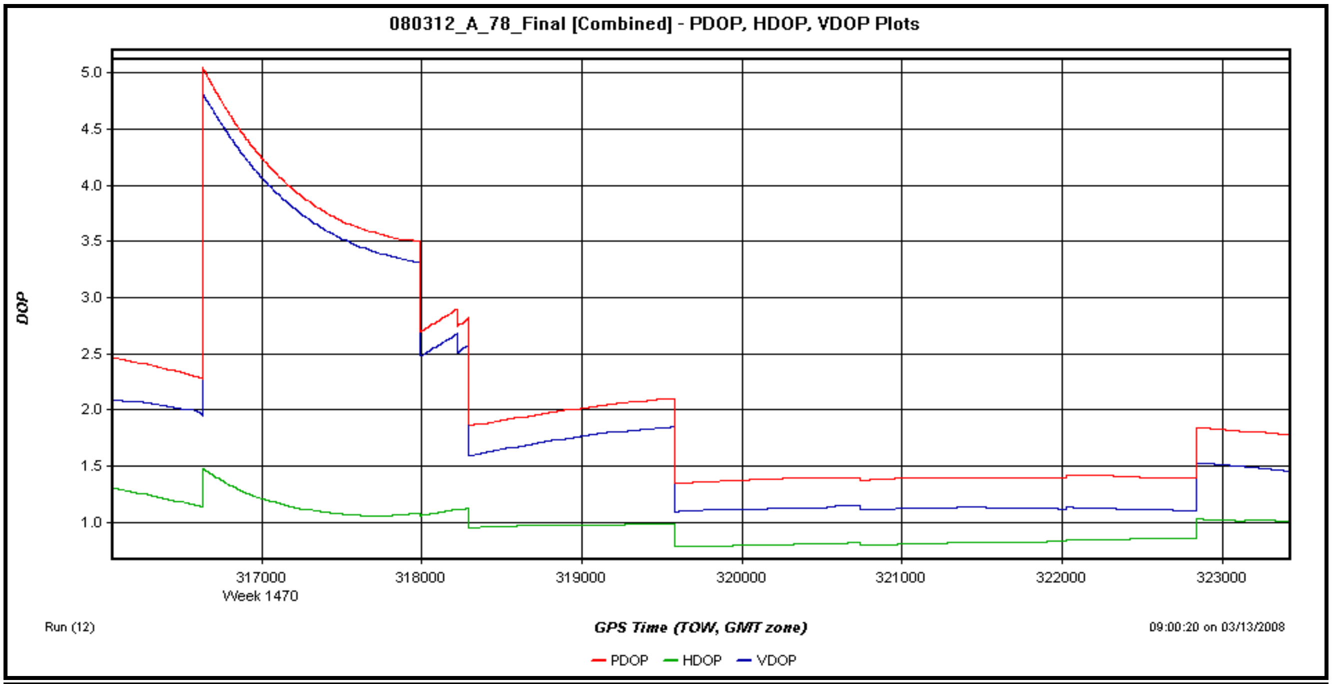
PDOP (Positional Dilution of Precision) Plot for mission 080311



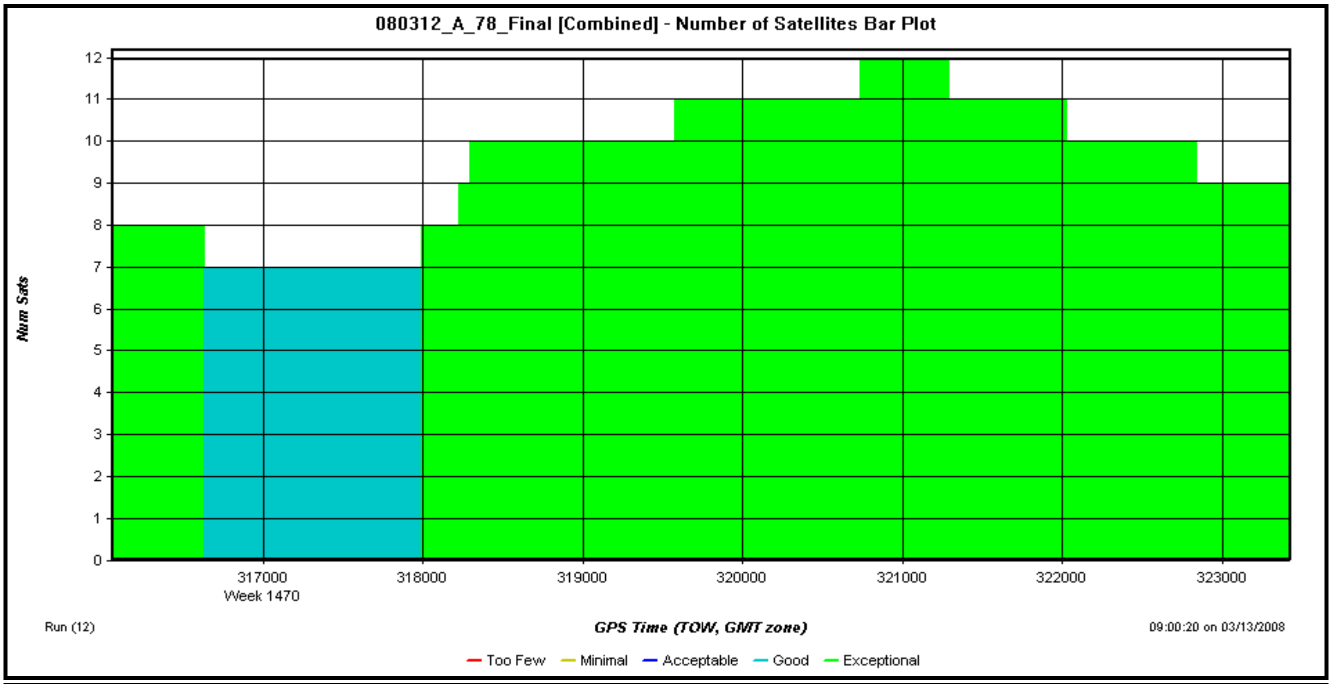
Number of Satellites for mission 080311



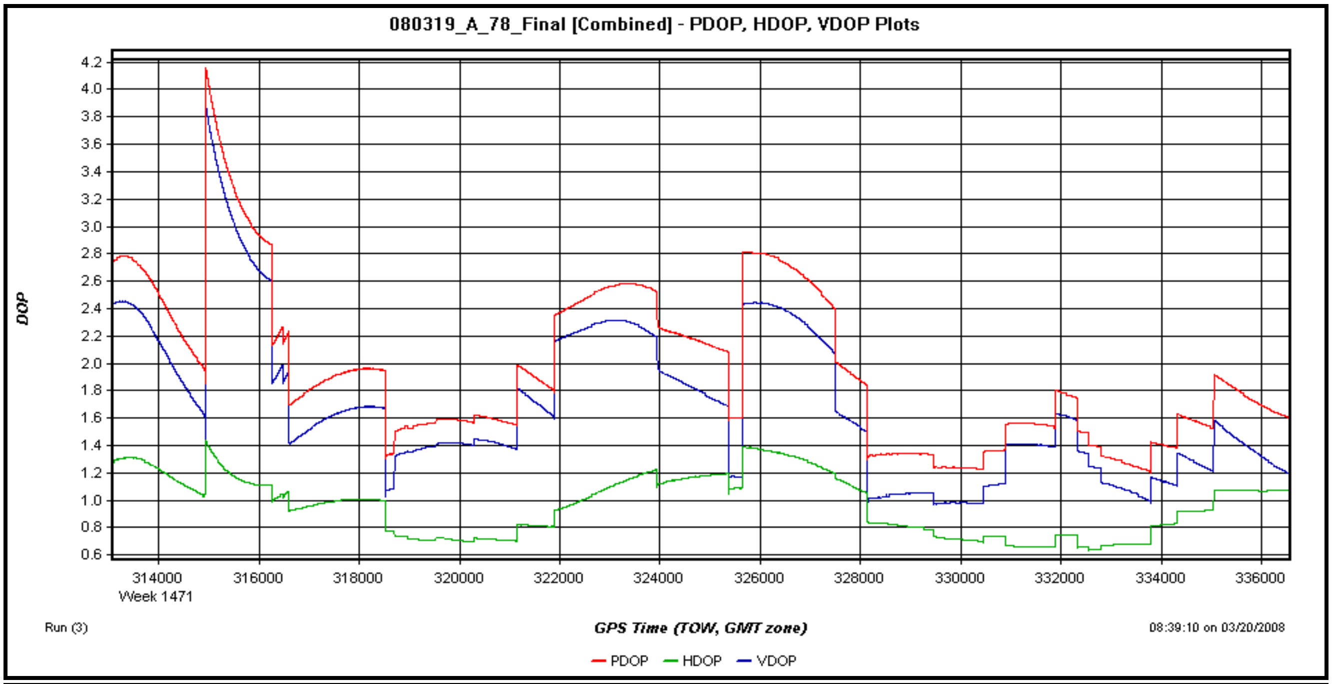
PDOP (Positional Dilution of Precision) Plot for mission 080312



