



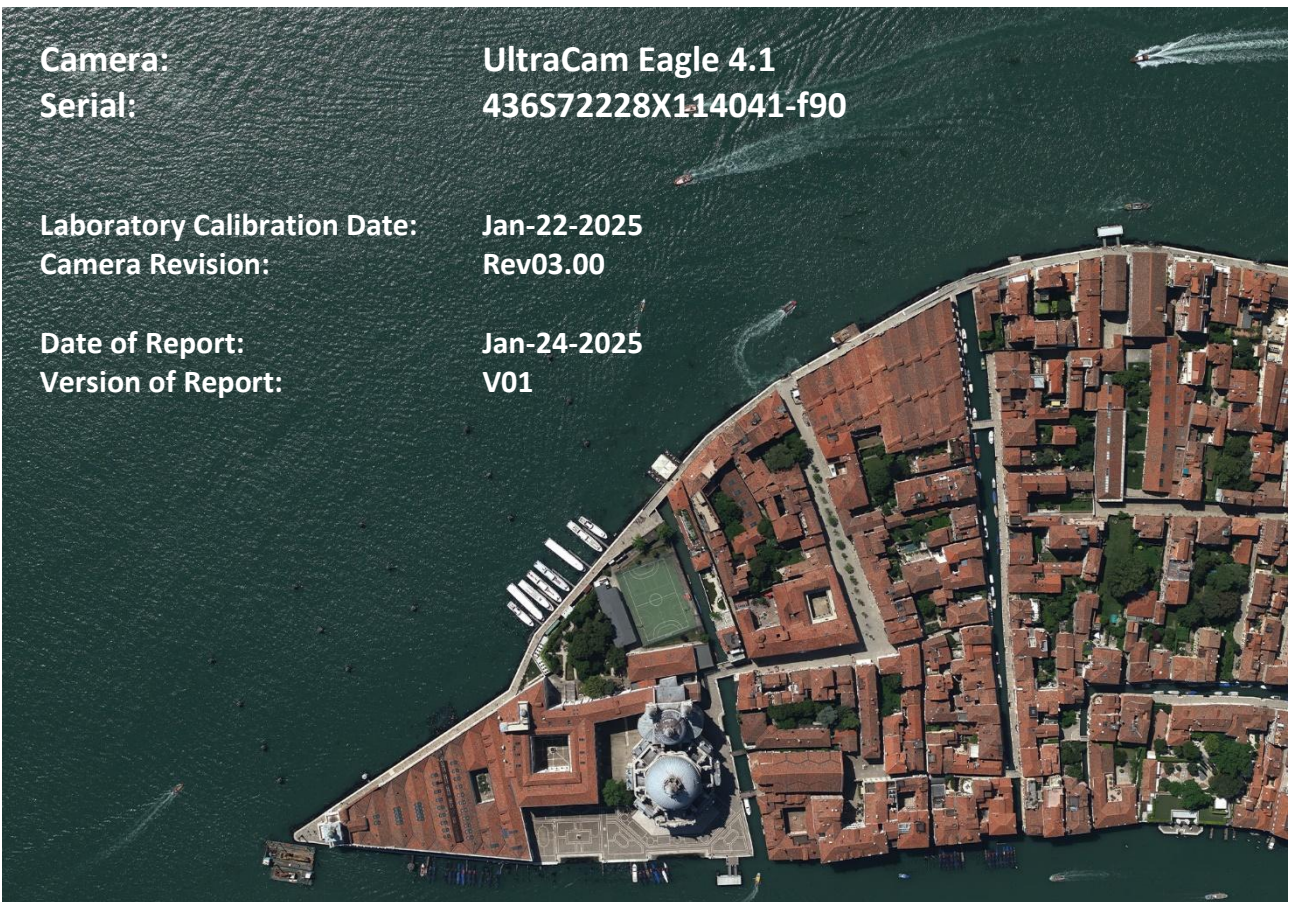
ULTRACAM

Calibration Report

Camera: UltraCam Eagle 4.1
Serial: 436S72228X114041-f90

Laboratory Calibration Date: Jan-22-2025
Camera Revision: Rev03.00

Date of Report: Jan-24-2025
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 4.1
Serial: 436S72228X114041-f90

Panchromatic Camera: ck = 90.600 mm
Multispectral Camera: ck = 90.600 mm

PPA Information Nadir: X: 0.000 mm
Y: 0.000 mm



Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track cross track	67.906mm 105.694mm	18060pixel 28110pixel
Image Extent		(-33.953, -52.847)mm	(33.953, 52.847)mm
Pixel Size		3.760µm*3.760µm	
Focal Length	ck	90.600mm	± 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		

