Arpentage
Gestion de projets agricoles
Glissements de terrain
Projets miniers Erosion des sols
Infrastructures routières et pipeline
Zones à risque d'inondations
Complexe hydro-électrique
Études environnementales
Réseaux de lignes électriques
Foresterie et gestion forestière
Imagerie de plan d'urbanisme

The Jacques Cartier and Champlain Bridges Incorporated

Restoration of the Nuns' Island Bridge
Project Number: 20006

TECHNICAL REPORT
Minute No. 163
February 20, 2013

NOTICE – Free Translation

The preparation and authentication of the original report, written in French, is the product of a professional act. The document translated from French to English must not be considered authentic and consequently, in case of contradiction or divergence between the French and English versions, the French version prevails.

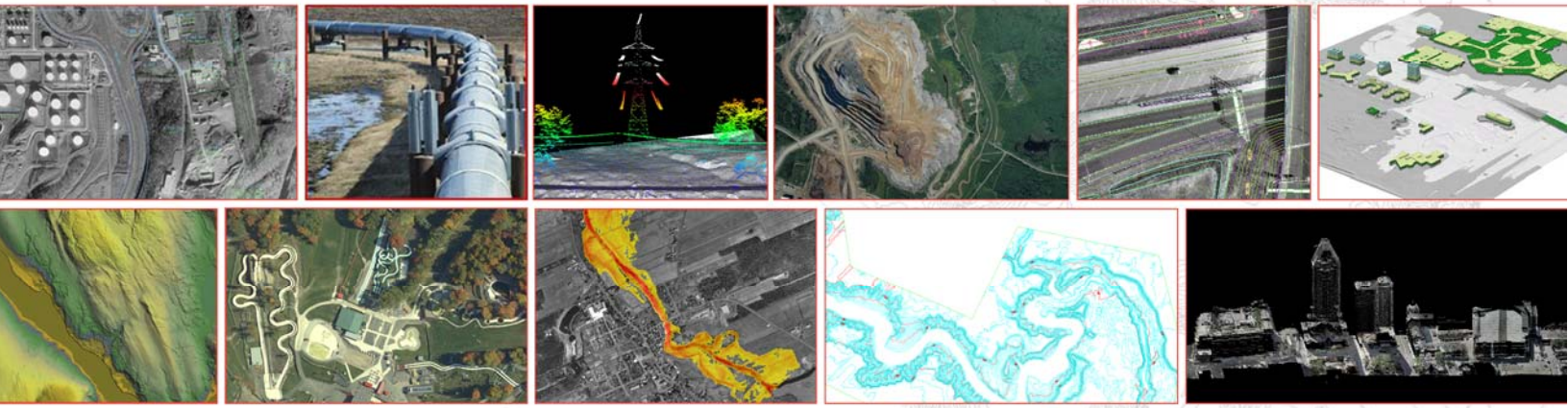

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TABLE OF CONTENTS

PROJECT GOALS **3**
LOCATION **3**
CLIENT **3**
OPERATIONAL CONTEXT **3**
ON-SITE WORK 3
OFFICE WORK 3
DIGITAL PHOTOGRAMMETRIC SURVEYS **4**
AIRCRAFT 4
AERIAL CAMERA 4
FLIGHT PARAMETERS (MAIN PROJECT) 4
FLIGHT PARAMETERS (RIPARIAN STRIPS) 5
GPS BASE STATION 5
GEODESY 5
PERIODS 5
SOFTWARE 5
GPS SURVEYS **6**
INSTRUMENTS 6
OBSERVATION TYPES 6
PERIODS 6
ELEMENTS OBSERVED 6
GEODESY 6
CLOSURES 6
CONVENTIONAL SURVEYS **7**
PURPOSE 7
INSTRUMENTS 7
PERIODS 7
ELEMENTS OBSERVED 7
GEODESY 7
SOFTWARE 7
CLOSURES 7
LEVELLING **8**
PURPOSE 8
INSTRUMENTS 8
PERIODS 8
GEODESY 8
CLOSURES 8
PHOTOGRAMMETRY **9**
IMAGES 9

AEROTRIANGULATION 9
PHOTOGRAMMETRIC DATA ACQUISITION 11
ORTHOPHOTOMOSAIC (CORRECTION AND MOSAIC) 11

CARTOGRAPHY 12
CONTOUR LINES 12
EDITING 12
LAYOUTS 12
MODELING FILE (ASCII) 12

REPORT AND DELIVERABLES 13
DIGITAL DELIVERABLES (EXTERNAL HARD DRIVE) 13

REFERENCE SYSTEM 14
PROJECTION 14
HORIZONTAL DATUM 14
VERTICAL DATUM 14

TECHNICAL SPECIFICATIONS 15
MICROSOFT VEXCEL ULTACAM D DIGITAL CAMERA 15

CALIBRATION REPORT 17
VEXCEL ULTRACAM D, S/N UCD-SU-2-0027 REVISION 13 17

APPENDIX 01 32
PROJECT BOUNDARIES 32

APPENDIX 02 34
STRUCTURES STUDIED DURING THE SITE SURVEYS 34
STRUCTURES STUDIED DURING THE SITE SURVEYS 35

PROJECT GOALS

Photogrammetric and field surveys for the restoration of the Nuns' Island Bridge

LOCATION

Montreal (Verdun sector) and Nuns' Island

(see Appendix 01)

CLIENT

Contact	Andy Woo
Title	Project Engineer, Engineering
Company	The Jacques Cartier and Champlain Bridges Incorporated

