Post-Flight Aerial Acquisition and Calibration Report

High Resolution Digital ORTHOS & LiDAR Data Acquisition and Processing for a portion of the
Musselshell River Corridor, Montana 2011
Completed by Photo Science, Inc
For Contract # W912P9-11-D-0505
With USACE, St Louis District

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Post-Flight Aerial Acquisition and Calibration Report
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The purpose of this project is to provide professional surveying and mapping services for the creation of a high-resolution digital elevation model developed from LIDAR data for the Musselshell Rive, Montana Area of Interest (AOI). The project area is shown in the graphic below as Figure 1.1 along with the sub block areas and flight lines.

All flights for the project were accomplished with customized twin-engine Piper Navajo Aircraft utilizing a Leica ALS70 (SNALS70178) LiDAR sensor. These aircraft provide an ideal, stable aerial base for LiDAR acquisition. This platform has relatively fast cruise speeds that are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds which can prove ideal for collection of a high-density, consistent data posting using the state of the art Leica system.

Photo Science utilized a Leica ALS70 - HP sensor, serial number 7178, on this project. These systems are capable of collecting data at a maximum frequency of 500 kHz, which affords elevation data collection of up to 500,000 points per second. The system utilizes a Multi-pulse in the Air option (MPIA) and a split beam in order to collect twice the data. This sensor is also equipped with the ability to measure up to 5 returns per outgoing pulse from the laser and these come in the form of 1st, 2nd, 3rd, 4th, and last returns. The intensity of the first four returns is also captured during the aerial acquisition.

The project covered approximately 365 square miles and required 5 collection blocks. The collection block or sub area is typically determined by the Base Station control locations and sometimes terrain or other natural features such as water bodies. The base stations determine where LiDAR can be collected with the highest confidence of accuracy as determined by reading the same satellites in the aircraft and on the ground. The base Stations are typically set at airports with ground control monuments available and provide coverage within 18 miles of the base if possible in order to cover in its entirety. In the Musselshell project there were 120 flight lines totaling 1,236.09 flight line miles, there were also 6 lines used for calibration for the project. The project also included collecting DMC Imagery.

