

SYMMETRY OF THE MTF OF AERIAL CAMERAS

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ABSTRACT

A camera calibration system for aerial cameras was developed at the Helsinki University of Technology in 1970-74. In connection with geometrical calibrations, test photographs for measuring the resolving power and MTF were also taken for several cameras. Later MTFs for four semidiagonals of six cameras were calculated. There were four field angles for each of the four radii. Generally, the symmetry of the MTF of cameras studied was surprisingly good. Especially in the newest cameras, the symmetry of the MTF both in radial and tangential directions was almost perfect. Based on the MTF measurements, the author has developed a criterion for the quality of aerial cameras.

Key words: Camera, Image Quality, Optical, Photogrammetry

1 INTRODUCTION

The newest measuring and mapping instrument generation used in practice has created new demands for the aerial images because of their accuracy. The quality of better lenses can now be fully exploited. This requires also the use of FMC.

Image evaluation of mapping cameras should now also be made by using more complete methods. Today all big manufacturers give data about the performance of their aerial cameras by using resolving power values from the middle to the corner of the photograph exposed on a certain film in the camera. The emulsion of this film is not necessarily used in normal aerial photography. The RP information is undeniably very useful, especially when the sensitivity of the emulsion corresponds the films used in aerial photography.

The RP values obtained in laboratory tests correspond rather well with the situation in aerial photography without forward and transverse image motion and effects of atmosphere and aeroplane vibrations.

MTF is used mainly in the development of prototypes. It could also be useful to give data about the performance of aerial lenses by using MTF values.

If we had optical MTF values of the lens, we could complete the simulative values of an aerial image for every film by combining the MTF values of the film given by the manufacturer and the MTF values of the lens obtained in a calibration. When we also combine the MTF value of forward image motion with these results we have a rather realistic simulation result for the quality of an aerial photograph. An MTF measurement by using test photography is also possible, but an MTF measurement of a lens in laboratory is much more practical and cheaper than an MTF determination from aerial photographs which have been taken of a test field. MTF determinations without test fields not accurate enough.

Technically the MTF measurement of whole aerial cameras has been solved. For example in Europe we have several such facilities which have been designed especially for mapping cameras and are reliable enough.

We only need a sensible criterion based on the MTF. The criterion must be so good that big camera manufacturers consider that the use of it gives valuable enough information for calibration certificates so that it is advantageous to use it. Many proposals have been made by several researchers to solve this problem. It is decisive how many MTF measurements of an aerial lens are needed to characterize the quality of the lens and the quality of the aerial image taken with the lens. To be able to decide the number of MTF measurements needed from different field angles, we must know the symmetry of the lenses in general. In this article the author gives new information about MTF and its asymmetry in some normal aerial lens types. All measured 6 aerial cameras are of different types.

2 THE METHOD USED FOR DETERMINING THE MTF

The goniometer of the Helsinki University of Technology was used for the MTF measurements of aerial cameras. In this method, the test target groups are on the frame plane of the camera to be studied. The figures are photographed through an observer telescope with an enlargement of about 10x on the film of the register camera. The MTF measurement is made so that it corresponds the object distance of infinity. The main steps of the method are the following:

1. Test photography through the observer telescope of the goniometer.
2. Sensitometric exposure of the register film and construction of the characteristic curve.
3. Microdensitometer measurement of the test figures on the register film.
4. Microdensitometer values are converted to effective exposure values using the characteristic curve.
5. Calculation of the square-wave modulation $(\max - \min) / (\max + \min)$.
6. Square-wave modulation is converted to sine-wave modulation MTF by using Fourier analysis.
7. Correction of microdensitometer slit and object figure modulation, some percent in total.
8. The MTF of the register film and the adjacency effect of the same film act in opposite directions. These errors and the MTF of the relay optics of the goniometer remain as error factors of the method.

The results of an aerial lens measured by using this method were compared with the corresponding results obtained by using the Eros Ealing method at the PTB Braunschweig in 1979. The HUT method gave on an average 7 % higher values than that of the PTB. The precision of the method is a few percent.

