AEROQUEST

MAPCON

Aerial Triangulation Report

2016 City of Nanaimo Aerial Mapping Project

City of Nanaimo,
455 Wallace Street,
Nanaimo, B.C.,
V9R 5J6

Attention: **Mr. Mark Willoughby,**

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APPENDICIES

1.1 SCOPE OF PROJECT

AeroQuest Mapcon Mapping Inc. adjusted a total of 1461 digital colour images to support a vector product of 14.1cm RMSE horizontally and 10CM RMSE vertically. An additional 140 models were created based solely on post processed airborne GPS/IMU data for images covering water. Summary of Aerial Triangulation input data, procedure and results are presented below.

1.2 PHOTOGRAPHY

Digital color images were flown at a mean photo scale of 1:8,236 to support a 6.25cm pixel size and 14.1cm (xy)/10cm (z) vector product. All images were captured by Kisik Aerial Survey of Richmond, B.C. using a Vexcel UCEagle-f80 digital camera with airborne GPS and inertial measuring unit. Flights took place on February 23rd, April 07th and April 19th, 2016. All images were flown at a nominal 60% forward gain and 30% sidelap. Three images contain omega rotation greater than 2º. These images fall outside the project area. Relevant camera calibrations for all cameras used can be found in Appendix C.

1.3 GROUND CONTROL

All ground controls used were photo identified location surveyed by J. E. Anderson & Associates (mapping control) of Nanaimo, B.C. and by Eagle Mapping Ltd. (Lidar control) of Port Coquitlam, B.C. An additional 28 marked survey points, used as check points (with nominal coordinates) were supplied by client.

1.3a Ground control and weights

I. **43** J.E. Anderson controls were used. All points were used as horizontal and vertical control. All points were photo identified locations.
II. **19** Eagle controls were used. Of these 7 were used as horizontal/vertical control, 7 were used as vertical-only control and 5 were used as horizontal-only control. All horizontal points were at photo identified locations.
III. All control points were assigned a horizontal/vertical weight of 4.0cm.

1.4 CONTROL DATUM

Projection – UTM zone 10
Horizontal Datum - North American 1983 (CSRS)
Vertical Datum – CGVD28
Units – Metres

1.5 PROCEDURE

All adjusted images were bridged using Intergraph's ISAT auto-correlation software (ver. 15.00.0000). The result of the ISAT correlation was analyzed and areas of failed correlation were densified by manual means. Ground control was then read and all bridged data exported to GIP's BINGO (ver. 6.8) adjustment software. The final adjustment was exported back to Intergraph's ISAT and models created. A final QC of the model was done using Intergraph's ISSD module. The QC involved checks for tie to ground control, parallax and line tie accuracy. The project extent covers areas of water were some images could not be adjusted. Model setups for these images are based on post processes airborne GPS and IMU received from Kisik Aerial Surveys.

No airborne data was used in the adjustment due to the high accuracy specified and the high density of ground control.

1.6 RESULTS

Statistical results for the adjusted images are set at RMSE (root/mean/square) or approximately 68% confidence interval.

Type of measurements	A priori Standard Deviation			Computed Standard Deviations		
	X	Y	Z	X	Y	Z
	Metres	Metres	Metres	Metres	Metres	Metres
Pass/tie points	3.0 microns	3.0 microns	n/a	1.6microns	1.3microns	n/a
Surveyed Control	0.04	0.04	0.04	0.022	0.022	0.014

Standard Deviations of Adjusted Terrain Coordinates

		X [m]	Y [m]	Z [m]
Total number	26,223			
Mean Precision		0.016	0.019	0.051

Standard Deviations of adjusted Orientation Parameters are:

		X0 [m]	Y0 [m]	Z0 [m]	Omega [Deg.]	Phi [Deg.]	Kappa [Deg.]
Total number	1461						
Mean Precision		0.067	0.056	0.050	0.00495	0.00423	0.00162

Image observation residuals are:

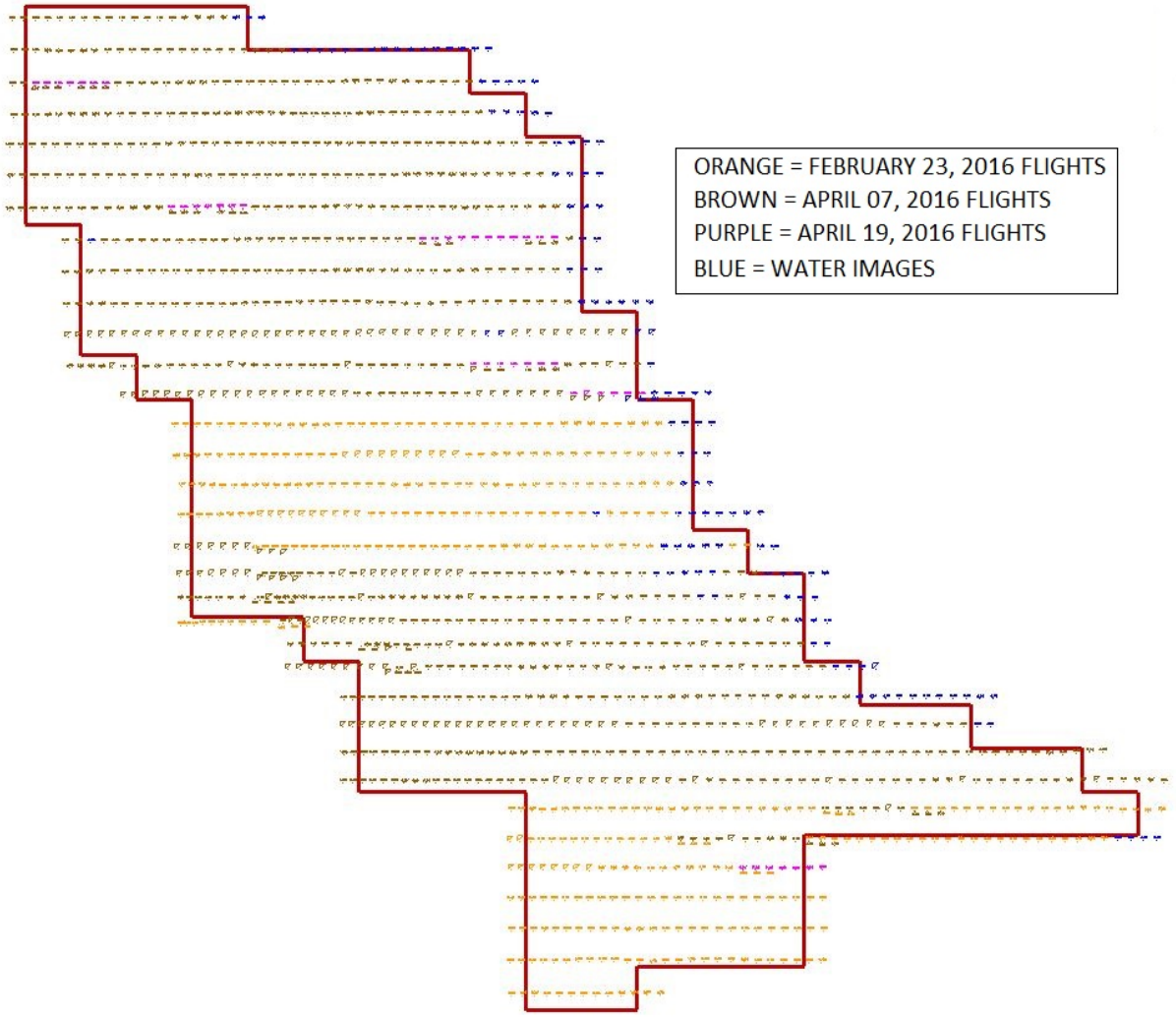
	X microns	Y microns
RMS value	1.6	1.3
Max residual	10.4	10.4