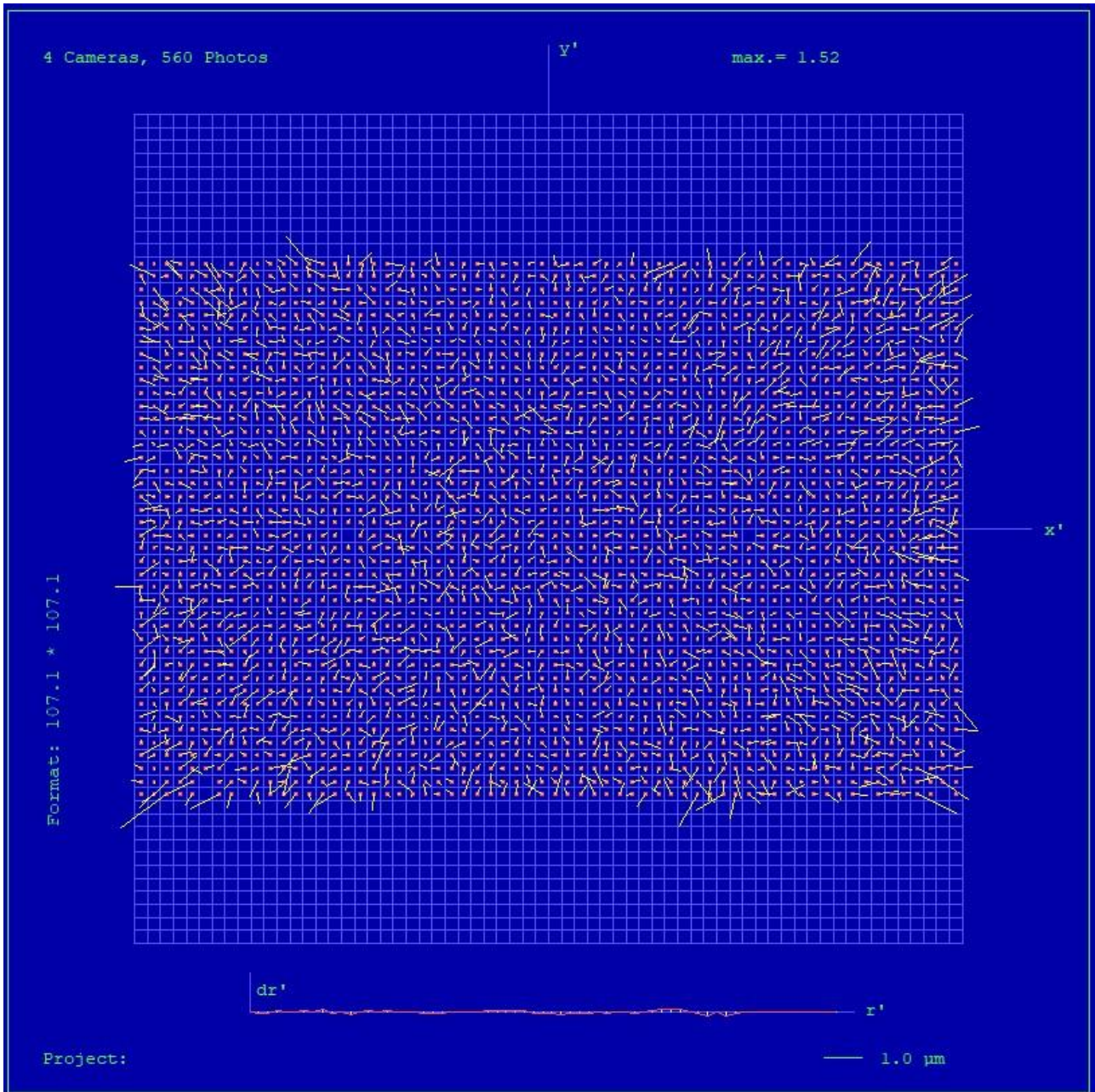
Multispectral Camera

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

Image Format	long track cross track	67.906mm 105.694mm	6020pixel 9370pixel
Image Extent		(-33.953, -52.847)mm	(33.953, 52.847)mm
Pixel Size		11.280µm*11.280µm	
Focal Length	ck	90.600mm	± 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		



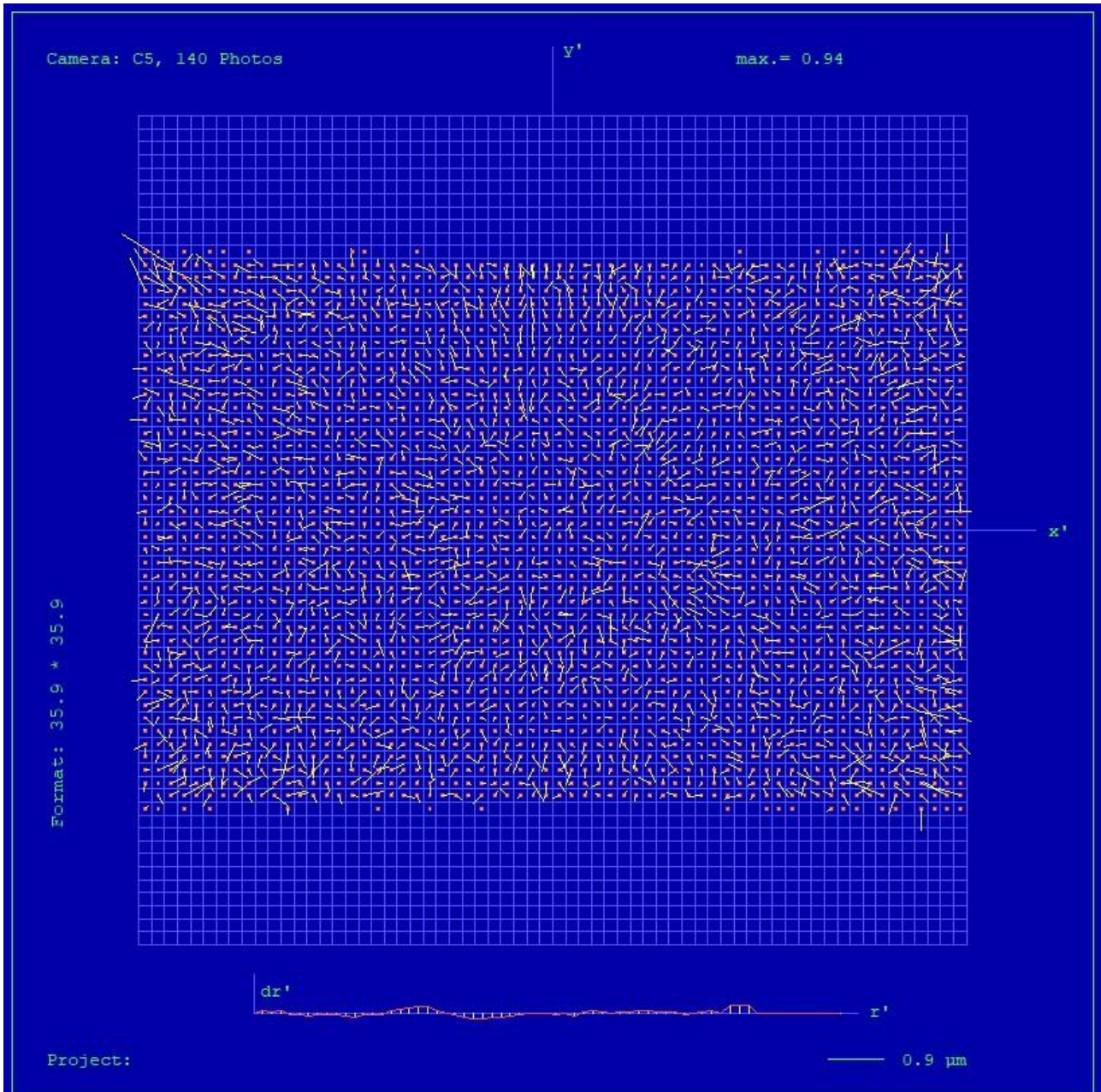
Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): **0.46 μm**



