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USGS QUALITY ASSURANCE PLAN FOR DIGITAL AERIAL IMAGERY

DIGITAL AERIAL SENSOR TYPE CERTIFICATION

Certification Report for the Microsoft Vexcel UltraCamD, UltraCamX, UltraCamXp, and UltraCamXp WA Models

DRAFT

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DIGITAL AERIAL SENSOR CERTIFICATION REPORT FOR THE

Microsoft Vexcel UltraCamD, UltraCamX, UltraCamXp, and UltraCamXp WA Models

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1 Executive Summary

The USGS Aerial Sensor Certification Team visited Microsoft Vexcel[1] (hereafter referred to as *Vexcel*), in Graz, Austria from September 6th through 8th, 2006. The purpose of the visit was to certify the Vexcel UltraCamD aerial camera system after discussing and verifying Vexcel's answers to USGS questions contained in the Manufacturer Certification document[2] provided to Vexcel prior to the visit. This visit and certification process was conducted under a Technical Assistance Agreement, TAA#: T-06-344, dated 12 Jan 2006 , between Microsoft Vexcel and the USGS. This TAA was initially established to undertake USGS Certification of the Vexcel UltraCamD aerial camera system and but was later expanded in scope to cover the UltraCamX series camera systems. Throughout this document, the information pertaining to the UltraCamD also applies to the UltraCamX series systems unless a difference is called out.

The Vexcel UltraCamD is a multi-lens aerial mapping system comprised of thirteen sensor arrays within eight separate optical "cones". The system produces a panchromatic image and a four band multispectral (blue, green, red, and near-infrared) images covering the same ground area as the panchromatic image. The multispectral imagery is pan-sharpened by a factor of three to produce an image that has the same resolution as the panchromatic image.

The UltraCamD systems were designed and built by Vexcel. Key components are produced and assembled by certified suppliers under contract to Vexcel. Final assembly and integration of each UltraCamD system is accomplished at Vexcel in Graz, Austria where the systems are calibrated and tested before delivery to the customer. This procedure has not changed for the UltraCamX family of systems.

The USGS Manufacturer Sensor Certification Team (hereafter referred to as the *Team)* has found the Vexcel UltraCamD System to be designed, manufactured, tested, and supported to the level required to reliably meet the performance claims[3] of the manufacturer when operated within manufacturer's intended operational parameters. These systems, when operated properly by a conscientious and technically qualified operator, are capable of meeting the accuracy claims given by Vexcel for digital aerial data.

[1] Vexcel is officially *Microsoft Vexcel Imaging GmbH*, Anzengrubergasse 8/4, 8010 Graz, Austria. The certification visit for the UltraCam D was at the old Vexcel facility at Münzgrabenstrasse 11, 8010 Graz, Austria. Throughout the document, the names *Vexcel*, *Microsoft*, and *Microsoft Vexcel* may be used to describe the same company, the designers and manufacturers of the *UltraCam* series of digital aerial sensors.

[2] Questions contained in Draft version 5 of Manufacturer Certification. Document can be viewed at: http://calval.cr.usgs.gov/documents/ManufacturerCertificationChecklist05.doc

[3] As given in *UltraCamD Technical Specifications* given in file: *UCD-specifications-May2003.pdfl* See Appendix B

The USGS agreed with Microsoft Vexcel to evaluate three additional camera models which were minor upgrades of the UltraCamD. The USGS determined that those specific upgrades did not require a second facility visit and were acceptable. The UltraCamX was evaluated and deemed certified on July 1, 2008. On April 26, 2010 both the UltraCamXp and the UltraCamXp WA (Wide Angle) were also certified.

2 Purpose and Report Organization

The purpose of this certification report is to provide a summary of the information acquired about the UltraCam family of sensor systems throughout the certification process. The report includes the design and capabilities of the UltraCam systems and documents the findings of the Team. Proprietary information has not been included in this report. Inquiries for technical information beyond what is in this report should be made directly to the point of contact (POC) for the manufacturer, Dr. Michael Gruber at +43 316 84 90 66 918. Any inquiries about the contents of this report should be directed to the USGS POC, Mr. Greg Stensaas at 605-594-2569.

The remainder of this document consists of the following sections.

Section 3: Facility Visit - provides an overview of the trip to Vexcel.

Section 4: System Design, Intended Use, and Expected Accuracy - provides the system description and design overview, intended photogrammetric use, and the expected accuracy of the system.

Section 5: Documentation - provides a synopsis of the documentation acquired by the USGS for the certification process.

Section 6: USGS Findings - documents the findings of the USGS Certification team.

Appendix A: Technical Specifications - provides the generic technical specifications for the UltraCamD, UltraCamX, UltraCamXp, and UltraCamXp WA systems.

