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Brown County, WI
2020 Orthophoto Mapping

Aerial Triangulation Report

August 28, 2020

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EXECUTIVE SUMMARY

Sanborn has successfully completed the aerial triangulation (AT) task for the aerial photography acquired on May 15th through May 21st, 2020 for the Brown County Digital Orthophotography project.

Using fully analytical aerial triangulation (FAAT) methods incorporating automatic analytical aerial triangulation (AAAT) procedures, Sanborn determined ground coordinates for each exposure by flying at an average altitude of 5,400ft AMSL for the 3in collection area, and 10,100ft AMSL for the 6in collection area.

The results of the final adjustment are sufficient to enable Sanborn to produce orthophoto imagery with an appropriate ground pixel resolution that meets project accuracy requirements for orthoimagery generation for ASPRS Class 1 1”=100’ mapping.

AT Accuracy Statement

The mean standard deviation of all adjusted terrain points indicate the AT solution exceeds the accuracy requirements for ASPRS Class 1 1”=100’ mapping.

Map Accuracy RMSE: 1.0ft in X and Y
Expected AT Accuracy RMSE at control points: 0.25ft in X and Y

3in Block:

```
Bundle adjustment RMSE at control points
          x         0.059 [feet]
          y         0.057 [feet]
          z         0.062 [feet]

Mean standard deviations of terrain points
            x          0.012
            y          0.015
            z          0.042
```

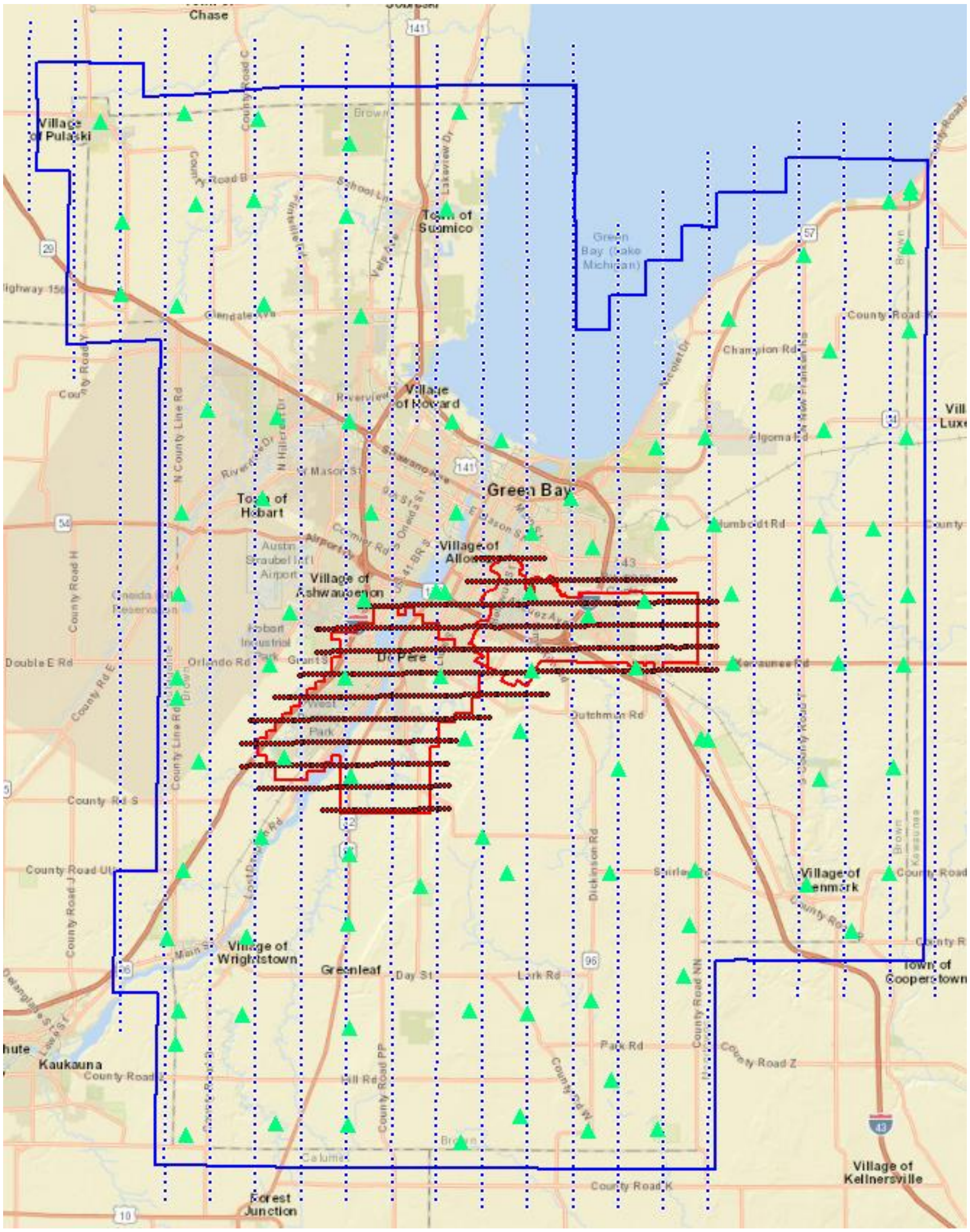
6in Block:

```
Bundle adjustment RMSE at control points
          x         0.128 [feet]
          y         0.113 [feet]
          z         0.257 [feet]

Mean standard deviations of terrain points
            x          0.026
            y          0.022
            z          0.074
```

