# ACCURACY AND RADIOMETRIC STUDY ON LATEST GENERATION LARGE FORMAT DIGITAL FRAME CAMERAS


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# MOTIVATION OF THE STUDY

**FOR THE MOMENT:**

1. **To find out through different block configuration, treatment of information, etc. how much is possible to obtain in terms geometrical accuracy for the two most popular and latest digital frame cameras existing in the market, i.e. the 3 versions of the Z/I DMC II and the UltraCam Eagle.**
2. **Given the geometric characteristics of the Test Field Area where the UltraCam Eagle took place and many other related parameters, to try to make a system calibration (i.e., Camera inner orientation parameters and their relation with the IMU-AGGPS of the camera system as well**
3. **Radiometrically speaking, the aim was concentrated in finding out the real against the theoretical/nominal resolution of the camera and in such a way to see if there is any possible lost of information on the acquired images**

## *EXPERIMENTAL TESTS*

4. **Areas chosen for the different experiments carried out with the different cameras**
5. **Flight parameters and number/distribution of Ground/Check control points used on each experimental test**
6. **Data acquisition, data reduction, without/with self-calibration approach in the adjustment phases. Analysis of the statistical results on Each case**

## *CONCLUSSIONS AND RECOMMENDATIONS*

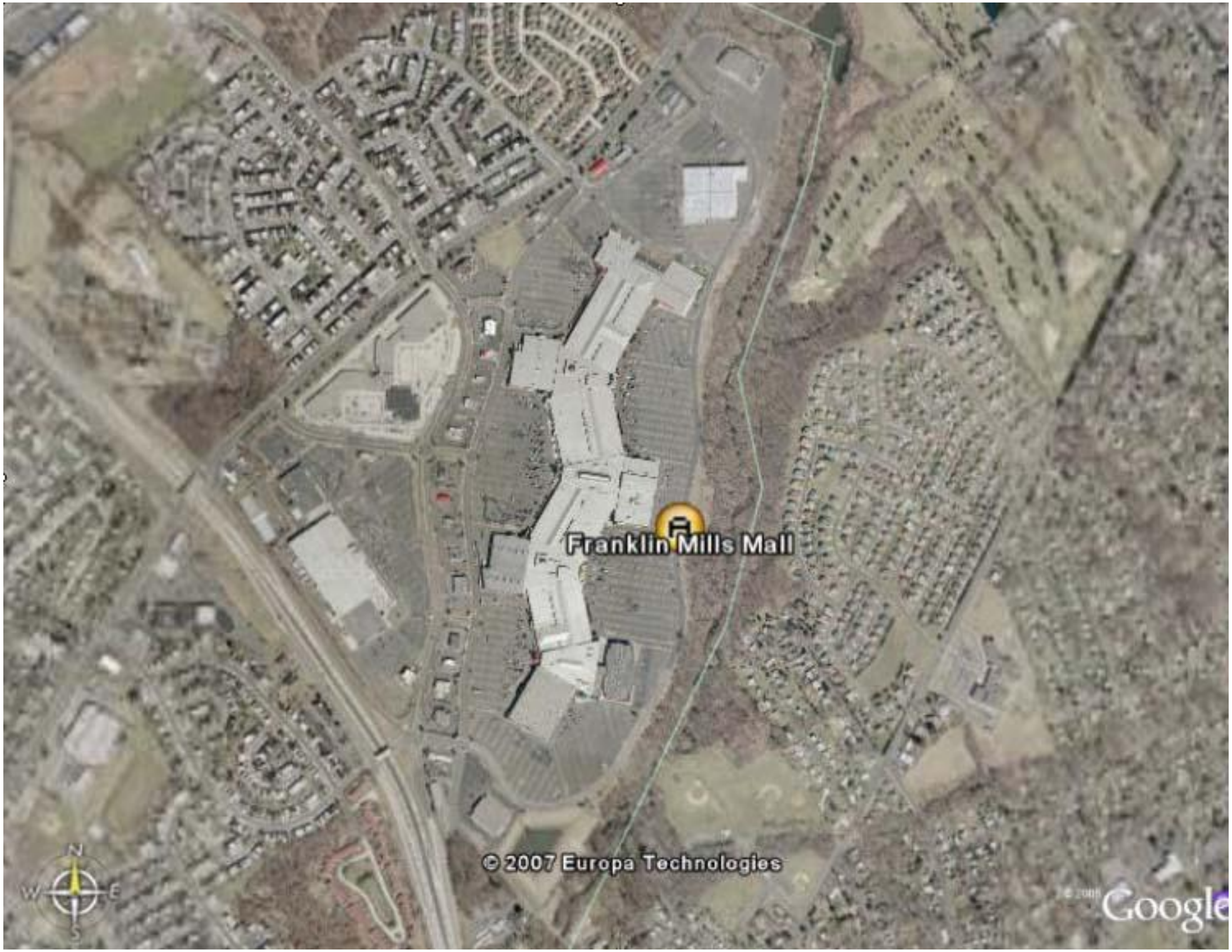
**Not a comparison study between the two types of cameras. Flights in different places and times of the year, different latitude of the places, hence different illumination of the terrain. Geometric parameters of the flights, number, distribution and characteristics of the GCPs different. GSD different for each camera/project.**