OPERATIONAL CONTEXT

ON-SITE WORK

Digital photogrammetric surveys

GPS surveys

Conventional surveys

Levelling

OFFICE WORK

Photogrammetry (aerotriangulation, photogrammetric data acquisition, orthophotomosaic)

Cartography (editing, digital terrain modeling)

Report and deliverables

DIGITAL PHOTOGRAMMETRIC SURVEYS

AIRCRAFT

Piper Navajo, registration C-GOVX
(Les Levés AéroScan Inc)

AERIAL CAMERA

Model	Vexcel UltraCAM D No. 027
Focal Length	101.4 mm
PAN sensor pixel size	9 microns
Pixel size on RGBI sensors	28.125 microns
PAN sensor size	11,500 pixels x 7,500 pixels
RGBI sensor size	2,400 pixels x 3,680 pixels
Calibration report	February 2012 (version 13)
	See appended technical specifications

FLIGHT PARAMETERS (MAIN PROJECT)

Scale	1:3350
Flying height	340 m
Acquisition bands	red, green, blue, infrared, panchromatic
Ground image size	350 m x 230 m
Ground resolution	3 cm
Lateral overlap	30%
Forward overlap	60%
Flight line spacing	245 m
Spacing between images	100 m
Number of images	154 images

FLIGHT PARAMETERS (RIPARIAN STRIPS)

Scale	1:5520
Flying height	560 m
Acquisition Bands	red, green, blue, infrared, panchromatic
Ground image size	350 m x 230 m
Ground resolution	5 cm
Lateral overlap	30%
Forward overlap	60%
Flight line spacing	400 m
Spacing between images	150 m
Number of images	41 images

GPS BASE STATION

Permanent GPS base

GEODESY

MRNF permanent GPS base

Montreal (97K0240)

The official coordinates of the permanent GPS bases are issued by the ministère des Ressources Naturelles et de la Faune du Québec geodetic service

PERIODS

Session 321-1, November 16, 2012, from 11:46 a.m. to 12:34 p.m. (local time)

SOFTWARE

Trimble POSPac (flight path calculations)

Vexcel UltraMap (digital image processing)

GPS SURVEYS

INSTRUMENTS

Trimble R8 GPS receivers with cellular connected to Can-Net

OBSERVATION TYPES

RTK connected to Can-Net

PERIODS

November 2 to December 4, 2012

ELEMENTS OBSERVED

Photogrammetric controls (multiple observations)

Base Stations for future works (conventional surveys)

GEODESY

26KM001

62KM014

86KMF01

86KMF15

86KMF16

86KMF18

86KMF20

94KM016

CLOSURES

The closures obtained are used to confirm that the GPS surveys meet the standards in the Quebec ministry of transport's *Manuel d'Arpentage et de Géomatique*

CONVENTIONAL SURVEYS

PURPOSE

Complementary surveys under certain identified structures (see Appendix 02)

INSTRUMENTS

Trimble S3 Total Station

PERIODS

December 11 to 14, 2012

ELEMENTS OBSERVED

Clearance below the structure

Piers

Abutments

Roadway

Jersey barriers, guardrails

Manholes, storm sewers

Etc.

GEODESY

Placement of points during GPS surveys, in proximity to the structures identified

SOFTWARE

AutoCAD Cadarp

CLOSURES

The closures obtained are used to confirm that the conventional surveys meet the standards in the Quebec ministry of transport's *Manuel d'Arpentage et de Géomatique* du Ministère des Transports du Québec

LEVELLING

PURPOSE

Levelling of relevant photogrammetric controls

INSTRUMENTS

Topcon digital level

PERIODS

November 23 to 28, 2012

GEODESY

Benchmarks

47L2630
62KM014
86KMF01
86KMF15
86KMF20
86KMF30
94KM016

The official coordinates of the survey markers are issued by the ministère des Ressources Naturelles et de la Faune du Québec geodetic service

CLOSURES

The closures obtained are used to confirm that levelling meets the standards in the Quebec ministry of transport's *Manuel d'Arpentage et de Géomatique*

PHOTOGRAMMETRY

IMAGES

Digital aerial images for this contract

AEROTRIANGULATION

PHOTOGRAMMETRIC CONTROLS

number	73 three-dimensional, well distributed in the photogrammetric area
Type	Post-photography physical details
	Pre-photography ground markers
Sources	PHB

PERSPECTIVE CENTRES

Position-fixed (X, Y, Z) and attitude-fixed (Omega, Phi, Kappa) perspective centres based on kinematic trajectory data (GPS and inertial)

TIE POINTS

Generated manually

DEVICE

Digital station (two screens, polarized lenses, set of handwheels and footdisks)

SOFTWARE

Leica Photogrammetric Suite (LPS) with Orima and Cap-A modules

RESULTS (MAIN PROJECT)

Sigma naught: 3.5 microns

Root mean square of perspective centres

RMS-X = 0.061 m

RMS-Y = 0.044 m

RMS-Z = 0.031 m

RMS-Omega = 0.0065 degrees

RMS-Phi = 0.0070 degrees

RMS-Kappa = 0.0064 degrees

Root mean square of photogrammetic controls

RMS-X = 0.0209 m

RMS-Y = 0.0174 m

RMS-Z = 0.0095 m

Results meet Ministère des Ressources Naturelles et de la Faune (MRNF) standards at a scale of 1:2000 (ground resolution of 3 cm)

For further result details, consult the project aerotriangulation report

RESULTS (RIPARIAN STRIPS)

