



ULTRACAM

Calibration Report



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Venice, Italy

Photo on page 1 courtesy of Vexcel Imaging GmbH



ULTRACAM

Geometric Calibration

Camera: UltraCam Falcon Prime
Serial: UC-Fp-1-50616147-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	67.860mm	11310pixel
	cross track	103.860mm	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		

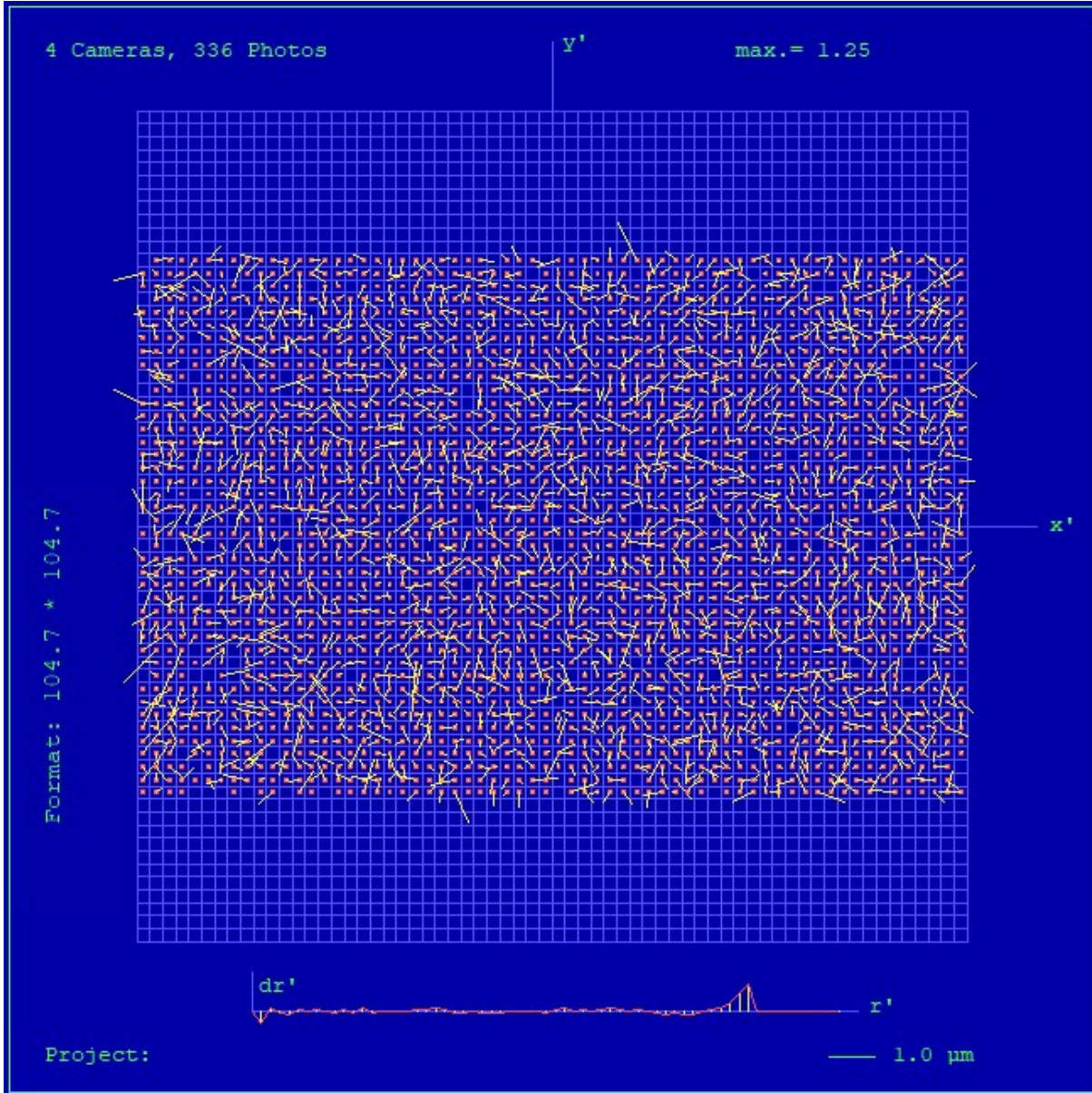
Multispectral Camera

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

Image Format	long track	67.860mm	3770pixel
	cross track	103.860mm	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		



