CORRELATION OF DATA FROM VARIOUS METHODS OF AERIAL CAMERA CALIBRATION

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Aerial mapping cameras must be accurately calibrated to determine the radial and tangential distortions in the lens-camera system and to compute the calibrated focal length of the camera if aerial maps with a high degree of accuracy are to result. The Air Force first used the field calibration range for calibrating aerial cameras; this calibration range was constructed at Wright-Patterson Air Force Base. Similar ranges were constructed later at Brookley Air Force Base (MOAMA) and Hill Air Force Base (OOAMA) for use of the depots in maintaining Air Force cameras.

Although the calibration range is an accurate method of calibrating mapping cameras, considerable space is required for this type of installation and its use is often inconvenient and limited by weather conditions. An accurate laboratory method, therefore, would be more desirable. Two laboratory devices--the collimator bank and the goniometer --are in current use by commercial and governmental agencies for camera calibration. The National Bureau of Standards has used a multicollimator bank for a number of years, and the Fairchild Camera & Instrument Corporation uses an instrument of similar principle. In order to produce a collimator-type instrument of simpler design, a contract was negotiated several years ago with the Perkin-Elmer Corporation, and an instrument was built for the Aerial Reconnaissance Laboratory. In the collimator-type instruments (and the field range, also) the cameras are calibrated by reproducing special targets photographically on glass plates, measuring their images on a comparator, and analyzing the results mathematically to produce a calibrated camera focal length and a lens distortion curve.

The T-4 goniometer is a commercial device developed by the Wild Instrument Company. This instrument provides a visual method of camera calibration by permitting the observer to view the target against a graduated plate through the lens of the camera. This particular goniometer measures radial distortion but cannot measure tangential distortion; the Wild Company has developed a later model with a filar-type eyepiece which can be used to measure both radial and tangential distortion.

Although close correlation was known to exist between computations made on the field range and on the collimating devices, no information was available as to their correlation with the goniometer technique. A series of tests was conducted to determine this correlation. This report presents the results of these tests.

This paper updates a Technical Report written by the author and published as WADD Technical Report 60-423, "Correlation of Data from Various Methods Camera Calibration", 5 March 1959, Wright Air Development Division.

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DESCRIPTION OF CALIBRATION EQUIPMENT AND TECHNIQUES

During the past several years, considerable work has been done to improve calibration techniques and equipment. Existing equipment has been improved in many ways. Mathematical equations have been perfected for calibrating the low-distortion lenses, particularly lenses for the Type KC-1 camera.

FIELD CALIBRATION RANGE

A number of improvements were made to the field calibration range shown in Figure 1, located at Wright-Patterson Air Force Base. A horizontal camera mount was designed and installed in the camera calibration building. A device that would enable the camera's optical axis to be centered closely on the central target and the format diagonal to be aligned precisely with the line of targets was designed and constructed. Targets were repainted and light leaks eliminated from the calibration building. All targets were positioned with their center crosses on a geodetic level, and the angles between target centers were measured. The special glass-plate holder for the camera was reworked to prevent the plate from being bent during calibration.

No action was taken to bring the vertical camera mount into use, which would provide further means for calibration. If the vertical mount is considered desirable, the target angles must be measured and the calibration results correlated with those of the horizontal camera station.

COLLIMATING CALIBRATOR

The collimating calibrator developed by the Perkin-Elmer Company is shown in Figure 2. Considerable difficulty has been experienced with this instrument from drift in the collimator tubes. The drift was caused by strains in the base positioning system and by vibrations from the light source transformers mounted on the rear of the collimator tubes. Considerable effort has been directed toward eliminating the drift, including installing large lock washers on the bolts of the collimator barrels and mounting them on the adjacent concrete base. Although these changes have reduced target displacements considerably, the instrument still cannot be used for calibration unless the target angles are measured with the T-2 theodolite just prior to the calibration.

Efforts are continuing to eliminate drift in this instrument. No results of its calibration have been correlated with calibrations by other devices as yet.

GONIOMETER

The goniometer shown in Figure 3 was procured from the Wild Instrument Company. Early tests with this device produced results that were at some variance with calibrated focal lengths determined by the field range and the Fairchild multicollimator. As a result, use of this

method for calibrating aerial cameras was not considered seriously for some time. By experimenting with a number of filter and light combinations, however, we found that we could approximate the calibrations obtained with the field range and multicollimator if the target plates were adequately illuminated. A combination of No. 73 Wratten filter and a flourescent light source provided optimum results.

