

## ANALYTICAL MULTICOLLIMATOR CAMERA CALIBRATION

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### ABSTRACT

Tayman, W.P., 1978. Analytical multicollimator camera calibration. *Photogrammetria*, 34: 179—197.

Calibration with the U.S. Geological Survey multicollimator determines the calibrated focal length, the point of symmetry, the radial distortion referred to the point of symmetry, and the asymmetric characteristics of the camera lens. For this project, two cameras were calibrated, a Zeiss RMK A 15/23 and a Wild RC 8. Four test exposures were made with each camera. Results are tabulated for each exposure and averaged for each set. Copies of the standard USGS calibration reports are included.

### INTRODUCTION

Analytical multicollimator calibration was performed by the U.S. Geological Survey (USGS) on two aerial mapping cameras equipped with réseaus. Standard calibration procedure, including two additional test exposures, followed the method described by Bean (1962) and Tayman (1974).

The camera under test is placed on the calibrator in a mount similar to that used in a survey aircraft. Its position is adjusted to put the front nodal point of the lens at the point of intersection of the collimator axes. The focal plane frame is made perpendicular to the axis of the central collimator by use of an autocollimating telescope and the precision grid (réseau) plate in front of the image plane; normally a plane-parallel plate is placed on the focal plane. The camera is rotated in azimuth so that the images of the collimator targets lie along the diagonals of the focal plane frame.

Two photographic test plates are exposed — the first with the camera data strip to the left side of the test stand (position A), and the second with the camera rotated 180° from A (position B). For the special test two additional exposures were made with the camera rotated -15° and +15° from position A. The exposed plates were processed at 20° ± 0.3°C as follows:

Develop: 3 min, Kodak D-19  
Rinse: 20 s, Kodak Stop Bath  
Fix: 5 min, Kodak Rapid Fixer

Wash: 20 min, running water  
 Rinse: 20 s, Kodak Photo-Flo 200  
 Dry: Room temperature, horizontal position.

All target images on each negative were measured with a Mann monocomparator type 422F calibrated to  $1\ \mu\text{m}$ . The results were averaged and included in this report (tests 1 and 2). This method is a modification of the one described by Tayman (1974). The modification consists primarily of the additional test exposures with the camera rotated  $-15^\circ$  and  $+15^\circ$ .

Fig. 1 indicates the positions of the collimator targets as they appear in the

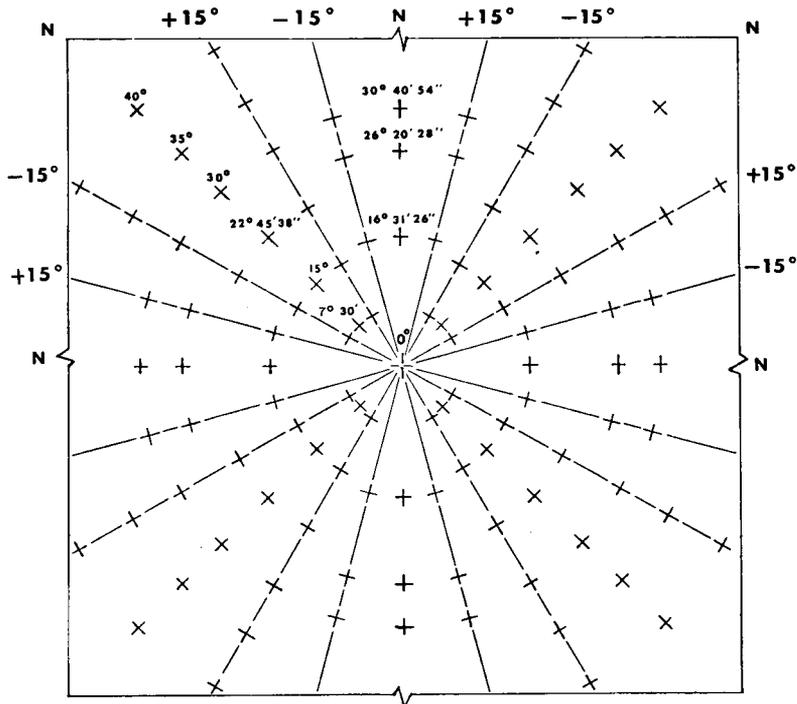


Fig. 1. Image positions of the collimator targets with camera in normal orientation (*N*) and rotated  $-15^\circ$  and  $+15^\circ$ .

field when the camera is rotated  $-15^\circ$  and  $+15^\circ$  from the normal location marked *N*.

