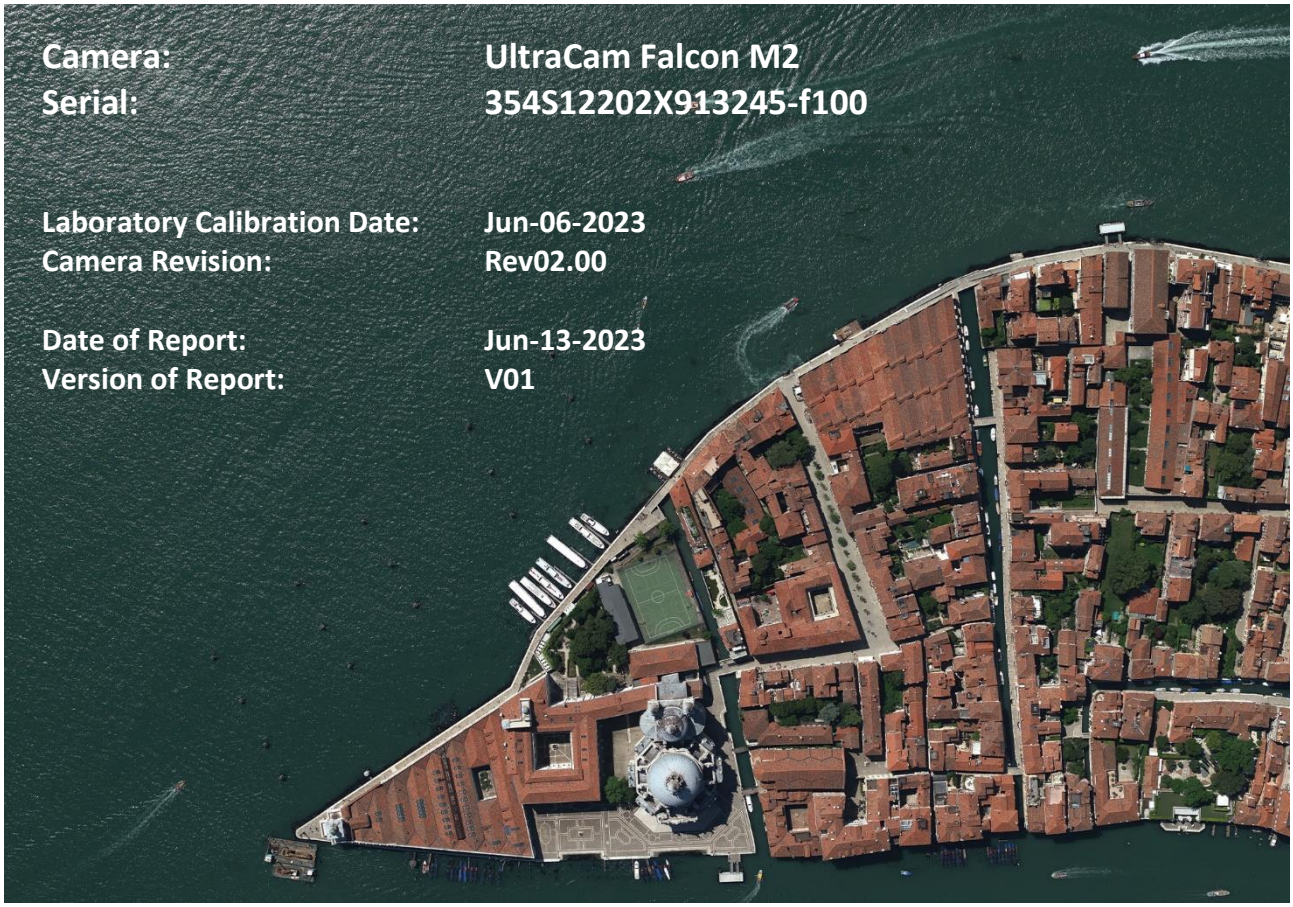
VEXCEL
IMAGING

ULTRACAM

Calibration Report



Venice, Italy

Photo on page 1 courtesy of Vexcel Imaging GmbH

ULTRACAM

Geometric Calibration

Camera:	**UltraCam Falcon M2**
Serial:	**354S12202X913245-f100**
Panchromatic Camera:	**ck = 100.500 mm**
Multispectral Camera:	**ck = 100.500 mm**
PPA Information:	**X: 0.000mm**
	Y: 0.000mm

Panchromatic Camera

Large Format Panchromatic Output Image

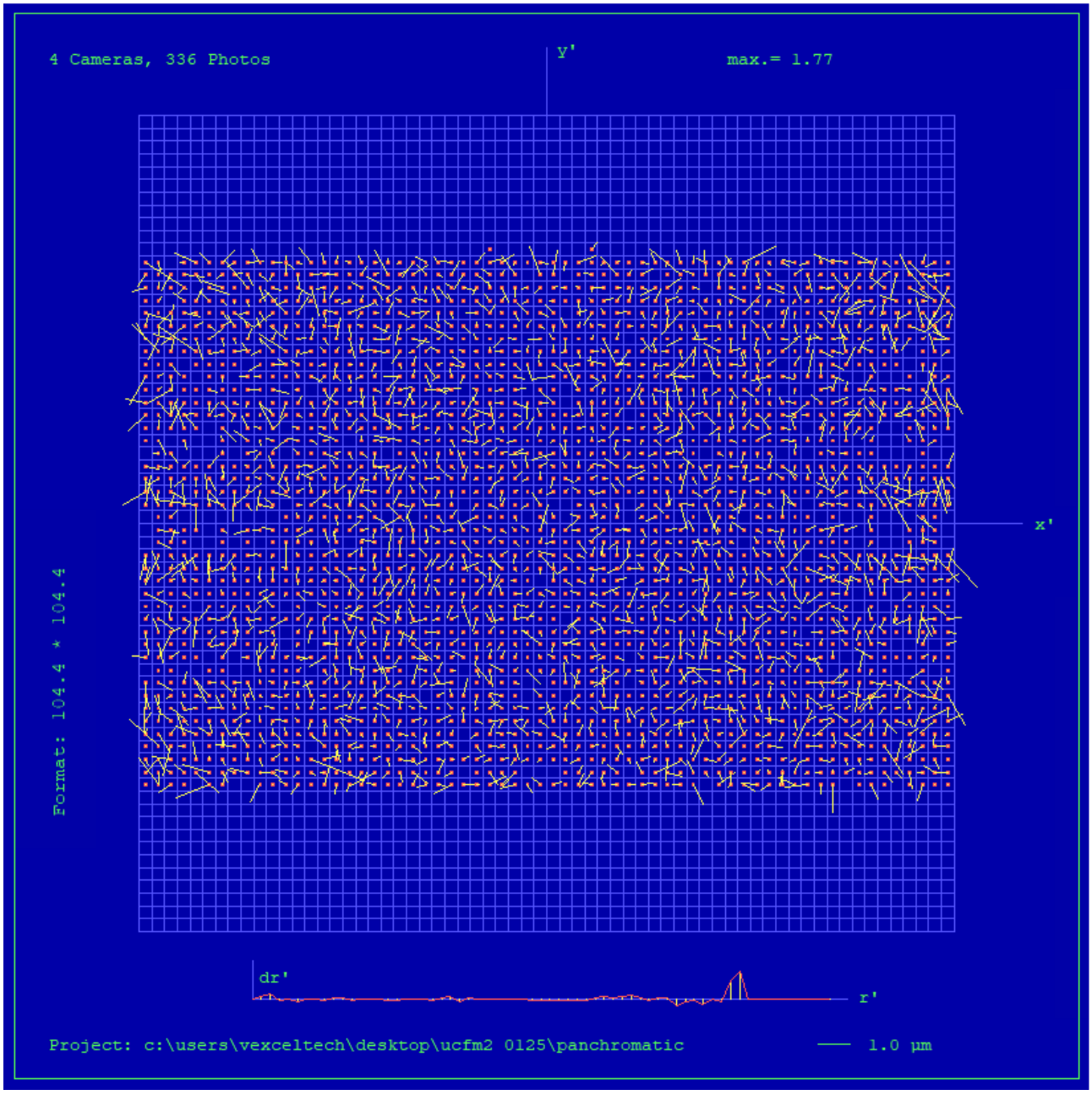
Image Format	long track cross track	67.860mm 103.860mm	11310pixel 17310pixel
Image Extent		(-33.930, -51.930)mm	(33.930, 51.930)mm
Pixel Size		6.000µm*6.000µm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Multispectral Camera