3 Facility Visit

The Team arrived at Münzgrabenstrasse facility of Vexcel in Graz, Austria on September 6th, 2006, to begin three days of discussions and facility tours with the staff from Vexcel. The on-site manufacturing facilities were toured in order to inspect where the critical elements of the Vexcel UltraCamD systems are built, assembled, and tested. Also inspected was the on-site laboratory where the systems are calibrated. On September 7th a visit was made to Völkermarkt,

Austria, to observe the WILD factory[4], a principal supplier to Vexcel of UltraCamD components.

The Team consisted of:

Gregory Stensaas, USGS EROS Remote Sensing Technologies Project Chief
Jon Christopherson, SAIC, contractor to the USGS EROS
Dr. George Lee, USGS, Menlo Park, California
Donald Moe, SAIC, contractor to the USGS EROS
Dr. Robert Ryan, SSAI, contractor to NASA Stennis Space Flight Center

Vexcel Imaging staff members who presented material and answered USGS questions included:

Markus Bacher
Stefan Bernögger
Andreas Drumbl
Dr. Michael Gruber
Michael Kröpfl
Gertraud Leberl
Martin Ponticelli

For the subsequent evaluation of UltraCamX family of sensors in 2010, Mr. Michael Benson, USGS/RST Deputy Project Manager, was added to the Team.

[4] WILD Austria GmbH, Wildstrasse 4, A 9100 Völkermarkt, Austria

4 System Design, Intended Use and Expected Accuracy

This section provides a summary of the Vexcel design and system calibration for the family of UltraCam systems, a description of the intended use of the systems, and the accuracy that can be expected from the systems. The UltraCam camera family is the large format digital aerial mapping camera product series of Vexcel, all with the camera sensor head based on Vexcel's multi cone design concept. This concept was initially presented in 2003 together with the introduction of the UltraCamD camera system.

4.1 Basic Design

The basic design concept behind UltraCam cameras is a sensor head consisting of eight independent camera cones, four of them contributing to the large format panchromatic image and four contributing to the multi-spectral image (See Figure 1). The sensor head of the UltraCam is equipped with 13 CCD sensor arrays, manufactured by DALSA Corp. (the FTF 4027M at 9 µm pixel size for UltraCamD, the FTF 5033M at 7.2 µm pixel size for UltraCamX, and FTF 6040M at 6 µm pixel size for both the UltraCamXp and Xp WA). All of these sensors provide a radiometric bandwidth of more than 12 bits.

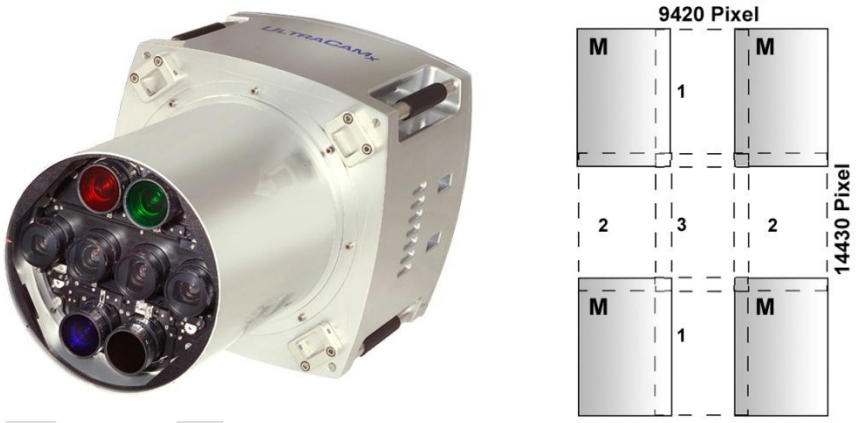


Figure 1: The UltraCam Sensor Unit and the concept of the four cones contributing to the large format panchromatic image.

The transition from 9 µm pixel size to the 7.2 µm CCD sensors (UltraCamD to UltraCamX) resulted in a redesign of the optical system from Schneider Kreuznack to LINOS/Rodenstock which is now able to resolve 70 lp/mm of the CCD pixel grid of the 7.2 µm pitch as well as the 80 lp/mm of the 6 µm pixel grid for the UltraCamXp. These three UltraCam systems have lenses with a focal length of 100 mm for the panchromatic cones and 33 mm for the multi-spectral cones. This set of two lenses supports the pan sharpening ratio of 1:3. The

UltraCamXp WA also uses LINOS/Rodenstock lenses but with focal lengths of 70 mm and 23 mm for the pan and multi-spectral bands respectively. This also supports the pan sharpening ratio of 1:3.