The USGS calibration includes a least-squares solution that determines the calibrated focal length, the point of symmetry, the radial distortion referred to the point of symmetry, and the asymmetric characteristics of the camera lens. A separate solution is obtained for each exposure. The final results are the average of the independent solutions. Computations are described by Karren (1968).

For a complete evaluation of the camera system, the calibration also includes tests of stereomodel flatness and film resolution for wide-angle and super-wide-

angle cameras. After the glass test plates have been exposed, the magazine is loaded with Kodak Double-X Aerographic film, type 2405. At least twelve exposures are made in two or more positions, with the camera rotated  $90^\circ$ ,  $180^\circ$ , or  $270^\circ$  on the test stand. The camera under test is operated normally for the film exposures.

Small defects in the camera, such as variation from planarity of the film platen, irregularity of the film flattening system (vacuum), distortions, centering of the camera lens, and nonparallelism and wedge angle of the filter surfaces all contribute to the results of the stereomodel flatness evaluation.

The collimators are so arranged that a pair of diapositives made from films exposed in the calibrator can be placed in a plotting instrument and model flatness measured by stereoscopic observations at points in the overlap area, as shown in Fig. 2. However, in the current method the selected points are

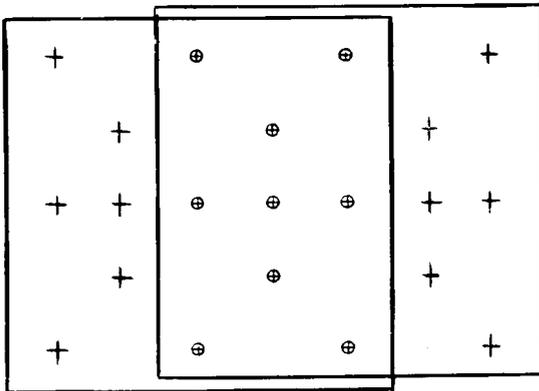


Fig. 2. Image positions used in stereomodel test.

measured with a monocomparator, and the model is produced analytically.

The target images, when projected stereoscopically, determine a nearly plane model whose base/height ratio is a function of the effective principal distance of the negatives. The base/height ratio is approximately 0.6 for wide-angle ( $90^\circ$ -field) and 1.0 for super-wide-angle ( $120^\circ$ -field) photographs. From the comparator measurements two sets of stereomodel deformation data are computed and averaged for the calibration report. Angular positions of the collimator used for cameras with a  $90^\circ$  field are shown in Fig. 3; additional collimators are used for cameras with a  $120^\circ$  field.

Any lack of stability in the test film can be detected and evaluated by rotating one or both diapositives of a pair  $90^\circ$ ,  $180^\circ$ , or  $270^\circ$ . Because the four quadrants of each negative are symmetrical, many combinations are possible. For example, the X-direction can be interchanged for Y, or one pair can be used in the X-direction and one in the Y-direction, or a continuous strip of stereopairs can be tested.

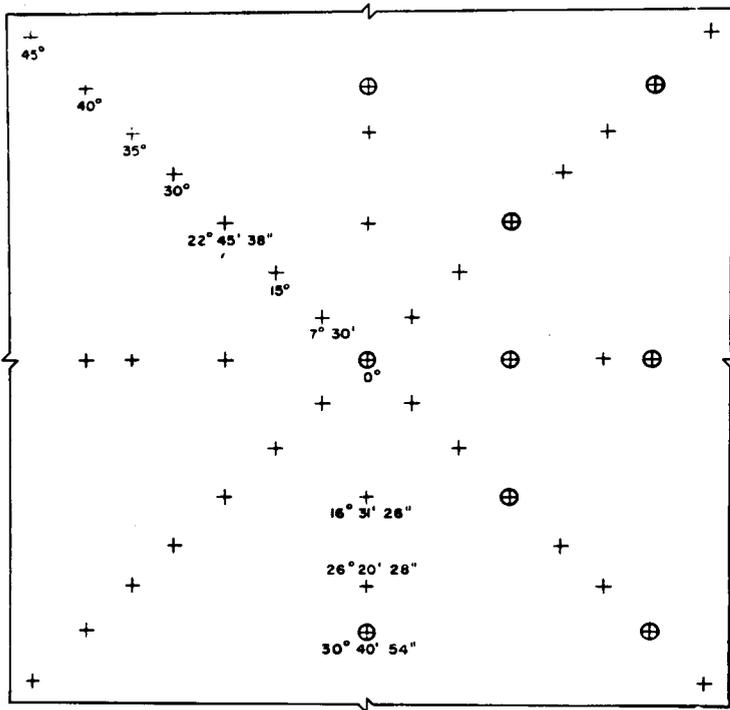


Fig. 3. Target images recorded by camera with  $90^\circ$  field. Stereomodel test positions are circled.