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

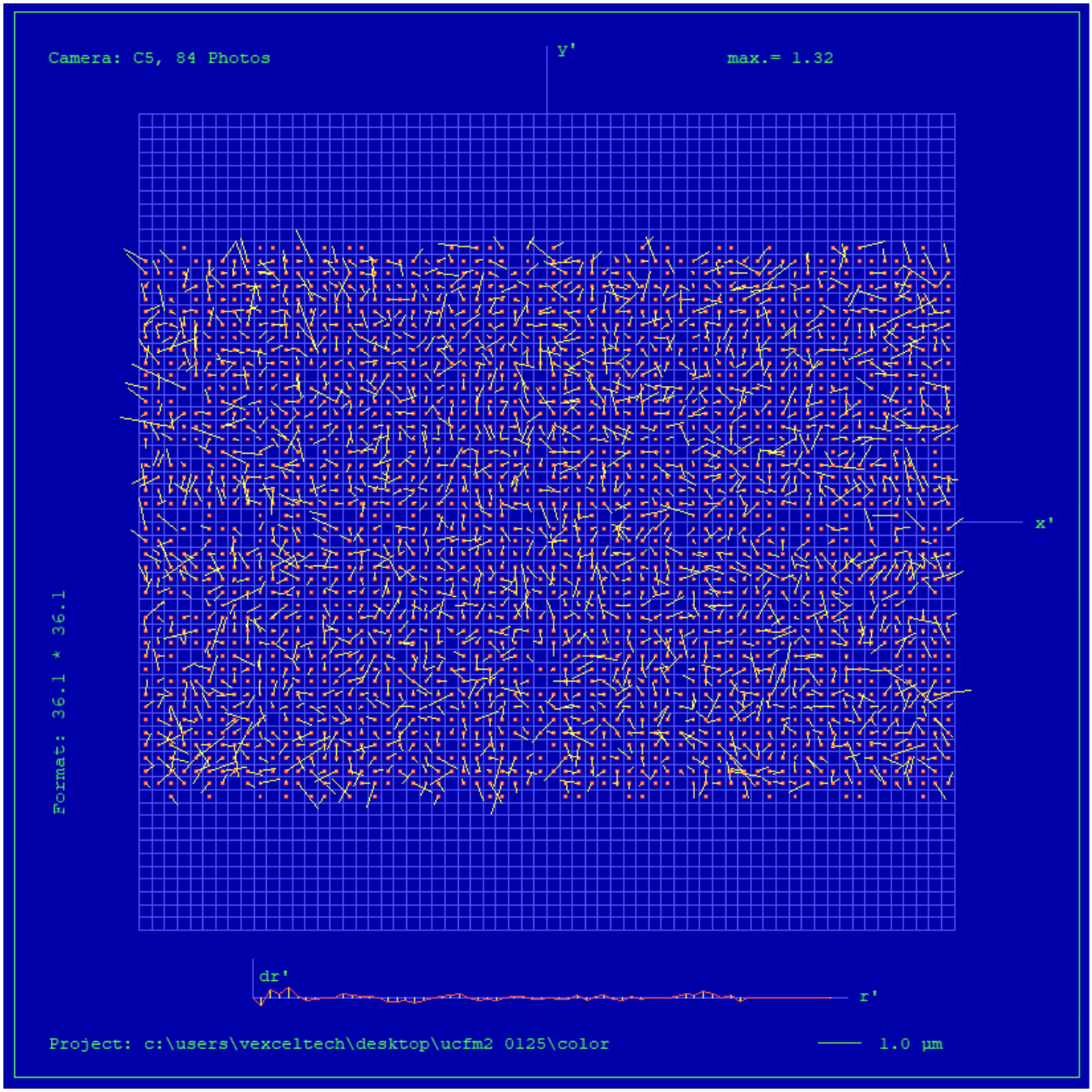
Image Format	long track cross track	67.860mm 103.860mm	3770pixel 5770pixel
Image Extent		(-33.930, -51.930)mm	(33.930, 51.930)mm
Pixel Size		18.000µm*18.000µm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): **0.81 µm**