TEST PROCEDURES AND RESULTS

CORRELATION

Since lens calibration data obtained from the goniometer when using the fluorescent light source and a No. 73 Wratten filter appeared to closely approximate the calibration data obtained from photographic methods, we conducted a series of tests to see how closely the two methods correlated. Camera lens Type T-11, No. XF-2256, was selected for the tests. Closely correlated calibration data already were available on this lens from the Fairchild Camera and Instrument Corporation's multicollimator and from the field calibration range. Results of these calibrations are presented in Table 1.

When comparing the results of calibrations in Table 1, a maximum deviation of 10 microns appears between the radial distortion curves for the goniometer and the multicollimator. The maximum deviation between the curves for the field range and the multicollimator is 3 microns.

REPEATABILITY

Further tests were conducted to determine whether the same precision could be obtained with repeated tests. Data was first recorded when using the No. 73 Wratten filter and a tungsten light source. Results of each of the calibrations were tabulated, and curves were drawn from an average of the four diagonal halves for each. These curves show that 75 percent of the targets fall within ± 1 micron and 94 percent within ± 3 microns of the average deviation. The remaining 6 percent of the targets, measured at angles of $45^{\circ}27'$ and $46^{\circ}40'$, fall within 5 to 6 microns of the average.

Similar calibrations were made on Type KC-1 camera lens cone No. XF-6765, using the goniometer with a No. 73 Wratten filter and a fluorescent light source. Four individuals recorded the results of seven observations. Plots of these readings indicated that 76 percent of the points fall within ± 1 micron of the mean and 97 percent within ± 3 microns. In addition, 84 percent of the readings of each diagonal fall within ± 3 microns of the mean. The adjusted average distortions for each observer and the mean for the group are presented in Table 2; the mean is plotted as a single distortion curve in Figure 4, as compared with the multicollimator calibrator.

Further comparisons of the KC-1 camera lens results, obtained on the T-4 Goniometer by each operator, and the calibration certificate published by Fairchild Camera & Instrument Corporation, show the largest deviation from the photographic method is 7 microns, with 86 percent of the readings within ±5 microns and 61 percent of the readings within ±3 microns. The calibrated focal length has better correlation, with three operators within 1 micron of the photographic method and one operator each at 2, 3, 4 and 7 microns deviation.

CONCLUSIONS

Calibrations made with the Wild T-4 goniometer equipped with a No. 73 Wratten filter on the eyepiece and a fluorescent light source to illuminate the targets are sufficiently accurate for aerial mapping cameras. Results of calibrations made with the goniometer closely correlate those made with the field calibration range and the multicollimator. Readings made by four individuals in several observations agreed closely, indicating that a high degree of precision can be attained with this device.

Only radial distortions could be measured with the goniometer tested. A new graduated plate having plus-type (+) targets and a filar-type eyepiece, however,would permit calibrating tangential distortions as well. A new model of the goniometer has such improvements.

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Table 1

Correlation of Visual and Photographic Methods of Camera Calibration
(T-11 Lens Cone No. XF-2256)

Method of Calibration			Lens Aperture (f-stop)	CFL (mm)	D_{max} (mm)	Observer	Remarks
Multicollimator (Fairchild)			6.3	152.95	0.12	Mrs. Norton	Recorded
" "			6.3	152.95	0.114	Mrs. Norton	Read from curve
Field Range (WADC)			6.3	152.959	0.114	Sgt. Spriggs	
Wild T-4 Goniometer (WADC)							
Light	Filter	Wave Length					
Tungsten	660 mμ	660 mμ	6.3	152.901	0.111	Sgt. Spriggs	
"	None	520 →	6.3	152.954	0.112	Sgt. Spriggs	Poor Image
"	#44	520-580	6.3	152.974	0.116	Sgt. Spriggs	
"	#23 & #38	570-660	6.3	152.932	0.109	Sgt. Spriggs	
"	#73	560-590;	6.3	152.940	0.113	Sgt. Spriggs	
"	"	690 →					
"	"	"	6.3	152.944	0.113	Mr. Berndsen	
"	"	"	6.3	152.947	0.114	Mr. Sewell	
"	"	"	11	152.947	0.115	Sgt. Spriggs	
"	"	"	6.3	152.922	0.115	Mr. Kosofsky	Lens not centered
"	"	"	6.3	152.939	0.114	Sgt. Spriggs	
Fluorescent	"	560-590	6.3	152.944	0.113	Sgt. Spriggs	