#### TEST 1

Camera:	Zeiss RMK AR 15/23 No. 21197
Lens:	Zeiss Pleogon AR No. 98222
Test aperture:	$f/5.6$
Date of test exposures:	January 31, 1975
Base:	0.25-in microflat glass
Emulsion:	Kodak Spectroscopic V-F
Number of target images measured:	109 per set of plates
Calibrated focal length	$152.058 \pm 0.002$ mm

Tables I–IV give the mean distortion for each plate and the standard error based on the plate residuals. These values are useful for comparing the quality of the plate measurements when more than one plate is made for the same camera.

Table V gives the mean values for the four sets.

Table VI gives lens-distortion correction values at 1-mm intervals.

TABLE I

## Camera in A Position

Field angle (deg)	Radial distance (mm)	Mean distortion ( $\mu\text{m}$ )	Standard deviation ( $\mu\text{m}$ )	Distortion range	
				lowest ( $\mu\text{m}$ )	highest ( $\mu\text{m}$ )
7.5	20.0	-12	3	-15	-9
15	40.7	-7	4	-11	-3
22.5	63.8	-5	2	-7	-4
30	87.8	2	1	1	3
35	106.5	2	2	0	4
40	127.6	4	1	2	5

Standard deviation of the  $x$ -coordinate = 0.00506

Standard deviation of the  $y$ -coordinate = 0.00506

Standard deviation of the calibrated focal length = 0.00170

Standard deviation of  $\omega$  (min) = 0.09938

Standard deviation of  $\phi$  (min) = 0.09938

Standard deviation of  $\kappa$  (min) = 0.03850

Standard deviation of unit weight (based on plate residuals) = 0.00536

Calibrated focal length = 152.056 mm

TABLE II

## Camera in B position

Field angle (deg)	Radial distance (mm)	Mean distortion ( $\mu\text{m}$ )	Standard deviation ( $\mu\text{m}$ )	Distortion range	
				lowest ( $\mu\text{m}$ )	highest ( $\mu\text{m}$ )
7.5	20.0	-12	4	-17	-8
15	40.7	-7	2	-9	-6
22.5	63.8	-5	3	-8	-3
30	87.8	3	1	1	4
35	106.5	2	2	-1	3
40	127.6	3	2	0	6

Standard deviation of the  $x$ -coordinate = 0.00500

Standard deviation of the  $y$ -coordinate = 0.00500

Standard deviation of the calibrated focal length = 0.00168

Standard deviation of  $\omega$  (min) = 0.09827

Standard deviation of  $\phi$  (min) = 0.09827

Standard deviation of  $\kappa$  (min) = 0.03807

Standard deviation of unit weight (based on plate residuals) = 0.00530

Calibrated focal length = 152.059 mm

TABLE III

Camera in A position  $-15^\circ$ 

Field angle (deg)	Radial distance (mm)	Mean distortion ( $\mu\text{m}$ )	Standard deviation ( $\mu\text{m}$ )	Distortion range	
				lowest ( $\mu\text{m}$ )	highest ( $\mu\text{m}$ )
7.5	20.0	-11	4	-16	-8
15	40.7	-6	3	-11	-3
22.5	63.8	-4	2	-6	-3
30	87.8	2	3	-1	6
35	106.5	0	2	-1	4
40	127.6	4	3	1	7

Standard deviation of the  $x$ -coordinate = 0.00459Standard deviation of the  $y$ -coordinate = 0.00459

Standard deviation of the calibrated focal length = 0.00154

Standard deviation of  $\omega$  (min) = 0.09013Standard deviation of  $\phi$  (min) = 0.09013Standard deviation of  $\kappa$  (min) = 0.03492

Standard deviation of unit weight (based on plate residuals) = 0.00486

Calibrated focal length = 152.059 mm

TABLE IV

Camera in A position  $+15^\circ$ 

Field angle (deg)	Radial distance (mm)	Mean distortion ( $\mu\text{m}$ )	Standard deviation ( $\mu\text{m}$ )	Distortion range	
				lowest ( $\mu\text{m}$ )	highest ( $\mu\text{m}$ )
7.5	20.0	-11	3	-15	-8
15	40.7	-8	3	-11	-5
22.5	63.8	-5	1	-6	-5
30	87.8	3	1	2	4
35	106.5	0	1	-1	1
40	127.6	4	1	3	6

Standard deviation of the  $x$ -coordinate = 0.00489Standard deviation of the  $y$ -coordinate = 0.00489

