



ULTRACAM

Calibration Report

Camera:	UltraCam Eagle M3
Serial:	UC-EpII-1-52319383-f100v2
Laboratory Calibration Date:	Mar-29-2022
Camera Revision:	Rev01.00
Date of Report:	Apr-19-2022
Version of Report:	V01



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Venice, Italy

Photo on page 1 courtesy of Vexcel Imaging GmbH



ULTRACAM

Geometric Calibration

Camera: UltraCam Eagle M3
Serial: UC-EpII-1-52319383-f100v2

Panchromatic Camera: ck = 101.700 mm
Multispectral Camera: ck = 101.700 mm

PPA Information: X: 0.000 mm
Y: 0.000 mm



Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track cross track	68.016 mm 105.840 mm	17004 pixel 26460 pixel
Image Extent		(-34.008, -52.920) mm	(34.008, 52.920) mm
Pixel Size		4.000 μm*4.000 μm	
Focal Length	ck	101.700 mm	± 0.002 mm
Principal Point (Level 2)	X_ppa	0.000 mm	± 0.002 mm
	Y_ppa	0.000 mm	± 0.002 mm
Lens Distortion	Remaining Distortion less than 0.002 mm		

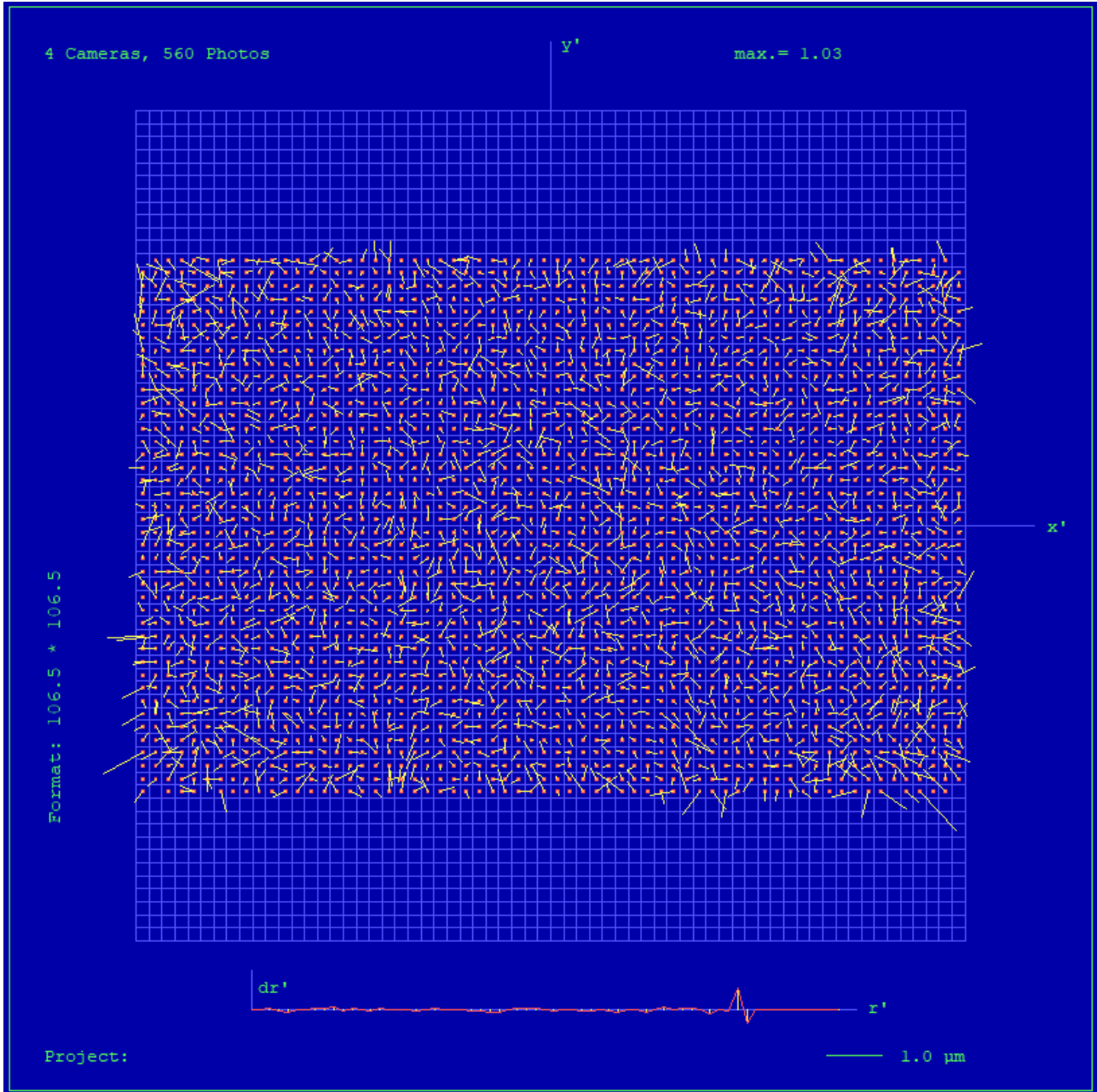
Multispectral Camera

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

Image Format	long track cross track	68.016 mm 105.840 mm	5668 pixel 8820 pixel
Image Extent		(-34.008, -52.920) mm	(34.008, 52.920) mm
Pixel Size		12.000 μm*12.000 μm	
Focal Length	ck	101.700 mm	± 0.002 mm
Principal Point (Level 2)	X_ppa	0.000 mm	± 0.002 mm
	Y_ppa	0.000 mm	± 0.002 mm
Lens Distortion	Remaining Distortion less than 0.002 mm		