Table 2

Correlation of Wild T-4 Goniometer Calibrations
Planigon Lens XF-6765

TARGET	SPRIGGS #1	LIVINGSTON #1	SEWELL	LIVINGSTON #2	BERNDSEN	LIVINGSTON #3	SPRIGGS #2	AVERAGE
CFL →	152.574	152.582	152.574	152.579	152.573	152.574	152.572	152.575
21	- 8	-15	-11	-15	-10	-17	-12	-13
20	+ 1	- 5	+ 3	- 4	+ 3	0	+ 1	0
19	+ 8	+ 8	+10	+ 6	+ 6	+10	+ 2	+ 7
18	+ 12	+11	+11	+11	+11	+11	+10	+11
17	+ 13	+11	+13	+10	+14	+12	+12	+12
16	+ 12	+12	+13	+ 9	+14	+10	+10	+11
15	+ 8	+ 8	+10	+ 7	+ 8	+ 8	+ 6	+ 8
14	+ 6	+ 5	+ 7	+ 4	+ 6	+ 5	+ 4	+ 5
13	+ 2	+ 2	+ 2	- 1	+ 4	+ 1	+ 2	+ 2
12	+ 1	0	- 1	- 1	+ 1	- 1	- 7	- 1
11	- 3	- 4	- 6	- 6	- 5	- 7	- 7	- 5
10	-12	- 9	- 9	-10	- 7	- 8	-11	- 9
9	-11	-11	-12	-12	-13	-11	-12	-12
8	-10	-11	-14	-10	- 9	-12	-12	-11
7	-10	-10	-11	-10	-12	-10	-10	-10
6	- 6	- 6	- 7	- 7	- 5	- 6	- 7	- 6
5	- 4	- 4	- 6	- 4	- 2	- 3	- 6	- 4
4	- 3	- 2	- 4	- 4	- 2	- 2	- 2	- 3
3	- 2	- 2	- 4	- 2	0	- 1	- 2	- 2
2	- 1	- 2	- 1	- 1	+ 1	0	- 1	- 1
1	+ 1	0	0	0	+ 2	0	0	0
0	0	0	0	0	0	0	0	0