Green Cone (Cone 5), Residual Error Diagram



Residual Error (RMS): **0.28 μm**



Explanations

Calibration Method:

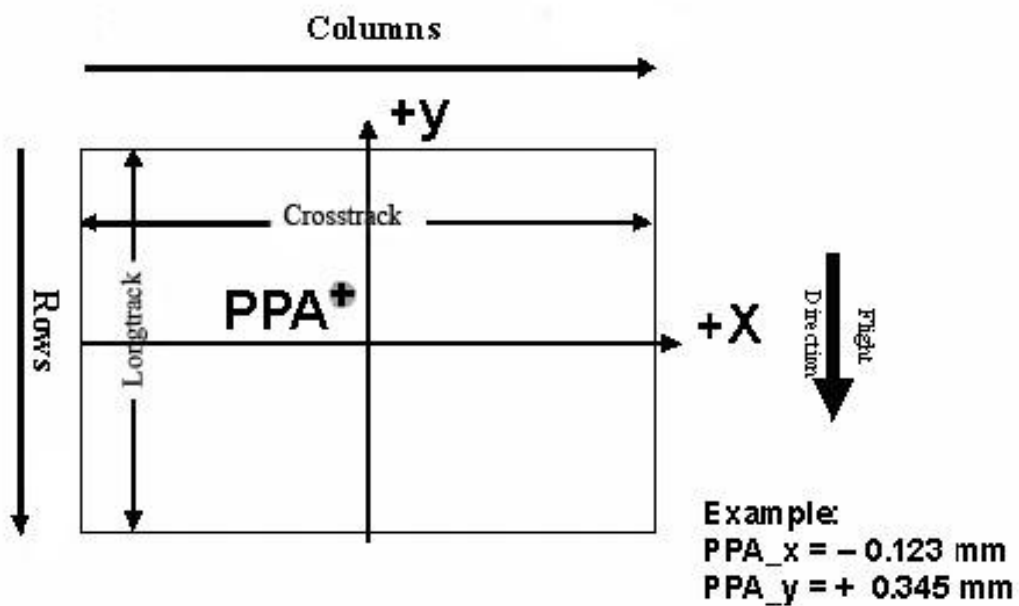
The geometric calibration is based on a set of 140 images of a defined geometry target with 394 GCPs.

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:

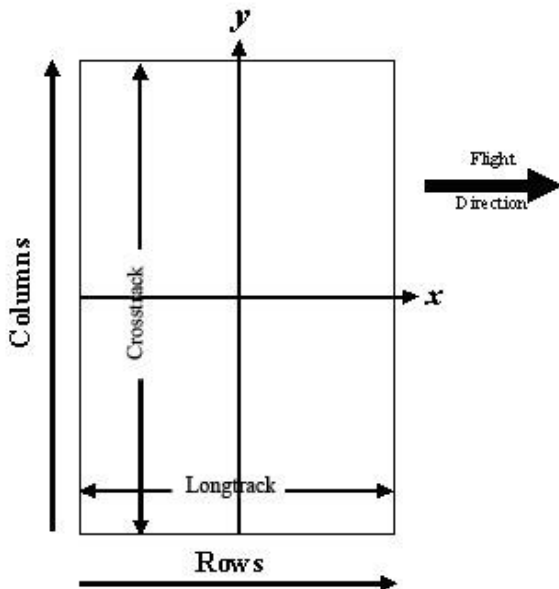
Lvl2, Camera prop. Orientation



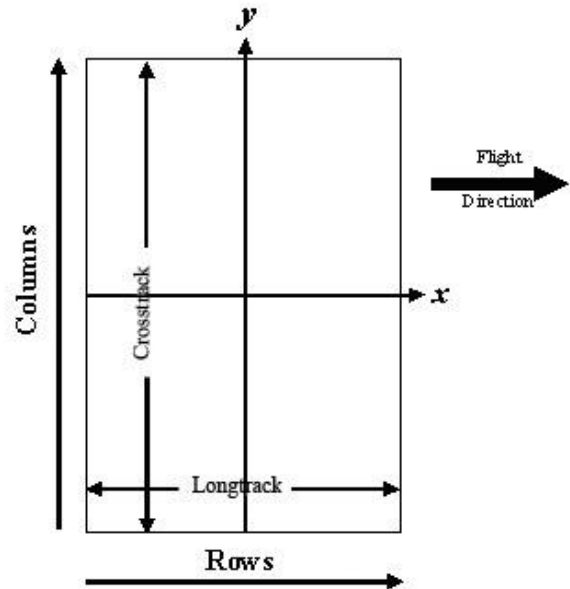
The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).



