



ULTRACAM

Calibration Report

Camera: UltraCam Eagle Prime
Serial: UC-Ep-1-41317592-f100

Laboratory Calibration Date: Dec-10-2021
Camera Revision: Rev09.00

Date of Report: Dec-22-2021
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 Prime
Serial:	UC-Ep-1-41317592-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	68.034mm	14790pixel
	cross track	105.846mm	23010pixel
Image Extent		(-34.017, -52.923)mm	(34.017, 52.923)mm
Pixel Size		4.600μm*4.600μm	
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		

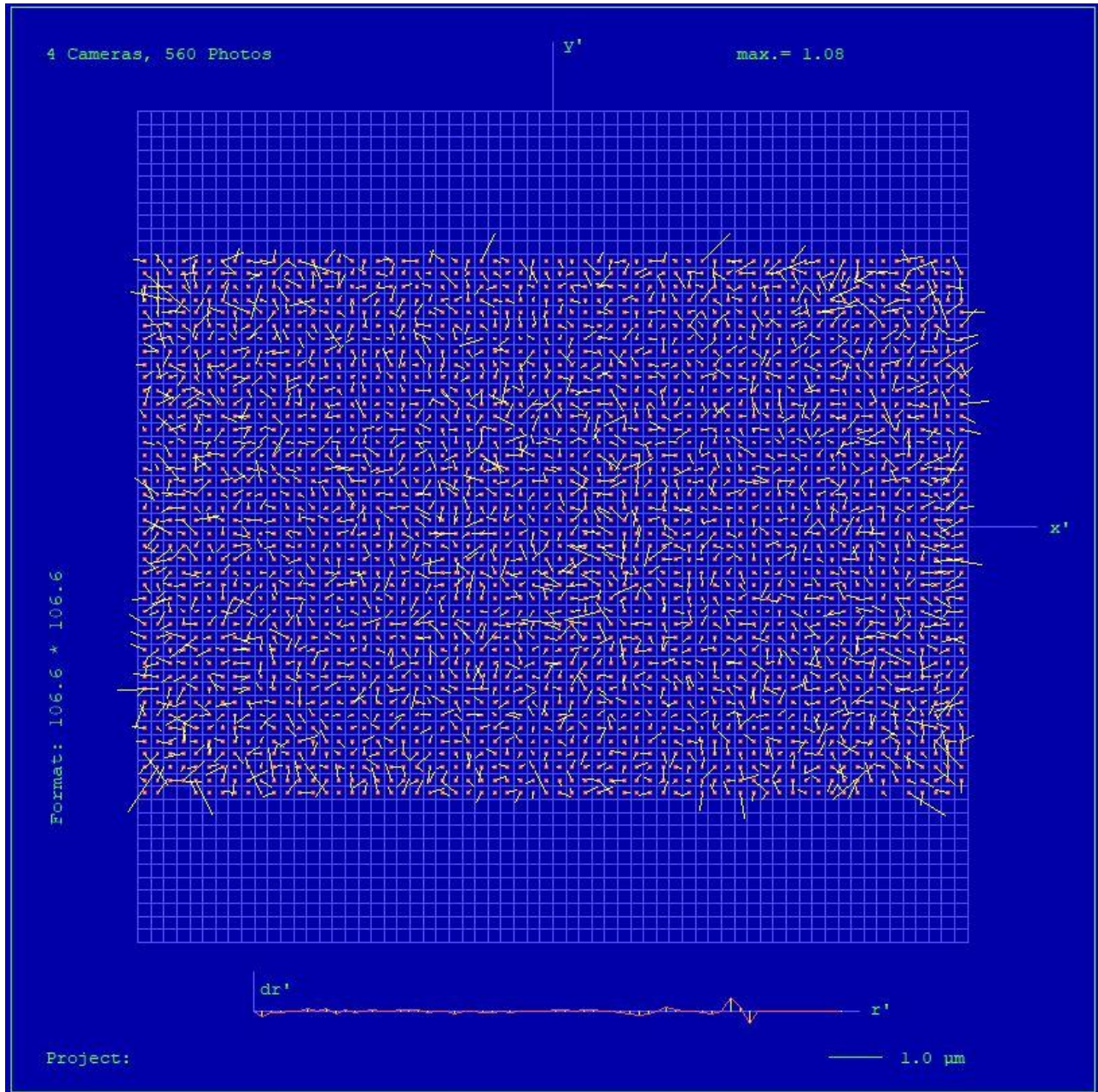
Multispectral Camera

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

Image Format	long track	68.034mm	4930pixel
	cross track	105.846mm	7670pixel
Image Extent		(-34.017, -52.923)mm	(34.017, 52.923)mm
Pixel Size		13.800μm*13.800μm	
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		