**In view of all above, the authors have summarized the obtained results of each test only.**

# UltraCam Eagle – Test Field Area ~ 38.6 sq. miles

KEYSTONE AERIAL SURVEYS

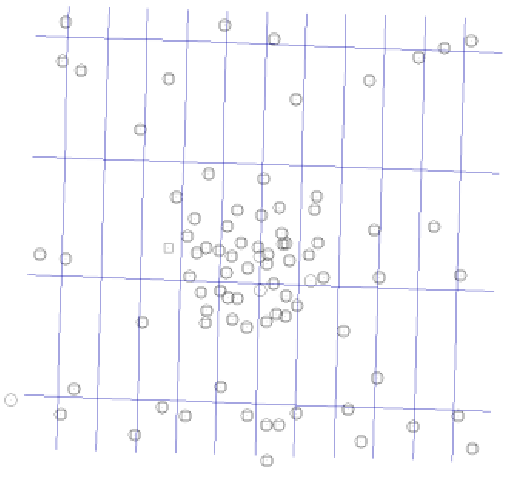
BAE SYSTEMS




**NORTH EAST PHILADELPHIA. RELATIVELY OPEN AREA. FLAT. LARGE SHOPPING MALL: FRANKLIN MILL MALL INCLUDING LARGE PARKING LOTS WITH PARKING STRIPES. WIDE ROADS AND STREETS WITH PAINTED TRAFFIC SIGNALIZATION**

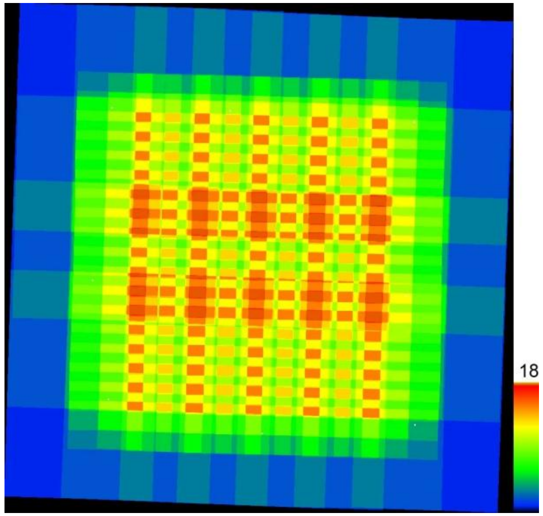
# UltraCam Eagle – Test Field Area ~ 38.6 sq. miles

BAE SYSTEMS



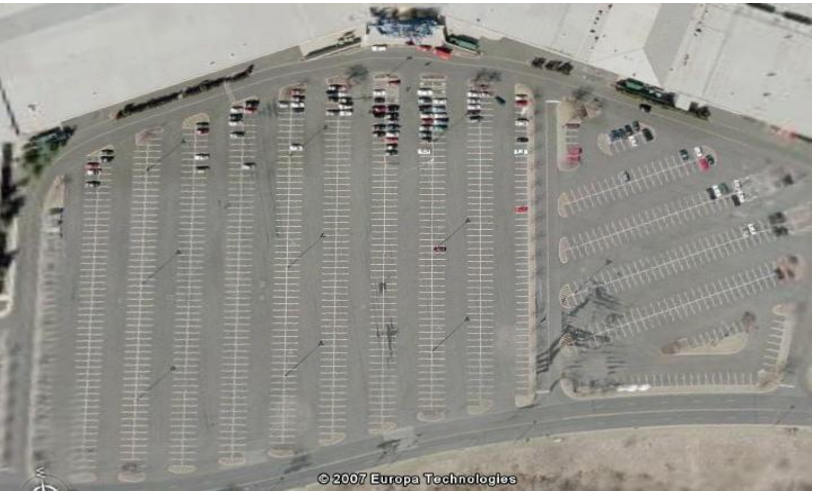
84 signalized GCPs.

~1.5 cm standard deviation




East-West 5 cm GSD, North-South 10cm → 60% end and 60% lat. overlap

Typical Targeted GCP. Intersection of Parking Stripes





Typical signal/signalized GCP/CHK points

1. **BUNDLE BLOCK ADJUSTMENT**
2. **BLUH** (**B**undl**e** block adjustment Leibniz **U**niversity **H**annover) Author: Karsten Jacobsen
3. **Self-calibration Models**

x, y = image coordinates normalized to maximal radial distance 162.6mm (scale factor: 162.6 / maximal radial distance) $r^2 = x^2 + y^2$ b = arctan (y/x)

| | | |
|---|---|---|
| 1. $x' = x - y \cdot P1$ | $y' = y - x \cdot P1$ | angular affinity |
| 2. $x' = x - x \cdot P2$ | $y' = y + y \cdot P2$ | affinity |
| 3. $x' = x - x \cdot \cos 2b \cdot P3$ | $y' = y - y \cdot \cos 2b \cdot P3$ | General additional parameters in Hannover program system BLUH |
| 4. $x' = x - x \cdot \sin 2b \cdot P4$ | $y' = y - y \cdot \sin 2b \cdot P4$ | |
| 5. $x' = x - x \cdot \cos b \cdot P5$ | $y' = y - y \cdot \cos b \cdot P5$ | |
| 6. $x' = x - x \cdot \sin b \cdot P6$ | $y' = y - y \cdot \sin b \cdot P6$ | |
| 7. $x' = x + y \cdot r \cdot \cos b \cdot P7$ | $y' = y - x \cdot r \cdot \cos b \cdot P7$ | tangential distortion 1 |
| 8. $x' = x + y \cdot r \cdot \sin b \cdot P8$ | $y' = y - x \cdot r \cdot \sin b \cdot P8$ | tangential distortion 2 |
| 9. $x' = x - x \cdot (r^2 - 16384) \cdot P9$ | $y' = y - y \cdot (r^2 - 16384) \cdot P9$ | radial symmetric $r^3$ |
| 10. $x' = x - x \cdot \sin(r \cdot 0.049087) \cdot P10$ | $y' = y - y \cdot \sin(r \cdot 0.049087) \cdot P10$ | radial symmetric |
| 11. $x' = x - x \cdot \sin(r \cdot 0.098174) \cdot P11$ | $y' = y - y * \sin(r \cdot 0\ 0.098174) \cdot P11$ | radial symmetric |
| 12. $x' = x - x \cdot \sin 4b \cdot P12$ | $y' = y - y \cdot \sin 4b \cdot P12$ | |