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



Panchromatic Image Format



Multispectral Image Format

Position of Principal Point in Level 3 Image

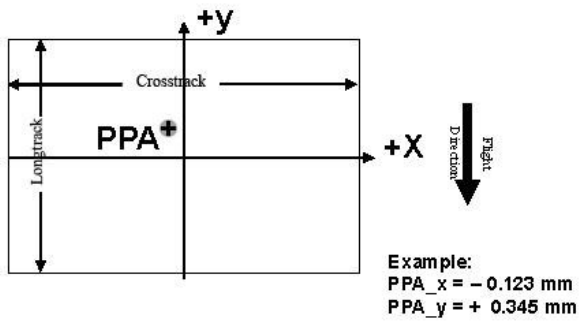
The position of the principal point in the level 3 image depends on the “rotation” setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified 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

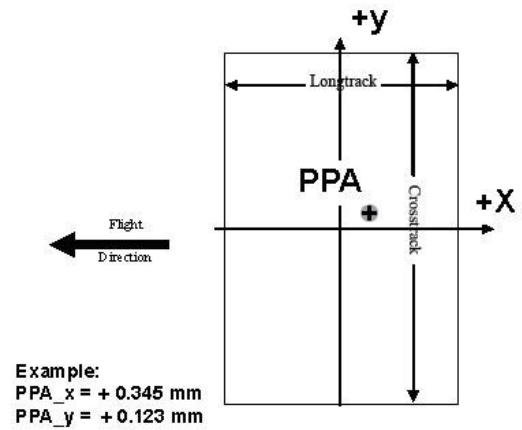


The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

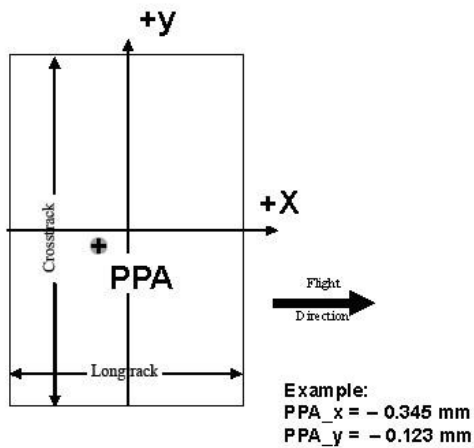
Lvl3, Rotation 0 deg clockwise



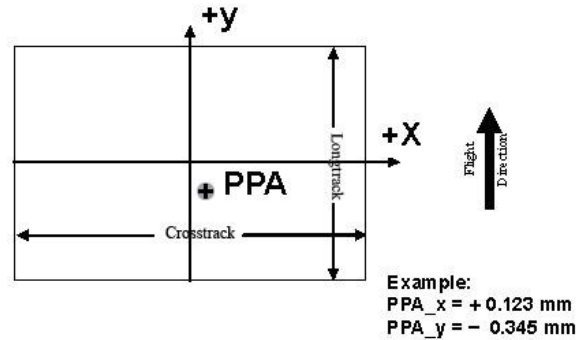
Lvl3, Rotation 90 deg clockwise



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.