1. FLIGHT/CONTROL MAP

Date of photography: May 15th through May 21st, 2020
Number of exposures: 3in: 748 / 6in: 2511
Flight Height: 3in: 5400ft / 6in: 10,100ft AMSL
GSD: 0.25ft / 0.5ft
Image Overlap: 80% FOL / 30% SOL



2. GPS-IMU POST PROCESSING

To process the Airborne GPS-IMU data for this project, Sanborn utilized Applanix POSPac – Mobile Mapping Suite processing software, **version 8.4**; specifically developed for accurate Direct Georeferencing of airborne sensors.

The POSPac MMS software computes a combined solution of position and attitude of the airborne sensor by processing the raw IMU and GPS data collected with a POS/AV system during the flight, along with recorded GPS time of the events when the digital sensor or aerial camera trigged a photo, within mili-second precision. With the use of differential correction techniques and Kalman filter, POSPac computes the GPS (Global Positional System) solution for the aerial path, and blends it with the inertial data, collected with the IMU (Inertial Measurement Unit). The differential correction of the Airborne GPS data is accomplished in the first 3 to 5 minutes of the processing and carried throughout the processing of entire mission. With POSPac, a solution is computed in a forward (begin-to-end) and reverse (end-to-begin) mode, and the variation between each mode, together with satellite configuration, is used for statistical evaluation of the quality and accuracy of the data. The use of AGPS-IMU allows for a positional accuracy of each aerial photo within 10cm or better of its real position.

Applanix POSPac MMS version 8 PP-RTX uses satellite data to apply real time corrections. PP-RTX is a Precise Point Positioning (PPP) technology. The satellites (geostationary L-band satellites) retrieve the data and transmit it through the L-band range of frequencies. The corrections are derived from Trimble's global network of base stations and applied using advanced algorithms on the rover receiver.

Workflow: Upon extraction of all files belonging to one mission (or sortie), POSPac was used to retrieve the positional corrections via satellite around the aerial mission area. The positional corrections are received from Trimble's global network of base stations and advanced algorithms are applied.

Sanborn used POSPac MMS with IN-Fusion technology for this project. The IN-fusion PP-RTX technology uses the L-band frequencies of satellites as reference for the differential processing and computation of coordinate for each epoch of the GPS-IMU dataset. After final GPS-IMU processing is completed; entire mission can be viewed and selected in many different ways including the 2D Plan View, 3D View, and Points Spreadsheet for final review.