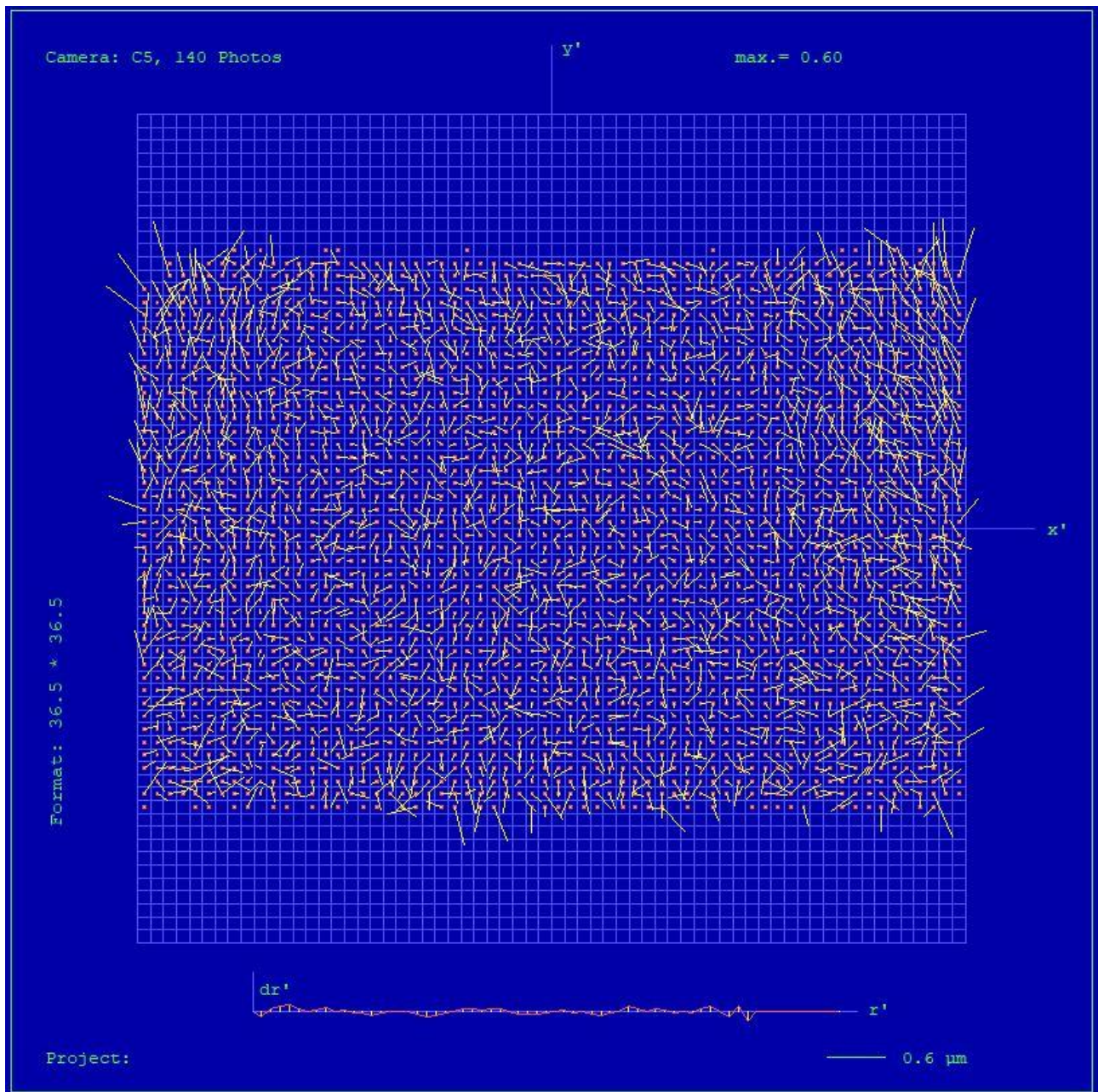
Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): 0.6 μm



Green Cone (Cone 5), Residual Error Diagram



Residual Error (RMS): **0.47 μm**



Explanations

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 : >16000

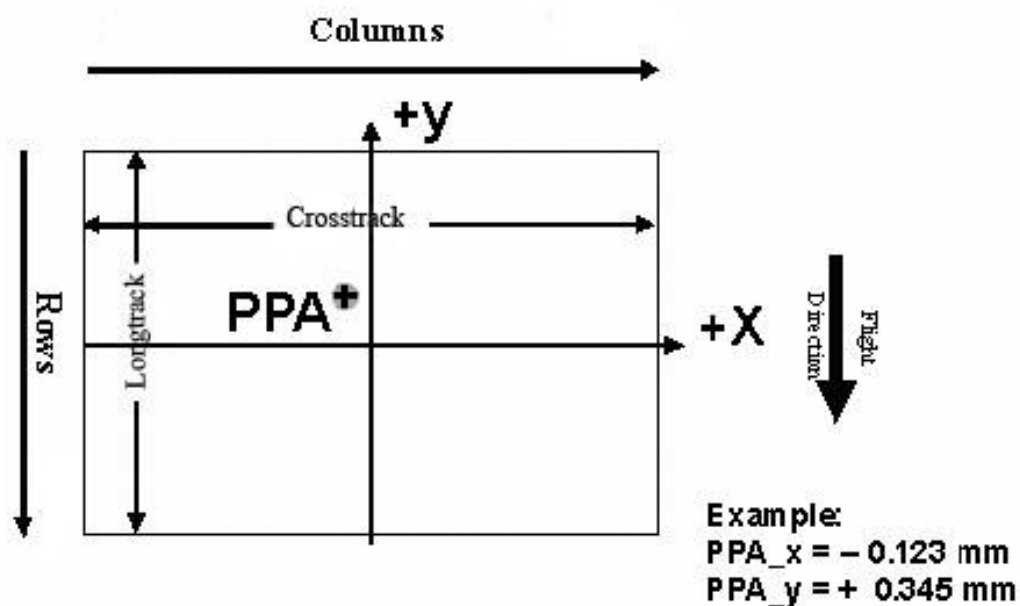
Number of point measurements for the multispectral camera : >60000

Determination of the image parameters by Least Squares Adjustment.