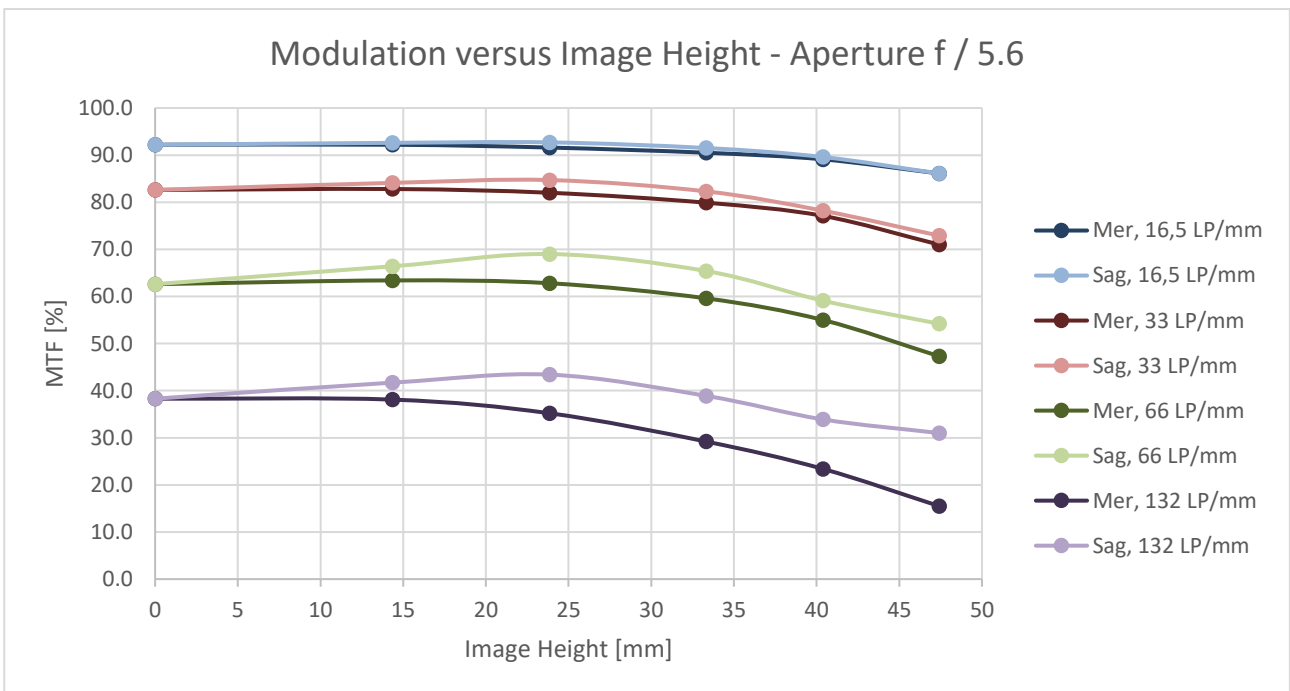
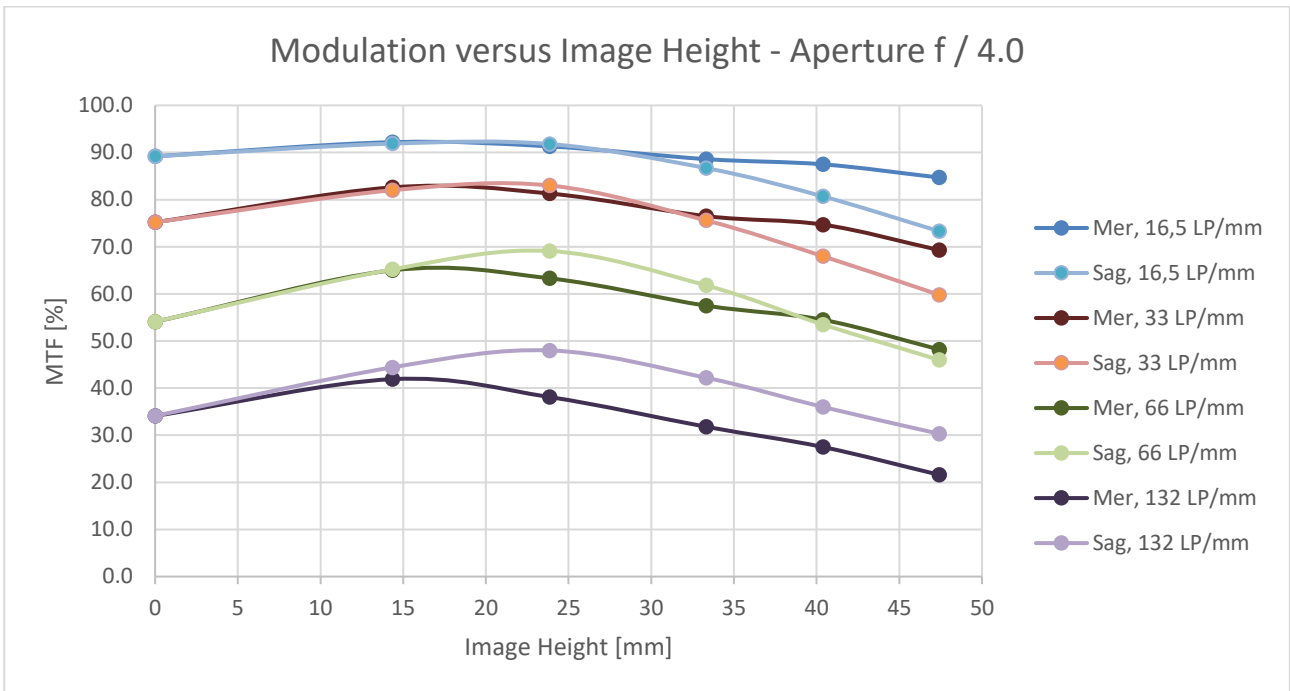
Please note that these values have been calculated and can vary up to 10% with optics from production (especially at high LP's).

The curves are given for the meridional (tangential) and sagital (radial) component of signals at frequencies of 16.5, 33, 66 and 132 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.