The processed GPS-IMU was combined with the GPS Event time for each photo. The GPS Event Time is a sequential time, stored in seconds of GPS time relative to the specific GPS week. GPS time is stored in seconds with 6 decimal places. The Exterior Orientation file was exported based on the interpolated position at the event-time for each photo, with all photo centers in WICRS Brown County Coordinate System, NAD83/HARN adjustment.

3. AERIAL TRIANGULATION

The Aerotriangulation is a process of densification of control points for accurate georeferencing of a block of images. Few ground control survey points combined with the Airborne GPS post-processed photo center position, are used as source of “ground” control coordinates for the aerotriangulation process. In the aerotriangulation phase, photogrammetric image points are measured on the area of two overlapping aerial photos and its photo-coordinates stored in units of micron (thousands of millimeter). The surveyed ground control points are also measured. The fundamental equation of aerial triangulation is the collinearity equation, which states that “*an object point, its homologous image point, and the perspective center are collinear*”. A bundle adjustment is processed and, as result, the ground coordinate is computed for all points measured on the block of aerial photos.

Sanborn’s standard workflow procedure for aerotriangulation starts with the release of the EO (Exterior Orientation) files from the GPS-IMU processing. Softcopy workstations are used for the aerotriangulation phase. For this project Sanborn used the Inpho Match-AT software. This software allows for automated measurement of pixel-matching points between two or more overlapping photos. Once matching points are processed the photogrammetrist evaluates its matching and investigates where additional points are needed for a solid aerotriangulation block.

The coordinate of targeted ground control points are loaded and measured on each photo where it appears. The GPS-IMU direct exterior orientation is combined with conventional ground control for an AT-bundle adjustment for entire block of photos.
Workflow: Once all aerial digital images are processed and approved for production, the processed airborne GPS photo center were matched with the image names and the EO (Exterior Orientation) file used to load the AT (aerotriangulation) files.

<u>AT Input</u>
Source data is imported into Match-AT during project setup:

- Aerial camera parameters
- Raw aerial imagery
- Airborne GPS/IMU orientation parameters for X, Y, Z, Omega, Phi, Kappa
- Ground control points in the mapping coordinate system with appropriated standard deviation weights.

<u>AT Strategy</u>
The most important features of a block adjustment with "MATCH-AT" are:

- application of image-matching techniques (image correlation)
- integrated block adjustment
- utilization of GPS/IMU data and of an approximate DEM

This leads to some typical characteristics which will be described in detail in the following:
A fast and highly accurate matching of homologous image areas and points is made possible by the methods of digital correlation. The methods have a limited

convergence radius of about 10 pixels for "MATCH-AT". The approximate positions of the von-Gruber areas need to be provided within this accuracy.

With the use of GNSS-supported flight navigation and GNSS evaluation techniques it is possible to achieve absolute accuracies of the GNSS antenna observations of at least 15cm, with a tendency to even higher accuracies. Small camera tilts and small height shifts are sufficient to achieve a successful initialization. In the case of considerable relief, occurring especially in large-scale applications and undulating terrain, it may be necessary to correct the approximate tie point areas. If there is a digital elevation model it is possible to compensate for this influence.

Experience shows that about 30 to 40 tie points are extracted per tie point area, amounting to 400 or more image points. These points are not always transferred into all overlapping images, but sometimes only into 2, 3 or 4 images. Although a complete point transfer would be desirable like in a conventional block adjustment, multiple point transfer into as many images as possible is done. The tie points themselves are automatically selected by the matching procedure with regard to their image features caused high contrasts at house corners, drain covers or shadow lines.

The measuring accuracy sigma naught of the automatic block adjustment in "MATCH-AT" is related to the accuracy of feature-based matching of about 1/3 pixel. These values are comparable to the sigma naught of a conventional block adjustment.