Green Cone (Cone 5), Residual Error Diagram



Residual Error (RMS): **0.72 µm**

Explanations

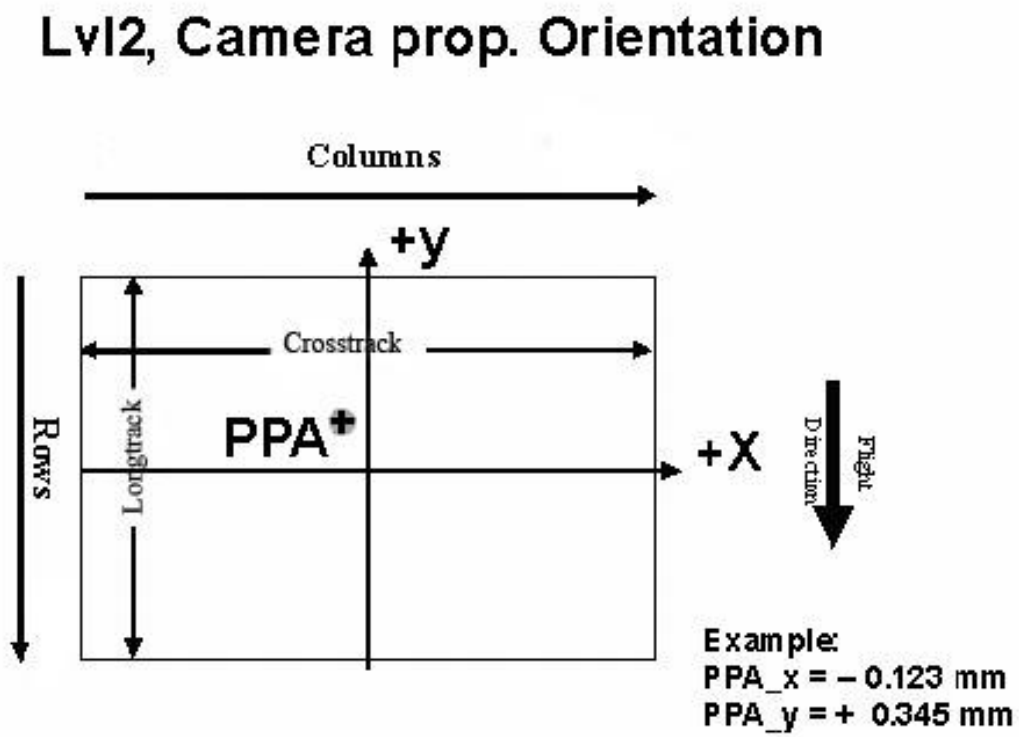
Calibration Method:

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

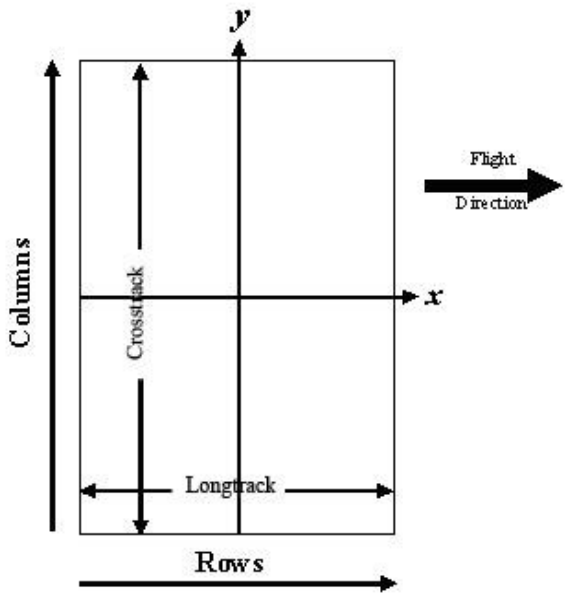
Determination of the image parameters by Least Squares Adjustment.
Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

Level 2 Image Coordinate System:

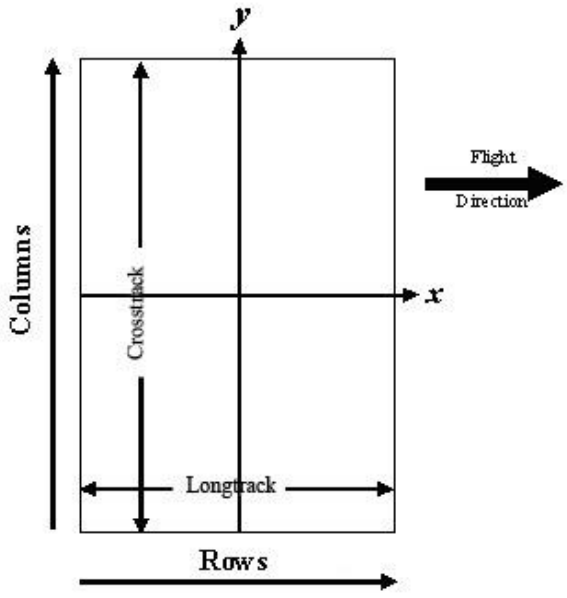


The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).

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



Panchromatic Image Format



Multispectral Image Format

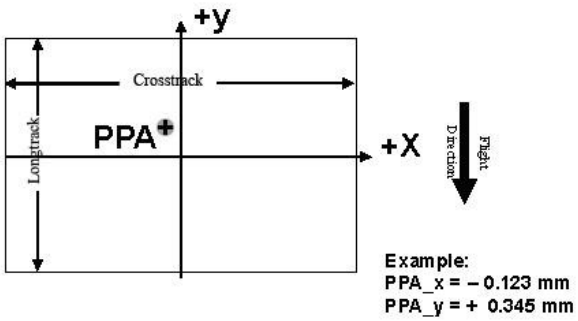
Position of Principal Point in Level 3 Image

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

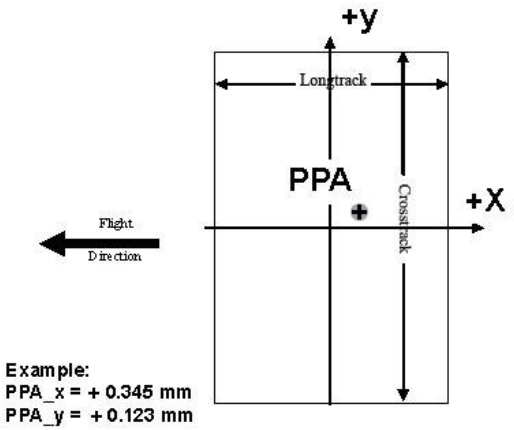
The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

Lvl3, Rotation 0 deg clockwise



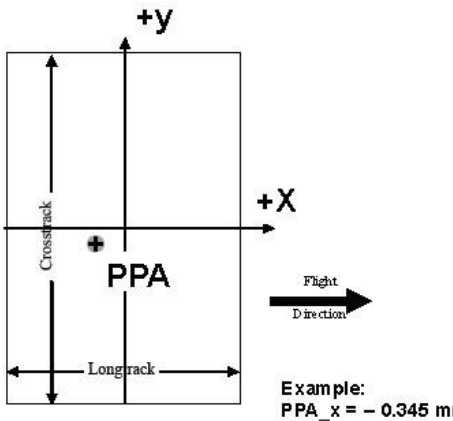
Example:
PPA_x = – 0.123 mm
PPA_y = + 0.345 mm

Lvl3, Rotation 90 deg clockwise



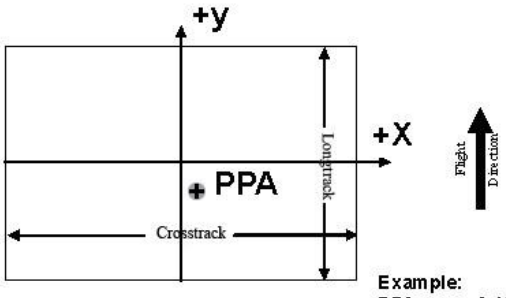
Example:
PPA_x = + 0.345 mm
PPA_y = + 0.123 mm