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

Level 2 Image Coordinate System:

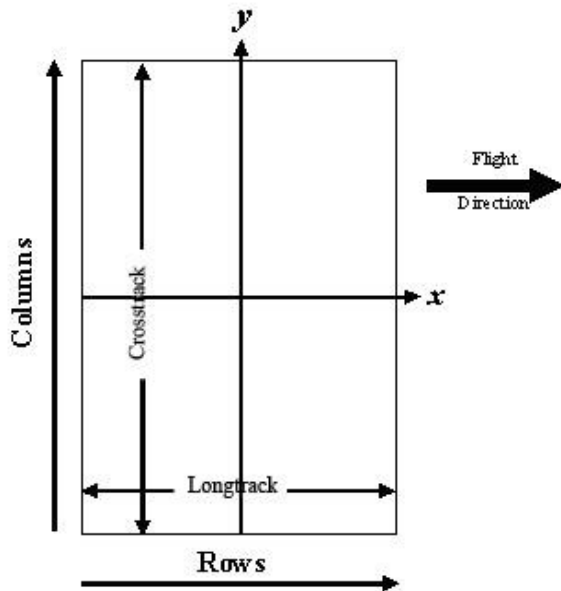
Lvl2, Camera prop. Orientation



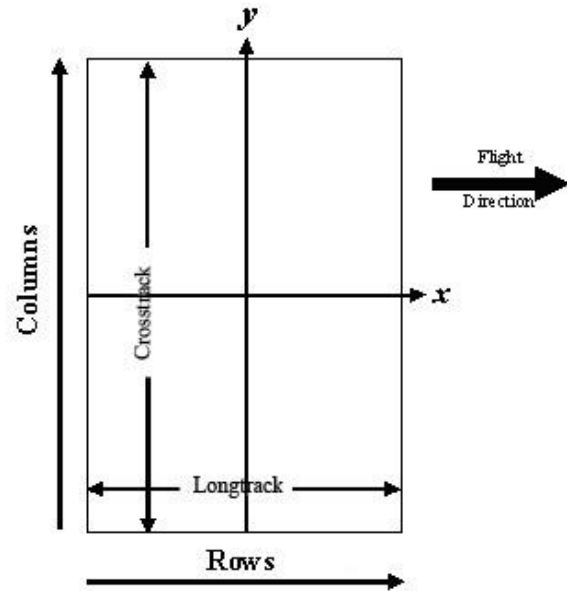
The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).



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



Panchromatic Image Format



Multispectral Image Format

Position of Principal Point in Level 3 Image

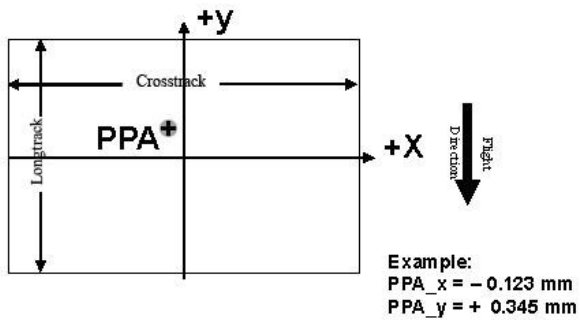
The position of the principal point in the level 3 image depends on the “rotation” setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified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

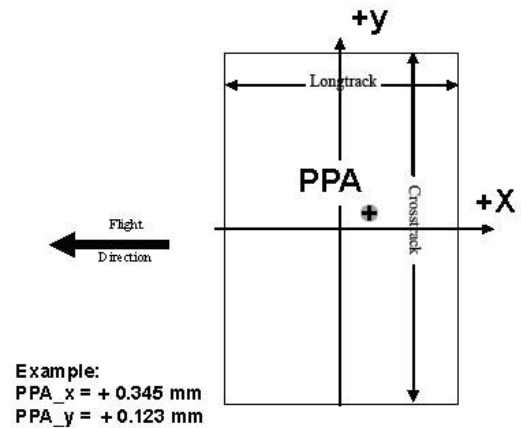


The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

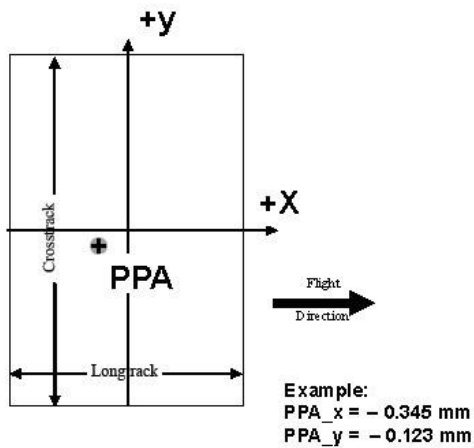
Lvl3, Rotation 0 deg clockwise



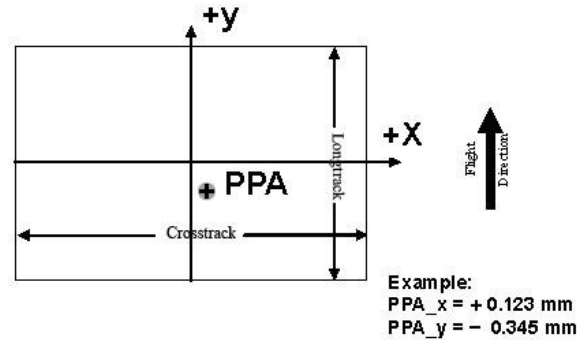
Lvl3, Rotation 90 deg clockwise



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.