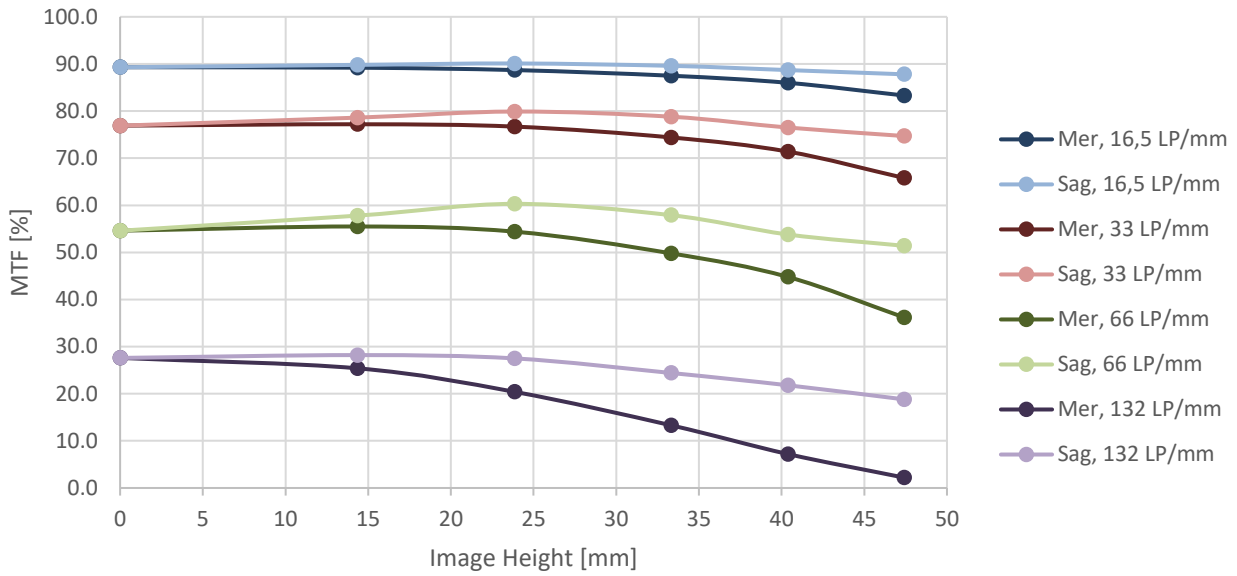
Lens types

Cone	Lens
C0 (PAN)	Qioptic Vexcel HR Digaron 1:5.6/90mm, Qioptic GmbH, Germany
C1 (PAN)	Qioptic Vexcel HR Digaron 1:5.6/90mm, Qioptic GmbH, Germany
C2 (PAN)	Qioptic Vexcel HR Digaron 1:5.6/90mm, Qioptic GmbH, Germany
C3 (PAN)	Qioptic Vexcel HR Digaron 1:5.6/90mm, Qioptic GmbH, Germany
C4 (RED)	Qioptic Vexcel HR Digaron 1:4.8/30mm, Qioptic GmbH, Germany
C5 (GREEN)	Qioptic Vexcel HR Digaron 1:4.8/30mm, Qioptic GmbH, Germany
C6 (BLUE)	Qioptic Vexcel HR Digaron 1:4.8/30mm, Qioptic GmbH, Germany
C7 (NIR)	Qioptic Vexcel HR Digaron 1:4.8/30mm, Qioptic GmbH, Germany