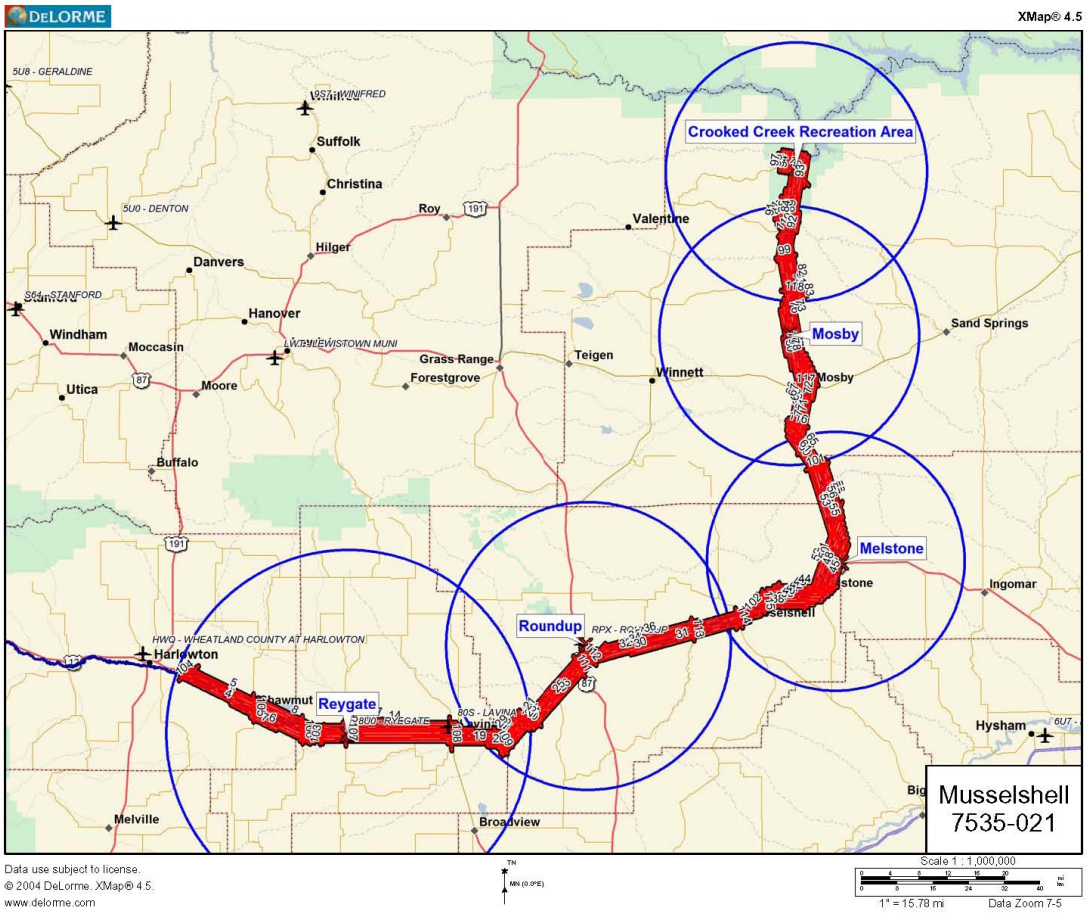

Figure 1.1: Musselshell LiDAR Coverage Area and Lines

2.0

Detailed project planning was performed for this project. This planning was based on project specific requirements and the characteristics of the project site. The basis of this planning included the required accuracies, type of development, amount and type of vegetation within the project area, the required data posting, and potential altitude restrictions for flights in the general area. A brief summary of the aerial acquisition parameters for this project are shown in the LiDAR System Specification (Table 2.1) below:

Terrain and Aircraft
Flying Height AGL: 1524 m; 5,000 feet
Recommended Ground Speed (GS): 150 kts

Scanner
Field of View (FOV): 33.0; degrees
Scan Rate Setting used (SR): 49.9 Hz

Laser
Laser Pulse Rate used: 363,000 Hz
Multi Pulse in Air Mode: Enabled

Gain Values (Up/Down): 12; 3
Range Intensity mode: 7
Nominal Maximum Slant Range; 1615.53 m
Recommended Range Gate MIN Setting; 1017.87 m
Recommended Range Gate MAX Setting; 1630.76 m
Recommended Laser Current; 100 %

Coverage
Full Swath Width; 903 m 2962.59 feet
Maximum Line Spacing (No DTM); 781.42 m; 2653.70 feet

Point Spacing and Density
Maximum Point Spacing Across Track; 0.77 m
Maximum Point Spacing Along Track; 0.77 m
Across Track/Along Track Ratio; 1.00
Average Point Density; 5.42 pts / m^2
Average Point Spacing; 0.44 m
Nadir Point Density; 3.42 pts / m^2

Reflectivity and SNR
Illuminated Footprint Diameter; 0.35 m
Average SNR; 16.17

Accuracy
Estimated Across Track Accuracy; 0.15 - 0.16 m
Estimated Along Track Accuracy; 0.15 - 0.16m
Estimated Height Accuracy; 0.07 - 0.09 m

LiDAR System Specification (Table 2.1)

Base Station Information

GPS base stations were utilized at one (1) location during all phases of flight. Typically existing monuments are utilized when available at airports for ease of location, but on occasion a monument consisting of a steel pin will be set and an OPUS solution will be used to determine the exact location. Five sites were used for the Base Stations including a point near Ryegate, MT; Roundup, MT Airport; Crooked Creek Recreation Area, MT; Mosby, MT; and Melstone, MT. The general locations area indicted on the graphic as part of figure 1.1 *Musselshell LiDAR Coverage Area and Lines*.

The three Base Station locations were generally set along roads and other convenient locations and monitored by ground personnel and the location solution provided via OPUS. Base Station data sheets are included with the flight logs in Appendix "A".

Time Period

The following table outlines the Flight Lines by the Area (sub block) ID; The flight line number, flight line miles; date flown; lift file name; sensor serial number and aircraft tail number.

The flights were conducted over seven (3) days beginning 5/7/2012 and ending on 5/9/2012.
Five (5) sorties or aircraft lifts were required.