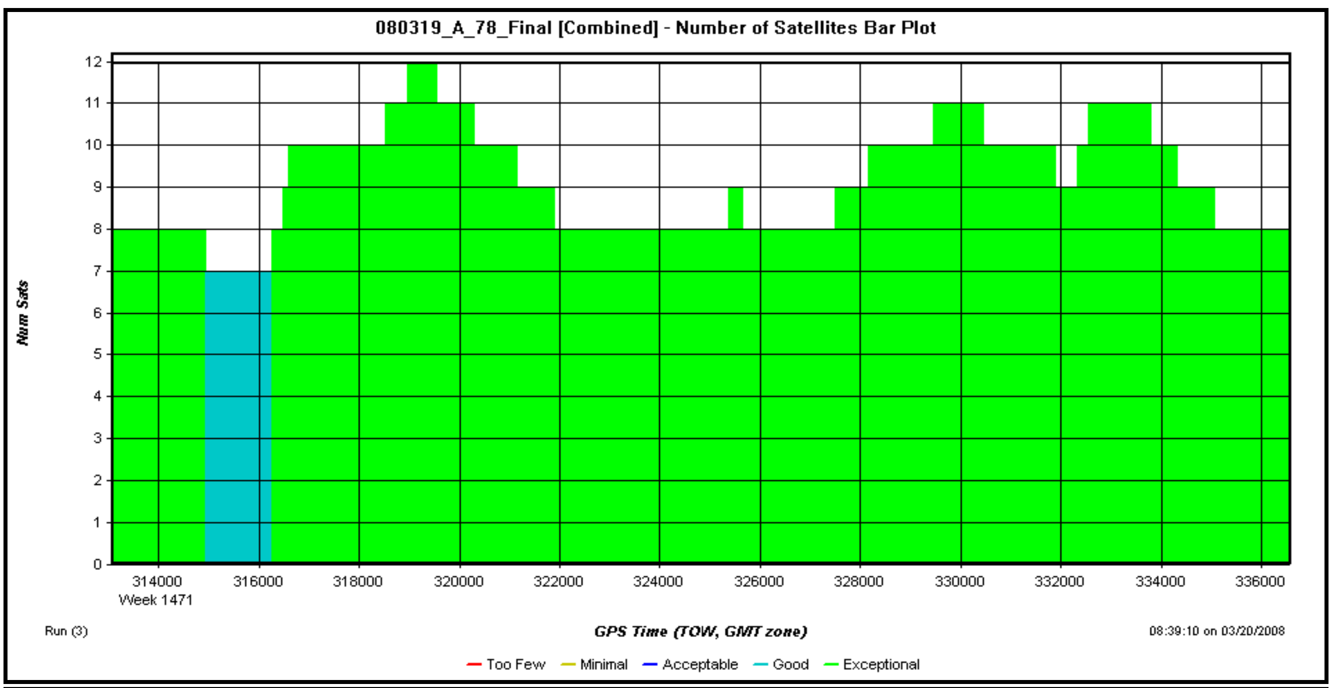
Number of Satellites for mission 080312



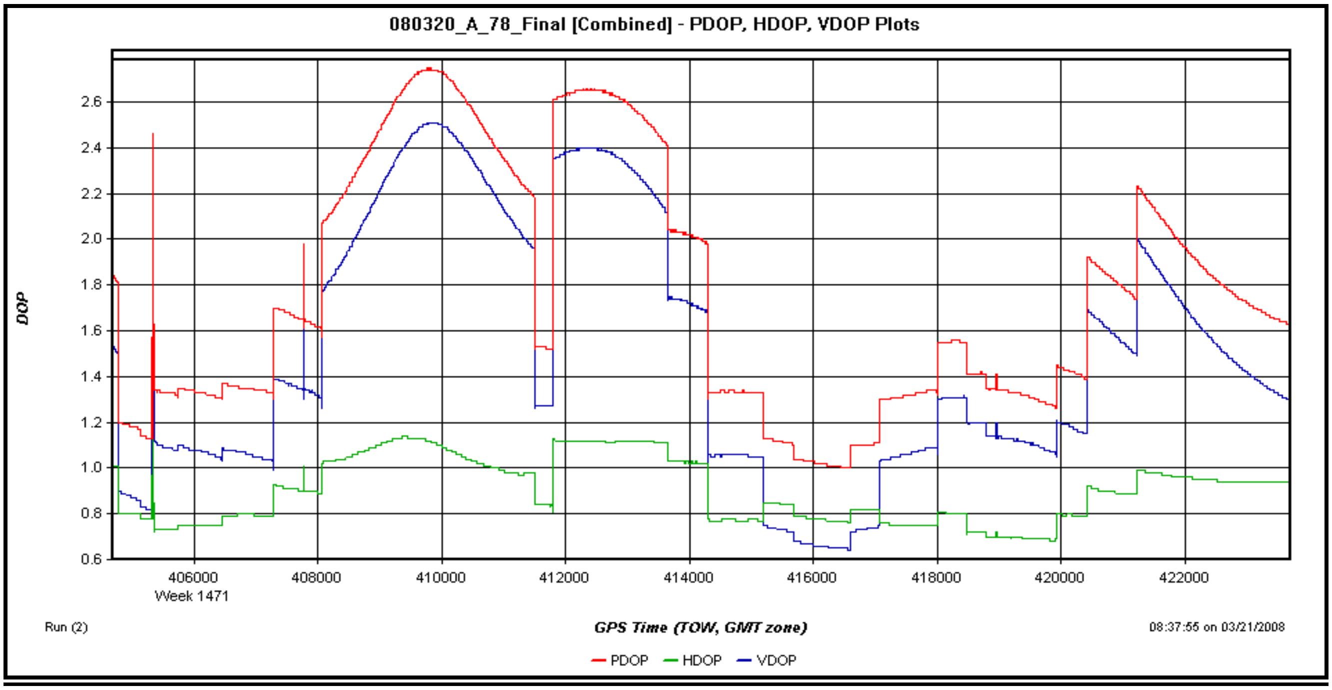
PDOP (Positional Dilution of Precision) Plot for mission 080319