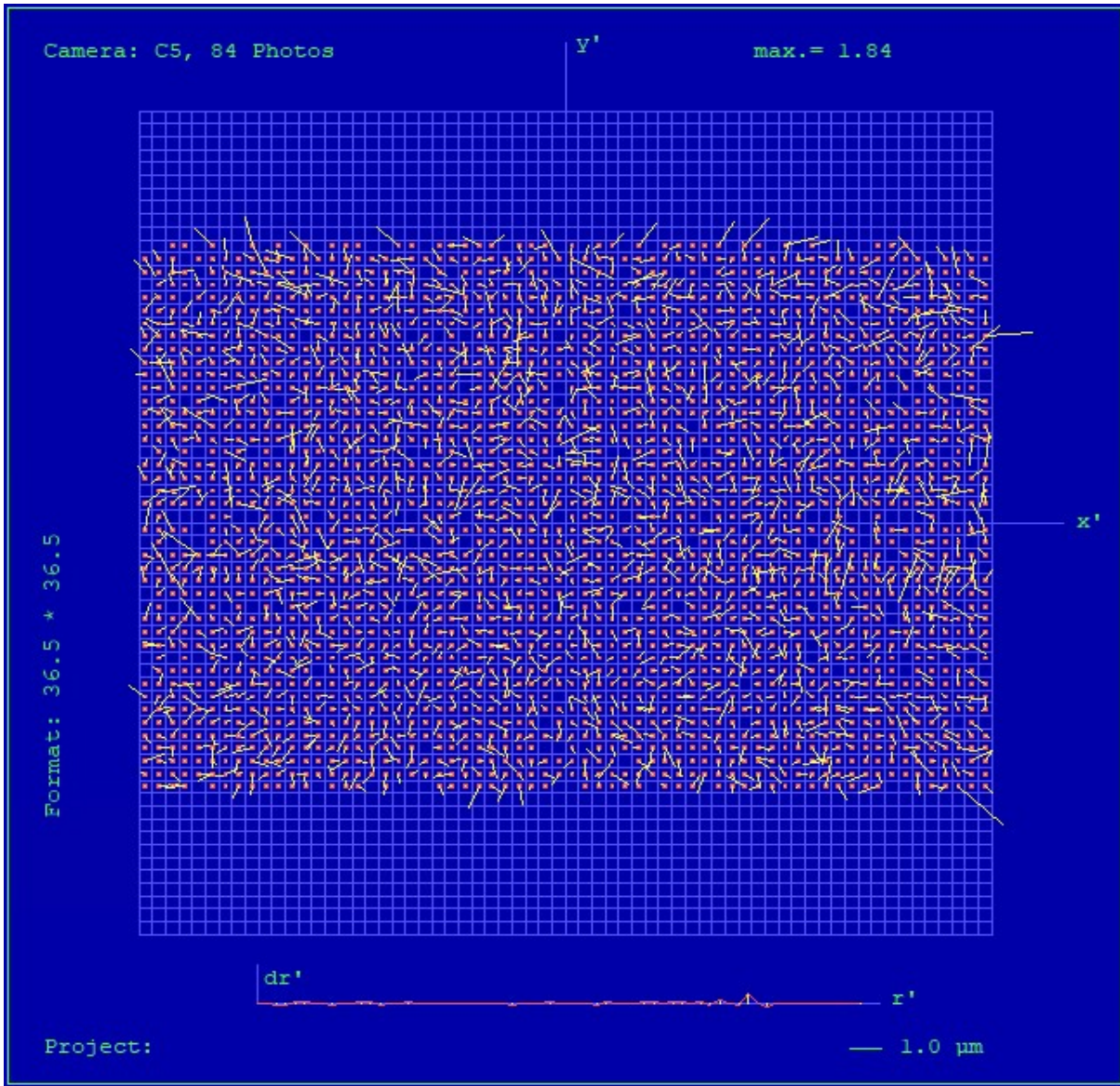
Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): **0.62 μm**



Green Cone (Cone 5), Residual Error Diagram



Residual Error (RMS): 0.67 μm



Explanations

Calibration Method:

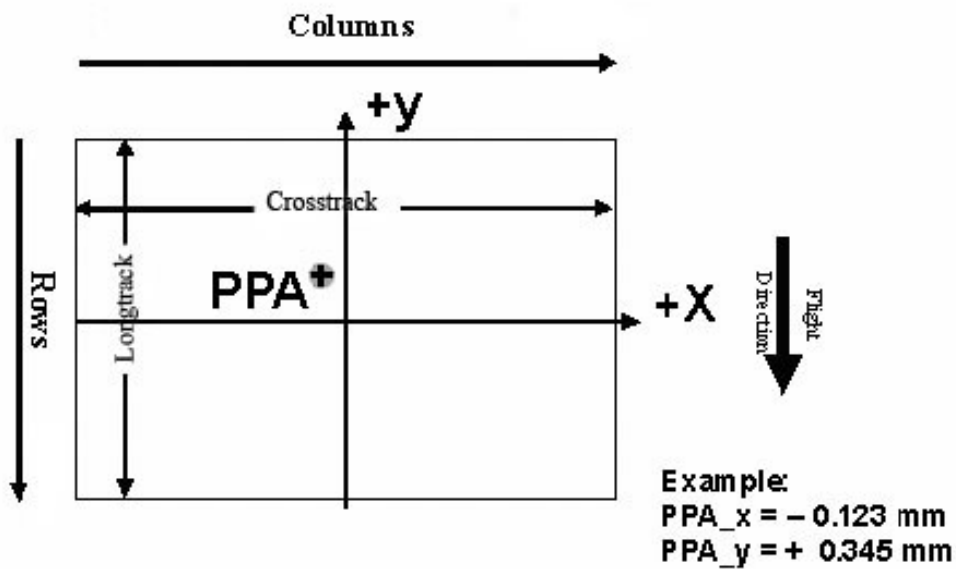
The geometric calibration is based on a set of 84 images of a defined geometry target with 394 GCPs.