KEYSTONE AERIAL SURVEYS

BAE SYSTEMS

## Special additional parameters in Hannover program system BLUH

BLUH includes additional parameters specifically for the Z/I DMC (1st version) and UltraCam cameras as well as for cameras having problems with the flatness of their CCD (parameters 81 to 88)

29. – 33 special parameters for the internal transformation of DMC sub-images

| | | | |
|---|---|---|---|
| 34. x' = x – x*y*P34 | y' = y | for upper right quarter | DMC Y 1 |
| 35. x' = x | y' = y – x*y*P35 | for upper right quarter | DMC X 1 |
| 36. x' = x – x*y*P36 | y' = y | for lower right quarter | DMC Y 2 |
| 37. x' = x | y' = y – x*y*P37 | for lower right quarter | DMC X 2 |
| 38. x' = x – x*y*P38 | y' = y | for lower left quarter | DMC Y 3 |
| 39. x' = x | y' = y – x*y*P39 | for lower left quarter | DMC X 3 |
| 40. x' = x – x*y*P40 | y' = y | for upper left quarter | DMC Y 4 |
| 41. x' = x | y' = y – x*y*P41 | for upper left quarter | DMC X 4 |

42 – 49 scale parameters for UltraCam
50 – 57 shift X parameters for UltraCam
58 – 65 shift Y parameters for UltraCam
66 – 73 UltraCam master images perspective
79 common perspective deformation of DMC version 1 sub-images
80 common radial symmetric parameter for DMC version 1 sub-images
81-88 parameters for geometry at the corners of the image (problem of CCD flatness)

## UltraCam Eagle results:
## Double coverage Block. All GCPs

KEYSTONE AERIAL SURVEYS

BAE SYSTEMS

| Block: Low + High Altitude Flight (GSD= 5cm respectively 15cm) | | | | | | | |
|---|---|---|---|---|---|---|---|
| additional parameters | $\sigma_o$ µm | RMSE 84 GCPs [m] | | | MAX Errors 84 GCPs [m] | | |
| | | RMX | RMY | RMZ | M-X | M-Y | M-Z |
| no selfcalibr. | 1.28 | .023 | .028 | .030 | .065 | .077 | .114 |
| 12 St | 1.23 | .023 | .027 | .028 | .064 | .077 | .105 |
| 12 ST+C.S. | 1.18 | .022 | .026 | .027 | .067 | .075 | .103 |
| C. Spec | 1.18 | .023 | .026 | .027 | .066 | .075 | .103 |
| C. Spec+Co | 1.18 | .023 | .026 | .026 | .066 | .076 | .102 |

Overall accuracy ($\sigma_o$ ) improved approx 10% by self-calibration. Horizontal accuracy not improved by self-calibration. Only vertical accuracy improved by self calibration

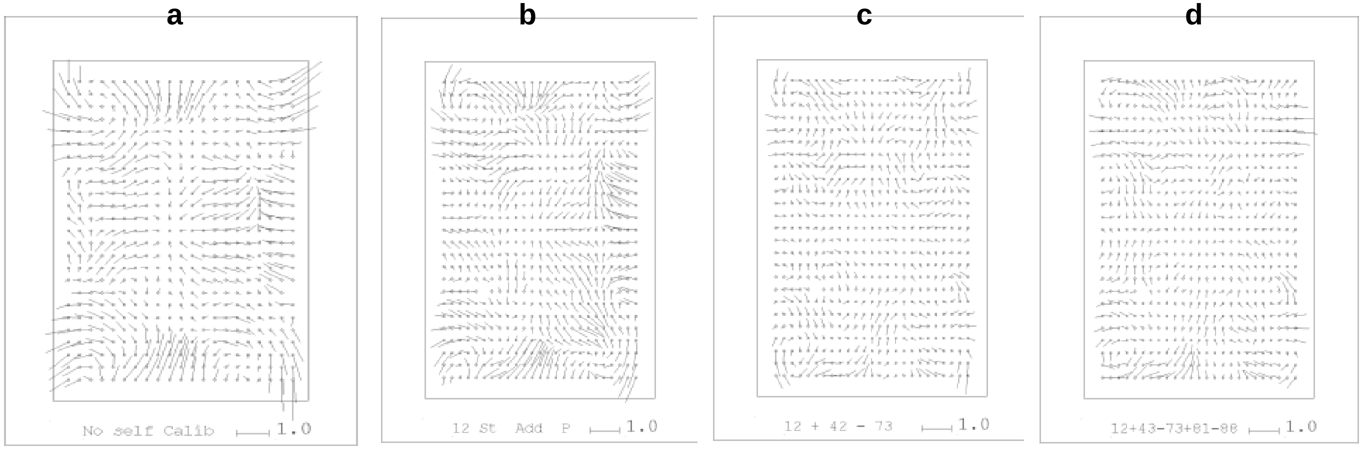
| Block: Low Altitude Flight (GSD=5cm) | | | | | | | |
|---|---|---|---|---|---|---|---|
| additional parameters | $\sigma_o$ µm | RMSE 84 GCPs [m] | | | Maximal Errors 84 GCPs [m] | | |
| | | RMX | RMY | RMZ | M-X | M-Y | M-Z |
| no self calibr | 1.15 | .022 | .025 | .028 | .050 | .078 | .072 |
| 12 St | 1.10 | .025 | .023 | .025 | .051 | .074 | .072 |
| 12 St +C. S. | 1.05 | .020 | .023 | .024 | .058 | .073 | .074 |
| C. Spec | 1.06 | .020 | .023 | .024 | .049 | .072 | .068 |
| C. Spec+Co | 1.07 | .020 | .024 | .024 | .049 | .073 | .068 |