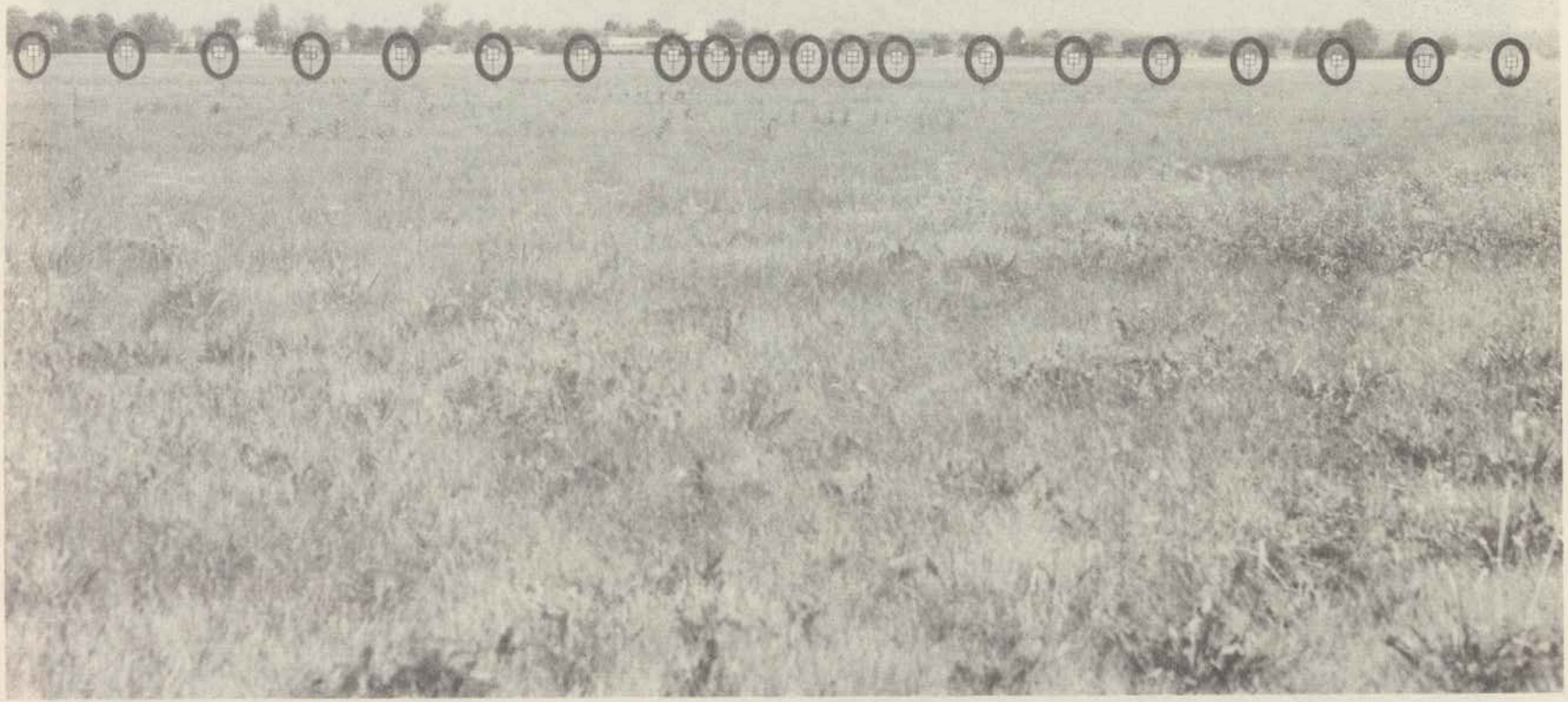

Figure 1. Field Calibration Range

Figure 2. Distortion Calibrator
on Concrete Pier

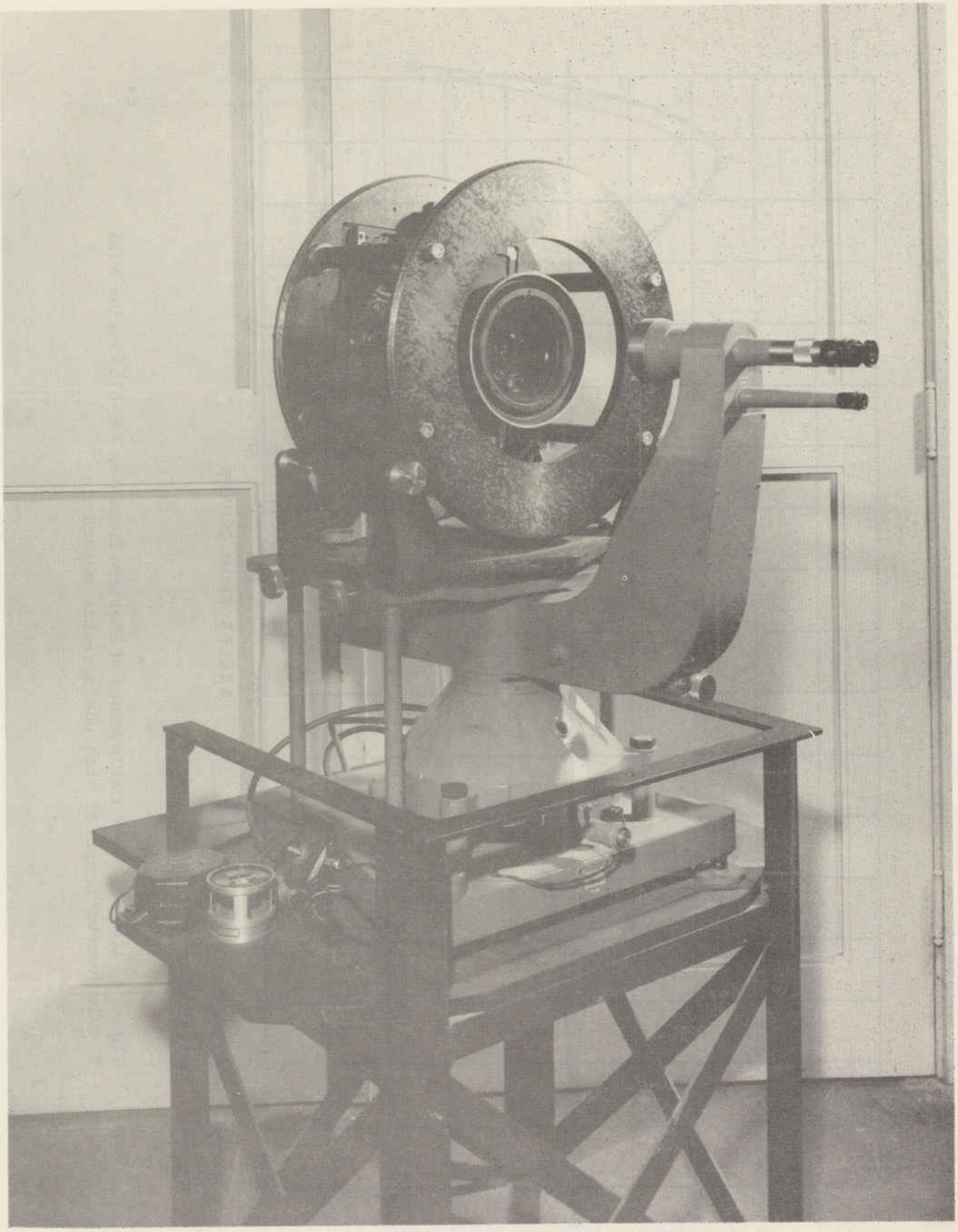

