GEOMETRICAL STABILITY OF AERIAL CAMERAS

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Commission I

ABSTRACT

A recommendation for a study on the geometrical stability of aerial mapping cameras was included in the resolutions of Commission I of the ISP in Hamburg in 1980. The study was carried out by computing the changes of calibrated focal length, fiducial marks, radial distortion and its asymmetry and in some cases also tangential distortion on the basis of calibrations made in about 1972-82. Results obtained at the NRC of Canada (27 cameras), Wild Heerbrugg (8 cameras) and Helsinki University of Technology (4 cameras) from successive calibrations of Carl Zeiss Oberkochen and Wild Heerbrugg wide- and super-wide-angle cameras were used as material of the study made by the abovementioned participants. The stability of the cfl and that of the mean radial distortion seem to be excellent. Changes of the components of decentering distortion were some few um during the period studied. Calibration is always necessary after dismounting of a camera or after an accident, but otherwise it could be done every third year.

INTRODUCTION

Many calibration laboratories in several countries have data about calibrations made during about 20 years. However, only a few reports have been published, where stability of aerial cameras is discussed. The geometric-optical stability of aerial mapping cameras naturally has an influence on the calibration period needed.

A recommendation for a study of the geometrical stability of aerial cameras was included in the resolutions of Commission I of the ISP in Hamburg in 1980. WG I/2 of Commission I began the study in 1981. NRC of Canada (Ziemann), Wild Heerbrugg (Bormann and Schlienger) and Helsinki University of Technology and Finnish Geodetic Institute (author) had for this study together data available of about 40 aerial mapping cameras over a period of 10 years, during which time (1972-82) the cameras had been used in practice. Two more calibration laboratories were also interested but could not find enough material for the study.

The characteristics studied were the changes of the cfl, the rotationally symmetrical radial distortion, the radial and tangential components of decentering distortion and the distance PPA-PBS, the 2. order asymmetry and the fiducial marks. The three calibration facilities, however, studied partially different characteristics.

Abbreviations used in the paper:
- PPA = principal point of autocollimation
- PBS = point of best symmetry
- FC = fiducial centre
- cfl = calibrated focal length
- HUT = Helsinki University of Technology

1 Material

1.1 Camera types studied

Canada C
Wild W
Finland F

Camera				C	W	F	Σ
Wild	RC-8	15Ag	1:5.6	3			3
		15UAg	1:5.6	4	4	1	9
	RC-10	15UAg	1:5.6	4			4
		15UAg I	1:5.6	1			1
		15UAg II	1:4	2	4	1	7
		8.8SAg II	1:5.6	4			4
Zeiss	RMK A 15/23	Pleogon A	1.5.6			1	1
		Pleogon A2	1:5.6	5		1	6
		Pleogon A2	1:4	2			2
	8.5/23	S-Pleogon A	1:4	2			2
							39

1.2 Numbering of cameras

Wild Heerbrugg			years	calibrations
RC-8	15Ag	C 1	6	7
		C 2	5	6
		C 3	6	6
	15UAg	C 4	6.5	10
		C 5	6.5	9
		C 6	7	8
		C 7	7	9
		F 1	7.5	4
		W 1	13	2
		W 2	14.5	2
		W 3	13	2
		W 4	11	2
RC-10	15UAg	C 8	7	8
		C 9	6	7
		C 10	7	8
		C 11	6	7
	15UAg I	C 12	6.5	8
	15UAg II	C 13	5	6
		C 14a	6	5
		C 14b	5	7
		F 2	9	5
		W 5	8.5	2
		W 6	6.5	2
		W 7	6	2
		W 8	8.5	2

Wild Heerbrugg			years	calibrations
RC-10 8.8SAg II		C 15	8	8
		C 16	7	8
		C 17	6	6
		C 18	8	7
Carl Zeiss Oberkochen				
RMK A 15/23	Pleogon A	F 3	6.5	3
	Pleogon A2	C 19	7	7
		C 20	6	7
		C 21	5.5	7
		C 22	4	6
		C 23	6	6
		F 4	9	5
	Pleogon A2	C 24	5	5
		C 25	4	6
8.5/23	S-Pleogon A	C 26	6	5
		C 27	2.5	4

2 Measurements

2.1 NRC of Canada

The Canadian Interdepartmental Committee on Air Surveys has a requirement that a camera to be used in aerial photography for Federal topographic mapping activities must have been calibrated within the last 12 months preceding the photography. Therefore the calibration laboratory of the NRC has plenty of suitable data for a stability investigation.