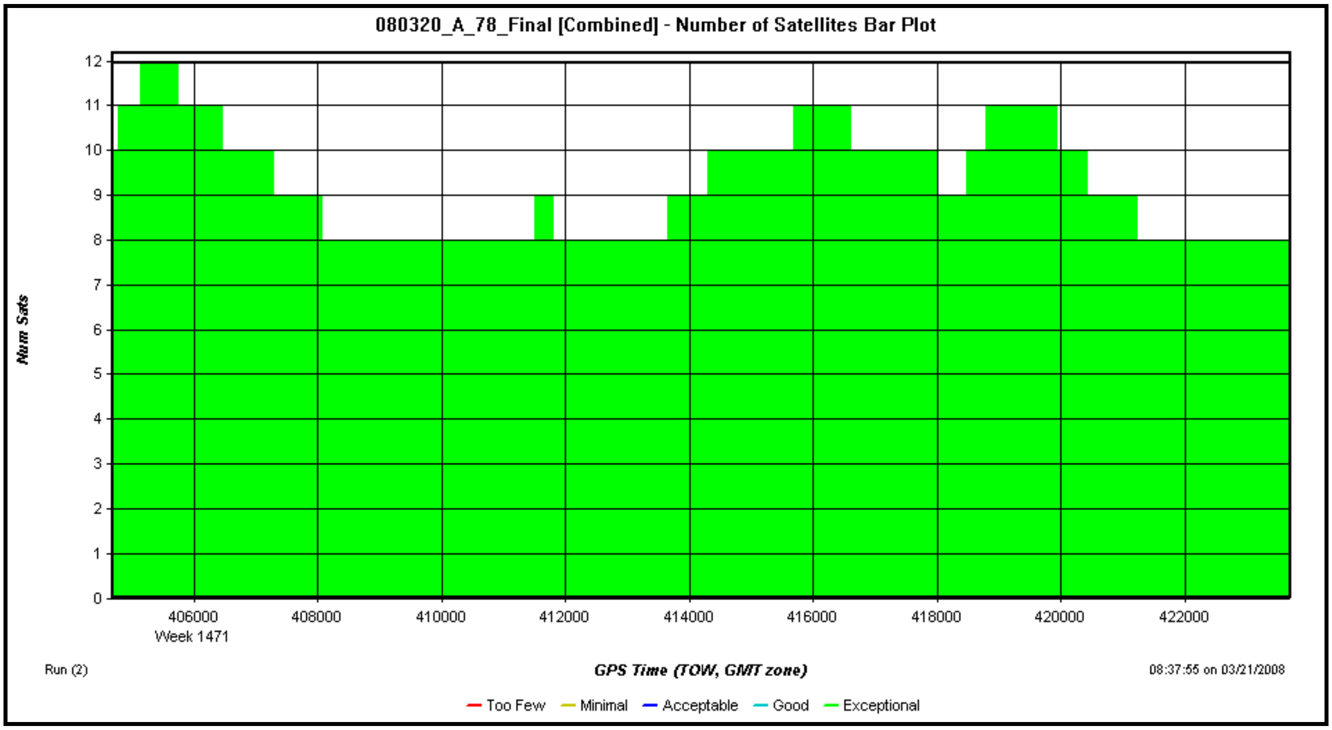
Number of Satellites for mission 080319



PDOP (Positional Dilution of Precision) Plot for mission 080320



Number of Satellites for mission 080320



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 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. HDOP stands for Horizontal Dilution Of Precision and VDOP stands for Vertical Dilution Of Precision. 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: 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. as detailed in *Wichita/Sedgwick County, Kansas Ground Control Survey Report*, signed and sealed by Mark Savoy, LS #788 on March 31, 2009.

Project: 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#	SP NAD83 Zone Kansas South		NAVD88	DESCRIPTION
Name	NORTHING	EASTING	Elevation	
	Y	X	Z	
	US Feet	US Feet	US Feet	
1401	1761976.26	1579649.02	1405.06	NW COR RD STRIPE
1403	1756886.15	1600748.75	1387.18	SE COR RD STRIPE
1407	1767722.67	1627140.56	1385.01	NW COR STRIPE
1408	1762465.88	1637793.83	1390.17	NW CRN STRIPE
1409	1741332.55	1639410.27	1346.73	PT. OF ARROW
1410	1720718.69	1685619.02	1406.82	COR 2 STRIPES
1411	1718666.88	1713212.99	1348.59	NE COR E STRIPE
1416	1718819.62	1585734.64	1380.60	NW COR RD STRIPE
1417	1725262.92	1617169.30	1350.35	NW COR RD STRIPE
1422	1704883.02	1685917.26	1389.06	SW COR BRICK SW
1423	1725898.37	1657417.04	1401.22	NE COR INLET
1425	1741020.82	1595659.13	1385.03	SW COR RD STRIPE
1501	1756670.89	1579646.26	1404.59	INTERSEC GRAV RD
1502	1735512.17	1580042.13	1410.39	INTERSEC ROADS

1503	1713473.05	1591066.09	1368.32	NE COR RD STRIPE
1511	1710503.01	1701789.52	1345.43	CTR RCBC E 159TH
1512	1736370.23	1661281.66	1384.11	E END RD STRIPE
1513	1767562.21	1611260.30	1376.16	CTR GRAVEL RDS
1514	1751779.66	1616684.93	1364.62	Y TARGET
1515	1757212.79	1637853.19	1378.84	N. END STRIPE
1516	1710201.18	1666692.93	1384.82	SE COR PRK STRIP
1525	1735947.49	1627516.15	1352.73	CTR Y TARGET
1526	1716876.83	1638396.59	1328.82	PT. OF ARROW
1527	1735384.92	1595728.81	1378.52	INTERSEC RD STRI
2402	1667662.48	1639376.53	1285.76	WLK
2404	1681987.18	1575991.67	1450.67	END STRIPE
2405	1671503.61	1581365.11	1460.14	WLK
2406	1660119.43	1607632.03	1338.46	EC
2412	1665913.28	1688653.16	1363.79	EC
2413	1641246.74	1688239.19	1315.26	END PAINT STRIPE
2414	1642132.35	1668420.03	1316.46	WLK
2415	1651529.03	1628169.07	1299.89	MAG
2418	1685653.79	1636875.88	1307.67	END PS
2419	1675390.79	1670607.75	1327.90	WLK
2420	1702397.54	1659584.34	1362.33	WLK
2421	1677575.17	1603535.56	1333.99	END STRIPE
2424	1673389.89	1707322.14	1320.32	END STRIPE
2504	1687466.45	1587762.61	1408.81	SAV TRAV PT
2505	1671825.48	1591769.90	1432.18	MAG
2506	1653813.43	1607740.75	1335.02	SAV TRAV PT
2507	1641308.35	1634829.25	1296.31	SAV TRAV PT
2508	1630978.44	1663743.28	1245.10	SAV TRAV PT
2509	1657017.10	1676418.07	1372.68	SAV TRAV PT
2510	1663026.31	1718201.33	1337.35	60D
2517	1689456.05	1717823.85	1343.78	60D
2518	1688801.12	1686714.63	1374.80	MAG
2519	1690187.76	1660870.29	1355.70	SAV TRAV PT
2520	1673108.84	1686473.09	1353.00	SAV TRAV PT
2521	1654454.80	1650456.82	1276.21	MAG
2522	1672695.27	1628565.80	1296.14	SAV TRAV PT
2523	1693906.94	1625670.24	1317.78	MAG
2524	1700202.61	1645474.03	1310.95	SAV TRAV PT
2528	1641326.24	1655649.55	1257.09	SAV TRAV PT
2529	1684110.22	1702195.76	1302.76	SAV TRAV PT
2530	1675113.40	1645273.30	1288.51	SAV TRAV PT
4411	1715822.40	1706785.01	1351.67	NE COR RD STRIPE
1	1703554.38	1604470.52	1353.17	Calfskin_Creek_CTR_BRIDGE
13	1689060.42	1602021.77	1351.14	Calfskin_Creek_CTR_32X18_CMAC
24	1682773.87	1614392.73	1323.37	Calfskin_Creek_CTR_BRIDGE

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 City of Wichita Kansas

Project File = MARSProjectWichita
Date = August 03 = 2008
Vertical Accuracy Objective
Requirement Type = Accuracy(z)
Accuracy(z) Objective = 0.60
Confidence Level = 95%
Control Points in Report = 156
Elevation Calculation Method = Interpolated from TIN
Control Points with LiDAR Coverage = 77
Control Points with Required Accuracy (0.60) = 77
Percent of Control Points with Required Accuracy (0.60) = 100.00
Average Control Error Reported = -0.01
Maximum (highest) Control Error Reported = 0.38
Median Control Error Reported = -0.02
Minimum (lowest) Control Error Reported = -0.24
Standard deviation (sigma) of Z for sample = 0.11
RMSE of Z for sample (RMSE(z)) = 0.11 = PASS
FGDC/NSSDA Vertical Accuracy (Accuracy(z)) = 0.22 = PASS
NSSDA Achievable Contour Interval = 0.4
ASPRS Class 1 Achievable Contour Interval = 0.4
NMAS Achievable Contour Interval = 0.4

Control	Control	Control	Coverage	Control	Z from	**Z Error**	Min.	Median	Max.
Point Id	Pt X (East)	Pt Y (North)		Pt Z (Elev)	LiDAR		Z	Z	Z
	USFeet	USFeet		USFeet	USFeet	**USFeet**	USFeet	USFeet	USFeet
1513	1611260.30	1767562.21	Yes	1376.16	1375.92	**-0.24**	1375.89	1375.95	1376.01
2736	1591677.78	1661383.56	Yes	1387.60	1387.37	**-0.23**	1387.32	1387.35	1387.40
1628	1664677.89	1720545.53	Yes	1398.58	1398.37	**-0.21**	1398.35	1398.38	1398.44
1515	1637853.19	1757212.79	Yes	1378.84	1378.65	**-0.19**	1378.57	1378.70	1378.70
1408	1637793.83	1762465.88	Yes	1390.17	1389.99	**-0.18**	1389.98	1389.99	1390.00
1503	1591066.09	1713473.05	Yes	1368.32	1368.14	**-0.18**	1368.02	1368.14	1368.23
2504	1587762.61	1687466.45	Yes	1408.81	1408.63	**-0.18**	1408.58	1408.64	1408.67
1659	1648546.64	1736174.72	Yes	1380.54	1380.38	**-0.16**	1380.34	1380.41	1380.50
1417	1617169.30	1725262.92	Yes	1350.35	1350.20	**-0.15**	1350.11	1350.22	1350.25
1516	1666692.93	1710201.18	Yes	1384.82	1384.68	**-0.14**	1384.57	1384.59	1384.71