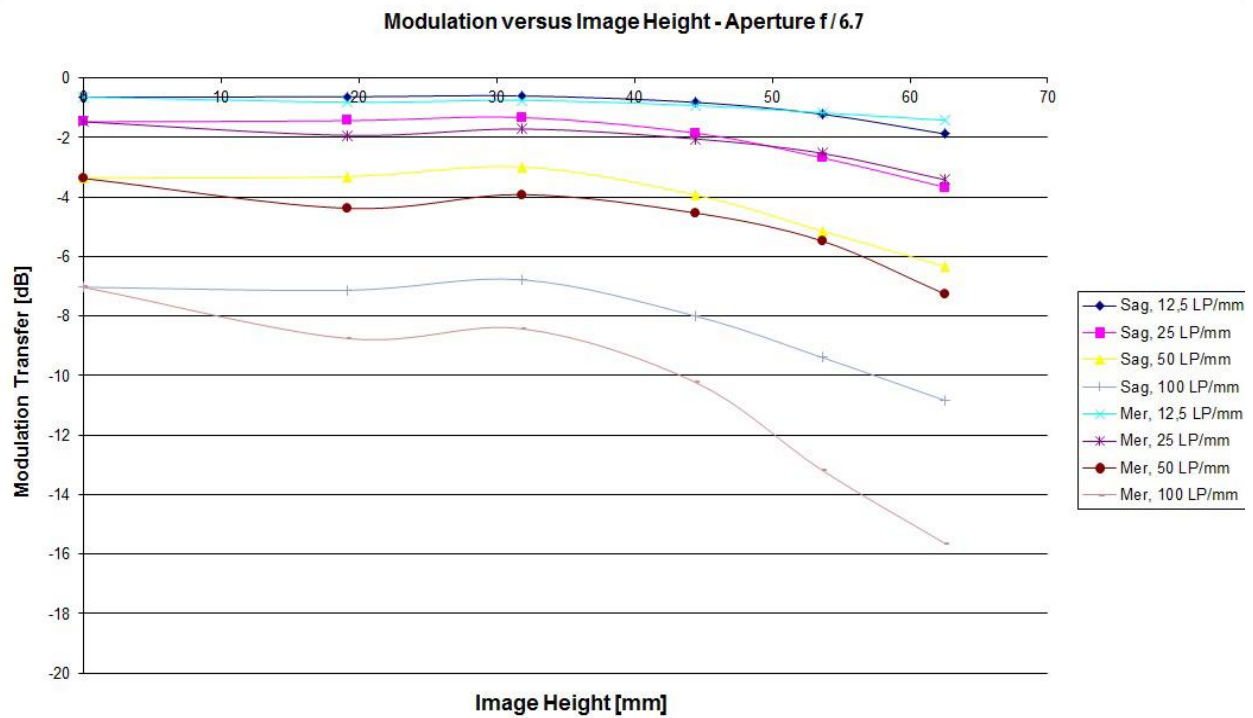
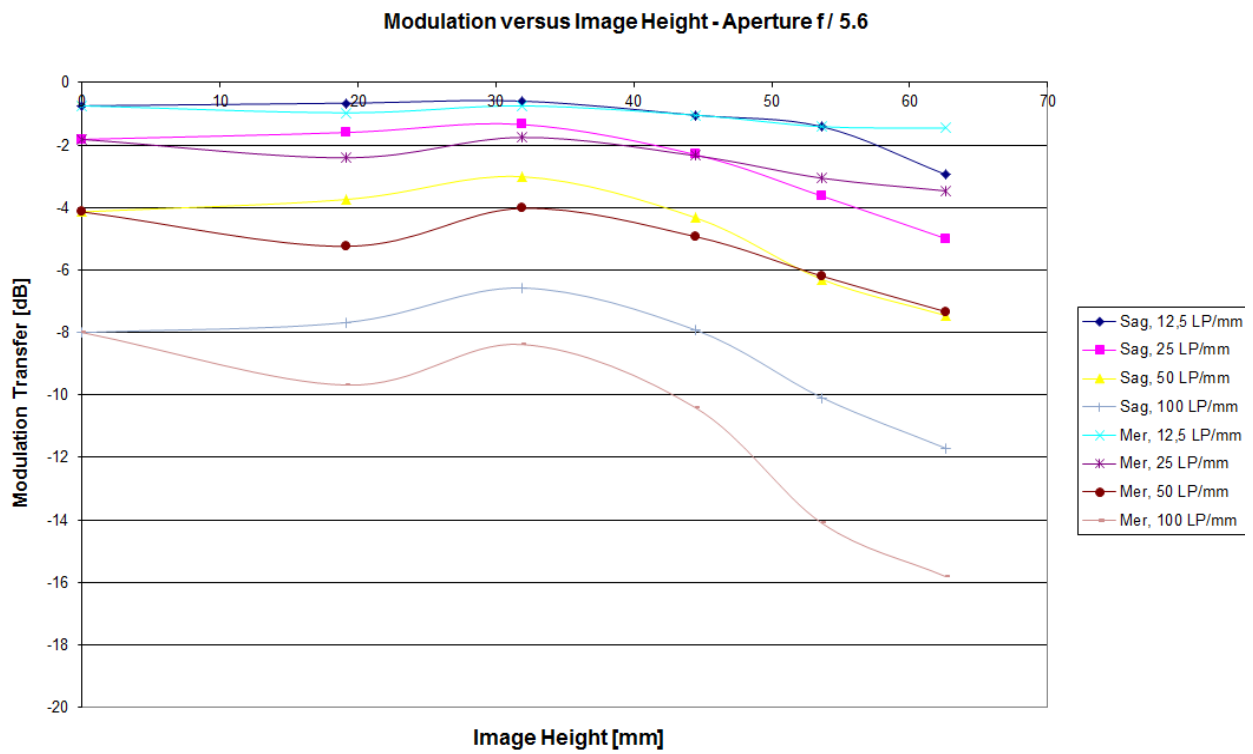
Please note that these values have been calculated and can vary up to 10% with optics from production (especially at high LP's).

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.