1.7 Statement of Accuracy

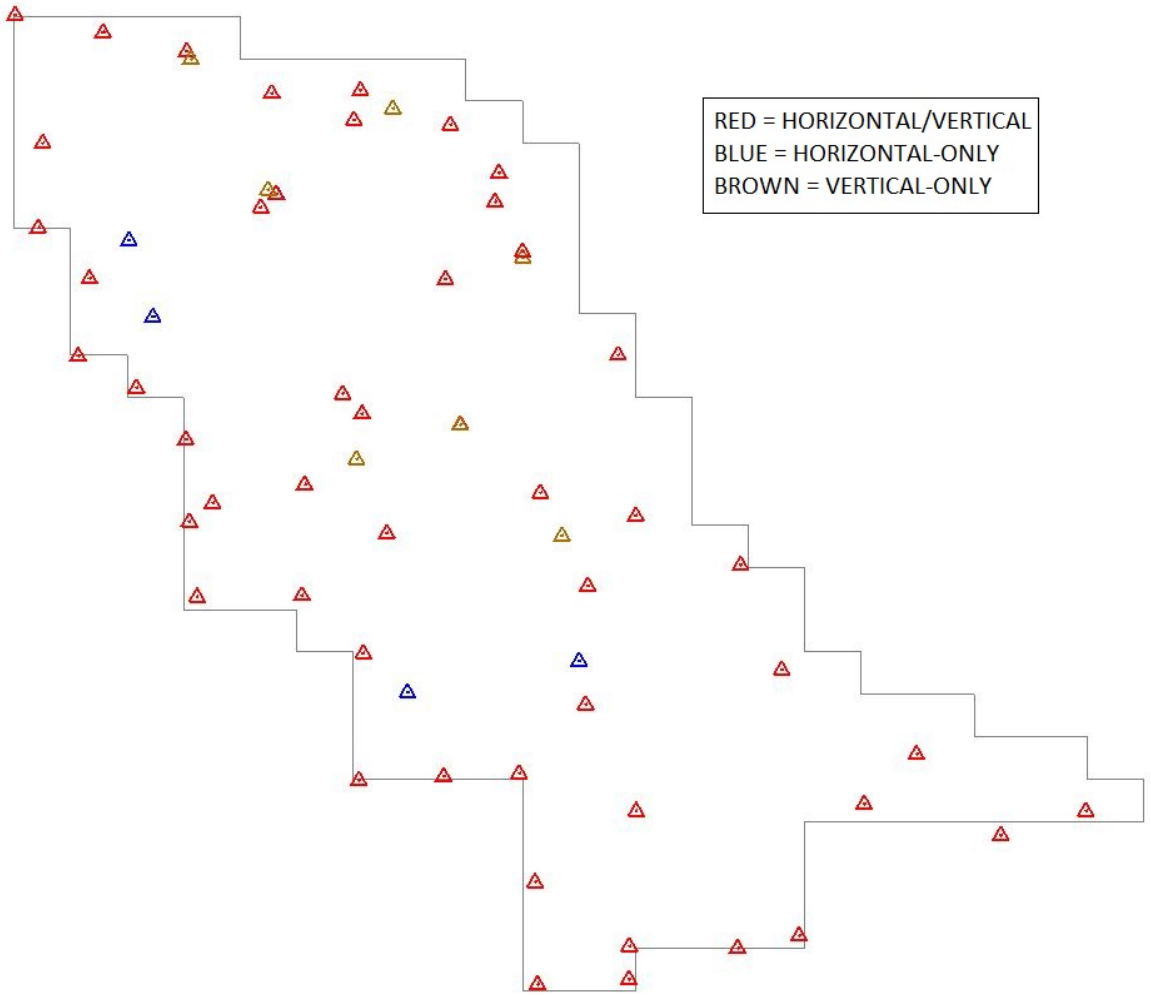
A total of 111,028 readings of 26,223 adjusted points were generated by the adjustment. This results in 4.2 readings per point and 18 point per image. The computed mean ground sample distance (GSD) for the adjusted images is 4.3cm. The mean standard deviation of ground control used is 0.031cm horizontally and 0.014cm vertical. The mean standard deviation of adjusted terrain points is 0.025cm horizontal and 0.051cm vertical. This shows that both photography and adjustment fall within specification for 6.25cm image resolution and 5.0cm horizontal and vertical AT accuracy.

Björn E. Norman CP # R1264,
Aerial Triangulation Manager

APPENDIX A: Image Centre Layout



APPENDIX B: Ground Control Layout



APPENDIX C: Camera Calibration Report

Calibration Report

Short version

Camera:	**UltraCam Eagle, S/N UC-Eagle-1-20814295-f80**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Date of Calibration:	**Jan-04-2016**
Date of Report:	**Jan-11-2016**
Revision of Camera:	**Rev07**
Version of Report:	**Rev07**

Calibration Report

Geometric Calibration

Camera:	**UltraCam Eagle, S/N UC-Eagle-1-20814295-f80**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Panchromatic Camera:	**ck = 79.800 mm**
Multispectral Camera:	**ck = 79.800 mm**
Date of Calibration:	**Jan-04-2016**
Date of Report:	**Jan-11-2016**
Revision of Camera:	**Rev07**
Version of Report:	**Rev07**