Sigma naught: 2.7 microns

Root mean squre of perspective centres

RMS-X = 0.054 m

RMS-Y = 0.062 m

RMS-Z = 0.069 m

RMS-Omega = 0.0067 degrees

RMS-Phi = 0.0052 degrees

RMS-Kappa = 0.0059 degrees

Root mean square of photogrammetic controls

RMS-X = 0.0171 m

RMS-Y = 0.0147 m

RMS-Z = 0.0143 m

Results meet Ministère des Ressources Naturelles et de la Faune (MRNF) standards at a scale of 1:4000 (ground resolution of 5 cm)

For further result details, consult the project aerotriangulation report

PHOTOGRAMMETRIC DATA ACQUISITION

STANDARDS

Guide de captage de données topographiques, Ministère des Transports du Québec

EQUIPMENT

Digital station (two screens, polarized lenses, set of handwheels and footdisks)

SOFTWARE

Leica Photogrammetric Suite (LPS) with Pro600 module

ORTHOPHOTOMOSAIC (CORRECTION AND MOSAIC)

SURFACE

Photogrammetric data acquisition (pavement edges, marker lines, ditches, rivers, changes in slope, spot elevations, etc.)

SECTIONING

Tiles (1,000 m by 1,000 m)

RESOLUTION

4 cm

SOFTWARE

Inpho with OrthoMaster, OrthoVista and OrthoVista Seam Editor modules

CARTOGRAPHY

CONTOUR LINES

MAJOR CONTOURS	2 metres
MINOR CONTOURS	0.5 metres

EDITING

STANDARDS

Genivar technical specifications

Guide de captage de données topographiques, Ministère des Transports du Québec

SOFTWARE

Bentley MicroStation V8 with internally developed modules

AutoDesk AutoCAD

LAYOUTS

No layouts are required for this project.

MODELING FILE (ASCII)

STANDARDS

Guide de captage de données topographiques, Ministère des Transports du Québec

SECTIONING

None

SOFTWARE

Bentley MicroStation V8 with modules developed in-house

REPORT AND DELIVERABLES

DIGITAL DELIVERABLES (EXTERNAL HARD DRIVE)

ON-SITE WORK

Digital photogrammetric surveys

Aerial camera calibration report (Adobe Acrobat)

Aerial photo index (AutoCAD)

OFFICE WORK

Photogrammetry

Sketches of the photogrammetric controls (Microsoft Word)

Coordinates of the photogrammetric controls (Text)

Original uncompressed 3-cm 8-bit RGB digital images (TIFF)

Original uncompressed 5-cm 8-bit RGB digital images (TIFF)

3-cm aerial triangulaton report (Text)

5-cm aerial triangulaton report (Text)

External orientation parameters after 3-cm aerotriangulation (Text)

External orientation parameters after 5-cm aerotriangulation (Text)

4-cm orthophotomosaic sectioned into tiles (GeoTIFF, TIFF World and ECW)

1 km by 1 km tile index (AutoCAD)

Photogrammetric controls index (AutoCAD)

Cartography

Project boundaries (AutoCAD)

2D and 3D hypsometry (AutoCAD)

2D and 3D cartography (AutoCAD)

Modellng file (ASCII)

2D structure surveys (AutoCAD)

REFERENCE SYSTEM

PROJECTION	Modified Transverse Mercator (MTM), zone 8
HORIZONTAL DATUM	NAD83(CSRS)
VERTICAL DATUM	CGVD28 (MSL)

See the French version of the report for signed original

PIERRE BÉLANGER, Land Surveyor., M.Sc.
Vice-President

Perron | Hudon |Bélanger
85 Grande-Côte Road
Boisbriand, Quebec, J7G 1C4
T 1.450.430.9266
F 1.450.437.2923
www.groupphb.com
www.lasermap.com

TECHNICAL SPECIFICATIONS

Microsoft Vexcel UltaCAM D digital camera

ULTRACAM*D*

LARGE FORMAT DIGITAL AERIAL CAMERA

Image Product Specification

Image format	Analogous to an aerial film image at a format of 23 cm x 15 cm
Image content when compared to aerial film	superior to film scanned at 15 mm pixel size
Image data formats	TIFF, JPEG, Tiled TIFF
Digital Camera Technical Data (Sensor Unit SU)	
Panchromatic image size	11500 * 7500 pixels
Panchromatic physical pixel size	9 µm
Physical format of the focal plane	103.5 mm * 67.5 mm
Panchromatic lens focal distance (Alternative exchangeable lenses)	100 mm (75 mm, 125 mm)
Lens aperture	f= 1/5.6
Angle-of-view from vertical, cross track (along track)	55° (37°)
Color (multi-spectral capability)	4 channels -- RGB & NIR
Color image size	4008 * 2672 pixels
Color physical pixel size	9 µm
Color lens system focal distance	28 mm
Color lens aperture	f = 1/4.0
Color field of view from vertical, cross track (along track)	65° (46°)
Shutter speed options	1/500 to 1/60
Forward-motion compensation (FMC)	TDI controlled
Maximum FMC-capability	50 pixels
Smallest pixels on the ground at flying height of 500 m (at 300m)	5 cm (3cm)
Frame rate per second (minimum inter-image interval)	1.3 frames (0.75 seconds)
Analog-to-digital conversion at	14 bits
Radiometric resolution in each color channel	>12 bit
Physical dimensions of the camera unit	45 cm x 45 cm x 60 cm
Weight	< 30 kg
Power consumption at full performance	150 W