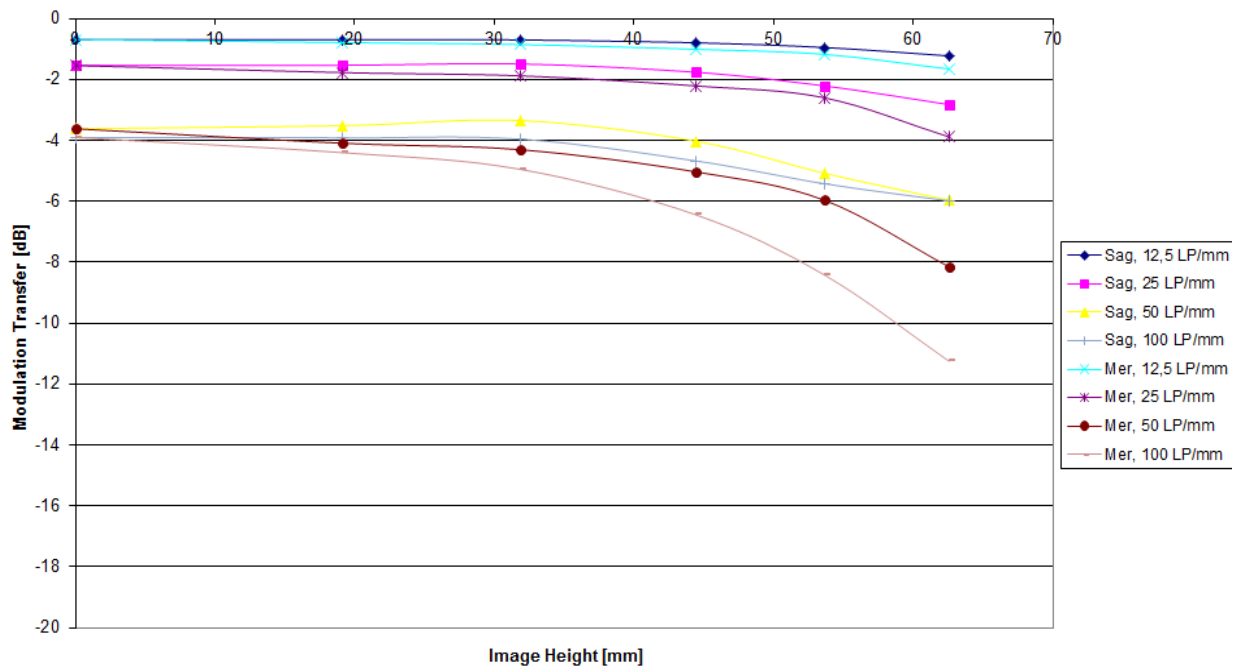
Lens types

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

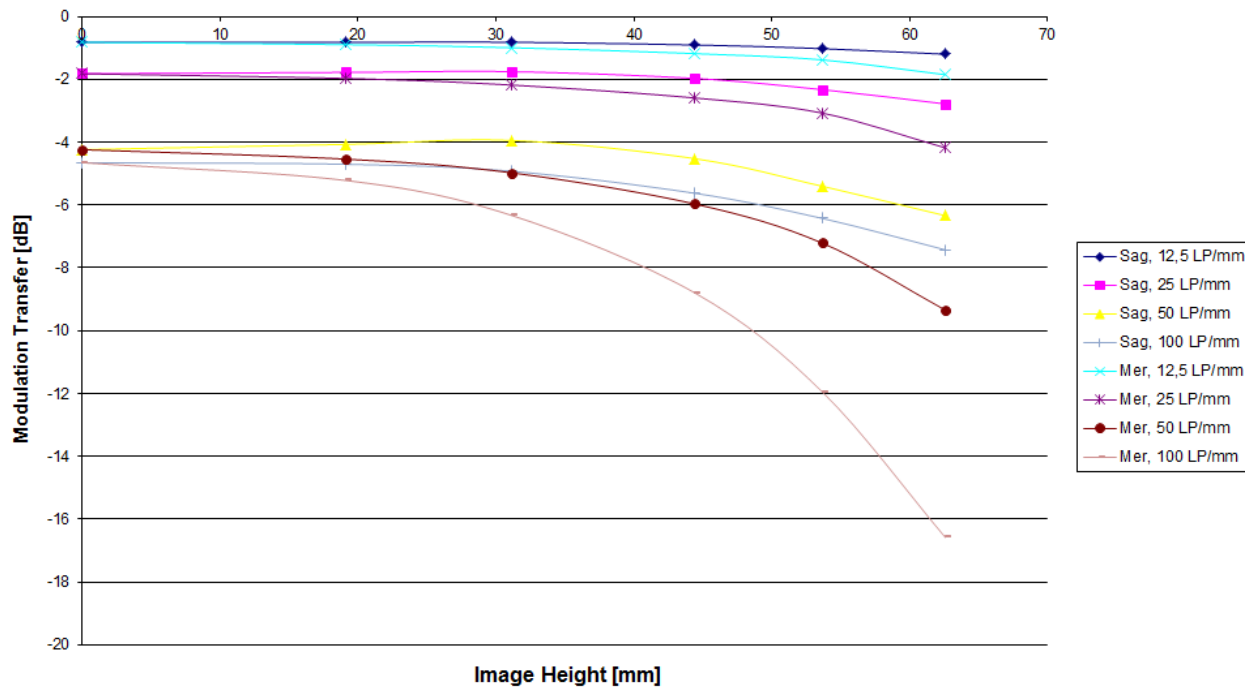




Modulation versus Image Height - Aperture f / 8

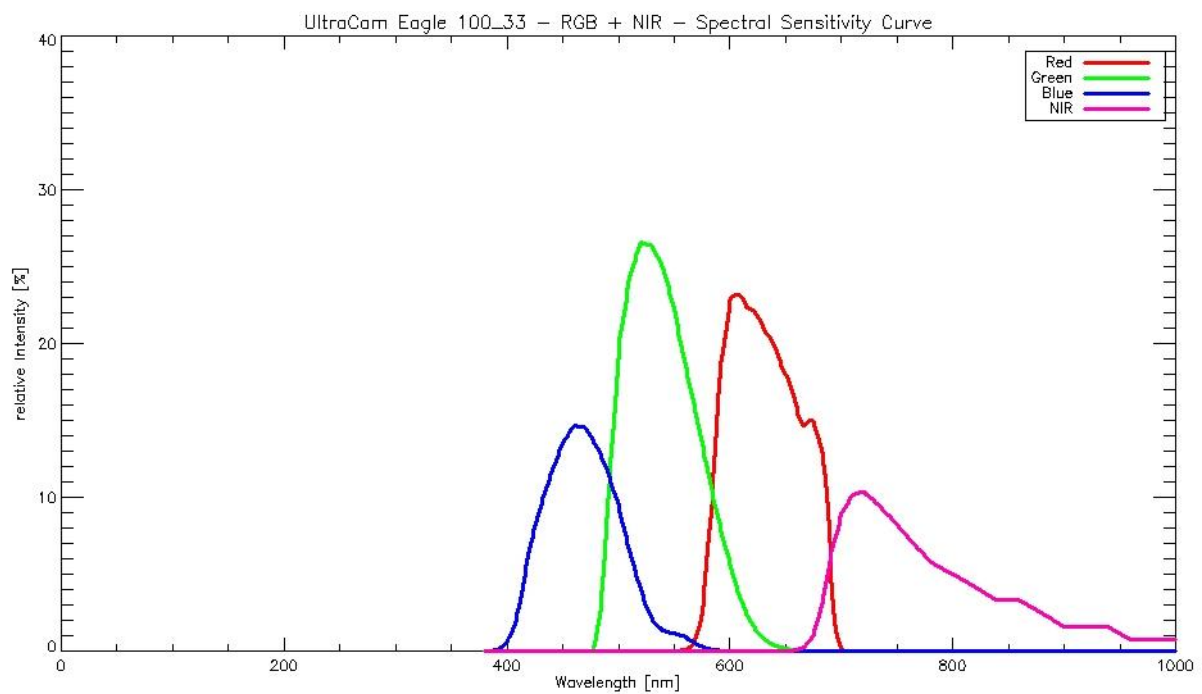
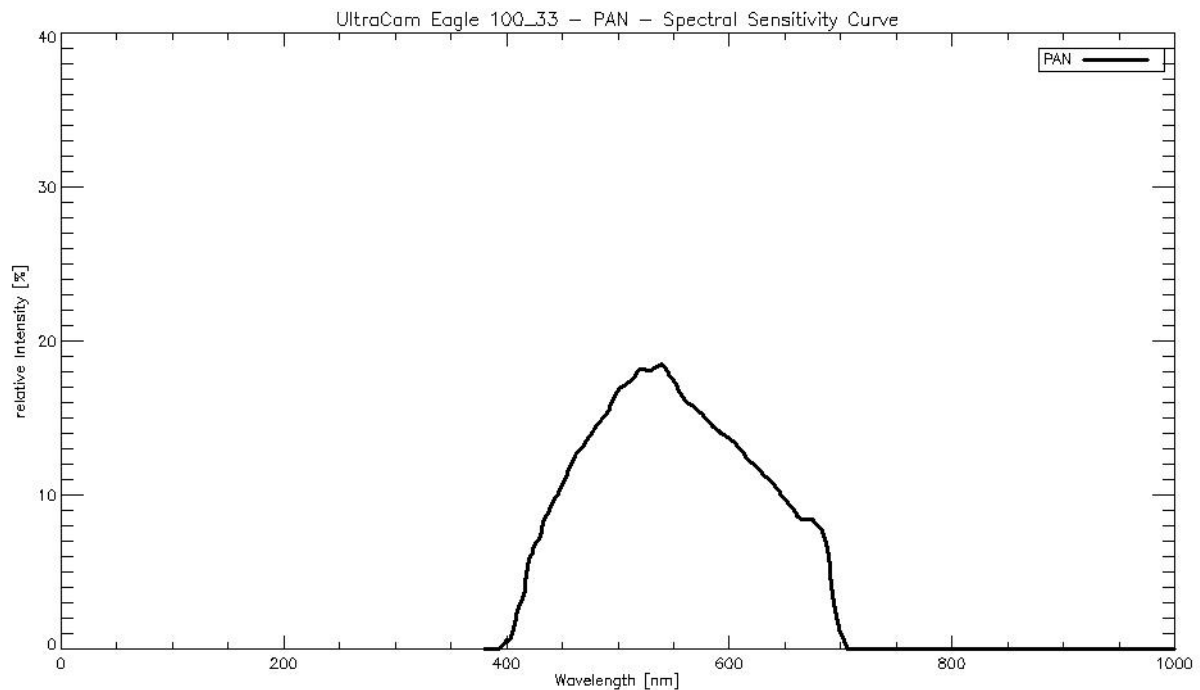


Modulation versus Image Height - Aperture f / 9.5





Spectral Sensitivity





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Radiometric Calibration

Camera: UltraCam Eagle Prime
Serial: UC-Ep-1-41317592-f100

Used Apertures	PAN	R, G, NIR	B
	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