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

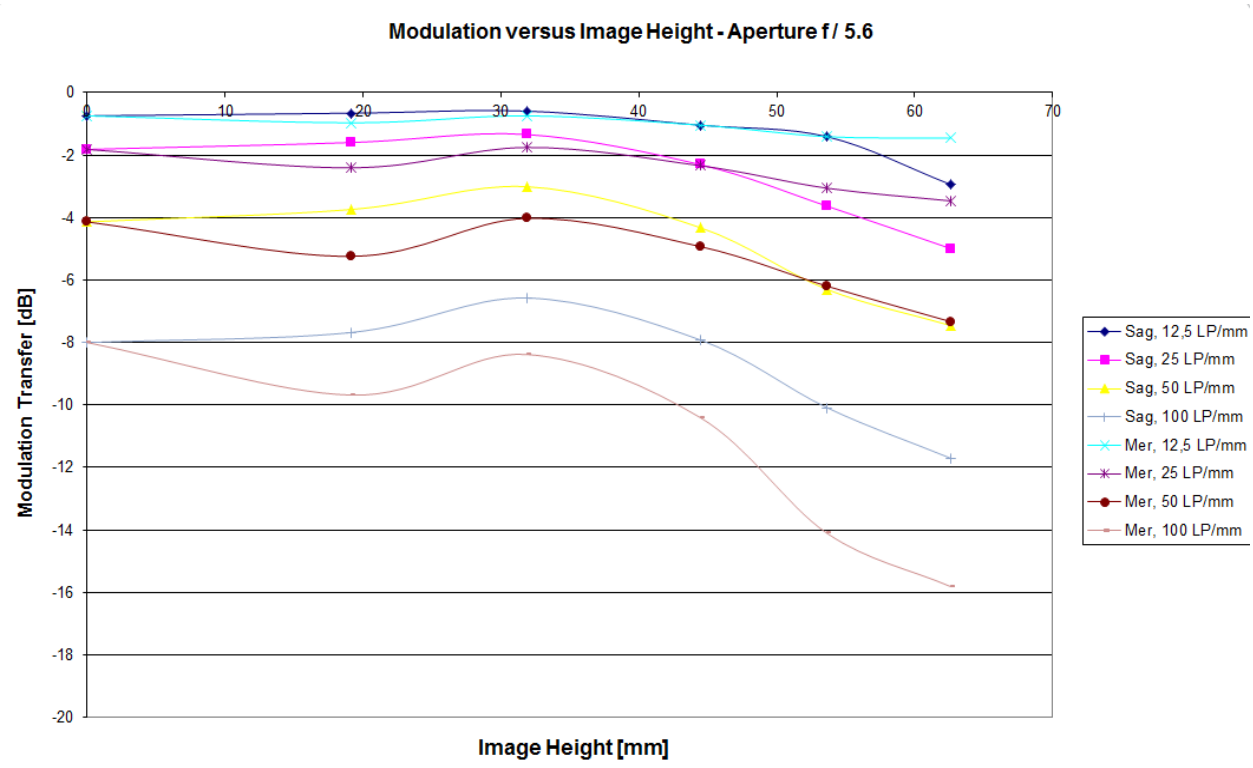
The following curves show the development of the modulation transfer function across different image heights of the panchromatic cones.
Please note that these values have been calculated and can vary up to 10% with optics from production (especially at high LP's).

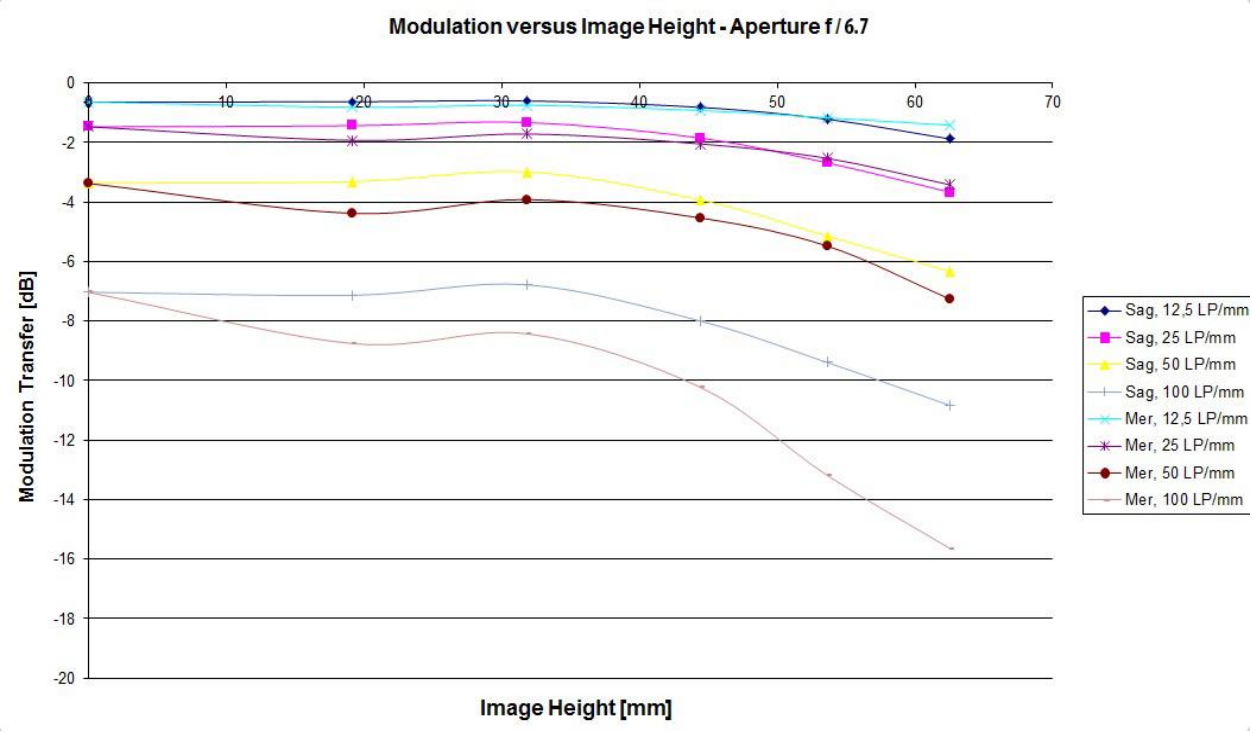
The curves are given for the meridonial (tangential) and sagital (radial) component of signals at frequencies of 12.5, 25, 50 and 100 line pairs per millimeter.