Controller, Data Storage and Processing Unit (SCU)

In-flight storage capacity	> 1 TB
Capacity to collect in-flight uncompressed frames	> 1850
Storage and computing configuration	Parallel arrangement with multiple CPUs and disks
Redundancy	Dual disks containing mirror images of the data
Data transfer into office environment	Removable, dual use as office post-processor
Physical dimensions	40 cm x 55 cm x 65 cm
Weight	< 35 kg
Power consumption at full performance	700 W

Power Supply (optional)

Set of PB-gel Storage Batteries	24 V / 70 Ah
Operating Time, stand by (full operation at max. frame rate)	10 h (1.5 h)
Physical dimensions	45 cm x 30 cm x 50 cm
Weight	2 x 35 kg

Operational Specification

Maximum collection period at 70% forward overlap, at 20 cm GSD (film scale 1:10,000)	~ 6 hours
Post-processing of collected raw image streams	Overnight on SCU
Data transfer from aircraft to office	By mobile server or by physical transfer of 35 kg SCU
Post-processing system	Accomplished inside the SCU, or at office PC network
Mounting of the camera	In current film camera mounts
Flight planning support	Compatible with IGI's CCNS and similar systems
Exterior orientation support	Compatible with IGI's Aero-Control, Applanix' Pos and similar systems
Image geometric accuracy	< ± 2 mm

Vexcel Imaging Austria, Münzgrabenstr. 11, A-8010 Graz, Austria; Tel. (+43) (316) 849 0660, Fax (+43) 316) 849 0669; www.vexcel.co.at, email: camera@vexcel.co.at
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CALIBRATION REPORT

VEXCEL UltraCam D, S/N UCD-SU-2-0027
Revision 13

UltraCam D, Serial Number UCD-SU-2-0027

Calibration Report

Short Version

Camera:	**UltraCam D, S/N UCD-SU-2-0027**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Date of Calibration:	**Feb-28-2012**
Date of Report:	**Feb-29-2012**
Camera Revision:	**13.0**
Revision of Report:	**13.0**

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UltraCam D, Serial Number UCD-SU-2-0027

Calibration Report

Geometric Calibration

Camera:	**UltraCam D, S/N UCD-SU-2-0027**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Panchromatic Camera:	**ck = 101.400mm**
Multispectral Camera:	**ck = 101.400mm**
Date of Calibration:	**Feb-28-2012**
Date of Report:	**Feb-29-2012**
Camera Revision:	**13.0**
Revision of Report:	**13.0**

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UltraCam D, Serial Number UCD-SU-2-0027

Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track	67.5mm	7500 pixel
	cross track	103.5mm	11500 pixel
Image Extent		(-33.75, -51.75)mm	(33.75, 51.75)mm
Pixel Size		9.000µm*9.000µm	
Focal Length	ck	101.400mm	± 0.002mm
Principal Point	X_ppa	-0.270 mm	± 0.002mm
(Level 2)	Y_ppa	0.270 mm	± 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	67.5mm	2400 pixel
	cross track	103.5mm	3680 pixel
Image Extent		(-33.75, -51.75)mm	(33.75, 51.75)mm
Pixel Size		28.125µm*28.125µm	
Focal Length	ck	101.400mm	
Principal Point	X_ppa	-0.270 mm	± 0.002mm
(Level 2)	Y_ppa	0.270 mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

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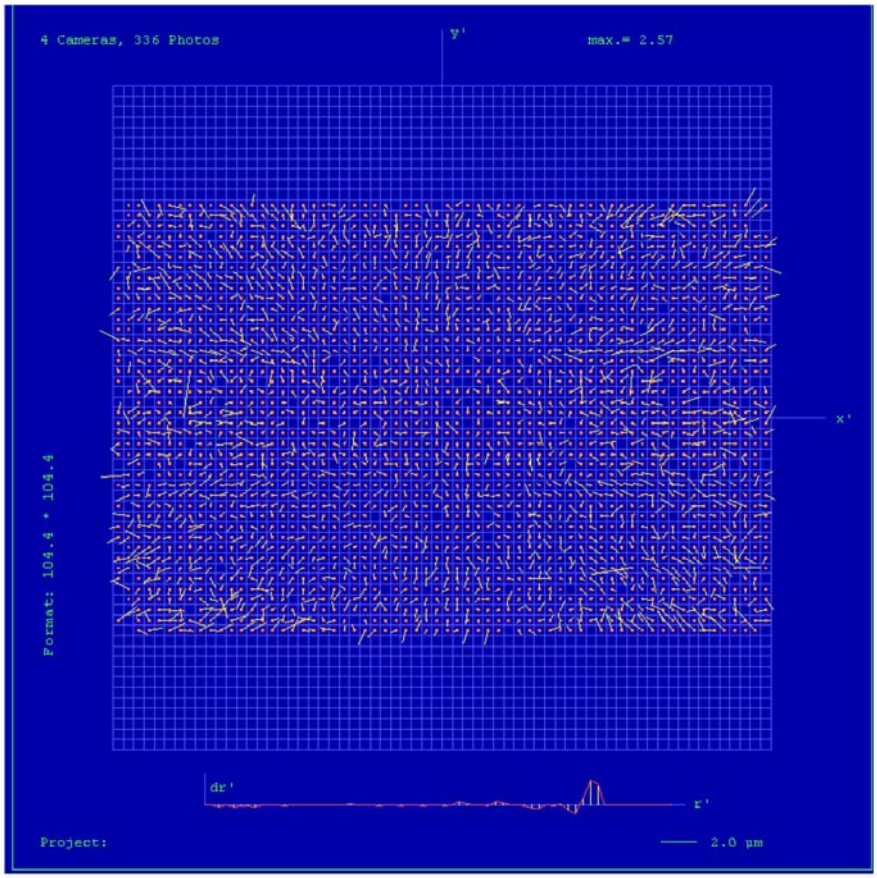
Full Pan Image, Residual Error Diagram