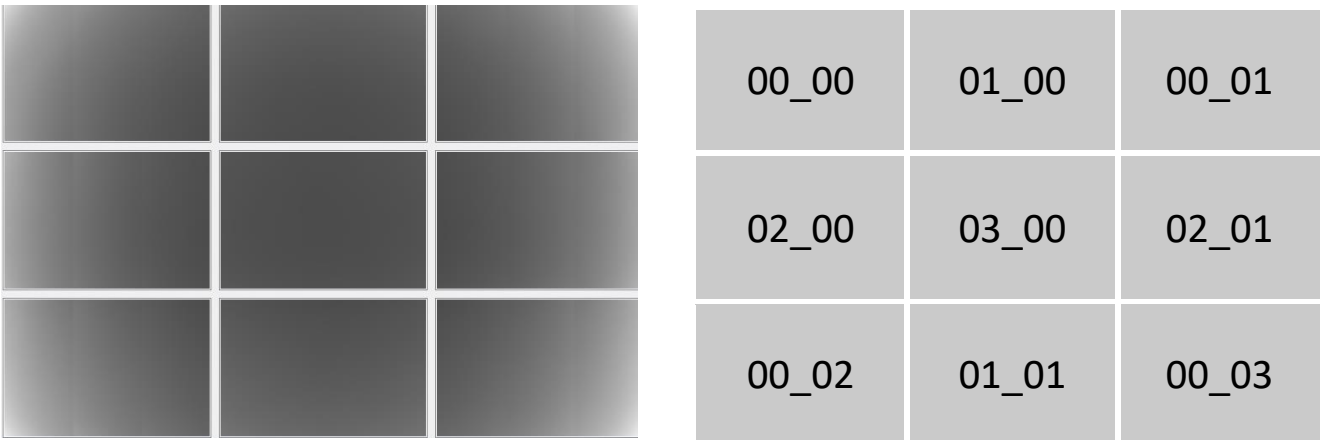
Dead Pixel Report: see Appendix I



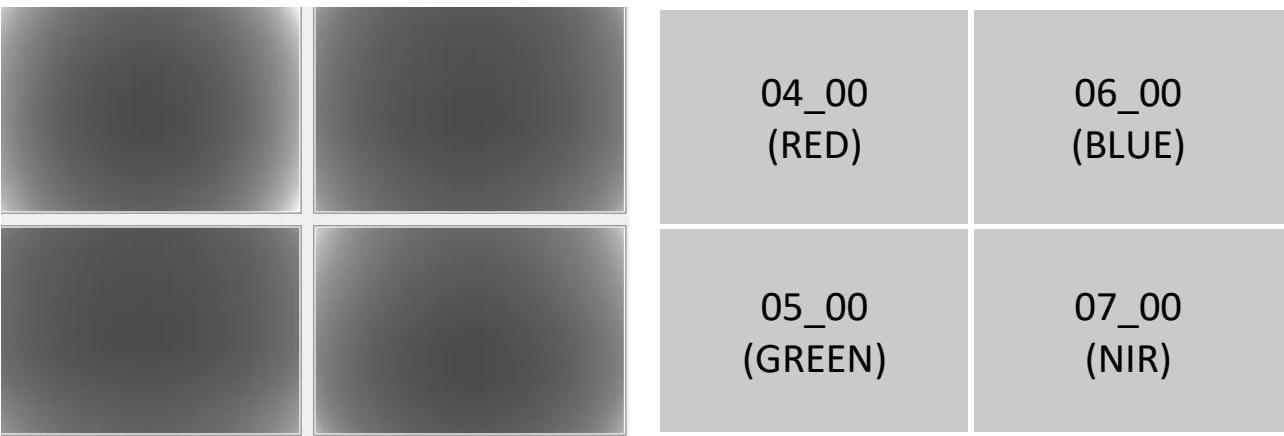
Calibration of Vignetting for working Aperture F6.7

	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 Prime
Serial: UC-Ep-1-41317592-f100

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 32 73 83	6.61	6.85	7.21	7.23	7.55	7.83	7.83	8.08	+/- 0.2
C1 (Pan)	12 22 11 13	6.59	6.91	7.28	7.46	7.66	7.84	7.92	8.33	+/- 0.2
C2 (Pan)	12 22 11 16	6.40	6.52	6.83	7.15	7.34	7.51	7.59	7.92	+/- 0.2
C3 (Pan)	12 31 20 91	6.74	7.14	7.53	7.76	7.81	8.16	8.24	8.46	+/- 0.2
C4 (Red)	12 31 45 95	7.47	7.64	7.77	7.95	7.96	8.09	8.33	8.35	+/- 0.2
C5 (Green)	12 21 89 89	6.99	7.12	7.34	7.46	7.54	7.61	7.87	7.94	+/- 0.2
C6 (Blue)	12 21 89 77	7.45	7.53	7.56	7.71	7.88	8.02	8.15	8.49	+/- 0.2
C7 (NIR)	12 21 89 88	7.28	7.36	7.66	7.83	7.89	8.02	8.24	8.61	+/- 0.2



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Electronics and Sensor Calibration

Camera:	UltraCam Eagle Prime
Serial:	UC-Ep-1-41317592-f100

Panchromatic Camera:	9 * FTF7852-M Area CCD Sensor by DALSA
Multispectral Camera:	4 * FTF7852-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	FTF7852-M	17 3682/086	27.00	5.05
00_01	FTF7852-M	17 3682/007	26.80	4.88
00_02	FTF7852-M	17 3682/083	27.00	4.81
00_03	FTF7852-M	17 3682/004	26.80	5.12
01_00	FTF7852-M	17 3682/027	26.40	4.90
01_01	FTF7852-M	17 3682/016	26.40	5.17
02_00	FTF7852-M	17 3682/079	27.00	5.22
02_01	FTF7852-M	17 3682/006	26.40	5.11
03_00	FTF7852-M	17 3682/064	27.00	5.14
04_00 (red)	FTF7852-M	17 3682/013	26.60	5.20
05_00 (green)	FTF7852-M	17 3682/012	26.80	5.08
06_00 (blue)	FTF7852-M	17 3682/051	27.00	5.02
07_00 (NIR)	FTF7852-M	17 3682/036	26.80	5.00