State	Proj_Num	Area_ID	No_FL	FL_NUM	Date_Flown	FL_miles	Lift_File_Name
Montana	7535-021	Musselshell	120	1	07-May-12	22.072	120507B
Montana	7535-021	Musselshell	120	2	07-May-12	22.072	120507B
Montana	7535-021	Musselshell	120	3	07-May-12	22.072	120507B
Montana	7535-021	Musselshell	120	4	07-May-12	20.956	120507B
Montana	7535-021	Musselshell	120	5	07-May-12	22.072	120507B
Montana	7535-021	Musselshell	120	6	07-May-12	12.4	120507B
Montana	7535-021	Musselshell	120	7	07-May-12	4.03	120507B
Montana	7535-021	Musselshell	120	8	07-May-12	10.85	120507B
Montana	7535-021	Musselshell	120	9	07-May-12	30.566	120507B
Montana	7535-021	Musselshell	120	10	07-May-12	30.566	120507B
Montana	7535-021	Musselshell	120	11	07-May-12	30.566	120507B
Montana	7535-021	Musselshell	120	12	07-May-12	24.366	120507B
Montana	7535-021	Musselshell	120	14	07-May-12	15.996	120507B
Montana	7535-021	Musselshell	120	15	07-May-12	22.63	120507B
Montana	7535-021	Musselshell	120	17	07-May-12	3.906	120507B
Montana	7535-021	Musselshell	120	18	07-May-12	30.566	120507B
Montana	7535-021	Musselshell	120	19	07-May-12	9.3	120507B
Montana	7535-021	Musselshell	120	20	07-May-12	3.534	120507B
Montana	7535-021	Musselshell	120	21	07-May-12	19.034	120507A
Montana	7535-021	Musselshell	120	22	07-May-12	19.034	120507A
Montana	7535-021	Musselshell	120	23	07-May-12	19.344	120507A
Montana	7535-021	Musselshell	120	24	07-May-12	19.84	120507A
Montana	7535-021	Musselshell	120	25	07-May-12	16.12	120507A
Montana	7535-021	Musselshell	120	26	07-May-12	15.624	120507A
Montana	7535-021	Musselshell	120	27	07-May-12	6.82	120507A
Montana	7535-021	Musselshell	120	28	07-May-12	5.27	120507A
Montana	7535-021	Musselshell	120	29	07-May-12	5.27	120507A
Montana	7535-021	Musselshell	120	30	07-May-12	25.048	120507A
Montana	7535-021	Musselshell	120	31	07-May-12	17.298	120507A
Montana	7535-021	Musselshell	120	32	07-May-12	28.458	120507A
Montana	7535-021	Musselshell	120	34	07-May-12	26.908	120507A
Montana	7535-021	Musselshell	120	35	07-May-12	26.908	120507A
Montana	7535-021	Musselshell	120	36	07-May-12	13.454	120507A
Montana	7535-021	Musselshell	120	37	09-May-12	8.618	120509a-7178
Montana	7535-021	Musselshell	120	38	09-May-12	8.184	120509a-7178
Montana	7535-021	Musselshell	120	39	09-May-12	9.548	120509a-7178
Montana	7535-021	Musselshell	120	40	09-May-12	9.672	120509a-7178
Montana	7535-021	Musselshell	120	41	09-May-12	9.982	120509a-7178
Montana	7535-021	Musselshell	120	42	09-May-12	9.858	120509a-7178
Montana	7535-021	Musselshell	120	43	09-May-12	9.362	120509a-7178