Residual Error (RMS): 0.60 µm

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UltraCam D, Serial Number UCD-SU-2-0027

Explanations:

1) Calibration Method:

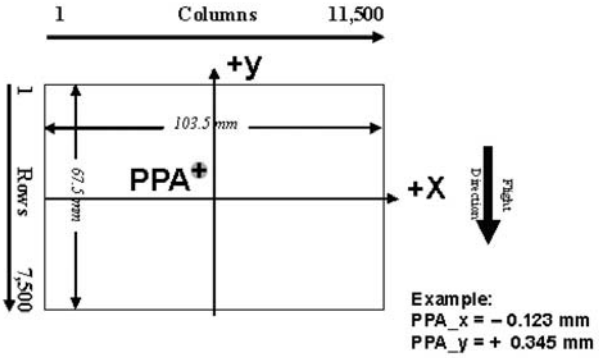
The geometric calibration is based on a set of 84 images of a defined geometry target with 240 GCPs.

Number of point measurements for the panchromatic camera :	16757
Number of point measurements for the multispectral camera :	67794

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

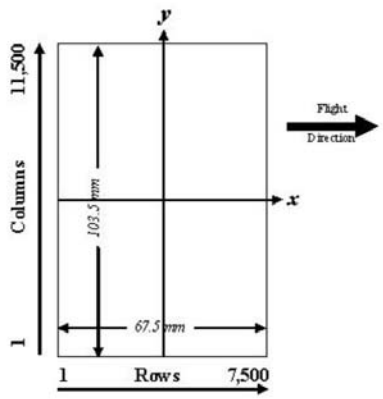
2) Level 2 Image Coordinate System:	pan	11500 pixel by 7500 pixel
	MS	3680 pixel by 2400 pixel

Lvl2, Camera prop. Orientation

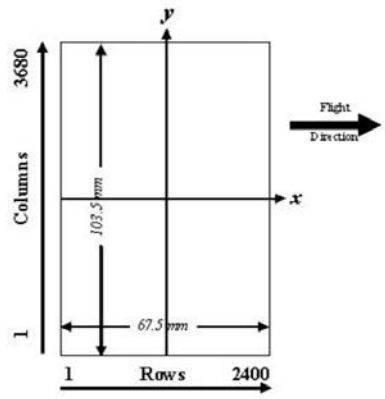


The image coordinate system of the Level 2 images is shown in the above figure. The level 2 image consists of 11500 columns and 7500 rows, which leads to a total image format of 103.5 * 67.5 mm. The coordinate of the principal point in the level 2 image is given on page 3 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).

3) Level 3 Image Coordinate System: pan 7500 pixel by 11500 pixel
(after rotation of 270° CW) MS 2400 pixel by 3680 pixel



Panchromatic Image Format



Multispectral Image Format

==========

4) 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 the OPC 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 the OPC. The coordinates are specified for clockwise (CW) rotation in steps of 90 degrees, according to the principal point coordinate given on page 3 for high- and low resolution images.

Image Format	Clockwise Rotation (Degree)	PPA	
		X	Y
Level 2	-	-0.270	0.270
Level 3	0	-0.270	0.270
Level 3	90	0.270	0.270
Level 3	180	0.270	-0.270
Level 3	270	-0.270	-0.270

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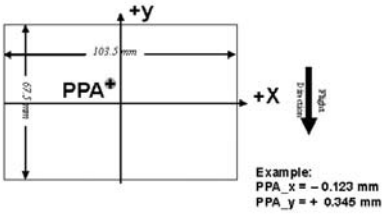
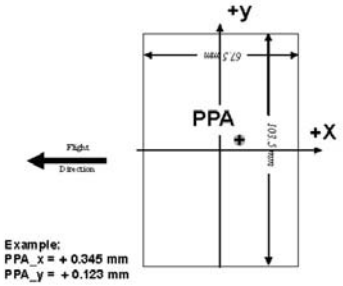
UltraCam D, Serial Number UCD-SU-2-0027

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.