Only East-West 5cm GSD - same effect as above. Although up to 4 mm in Z again negligible. UC Eagle height-to-base ratio 2.93 - smaller than in other UltraCam models

| Block: High Altitude Flight (GSD=15cm) | | | | | | | |
|---|---|---|---|---|---|---|---|
| additional parameters | $\sigma_o$ µm | RMSE 84 GCPs [m] | | | Maximal Errors 84 GCPs [m] | | |
| | | RMX | RMY | RMZ | M-X | M-Y | M-Z |
| no self calibr. | 1.16 | .062 | .067 | .075 | .233 | .181 | .291 |
| 12 St | 1.14 | .059 | .064 | .070 | .214 | .175 | .293 |
| 12 St +C. S. | 1.10 | .060 | .063 | .072 | .220 | .174 | .298 |
| C. Spec | 1.09 | .060 | .063 | .072 | .219 | .173 | .298 |
| C. Spec+C | 1.09 | .060 | .063 | .072 | .221 | .173 | .303 |

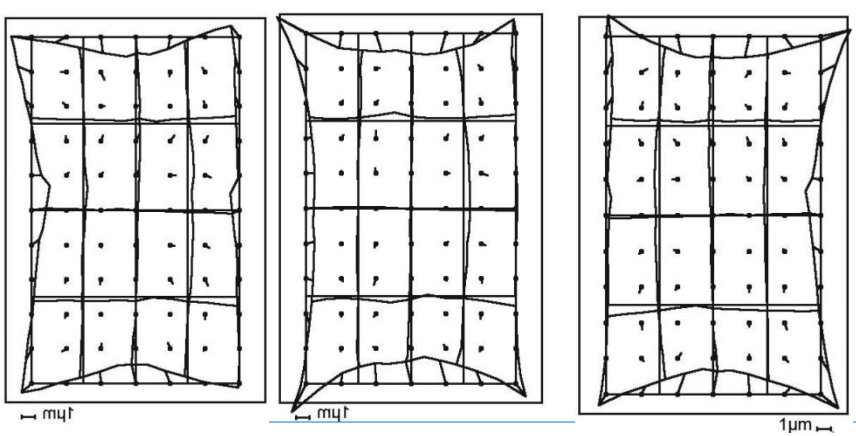
Only North-South 15 cm GSD - same tendency

| No self Calibration | 12 Additional Par. | 12 ST + Camera Specific | Camera Specific + corner effects |
| --- | --- | --- | --- |
| a | b | c | d |




Remaining systematic image errors (by analysis of residuals)

Although very small - with 12 standard parameters remaining systematic image errors (b). Becomes small with camera specific Add Param (c). cleaning of the corner effect by (d) – even if only negligible effect to ground coordinates




**Systematic image errors by self-calibration**

advisable to use all additional parameters (automatically reduced by program to required parameters )

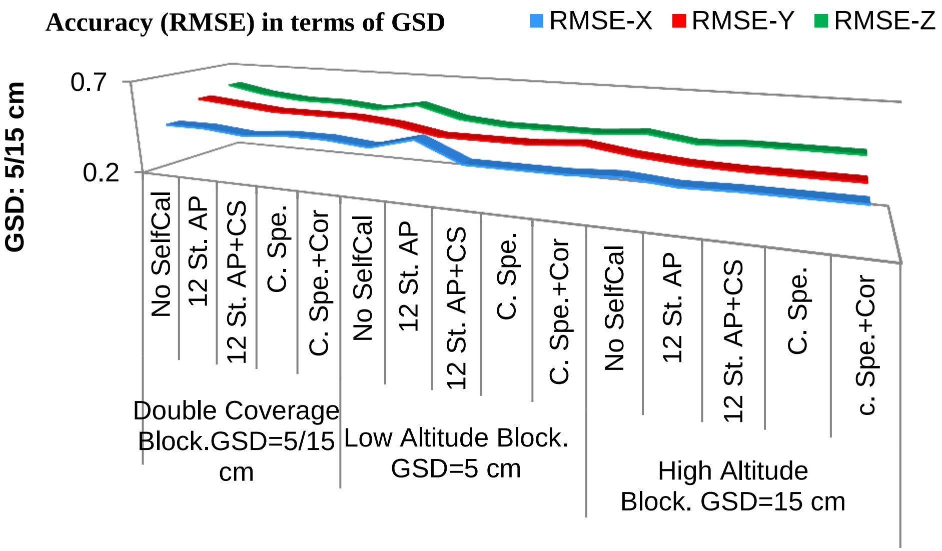
## Accuracy versus number and distribution of GCPs