The panchromatic sensor head of the UltraCam large format camera series has four individual camera heads (i.e., camera cones). These cones have a specific mechanical distance from the camera center which needs to be compensated for during exposure in order to produce a consistent virtual image. This process is unique for the UltraCam digital aerial cameras and is known as “syntopic exposure”. It exploits the movement of the aircraft in such way that the shutters of the cones are delayed so they don’t open at the same time (synchronic) but at the same position (syntopic).

4.2 Radiometric Properties

The radiometric bandwidth of the UltraCam is based on the dynamic range of the CCD sensor arrays (> 12 bit or >72 dB). The analog signal is converted into a digital signal by the 14 bit ADC and all of the image data are stored at a bandwidth of 16 bits.

The band separation of the UltraCam large format cameras is based on volume filters for the red, green and blue color channels. The four channels of visible light (pan, red, green and blue) are also equipped with Infrared cut off filters and the infrared channel is equipped with a 690nm IR Filter. The spectral signatures of the panchromatic, infrared, red, green, and blue are graphically shown in Figures 2a-d.

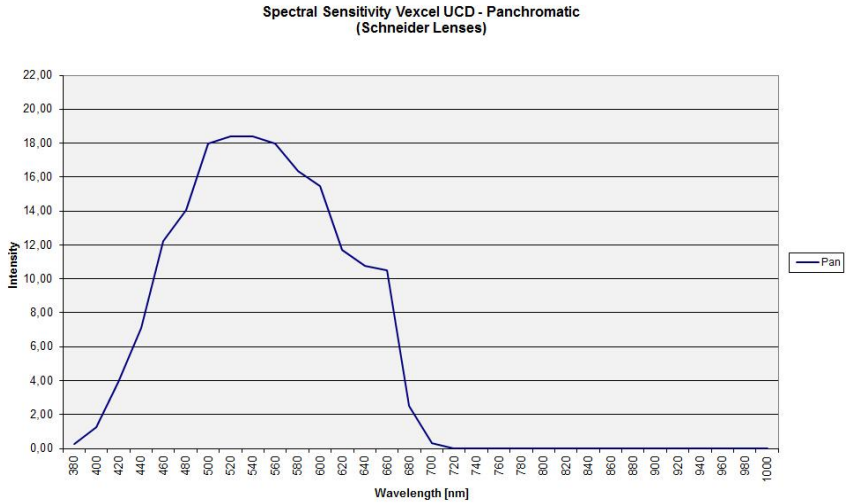


Figure 2a: UltraCam D Panchromatic Spectral Sensitivity

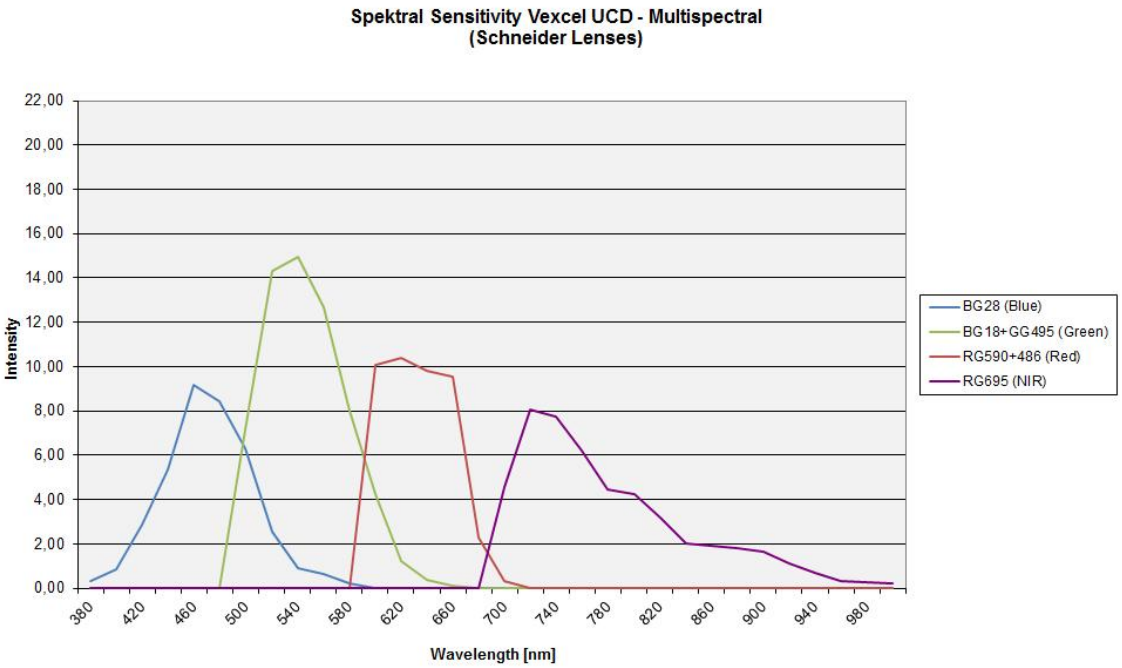


Figure 2b: UltraCam D 4-band Spectral Sensitivity

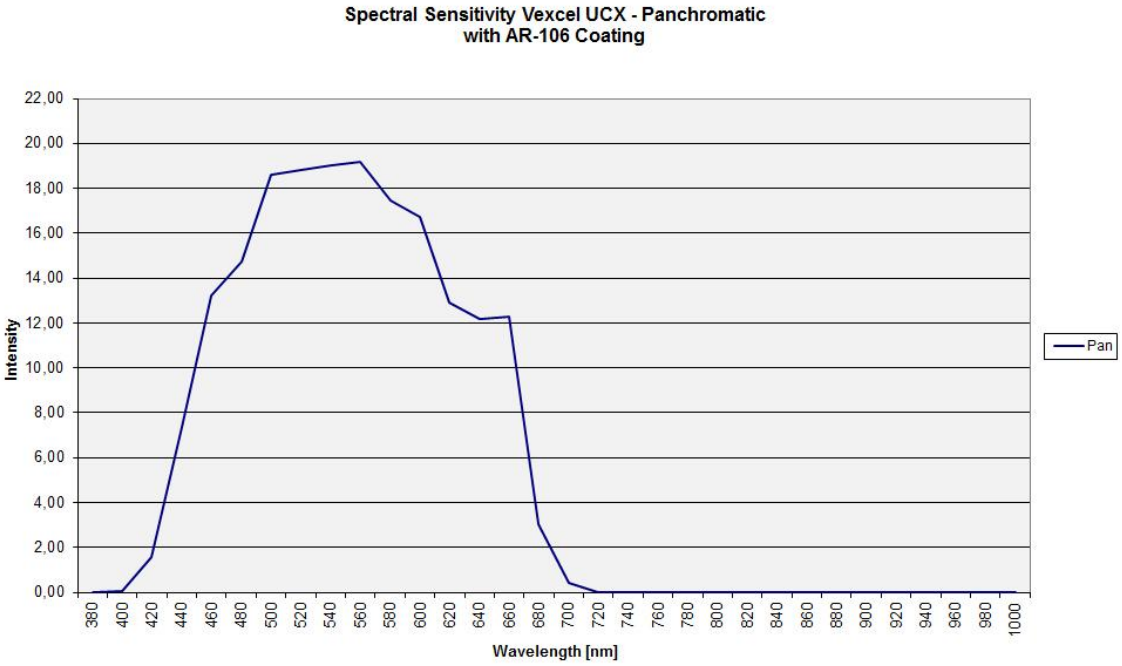


Figure 2c: UltraCam X Family Panchromatic Spectral Sensitivity

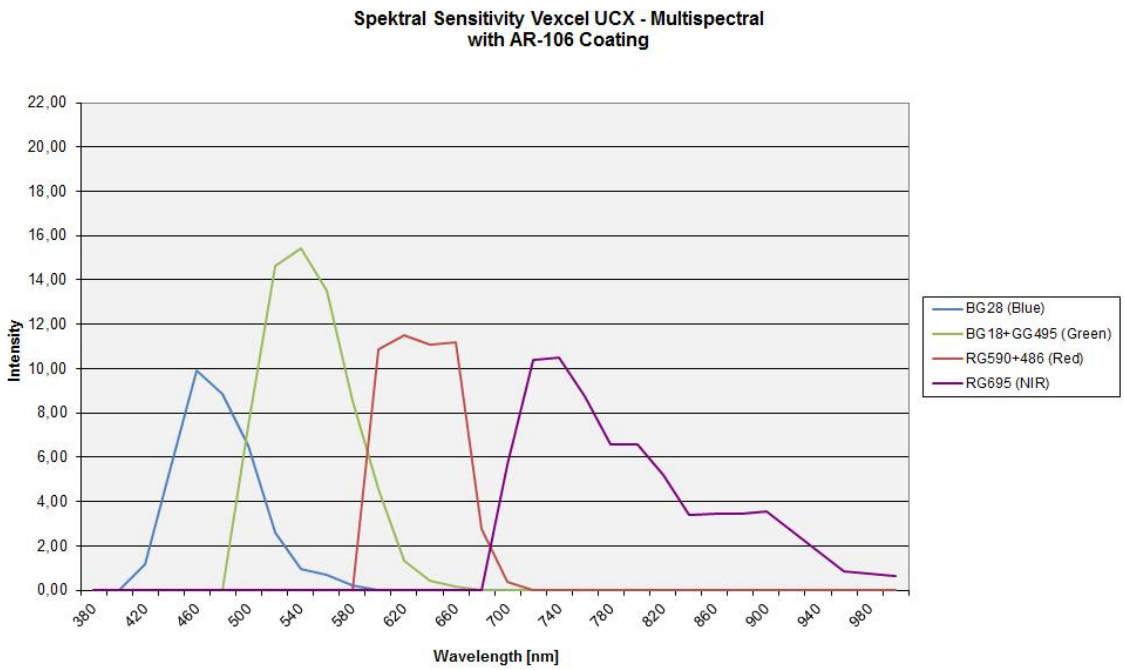


Figure 2d: UltraCam X Family 4-band Spectral Sensitivity

UltraCam image data are collected at a 12+ bit level (analog signal), converted to digital at a 14 bit level (14 bit ADC), and stored without compression at a 16 bit level (the so-called raw data). There is no compression performed from the Level-0 (raw) through the Level-2 (initial image, 16-bit, temporary TIF) processes. At Level-3 (final image, user-selected manipulations applied such as pan sharpening or number of bits/pixel) there is an option for the user to select JPEG compression or uncompressed TIF. Conversion to 8-bit from 16-bit data is accomplished using gradation curves.

4.3 Geometric Calibration

The routine calibration of the UltraCamD sensor head took place in the calibration laboratory at the Münzgrabenstrasse facility. The UltraCamX family is calibrated at the new Anzengrubergasse