Compared to conventional aerial triangulation it is hard to assess the accuracy of digital AT by inspecting the residuals and connections of each single point in the block. The number of points in each image is just too high.
The quality of the block adjustment can be evaluated by considering the standard deviation of the orientation parameters estimated during block adjustment (SAO = standard deviation of exterior orientation). Six values per image show the accuracy of the rotations and the coordinates of the projection center. All six parameters are influenced by the number and the distribution of the connecting points in the images and are a suitable measure for checking and evaluating the results of the block triangulation. SAO can be displayed in the module "Photo Measurement" for each image, after a successful "MATCH-AT" run. Re-measurements and corrections can be carried out, if necessary.

The evaluation of the absolute accuracy of block triangulation can also be performed in the same way as in conventional AT, i.e. with the help of so-called "check points". "Check points" are additional control points which are measured in the images, but whose coordinates are introduced with a zero weight into block adjustment. After the block adjustment the difference between the photogrammetrically determined ground coordinate and the check point coordinate will show the difference between the photogrammetric point determination and the system of "check points". The root mean squares (RMS) of the check points can be used as a measure for the absolute accuracy of the block adjustment. The attribute of "check point" can be selected for control points in the control point editor, RMS is recorded in the <log file> of the corresponding "MATCH-AT" run.

3.1 Brown County Control Points

PtName	Easting	Northing	Elev	Code
100MAG	42149.575	623991.520	797.128	MAG-T104
101SW	54964.864	625241.424	763.883	NW WALK COR
102STONE	66104.902	624399.215	765.484	SW COR DEC STONE
103STP	80045.318	620635.038	642.727	CRS IN STP
104STP	96718.487	625372.272	596.247	N END STP
105JOINT	94784.072	610741.435	591.226	JOINT IN CONC
106STONE	79618.032	609577.989	640.674	SE COR DEC STONE
107CONC	65454.053	611986.962	739.463	DRIVEWAY CONC EDGE
108CONC	56795.021	611464.083	759.945	SW COR CONC
109MAG	45425.017	608798.228	784.102	MAG-T126
110MAG	45293.632	597726.327	791.275	MAG-T147
111ARROW	53905.151	595977.410	752.369	ARROW POINT
112STONE	67165.074	596155.574	738.451	SE COR DEC STONE
113STP	81781.104	594493.141	630.618	NW STP COR OF TRIANGLE
114STP	95741.943	578266.719	591.206	END OF STP
115STP	80140.025	578267.605	606.801	END OF STP
116CBS	68977.910	579073.799	677.140	NE COR OF INLET AT FLANGE
117BRICK	58496.591	580186.790	755.943	N COR MEM BRICK
118STP	54639.983	564427.809	764.493	S END PRK STP
119STP	66867.781	566676.274	703.942	W END N CL STP
120STP	83325.790	564510.067	642.326	W END PRK STP
121STP	96444.473	564494.348	586.099	W END PRK STP
122MAG	93263.310	552480.639	591.620	MAGinCRS T121
123STP	82182.537	551149.720	607.857	CRS IN PRK STP
124STP	70979.237	549335.022	669.915	N END PRK STP
125STP	53999.912	552068.356	692.497	N END WHITE STP
126STONE	65454.071	611966.726	739.218	DRIVEWAY CONC EDGE W BIT
200CRS	165449.492	613230.016	623.832	CRS IN PRK STP
201STP	165162.113	605024.578	696.084	E END CL STP
202STP	149339.091	603687.440	726.361	S END CL STP
203STP	137773.611	594030.354	711.502	W END PRK STP
204STP	153288.581	589236.638	803.725	N END PRK STP
205CONC	165246.293	592204.715	756.701	NW COR CONC
206CONC	164854.628	575923.602	810.350	SE COR CONC
207CONC	152301.381	577117.528	811.449	NE COR CONC
208STP	134343.689	575986.593	771.331	S END PRK STP
209CRS	126889.568	574432.022	663.298	CRS IN PRK STP
210CRS	103143.970	575473.082	585.598	CRS IN PRK STP