Montana	7535-021	Musselshell	120	44	09-May-12	8.928	120509a-7178
Montana	7535-021	Musselshell	120	45	09-May-12	7.006	120509a-7178
Montana	7535-021	Musselshell	120	46	09-May-12	7.75	120509a-7178
Montana	7535-021	Musselshell	120	47	09-May-12	8.37	120509a-7178
Montana	7535-021	Musselshell	120	48	09-May-12	9.176	120509a-7178
Montana	7535-021	Musselshell	120	49	09-May-12	9.92	120509a-7178
Montana	7535-021	Musselshell	120	50	09-May-12	10.54	120509a-7178
Montana	7535-021	Musselshell	120	51	09-May-12	11.656	120509a-7178
Montana	7535-021	Musselshell	120	52	09-May-12	15.81	120509a-7178
Montana	7535-021	Musselshell	120	53	09-May-12	10.912	120509a-7178
Montana	7535-021	Musselshell	120	54	09-May-12	10.478	120509a-7178
Montana	7535-021	Musselshell	120	55	09-May-12	14.322	120509a-7178
Montana	7535-021	Musselshell	120	56	09-May-12	9.238	120509a-7178
Montana	7535-021	Musselshell	120	57	09-May-12	8.804	120509a-7178
Montana	7535-021	Musselshell	120	58	09-May-12	8.494	120509a-7178
Montana	7535-021	Musselshell	120	59	09-May-12	8.494	120509a-7178
Montana	7535-021	Musselshell	120	60	08-May-12	6.138	120508B-7178
Montana	7535-021	Musselshell	120	61	08-May-12	6.944	120508B-7178
Montana	7535-021	Musselshell	120	62	08-May-12	7.688	120508B-7178
Montana	7535-021	Musselshell	120	64	08-May-12	8.184	120508B-7178
Montana	7535-021	Musselshell	120	65	08-May-12	8.618	120508B-7178
Montana	7535-021	Musselshell	120	66	08-May-12	9.982	120508B-7178
Montana	7535-021	Musselshell	120	67	08-May-12	10.478	120508B-7178
Montana	7535-021	Musselshell	120	68	08-May-12	10.168	120508B-7178
Montana	7535-021	Musselshell	120	69	08-May-12	10.478	120508B-7178
Montana	7535-021	Musselshell	120	70	08-May-12	12.152	120508B-7178
Montana	7535-021	Musselshell	120	71	08-May-12	9.548	120508B-7178
Montana	7535-021	Musselshell	120	72	08-May-12	3.224	120508B-7178
Montana	7535-021	Musselshell	120	73	08-May-12	18.848	120508B-7178
Montana	7535-021	Musselshell	120	74	08-May-12	7.626	120508A-7178
Montana	7535-021	Musselshell	120	75	08-May-12	18.848	120508B-7178
Montana	7535-021	Musselshell	120	76	08-May-12	18.724	120508B-7178
Montana	7535-021	Musselshell	120	77	08-May-12	12.462	120508B-7178
Montana	7535-021	Musselshell	120	78	08-May-12	11.842	120508B-7178
Montana	7535-021	Musselshell	120	79	08-May-12	8.432	120508B-7178
Montana	7535-021	Musselshell	120	80	08-May-12	2.48	120508B-7178
Montana	7535-021	Musselshell	120	81	08-May-12	7.192	120508A-7178
Montana	7535-021	Musselshell	120	82	08-May-12	8.742	120508A-7178
Montana	7535-021	Musselshell	120	83	08-May-12	2.046	120508A-7178
Montana	7535-021	Musselshell	120	84	08-May-12	15.128	120508A-7178
Montana	7535-021	Musselshell	120	85	08-May-12	15.252	120508A-7178