facility with a very similar, but expanded, calibration laboratory consisting of a three dimensional calibration target with 367 circular marks (See Figure 3). These marks are surveyed to an accuracy of about +/- 0.1 mm in X, Y and +/- 0.2 mm in Z and show a well defined circular pattern. The dimensional size of the entire structure is 8.4m by 2.5m at the rear wall and 2.4m in depth. Rear wall, ceiling and floor carry 70 metal bars with 280 marks; four additional vertical bars in the center of the structure carry 16 marks; 98 marks are mounted at the rear wall. The mean distance between marks is about 30cm.

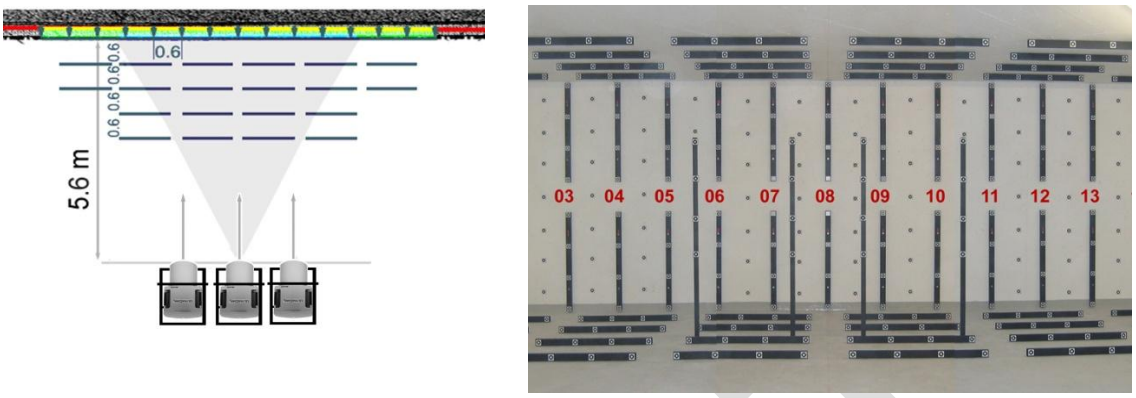
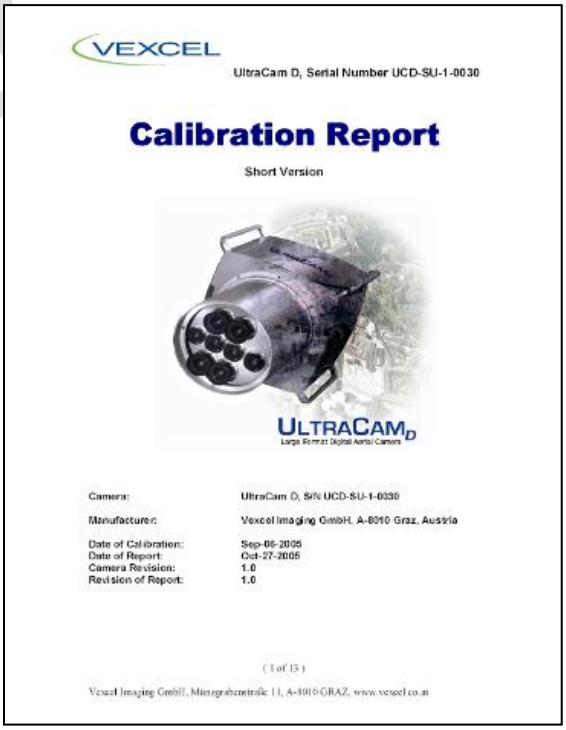


Figure 3: New Camera Calibration Laboratory

Layout of the Lab (left) and Photo of the 3D Targets (right)

The data capture of 84 images is taken from three different camera stations in such way that the camera is tilted and rotated. Software is used to compute sub-pixel accurate image positions of each mark in each image of the entire set of images. This results into a dense and complete coverage of coordinate measurements over the entire the image format. A single calibration dataset consists of almost 90,000 measured image points.