The NRC has calibrated aerial cameras with a multicollimator since 1956. The present calibrator was taken into service in 1967 and modified in 1973.

Between Dec. 1973 and Aug. 1981 632 photographic plates in total were exposed to calibrate different lens/filter combinations. There were 121 lenses of 21 lens types.198 plates for 27 cameras were taken into the study. All cameras were always calibrated with the same filter, except one camera which had two combinations.It was not possible to take more plates for the study because all plates must be remeasured.The most often calibrated cameras were taken to the investigation; however, not more than 4 cameras of the same lens type.

All plates were measured on a Zeiss PSK 1 stereocomparator used as monocomparator. Two sets of measurements were made using a reversed point order for the second set. Points where the difference between two observations was over 10 um were remeasured (2 per plate).

Each plate had 4 fiducial images, the image of the center collimator cross doubled and then 16 cross images on each semidiagonal = 4 + 2 + 64 points (for wide-angle cameras). The collimator locations are recalibrated at intervals of approximately a year using a procedure which bisects angles sequentially since 1973. Normal variations during the period 1973-81 do not exceed 2" between two successive calibrations which means 2.7 um in the side of the image. Two collimators showed larger changes.(Ziemann /4/).

The determined data include:
1) The location of the fiducial marks,
2) The calibrated focal length,
3) The rotationally symmetrical radial distortion,
4) The positions of the principal point of autocollimation and the point of best symmetry, and
5) The calculated decentering distortions.

Determination of decentering factors demands additonal measurements and computations which are going on.

2.2 Wild Heerbrugg

Wild has studied calibrations of RC-8 15UAg and RC-10 15UAg II. Before 1982 the cameras have been calibrated with the horizontal goniometer AKG 1 and since early 1982 with the vertical goniometer EVG 1. The differences observed between the results obtained with these two equipment types were small.

The cameras were at the manufacturer only for calibration. They were not dismounted and so no optical changes did take place. All calibrations were computed with the new computing program made for the EVG 1, therefore the results of AKG 1 and EVG 1 are fully comparable with each other.

We can see in Table 2 that that the calibration periods for the lens type 15UAg were from 11 to 14.5 years (4 cameras) and for 15UAg II from 6 to 8.5 years (4 cameras). The data are given of the beginning and at the end of the calibration period. The radial distortion was determined for four semidiagonals. Point interval in diagonals was 10 mm. Accuracy of radial distortion values is ± 2 um with AKG 1 and ± 1 um with the EVG 1. Data given for this study were:

1) Maximum and minimum values of mean radial distortion,
2) Asymmetry of radial distortion with the value of PPA-PBS, (1. order asymmetry),
3) The maximal difference between four semidiagonals with the PBS as reference point (indicator for 2. order asymmetry)in the image format area,

4) Quality of centering the lens with a circle where the principal points FC, PPA and PBS are situated,
5) The calibrated focal length.

The cameras were choosen so that there are good, normal and bad cases (Bormann and Schlienger /1/).

2.3 Helsinki University of Technology

The calibrations were carried out by the horizontal goniometer of the HUT. The calibration method is principally the same as that of Wild.

Characteristics determined were:
1) The calibrated focal length,
2) The mean radial distortion curve,
3) The radial component of decentering distortion and PPA-PBS,
4) The tangential component of decentering distortion,
5) The axis of the 0-value of tangential and that of the maximum value of radial component.

In the measurement of radial distortion, diagonals (20 points/radius) and diameters parallel to the frame sides (10 points/radius) were measured. All points were measured in two goniometer and grid positions, in total 4 observations/point. The standard error of one measurement is better than ± 2 um.