Panchromatic Camera

Large Format Panchromatic Output Image

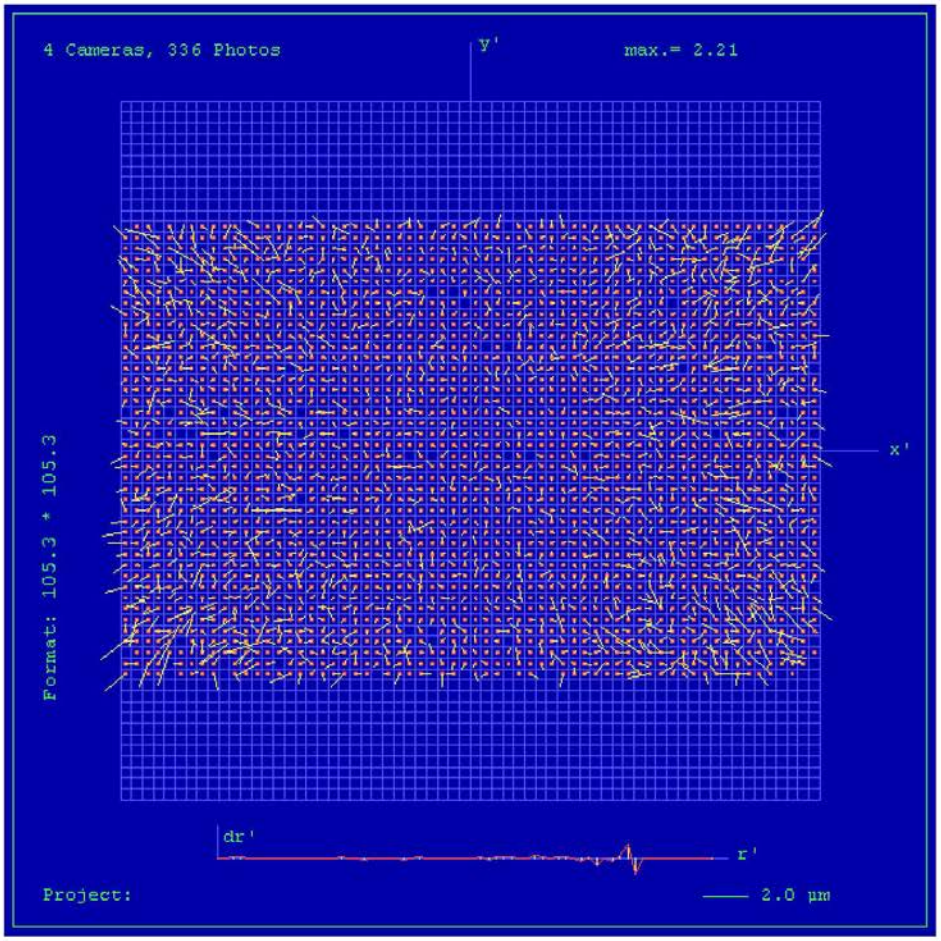
Image Format	long track	68.016mm	13080pixel
	cross track	104.052mm	20010pixel
Image Extent		(-34.01, -52.02)mm	(34.01, 52.02)mm
Pixel Size		5.200µm*5.200µm	
Focal Length	ck	79.800 mm	± 0.002mm
Principal Point	X_ppa	0.000 mm	± 0.002mm
(Level 2)	Y_ppa	0.000 mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Multispectral Camera

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

Image Format	long track	68.016mm	4360pixel
	cross track	104.052mm	6670pixel
Image Extent		(-34.01, -52.02)mm	(34.01, 52.02)mm
Pixel Size		15.600µm*15.600µm	
Focal Length	ck	79.800 mm	
Principal Point	X_ppa	0.000 mm	± 0.002mm
(Level 2)	Y_ppa	0.000 mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Full Pan Image, Residual Error Diagram



Residual Error (RMS): **0.59 µm**

Explanations:

1) Calibration Method:

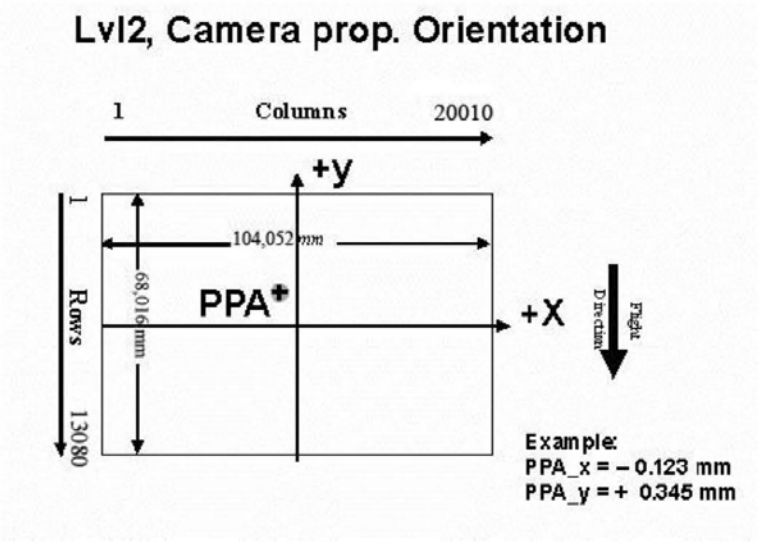
The geometric calibration is based on a set of 84 images of a defined geometry target with 394 GCPs.