The unknown camera parameters are computed using the commercially available photogrammetric bundle adjustment called BINGO which was modified to accommodate the multi-cone design of the UltraCam sensor head. It was critical to have the ability to estimate the positions of the multiple CCD sensor arrays in the one virtual focal plane of a camera head.


VEXCEL

UltraCam D, Serial Number UCD-SU-1-0030

Calibration Report

Short Version

ULTRACAM$_D$

Large Format Digital Aerial Camera

Camera:	UltraCam D, S/N UCD-SU-1-0030
Manufacturer:	Vexcel Imaging GmbH, A-8010 Graz, Austria
Date of Calibration:	Sep-06-2005
Date of Report:	Oct-27-2005
Camera Revision:	1.0
Revision of Report:	1.0

(1 of 15)

Vexcel Imaging GmbH, Münzgrabenstraße 11, A-8010 GRAZ, www.vexcel.co.at

The radiometric calibration of the UltraCam sensor head is done by taking a set of images and then automatically processing these images in order to detect defective pixels, lens vignetting, and pixel based offset and gain values for each CCD sensor element. During the radiometric calibration the shutter response time is also measured and

stored for each individual shutter.

The result of the laboratory calibration is documented in the delivered camera calibration report. The calibration parameters relevant to the post processing of the imagery are stored in the camera calibration dataset.

4.4 Intended Use

According to Vexcel, the UltraCamD digital aerial cameras have been designed for any type of aerial monoscopic or stereoscopic photogrammetric application. It can support high and low altitude missions while collecting four-band multispectral (red, green, blue, and infra red) and panchromatic imagery simultaneously. Additionally, the UltraCamX and UltraCamXp provide successively higher resolution data over the same ground coverage as the UltraCamD, or provide greater ground coverage at the same ground resolution, by utilizing higher density sensor chips. The UltraCamXp WA utilizes the same sensor chip as the UltraCamXp but has a shorter focal length lens which produces either a higher resolution image or provides greater ground coverage.

For large scale mapping, the fast cycle rates and the special exposure concept of syntopic exposure control allows the system to collect down to a ground pixel size of 3 cm or 1.2 inches. The inclusion of large capacity high density disks (HDDs) for on-board storage also directly supports large scale activities. For medium and small scale mapping, flight altitudes up to 15,000 feet in non-pressurized aircraft are supported since the HDDs are sealed.

4.5 Expected Accuracy

The expected accuracy values presented in the following tables were provided by Vexcel. These accuracies were derived on the basis of a small orthophoto project area consisting of a single mosaicked orthophoto from four images, two from each of two strips of imagery covering the area of interest.

According to the manufacturer, the UltraCamD, UltraCamX and UltraCamXp all have the same expected accuracies as shown below. The expected accuracy for the UltraCamXp WA is shown in a separate table.

UltraCam Models D, X, and Xp

	CE95 Accuracy					
	With GPS/IMU			Without GPS/IMU		
	Number of Control Points			Number of Control Points		
Resolution (GSD)	0	1	4	0	1	4
1 Meter	N/A	N/A	N/A	N/A	N/A	N/A
12-inch (30cm)	11”	11”	10”	N/A	N/A	10”
6-inch (15cm)	5.5”	5.5”	5.0”	N/A	N/A	5”
3-inch (7.5cm)	4”	4”	3”	N/A		3”
Highest advertised resolution: 1.2–inch (3 cm)	N/A	N/A	N/A	N/A	N/A	1”

UltraCam Xp WA

	CE95 Accuracy					
	With GPS/IMU			Without GPS/IMU		
	Number of Control Points			Number of Control Points		
Resolution (GSD)	0	1	4	0	1	4
1 Meter	33”	33”	30”	N/A	NA	30”
12-inch (30cm)	11”	11”	10”	N/A	N/A	10”
6-inch (15cm)	5.5”	5.5”	5”	N/A	N/A	5”
3-inch (7.5cm)	4”	4”	3”	N/A	N/A	3”
Highest advertised resolution: 1.2–inch (3 cm)	N/A	N/A	N/A	N/A	N/A	1”

5 Documentation

Prior to the facility visit, the Team reviewed various documents received from Vexcel and public domain documents retrieved primarily from the internet. Detailed comments and questions were derived from these materials and were deemed to be at a level that did not to require formal answers prior to the facility visit but could be answered during the visit.