1407	1627140.56	1767722.67	Yes	1385.01	1384.88	**-0.13**	1384.87	1384.88	1384.90
1423	1657417.04	1725898.37	Yes	1401.22	1401.09	**-0.13**	1401.00	1401.11	1401.14
1720	1674928.12	1725900.07	Yes	1423.17	1423.04	**-0.13**	1422.88	1423.03	1423.07
2414	1668420.03	1642132.35	Yes	1316.46	1316.33	**-0.13**	1316.30	1316.32	1316.39
2507	1634829.25	1641308.35	Yes	1296.31	1296.18	**-0.13**	1296.15	1296.17	1296.23
1526	1638396.59	1716876.83	Yes	1328.82	1328.70	**-0.12**	1328.53	1328.79	1328.89
2424	1707322.14	1673389.89	Yes	1320.32	1320.21	**-0.11**	1320.17	1320.23	1320.24
2505	1591769.90	1671825.48	Yes	1432.18	1432.08	**-0.10**	1432.03	1432.09	1432.11
2412	1688653.16	1665913.28	Yes	1363.79	1363.70	**-0.09**	1363.62	1363.69	1363.76
2732	1655795.39	1625507.17	Yes	1244.86	1244.77	**-0.09**	1244.76	1244.86	1244.87
1401	1579649.02	1761976.26	Yes	1405.06	1404.98	**-0.08**	1404.93	1404.94	1405.05
2509	1676418.07	1657017.10	Yes	1372.68	1372.60	**-0.08**	1372.57	1372.65	1372.71
2415	1628169.07	1651529.03	Yes	1299.89	1299.82	**-0.07**	1299.77	1299.81	1299.87
2421	1603535.56	1677575.17	Yes	1333.99	1333.92	**-0.07**	1333.91	1333.91	1333.99
1514	1616684.93	1751779.66	Yes	1364.62	1364.56	**-0.06**	1364.53	1364.57	1364.61
2418	1636875.88	1685653.79	Yes	1307.67	1307.61	**-0.06**	1307.53	1307.63	1307.65
1410	1685619.02	1720718.69	Yes	1406.82	1406.77	**-0.05**	1406.77	1406.77	1406.78
1425	1595659.13	1741020.82	Yes	1385.03	1384.98	**-0.05**	1384.92	1385.01	1385.02
1511	1701789.52	1710503.01	Yes	1345.43	1345.38	**-0.05**	1345.29	1345.39	1345.43
1702	1590219.79	1762091.00	Yes	1397.56	1397.51	**-0.05**	1397.48	1397.52	1397.52
2523	1625670.24	1693906.94	Yes	1317.78	1317.73	**-0.05**	1317.71	1317.71	1317.82
1617	1653548.75	1757312.27	Yes	1456.70	1456.66	**-0.04**	1456.64	1456.65	1456.69
2510	1718201.33	1663026.31	Yes	1337.35	1337.31	**-0.04**	1337.23	1337.31	1337.34
2518	1686714.63	1688801.12	Yes	1374.80	1374.76	**-0.04**	1374.70	1374.78	1374.94
2413	1688239.19	1641246.74	Yes	1315.26	1315.23	**-0.03**	1315.12	1315.16	1315.26
1512	1661281.66	1736370.23	Yes	1384.11	1384.09	**-0.02**	1383.91	1384.05	1384.12
1622	1609445.56	1751654.48	Yes	1375.12	1375.10	**-0.02**	1375.03	1375.10	1375.16
2506	1607740.75	1653813.43	Yes	1335.02	1335.00	**-0.02**	1334.99	1335.01	1335.01
2739	1682934.36	1641134.15	Yes	1288.11	1288.09	**-0.02**	1287.96	1288.16	1288.22
2402	1639376.53	1667662.48	Yes	1285.76	1285.75	**-0.01**	1285.73	1285.75	1285.80
1416	1585734.64	1718819.62	Yes	1380.60	1380.60	**0.00**	1380.55	1380.61	1380.63
2420	1659584.34	1702397.54	Yes	1362.33	1362.33	**0.00**	1362.19	1362.37	1362.65
2609	1650663.37	1614823.12	Yes	1255.16	1255.17	**0.01**	1255.06	1255.19	1255.22
2654	1686724.42	1651932.34	Yes	1342.64	1342.65	**0.01**	1342.65	1342.66	1342.72
4411	1706785.01	1715822.40	Yes	1351.67	1351.68	**0.01**	1351.67	1351.68	1351.68
2521	1650456.82	1654454.80	Yes	1276.21	1276.23	**0.02**	1276.18	1276.25	1276.30
1623	1606775.24	1719385.31	Yes	1358.25	1358.28	**0.03**	1358.24	1358.26	1358.35
2404	1575991.67	1681987.18	Yes	1450.67	1450.70	**0.03**	1450.63	1450.65	1450.72
2651	1666818.26	1615061.53	Yes	1231.51	1231.54	**0.03**	1231.50	1231.54	1231.56
2713	1656321.59	1609843.56	Yes	1235.71	1235.74	**0.03**	1235.66	1235.67	1235.76
2647	1629262.89	1635620.78	Yes	1295.70	1295.74	**0.04**	1295.65	1295.80	1295.81

2649	1639998.78	1630565.80	Yes	1283.62	1283.66	**0.04**	1283.62	1283.69	1283.69
1722	1653738.96	1746702.76	Yes	1419.01	1419.06	**0.05**	1419.05	1419.11	1419.14
2517	1717823.85	1689456.05	Yes	1343.78	1343.83	**0.05**	1343.82	1343.83	1343.84
2524	1645474.03	1700202.61	Yes	1310.95	1311.00	**0.05**	1310.99	1310.99	1311.01
1501	1579646.26	1756670.89	Yes	1404.59	1404.65	**0.06**	1404.58	1404.67	1404.71
2406	1607632.03	1660119.43	Yes	1338.46	1338.52	**0.06**	1338.43	1338.52	1338.53
2522	1628565.80	1672695.27	Yes	1296.14	1296.20	**0.06**	1296.16	1296.18	1296.23
1502	1580042.13	1735512.17	Yes	1410.39	1410.46	**0.07**	1410.45	1410.45	1410.55
2519	1660870.29	1690187.76	Yes	1355.70	1355.77	**0.07**	1355.73	1355.76	1355.81
2529	1702195.76	1684110.22	Yes	1302.76	1302.83	**0.07**	1302.81	1302.84	1302.86
2650	1629983.14	1609138.97	Yes	1243.49	1243.56	**0.07**	1243.54	1243.55	1243.56
2740	1701929.37	1662713.89	Yes	1334.46	1334.53	**0.07**	1334.52	1334.56	1334.57
1422	1685917.26	1704883.02	Yes	1389.06	1389.15	**0.09**	1389.11	1389.14	1389.20
2528	1655649.55	1641326.24	Yes	1257.09	1257.18	**0.09**	1257.13	1257.13	1257.24
1525	1627516.15	1735947.49	Yes	1352.73	1352.83	**0.10**	1352.81	1352.87	1352.87
2520	1686473.09	1673108.84	Yes	1353.00	1353.10	**0.10**	1353.08	1353.09	1353.12
2419	1670607.75	1675390.79	Yes	1327.90	1328.01	**0.11**	1327.91	1327.92	1328.01
1527	1595728.81	1735384.92	Yes	1378.52	1378.64	**0.12**	1378.48	1378.63	1378.67
1716	1585941.59	1703068.52	Yes	1403.09	1403.21	**0.12**	1403.02	1403.22	1403.23
2508	1663743.28	1630978.44	Yes	1245.10	1245.22	**0.12**	1245.21	1245.23	1245.32
2629	1591271.73	1697991.63	Yes	1379.77	1379.89	**0.12**	1379.82	1379.86	1380.00
2530	1645273.30	1675113.40	Yes	1288.51	1288.67	**0.16**	1288.67	1288.67	1288.69
1403	1600748.75	1756886.15	Yes	1387.18	1387.35	**0.17**	1387.25	1387.35	1387.38
2405	1581365.11	1671503.61	Yes	1460.14	1460.31	**0.17**	1460.26	1460.32	1460.35
1627	1606429.96	1730192.77	Yes	1362.68	1362.89	**0.21**	1362.81	1362.86	1363.04
1409	1639410.27	1741332.55	Yes	1346.73	1347.11	**0.38**	1347.00	1347.05	1347.22

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:
Urban (Pavement or Concrete area)
Bare-Ground, Short Grass
Woodlands, Shrubs, Tall Grass
The ground cover survey (Ground Truth) was performed by Savoy Company P.A.