In the determination of tangential distortion the symmetrical component was measured in 4 or 12 diameters of the image format. The influence of measuring devices was totally eliminated. The standard error of the method is better than ± 0.5 um.

There were 2 cameras from Wild and 2 from Zeiss. Periods were from 6.5 to 9 years and numbers of calibrations 3-5/camera (Hakkarainen /2/).

	F_c	Mean rad.	PPA-PBS	Tan.	Decentering axes	Fiducial marks	2. order asymmetry
NRC	x	x	(x)			x	
Wild	x	x	x				x
HUT	x	x	x	x	x		

Table 3. Characteristics of lenses determined by different calibration institutes.

3 Changes in the calibrated focal length

The cfl seems to be remarkably stabile in the cameras studied. The annual changes were normally only a few um, a little more than the standard deviation of the determination of the cfl. The oldest Wild cameras C 1, C 4 and C 5 show greater deviations, but there are no significant differences between camera types.

The large changes of cameras F 2 and C 21 are caused by lens dismounting during the service by the manufacturer. The change in camera W 5 is with great probability caused by an accident in practice. Other 6 changes over 15 um (in cameras C 1,C 4, W 8 and C 17) are at present without explanation. These represent 3 % of the calibration periods studied.

The material also gives information about the precision of the determination of the cfl. The standard errors of all three calibration institutes seem to be below ± 5 um.

C 1	-74	-2
		-8
		1
		51 +
		-7
	-80	-84 +
C 2	-75	2
		-1
		2
		1
	-80	-1
C3	-74	-6
		4
		-1
		-3
	-80	-10
C 4	-74	-1
		-11
		46 +
		3
		-17 +
		0
		8
		8
	-80	-10
C 5	-74	-5
		12
		14
		-5
		1
		1
		9
	-81	-5
C 6	-74	6
		-4
		1
		0
		-2
		-1
	-81	-3
C 7	-74	-1
		-3
		2
		4
		1
		-6
		1
	-81	3
F 1	-74	2
		2
		5
		-1
	-81	1
W 1	-67	-1
	-80	
W 2	-68	6
	-82	
W 3	-68	-10
	-81	
W 4	-69	-5
	-80	
C 8	-74	-7
		-4
		6
		-5
		3
		-2
	-81	-3
C 9	-75	-3
		-2
		1
		0
		-4
		1
	-81	4
C 10	-74	1
		2
		-7
		4
		-3
		3
	-81	3
C 11	-75	2
		-3
		4
		7
		-12
	-81	1
C 12	-74	-5
		12
		-6
		-1
		2
		-5
	-80	0
C 13	-74	-3
		-1
		-3
		7
	-79	-7
C 14a	-75	-5
		1
		-6
	-80	3
C 14b	-75	0
		-2
		1
		0
		-2
	-80	3
F 2	-75	-58 +
		-5
		-23 +
	-84	2
W 5	-73	-91 +
	-81	
W 6	-74	2
	-80	
W 7	-74	0
	-80	
W 8	-74	21 +
	-83	
C 15	-73	5
		-1
		-5
		-4
		5
		-3
	-81	3
C 16	-74	2
		-3
		0
		-1
		5
		-4
	-81	-1
C 17	-74	-19 +
		1
		-3
		2
	-80	-4
C 18	-73	-7
		1
		2
		-4
		0
	-81	10
C 19	-74	-7
		5
		-4
		0
		-2
	-81	3
F 3	-74	-2
	-81	6
C 20	-74	-3
		3
		-1
		-3
		7
	-80	1
C 21	-74	1
		84 +
		-1
		-4
		2
	-80	1
C 22	-75	0
		2
		4
	-79	-3
C 23	-74	1
		-5
		4
		-2
	-80	10
F 4	-72	-3
		1
		0
		0
	-81	7
C 24	-75	-3
		0
		-5
	-81	-1
C 25	-76	-5
		-7
		4
		-3
	-80	15
C 27	-74	-1
		1
		-5
	-80	3
C 27	-74	4
		-3
	-76	-1

Table 4. Changes in the cfl between successive calibrations in um.