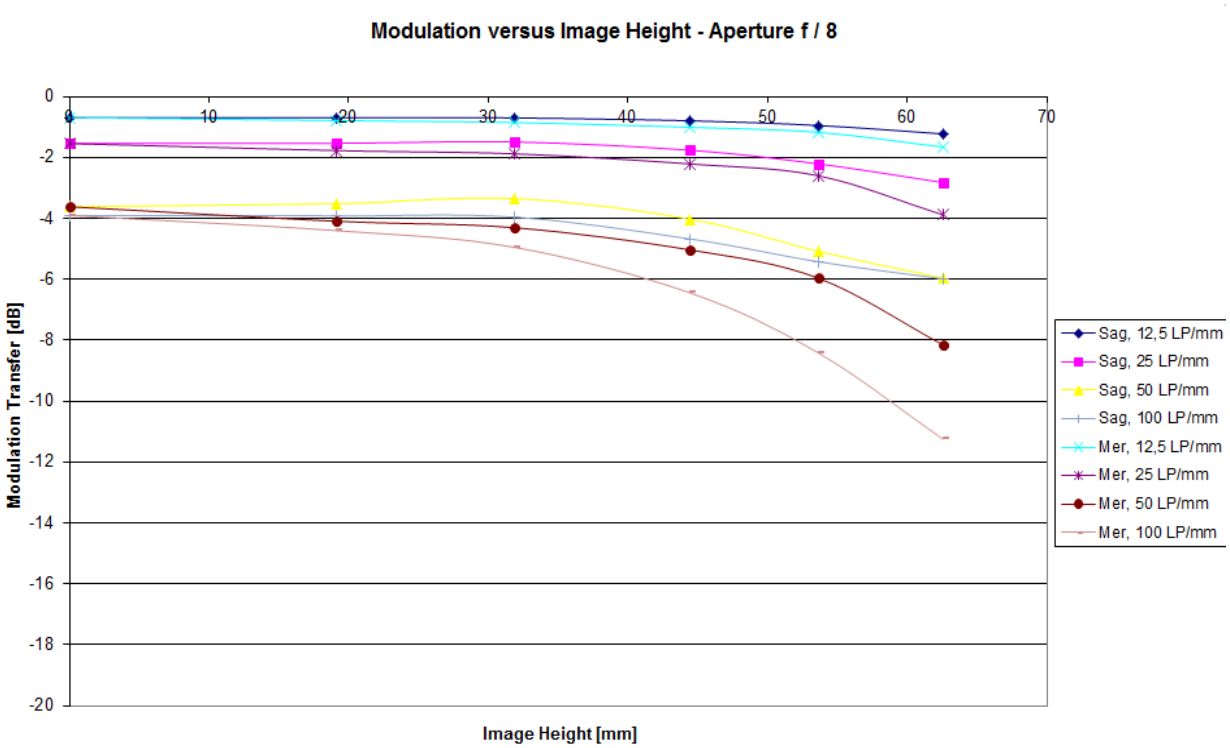
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

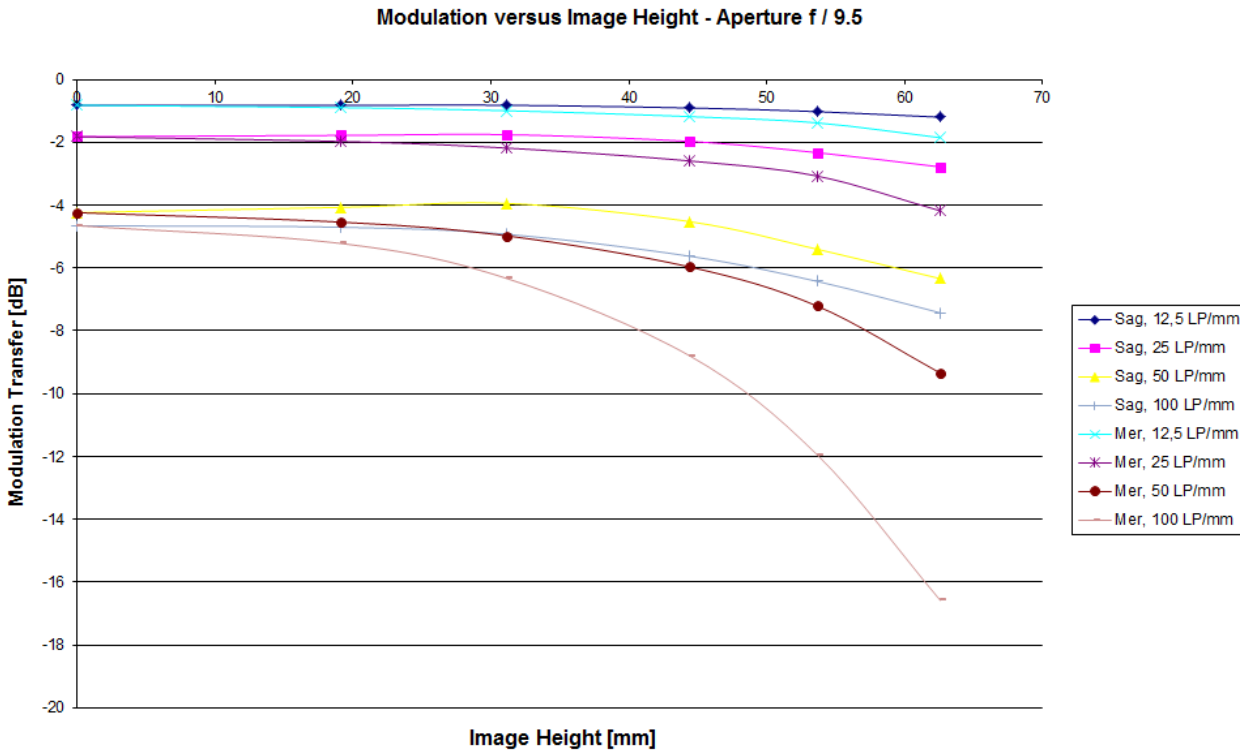
Lens types

Cone	Lens
C0	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C1	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C2	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C3	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C4 (RED)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C5 (GREEN)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C6 (BLUE)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C7 (NIR)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany