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

Coordinate System: US State Plane NAD83(2007)
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	
2200	1676984.17	1580901.94	1462.18	Urban-Pavement-Concrete
2201	1729730.13	1595823.17	1380.88	Urban-Pavement-Concrete
2202	1746459.16	1622120.33	1364.75	Urban-Pavement-Concrete
2203	1740070.23	1639821.96	1343.93	Urban-Pavement-Concrete
2204	1733658.68	1653928.76	1371.23	Urban-Pavement-Concrete
2205	1642866.72	1688174.24	1336.55	Urban-Pavement-Concrete
2206	1665138.36	1648536.24	1283.08	Urban-Pavement-Concrete
2207	1662378.07	1628650.86	1310.09	Urban-Pavement-Concrete
2209	1693120.66	1602121.34	1350.98	Urban-Pavement-Concrete
2210	1718760.52	1591311.58	1387.48	Urban-Pavement-Concrete
2211	1689132.20	1633554.76	1308.30	Urban-Pavement-Concrete
2212	1684285.13	1657162.84	1298.21	Urban-Pavement-Concrete
2213	1678597.77	1696906.12	1322.74	Urban-Pavement-Concrete
2214	1698804.95	1659836.86	1363.10	Urban-Pavement-Concrete
2215	1693645.28	1674291.23	1384.32	Urban-Pavement-Concrete
2216	1720290.80	1643457.85	1331.52	Urban-Pavement-Concrete
2217	1714382.50	1612172.92	1350.31	Urban-Pavement-Concrete
2218	1701975.75	1641252.06	1315.35	Urban-Pavement-Concrete
2219	1681975.16	1602245.82	1339.60	Urban-Pavement-Concrete
2220	1715084.99	1657090.16	1346.28	Urban-Pavement-Concrete
2225	1736384.19	1585126.48	1391.95	Urban-Pavement-Concrete
2251	1704521.35	1617513.85	1361.85	Bare_Ground-Short_Grass
2252	1751554.27	1595446.65	1384.59	Bare_Ground-Short_Grass

2253	1741128.99	1616913.15	1361.98	Bare_Ground-Short_Grass
2254	1757090.51	1622042.21	1367.14	Bare_Ground-Short_Grass
2255	1730802.70	1632829.57	1345.17	Bare_Ground-Short_Grass
2256	1731266.97	1643661.60	1341.61	Bare_Ground-Short_Grass
2257	1720129.16	1631831.64	1340.82	Bare_Ground-Short_Grass
2258	1720680.13	1674937.68	1407.59	Bare_Ground-Short_Grass
2259	1715438.13	1680543.41	1409.12	Bare_Ground-Short_Grass
2260	1701649.52	1690971.56	1383.22	Bare_Ground-Short_Grass
2261	1682776.52	1681454.42	1368.65	Bare_Ground-Short_Grass
2262	1695201.82	1686011.45	1379.40	Bare_Ground-Short_Grass
2263	1708714.87	1633193.83	1326.29	Bare_Ground-Short_Grass
2264	1708605.85	1596333.84	1356.21	Bare_Ground-Short_Grass
2265	1663847.71	1602319.56	1365.21	Bare_Ground-Short_Grass
2266	1651139.57	1628921.67	1295.83	Bare_Ground-Short_Grass
2267	1677349.78	1633276.33	1299.39	Bare_Ground-Short_Grass
2268	1677948.25	1663568.22	1340.56	Bare_Ground-Short_Grass
2269	1652003.11	1644800.29	1271.02	Bare_Ground-Short_Grass
2270	1669517.88	1663874.20	1329.24	Bare_Ground-Short_Grass
2301	1689388.48	1717879.92	1344.83	Woodlands-Shrubs-Tall_Grass
2302	1688814.71	1610279.66	1324.40	Woodlands-Shrubs-Tall_Grass
2303	1670842.03	1617455.60	1309.03	Woodlands-Shrubs-Tall_Grass
2304	1689124.99	1640562.19	1307.38	Woodlands-Shrubs-Tall_Grass
2305	1630879.43	1658355.93	1243.73	Woodlands-Shrubs-Tall_Grass
2306	1667959.12	1691843.26	1353.16	Woodlands-Shrubs-Tall_Grass
2307	1698454.42	1625804.46	1322.49	Woodlands-Shrubs-Tall_Grass
2308	1704826.47	1669479.48	1364.76	Woodlands-Shrubs-Tall_Grass
2309	1711018.72	1649043.25	1323.31	Woodlands-Shrubs-Tall_Grass
2310	1726921.68	1617220.99	1350.08	Woodlands-Shrubs-Tall_Grass
2311	1742373.13	1600681.65	1373.83	Woodlands-Shrubs-Tall_Grass
2312	1756453.48	1584997.08	1396.96	Woodlands-Shrubs-Tall_Grass
2313	1749101.98	1628155.85	1357.12	Woodlands-Shrubs-Tall_Grass
2314	1767528.06	1627066.08	1382.94	Woodlands-Shrubs-Tall_Grass
2315	1669306.69	1588140.46	1425.63	Woodlands-Shrubs-Tall_Grass
2316	1692866.94	1597883.02	1373.52	Woodlands-Shrubs-Tall_Grass
2317	1658744.98	1613061.56	1317.08	Woodlands-Shrubs-Tall_Grass
2318	1651616.17	1680440.63	1320.61	Woodlands-Shrubs-Tall_Grass
2319	1705352.78	1713104.82	1318.60	Woodlands-Shrubs-Tall_Grass
2320	1647968.56	1666576.09	1297.33	Woodlands-Shrubs-Tall_Grass
2321	1706779.96	1696448.06	1354.67	Woodlands-Shrubs-Tall_Grass

LiDAR Accuracy / Validation Results for Ground Cover Classification (Ground Truth)

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

Post-Filter Cover Report for Urban-Pavement-Concrete

Project File = MARSProjectWichita_Urban_Cover
Date = August 03 = 2008
Vertical Accuracy Objective
Requirement Type = Accuracy(z)
Accuracy(z) Objective = 0.60
Confidence Level = 95%
Control Points in Report = 21
Elevation Calculation Method = Interpolated from TIN
Control Points with LiDAR Coverage = 21
Control Points with Required Accuracy (+/- 0.60) = 21
Percent of Control Points with Required Accuracy (+/- 0.60) = 100.00
Average Control Error Reported = -0.08
Maximum (highest) Control Error Reported = 0.14
Median Control Error Reported = -0.04
Minimum (lowest) Control Error Reported = -0.44
Standard deviation (sigma) of Z for sample = 0.15
RMSE of Z for sample (RMSE(z)) = 0.16 = PASS
FGDC/NSSDA Vertical Accuracy (Accuracy(z)) = 0.32 = PASS
NSSDA Achievable Contour Interval = 0.6
ASPRS Class 1 Achievable Contour Interval = 0.5
NMAS Achievable Contour Interval = 0.6