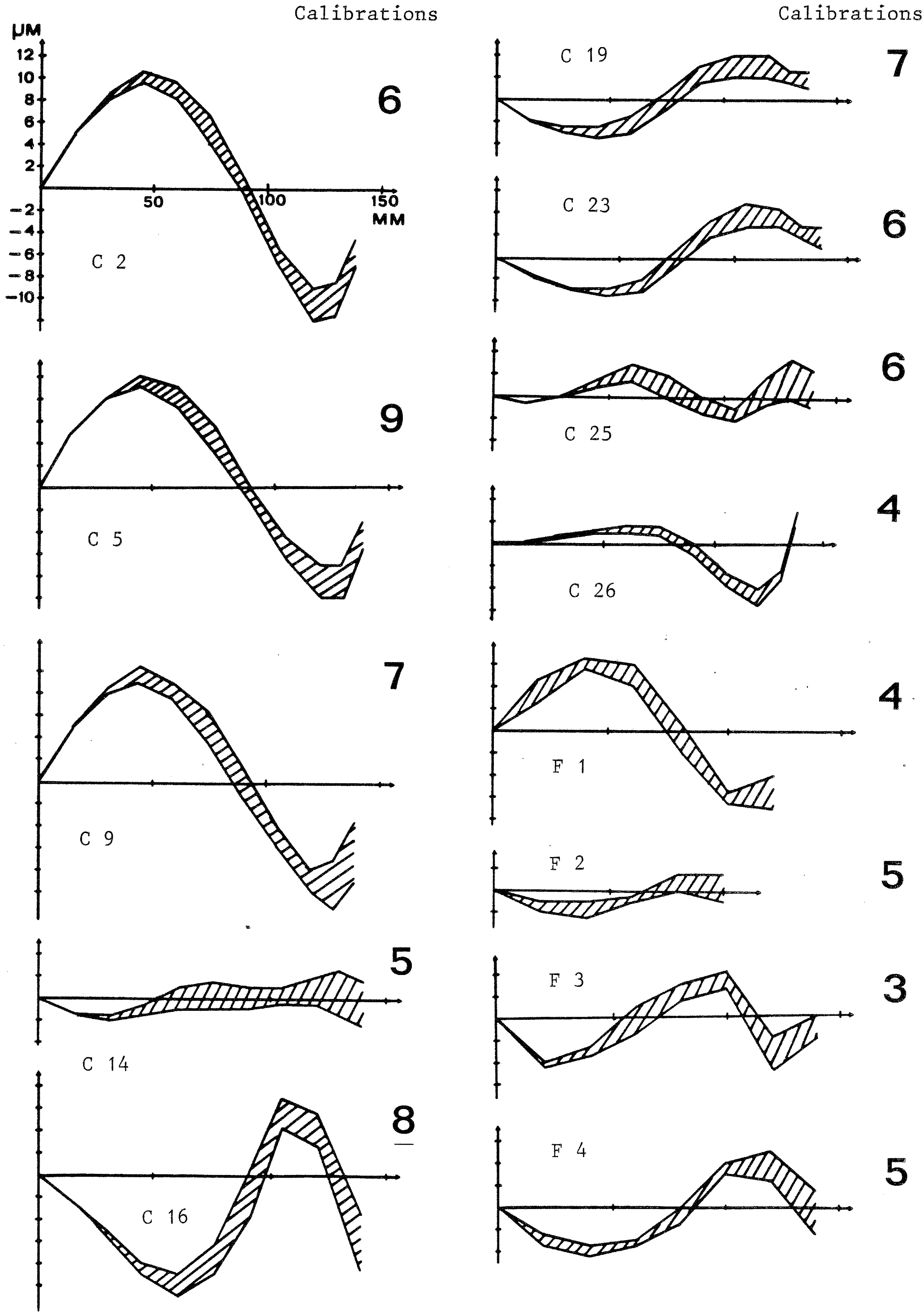


Fig. 1. Examples of changes in the mean radial distortion in different camera types.