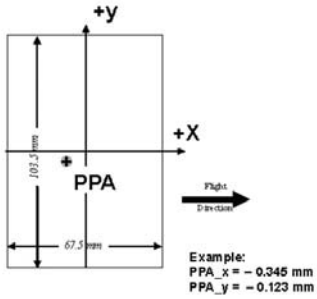
Lvl3, Rotation 0 deg clockwise



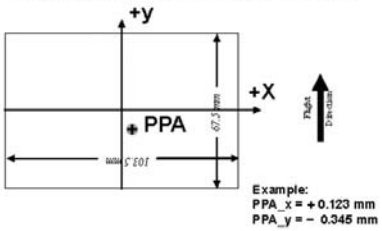
Lvl3, Rotation 90 deg clockwise



Lvl3, Rotation 270 deg clockwise



Lvl3, Rotation 180 deg clockwise

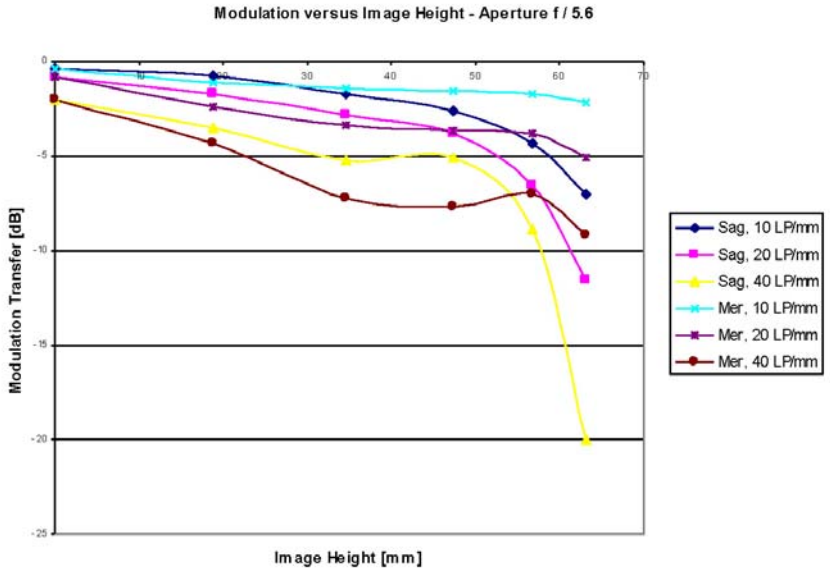


Lens Resolving Power

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 meridonial (tangential) and sagital (radial) component of signals at frequencies of 10, 20 and 40 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.



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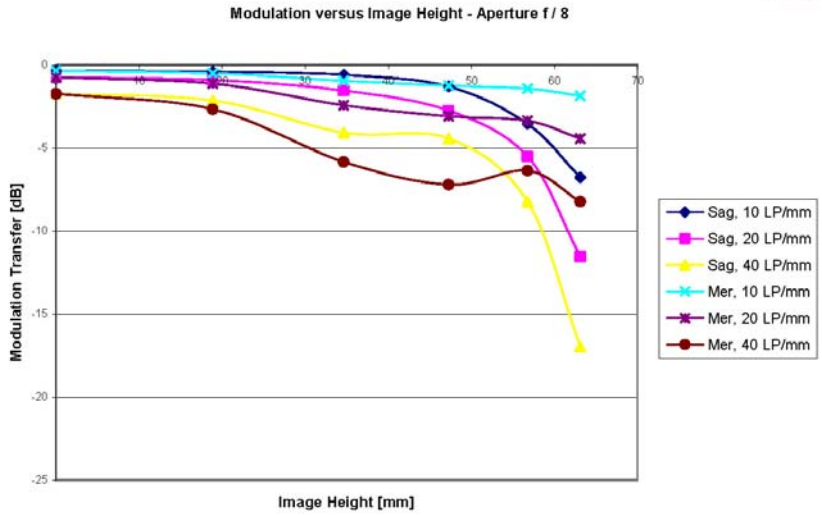