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
2205	1688174.24	1642866.72	Yes	1336.55	1336.11	**-0.44**	1336.05	1336.09	1336.13
2211	1633554.76	1689132.20	Yes	1308.30	1307.98	**-0.32**	1307.76	1307.89	1308.06
2218	1641252.06	1701975.75	Yes	1315.35	1315.08	**-0.27**	1315.03	1315.06	1315.16
2217	1612172.92	1714382.50	Yes	1350.31	1350.05	**-0.26**	1350.03	1350.05	1350.08
2213	1696906.12	1678597.77	Yes	1322.74	1322.56	**-0.18**	1322.54	1322.58	1322.61
2209	1602121.34	1693120.66	Yes	1350.98	1350.83	**-0.15**	1350.80	1350.83	1350.86
2201	1595823.17	1729730.13	Yes	1380.88	1380.75	**-0.13**	1380.70	1380.76	1380.76
2204	1653928.76	1733658.68	Yes	1371.23	1371.14	**-0.09**	1371.11	1371.14	1371.18
2212	1657162.84	1684285.13	Yes	1298.21	1298.12	**-0.09**	1298.07	1298.09	1298.20
2207	1628650.86	1662378.07	Yes	1310.09	1310.05	**-0.04**	1310.02	1310.05	1310.12
2210	1591311.58	1718760.52	Yes	1387.48	1387.44	**-0.04**	1387.43	1387.43	1387.45

2202	1622120.33	1746459.16	Yes	1364.75	1364.72	**-0.03**	1364.70	1364.74	1364.78
2200	1580901.94	1676984.17	Yes	1462.18	1462.18	**0.00**	1462.09	1462.23	1462.26
2219	1602245.82	1681975.16	Yes	1339.60	1339.60	**0.00**	1339.58	1339.62	1339.70
2203	1639821.96	1740070.23	Yes	1343.93	1343.94	**0.01**	1343.87	1343.93	1343.95
2225	1585126.48	1736384.19	Yes	1391.95	1391.96	**0.01**	1391.92	1391.95	1391.97
2206	1648536.24	1665138.36	Yes	1283.08	1283.13	**0.05**	1283.12	1283.15	1283.16
2215	1674291.23	1693645.28	Yes	1384.32	1384.38	**0.06**	1384.24	1384.44	1384.53
2214	1659836.86	1698804.95	Yes	1363.10	1363.18	**0.08**	1363.16	1363.17	1363.31
2220	1657090.16	1715084.99	Yes	1346.28	1346.36	**0.08**	1346.15	1346.36	1346.44
2216	1643457.85	1720290.80	Yes	1331.52	1331.66	**0.14**	1331.41	1331.65	1331.68

Post-Filter Cover Report for Bare_Ground-Short_Grass

Project File = MARSProjectBareGround_ShortGrass
Date = August 03 = 2008
Vertical Accuracy Objective
Requirement Type = Accuracy(z)
Accuracy(z) Objective = 0.60
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 (+/- 0.60) = 20
Percent of Control Points with Required Accuracy (+/- 0.60) = 100.00
Average Control Error Reported = -0.02
Maximum (highest) Control Error Reported = 0.24
Median Control Error Reported = 0.02
Minimum (lowest) Control Error Reported = -0.30
Standard deviation (sigma) of Z for sample = 0.15
RMSE of Z for sample (RMSE(z)) = 0.14 = PASS
FGDC/NSSDA Vertical Accuracy (Accuracy(z)) = 0.28 = PASS
NSSDA Achievable Contour Interval = 0.5
ASPRS Class 1 Achievable Contour Interval = 0.5
NMAS Achievable Contour Interval = 0.5

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
2255	1632829.57	1730802.70	Yes	1345.17	1344.87	**-0.30**	1344.87	1344.87	1344.88
2263	1633193.83	1708714.87	Yes	1326.29	1326.03	**-0.26**	1325.99	1326.05	1326.08
2257	1631831.64	1720129.16	Yes	1340.82	1340.57	**-0.25**	1340.45	1340.58	1340.66
2253	1616913.15	1741128.99	Yes	1361.98	1361.83	**-0.15**	1361.75	1361.84	1361.96

2256	1643661.60	1731266.97	Yes	1341.61	1341.49	**-0.12**	1341.41	1341.44	1341.54
2260	1690971.56	1701649.52	Yes	1383.22	1383.12	**-0.10**	1383.10	1383.13	1383.13
2266	1628921.67	1651139.57	Yes	1295.83	1295.74	**-0.09**	1295.73	1295.75	1295.76
2258	1674937.68	1720680.13	Yes	1407.59	1407.56	**-0.03**	1407.45	1407.56	1407.58
2251	1617513.85	1704521.35	Yes	1361.85	1361.87	**0.02**	1361.79	1361.80	1361.89
2264	1596333.84	1708605.85	Yes	1356.21	1356.23	**0.02**	1356.18	1356.19	1356.27
2252	1595446.65	1751554.27	Yes	1384.59	1384.61	**0.02**	1384.60	1384.65	1384.66
2267	1633276.33	1677349.78	Yes	1299.39	1299.41	**0.02**	1299.36	1299.41	1299.45
2259	1680543.41	1715438.13	Yes	1409.12	1409.15	**0.03**	1409.11	1409.12	1409.19
2269	1644800.29	1652003.11	Yes	1271.02	1271.05	**0.03**	1270.93	1271.04	1271.15
2254	1622042.21	1757090.51	Yes	1367.14	1367.18	**0.04**	1367.13	1367.19	1367.24
2270	1663874.20	1669517.88	Yes	1329.24	1329.29	**0.05**	1329.18	1329.28	1329.33
2262	1686011.45	1695201.82	Yes	1379.40	1379.53	**0.13**	1379.46	1379.51	1379.59
2265	1602319.56	1663847.71	Yes	1365.21	1365.37	**0.16**	1365.23	1365.25	1365.41
2268	1663568.22	1677948.25	Yes	1340.56	1340.75	**0.19**	1340.73	1340.76	1340.79
2261	1681454.42	1682776.52	Yes	1368.65	1368.89	**0.24**	1368.86	1368.89	1368.97

Post-Filter Cover Report for Woodlands-Shrubs-Tall_Grass

Project File = MARSProjectWoodlands_Shrubs_TallGrass
Date = August 03 = 2008
Vertical Accuracy Objective
Requirement Type = Accuracy(z)
Accuracy(z) Objective = 0.60
Confidence Level = 95%
Control Points in Report = 21
Elevation Calculation Method = Interpolated from TIN
Control Points with LiDAR Coverage = 21
Control Points with Required Accuracy (+/- 0.60) = 19
Percent of Control Points with Required Accuracy (+/- 0.60) = 90.48
Average Control Error Reported = -0.06
Maximum (highest) Control Error Reported = 0.47
Median Control Error Reported = -0.04
Minimum (lowest) Control Error Reported = -0.82
Standard deviation (sigma) of Z for sample = 0.32
RMSE of Z for sample (RMSE(z)) = 0.32
FGDC/NSSDA Vertical Accuracy (Accuracy(z)) = 0.62
NSSDA Achievable Contour Interval = 2.0
ASPRS Class 1 Achievable Contour Interval = 1.0
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
2317	1613061.56	1658744.98	Yes	1317.08	1316.26	-0.82	1316.06	1316.41	1316.65
2304	1640562.19	1689124.99	Yes	1307.38	1306.76	-0.62	1306.72	1306.77	1306.80
2320	1666576.09	1647968.56	Yes	1297.33	1296.88	-0.45	1296.80	1297.00	1297.01
2321	1696448.06	1706779.96	Yes	1354.67	1354.34	-0.33	1353.92	1354.97	1355.20
2313	1628155.85	1749101.98	Yes	1357.12	1356.81	-0.31	1356.56	1356.81	1356.83
2303	1617455.60	1670842.03	Yes	1309.03	1308.78	-0.25	1308.74	1308.75	1308.84
2305	1658355.93	1630879.43	Yes	1243.73	1243.54	-0.19	1243.36	1243.49	1243.64
2306	1691843.26	1667959.12	Yes	1353.16	1353.07	-0.09	1352.65	1353.11	1353.23
2308	1669479.48	1704826.47	Yes	1364.76	1364.70	-0.06	1364.68	1364.70	1364.71
2316	1597883.02	1692866.94	Yes	1373.52	1373.48	-0.04	1373.33	1373.45	1373.55
2302	1610279.66	1688814.71	Yes	1324.40	1324.36	-0.04	1324.31	1324.56	1324.60
2307	1625804.46	1698454.42	Yes	1322.49	1322.47	-0.02	1322.36	1322.53	1322.63
2309	1649043.25	1711018.72	Yes	1323.31	1323.35	0.04	1323.25	1323.42	1323.62
2310	1617220.99	1726921.68	Yes	1350.08	1350.13	0.05	1350.11	1350.12	1350.17
2319	1713104.82	1705352.78	Yes	1318.60	1318.72	0.12	1318.49	1318.72	1318.84
2318	1680440.63	1651616.17	Yes	1320.61	1320.81	0.20	1320.66	1320.77	1320.86
2312	1584997.08	1756453.48	Yes	1396.96	1397.16	0.20	1397.04	1397.20	1397.37
2301	1717879.92	1689388.48	Yes	1344.83	1345.04	0.21	1344.96	1345.02	1345.08
2315	1588140.46	1669306.69	Yes	1425.63	1425.91	0.28	1425.61	1426.10	1426.13
2311	1600681.65	1742373.13	Yes	1373.83	1374.13	0.30	1373.99	1374.14	1374.15
2314	1627066.08	1767528.06	Yes	1382.94	1383.41	0.47	1383.05	1383.57	1383.84

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.