The cfl of different lens types considered in the study vary as follows:

				Δ cfl mm	lenses
Wild	RC-8	15Ag		0.77	3
		15UAg		0.68	9
	RC-10	15UAg		0.69	4
		15UAg II		0.59	7
		8.8SAg II		0.98	4
Zeiss	RMK 15/23	Pleogon A2	5.6	0.41	6

4 Changes in the fiducial marks

The results are from the study of the NRC. All measured coordinates were transformed into an ideal fiducial mark coordinate system defined with the origin at the centre and with fiducial mark locations as follows:
Wild corner marks: (+106,+106),(+106,-106),(-106,-106),(-106,+106)
Zeiss side marks : (+130, 0),(0, +130),(-130, 0),(0, -130) all in mm.

The fiducial marks of all the studied 18 cameras of Wild and 6 cameras of Zeiss were very stabile. Residuals after linear conformal transformation were within a range of 5 um from the set average. The scale factor was in a range of 0.00006 for all of these cameras which means a 15 um change in the image side distance.

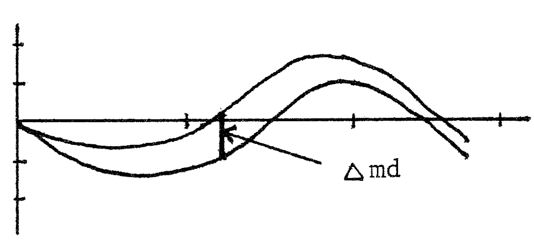
In camera C 19 it was verified that one fiducial mark had moved. The camera was repared. In camera C 20 one fiducial mark had moved between calibrations 1974 and -75 and another between calibrations 1977 and -80. The camera failed to meet the requirements of the specifications of Canada. Camera C 23 indicated scale changes as a result of changes of fiducial mark locations. The fiducial marks were reset.

5 Changes in mean radial distortion curve

The mean radial distortion curve is very stabile on the basis of calibrations of 39 cameras studied. In the following Table 5a there are results of the NRC and the HUT. Maximum difference in um between mean radial distortion curves in the distance from r = 0 mm to r = 100 mm is given for each camera.

	Δmd um		Δmd um		Δmd um
C 1	4.0	C 15	4.5	F 1	2.0
C 2	2.0	C 16	4.0	F 2	2.5
C 3	2.0	C 17	2.5	F 3	2.5
C 4	2.0	C 18	1.5	F 4	1.5
C 5	2.0	C 19	2.0		
C 6	1.5	C 20	3.0		
C 7	2.5	C 21	2.0		
C 8	2.0	C 22	1.5		
C 9	3.0	C 23	2.0		
C 10	2.0	C 24	1.5		
C 11	1.5	C 25	2.0		
C 12	1.5	C 26	1.0		
C 13	2.5	C 27	2.5		
C 14	2.0				

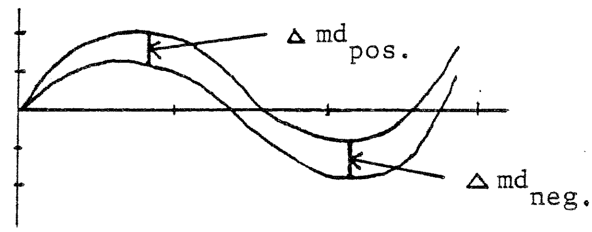
Table 5a. Changes in mean radial distortion curve in um, C and F cameras.



Wild gave maximum and minimum values of the mean radial distortion curve, in the beginning and at the end of the periods studied. In Table 5b there are changes of maximum and minimum values in um.

	$\Delta md_{pos.}$ um	$\Delta md_{neg.}$ um
W 1	6	1
W 2	5	0
W 3	0	0
W 4	0	1
W 5	1	12
W 6	1	1
W 7	1	1
W 8	2	2

Table 5b. Changes in mean radial distortion curve in um, W cameras.