Standard deviation of the calibrated focal length = 0.00164

Standard deviation of  $\omega$  (min) = 0.09596Standard deviation of  $\phi$  (min) = 0.09597Standard deviation of  $\kappa$  (min) = 0.03718

Standard deviation of unit weight (based on plate residuals) = 0.00518

Calibrated focal length = 152.058 mm

TABLE V

Mean values for the four sets

Field angle (deg)	Radial distance (mm)	Mean distortion ( $\mu\text{m}$ )	Standard deviation ( $\mu\text{m}$ )
7.5	20.0	-12	1
15	40.7	-7	1
22.5	63.8	-5	0
30	87.8	2	0
35	106.5	1	1
40	127.6	4	1

Calibrated focal length = 152.058 mm

TABLE VI

Mean radial-distortion correction values (in  $\mu\text{m}$ ) at 1-mm intervals from axis to 150 mm off axis

Intervals (mm)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
1-14	1.	1.	2.	2.	3.	3.	4.	4.	5.	5.	6.	6.	6.	7.	7.
15-28	7.	7.	8.	8.	8.	8.	9.	9.	9.	9.	9.	9.	9.	9.	9.
29-42	10.	10.	10.	10.	10.	10.	10.	10.	10.	10.	10.	9.	9.	9.	9.
43-56	9.	9.	9.	9.	9.	8.	8.	8.	8.	8.	8.	7.	7.	7.	7.
57-70	7.	7.	6.	6.	6.	6.	5.	5.	5.	5.	4.	4.	4.	4.	4.
71-84	3.	3.	3.	3.	2.	2.	2.	2.	1.	1.	1.	0.	0.	0.	0.
85-98	0.	0.	-1.	-1.	-1.	-1.	-2.	-2.	-2.	-2.	-2.	-3.	-3.	-3.	-3.
99-112	-3.	-3.	-3.	-3.	-4.	-4.	-4.	-4.	-4.	-4.	-4.	-4.	-4.	-4.	-4.
113-126	-4.	-4.	-4.	-4.	-4.	-4.	-4.	-4.	-4.	-4.	-3.	-3.	-3.	-3.	-3.
127-140	-3.	-2.	-2.	-2.	-2.	-1.	-1.	-1.	0.	0.	1.	1.	1.	1.	2.
141-150	2.	3.	4.	4.	5.	5.	6.	7.	7.	8.					

## REPORT 1

**Camera:** Zeiss RMK AR 15/23 No. 21197  
**Lens:** Zeiss Pleogon AR No. 98222  
**Date of test exposures:** January 31, 1975  
**Base:** 0.25-in microflat glass  
**Emulsion:** Kodak Spectroscopic V-F  
**Number of target images measured:** 25 per plate  
**Calibrated focal length:** 152.058  $\pm$  0.002 mm  
 For further details see the standard U.S. Geological Survey Report of Calibration.



## United States Department of the Interior

GEOLOGICAL SURVEY  
RESTON, VIRGINIA 22092

## REPORT OF CALIBRATION

October , 1975

of Aerial Mapping Camera

Camera type	<u>Zeiss RMK AR 15/23</u>	Camera serial no.	<u>21197</u>
Lens type	<u>Zeiss Pleogon AR</u>	Lens serial no.	<u>98222</u>
Nominal focal length	<u>153 mm</u>	Maximum aperture	<u>f/5.6</u>
		Test aperture	<u>f/5.6</u>

Submitted by

Commission I, Image Geometry

International Society of Photogrammetry

Reference: Letter dated July 27, 1973 from Dr. H. Ziemann

These measurements were made on Kodak micro flat glass plates, 0.25 inch thick with spectroscopic emulsion type V-F Panchromatic, developed in D-19 at 68°F for 3 minutes with continuous agitation. These photographic plates were exposed on a multicollimator camera calibrator using a white light source rated at approximately 3500K.

I. Calibrated Focal Length: 152.058 mm

This measurement is considered accurate within 0.005 mm

II. Radial Distortion:

Field angle (degrees)	$\bar{D}_c$ μm	$D_c$ for azimuth angle			
		0° A-C	90° A-D	180° B-D	270° B-C
7.5	-12	-11	-13	-13	-12
15	-7	-9	-9	-6	-6
22.5	-5	-5	-3	-6	-6
30	2	1	3	2	3
35	2	1	1	2	3
40	3	2	3	4	4

The radial distortion is measured for each of 4 radii of the focal plane separated by 90° in azimuth. To minimize plotting error due to distortion, a full least-squares solution is used to determine the calibrated focal length.  $\bar{D}_c$  is the average distortion for a given field angle. Values of distortion  $D_c$  based on the calibrated focal length referred to the calibrated principal point (point of symmetry) are listed for azimuths 0°, 90°, 180°, and 270°. The radial distortion is given in micrometres and indicates the radial displacement of the image from its ideal position for the calibrated focal length. A positive value indicates a displacement away from the center of the field. These measurements are considered accurate within 5 μm.