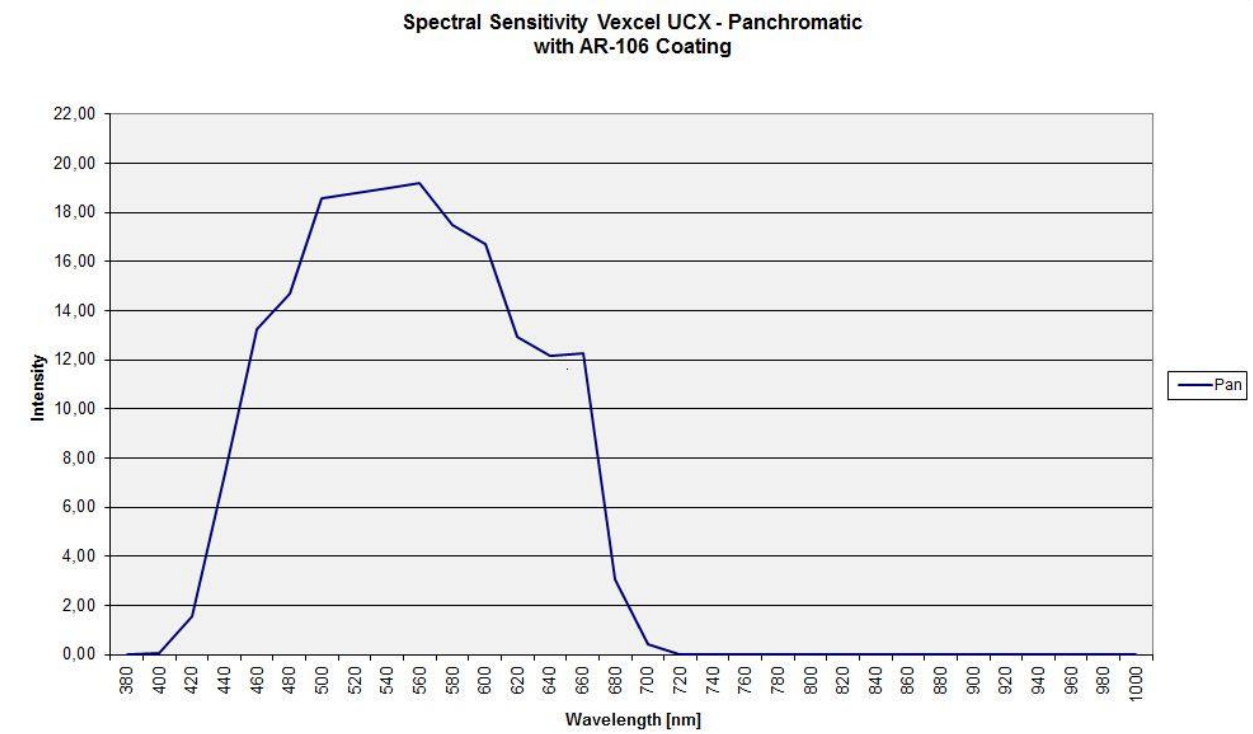

Modulation versus Image Height - Aperture f / 5.6
Modulation Transfer [dB]
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
Image Height [mm]
Sag, 12,5 LP/mm
Sag, 25 LP/mm
Sag, 50 LP/mm
Sag, 100 LP/mm
Mer, 12,5 LP/mm
Mer, 25 LP/mm
Mer, 50 LP/mm
Mer, 100 LP/mm

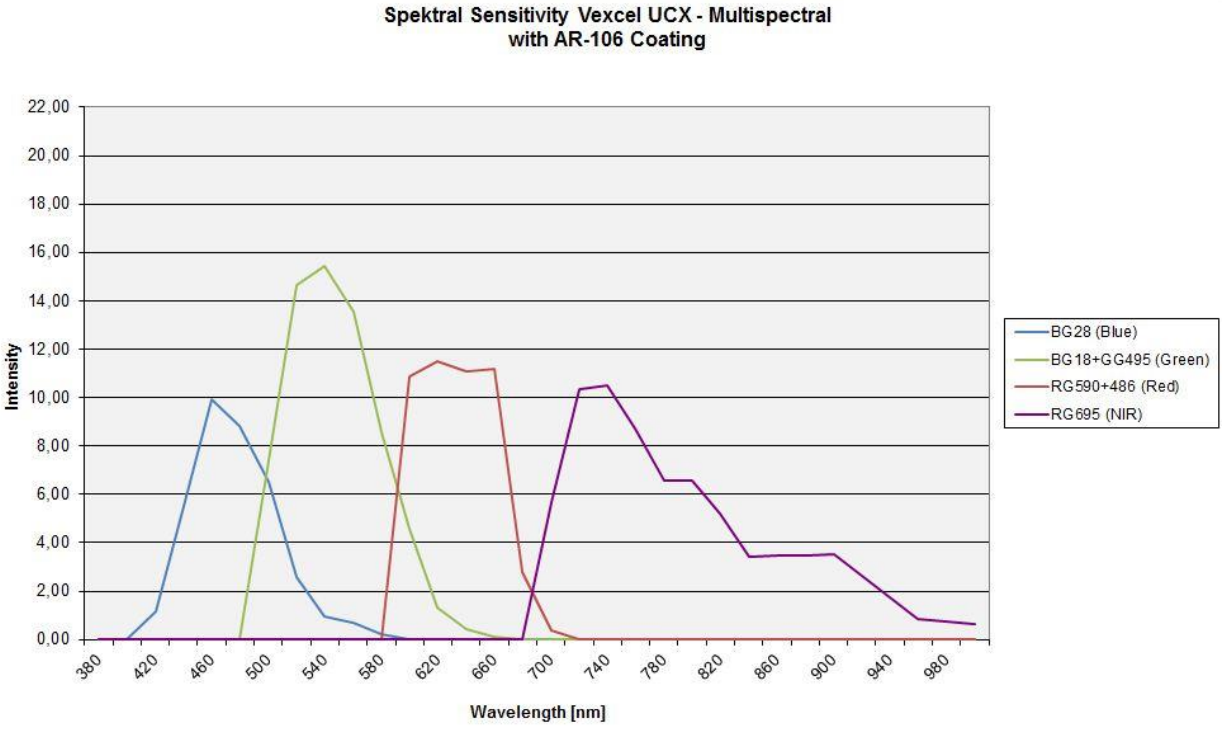

Modulation versus Image Height - Aperture f / 6.7
Modulation Transfer [dB]
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
Image Height [mm]
Sag, 12,5 LP/mm
Sag, 25 LP/mm
Sag, 50 LP/mm
Sag, 100 LP/mm
Mer, 12,5 LP/mm
Mer, 25 LP/mm
Mer, 50 LP/mm
Mer, 100 LP/mm


Modulation versus Image Height - Aperture f / 8
Modulation Transfer [dB]
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
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 / 9.5
Modulation Transfer [dB]
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
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

Spectral Sensitivity





ULTRACAM

Radiometric Calibration

Camera: **UltraCam Falcon M2**
Serial: **354S12202X913245-f100**

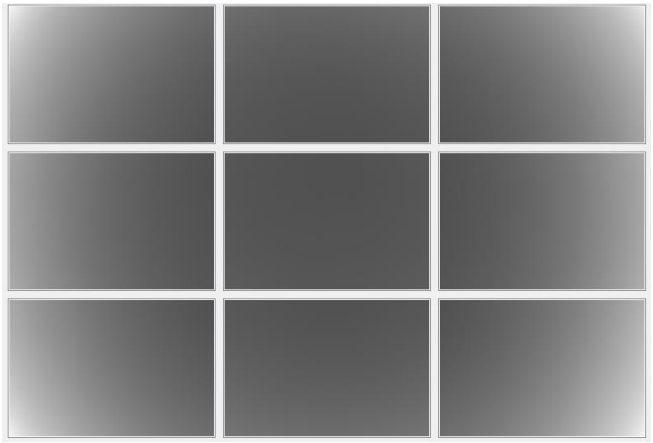
	PAN	R, G, NIR	B
Used Apertures	F5.6	F4.8	F4.8
	F6.7	F5.6	F4.8
	F8	F6.7	F4.8
	F9.5	F8	F5.6
	F11	F9.5	F6.7
	F13	F11	F8
	F16	F13	F9.5
	F22	F19	F13