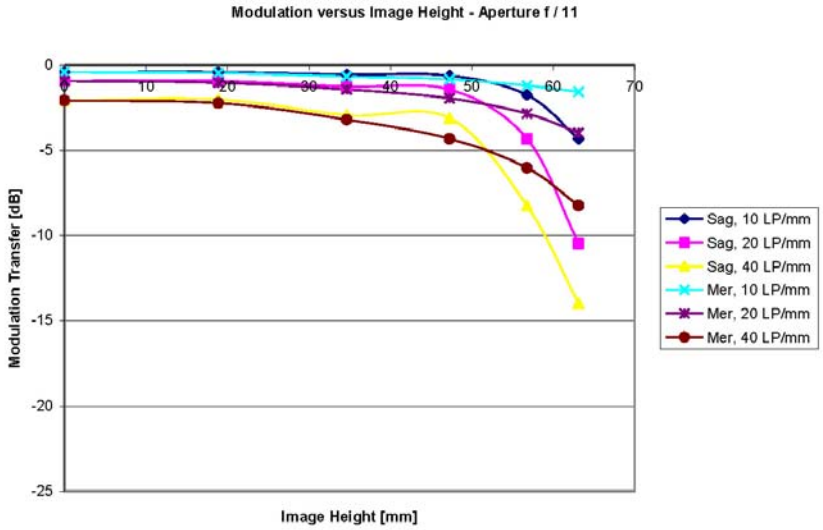

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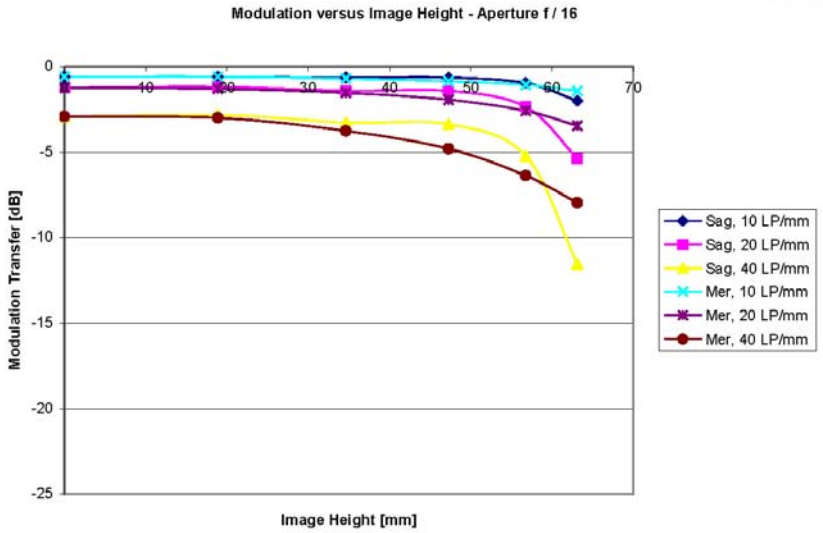
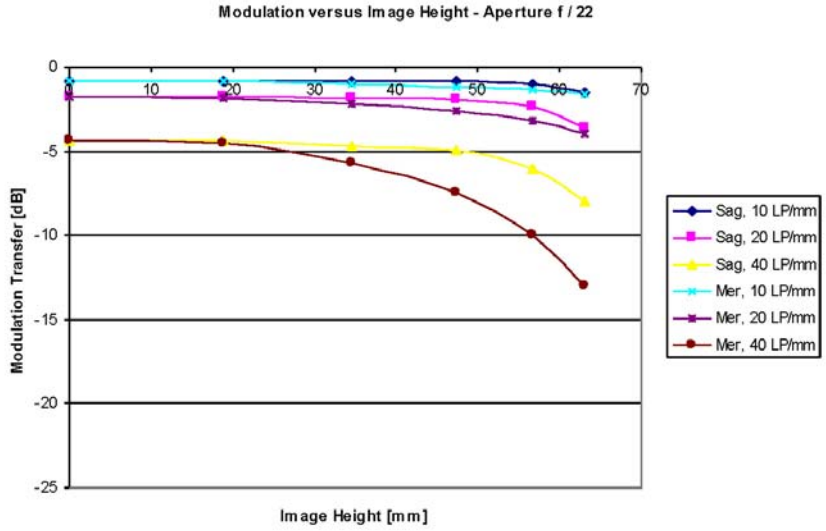
UltraCam D, Serial Number UCD-SU-2-0027





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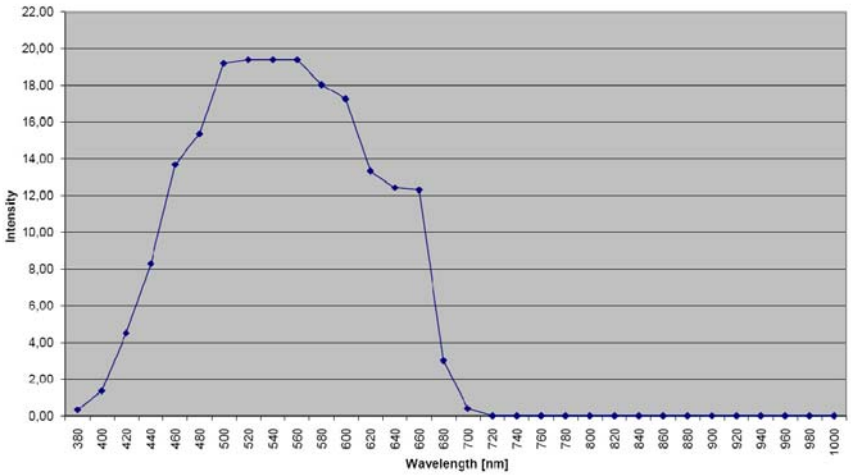
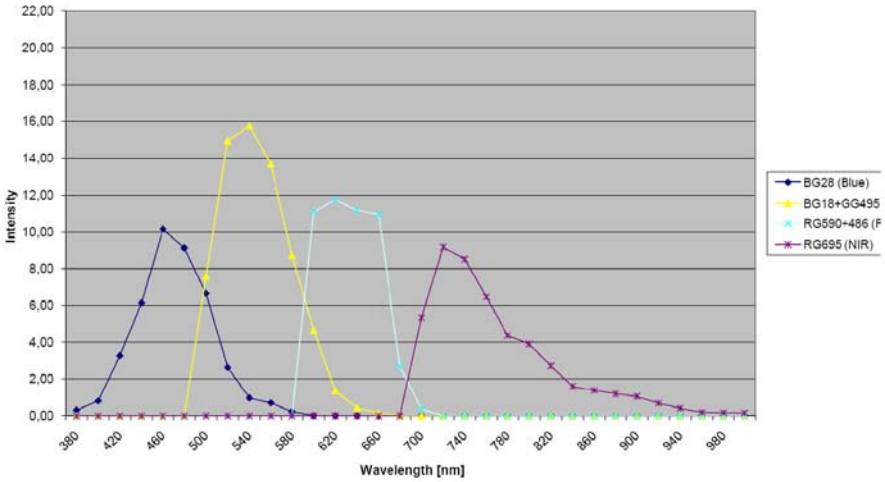
UltraCam D, Serial Number UCD-SU-2-0027

Spectral Sensitivity

Spectral Sensitivity Vexcel UCD - Panchromatic
with AR-103 Coating



Spektral Sensitivity Vexcel UCD - Multispectral
with AR-103 Coating



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UltraCam D, Serial Number UCD-SU-2-0027

Calibration Report

Radiometric Calibration

Camera:	**UltraCam D, S/N UCD-SU-2-0027**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Panchromatic Camera:	**Apertures: f/5.6, f/8, f/11, f/16, f/22 (All Pan)**
Multispectral Camera:	**Apertures: f/4, f/5.6, f/8, f/11, f/16 (Red, Green)** **f/2.8, f/4, f/5.6, f/8, f/11 (Blue, NIR)**

Date of Calibration:	**Feb-28-2012**
Date of Report:	**Feb-29-2012**
Camera Revision:	**13.0**
Revision of Report:	**13.0**

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UltraCam D, Serial Number UCD-SU-2-0027

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 two 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.