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:

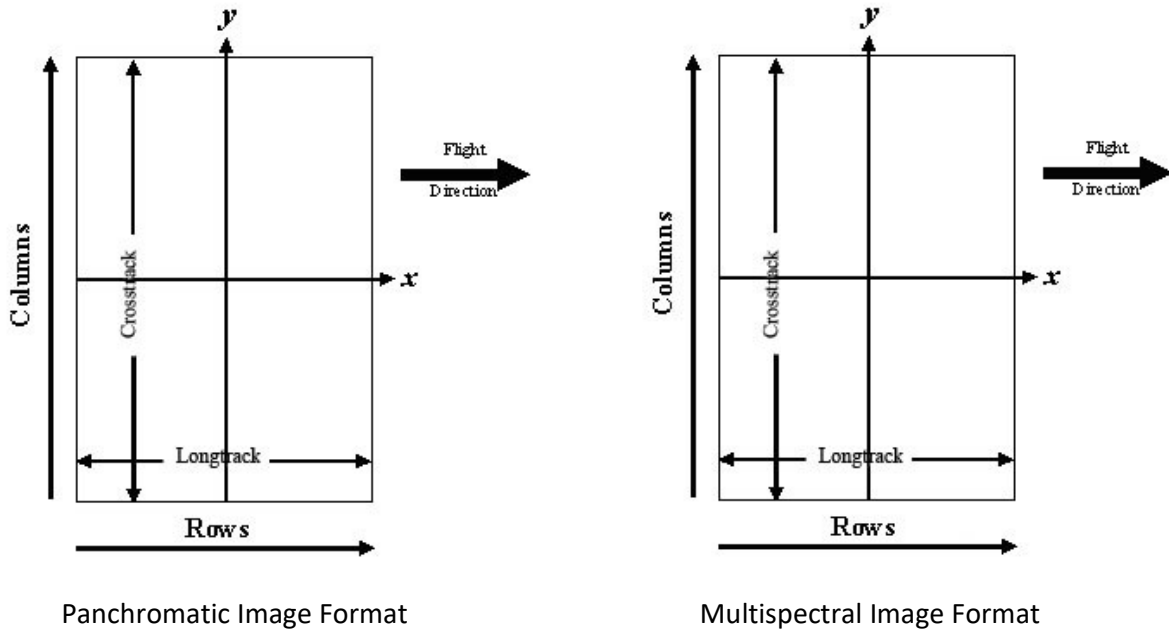
Lvl2, Camera prop. Orientation



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)



Position of Principal Point in Level 3 Image

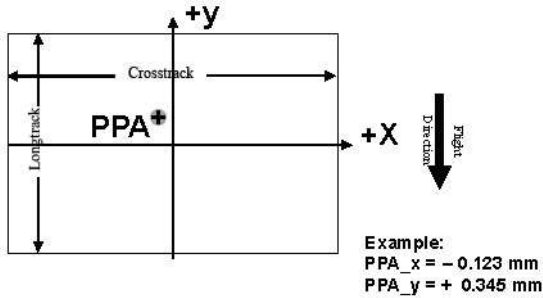
The position of the principal point in the level 3 image depends on the “rotation” setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified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