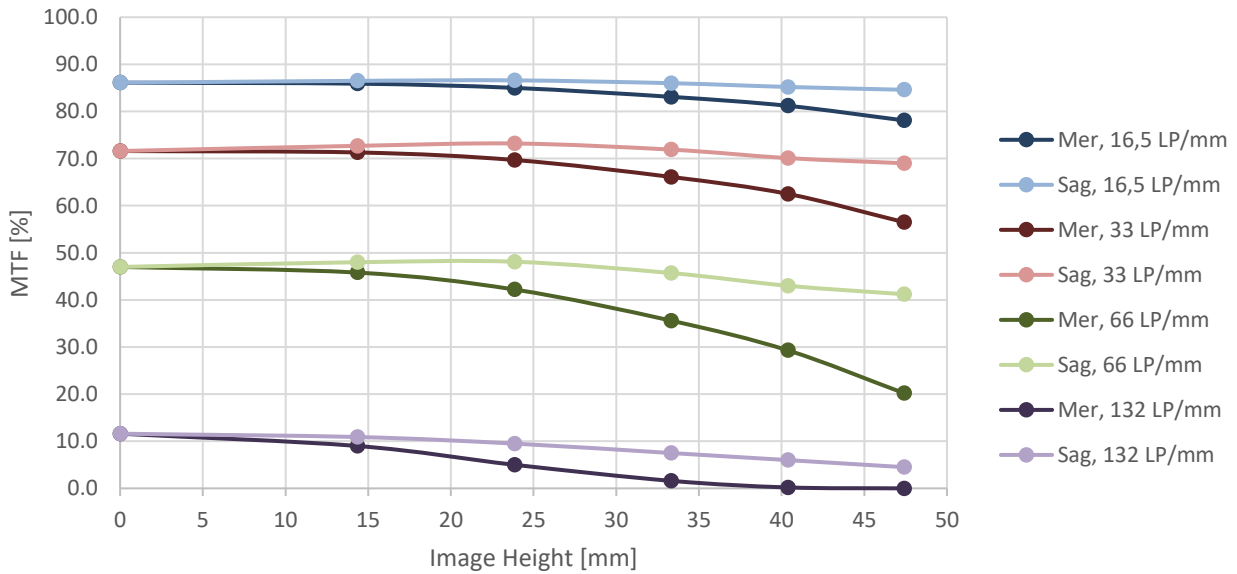




Modulation versus Image Height - Aperture f / 8

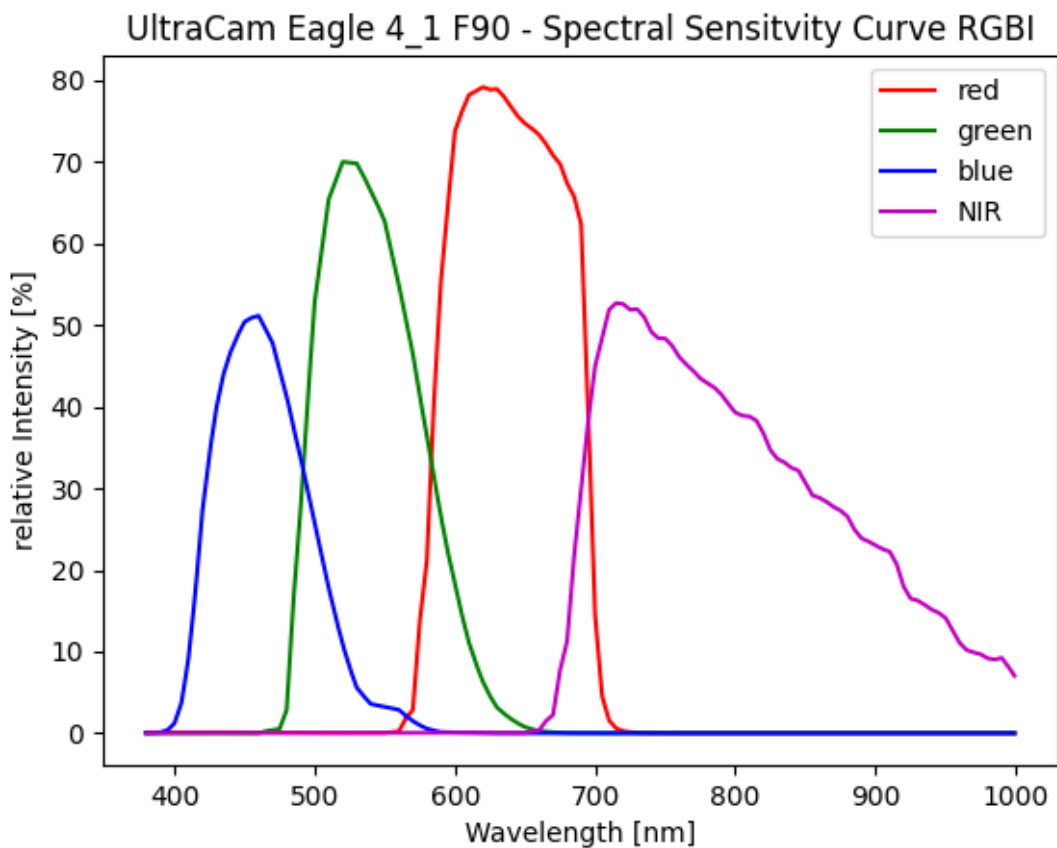
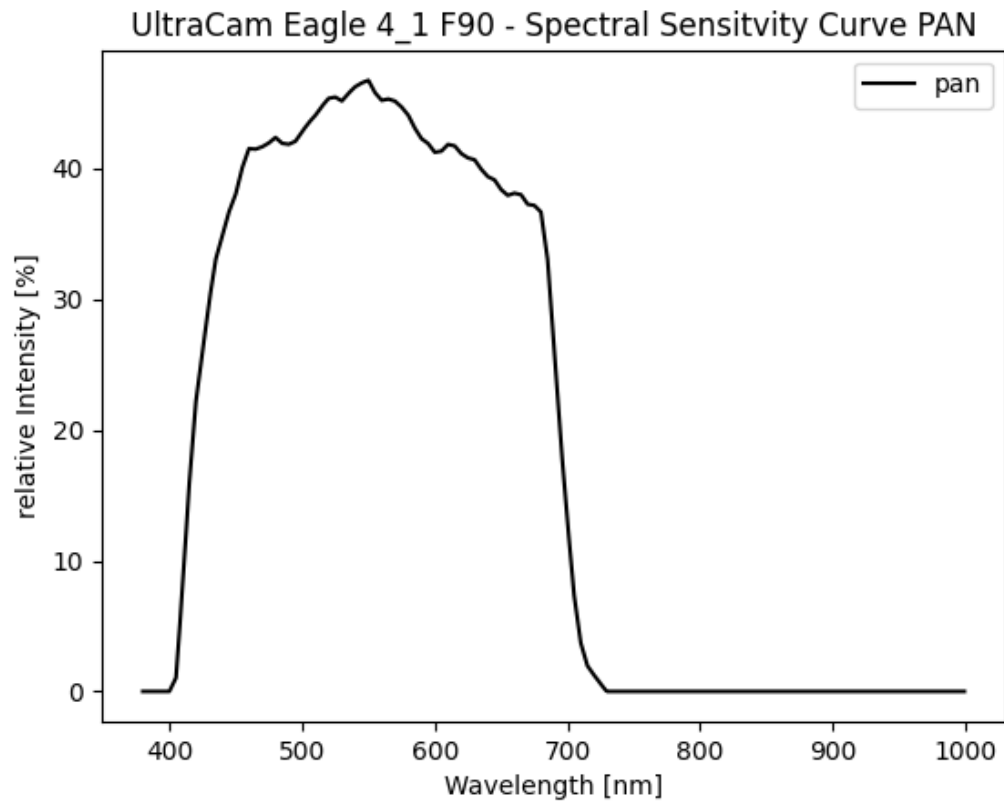