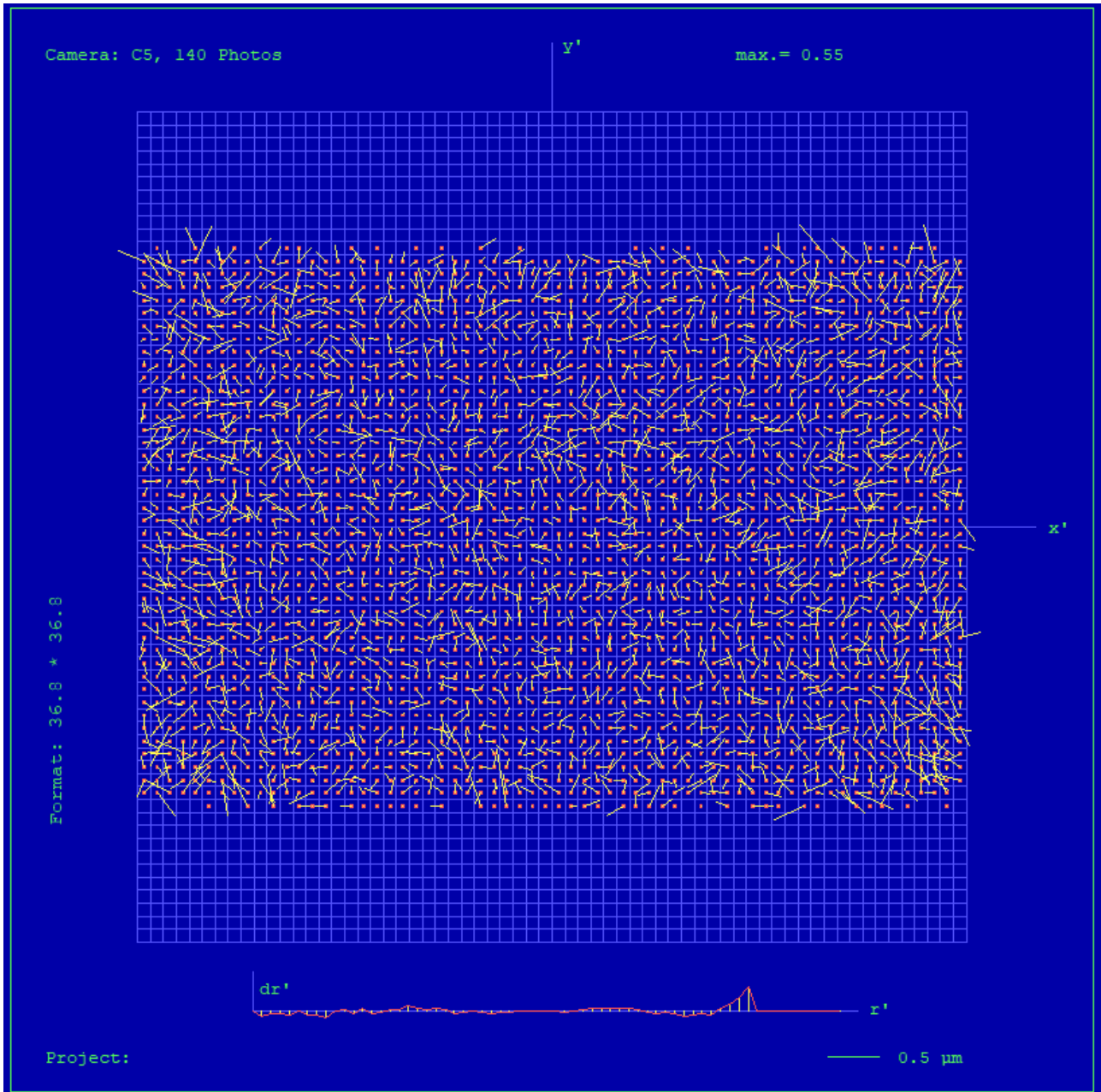
Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): **0.58 μm**



Green Cone (Cone 5), Residual Error Diagram



Residual Error (RMS): **0.45 μm**



Explanations

Calibration Method:

The geometric calibration is based on a set of 140 images of a defined geometry target with 394 GCPs.

Number of point measurements for the panchromatic camera : >16000

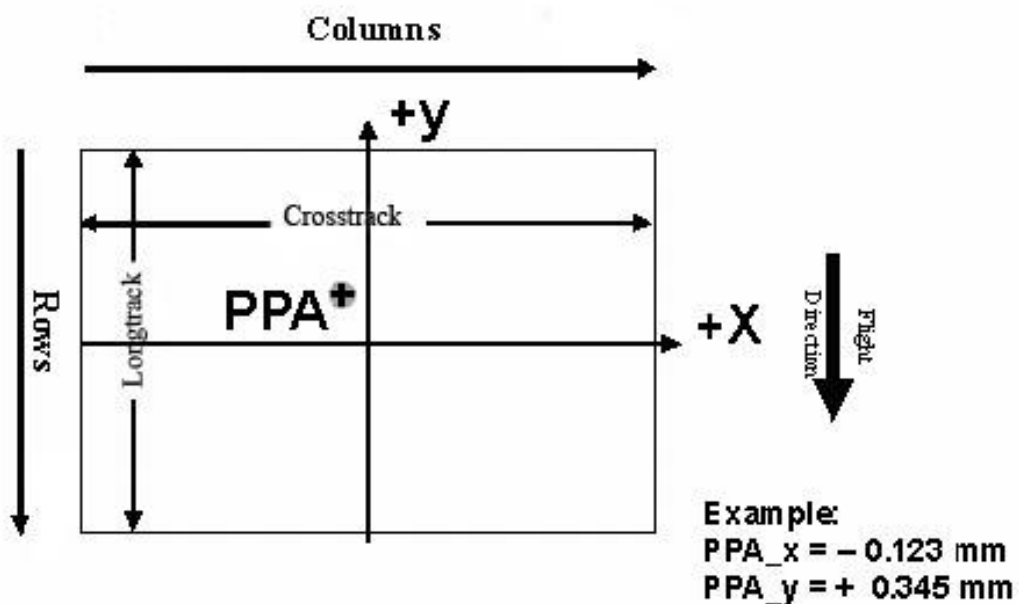
Number of point measurements for the multispectral camera : >60000

Determination of the image parameters by Least Squares Adjustment.

Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

Level 2 Image Coordinate System:

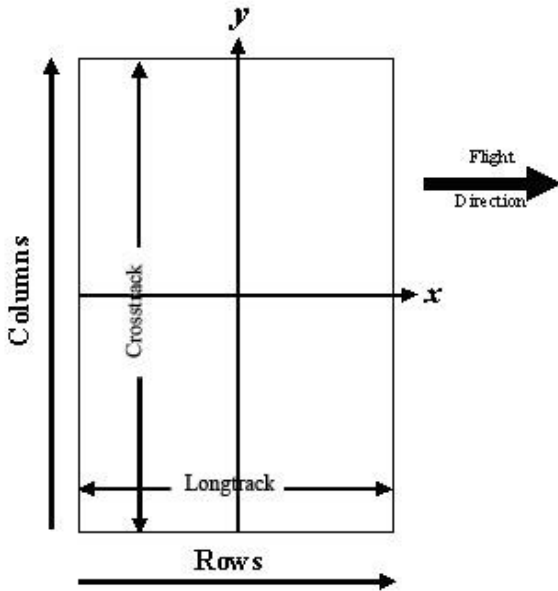
Lvl2, Camera prop. Orientation



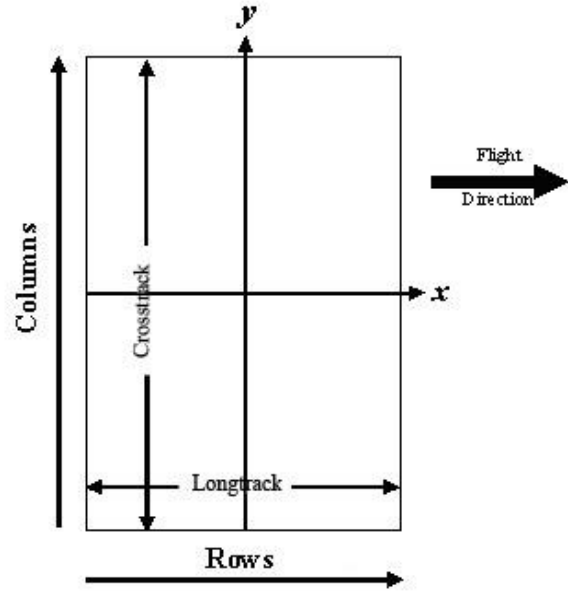
The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).



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



Panchromatic Image Format



Multispectral Image Format

Position of Principal Point in Level 3 Image

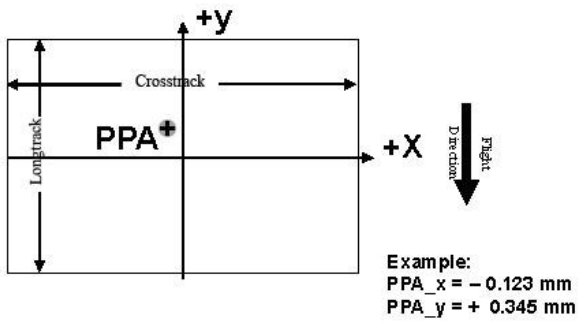
The position of the principal point in the level 3 image depends on the “rotation” setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified for clockwise (CW) rotation in steps of 90 degrees, according to the principal point coordinate given on page 4 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

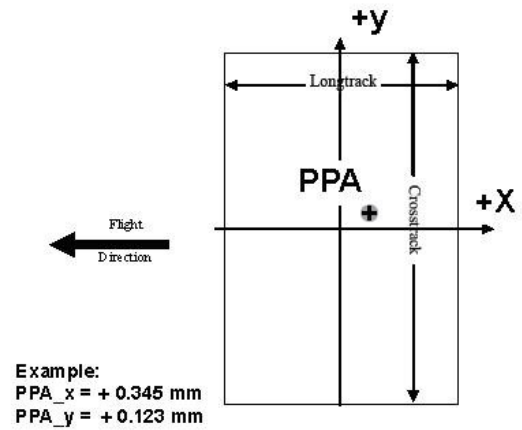


The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

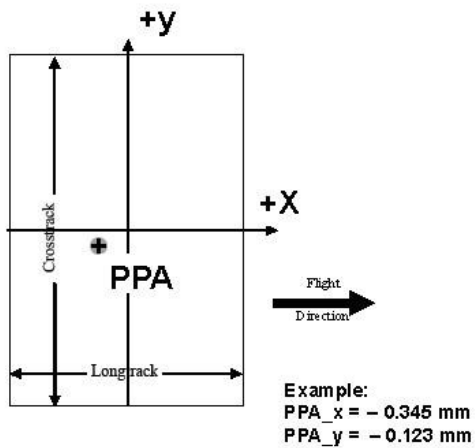
Lvl3, Rotation 0 deg clockwise



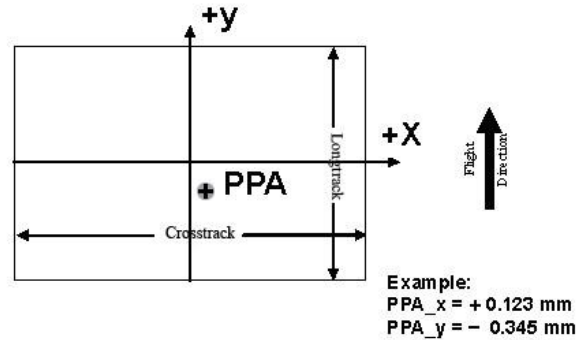
Lvl3, Rotation 90 deg clockwise



Lvl3, Rotation 270 deg clockwise



Lvl3, Rotation 180 deg clockwise





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 meridional (tangential) and sagital (radial) component of signals at frequencies of 12.5, 25, 50 and 100 line pairs per millimeter.