| GCPs/ CHKs | ADJ. TYPE | Root mean square differences at check points [m] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $\sigma_{0\ \mu m}$ | RMX | RMY | RMZ | max X | max Y | max Z |
| 44/ 40 | no self calibr. | 1.22 | .019 | .032 | .040 | .057 | .075 | .099 |
| | 12 St. | 1.18 | .019 | .032 | .041 | .057 | .074 | .093 |
| | 12 St. + C S | 1.13 | .019 | .032 | .040 | .058 | .076 | .089 |
| | C Spec+81-88 | 1.13 | .019 | .033 | .046 | .058 | .075 | .095 |
| 28/ 56 | no self calibr. | 1.18 | .023 | .033 | -.051 | .079 | .083 | .175 |
| | 12 St. | 1.14 | .024 | .033 | .044 | .086 | .081 | .170 |
| | 12 St. + C S | 1.09 | .024 | .033 | .043 | .086 | .082 | .164 |
| | C Spec | 1.10 | .024 | .033 | .049 | .084 | -.082 | .158 |
| | C Spec+81-88 | 1.09 | .024 | .033 | .048 | .084 | .082 | .158 |
| 10/ 74 | no self calibr. | 1.13 | .027 | .036 | .061 | .076 | .108 | .213 |
| | 12 St. | 1.10 | .025 | .037 | .058 | .083 | .114 | .215 |
| | 12 St. + C S | 1.02 | .025 | .036 | .058 | .083 | .114 | .219 |
| | C Spec | 1.05 | .026 | .036 | .058 | .079 | .110 | .190 |
| | C Spec+81-88 | 1.06 | .026 | .037 | .058 | .078 | .111 | .179 |
| 5/ 79 | no self calibr. | 1.13 | .037 | .048 | .085 | .108 | .124 | .278 |
| | 12 St. | 1.09 | .037 | .046 | .071 | .111 | .129 | .261 |
| | 12 St. + C S | 1.03 | .036 | .044 | .058 | .113 | .124 | .235 |
| | C Spec | 1.04 | .037 | .045 | .060 | .111 | .122 | .216 |
| | C Spec+81-88 | 1.04 | .038 | .046 | .062 | .111 | .124 | .209 |

accuracy for less number of GCPs along with different sets of additional parameters

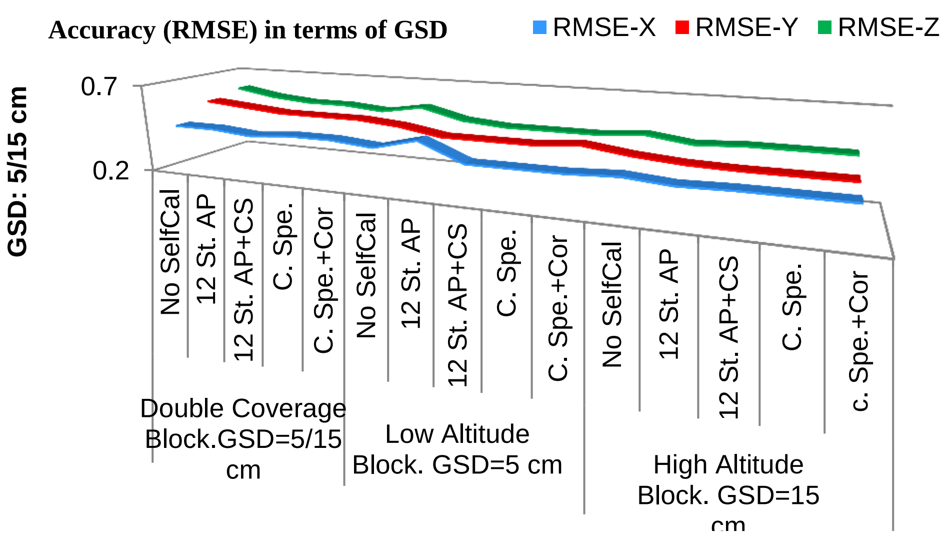
In general :

Larger Standard Deviation for less number of GCPs




## Absolute accuracy (RMSE) at check points in terms of GSD (5 cm)

## Accuracy (RMSE) on GCPs expressed in GSDs




**IN ALL CASES BELOW THE GSD VALUE**

For "DIRECT SENSOR ORIENTATION or INTEGRATED SENSOR ORIENTATION", meaning Orientation with no use of control points, or in other words to use readings from exterior sensors of the camera, we need to know or to assure the following:

1. Location of camera principal point. ABGPS and PPC are highly correlated → any ABGPS shift affects this and consequently the image coordinates
2. If the angular EOs are to be obtained from IMU (Roll, Pitch, roll) → (Omega, Phi, Kappa) angular misalignment required
3. IMU – ABGPS includes usually Kalman filter, "ARM" important =distance between IMU and camera projection center
4. calibrated distance focal length of the camera may change with flying height

| | **Pressurized cabin, cover glass** | | **Lens in free atmosphere 7 = 7 ° C** | | **Lens in free atmosphere t like air** | |
|---|---|---|---|---|---|---|
| Flying Altitude | 6 Km | 14 km | 6 Km | 14 KM | 6 Km | 14 Km |
| Wide Angle f=153 mm | -20µm | -38µm | -36µm | -58µm | -47µm | -80µm |
| Normal Angle f= 305 mm | +12µm | -17µm | -33µm | -28µm | -110µm | -172µm |

**Change of focal length with altitude of Platform, according to Mayer 1978**

# EEFECT OF CHANGE OF FOCAL LENGTH

## DOES NOT INFLUENCE X and Y. IT ONLY PRODUCES AN AFFINE DEFORMATION OF ALTITUDE

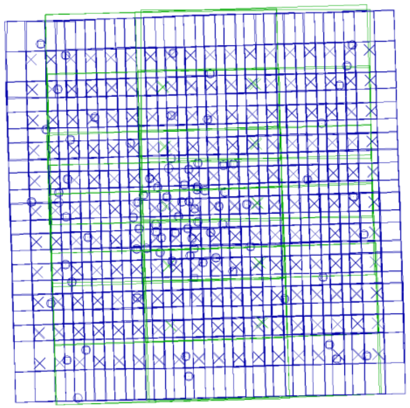
**Suppose df= 15 µm, in case of traditional orientation with control points – for image scale 1:6,500 and a Δh= 100 m against leveled control points is**