III. Resolving power in cycles/mm Area-weighted average resolution 48.9

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	113	113	95	57	28	28	34
Tangential lines	113	80	57	57	67	48	24

The resolving power is obtained by photographing a series of test bars and examining the resulting image with appropriate magnification to find the spatial frequency of the finest pattern in which the bars can be counted with reasonable confidence. The series of patterns has spatial frequencies from 5 to 113 cycles/mm in a geometric series having a ratio of the 4th root of 2. Radial lines are parallel to a radius from the center of the field, and tangential lines are perpendicular to a radius.

IV. Filter Parallelism

The two surfaces of the B No. 14480, D No. 15497, and KL No. 15438 filters accompanying this camera are within ten seconds of being parallel. The B filter was used for the calibration.

V. Shutter Calibration

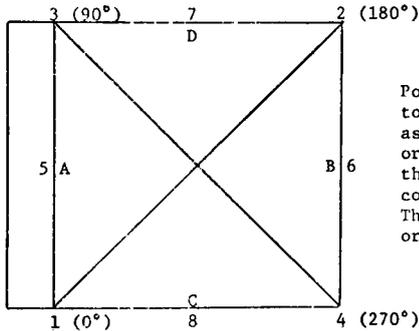
(Not Applicable)

Indicated shutter speed      Effective shutter speed      Efficiency

The effective shutter speeds were determined with the lens at aperture  $f/$ . The method is considered accurate within 3%. The technique used is Method I described in American National Standard PH3.48-1972.

VI. Magazine Platen

The platen mounted in FK 24/120 film magazine No. 110026 does not depart from a true plane by more than 13  $\mu$ m (0.0005 in).

VII. Principal Point and Fiducial Coordinates

Positions of all points are referenced to the principal point of autocollimation as origin. The diagram indicates the orientation of the reference points when the camera is viewed from the back, or a contact positive with the emulsion up. The direction-of-flight fiducial marker or data strip is to the left.

	<u>X coordinate</u>	<u>Y coordinate</u>
Indicated principal point, corner fiducials	-0.006 mm	-0.026 mm
Indicated principal point, midside fiducials	-0.004	-0.024
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	0.041	0.001

Fiducial Marks

1	-100.028 mm	-100.044 mm
2	100.006	99.988
3	-100.020	99.993
4	100.003	-100.044
5	-113.026	-0.020
6	113.002	-0.028
7	-0.005	112.993
8	-0.009	113.045

VIII. Distances Between Fiducial Marks

Corner fiducials (diagonals)

1-2 282.890 mm      3-4 282.884 mm

Lines joining these markers intersect at an angle of 89° 59' 55"

Midside fiducials

5-6 226.028 mm      7-8 226.038 mm

Lines joining these markers intersect at an angle of 89° 59' 56"

Corner fiducials (perimeter)

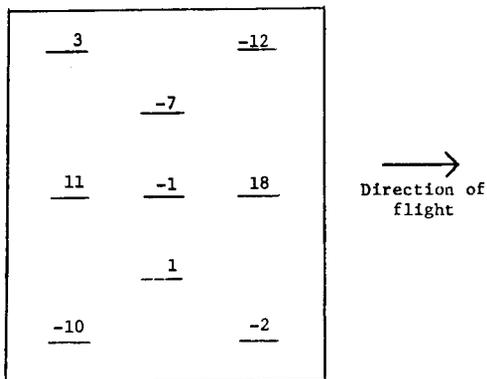
1-3 200.037 mm      2-3 200.026 mm

1-4 200.031 mm      2-4 200.032 mm

The method of measuring these distances is considered accurate within 0.005 mm.

STEREOMODEL FLATNESS TEST AND FILM RESOLUTION

Camera No. 21197      Lens No. 98222      Magazine No. 110026  
 Focal length 152.058 mm      Maximum angle of field tested 40°  
 Base-height ratio 0.6      Accuracy of determination 5 μm



Stereomodel  
 Test point array  
 (values in micrometres)

The values shown on the diagram are the average departures from flatness (at negative scale) for two computer-simulated stereomodels based on comparator measurements on contact glass (Kodak micro flat) diapositives made from Kodak 2405 film exposures.