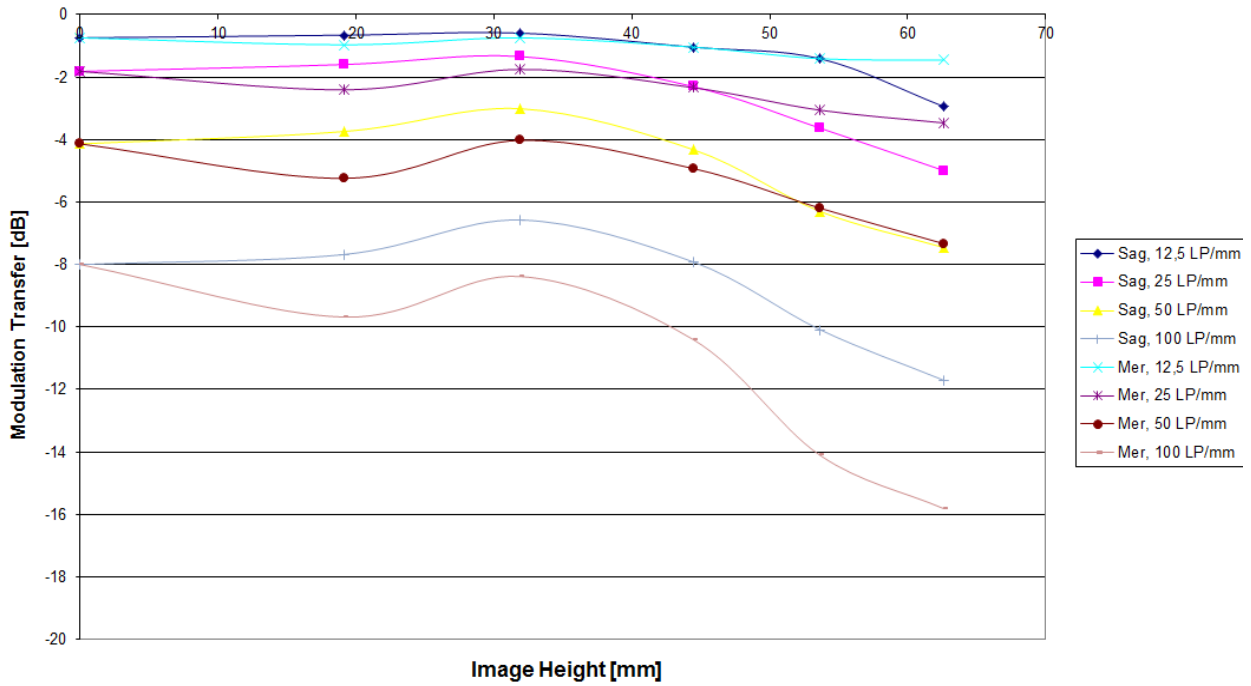
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

Lens types

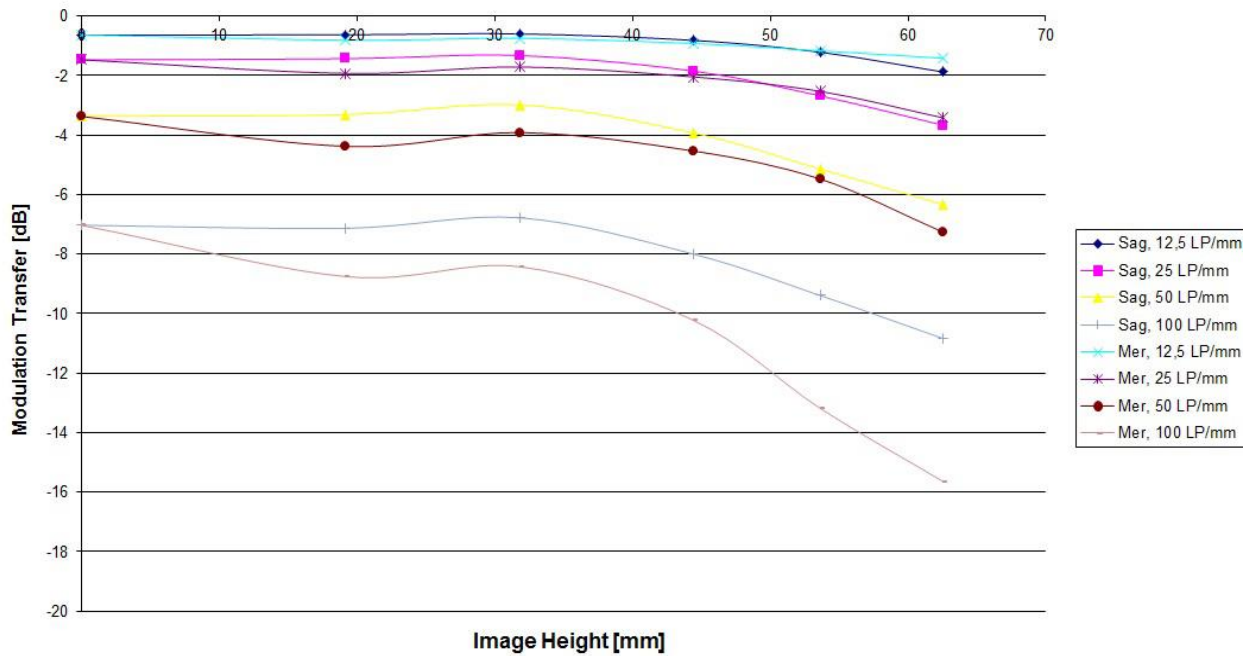
Cone	Lens
C0 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/100mm, Qioptic GmbH, Germany
C1 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/100mm, Qioptic GmbH, Germany
C2 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/100mm, Qioptic GmbH, Germany
C3 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/100mm, Qioptic GmbH, Germany
C4 (RED)	Qioptic Vexcel HR Digaron 1:4/33mm, Qioptic GmbH, Germany
C5 (GREEN)	Qioptic Vexcel HR Digaron 1:4/33mm, Qioptic GmbH, Germany
C6 (BLUE)	Qioptic Vexcel HR Digaron 1:4/33mm, Qioptic GmbH, Germany
C7 (NIR)	Qioptic Vexcel HR Digaron 1:4/33mm, Qioptic GmbH, Germany