Figure 3. Goniometer

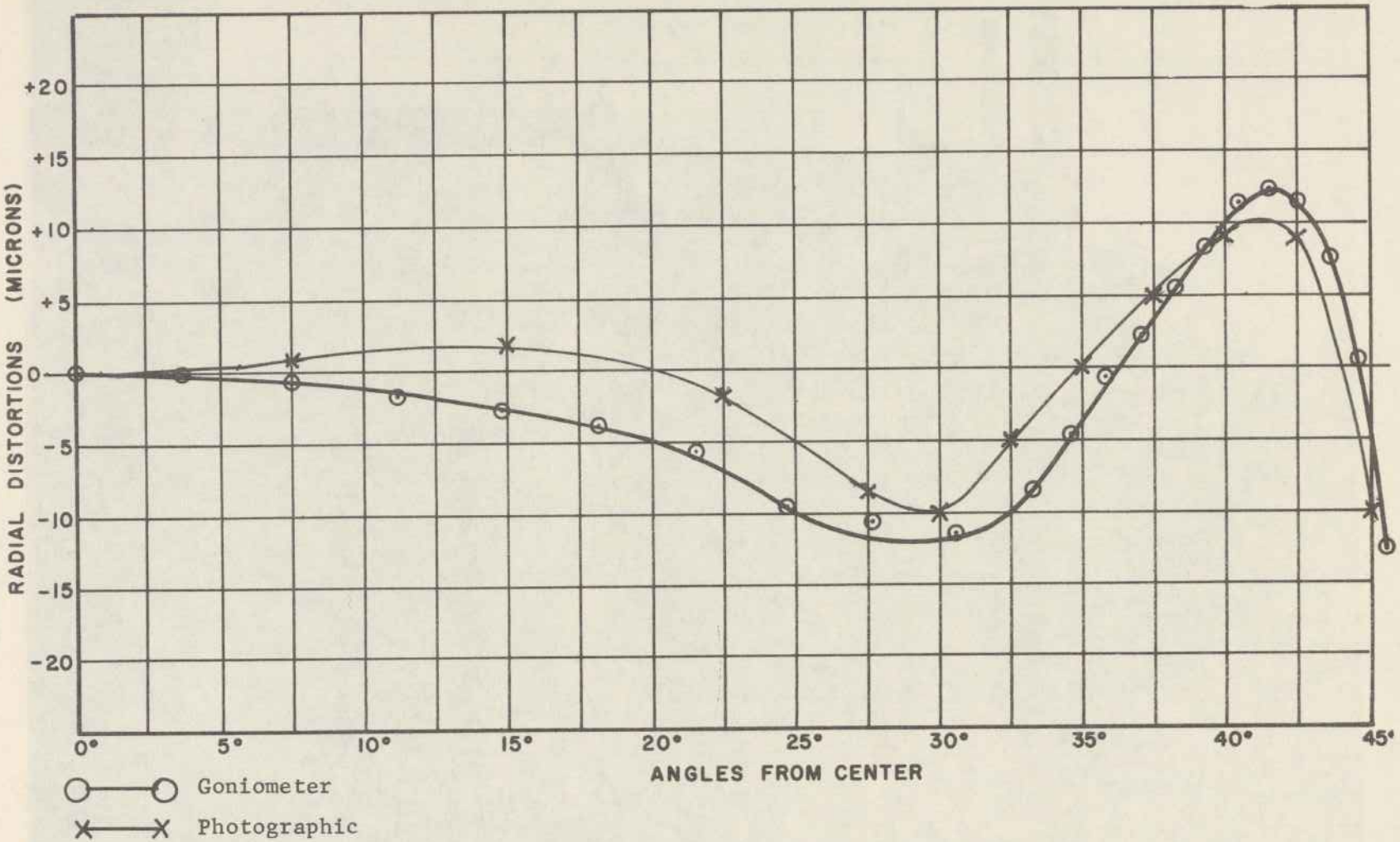

Figure 4. Mean of Seven Calibrations of Planigon Lens No. XF-6765 on the Wild T-4 Goniometer Compared with photographic method