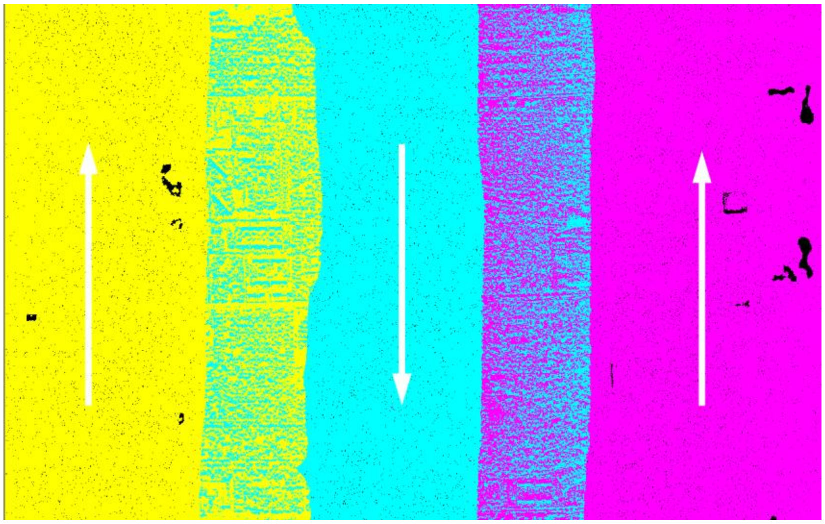


Figure 1: Flight pattern required for calibration

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.

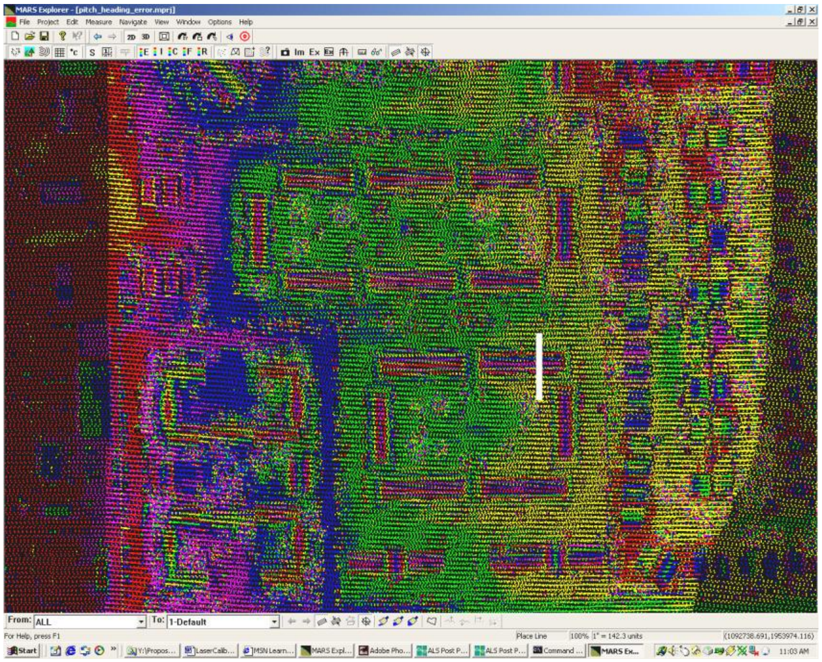


Figure 2: Orthographic view with profile line

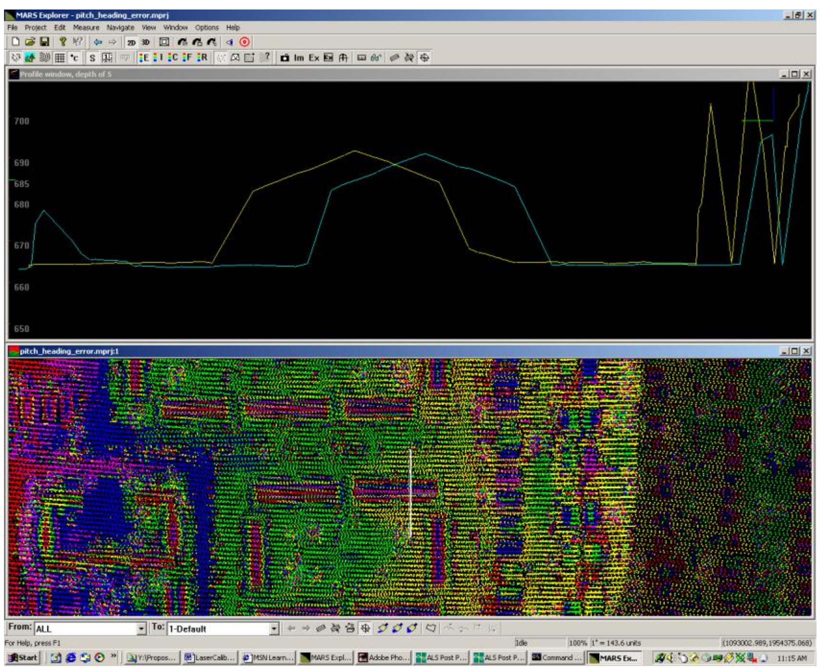


Figure 3: Profile view of misalignment

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).

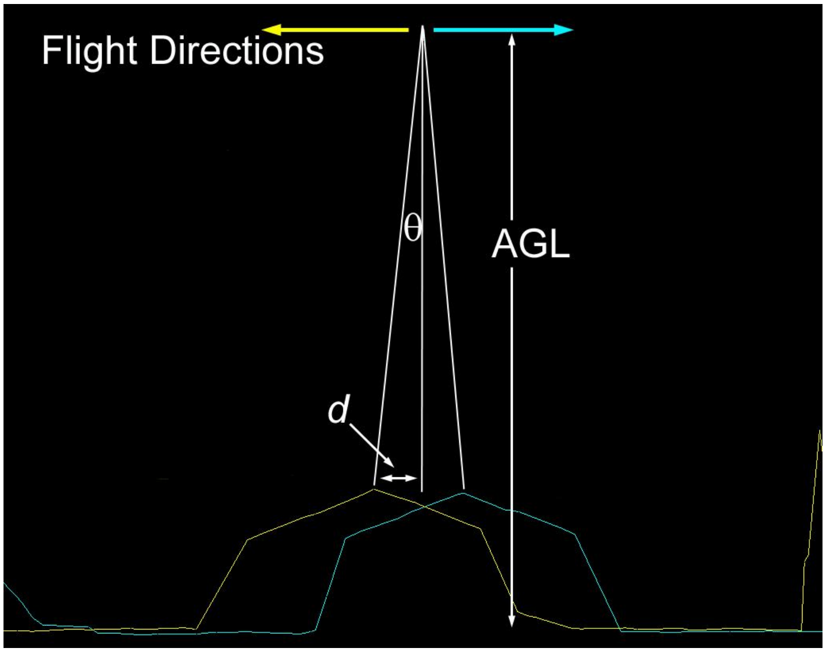


Figure 4: Adjusting pitch

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…

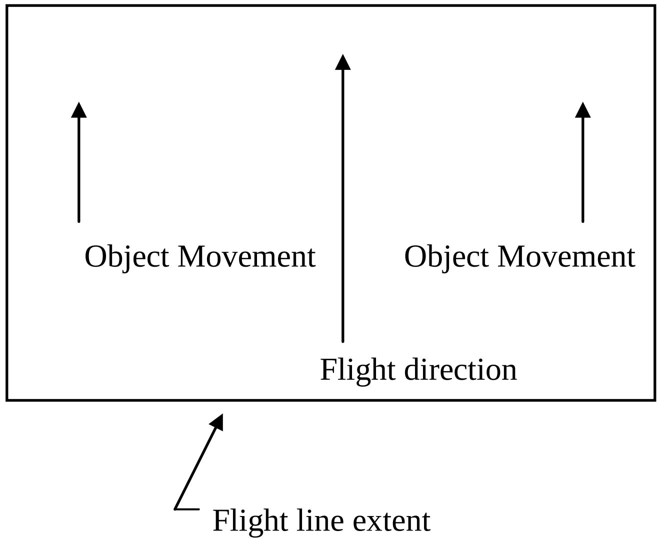
$$\theta = \frac{\arctan\left(\frac{d}{AGL}\right)}{57.2958}$$

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.