Modulation versus Image Height - Aperture f / 5.6

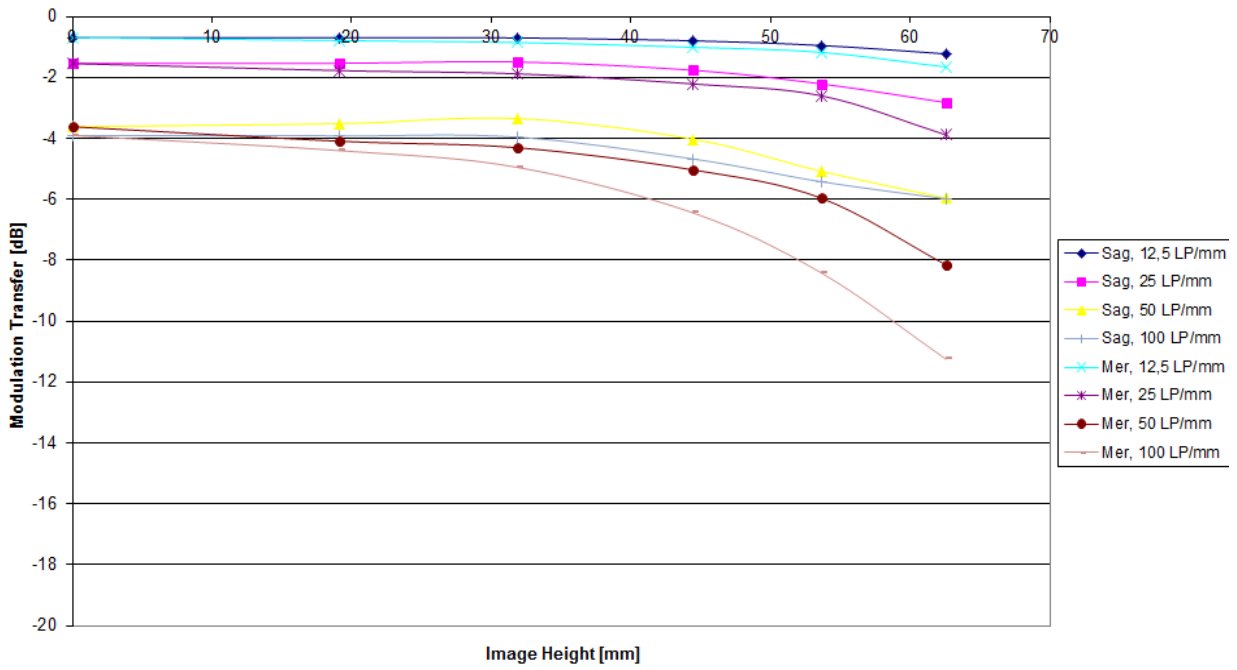


Modulation versus Image Height - Aperture f / 6.7

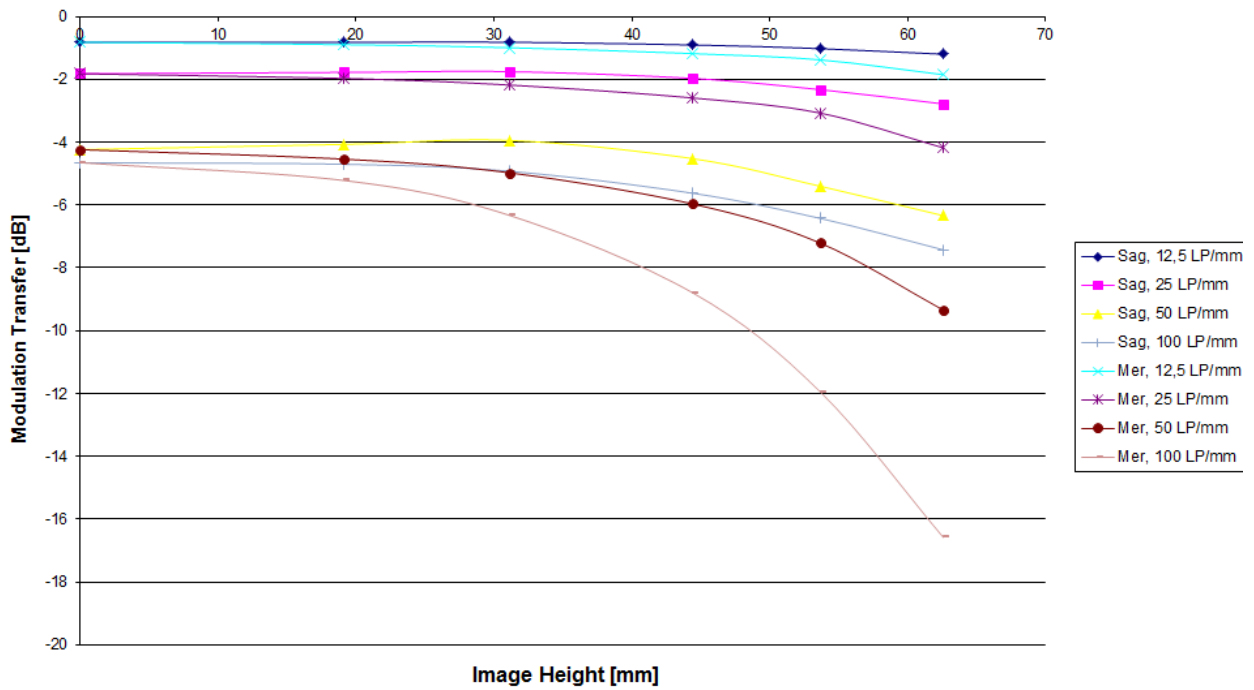




Modulation versus Image Height - Aperture f / 8

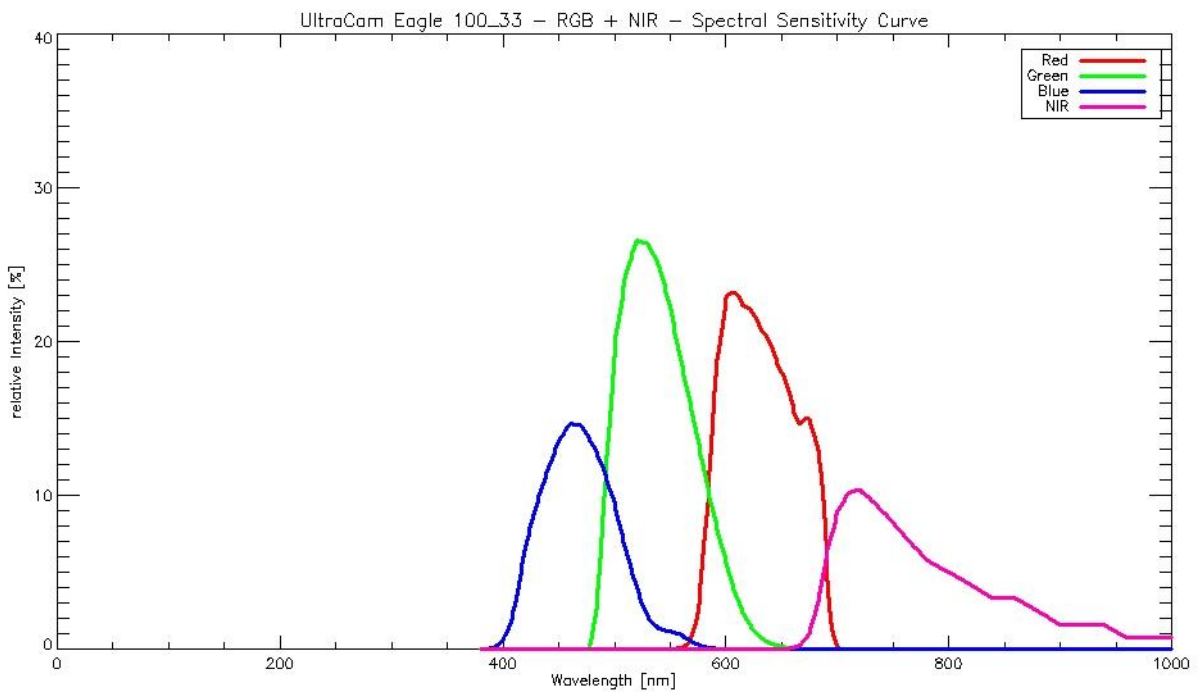
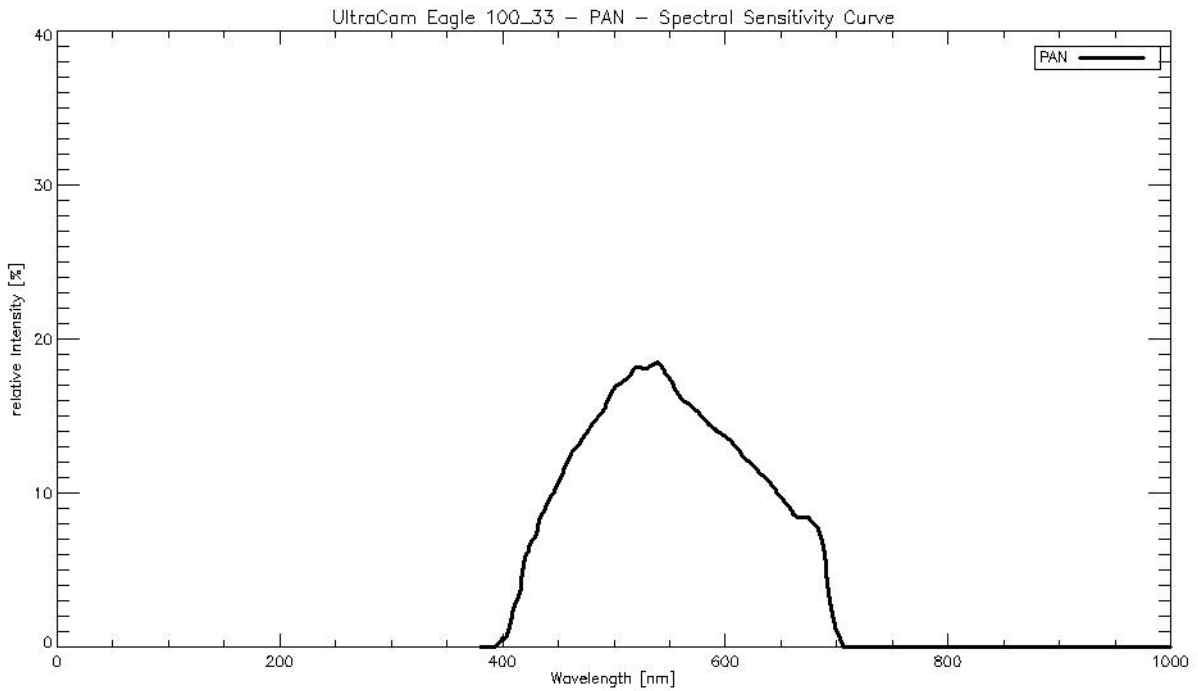


Modulation versus Image Height - Aperture f / 9.5





Spectral Sensitivity





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Radiometric Calibration

Camera: UltraCam Eagle M3
Serial: UC-EpII-1-52319383-f100v2

	PAN	R, G, NIR	B
Used Apertures	F5.6	F4.8	F4.8
	F6.7	F5.6	F4.8
	F8	F6.7	F4.8
	F9.5	F8	F5.6
	F11	F9.5	F6.7
	F13	F11	F8
	F16	F13	F9.5
	F22	F19	F13