Resolving Power, in cycles/mm      Area-weighted average resolution 27.7  
 Film: Type 2405

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	48	40	40	28	24	24	24
Tangential lines	48	40	34	28	28	28	20

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## TEST 2

Camera:	Wild RC8 R No. 107
Lens:	Wild Universal-Aviogon UAg R10
Test aperture:	$f/5.6$
Date of test exposures:	February 3, 1975
Base:	0.25-in microflat glass
Emulsion:	Kodak Spectroscopic V-F
Number of target images measured:	109 per set of plates
Calibrated focal length:	$152.148 \pm 0.002$ mm

Tables VII—X give the mean distortion for each plate and the standard error based on the plate residuals. These values are useful for comparing the quality of the plate measurements when more than one plate is made for the same camera.

Table XI gives the mean values for the four sets.

Table XII gives the lens-distortion correction values at 1-mm intervals.

TABLE VII

Camera in A position

Field angle (deg)	Radial distance (mm)	Mean distortion ( $\mu\text{m}$ )	Standard deviation ( $\mu\text{m}$ )	Distortion range	
				lowest ( $\mu\text{m}$ )	highest ( $\mu\text{m}$ )
7.5	20.0	4	1	2	5
15	40.7	6	2	5	8
22.5	63.8	4	1	2	5
30	87.8	-1	1	-2	1
35	106.5	-5	2	-7	-3
40	127.6	-4	2	-6	-2

Standard deviation of the  $x$ -coordinate = 0.00339

Standard deviation of the  $y$ -coordinate = 0.00339

Standard deviation of the calibrated focal length = 0.00114

Standard deviation of  $\omega$  (min) = 0.06648

Standard deviation of  $\phi$  (min) = 0.06648

Standard deviation of  $\kappa$  (min) = 0.02575

Standard deviation of unit weight (based on plate residuals) = 0.00359

Calibrated focal length = 152.150 mm

TABLE VIII

Camera in B position

Field angle (deg)	Radial distance (mm)	Mean distortion ( $\mu\text{m}$ )	Standard deviation ( $\mu\text{m}$ )	Distortion range	
				lowest ( $\mu\text{m}$ )	highest ( $\mu\text{m}$ )
7.5	20.0	4	1	3	5
15	40.7	6	1	6	7
22.5	63.8	4	2	2	7
30	87.8	0	2	-2	2
35	106.5	-6	2	-8	-4
40	127.6	-4	4	-9	-1

Standard deviation of the  $x$ -coordinate = 0.00383Standard deviation of the  $y$ -coordinate = 0.00383

Standard deviation of the calibrated focal length = 0.00129

Standard deviation of  $\omega$  (min) = 0.07513Standard deviation of  $\phi$  (min) = 0.07513Standard deviation of  $\kappa$  (min) = 0.02910

Standard deviation of unit weight (based on plate residuals) = 0.00405

Calibrated focal length = 152.150 mm

TABLE IX

Camera in A position  $-15^\circ$ 

Field angle (deg)	Radial distance (mm)	Mean distortion ( $\mu\text{m}$ )	Standard deviation ( $\mu\text{m}$ )	Distortion range	
				lowest ( $\mu\text{m}$ )	highest ( $\mu\text{m}$ )
7.5	20.0	3	1	2	5
15	40.7	6	2	4	7
22.5	63.8	3	1	3	4
30	87.8	-1	2	-4	1
35	106.5	-6	3	-8	-2
40	127.6	-4	4	-7	0

Standard deviation of the  $x$ -coordinate = 0.00340Standard deviation of the  $y$ -coordinate = 0.00340

Standard deviation of the calibrated focal length = 0.00114

Standard deviation of  $\omega$  (min) = 0.06664Standard deviation of  $\phi$  (min) = 0.06665Standard deviation of  $\kappa$  (min) = 0.02581

Standard deviation of unit weight (based on plate residuals) = 0.00360

Calibrated focal length = 152.149 mm

TABLE X

Camera in A position +15°

Field angle (deg)	Radial distance (mm)	Mean distortion ( $\mu\text{m}$ )	Standard deviation ( $\mu\text{m}$ )	Distortion range	
				lowest ( $\mu\text{m}$ )	highest ( $\mu\text{m}$ )
7.5	20.0	4	1	2	4
15	40.7	6	1	4	8
22.5	63.8	4	1	3	6
30	87.8	-1	2	-3	0
35	106.5	-6	3	-9	-3
40	127.6	-2	4	-7	2

Standard deviation of the  $x$ -coordinate = 0.00337Standard deviation of the  $y$ -coordinate = 0.00337

Standard deviation of the calibrated focal length = 0.00113

Standard deviation of  $\omega$  (min) = 0.06610Standard deviation of  $\phi$  (min) = 0.06610Standard deviation of  $\kappa$  (min) = 0.02560