Number of point measurements for the panchromatic camera : 19241
Number of point measurements for the multispectral camera : 77448

Determination of the image parameters by Least Squares Adjustment.
Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

2) Level 2 Image Coordinate System:

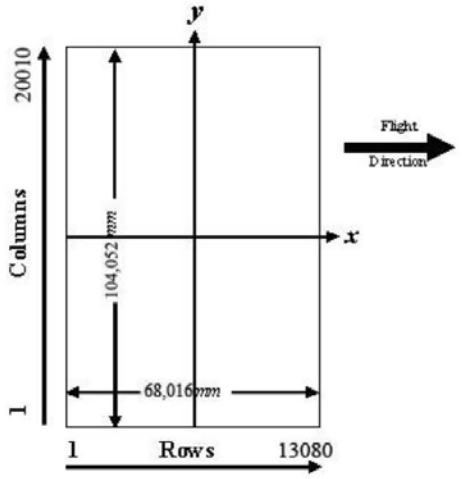
PAN 20010 pixel by 13080 pixel
MS 6670 pixel by 4360 pixel



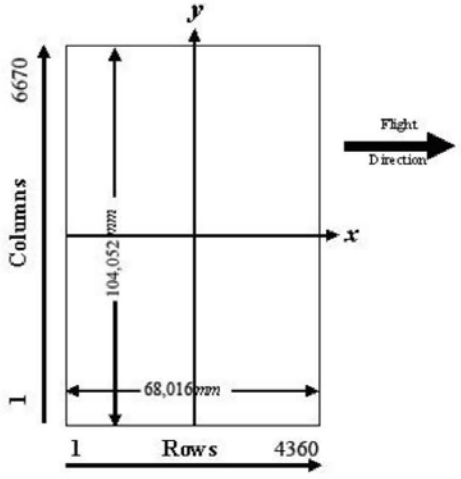
The image coordinate system of the Level 2 images is shown in the above figure. The level 2 image consists of 20010 columns and 13080 rows, which leads to a total image format of 104.052 x 68.016 mm. The coordinate of the principal point in the level 2 image is given on page 3 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).

3) Level 3 Image Coordinate System:
(after rotation of 270° CW)

PAN 20010 pixel by 13080 pixel
MS 6670 pixel by 4360 pixel



Panchromatic Image Format



Multispectral Image Format

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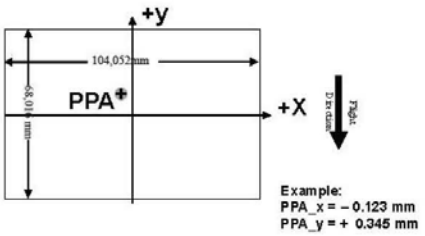
4) Position of Principal Point in Level 3 Image

The position of the principal point in the level 3 image depends on the "rotation" setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified for clockwise (CW) rotation in steps of 90 degrees, according to the principal point coordinate given on page 3 for high- and low resolution images.

Image Format	Clockwise Rotation (Degree)	PPA	
		X	Y
Level 2	-	0.000	0.000
Level 3	0	0.000	0.000
Level 3	90	0.000	0.000
Level 3	180	0.000	0.000
Level 3	270	0.000	0.000

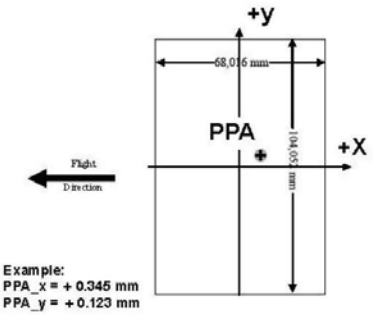
The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

Lvl3, Rotation 0 deg clockwise



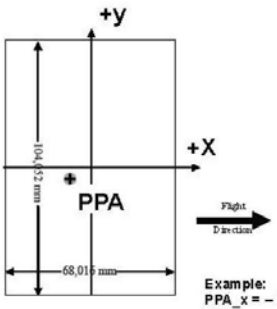
Example:
PPA_x = – 0.123 mm
PPA_y = + 0.345 mm

Lvl3, Rotation 90 deg clockwise



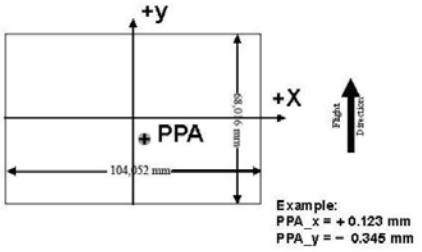
Example:
PPA_x = + 0.345 mm
PPA_y = + 0.123 mm