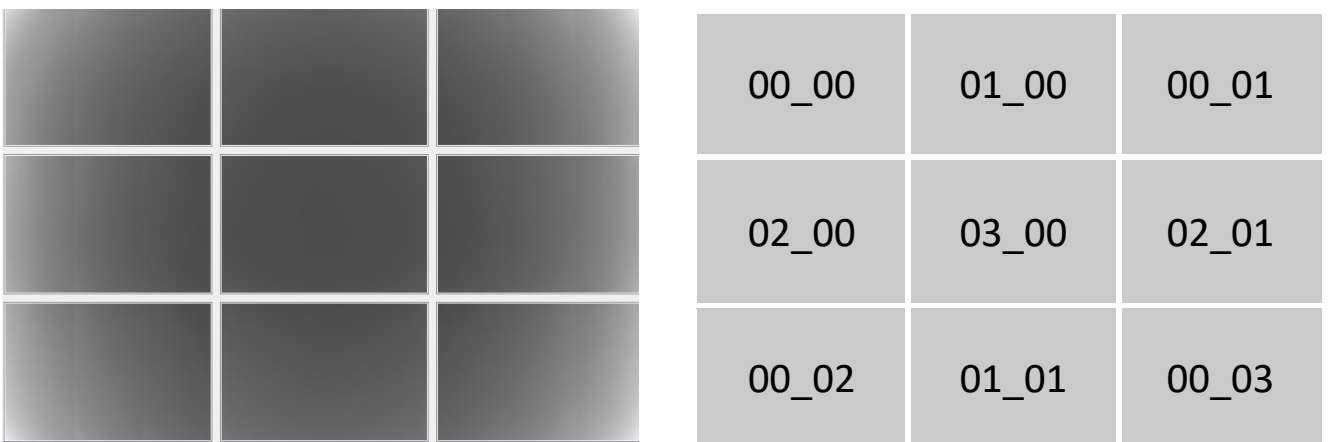
Dead Pixel Report: see Appendix I



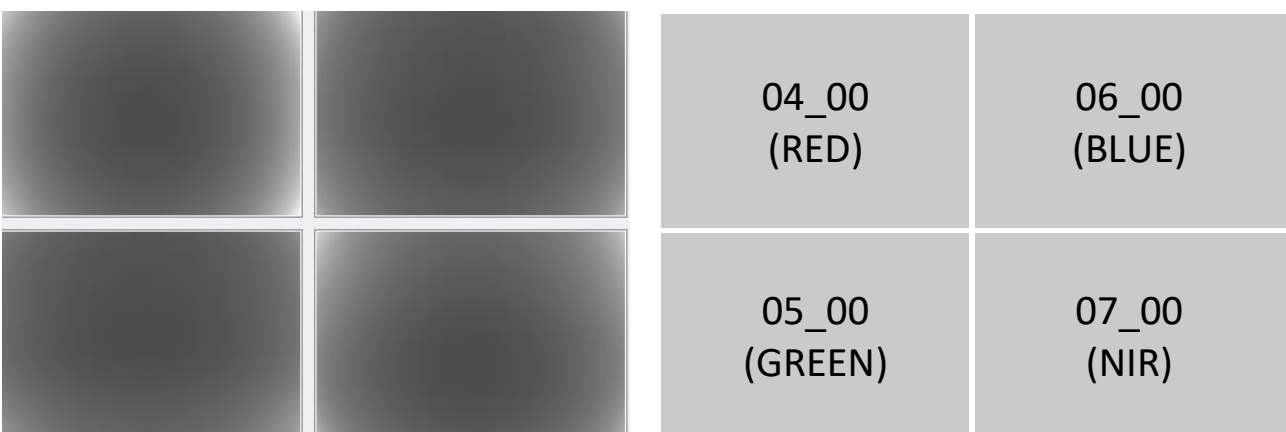
Calibration of Vignetting for working Aperture F6.7

	PAN	R, G, NIR	B
Aperture	F6.7	F5.6	F4.8

Graphical Overview of Pan Sensors:



Graphical Overview of Multispectral Sensors:





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.



ULTRACAM

Shutter Calibration

Camera: UltraCam Eagle M3
Serial: UC-EpII-1-52319383-f100v2

Panchromatic Camera: 4 * Prontor Magnetic 0 HS
Prontor-Werk Alfred Gauthier GmbH, Germany

Multispectral Camera: 4 * Prontor Magnetic 0 HS
Prontor-Werk Alfred Gauthier GmbH, Germany



Calibration of Shutter Release Times:

The shutter release times measured during the calibration describe the time from the moment when the electrical current through the shutter is turned off by the electronics, until the shutter is mechanically closed.

This time is relevant for the exposure control and needs to be known before image recording can take place.

Currently used SRT values (operation values):

Cone Number	Lens Serial Number	SRT F5.6 [ms]	SRT F6.7 [ms]	SRT F8 [ms]	SRT F9.5 [ms]	SRT F11 [ms]	SRT F13 [ms]	SRT F16 [ms]	SRT F22 [ms]	Measurement Tolerance [ms]
C0 (Pan)	12 60 56 34	6.01	6.26	6.56	6.78	6.87	6.98	7.25	7.49	+/- 0.2
C1 (Pan)	12 60 56 46	5.86	6.08	6.38	6.61	6.70	6.85	7.09	7.35	+/- 0.2
C2 (Pan)	12 60 56 37	5.83	6.13	6.47	6.73	6.78	6.91	7.24	7.34	+/- 0.2
C3 (Pan)	12 60 56 33	6.20	6.46	6.77	6.98	7.14	7.24	7.38	7.61	+/- 0.2
C4 (Red)	12 64 45 94	7.50	7.59	7.79	7.79	7.92	8.03	8.22	8.31	+/- 0.2
C5 (Green)	12 60 56 71	7.55	7.55	7.72	7.89	8.01	8.17	8.23	8.53	+/- 0.2
C6 (Blue)	12 64 45 91	7.29	7.29	7.29	7.29	7.27	7.73	7.90	8.10	+/- 0.2
C7 (NIR)	12 64 45 98	6.94	7.17	7.25	7.30	7.52	7.52	7.69	7.84	+/- 0.2



ULTRACAM

Electronics and Sensor Calibration

Camera: UltraCam Eagle M3
Serial: UC-EpII-1-52319383-f100v2

Panchromatic Camera: 9 * FTF9060-M Area CCD Sensor by DALSA
Multispectral Camera: 4 * FTF9060-M Area CCD Sensor by DALSA



Calibration of Negative Substrate Voltage (VNS):

For optimum performance of the DALSA CCD sensors, the negative substrate voltage is adjusted to a value specified by DALSA.

This voltage value is measured to achieve the best anti-blooming performance possible for each particular sensor.

Currently used VNS and VOG values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	VNS Voltage [V]	VOG Voltage [V]
00_00	FTF9060-M	19 7663/077	22.00	6.55
00_01	FTF9060-M	19 7663/066	22.00	6.44
00_02	FTF9060-M	19 7663/051	21.80	6.42
00_03	FTF9060-M	19 7663/048	21.60	6.25
01_00	FTF9060-M	19 7663/044	22.00	6.18
01_01	FTF9060-M	19 7663/007	21.60	6.09
02_00	FTF9060-M	19 7663/079	22.20	6.06
02_01	FTF9060-M	19 7663/005	21.60	6.13
03_00	FTF9060-M	19 7663/008	22.00	6.30
04_00 (red)	FTF9060-M	19 7663/038	22.00	6.21
05_00 (green)	FTF9060-M	19 7663/069	22.00	6.34
06_00 (blue)	FTF9060-M	19 7663/084	21.80	6.44
07_00 (NIR)	FTF9060-M	19 7663/010	21.60	6.22



Calibration of Intensity Threshold for Exposure Control:

Each CCD sensor and electronics module varies slightly in global sensitivity and intensity scale.