Standard deviation of unit weight (based on plate residuals) = 0.00357

Calibrated focal length = 152.144 mm

TABLE XI

Mean values for the four sets

Field angle (deg)	Radial distance (mm)	Mean distortion ( $\mu\text{m}$ )	Standard deviation ( $\mu\text{m}$ )
7.5	20.0	4	0
15	40.7	6	0
22.5	63.8	4	0
30	87.8	-1	0
35	106.5	-6	0
40	127.6	-3	1

Calibrated focal length = 152.148 mm

TABLE XII

Mean radial-distortion correction values (in  $\mu\text{m}$ ) at 1-mm intervals from axis to 150 mm off axis

Intervals (mm)														
1-14	0.	-1.	-1.	-1.	-2.	-2.	-2.	-3.	-3.	-3.	-3.	-4.	-4.	-4.
15-28	-4.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-6.	-6.	-6.	-6.	-6.
29-42	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.
43-56	-6.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-4.	-4.	-4.	-4.
57-70	-4.	-4.	-4.	-3.	-3.	-3.	-3.	-3.	-3.	-2.	-2.	-2.	-2.	-2.
71-84	-2	-1.	-1.	-1.	-1.	-1.	0.	0.	0.	0.	0.	1.	1.	1.
85-98	1.	1.	1.	2.	2.	2.	2.	2.	2.	3.	3.	3.	3.	3.
99-112	3.	3.	3.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.
113-126	4.	4.	4.	4.	5.	5.	4.	4.	4.	4.	4.	4.	4.	4.
127-140	4.	4.	4.	4.	4.	4.	3.	3.	3.	3.	3.	2.	2.	2.
141-150	2.	1.	1.	1.	1.	0.	0.	0.	-1.	-1.				

## REPORT 2

Camera: Wild RC8 R No. 107  
 Lens: Wild Universal-Aviogon UAg R10  
 Date of test exposures: February 3, 1975  
 Base: 0.25-in microflat glass  
 Emulsion: Kodak Spectroscopic V-F  
 Number of target images measured: 25 per plate  
 Calibrated focal length: 152.150 mm  $\pm$  0.002 mm  
 For further details see the standard U.S. Geological Survey Report of Calibration.

Form 9-1780  
(rev. 8-75)

USGS Report No. RT-R/ISP-2

## United States Department of the Interior

GEOLOGICAL SURVEY  
RESTON, VIRGINIA 22092

REPORT OF CALIBRATION October , 1975

of Aerial Mapping Camera

Camera type <u>Wild Heerbrugg RC8R</u>	Camera serial no. <u>107</u>
Lens type <u>Wild Universal Aviogon</u>	Lens serial no. <u>UAg R10</u>
Nominal focal length <u>152 mm</u>	Maximum aperture <u>f/5.6</u>
	Test aperture <u>f/5.6</u>

Submitted by  
Commission I, Image Geometry  
International Society of Photogrammetry  
Reference: Letter dated July 27, 1973 from Dr. H. Ziemann

These measurements were made on Kodak micro flat glass plates, 0.25 inch thick with spectroscopic emulsion type V-F Panchromatic, developed in D-19 at 68°F for 3 minutes with continuous agitation. These photographic plates were

exposed on a multicollimator camera calibrator using a white light source rated at approximately 3500K.

I. Calibrated Focal Length: 152.150 mm

This measurement is considered accurate within 0.005 mm

II. Radial Distortion:

Field angle (degrees)	$\bar{D}_c$ $\mu\text{m}$	$D_c$ for azimuth angle			
		0° A-C $\mu\text{m}$	90° A-D $\mu\text{m}$	180° B-D $\mu\text{m}$	270° B-C $\mu\text{m}$
7.5	4	4	4	2	4
15	6	5	6	7	8
22.5	4	3	6	3	3
30	-1	-2	1	-2	1
35	-6	-8	-5	-7	-4
40	-4	-7	-2	-4	-1

The radial distortion is measured for each of 4 radii of the focal plane separated by 90° in azimuth. To minimize plotting error due to distortion, a full least-squares solution is used to determine the calibrated focal length.  $\bar{D}_c$  is the average distortion for a given field angle. Values of distortion  $D_c$  based on the calibrated focal length referred to the calibrated principal point (point of symmetry) are listed for azimuths 0°, 90°, 180°, and 270°. The radial distortion is given in micrometres and indicates the radial displacement of the image from its ideal position for the calibrated focal length. A positive value indicates a displacement away from the center of the field. These measurements are considered accurate within 5  $\mu\text{m}$ .