We cannot verify any significant differences between Wild and Zeiss cameras concerning changes of the mean radial distortion curve. The age of a camera doesn't seem to be a factor either. In most cameras studied Δmd can on very good grounds be considered only scattering of the measuring method and laboratory environment. Camera W 5 is exceptionally bad and was choosen on purpose as an example.

The influence of changes of mean radial distortion presented here on the accuracy of terrain point coordinates determined by photogrammetric methods is obviously minimal. On page 6 there are examples of scattering of mean radial distortion curves of different camera types studied.

6 Changes in decentering distortion

The asymmetry of distortion of a camera can be caused by decentering of individual lens elements, by tensions between the lens elements and camera conus and in small amount also by the radial component when the camera frame plane is not perpendicular to the optical axis. These effects are discussed here together as "decentering distortion".

Both the radial and tangential component were studied. All three participants delivered slightly different material for this purpose. The data from the NRC was not yet final.

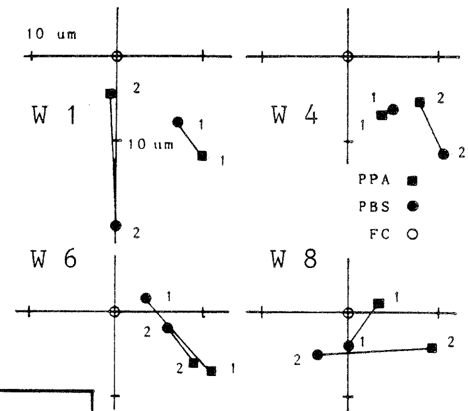
6.1 Changes of radial component

Canadian cameras

The direction of asymmetry was very accurately the same in 10 cameras, 1-2 calibrations differed from others in 10 cameras and the asymmetry and its direction changed remarkably in 7 cameras during the period studied. The asymmetry of all super-wide-angle cameras was very stabile. These results are just preliminary. Some control measurements are still going on.

Cameras studied by Wild

The direction of radial asymmetry changed remarkably in 6 cameras of 8 during the periods studied, but in only two cameras the distance PPA-PBS grew slightly above the allowed limit of 20 um. The distance PPA-PBS in the beginning and at the end of the periods studied is presented in Table 6. In column 2 there are values for the minimum diameter of a circle which includes the ponints PPA, PBS and FC. Four examples of changes in principal point positions are in Figs. 2a-2d. The maximum difference of distortions of semidiagonals which is an indicator for the asymmetry of 2. order, is seen in column 3. The changes are very small with the exception of camera W 5 which has probably been in accident, as mentioned.



Figs. 2a-2d. The positions of the PPA, PBS and FC in W cameras in the beginning and at the end of the period studied.

Camera	years	1 PPA-PBS um		2 Circle with PPA,PBS,FC um		3 Max.diff. of semidiagonals	
W 1	13	5	24	15	24	4	7
W 2	14.5	3	12	13	16	5	7
W 3	13	12	22	17	33	6	4
W 4	11	2	6	8	15	4	5
W 5	8.5	7	11	7	15	6	10
W 6	6.5	12	6	13	11	6	6
W 7	6	9	13	9	13	4	3
W 8	8.5	7	11	7	11	5	2

Table 6. Development in decentering distortion in W cameras.

Cameras studied in Finland

The direction and amount of radial asymmetry had changed very little in cameras F 3 and F 4. The changes observed were in the tolerances of measuring accuracy. Cameras F 1 and F 2 show clear changes in the direction and F 2 also in the amount of radial asymmetry. The large changes in camera F 4 are caused by a dismounting of the camera during normal service. Table 7. presents the the values of the distance PPA-PBS of cameras F 1 - F 4.

	Date	PPA-PBS um		Date	PPA-PBS um
F 1	Jan 74	5	F 3	Dec 74	16
	Jun 77	7		Feb 77	17
	Feb 78	6		Apr 81	20
	Sep 81	5	F 4	Jun 72	15
F 2	Apr 75	6		Dec 74	18
	Nov 78	10		Feb 77	18
	Nov 80	14		Jul 77	20
	Jan 82	9		Mar 81	19
	Mar 84	8			

Table 7. The values of the PPA-PBS distance for F cameras in um.