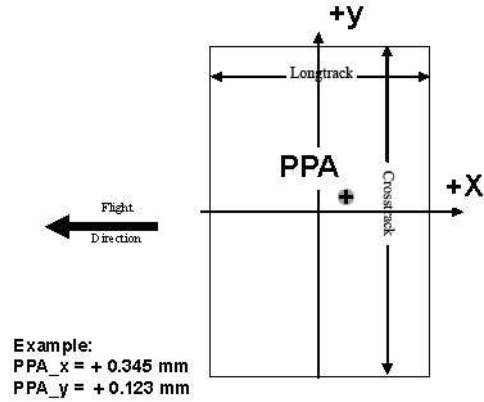


The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

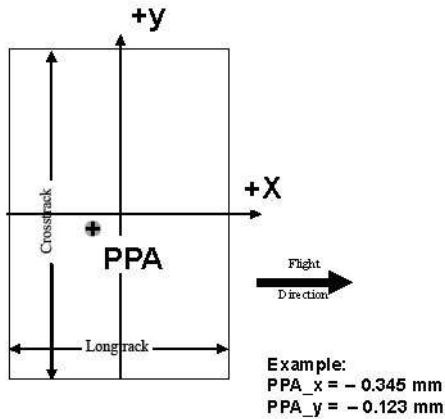
Lvl3, Rotation 0 deg clockwise



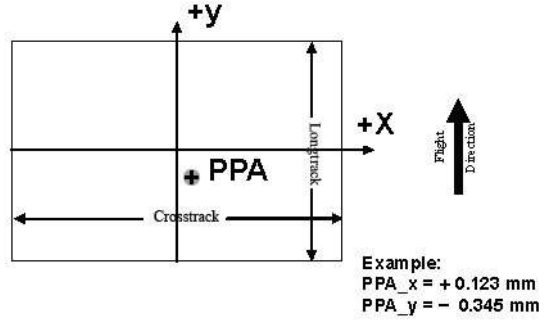
Lvl3, Rotation 90 deg clockwise



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.

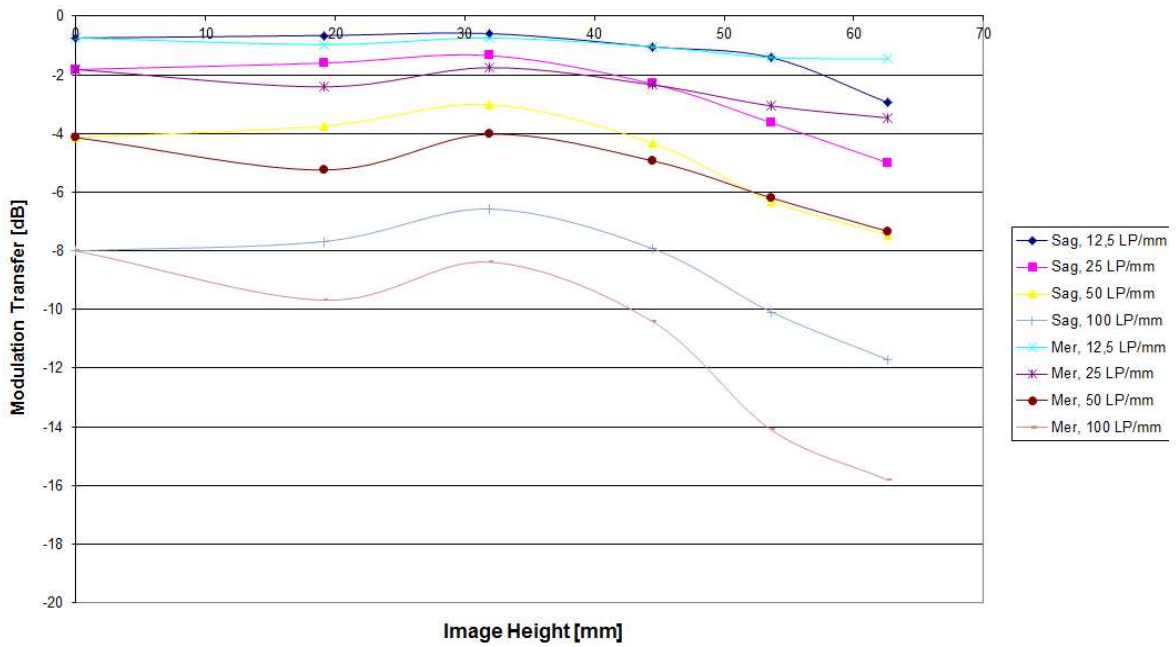
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