**6,500 = H+dh/(f+df); or dh = 6,500 (f+df) – H; replacing dh~1 cm**

**As above in the case for Direct Sensor Orientation it can be proved that dh ~ 10 cm.**

**HENCE, FOR DIRECT SENSOR ORIENTATION, LABORATORY CALIBRATION IS NOT SUFFICIENT**

UCE CAMERA SYSTEN CALIBRATION



**SYSTEM CALIBRATION PARAMETERS**:

1. Location of camera principal point
2. Operational focal length of the camera
3. Misalignment angles between the IMU axis and Camera axis
4. Calibrated distance between the IMU origin and camera projection center (also called as the arm)

same UC Eagle, same block GSDs, IMU and Airborne GPS, same GCPs as before, but with strip line flown in a forward and reverse direction. This allows independent determination of airborne GPS shift and principal point.

| | |
|---|---|
| Correction for focal length | -.008 mm |
| Shift of principal point in x | .004 mm |
| Shift of the principal point in y | -.006 mm |

| | | | | | |
|---|---|---|---|---|---|
| .00326 | .00520 | .00065 | -.262 | .123 | .286 |
| CPITCH | CROLL | CYAW | CX | CY | CZ |

[GRADS]

These parameters are used to correct the IMU-GPS.

**SQUARE MEAN OF DIFFERENCES**

**RMSX = +/- 3cm  RMSY = +/- 3cm  RMSZ = +/- 6cm**

**root mean square differences at 84 GCPs used as check points**

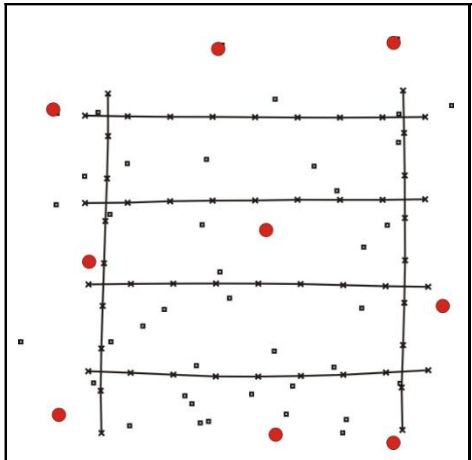
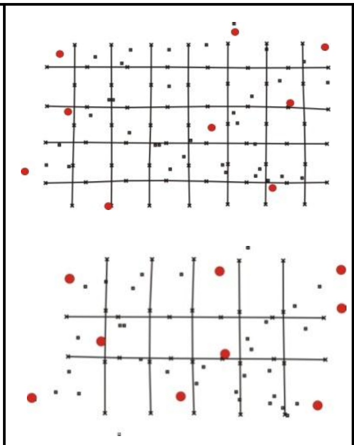
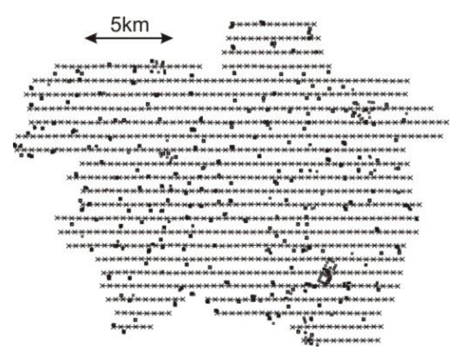
**MAXIMAL DIFFERENCES**

**MAX DX = 7cm  MAX DY = 10cm  MAX DZ = -14cm**

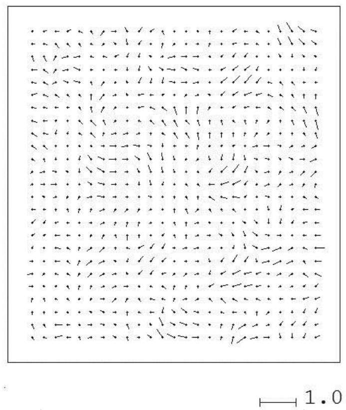
**Using the calibrated focal length and the calibrated/corrected image coordinates as well as the corrected IMU readings →**

**MAXIMUM – PARALLAX = 8.7 Microns**

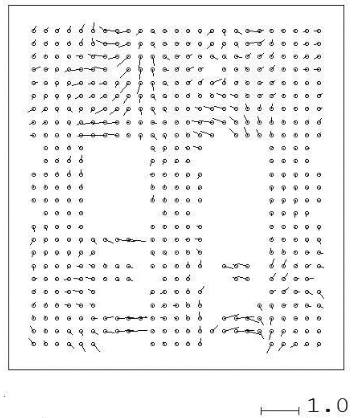
# ZI IMAGING DMCII TEST

| | | |
|---|---|---|
|  |  |   |
| **DMCII 250 block, 5cm GSD** | **DMCII 250 block,**<br>**above 9cm GSD below 15cm GSD** | **DMCII 230 block, 7cm GSD**<br>**(Operational Block)** |

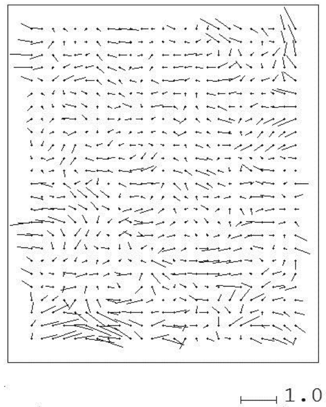
DMCII-versions based on a monolithic large size CCD, so no camera specific additional parameters required. Only the standard parameters 1 – 12 and the special parameters for the image corners 81 – 88 are justified. All 8 DMCII-blocks did not require the special additional parameters 81 – 88, so for optimal results only the standard parameter 1 – 12 had to be used