The observed changes in the radial component of decentering distortion in 10 cameras have no practical importance. Only in 2 cameras they can have an effect of a few um in a part of the image. Figs. 3a-3d. show changes of the radial components and relative positions of the PPA and PBS of the cameras F 1 - F 4.

6.2 Changes in tangential distortion

Figs. 4a-4d. show the changes of the tangential components of decentering distortion for cameras F 1 - F 4. For cameras F 3 and F 4 the changes

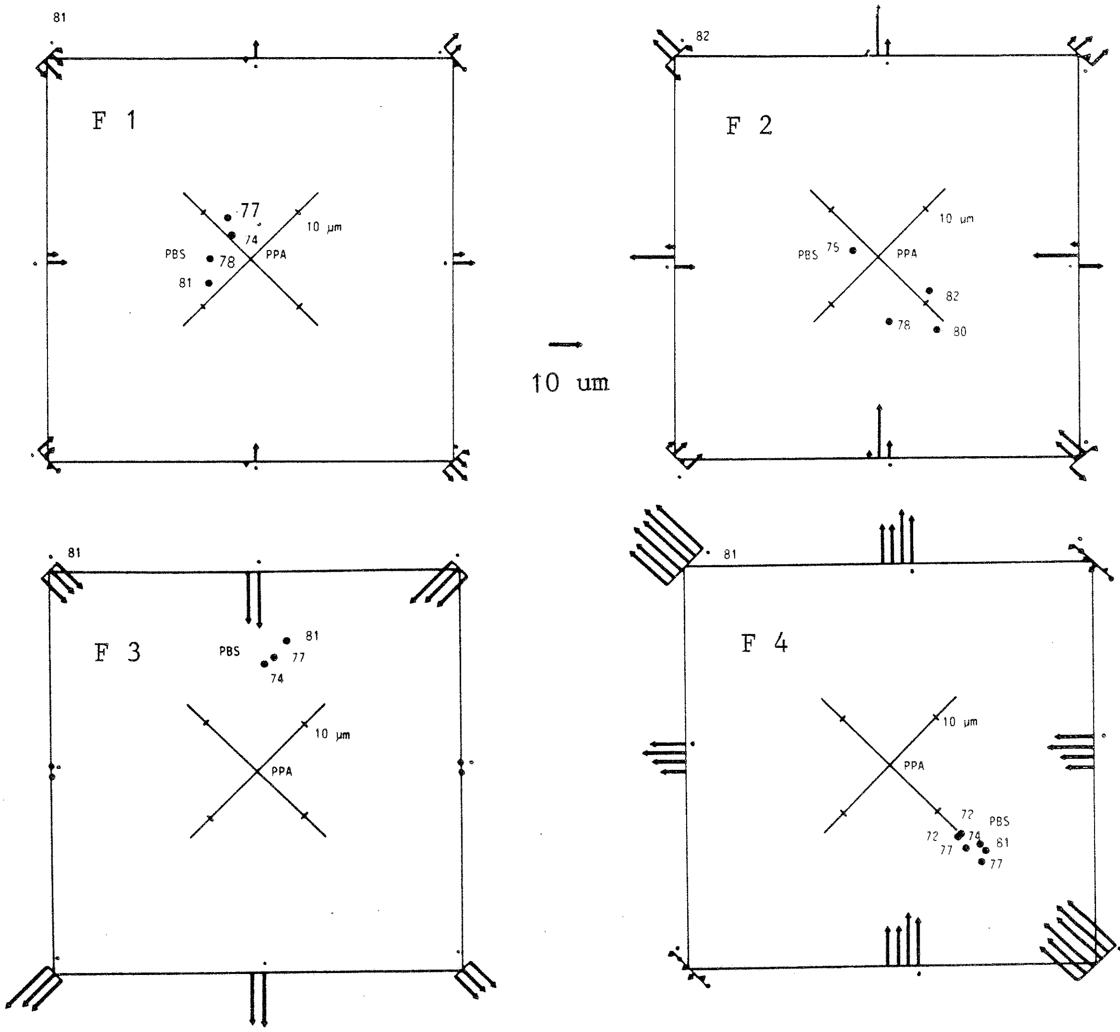


Fig. 3a-3d. Radial components of decentering distortion and mutual positions of the PPA and PBS for F cameras.