Montana	7535-021	Musselshell	120	86	08-May-12	15.252	120508A-7178
Montana	7535-021	Musselshell	120	87	08-May-12	5.456	120508A-7178
Montana	7535-021	Musselshell	120	88	08-May-12	14.942	120508A-7178
Montana	7535-021	Musselshell	120	89	08-May-12	14.942	120508A-7178
Montana	7535-021	Musselshell	120	90	08-May-12	3.906	120508A-7178
Montana	7535-021	Musselshell	120	91	08-May-12	2.356	120508A-7178
Montana	7535-021	Musselshell	120	92	08-May-12	2.48	120508A-7178
Montana	7535-021	Musselshell	120	93	08-May-12	4.216	120508A-7178
Montana	7535-021	Musselshell	120	94	08-May-12	2.976	120508A-7178
Montana	7535-021	Musselshell	120	95	08-May-12	2.976	120508A-7178
Montana	7535-021	Musselshell	120	96	08-May-12	2.976	120508A-7178
Montana	7535-021	Musselshell	120	97	08-May-12	2.976	120508A-7178
Montana	7535-021	Musselshell	120	99	08-May-12	2.852	120508A-7178
Montana	7535-021	Musselshell	120	101	08-May-12	3.286	120508b-7178
Montana	7535-021	Musselshell	120	102	09-May-12	8.742	120509a-7178
Montana	7535-021	Musselshell	120	103	07-May-12	2.666	120507B
Montana	7535-021	Musselshell	120	104	07-May-12	3.348	120507B
Montana	7535-021	Musselshell	120	105	07-May-12	3.782	120507B
Montana	7535-021	Musselshell	120	106	07-May-12	3.782	120507B
Montana	7535-021	Musselshell	120	107	07-May-12	3.596	120507B
Montana	7535-021	Musselshell	120	108	07-May-12	4.588	120507B
Montana	7535-021	Musselshell	120	109	07-May-12	4.03	120507a
Montana	7535-021	Musselshell	120	110	07-May-12	4.34	120507a
Montana	7535-021	Musselshell	120	111	07-May-12	3.224	120507a
Montana	7535-021	Musselshell	120	112	07-May-12	3.224	120507a
Montana	7535-021	Musselshell	120	113	07-May-12	3.038	120507a
Montana	7535-021	Musselshell	120	114	09-May-12	2.852	120509a-7178
Montana	7535-021	Musselshell	120	115	09-May-12	3.286	120509a-7178
Montana	7535-021	Musselshell	120	116	08-May-12	3.1	120508b-7178
Montana	7535-021	Musselshell	120	117	08-May-12	3.348	120508b-7178
Montana	7535-021	Musselshell	120	118	08-May-12	3.72	120508a-7178
Montana	7535-021	Musselshell	120	119	08-May-12	4.464	120508a-7178
Montana	7535-021	Musselshell	120	120	08-May-12	6.076	120508a-7178
						1236.094	