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III. Resolving power in cycles/mm Area-weighted average resolution 58.2

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	95	95	95	57	80	67	17
Tangential lines	95	67	57	57	67	57	40

The resolving power is obtained by photographing a series of test bars and examining the resulting image with appropriate magnification to find the spatial frequency of the finest pattern in which the bars can be counted with reasonable confidence. The series of patterns has spatial frequencies from 5 to 113 cycles/mm in a geometric series having a ratio of the 4th root of 2. Radial lines are parallel to a radius from the center of the field, and tangential lines are perpendicular to a radius.

IV. Filter Parallelism

The two surfaces of the 450 Pan No. 1527, and 600 Pan No. 2880 filters accompanying this camera are within ten seconds of being parallel. The 450 filter was used for the calibration.

V. Shutter Calibration

(Not Applicable)

Indicated shutter speed      Effective shutter speed      Efficiency

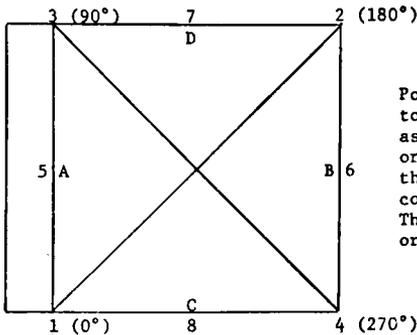
The effective shutter speeds were determined with the lens at aperture  $f/$   
The method is considered accurate within 3%. The technique used is Method 1  
described in American National Standard PH3.48-1972.

VI. Magazine Platen

The platen mounted in Wild RC8 film magazine No. 238  
does not depart from a true plane by more than 13  $\mu$ m (0.0005 in).

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VII. Principal Point and Fiducial Coordinates



Positions of all points are referenced to the principal point of autocollimation as origin. The diagram indicates the orientation of the reference points when the camera is viewed from the back, or a contact positive with the emulsion up. The direction-of-flight fiducial marker or data strip is to the left.

	<u>X coordinate</u>	<u>Y coordinate</u>
Indicated principal point, corner fiducials	0.008 mm	0.022 mm
Indicated principal point, midside fiducials	0.013	0.021
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	-0.002	-0.002

Fiducial Marks

1	-106.108 mm	-106.098 mm
2	106.119	106.137
3	-106.108	106.135
4	106.131	-106.098
5	-110.107	0.019
6	110.130	0.023
7	0.008	110.137
8	0.017	-110.103

VIII. Distances between Fiducial Marks

Corner fiducials (diagonals)

1-2 300.140 mm      3-4 300.146 mm

Lines joining these markers intersect at an angle of 90° 00' 0"

Midside fiducials

5-6 220.237 mm      7-8 220.240 mm

Lines joining these markers intersect at an angle of 89° 59' 55"

Corner fiducials (perimeter)

1-3 212.233 mm      2-3 212.227 mm  
 1-4 212.239 mm      2-4 212.235 mm

The method of measuring these distances is considered accurate within 0.005 mm.

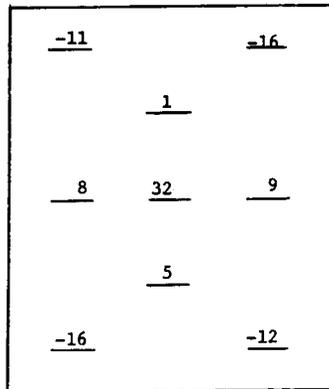
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STEREOMODEL FLATNESS TEST AND FILM RESOLUTION

Camera No. 107      Lens No. UAg R10      Magazine No. 238

Focal length 152.150 mm      Maximum angle of field tested 40°

Base-height ratio 0.6      Accuracy of determination 5 μm



→  
Direction of flight

Stereomodel  
 Test point array  
 (values in micrometres)

The values shown on the diagram are the average departures from flatness (at negative scale) for two computer-simulated stereomodels based on comparator measurements on contact glass (Kodak micro flat) diapositives made from Kodak 2405 film exposures.

Resolving Power, in cycles/mm      Area-weighted average resolution 33.3  
 Film: Type 2405

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	48	40	48	40	40	40	17
Tangential lines	48	40	40	34	34	28	24

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## REFERENCES

- Bean, R.K., 1962. U.S. Geological Survey camera calibrator. Paper presented at ACSM-ASP Annual Convention, Washington, D.C.
- Karren, R.J., 1968. Camera calibration by the multicollimator method. *Photogramm. Eng.*, 34 (7): 706-719.
- Tayman, W.P., 1974. Calibration of lenses and cameras at the USGS. *Photogramm. Eng.*, 40 (11): 1331-1334.