211INL	127563.582	562978.488	769.468	NE CURB INLET
211STP	107895.405	561342.719	600.384	STRIPE T
213STP	135699.165	562709.304	788.151	END STRIPE
214STP	151685.794	562562.792	807.762	END STRIPE
215STP	159761.100	562053.624	847.711	STRIPE T
216TP	165023.724	552006.486	895.160	END CL STRIPE
217CON	154252.813	552017.278	850.977	CONC CORNER
218CON	138320.393	552233.038	792.285	CONC CORNER
219STP	125096.154	551022.378	763.839	STRIPE CROSS
220STP	107573.607	552348.725	596.725	STRIPE END
221STP	116345.796	548868.051	681.551	STRIPE CROSS
222STP	117038.300	559215.330	734.708	STRIPE CROSS
223STP	113851.054	566626.880	602.386	E END PRK STP
224CRS	165589.547	614100.769	592.651	S CRS IN CEN TENNIS CT
225STP	162216.538	611781.394	626.734	N END PRK STP IN PARK N RIDE
300STP	164408.853	541418.503	873.801	STRIPE END
301CON	154502.211	541454.702	850.004	CONC CORNER
302CON	138390.266	541471.139	803.237	CONC CORNER
303STP	123790.822	540985.723	756.808	STRIPE CROSS
304CON	107912.191	540534.931	605.968	CONC CORNER
305STP	105996.154	531296.567	874.544	STRIPE CROSS
306JNT	121068.331	525480.171	859.549	CONC JOINT
307CRS	133563.406	530183.877	867.755	CRS
307STP	134797.111	529795.914	864.583	W END PRK STP
308STP	151696.188	523927.371	743.019	STRIPE CROSS
309CON	162930.152	525803.219	839.545	CONC CORNER
310CON	162272.632	509509.626	791.304	CONC CORNER
311STP	149693.052	507774.809	871.737	STRIPE END
312STP	156507.461	500798.148	821.368	STRIPE END
313STP	132797.202	509981.242	929.274	STRIPE END
314CON	119800.078	509668.934	951.907	CONC CORNER
315CONC	104023.342	509722.955	934.192	NW CONC COR
316STP	107073.668	488173.201	915.275	STRIPE T
317CON	116902.726	490233.626	910.532	CONC CORNER
318CON	130928.488	493925.603	898.238	CONC CORNER
319CON	119856.392	478029.353	833.076	CONC CORNER
320STP	127036.031	470711.545	830.992	STRIPE CROSS
321STP	116511.316	470417.983	854.360	E END PRK STP
322CON	106056.886	472586.791	888.422	CONC CORNER
323CON	131891.788	501606.773	878.276	CONC CORNER
325MAG	94567.596	552363.444	614.673	MAG CROSS
400STP	93963.564	539668.843	602.812	STRIPE CROSS

401STP	79352.497	539428.522	617.014	STRIPE CROSS
402STP	67890.392	541325.165	673.565	STRIPE END
403STP	53935.861	539439.928	706.755	STRIPE END
404CON	57195.449	526673.690	680.440	CONC CORNER
405STP	70069.903	527336.342	637.716	STRIPE CROSS
407STP	80344.977	524422.280	647.654	STRIPE END
408STP	97638.916	530071.275	706.635	STRIPE END
409CON	100418.493	515178.698	935.337	NW CONC COR
410STP	79990.758	512539.817	639.450	STRIPE END
411CON	66644.839	515177.484	647.125	SW CORNER RR X
412STP	54853.107	510153.707	674.919	STRIPE CROSS
413STP	52423.160	499653.744	668.310	STRIPE CROSS
414CON	64447.215	499896.791	656.096	CONC CORNER
415CON	79851.782	501899.785	706.527	CONC CORNER
416TP	90810.821	507663.894	816.651	STRIPE END
417CON	98358.706	488664.612	914.077	SW CONC COR
418CON	80016.263	486030.517	761.442	CONC CORNER
419CONC	63720.673	487946.523	697.818	SW COR WALK
420CON	54134.568	488701.030	662.453	CONC CORNER
421CON	55224.867	469751.877	780.039	CONC CORNER
422CON	68834.945	471564.632	756.574	CONC CORNER
423COR	79954.207	471206.806	874.471	SE SCALE COR
424STP	97122.212	468597.120	893.681	STRIPE END
425PK	53627.085	483600.122	670.451	PK/WASH CROSS
426MAG	53923.602	536300.721	709.073	MAG/WASH