Modulation versus Image Height - Aperture f / 11





Spectral Sensitivity





ULTRACAM

Radiometric Calibration

Camera: UltraCam Eagle 4.1
Serial: 436S72228X114041-f90

	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



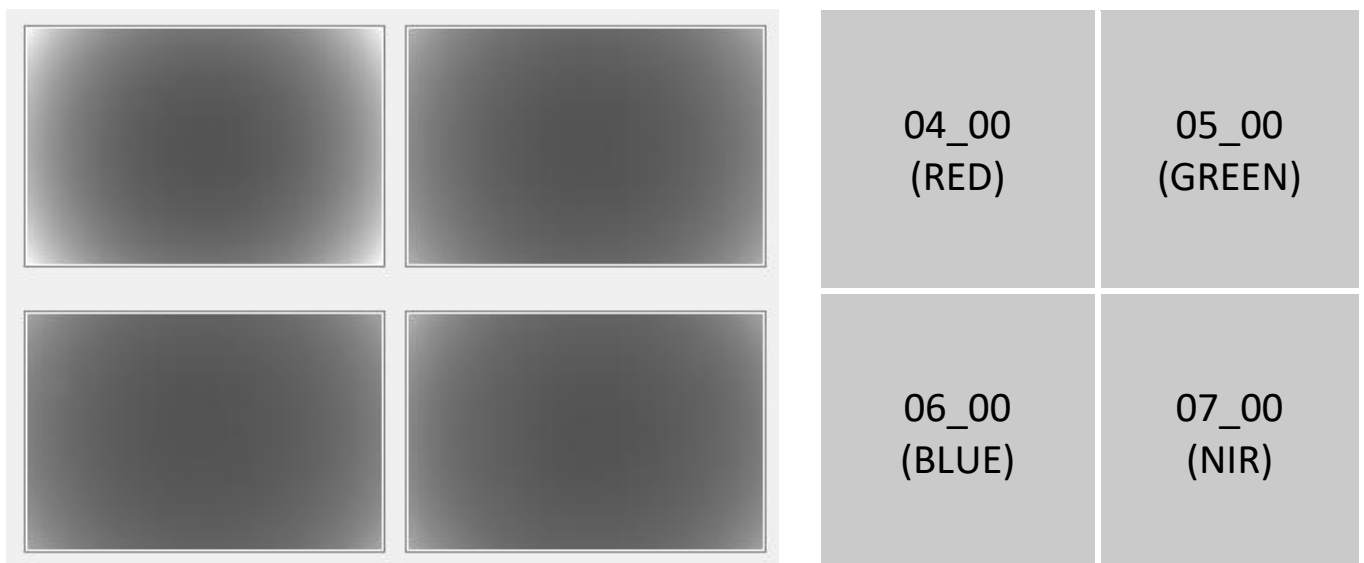
Calibration of Vignetting for working Aperture F5.6

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

Graphical Overview of Pan Sensor Gain Values:



Graphical Overview of Multispectral Sensor Gain Values:





Explanations

Calibration Method:

The radiometric calibration is based on a series of 60 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 CMOS 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.



ULTRACAM

Shutter Calibration

Camera: UltraCam Eagle 4.1
Serial: 436S72228X114041-f90

Panchromatic Camera: 4 * Prontor Magnetic 0 HS2
Prontor-Werk Alfred Gauthier GmbH, Germany

Multispectral Camera: 4 * Prontor Magnetic 0 HS2
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 70 14 84	6.05	6.38	6.80	7.03	7.25	7.41	7.58	7.81	+/- 0.2
C1 (Pan)	12 70 14 87	6.28	6.65	7.21	7.49	7.70	7.89	8.03	8.25	+/- 0.2
C2 (Pan)	12 70 14 91	6.15	6.57	7.03	7.28	7.52	7.71	7.86	8.07	+/- 0.2
C3 (Pan)	12 70 14 92	6.01	6.44	6.94	7.22	7.48	7.70	7.86	8.12	+/- 0.2
C4 (Red)	12 69 32 87	7.89	8.00	8.15	8.31	8.42	8.49	8.54	8.61	+/- 0.2
C5 (Green)	12 69 32 81	7.23	7.33	7.54	7.64	7.76	7.84	7.94	8.06	+/- 0.2
C6 (Blue)	12 69 32 77	7.87	7.89	7.86	7.97	8.15	8.28	8.38	8.53	+/- 0.2
C7 (NIR)	12 69 32 76	7.50	7.60	7.74	7.84	7.94	8.01	8.03	8.11	+/- 0.2



ULTRACAM

Electronics and Sensor Calibration

Camera: UltraCam Eagle 4.1
Serial: 436S72228X114041-f90

Panchromatic Camera: 9 * IMX455-ALK-M CMOS Sensor by SONY
Multispectral Camera: 4 * IMX455-ALK-M CMOS Sensor by SONY



Calibration of Intensity Threshold for Exposure Control:

Each CMOS 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 CMOS and electronics.

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

Currently used Threshold values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	Intensity Threshold [DN]
00_00	IMX455-ALK-M	00001CC9035F	16130
00_01	IMX455-ALK-M	00001CC90835	16130
00_02	IMX455-ALK-M	00001CC8EFB8	16130
00_03	IMX455-ALK-M	00001CC91F3F	16130
01_00	IMX455-ALK-M	00001CC91073	16130
01_01	IMX455-ALK-M	00001CCA06EF	16130
02_00	IMX455-ALK-M	00001CC8F275	16130
02_01	IMX455-ALK-M	00001CC8F0BB	16130
03_00	IMX455-ALK-M	00001CC91B52	16130
04_00 (red)	IMX455-ALK-M	00001CC90707	16130
05_00 (green)	IMX455-ALK-M	00001CCA86FB	16130
06_00 (blue)	IMX455-ALK-M	00001CCA8157	16130
07_00 (NIR)	IMX455-ALK-M	00001CC90FED	16090



ULTRACAM

Summary

Camera:	UltraCam Eagle 4.1
Serial:	436S72228X114041-f90
Laboratory Calibration Date:	Jan-22-2025
Camera Revision:	Rev03.00
Date of Report:	Jan-24-2025
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.

Marc Muick MSc.
Head of Applied Photogrammetry -
Camera & Calibration

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



Appendix I

Dead Pixel Report:

Cone_Sensor	Dead Pixel Count
00_00	361
00_01	317
00_02	343
00_03	334
01_00	334
01_01	312
02_00	329
02_01	296
03_00	350
04_00 (red)	307
05_00 (green)	284
06_00 (blue)	247
07_00 (NIR)	326



Appendix II

Calibration and Modification Dates

Type of Calibration	Laboratory Calibration Date	Modification Date	Modification Reason
Geometric Calibration	22.Jan.2024		
Radiometric Calibration	22.Jan.2024		
Shutter Calibration	22.Jan.2024		
Electronics and Sensor Calibration	22.Jan.2024		

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.