Lvl3, Rotation 270 deg clockwise



Example:
PPA_x = – 0.345 mm
PPA_y = – 0.123 mm

Lvl3, Rotation 180 deg clockwise



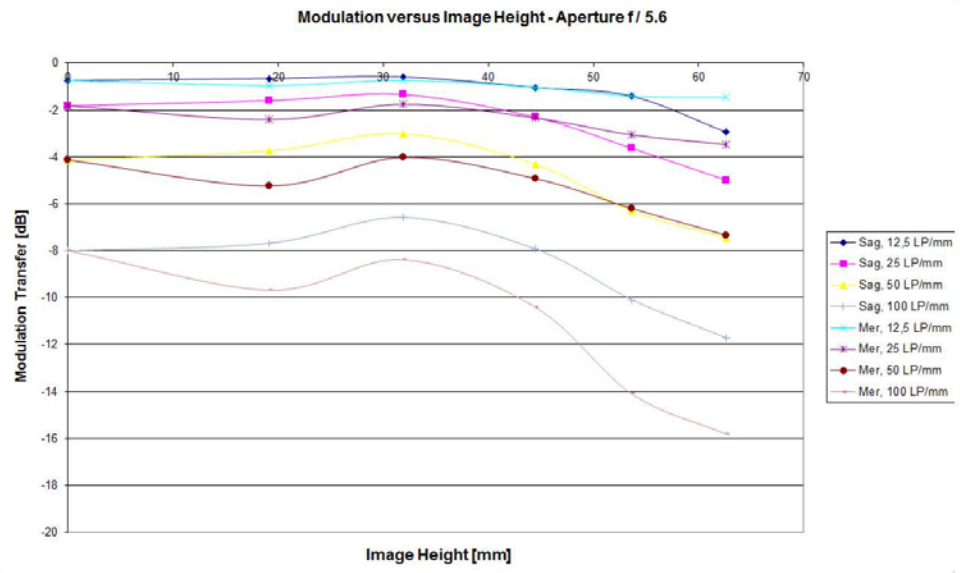
Example:
PPA_x = + 0.123 mm
PPA_y = – 0.345 mm

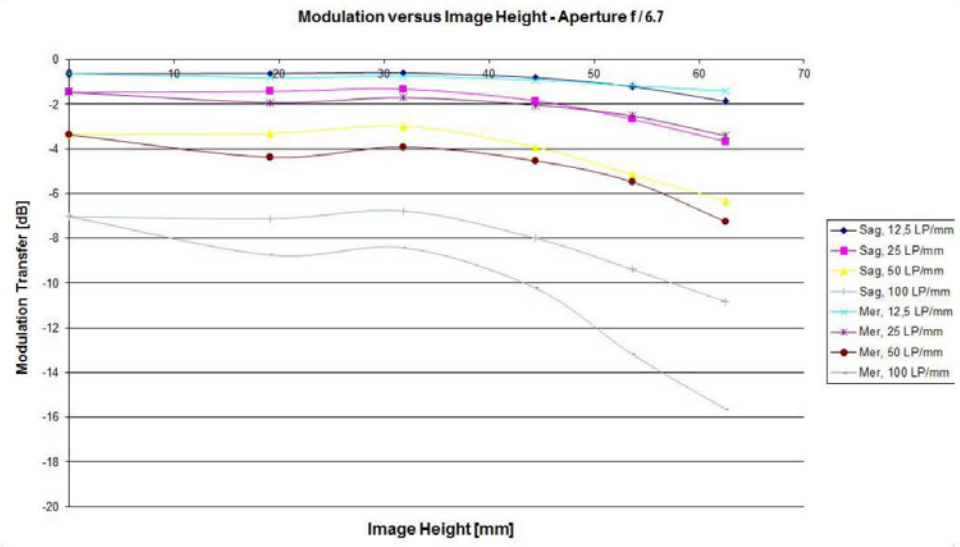
Lens Resolving Power

The following curves show the development of the modulation transfer function across different image heights of the panchromatic cones. Please note that these values have been calculated and can vary up to 10% with optics from production (especially at high LP's).