DMCII 140, 9cm GSD

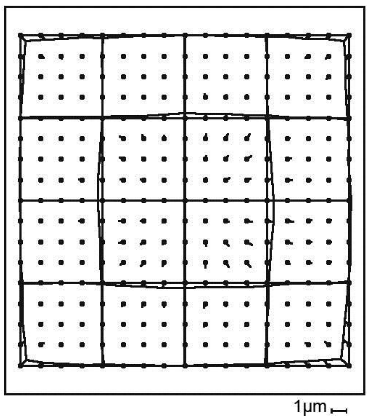



DMCII 230, 7cm GSD

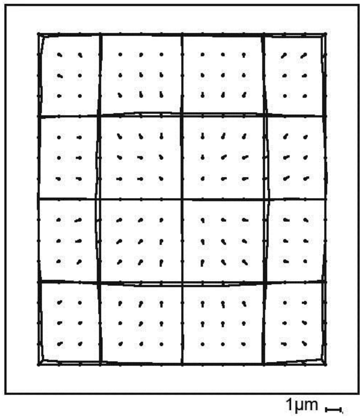



DMCII 250, 9cm GSD

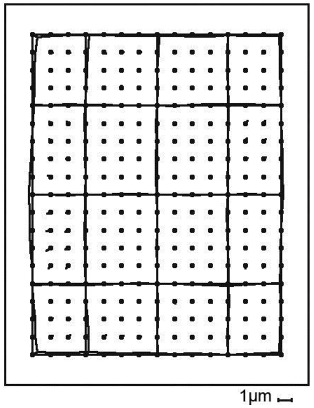
**remaining systematic image errors DMCII**