Lens types

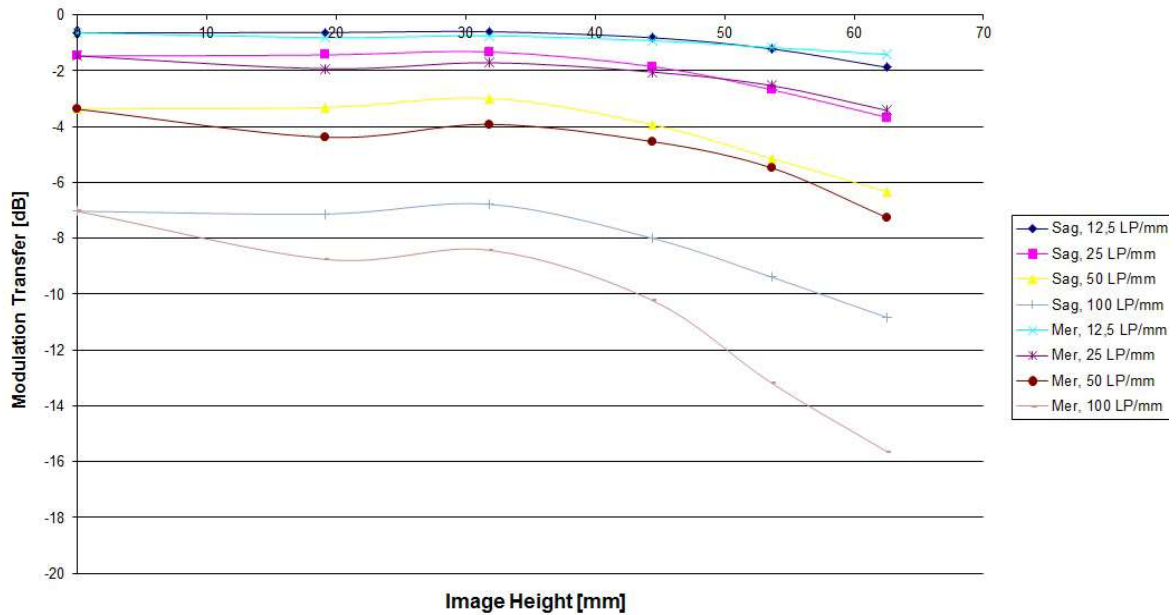
Cone	Lens
C0	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C1	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C2	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C3	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C4 (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