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UltraCam D, Serial Number UCD-SU-2-0027

Calibration Report

Summary

Camera:	**UltraCam D, S/N UCD-SU-2-0027**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Date of Calibration:	**Feb-28-2012**
Date of Report:	**Feb-29-2012**
Camera Revision:	**13.0**
Revision of Report:	**13.0**

The following calibrations have been performed for the above mentioned digital aerial mapping camera:

- Geometric Calibration
- Verification of Lens Quality and Sensor Adjustment
- Radiometric Calibration
- Calibration of Defective Pixel Elements
- 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

Ing. Peter Prassl
Senior Calibration Engineer
Vexcel Imaging GmbH

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APPENDIX 01

Project Boundaries

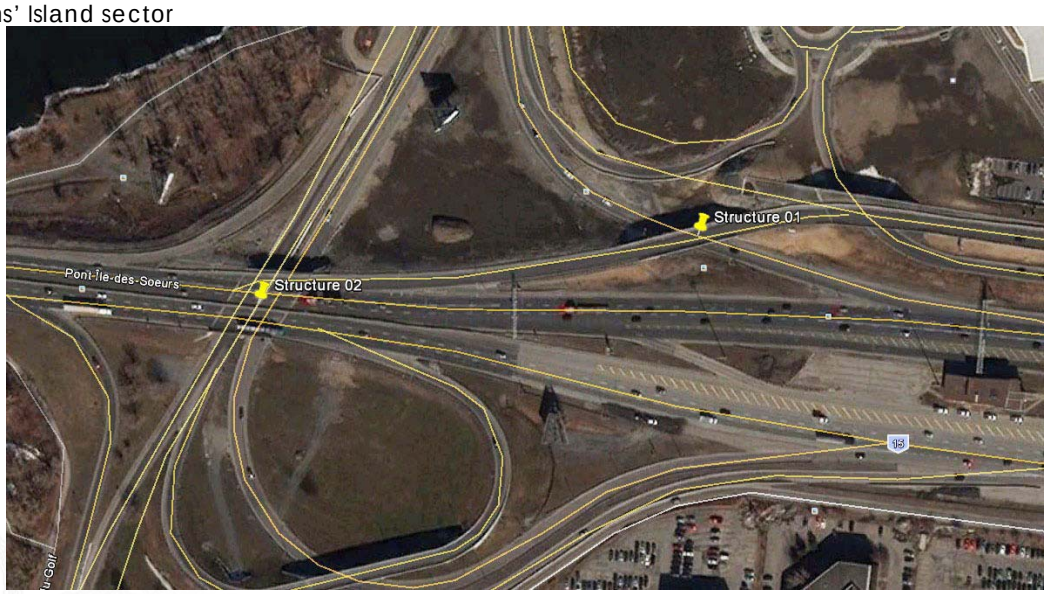
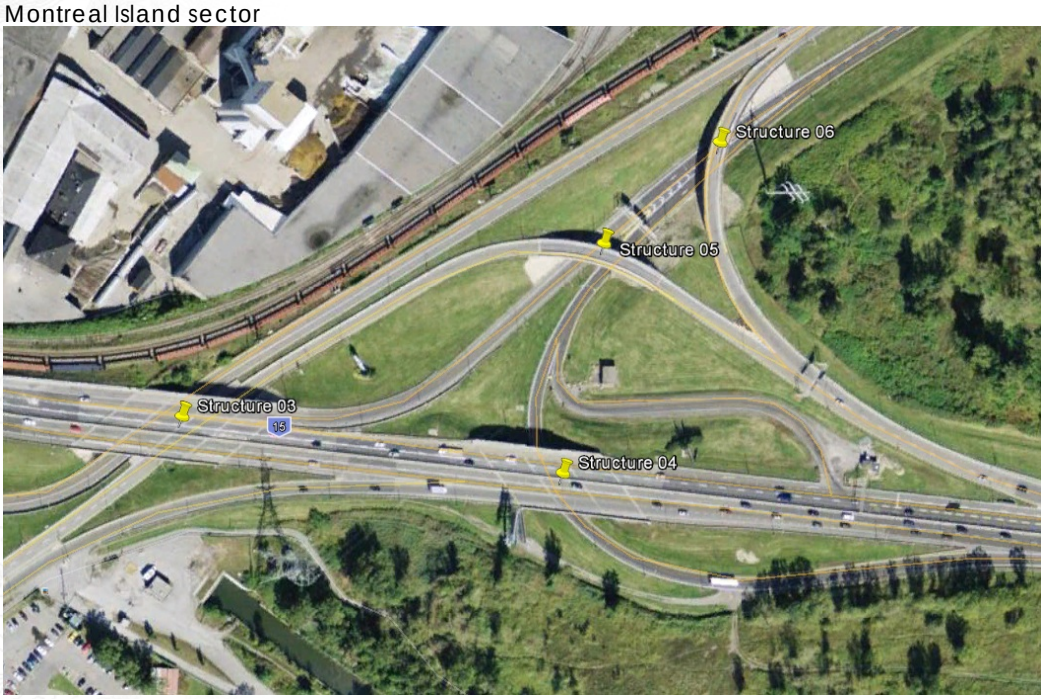
Project Boundaries

APPENDIX 02

Structures Studied During the Site Surveys

Structures Studied During the Site Surveys

Nuns' Island sector



Montreal Island sector