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]	
			Normal	Turbo
00_00	FTF7852-M	17 3682/086	13200	11830
00_01	FTF7852-M	17 3682/007	13030	11540
00_02	FTF7852-M	17 3682/083	12220	11070
00_03	FTF7852-M	17 3682/004	12280	11030
01_00	FTF7852-M	17 3682/027	11880	10780
01_01	FTF7852-M	17 3682/016	12320	11130
02_00	FTF7852-M	17 3682/079	12340	11070
02_01	FTF7852-M	17 3682/006	12450	11220
03_00	FTF7852-M	17 3682/064	12480	11330
04_00 (red)	FTF7852-M	17 3682/013	12390	11310
05_00 (green)	FTF7852-M	17 3682/012	12440	11280
06_00 (blue)	FTF7852-M	17 3682/051	11970	10990
07_00 (NIR)	FTF7852-M	17 3682/036	11950	10940



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Summary

Camera:	UltraCam Eagle Prime
Serial:	UC-Ep-1-41317592-f100
Laboratory Calibration Date:	Dec-10-2021
Camera Revision:	Rev 09.00
Date of Report:	Dec-22-2021
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: 2217/1239	PIXEL: 2227/2064	PIXEL: 6661/3027	
PIXEL: 722/3147	PIXEL: 722/3148	PIXEL: 4778/3932	PIXEL: 3774/3994
PIXEL: 1586/4149	PIXEL: 4904/ 190		
C00-01			
PIXEL: 6780/1202	PIXEL: 3146/1334	PIXEL: 1022/1688	PIXEL: 1118/1869
PIXEL: 7191/2208	PIXEL: 2949/4115	PIXEL: 6564/4154	PIXEL: 3748/4767
PIXEL: 1554/2168	PIXEL: 1555/2168	PIXEL: 6155/3636	
C00-02			
PIXEL: 2367/ 152	PIXEL: 5552/ 875	PIXEL: 4581/2519	
PIXEL: 1954/3017	PIXEL: 6783/4471		
C00-03			
PIXEL: 1693/ 529	PIXEL: 2689/ 867	PIXEL: 2688/ 868	PIXEL: 2560/3753
PIXEL: 3829/1344			
C01-00			
PIXEL: 5479/ 124			
PIXEL: 1500/ 662	PIXEL: 4328/1580	PIXEL: 5873/1709	PIXEL: 3342/1822
PIXEL: 3792/1897	PIXEL: 6212/2603	PIXEL: 5291/3440	PIXEL: 5115/3484
PIXEL: 1550/4081	PIXEL: 243/4834	PIXEL: 5969/ 155	
C01-01			
PIXEL: 587/ 592	PIXEL: 559/1425	PIXEL: 1061/2756	
PIXEL: 6445/3497	PIXEL: 6092/4525	PIXEL: 2103/5064	PIXEL: 3962/2850
C02-00			
PIXEL: 3475/ 578	PIXEL: 6870/1074		
PIXEL: 6768/1264	PIXEL: 4968/1617	PIXEL: 5994/3046	PIXEL: 154/3470
PIXEL: 2906/4169	PIXEL: 774/4667	PIXEL: 2189/3759	PIXEL: 2718/4196
C02-01			
PIXEL: 3570/ 232	PIXEL: 6325/ 483		



PIXEL: 2743/ 556	PIXEL: 3517/ 909	PIXEL: 6320/1057	PIXEL: 1394/1538
PIXEL: 2118/1808	PIXEL: 5417/2404	PIXEL: 4578/2815	PIXEL: 2324/3271
PIXEL: 3574/3893	PIXEL: 6305/4247	PIXEL: 5764/4566	PIXEL: 5462/4681
PIXEL: 5463/4681	PIXEL: 5461/4682	PIXEL: 5462/4682	PIXEL: 5463/4682
PIXEL: 5462/4683	PIXEL: 2330/4802	PIXEL: 4874/1003	

C03-00

PIXEL: 1514/ 115	PIXEL: 2293/1263	PIXEL: 3454/1878	
PIXEL: 3947/2089	PIXEL: 4722/2425	PIXEL: 2991/2690	PIXEL: 5062/3889
PIXEL: 391/4177	PIXEL: 123/4731	PIXEL: 2716/ 768	

C04-00

PIXEL: 1305/1876	PIXEL: 4191/2564	PIXEL: 7405/3982
PIXEL: 3519/4212	PIXEL: 5814/4860	

C05-00

PIXEL: 4366/ 743	PIXEL: 7302/ 970	PIXEL: 1109/1411	PIXEL: 5273/2304
PIXEL: 6836/2324	PIXEL: 7861/2372	PIXEL: 2663/2574	PIXEL: 3709/2590
PIXEL: 3586/3105	PIXEL: 2954/3444	PIXEL: 6304/3458	PIXEL: 6635/4050
PIXEL: 2903/4828	PIXEL: 170/4909	PIXEL: 354/5144	

C06-00

PIXEL: 111/ 110	PIXEL: 5064/ 509	PIXEL: 4228/1684	
PIXEL: 6717/2210	PIXEL: 4956/2608	PIXEL: 5360/3534	PIXEL: 5796/3919
PIXEL: 4299/4850	PIXEL: 6349/5011	PIXEL: 6399/2267	PIXEL: 6400/2267
PIXEL: 6399/2268	PIXEL: 6400/2268	PIXEL: 49/2971	PIXEL: 50/2971
PIXEL: 49/2972	PIXEL: 50/2972	PIXEL: 5968/3726	PIXEL: 1176/4414
PIXEL: 2569/4640	PIXEL: 2570/4640	PIXEL: 2569/4641	PIXEL: 2570/4641

C07-00

PIXEL: 2615/1571	PIXEL: 3044/2571		
PIXEL: 3042/2572	PIXEL: 3043/2572	PIXEL: 3044/2572	PIXEL: 3042/2573
PIXEL: 3043/2577	PIXEL: 7824/1242		

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	10.dec.2021		
Radiometric Calibration	10.dec.2021		
Shutter Calibration	10.dec.2021		
Electronics and Sensor Calibration	10.dec.2021		

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.