Therefore the maximum possible intensity of each sensor needs to be measured to evaluate the sensitivity behavior of the CCD and electronics.

This value is used as a threshold for the exposure control dialogue shown in the in-flight user interface of the Eagle.

Currently used Threshold values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	Intensity Threshold [DN]	
			Tap 1	Tap2
00_00	FTF9060-M	19 7663/077	13360	12550
00_01	FTF9060-M	19 7663/066	13720	12600
00_02	FTF9060-M	19 7663/051	13740	12890
00_03	FTF9060-M	19 7663/048	13880	12860
01_00	FTF9060-M	19 7663/044	13650	12690
01_01	FTF9060-M	19 7663/007	13950	13050
02_00	FTF9060-M	19 7663/079	13180	12810
02_01	FTF9060-M	19 7663/005	13960	12890
03_00	FTF9060-M	19 7663/008	13700	12960
04_00 (red)	FTF9060-M	19 7663/038	13400	12600
05_00 (green)	FTF9060-M	19 7663/069	13780	12940
06_00 (blue)	FTF9060-M	19 7663/084	13960	13080
07_00 (NIR)	FTF9060-M	19 7663/010	14070	13150



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Summary

Camera:	UltraCam Eagle M3
Serial:	UC-EpII-1-52319383-f100v2
Laboratory Calibration Date:	Mar-29-2022
Camera Revision:	Rev01.00
Date of Report:	Apr-19-2022
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



Appendix I

Dead Pixel Report:

Sensor number	Anomaly type	X-Coordinate	Y-Coordinate
C00-00	PIXEL: 3941/5228	PIXEL: 1458/4586	PIXEL: 1459/4586
C00-01	PIXEL: 6391/2419 PIXEL: 8573/5476 PIXEL: 953/ 855 PIXEL: 5143/1622 PIXEL: 410/4798	PIXEL: 5246/2595 PIXEL: 6889/5860 PIXEL: 5142/1621 PIXEL: 6952/2129	PIXEL: 3662/ 39 PIXEL: 5143/1621 PIXEL: 4655/4447 PIXEL: 6302/ 83 PIXEL: 5142/1622 PIXEL: 560/4739
C00-02	PIXEL: 3589/ 271 PIXEL: 3735/ 728 PIXEL: 8463/ 532	PIXEL: 2721/5505 PIXEL: 4989/4091	PIXEL: 1943/5652 PIXEL: 4090/5743
C00-03	PIXEL: 7167/1737 PIXEL: 8427/4062	PIXEL: 3877/5967 PIXEL: 380/5057	PIXEL: 7530/3497 PIXEL: 7757/5456 PIXEL: 8427/4061
C01-00	PIXEL: 2681/1853 PIXEL: 5269/3789 PIXEL: 3434/1635 PIXEL: 3236/2819 PIXEL: 3483/3613	PIXEL: 952/2308 PIXEL: 8843/5409 PIXEL: 3237/2817 PIXEL: 3237/2819 PIXEL: 6408/3761	PIXEL: 4222/3787 PIXEL: 2516/5790 PIXEL: 3236/2818 PIXEL: 890/3001 PIXEL: 6232/5100 PIXEL: 2497/5803 PIXEL: 3237/2818 PIXEL: 3145/3074
C01-01	PIXEL: 7655/ 843 PIXEL: 1707/5084	PIXEL: 5064/4570 PIXEL: 8335/ 324	PIXEL: 8620/4790 PIXEL: 4538/4108
C02-00	PIXEL: 4381/ 108 PIXEL: 8996/ 508 PIXEL: 6687/ 813 COLUMN: 2957/3233	PIXEL: 8736/5037 PIXEL: 8997/ 508 PIXEL: 5122/1015	PIXEL: 5888/ 285 PIXEL: 9012/ 511 PIXEL: 1317/2901 PIXEL: 9012/ 512 PIXEL: 7163/5769
C02-01	PIXEL: 2894/5489 PIXEL: 4444/1370 PIXEL: 8143/5673	PIXEL: 4145/2601 PIXEL: 8143/5674	PIXEL: 4145/2602 PIXEL: 8144/5674 PIXEL: 3665/4256



C03-00

PIXEL: 2521/ 519	PIXEL: 3834/3468	PIXEL: 5028/4256	
PIXEL: 7812/4452	PIXEL: 6194/4540	PIXEL: 2269/5411	PIXEL: 6584/ 475
PIXEL: 6585/ 475	PIXEL: 5662/ 494	PIXEL: 5662/ 495	PIXEL: 8995/5689
PIXEL: 8996/5689			

C04-00

PIXEL: 5468/ 59
PIXEL: 8577/ 367

C05-00

PIXEL: 2657/2476
PIXEL: 611/ 30 PIXEL: 5582/2926

C06-00

PIXEL: 3227/2872	PIXEL: 7762/5421	PIXEL: 5227/ 33	PIXEL: 5417/ 146
PIXEL: 8935/1068	PIXEL: 8868/1089	PIXEL: 1198/2396	

C07-00

PIXEL: 5574/ 364	PIXEL: 4938/2810	PIXEL: 7591/4648
PIXEL: 8959/ 81	PIXEL: 5120/1175	PIXEL: 6292/5980

Notes

COLUMN anomaly: all pixels below the Qmax detector at location (X,Y) may be affected.

PIXEL anomaly: single detector at location (X,Y) is not functioning within normal range

The Level0 coordinates exclude the two leftmost pixels containing the line index: the corresponding pixel can therefore be located at column (X+2,Y).



Appendix II

Calibration and Modification Dates

Type of Calibration	Laboratory Calibration Date	Modification Date	Modification Reason
Geometric Calibration	29.Mar.2022	29.Mar.2022	
Radiometric Calibration	29.Mar.2022	29.Mar.2022	
Shutter Calibration	29.Mar.2022	29.Mar.2022	
Electronics and Sensor Calibration	29.Mar.2022	29.Mar.2022	

Note: The above-mentioned Laboratory Calibration Dates represent the dates the camera was calibrated in one of our calibration labs for a full Laboratory Calibration. The Modification date represents a date on which the calibration has been modified due to a calibration enhancement or part exchange. It is an additional information and does not replace the Laboratory Calibration date in any way. With the Modification Reason, always the last modification to the calibration is highlighted.