During the visit, the Vexcel staff presented and/or provided additional documents that included the following:

1. Manufacturing Process
2. Suppliers & Material Qualification
3. Design Documentation
4. Sample Quality Report
5. Radiometric Calibration
6. Radiometry of UCD/UCX
7. Geometric Calibration
8. Sample Calibration Report
9. Standard Article Test Plans and Results Documentation
10. Quality Report
11. Copies of Published Technical Papers
12. Technical Specification Sheets

There were no additional documents required after the facility visit for the UltraCam D.

Finally, the individual members of the Team took notes, pictures, and wrote comments regarding what they saw and heard during the visit to Vexcel and while researching the UltraCam D system. Copies of these notes have been collected and are filed with the Vexcel Certification files at the USGS EROS.

Additional information was provided after the visit on the UltraCamX family of sensors to document the differences with the UltraCamD system. During a telephone conversation with the Vexcel staff about the information presented in the supplied documents, all questions about these differences were adequately covered.

Copies of all documentation described above are kept in the UltraCam Certification files for the UltraCam family of sensors at the USGS EROS for future reference by the Team. Many of these documents and the information within or derived from are Vexcel proprietary information.

6 USGS Team Findings

Prior to the visit with Vexcel, the Team was provided technical information, datasheets and relevant documentation. During the visit, updated materials were provided along with detailed presentations. The Team also took considerable notes during the visit and researched other sources of information from various sources to augment the understanding of the Vexcel UltraCamD. The Team notes and various materials containing proprietary information are not included in this report but are kept on file with the USGS for future internal reference. Subsequent to the Vexcel visit, the Team reviewed the information about the UltraCam X family of sensors and determined that the findings in this section also apply to those sensors. Based on this information, the following findings are presented.

The quality program in use at Vexcel covers every step of the manufacturing process. Vexcel enjoys a very close relationship with their primary supplier, WILD Austria, in nearby Völkermarkt. The Quality Program at WILD is very thorough. The close working relationship between Vexcel and WILD allows for physical collaboration between engineers and assemblers and thus gives Vexcel the ability to monitor quality and performance at the subsystem level during assembly and testing.

System engineering processes, including configuration control and management, in use at Vexcel follow standard industry practices, as do manufacturing engineering, testing, and quality monitoring processes.

Geometric calibration of the Vexcel UltraCamD is performed in-house at Vexcel in Graz, using multiple images taken in a control-point chamber (room). The distortion coefficients from this calibration are then further refined using aerial imagery over a survey-controlled test range. These final results are delivered with each UltraCamD sold. This calibration process generates calibration parameters that are very precise and virtually eliminates systematic distortions within the system.

Radiometric calibration for the UltraCamD is limited to defective pixel identification and correction, normalization, and aperture correction. These measures control the qualitative radiometry of the imagery produced. The UltraCamD has not been designed to deliver spectral measurements in reflectance units, but rather to produce four-band color images ready for imaging applications and requirements.

Vexcel strongly recommends annual factory servicing of the UltraCamD and provides a Service Plan including this. During annual servicing, the calibration of the system is verified using the methods above. Vexcel's incentives to purchasers to enroll in the service plan, which will provide verification of

performance, went a long way to ensure data quality. Vexcel's service and support operations were found to be excellent.

The Team was presented with overviews of the Vexcel software that is used to process the UltraCamD output into photography that can then be processed into products using standard softcopy photogrammetric software. The Vexcel software is produced using good software engineering processes.

Vexcel has thoroughly tested and verified the technical performance of the UltraCamD systems, including test flights under harsh environmental extremes. Each system is flown and verified before delivery.

The Team has found the Vexcel UltraCamD System to be designed, manufactured, tested, and supported to the level required to reliably meet the performance claims of the manufacturer when operated within manufacturer's intended operational parameters. These systems, when operated properly by a conscientious and technically qualified operator, are capable of meeting the accuracy claims given by Vexcel for digital aerial data.

Appendix A: UltraCam Technical Specs (All Models)