3.1.1 Final Coordinates and Elevations

PROJCS["NAD_1983_HARN_WISCRS_Brown_County_Feet",GEOGCS["GCS_North_American_1983_HARN",DATUM["D_North_American_1983_HARN",SPHEROID["GRS_1980",6378137.0,298.257222101]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],PROJECTION["Transverse_Mercator"],PARAMETER["False_Easting",103674.333],PARAMETER["False_Northing",15091.833],PARAMETER["Central_Meridian",-88.0],PARAMETER["Scale_Factor",1.00002],PARAMETER["Latitude_Of_Origin",43.0],UNIT["Foot_US",0.3048006096012192]],VERTCS["NAVD_1988",VDATUM["North_American_Vertical_Datum_1988"],PARAMETER["Vertical_Shift",0.0],PARAMETER["Direction",1.0],UNIT["Meter",1.0]]

3.2 Summary of AT Results – 3in Block

```
RMS automatic points in photo (number: 294168)
        x           0.4 micron
        y           0.4 micron

RMS   control and manual points in photo (number: 70)
        x           1.0 micron
        y           1.2 micron


RMS control points with default standard deviation set (number: 12)
        x         0.059 [feet]
        y         0.057 [feet]

RMS control points  with default standard deviation set (number: 12)
        z         0.062 [feet]

RMS IMU observations (number: 748)
        omega     0.002 [deg]
        phi       0.002 [deg]
        kappa     0.004 [deg]

RMS GNSS observations (number: 748)
        x         0.116 [feet]
        y         0.083 [feet]
        z         0.111 [feet]

sigma naught        0.5 micron (22:02:51)
```

3.2.1 Object Statistics – 3in Block

residuals horizontal control points in [feet]

control point ID	rx	ry
122MAG	-0.042	-0.011
123STP	-0.052	0.036
219STP	-0.024	0.121
220STP	-0.041	0.025
303STP	-0.034	0.018
304CON	0.138	0.034
325MAG	0.006	-0.007
400STP	-0.003	-0.020
401STP	0.109	-0.011
405STP	0.009	-0.033
407STP	-0.057	-0.136
408STP	-0.011	-0.017

residuals vertical control points in [feet]

control point ID	rz
122MAG	0.010
123STP	0.050
219STP	0.073
220STP	0.113
303STP	0.013
304CON	0.015
325MAG	0.014
400STP	-0.099
401STP	-0.003
405STP	-0.102
407STP	-0.067
408STP	-0.017

3.3. Summary of AT Results – 6in Block

```
RMS automatic points in photo (number: 1059516)
        x           0.5 micron
        y           0.5 micron

RMS   control and manual points in photo (number: 282)
        x           0.9 micron
        y           0.9 micron


RMS control points with default standard deviation set (number: 34)
        x         0.128 [feet]
        y         0.113 [feet]

RMS control points  with default standard deviation set (number: 40)
        z         0.257 [feet]

RMS IMU observations (number: 2484)
        omega     0.003 [deg]
        phi       0.002 [deg]
        kappa     0.005 [deg]

RMS GNSS observations (number: 2484)
        x         0.120 [feet]
        y         0.146 [feet]
        z         0.150 [feet]

sigma naught        0.5 micron (21:55:05)
```