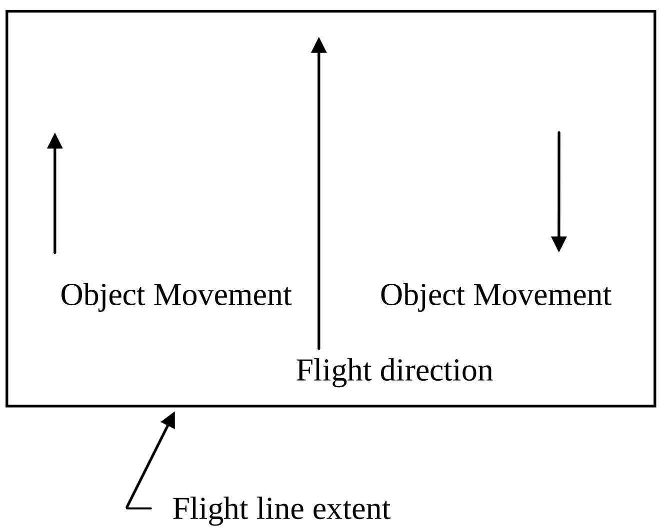
The next issue to resolve, before actually changing the pitch value, is to determine if this shift is at all due to an incorrect heading value, since heading will move data in the direction of flight also. The difference is that heading rotates the data, meaning that when heading is changed, objects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

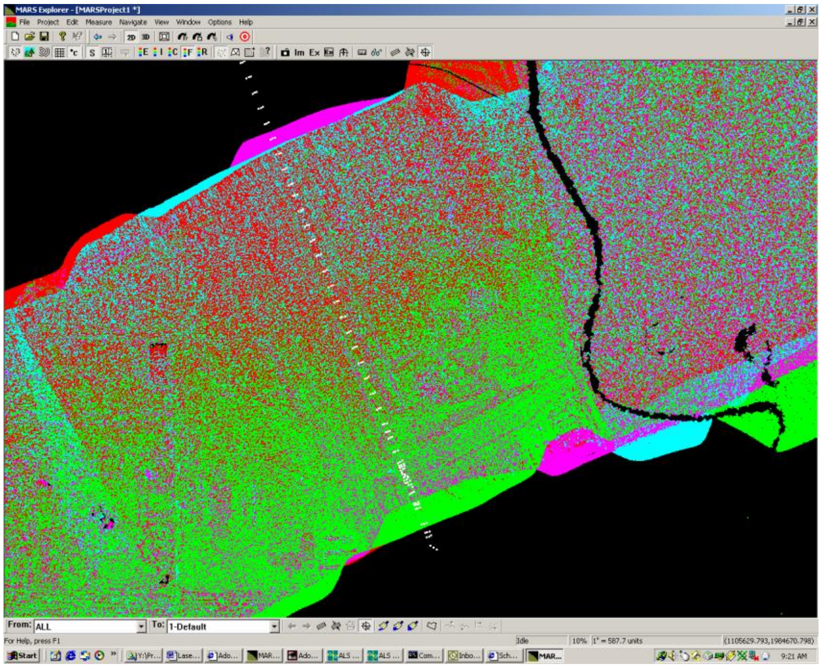


Figure 7: The truth survey

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)

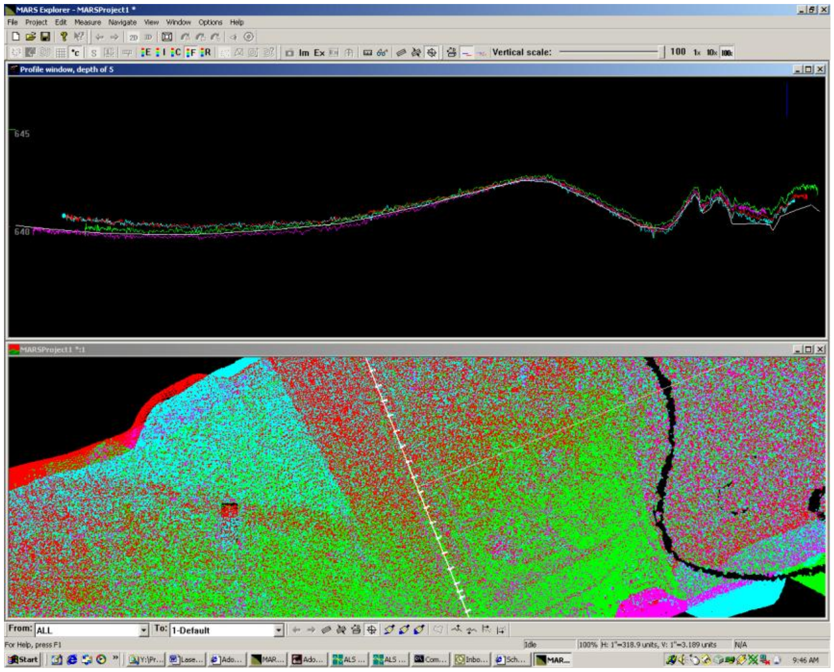


Figure 8: Profile view of calibration flight lines

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)

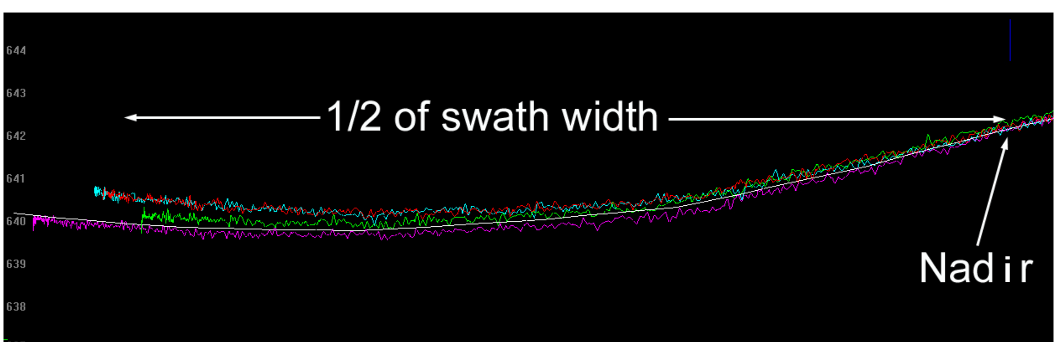


Figure 9: Half of calibration profile

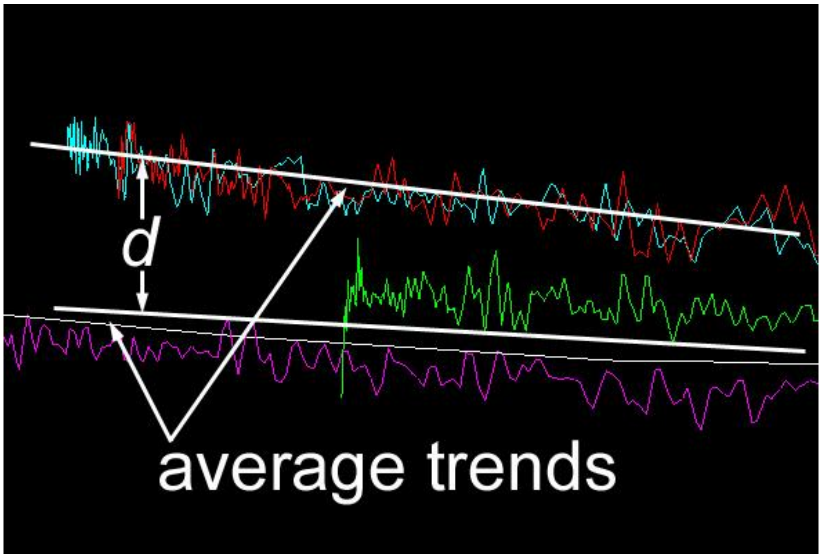


Figure 10: Differences in average roll trends

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.