A.1:UltraCam -D through –XpWA System Specifications

System	System Nomenclature	**UltraCamD**	**UltraCamX**	**UltraCamXp**	**UltraCamXp WA**
	Number of Lens Cones	8			
	Number of Sensor Chips/Lines	13			
	On-board Storage (GB/TB)	4.2 TB	4.2 TB	4.2 TB	4.2 TB
	On-board Storage (images)	15,000	9,500	6,600	6,600
	Image Storage Redundancy (Y/N)	Y			
	Power Consumption (Watts)	850 W			
	Camera Temperature Range (°C)	0°C to +45°C			
	Computer Temperature Range (°C)	0°C to +45°C			
	Humidity Range	95% @ no condensation			
	Mount Type	GSM 3000, T-AS, PAV30, PAV 80			
	Output Pixel Size(s)	9um x 9um	7.2um x 7.2um	6um x 6um	
	Fwd Motion Comp (FMC) Type	TDI controlled			
	Maximum FMC Correction (pixels)	50 pixel			
	Recommended Forward Overlap (%)	as per project definition			
	Recommended Side Overlap (%)	as per project definition			
Size & Weight	Camera Size/Weight	45 x 45 x 60 cm / 55kg			
	Processing System Size/Weight	50 x 36 x 65 cm / 65kg			
	Storage System Size/Weight	40 x 30 x 20 cm / 16 kg			
	Mount Weight	depends on configuration			
	Total System Weight	147kg			
Controls	Exposure Control Options	Time & Aperture			
	Light Metering Type	Manual settings			
	Shutter Type	Prontor Magnetic 0 – Vexcel			
	Shutter Speed Range	1/500 to 1/32			
	ISO Range	N/A			
	Exposure Compensation	N/A			

A.2:UltraCam -D through –XpWA Panchromatic Specifications

UltraCam Model		UltraCamD	UltraCamX	UltraCamXp	UltraCamXpWA
Sensor	Sensor Type	Full Frame CCD			
	Sensor Nomenclature	Dalsa FTF 4027M	Dalsa FTF5033M	Dalsa FTF6040-M	
	Total Pixels (MP)	11 MP	17 MP	24 MP	24 MP
	Along Track Pixels	2672	3328	4008	
	Cross Track Pixels	4008	4992	6051	
	Aspect Ratio	3:2			
	Pixel Size (mm)	0.009	0.0072	0.006	
	Fill Factor (%)	90%			
	Radiometric Resolution (bits)	12+ bit			
	Dynamic Range	>72 db			
	Max Exposure Rate (images/sec)	0.5			
Lens	Lens Manufacturer	Linos Rodenstock			
	Lens Nomenclature	Linos Vexcel Apo-Sironar Digital HR 5.6/105 mm			Linos Vexcel Apo-Sironar Digital HR 5.6/70 mm
	Focal Length (mm)	100 mm			70 mm
	Aperture Range (f-stop)	1/5.6 - 1/22			
	Along Track FOV (deg)	13.7°			19.5°
	Cross Track FOV (deg)	20.5°			29.2°
Spectral Response	Panchromatic	410 – 690 nm			
Virtual Image	Total Pixels (MP)	82	130	196	196
	Along Track Pixels	7500	9420	11310	
	Cross Track Pixels	11500	14430	17310	
	Aspect Ratio	3:2			
	Pixel Size (mm)	0.009	0.0072	0.006	
	Along Track FOV (deg)	37°			51.7°
	Cross Track FOV (deg)	55°			77.6°
	Radiometric Resolution (bits)	12+ bit			
	Dynamic Range	>72 db			

A.3:UltraCam -D through –XpWA Multispectral Specifications

	UltraCam Model	UltraCamD	UltraCamX	UltraCamXp	UltraCamXpWA
Sensor	Sensor Type	Full Frame CCD			
	Sensor Nomenclature	Dalsa FTF 4027M	Dalsa FTF5033M	Dalsa FTF6040-M	
	Total Pixels (MP)	11 MP	17 MP	24 MP	
	Along Track Pixels	2672	3328	4008	
	Cross Track Pixels	4008	4992	6051	
	Aspect Ratio	3:2			
	Pixel Size (mm)	0.009	0.0072	0.006	
	Fill Factor (%)	90%			
	Radiometric Resolution (bits)	12+ bit			
	Dynamic Range	72+ db			
	Max Exposure Rate (images/sec)	0.5			
Lens	Lens Type	Linos Rodenstock			
	Lens Nomenclature	Linos Vexcel Apo-Sironar Digital HR 4/33 mm			Linos Vexcel Apo-Sironar Digital HR 4/23 mm
	Focal Length (mm)	33 mm			23 mm
	Aperture Range (f-stop)	1/4.0			
	Along Track FOV (deg)	40°			55.2°
	Cross Track FOV (deg)	60°			82.8°
Spectral Response	Blue	410 - 540 nm			
	Green	480 - 630 nm			
	Red	580 - 700 nm			
	NIR	690 - 1000 nm			
Virtual Image	Total Pixels (MP)	82	130	196	196
	Along Track Pixels	7500	9420	11310	
	Cross Track Pixels	11500	14430	17310	
	Aspect Ratio	3:2			
	Pixel Size (mm)	0.009	0.0072	0.006	
	Along Track FOV (deg)	37°			51.7°
	Cross Track FOV (deg)	55°			77.6°
	Radiometric Resolution (bits)	12+ bit			
	Dynamic Range	>72 db			