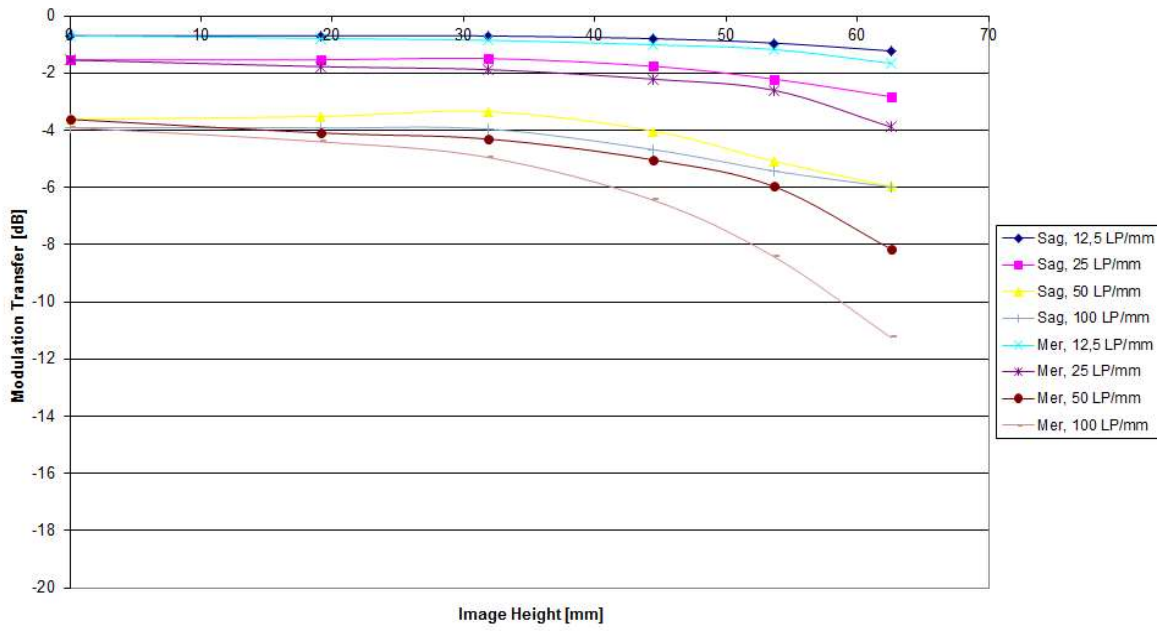


Modulation versus Image Height - Aperture f / 6.7

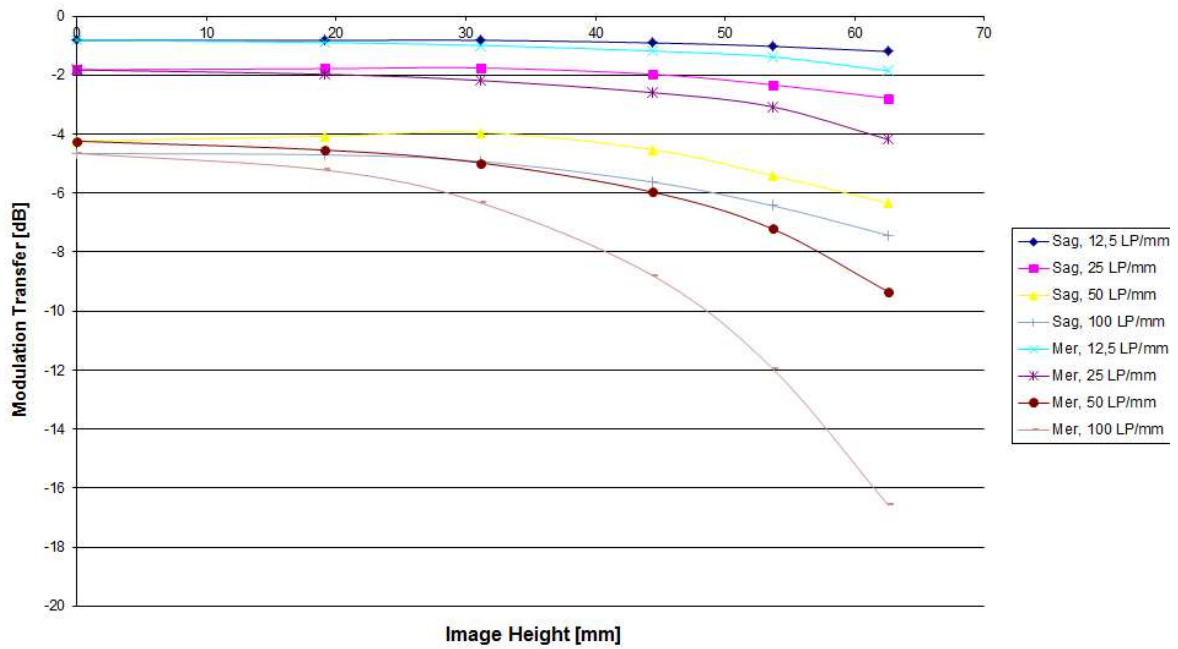




Modulation versus Image Height - Aperture f / 8



Modulation versus Image Height - Aperture f / 9.5



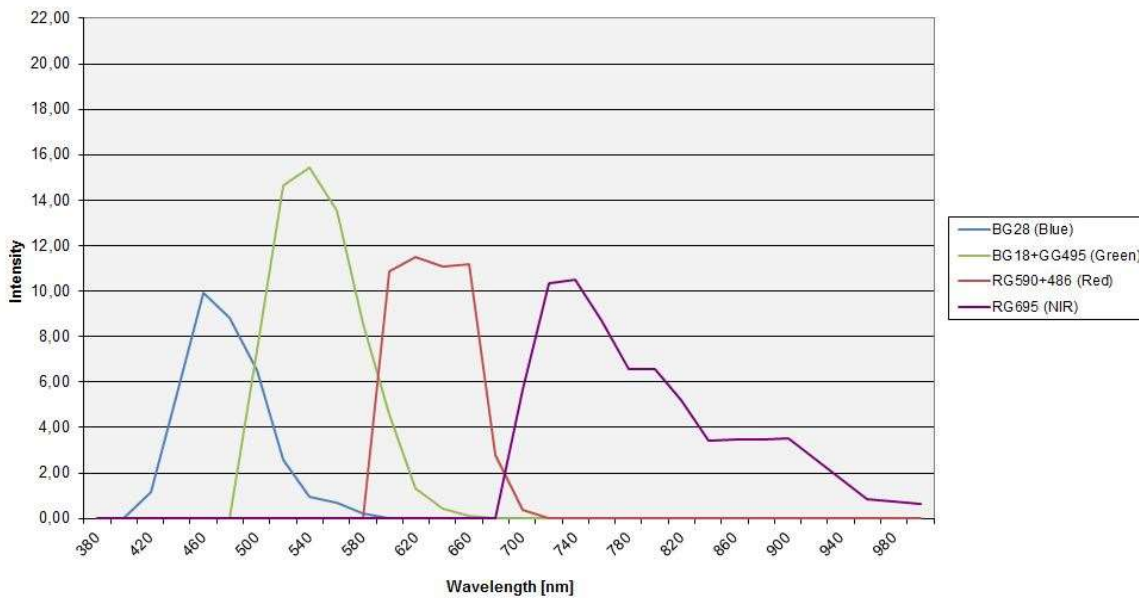


Spectral Sensitivity

Spectral Sensitivity Vexcel UCX - Panchromatic with AR-106 Coating



Spektral Sensitivity Vexcel UCX - Multispectral with AR-106 Coating





ULTRACAM

Radiometric Calibration

Camera: UltraCam Falcon Prime
Serial: UC-Fp-1-50616147-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