3.3.1 Object Statistics – 6in Block

residuals horizontal control points in [feet]

control point ID	rx	ry
101SW	-0.207	0.013
425PK	-0.042	-0.060
104STP	0.265	0.022
109MAG	-0.119	0.029
113STP	0.114	-0.147
123STP	-0.080	-0.022
124STP	0.072	0.218
202STP	-0.071	0.180
203STP	-0.195	0.070
210CRS	0.101	-0.152
211INL	0.079	-0.158
220STP	0.084	-0.132
224CRS	-0.177	0.040
301CON	0.044	-0.041
303STP	-0.075	0.021
309CON	0.035	0.025
314CON	0.033	-0.014
317CON	-0.032	-0.077
318CON	0.123	-0.168
320STP	0.022	0.246
403STP	-0.109	0.105
408STP	0.196	-0.009
411CON	-0.025	-0.091
413STP	-0.056	-0.055
415CON	-0.182	0.022
417CON	-0.079	0.018
422CON	0.038	-0.023
424STP	-0.176	0.164
108CONC	-0.035	-0.003
206CONC	0.018	-0.032
207CONC	0.126	0.006
105JOINT	0.226	0.112
106STONE	0.248	-0.260
117BRICK	-0.165	0.152

residuals vertical control points in [feet]

control point ID	rz
101SW	-0.513
216TP	0.346
425PK	-0.263
104STP	0.264
109MAG	-0.159
113STP	0.099
115STP	-0.148
118STP	-0.483
123STP	-0.177
124STP	-0.400
202STP	0.315

203STP	0.151
210CRS	-0.020
211INL	0.195
220STP	0.187
224CRS	0.242
301CON	0.157
303STP	0.414
307CRS	0.180
309CON	0.095
312STP	-0.071
314CON	0.127
317CON	0.407
318CON	0.259
320STP	-0.093
403STP	-0.204
408STP	0.157
409CON	-0.002
411CON	-0.103
413STP	-0.210
415CON	-0.418
417CON	0.185
422CON	-0.235
424STP	-0.110
108CONC	-0.547
206CONC	0.215
207CONC	0.073
105JOINT	0.329
106STONE	-0.118
117BRICK	-0.122

APPENDIX A – CAMERA CALIBRATION REPORT

VEXCEL
IMAGING

ULTRACAM

Calibration Report

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ULTRACAM

Geometric Calibration

Camera: **UltraCam Eagle**
Serial: **UC-E-1-60819257-f100**

Panchromatic Camera: **ck = 100.500 mm**
Multispectral Camera: **ck = 100.500 mm**

PPA Information: **X: 0.000 mm**
Y: 0.000 mm

Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track cross track	68.016mm 104.052mm	13080pixel 20010pixel
Image Extent		(-34.008, -52.026)mm	(34.008, 52.026)mm
Pixel Size		5.200µm*5.200µm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	-0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Multispectral Camera

Medium Format Multispectral Output Image
(Upscaled to panchromatic image format)

Image Format	long track cross track	68.016mm 104.052mm	4360pixel 6670pixel
Image Extent		(-34.008, -52.026)mm	(34.008, 52.026)mm
Pixel Size		15.600µm*15.600µm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	-0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

ULTRACAM

Summary

Camera:	**UltraCam Eagle**
Serial:	**UC-E-1-60819257-f100**
Laboratory Calibration Date:	**Dec-10-2019**
Camera Revision:	**Rev11.00**
Date of Report:	**Dec-12-2019**
Version of Report:	**V01**

The following calibrations have been performed for the above mentioned digital aerial mapping camera:

- Geometric Calibration
- Radiometric Calibration
- Shutter Calibration
- Sensor and Electronics Calibration

This equipment is operating fully within specification as defined by Vexcel Imaging GmbH.

Dr. Michael Gruber
Chief Scientist, Photogrammetry
Vexcel Imaging GmbH

Dipl. Ing. (FH) Helmut Jauk
Senior Project Engineer R&D
Vexcel Imaging GmbH