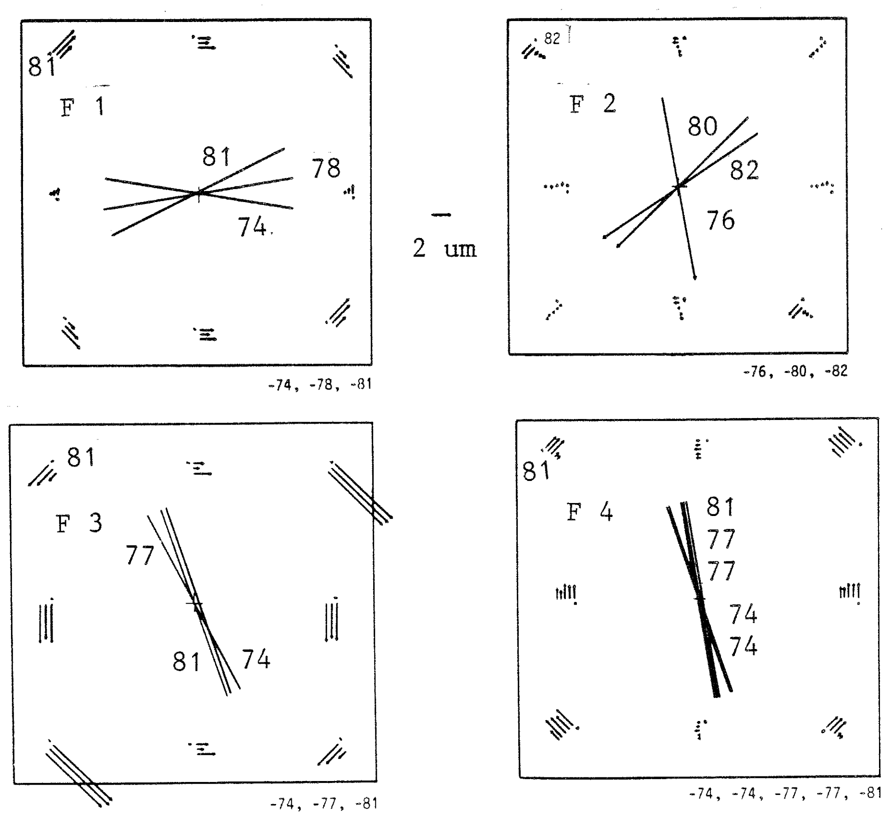


Fig. 4a-4d. Changes of the tangential component of decentering distortion for F cameras.

between calibrations were in the order of 1 um or less. The 0-axis of the tangential distortion was about in the same direction during the entire periods. The cameras F 1 and F 2 show small systematic changes in tangential distortion which are also in the order of 1 um between calibrations. The changes observed in the tangential distortion are in agreement with the changes observed in radial components. The all changes observed in tangential distortion have no practical importance.

CONCLUSION

The cfl had changed more than 15 um in 4 cameras of 39 caused by normal practical use in about 10 years. Dismounting of the camera in connection of a service often causes cfl changes of over 15 um. 3 cameras of 27 showed remarkable changes in fiducial marks. The mean radial distortion curve was the most stabile property of the cameras studied. No sibnificant differences between manufacturers could be observed regarding changes of distortion.

The dcentering distortion had changed more than the abovementioned properties, but only in 2 cameras studied it could have a small effect on the coordinates determined photogrammetrically.

On the basis of the calibration data of 40 cameras during periods of mainly from 6 to 10 years, the geometry of aerial cameras seems to be fairly stabile, if no strongly affecting outer factors occur. A recommendation for calibrations could be:

1) The camera must always be calibrated after an accident and after a service.
2) When the camera is used in normal practice a suitable calibration period could be 3 years.

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