Dead Pixel Report: see Appendix I

Calibration of Vignetting for working Aperture F6.7

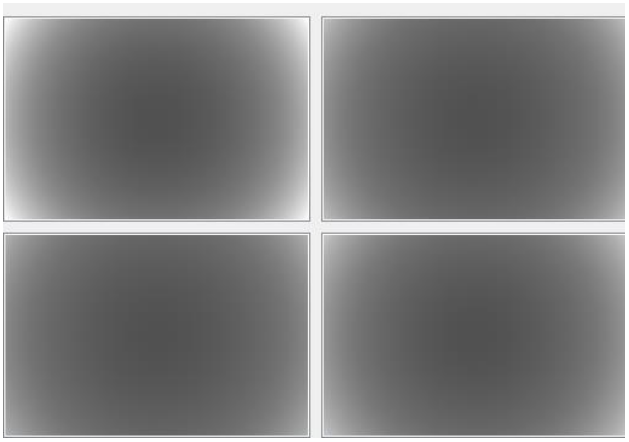
	PAN	R, G, NIR	B
Aperture	F6.7	F5.6	F4.8

Graphical Overview of Pan Sensors:



00_00	01_00	00_01
02_00	03_00	02_01
00_02	01_01	00_03

Graphical Overview of Multispectral Sensors:



04_00 (RED)	06_00 (BLUE)
05_00 (GREEN)	07_00 (NIR)

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 Falcon M2**
Serial:	**354S12202X913245-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 52 75 41	6.33	6.47	6.56	6.69	6.90	7.14	7.27	7.38	+/- 0.2
C1 (Pan)	12 52 75 39	6.49	6.57	6.72	6.99	7.22	7.35	7.59	7.62	+/- 0.2
C2 (Pan)	12 52 75 34	6.45	6.53	6.66	6.88	7.13	7.28	7.50	7.64	+/- 0.2
C3 (Pan)	12 52 75 29	6.42	6.57	6.86	7.12	7.33	7.49	7.70	7.80	+/- 0.2
C4 (Red)	12 52 68 66	7.56	7.62	7.82	8.01	8.17	8.22	8.28	8.44	+/- 0.2
C5 (Green)	12 52 68 52	7.25	7.34	7.60	7.73	7.91	8.06	8.14	8.20	+/- 0.2
C6 (Blue)	12 52 68 57	6.55	6.56	6.57	6.68	6.92	7.10	7.27	7.29	+/- 0.2
C7 (NIR)	12 52 68 72	7.45	7.55	7.64	7.80	7.94	8.10	8.17	8.17	+/- 0.2

ULTRACAM

Electronics and Sensor Calibration

Camera:	**UltraCam Falcon M2**
Serial:	**354S12202X913245-f100**
Panchromatic Camera:	**9 * FTF6040-M Area CCD Sensor by DALSA**
Multispectral Camera:	**4 * FTF6040-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]
00_00	FTF6040-M	15 7701/074	22.50
00_01	FTF6040-M	15 7701/118	22.30
00_02	FTF6040-M	15 7701/109	22.50
00_03	FTF6040-M	15 7701/106	22.60
01_00	FTF6040-M	14 3178/113	22.50
01_01	FTF6040-M	15 7701/077	22.50
02_00	FTF6040-M	15 7701/078	22.60
02_01	FTF6040-M	14 3392/007	22.30
03_00	FTF6040-M	14 3392/011	22.30
04_00 (red)	FTF6040-M	15 7701/116	22.60
05_00 (green)	FTF6040-M	14 1951/051	22.50
06_00 (blue)	FTF6040-M	15 7701/117	22.60
07_00 (NIR)	FTF6040-M	16 3392/024	22.30

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]
00_00	FTF6040-M	15 7701/074	13150
00_01	FTF6040-M	15 7701/118	13450
00_02	FTF6040-M	15 7701/109	13760
00_03	FTF6040-M	15 7701/106	13180
01_00	FTF6040-M	14 3178/113	13920
01_01	FTF6040-M	15 7701/077	14150
02_00	FTF6040-M	15 7701/078	13550
02_01	FTF6040-M	14 3392/007	13030
03_00	FTF6040-M	14 3392/011	13260
04_00 (red)	FTF6040-M	15 7701/116	13420
05_00 (green)	FTF6040-M	14 1951/051	12520
06_00 (blue)	FTF6040-M	15 7701/117	13090
07_00 (NIR)	FTF6040-M	16 3392/024	13580

ULTRACAM

Summary

Camera:	**UltraCam Falcon M2**
Serial:	**354S12202X913245-f100**
Laboratory Calibration Date:	**Jun-06-2023**
Camera Revision:	**Rev02.00**
Date of Report:	**Jun-13-2023**
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: 1489/ 33	PIXEL: 2632/ 130	PIXEL: 4948/ 234	
PIXEL: 1632/ 394	PIXEL: 1665/ 462	PIXEL: 628/ 472	PIXEL: 2262/ 561
PIXEL: 4141/ 681	PIXEL: 3321/ 728	PIXEL: 4848/ 739	PIXEL: 4803/ 837
PIXEL: 5573/ 959	PIXEL: 2886/1093	PIXEL: 1703/1102	PIXEL: 2372/1122
PIXEL: 1126/1169	PIXEL: 5769/1239	PIXEL: 941/1268	PIXEL: 2158/1303
PIXEL: 5157/1344	PIXEL: 5977/1505	PIXEL: 2015/1530	PIXEL: 1160/1583
PIXEL: 3492/1624	PIXEL: 3825/1644	PIXEL: 5977/1727	PIXEL: 323/1746
PIXEL: 3710/1835	PIXEL: 4368/1878	PIXEL: 1212/1887	PIXEL: 5166/1907
PIXEL: 4022/1925	PIXEL: 5541/2017	PIXEL: 4465/2039	PIXEL: 1139/2053
PIXEL: 4983/2101	PIXEL: 3929/2238	PIXEL: 3729/2412	PIXEL: 1469/2498
PIXEL: 4562/2686	PIXEL: 5340/2740	PIXEL: 2563/2798	PIXEL: 1348/2821
PIXEL: 3602/2829	PIXEL: 1797/2974	PIXEL: 993/3339	PIXEL: 3436/3399
PIXEL: 614/3430	PIXEL: 5008/3506	PIXEL: 3503/3526	PIXEL: 4582/3589
PIXEL: 5761/3589	PIXEL: 698/3646	PIXEL: 2313/3697	PIXEL: 5753/3755
PIXEL: 5759/3909	PIXEL: 409/3931	PIXEL: 1450/3984	