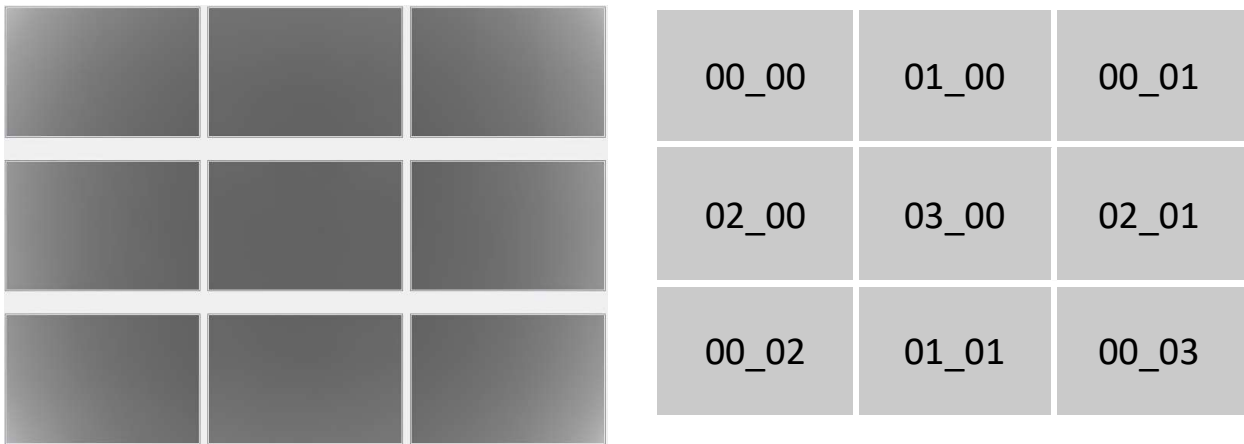
Dead Pixel Report: see Appendix I



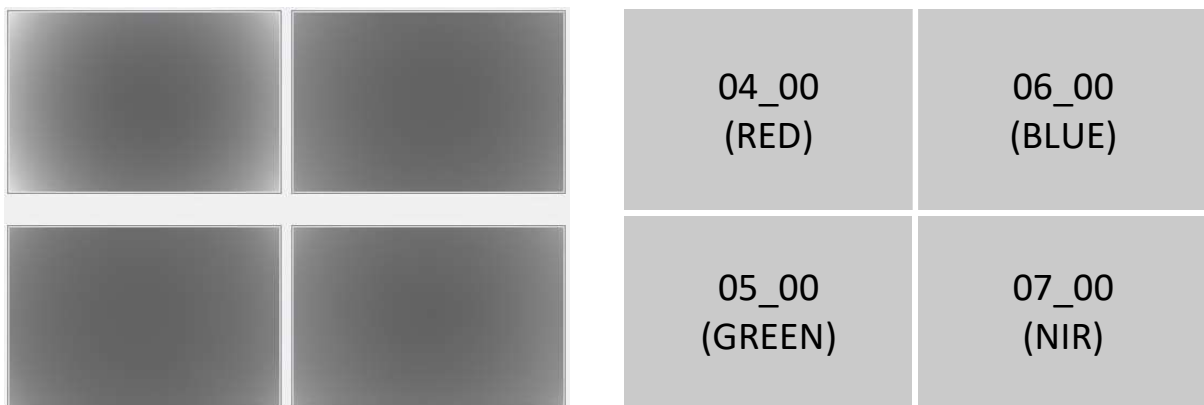
Calibration of Vignetting for working Aperture F6.7

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

Graphical Overview of Pan Sensors:



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 Falcon Prime
Serial: UC-Fp-1-50616147-f100

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

Multispectral Camera: 4 * Prontor Magnetic 0
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 27 19 05	7.34	7.45	7.43	7.59	7.79	8.01	8.17	8.31	+/- 0.2
C1 (Pan)	12 27 19 06	6.61	6.73	6.82	7.07	7.30	7.45	7.61	7.63	+/- 0.2
C2 (Pan)	12 23 55 11	6.76	6.95	7.06	7.29	7.53	7.72	7.88	8.02	+/- 0.2
C3 (Pan)	12 23 55 07	6.65	6.70	6.90	7.14	7.22	7.38	7.47	7.60	+/- 0.2
C4 (Red)	12 23 11 66	7.36	7.42	7.60	7.80	8.01	8.10	8.17	8.21	+/- 0.2
C5 (Green)	12 24 50 24	7.29	7.45	7.53	7.90	8.01	8.15	8.18	8.18	+/- 0.2
C6 (Blue)	12 24 50 23	7.32	7.34	7.34	7.41	7.59	7.77	7.85	7.98	+/- 0.2
C7 (NIR)	12 23 11 83	8.09	8.28	8.45	8.45	8.66	8.72	9.00	8.47	+/- 0.2