DMCII 140, 9cm GSD




DMCII 230, 7cm GSD



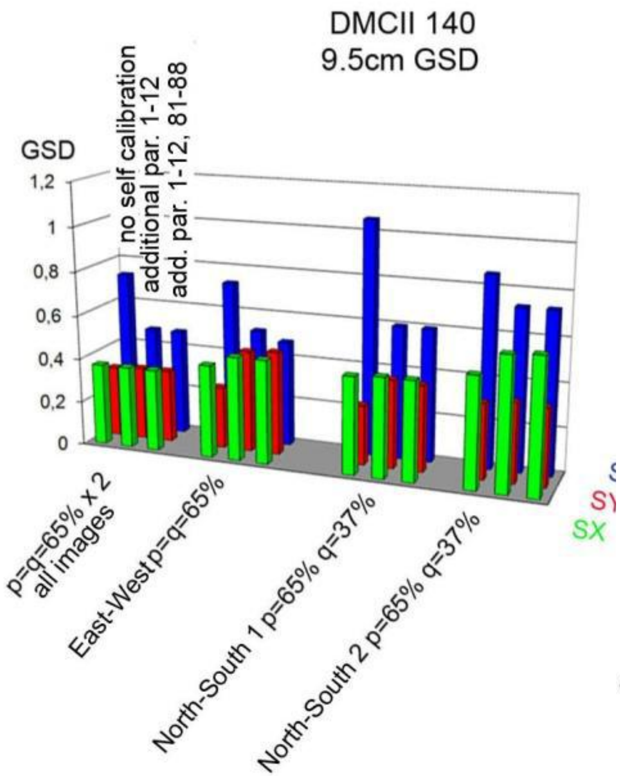

DMCII 250, 9cm GSD

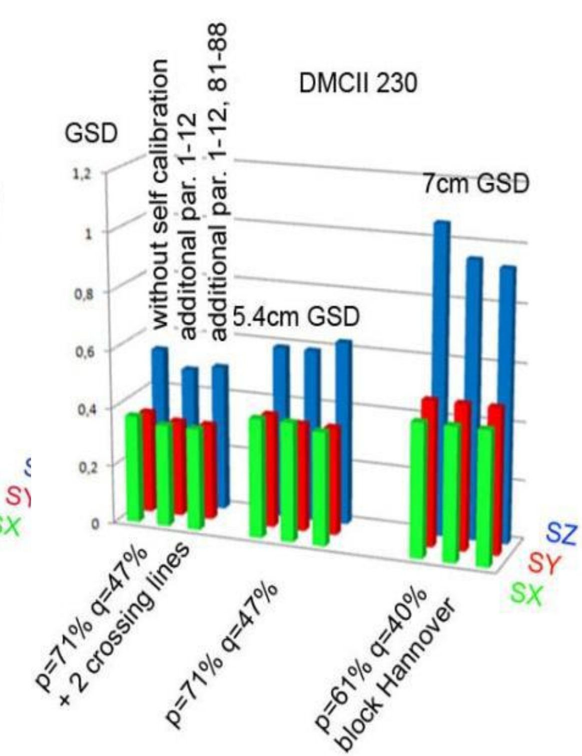
**systematic image errors DMCII**

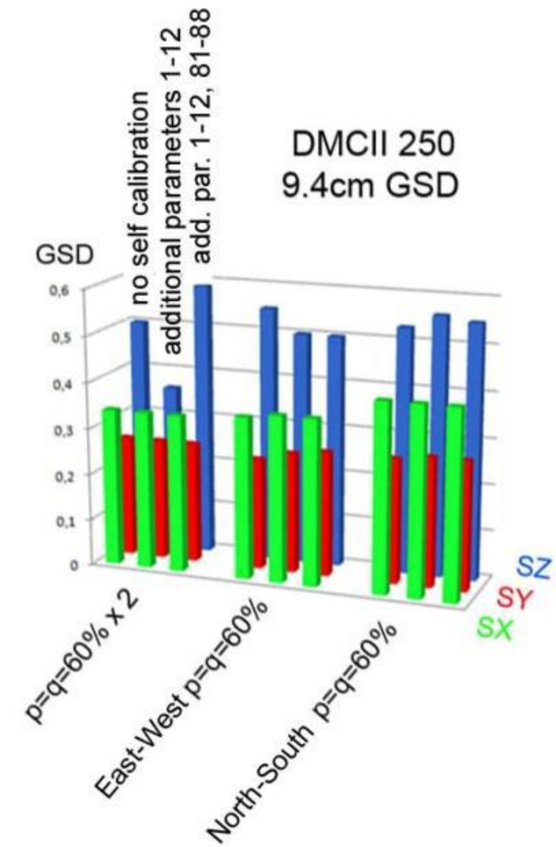
Image points of operational block not equally distributed, so gaps in remaining systematic image errors, vectors above and below gaps are larger because of limited number of points in these sub-areas

In general, systematic image errors and remaining systematic image errors very small. Over all blocks and images average of the systematic image errors are 0.32µm or 0.06 pixels

# THE Z/I IMAGING DMC II TESTS




DMC II 140 test block 9 cm GSD

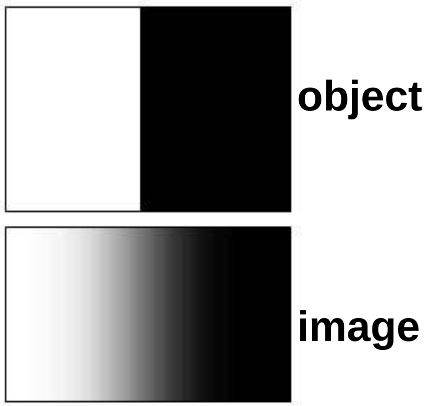
DMCII 230 test block 5cm GSD

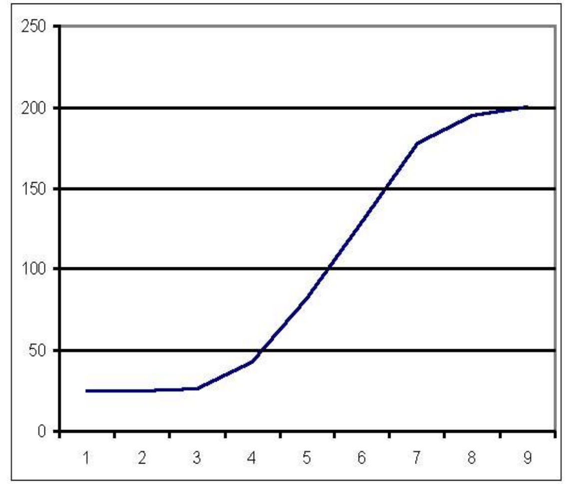
operational block 7cm GSD

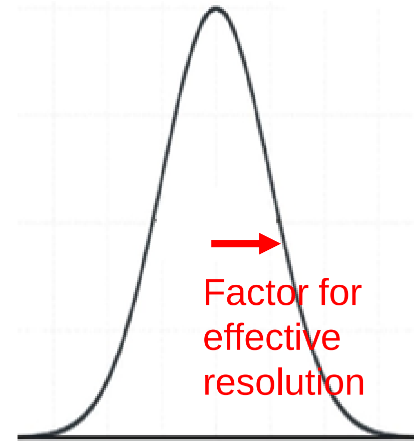
DMCII 250, 9cm GSD

# Radiometric image quality (edge analysis)

BAE SYSTEMS




edge in image | gray value profile | point spread function

| camera | blue, pan-sharpened | green, pan-sharpened | red, pan-sharpened |
|---|---|---|---|
| DMCII 230 | 0.98 | 0.97 | 0.98 |
| DMCII 250 | 0.87 | 0.88 | 0.84 |
| UltraCam Eagle | 1.01 | 1.02 | 1.03 |

Factors for effective resolution - multiplication with GSD or pixel size

→ for identification of objects important figure

From Jacobsen, 2008)

## UltraCam Eagle

1. Reduction of GCP number does not aggressively affects the overall accuracy of the block. The rate of change of the $\sigma_0$ is practically negligible
2. Nevertheless, with less and less control vertical component influenced. Changes in horizontal components insignificant
3. Nearly same result with self-calibration using the 12 standard parameters plus the camera specific add param, or camera specific alone. Corner additional parameters do not improve ground coordinates. Nevertheless, it is advisable to use all parameters.
4. A boresight calibration field area was flown with all their requirements. Results of the calibration of the camera parameters and other data acquisition systems were totally acceptable. **Direct Sensor Orientation** was carried out with discrepancies on 84 GCPs with RMS in the range of 4 to 6 cm for plan and height with maximum discrepancies of 9 cm and 14 cm - largest computed y-parallax = 8.6µm
5. Factor for effective resolution only slightly >1.0→ real GSD is practically equal to nominal GSD

## Z/I DMCII

1. Very small systematic errors. They can be ignored for data acquisition in model
2. For block configurations p=60% and q=40% RMSE at the critical height component clearly below 1 GSD - lower than for any other frame digital camera. Real GSD is practically equal to nominal GSD

# Thank you very much for your kind attention

## QUESTIONS..?

**Ricardo M. Passini**

**David Day**

**Karsten Jacobsen**