C00-01

PIXEL: 3263/ 148	PIXEL: 2577/ 910	PIXEL: 751/1206	
PIXEL: 2026/1681	PIXEL: 2242/2090	PIXEL: 3186/2158	PIXEL: 42/2365
PIXEL: 5074/2755	PIXEL: 4391/2919	PIXEL: 5638/3231	PIXEL: 5720/3572
PIXEL: 111/3833			

C00-02

PIXEL: 5020/ 20			
PIXEL: 3437/ 141	PIXEL: 2021/ 859	PIXEL: 5966/1233	PIXEL: 4993/1250
PIXEL: 2717/1824	PIXEL: 5161/1832	PIXEL: 3730/2062	PIXEL: 4664/2249
PIXEL: 379/2459	PIXEL: 5514/2826	PIXEL: 377/2846	PIXEL: 731/3250
PIXEL: 4842/3319	PIXEL: 4761/ 94		

C00-03

PIXEL: 2474/ 265	PIXEL: 1027/ 763	PIXEL: 5897/1061	PIXEL: 4834/1212
PIXEL: 5215/1756	PIXEL: 4155/1962	PIXEL: 698/1998	PIXEL: 1672/2179
PIXEL: 4882/2588	PIXEL: 5543/2980	PIXEL: 5279/3065	PIXEL: 4894/3084
PIXEL: 1888/3533	PIXEL: 2456/3595	PIXEL: 5652/1082	PIXEL: 5577/1681
PIXEL: 298/3586	PIXEL: 59/3686	PIXEL: 1083/3838	

C01-00

PIXEL: 4091/ 468	PIXEL: 2601/ 903	PIXEL: 494/1126	
PIXEL: 1075/1253	PIXEL: 1050/1266	PIXEL: 4002/1445	PIXEL: 3217/1500
PIXEL: 891/1660	PIXEL: 4044/1781	PIXEL: 5765/2063	PIXEL: 2838/2629
PIXEL: 1417/2770	PIXEL: 5695/3013	PIXEL: 5763/3517	PIXEL: 2785/3535
PIXEL: 2156/3818	PIXEL: 4403/3905	PIXEL: 1922/3967	PIXEL: 138/ 59
PIXEL: 138/ 60	PIXEL: 138/ 61	PIXEL: 139/ 61	PIXEL: 309/ 155
PIXEL: 716/ 380	PIXEL: 1171/ 961	PIXEL: 4384/1124	PIXEL: 909/1747
PIXEL: 4264/2599	PIXEL: 1212/2898	PIXEL: 1041/3133	PIXEL: 997/3167
PIXEL: 283/3673			

C01-01

PIXEL: 3684/ 118			
PIXEL: 3515/ 149	PIXEL: 2474/ 224	PIXEL: 518/ 721	PIXEL: 92/ 762
PIXEL: 4713/1392	PIXEL: 5179/1651	PIXEL: 4750/1994	PIXEL: 1484/2013
PIXEL: 4984/2088	PIXEL: 1324/2105	PIXEL: 912/2357	PIXEL: 833/2656
PIXEL: 3798/2759	PIXEL: 65/2773	PIXEL: 2631/3401	

C02-00

PIXEL: 5781/ 157	PIXEL: 4674/ 245	PIXEL: 1508/ 332	
PIXEL: 1369/ 338	PIXEL: 1437/ 356	PIXEL: 1438/ 356	PIXEL: 1437/ 357
PIXEL: 4381/ 443	PIXEL: 793/ 716	PIXEL: 362/ 726	PIXEL: 4282/ 779
PIXEL: 1089/ 872	PIXEL: 4798/1789	PIXEL: 5693/1799	PIXEL: 1589/1860
PIXEL: 5453/2109	PIXEL: 313/2465	PIXEL: 3511/2856	PIXEL: 3514/3093
PIXEL: 340/3189	PIXEL: 2872/3901	PIXEL: 2021/3942	

C02-01

PIXEL: 461/ 125	PIXEL: 1656/ 225	PIXEL: 4798/ 364	
PIXEL: 2369/ 401	PIXEL: 3506/ 808	PIXEL: 2266/1135	PIXEL: 5408/1308
PIXEL: 3409/1477	PIXEL: 2044/1491	PIXEL: 3862/1757	PIXEL: 2290/2098
PIXEL: 1242/2378	PIXEL: 1875/2540	PIXEL: 5293/3879	PIXEL: 5978/1863
PIXEL: 5266/2831	PIXEL: 5267/2831		

C03-00

PIXEL: 809/ 861	PIXEL: 5374/ 903	PIXEL: 4527/ 975	PIXEL: 2236/1482
PIXEL: 361/1557	PIXEL: 3205/1716	PIXEL: 4835/2386	PIXEL: 415/2702
PIXEL: 5248/2745	PIXEL: 1720/3194		

C04-00

PIXEL: 1671/ 307	PIXEL: 5528/ 718	PIXEL: 231/ 760	PIXEL: 3979/1230
PIXEL: 5967/2667	PIXEL: 2955/3141	PIXEL: 4913/3403	PIXEL: 2117/3846
PIXEL: 5579/ 59	PIXEL: 6007/ 635	PIXEL: 5132/1500	

C05-00

PIXEL: 5860/ 362	PIXEL: 3363/ 722	PIXEL: 3460/1193	
PIXEL: 1926/1543	PIXEL: 848/1743	PIXEL: 5263/1772	PIXEL: 4173/1934
PIXEL: 2364/2018	PIXEL: 2753/2051	PIXEL: 1286/2073	PIXEL: 752/2209
PIXEL: 1060/2414	PIXEL: 4266/2449	PIXEL: 3017/2650	PIXEL: 1513/2860
PIXEL: 3880/2881	PIXEL: 1588/3576		

C06-00

PIXEL: 1082/1067	PIXEL: 538/1323	PIXEL: 3556/1492	PIXEL: 4518/1534
PIXEL: 1737/1829	PIXEL: 4253/1925	PIXEL: 2193/1999	PIXEL: 472/3444
PIXEL: 687/2443			

C07-00

PIXEL: 4794/1526			
PIXEL: 2087/2445	PIXEL: 1662/3152	PIXEL: 1085/3615	PIXEL: 153/3934

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	**09.Jun.2023**		
Radiometric Calibration	**09.Jun.2023**		
Shutter Calibration	**09.Jun.2023**		
Electronics and Sensor Calibration	**09.Jun.2023**		

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.