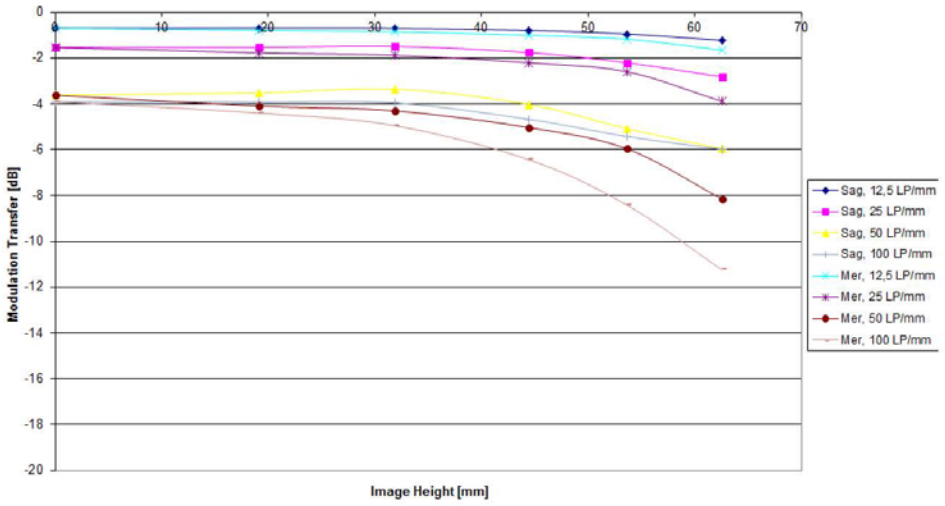
The curves are given for the meridonial (tangential) and sagital (radial) component of signals at frequencies of 12.5, 25, 50 and 100 line pairs per millimeter.

As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

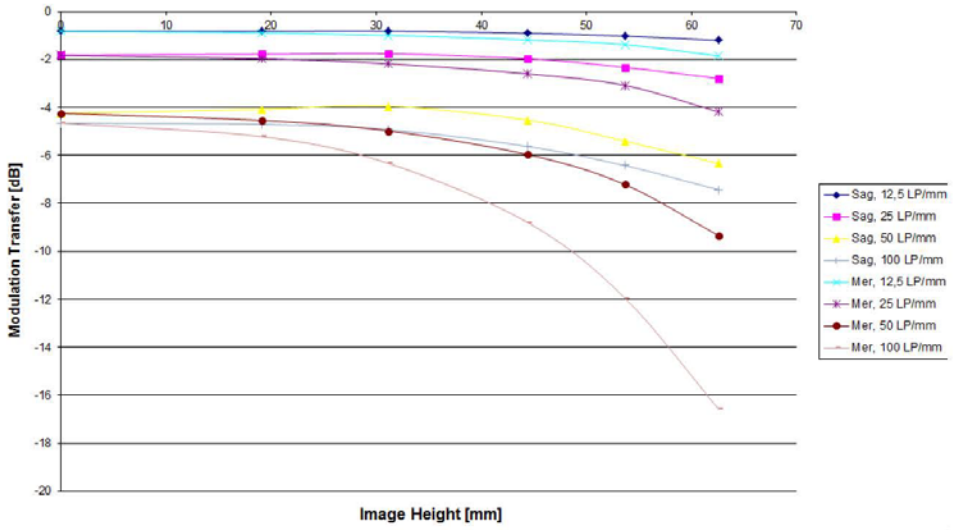

Modulation versus Image Height - Aperture f / 5.6
Modulation Transfer [dB]
Image Height [mm]
Sag, 12,5 LP/mm
Sag, 25 LP/mm
Sag, 50 LP/mm
Sag, 100 LP/mm
Mer, 12,5 LP/mm
Mer, 25 LP/mm
Mer, 50 LP/mm
Mer, 100 LP/mm


Modulation versus Image Height - Aperture f / 6.7
Modulation Transfer [dB]
Image Height [mm]
Sag, 12,5 LP/mm
Sag, 25 LP/mm
Sag, 50 LP/mm
Sag, 100 LP/mm
Mer, 12,5 LP/mm
Mer, 25 LP/mm
Mer, 50 LP/mm
Mer, 100 LP/mm

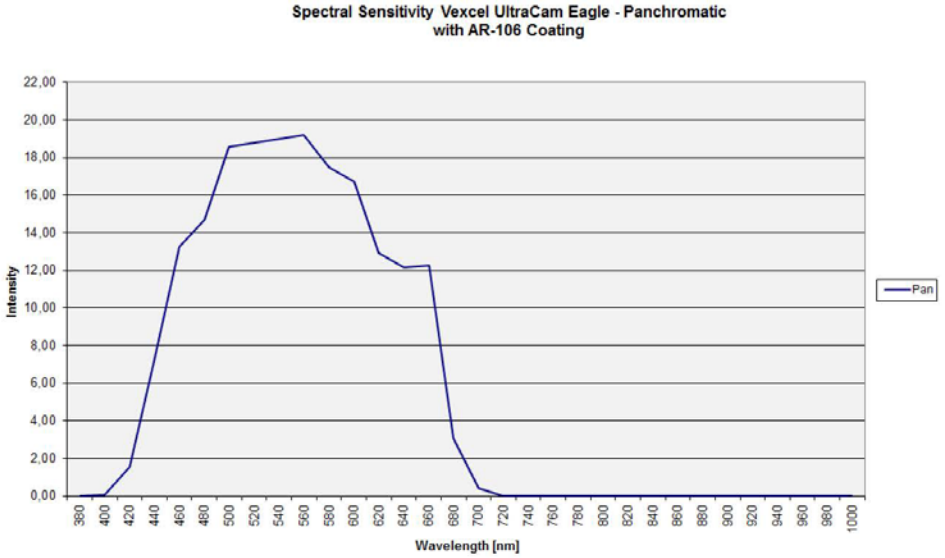
Modulation versus Image Height - Aperture f / 8