Table 2.3: Airborne LiDAR Acquisition Flight Summary

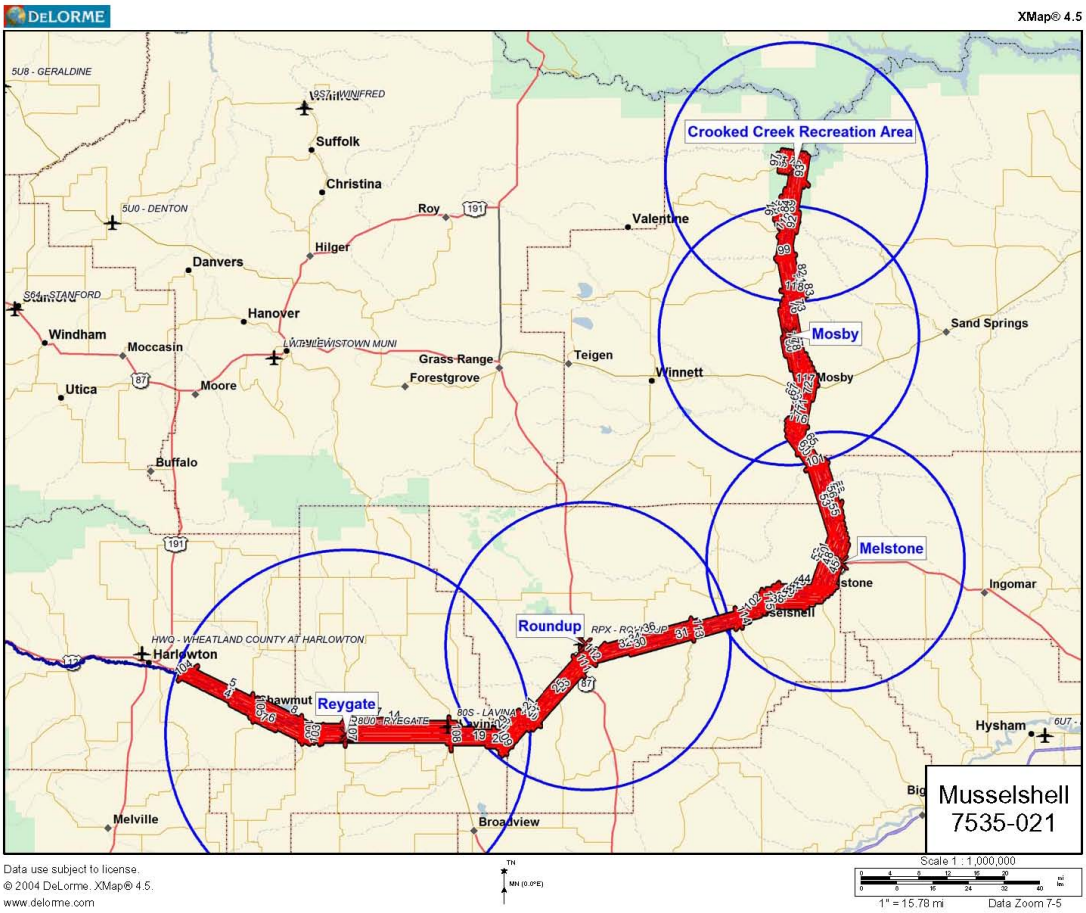

Figure 2.2: LiDAR Flight Layout

3.0

Processing Summary

Leica proprietary software was used in the post-processing of the airborne GPS and inertial data that is critical to the positioning and orientation of the sensor during all flights. Pairing the aircraft's raw trajectory data with the stationary GPS base station data, this software yields Leica's IPAS TC ("Inertial Positioning & Attitude Sensor – Tightly Coupled") smoothed best estimate of trajectory (an "SBET", in Leica's .sol file format) that is necessary for Leica's ALSPP post processing software to develop the resulting geo-referenced point cloud from the LiDAR missions. The point cloud is the mathematical three dimensional composite of all returns from all laser pulses as determined from the aerial mission. At this point this data is ready for analysis, classification, and filtering to generate a bare earth surface model in which the above-ground features are removed from the data set.

The point cloud was created using Leica's Post Processor software. GeoCue was used in the creation of some of the files needed in downstream processing, as well as in the tiling of the dataset into more manageable file sizes. The TerraScan and TerraModeler software packages are then used for the automated data classification, manual cleanup, and bare earth generation from this data. Project specific macros were used to classify the ground and to remove the side overlap between parallel flight lines. All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. QT Modeler was used as a final check of the bare earth dataset. GeoCue was then used to create the deliverable industry-standard LAS files for both the All Point Cloud Data and the Bare Earth. In-house software was then used to perform final statistical analysis of the classes in the LAS files.

Flight Log Overview:

-Post Spacing (Minimum): 0.77 m
-AGL (Above Ground Level) average flying height: 1,524 m; 5,000 feet
-Average Ground Speed: 150 kts
-Field of View (full): 33°
-Pulse Rate: 363,000 Hz
-Scan Rate: 49.9 Hz
-Side Lap (Average): 30%

During the sensor's (aircraft's) trajectory processing (combining GPS & IMU datasets) certain statistics and tables are generated within Leica's IPAS-TC software, all of which are attached in the appendices (Appendix C Trajectories Musselshell River MT.zip). Additionally for each lift there is a chart for the software's estimation of sensor position accuracy with satellite PDOP superimposed, a graphical Latitude/Longitude depiction of the aircraft's position, the software's estimation of how well the trajectory compared to itself when processed forward vs. backward, and an indication of each individual satellite's lock from the aircraft's antenna during collection activities.

4.0

A number of points were provided (or surveyed as part of the project) in order to provide a ground calibration and to help assure the accuracy of the data model. Initially any bias identified between the LiDAR surface and the provided control points are analyzed to average out the difference. The bias is then removed from LiDAR surface to provide a final ground surface. The two sets of data are then compared again and the results indicated below:

L:\8110011\Ground_Control\Lower_Green_Control_UTM16_Bare_Earth_FEET.ctl

Number	Easting	Northing	Known Z	Laser Z	Dz
75	460775.286	4170521.659	391.131	391.630	+0.499
76	466336.923	4179355.380	412.499	412.430	-0.069
77	475605.394	4187558.731	383.798	383.720	-0.078
80	461848.468	4150982.534	410.081	409.790	-0.291
81	475438.689	4150552.803	378.270	378.430	+0.160
82	478179.297	4167255.925	410.951	411.110	+0.159
83	486205.851	4160141.984	410.429	410.430	+0.001
86	499326.727	4168272.183	404.051	404.370	+0.319
87	490364.772	4175258.579	392.352	392.800	+0.448
89	527211.276	4156193.937	420.531	420.570	+0.039
90	518866.096	4151564.624	427.391	427.470	+0.079
91	503716.526	4178820.782	424.510	424.350	-0.160
92	528472.000	4173804.297	715.569	715.600	+0.031
94	513448.221	4161999.508	437.230	437.440	+0.210
95	506530.776	4148592.809	415.570	415.800	+0.230
97	495368.465	4131313.535	413.602	413.690	+0.088
101	490674.977	4145216.355	381.899	382.410	+0.511
103	541890.687	4130700.368	637.709	637.710	+0.001
104	525892.329	4130071.491	573.319	573.180	-0.139
105	510466.245	4133808.899	414.251	414.360	+0.109
108	510002.579	4122774.902	414.799	414.820	+0.021
109	485976.045	4119903.460	417.739	418.000	+0.261
113	473308.271	4109069.950	490.531	490.100	-0.431
115	467925.516	4093004.146	585.379	585.320	-0.059
117	495594.981	4088108.261	591.229	591.160	-0.069
118	489012.515	4099250.483	693.030	692.660	-0.370
119	500734.777	4102616.102	609.139	609.440	+0.301
120	514186.874	4097783.964	542.870	542.740	-0.130
121	516110.177	4109530.336	663.539	663.610	+0.071
123	487862.144	4112066.921	442.591	442.300	-0.291
125	475618.036	4120824.588	427.591	427.250	-0.341
126	457459.347	4108806.586	462.801	462.690	-0.111
127	460176.733	4123184.416	401.180	401.140	-0.040
129	453657.374	4143133.662	490.819	490.930	+0.111

131	444556.301	4153488.628	407.381	407.050	-0.331
201	463627.850	4190639.637	425.209	425.110	-0.099
232	463837.034	4189721.214	370.839	370.460	-0.379
240	462587.670	4189122.534	470.360	470.170	-0.190
439	479146.786	4177659.983	393.411	393.210	-0.201
448	480655.144	4178219.489	398.651	398.380	-0.271
614	457043.226	4137303.176	433.470	433.260	-0.210
616	458306.345	4138771.777	430.481	430.320	-0.161
673	457403.887	4134968.214	462.319	462.520	+0.201
842	459751.600	4098945.576	564.759	564.480	-0.279
873	457266.414	4099071.667	599.999	599.640	-0.359
876	457650.302	4101130.686	570.691	570.160	-0.531
1115	465362.129	4160954.147	509.340	509.150	-0.190
1124	464922.406	4163247.477	401.361	401.420	+0.059
1134	465303.065	4164055.402	425.170	424.940	-0.230
1164	463420.242	4163239.589	445.199	445.260	+0.061
1339	480530.700	4135909.803	432.479	432.540	+0.061
1409	481217.660	4086748.747	616.839	616.820	-0.019
1522	524700.811	4141631.033	607.371	607.330	-0.041
1527	526402.644	4142794.407	571.239	571.410	+0.171
1732	525998.625	4165823.765	618.309	618.600	+0.291
1755	525079.715	4165191.687	466.810	467.120	+0.310
1928	511482.860	4171618.249	482.519	482.970	+0.451
2107	525625.259	4120431.553	632.919	633.200	+0.281
2343	498676.126	4141155.442	544.720	544.840	+0.120
2363	498775.461	4142766.684	404.310	404.440	+0.130
2379	500217.992	4141577.944	456.951	457.100	+0.149
2520	497068.882	4112906.541	436.111	436.430	+0.319
2708	506217.592	4093920.384	472.420	472.370	-0.050
2722	505979.561	4092705.611	496.341	496.280	-0.061
2769	504058.065	4094549.384	467.109	467.460	+0.351

Average dz	+0.007
Minimum dz	-0.531
Maximum dz	+0.511
Average magnitude	0.197
Root mean square	0.240
Std deviation	0.242

Table 4.1: Overall Vertical Accuracy Statistics

QA/QC Analysis

Additionally, points for the SVA and CVA analysis were to be provided to the client as blind check points. We do not have the results for this report but assume that it was sufficient.

5.0

(To Be Populated By Others)

Appendices

Appendix A Musselshell River MT Original Flight Logs.zip

Appendix B Musselshell River MT Control.zip

Appendix C Trajectories Musselshell River MT.rar

Appendix D Planning and LAS Shape Files Musselshell River MT.zip