ULTRACAM

Electronics and Sensor Calibration

Camera: UltraCam Falcon Prime
Serial: UC-Fp-1-50616147-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 7701/020	22.50
00_01	FTF6040-M	15 7701/015	22.50
00_02	FTF6040-M	15 7701/032	22.50
00_03	FTF6040-M	15 5293/112	22.50
01_00	FTF6040-M	15 7701/026	22.50
01_01	FTF6040-M	15 5293/068	22.50
02_00	FTF6040-M	15 7701/019	22.60
02_01	FTF6040-M	15 5293/087	22.00
03_00	FTF6040-M	15 7701/022	22.50
04_00 (red)	FTF6040-M	15 7701/024	22.30
05_00 (green)	FTF6040-M	15 5293/110	22.30
06_00 (blue)	FTF6040-M	15 7701/021	22.50
07_00 (NIR)	FTF6040-M	15 7701/048	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 7701/020	13650
00_01	FTF6040-M	15 7701/015	13790
00_02	FTF6040-M	15 7701/032	13830
00_03	FTF6040-M	15 5293/112	13570
01_00	FTF6040-M	15 7701/026	13800
01_01	FTF6040-M	15 5293/068	12720
02_00	FTF6040-M	15 7701/019	13450
02_01	FTF6040-M	15 5293/087	12850
03_00	FTF6040-M	15 7701/022	13760
04_00 (red)	FTF6040-M	15 7701/024	13330
05_00 (green)	FTF6040-M	15 5293/110	12930
06_00 (blue)	FTF6040-M	15 7701/021	14170
07_00 (NIR)	FTF6040-M	15 7701/048	13170



ULTRACAM

Summary

Camera:	UltraCam Falcon Prime
Serial:	UC-Fp-1-50616147-f100
Laboratory Calibration Date:	Mar-19-2021
Camera Revision:	Rev03.00
Date of Report:	Mar-24-2021
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
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C00-00

- PIXEL: 876/ 157
- PIXEL: 2141/3156
- PIXEL: 2226/2723
- PIXEL: 4782/ 305
- PIXEL: 4994/3003
- PIXEL: 5031/3148
- PIXEL: 1591/1463
- PIXEL: 4284/2314
- PIXEL: 4284/2315
- PIXEL: 4285/2314
- PIXEL: 4285/2315

C00-01

- PIXEL: 1225/1171
- PIXEL: 4599/ 194
- PIXEL: 4767/2638
- PIXEL: 329/3832
- PIXEL: 4740/3299

C00-02

- PIXEL: 536/2665
- PIXEL: 1831/ 347
- PIXEL: 2023/ 918

C00-03

- PIXEL: 1481/1299
- PIXEL: 1573/ 693
- PIXEL: 2220/1157
- PIXEL: 2590/2777
- PIXEL: 3897/2455
- PIXEL: 4367/2129
- PIXEL: 4583/3933
- PIXEL: 5110/3668



PIXEL: 5442/3371
PIXEL: 4727/1453
PIXEL: 4728/1453
PIXEL: 4943/1444
PIXEL: 5104/1430
PIXEL: 5108/1367
PIXEL: 5108/1368
PIXEL: 5120/1370
PIXEL: 5129/1364
PIXEL: 5134/1371
PIXEL: 5142/1365
PIXEL: 5145/1365
PIXEL: 5155/1363
PIXEL: 5163/1372
PIXEL: 5165/1366
PIXEL: 5193/1369
PIXEL: 5193/1378
PIXEL: 5261/ 429
PIXEL: 5275/1391
PIXEL: 5309/1399
PIXEL: 5378/1401
PIXEL: 5379/1401
PIXEL: 5413/1402
PIXEL: 5436/1381
PIXEL: 5482/1380
PIXEL: 5484/1380

C01-00

PIXEL: 465/1062
PIXEL: 1039/ 571

C01-01

PIXEL: 274/1597
PIXEL: 1375/ 468
PIXEL: 2054/3729
PIXEL: 3974/3534

C02-00

C02-01

PIXEL: 1057/2557
PIXEL: 3629/2184
PIXEL: 3898/2091
PIXEL: 4054/3350
PIXEL: 4521/3138
PIXEL: 4521/3139
PIXEL: 4859/1920
PIXEL: 5555/2250



C03-00

C04-00

PIXEL: 2093/1984
PIXEL: 3222/3816
PIXEL: 4874/1687
PIXEL: 250/3937
PIXEL: 1674/1192
PIXEL: 2979/ 904

C05-00

PIXEL: 3466/ 973
PIXEL: 3789/3972
PIXEL: 5244/1842
PIXEL: 188/2186
PIXEL: 833/3640

C06-00

PIXEL: 119/ 863
PIXEL: 119/ 864
PIXEL: 119/ 865
PIXEL: 120/ 866
PIXEL: 1433/ 911
PIXEL: 2542/3173
PIXEL: 2543/3173

C07-00

PIXEL: 1509/2840
PIXEL: 1934/1643
PIXEL: 2839/ 48
PIXEL: 5970/3828



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	24.Mar.2021	N/A	
Radiometric Calibration	24.Mar.2021	N/A	
Shutter Calibration	24.Mar.2021	N/A	
Electronics and Sensor Calibration	24.Mar.2021	N/A	

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.