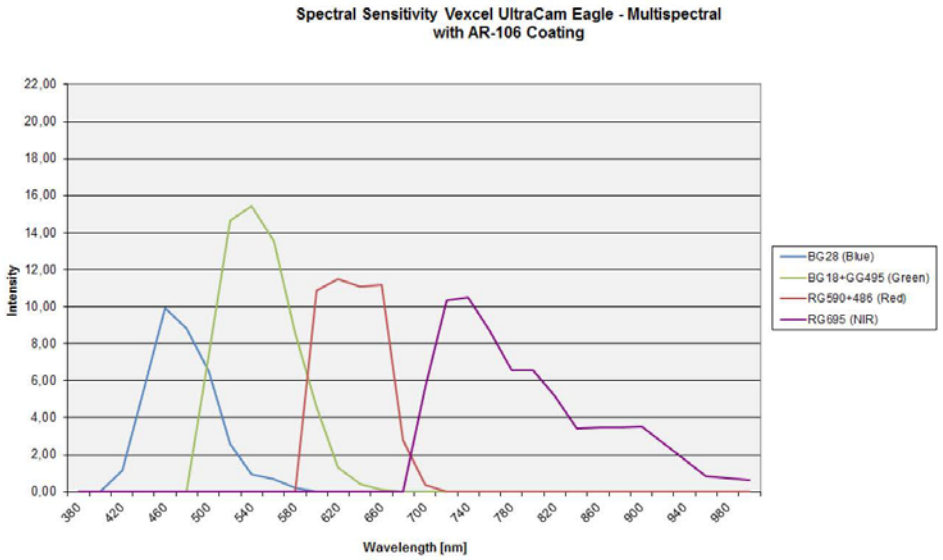


Modulation versus Image Height - Aperture f / 9.5



Spectral Sensitivity





Calibration Report

Radiometric Calibration

Camera: UltraCam Eagle, S/N UC-Eagle-1-20814295-f80

Manufacturer: Vexcel Imaging GmbH, A-8010 Graz, Austria

Aperture	PAN	R, G, NIR	B
	F5.6	F8.0	F5.6
	F6.7	F9.3	F6.5
	F8	F11	F8
	F9.5	F13	F9.5
	F11	F16	F11
	F13	F19	F13
	F16	F22	F16
	F22	F27	F22

Date of Calibration: Jan-04-2016
Date of Report: Jan-11-2016
Revision of Camera: Rev07
Version of Report: Rev07

Explanations:

Calibration Method:

The radiometric calibration is based on a series of 50 flat field images for each aperture size and sensor. The flat field is illuminated by eight normal light lamps with known spectral illumination curves.

These images are used to calculate the specific sensitivity of each pixel to compensate local as well as global variations in sensitivity. Sensitivity tables are calculated for each sensor and aperture setting, and applied during post processing from level 0 to level 1.

Outlier Pixels that do not have a linear behavior as described in the CCD specifications are marked as defective during the calibration procedure. These pixels are not used or only partially used during post processing and the information is restored by interpolation between the neighborhood pixels surrounding the defective pixels.

Certain pixels that are named Qmax pixels due to the fact that they can only store and transfer charge up to a certain maximum amount are detected in an additional calibration step. These pixels are treated differently during post processing, since their behavior can affect not only single pixel values but whole columns.

Calibration Report

Summary

Camera:	**UltraCam Eagle, S/N UC-Eagle-1-20814295-f80**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Date of Calibration:	**Jan-04-2016**
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Revision of Camera:	**Rev07**
Version of Report:	**Rev07**

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

- Geometric Calibration
- Verification of Lens Quality and Sensor Adjustment
- Radiometric Calibration
- Calibration of Defective Pixel Elements
- 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

Ing. Peter Prassl
Senior Calibration Engineer
Vexcel Imaging GmbH