3 THE MTF DETERMINATIONS AND RESULTS OF 6 CAMERAS

The MTFs of 6 cameras of different types and ages were measured. The cameras had been manufactured by Wild Heerbrugg, Car Zeiss Oberkochen and VEB Carl

Zeiss JENA. All six cameras were of different types. The measurements were made by using full aperture, which was 4 - 5.6. The cameras had been manufactured as follows:

Camera	Year	Photography in the goniometer
Camera 1	1960s	30.8.79
Camera 3	1970s	20.3.77
Camera 4		20.10.86
Camera 2	1980s	24.4.82
Camera 5		31.1.85
Camera 6		25.1.85

The MTFs of four different semidiagonals were measured for radial and tangential lines in the following 9 field angles:

r (mm)	0	20	40	60	80	100	118	132	141
0°	0	7.5	14.5	21.5	27.5	33.0	37.5	40.5	42.5

The field angles come from the places of the figures in the test plate. In addition, resolving power determinations were made from photographs taken of these same test figures placed in four diagonals.

Photography of the RP test figures has been made in connection with other investigations. The MTFs of these test films have been then computed later for trend and symmetry curves.

In many cases the total RPs (AWAR) of the studied cameras could have been better, if the focusing had been changed.

According to experiences gained from RP profile curves, the situation concerning these curves in the plane of best focusing is in general about as follows:

- The correction of spherical aberration decides the height of the curves.
- Field curvature decides the shape of the RP curves.
- Coma decides the steepness of an RP curve.

Optimization of the focusing changes these three main characteristics of the lens. The curve of field curvature could explain many deformations of targets used in aerial photography.

The measurements of MTF symmetry are the most important task of this study. Therefore the MTFs for four semidiagonals are presented separately in Fig. 2. The field angles for cameras 1, 3, 4, 5 and 6 are 0°, 14.5°, 27.5° and 37.5°, and for camera 2 0°, 7.5°, 27.5° and 40.5°. The symmetry of MTF is in general surprisingly good. The age of the camera seems to be the most important factor affecting the distribution of the MTF curves. The newest cameras, 5 and 6, have almost total symmetry of MTF. Field angles for different camera types are not always the same because the test photography was initially made for other purposes.

4 A PROPOSAL FOR ROUTINE LENS QUALITY TESTS IN MAPPING CAMERA CALIBRATION

MTF should be taken to one criterion for lens quality in mapping camera calibration. The use of MTF makes tests more objective and gives possibility for automation. Here is a proposal for an image quality test, with some comments:

- 1) Determination of the RP values of four semidiagonals of the frame plane in at least 6 field angles. The determination can be made for only optics or for a photograph using at least a 100 ASA film. At present, the RP determination is always made for calibration certificates by manufacturers, but the sensitivity used can be much smaller than 100 ASA and so the granularity of the test film much smaller than that of the film used in practice.
- 2) It shall be considered which semidiagonal gives a profile nearest to the average RP values of the camera. The MTF is measured on this semidiagonal in at least 4 field angles, e.g. 0°, 20°, 30° and 40° (or r = 0, 60, 100 and 125 mm in an aerial photograph) for radial and tangential lines. The relative aperture of 1:5.6 is used. Because the symmetry of MTF in mapping cameras is in general very good, the choice of the radius where the MTF measurements will be performed can be made as above.
- 3) For symmetry control, the MTF is measured on every semidiagonal in the field angle of 30°. The MTF of the optical axis is measured also with maximum aperture, which in modern aerial cameras very often is 1:4.
- 4) The results will be presented in the calibration certificate, e.g. as AWAM or then all MTF trend curves are given.
- 5) The MTF value which corresponds the spatial frequency of 30 cycles/mm is taken from the AWAM curve as the criterion of lens quality. It is only one number and the information given by it is about the same as the AWAM, a usual criterion in calibration certificates, but its objectivity is greater.

In MTF calibration measurements only 8 determinations for (R) and (T) lines = 16 curves are needed. All measurements should be made by using minus blue filter in white light. The available method, however, affects the light possible to use in the measurement. Fig. 3. shows points and field angles recommended by the author for MTF measurements in connection of camera calibration:

Full aperture	00
MTF trend, aperture 5.6	0, 1, 2, 3
MTF symmetry	21, 22, 23, 24

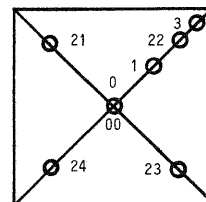


Fig. 3. Recommended MTF measurement points in an aerial image.

One possibility for a criterion is the use of Transfer Index (See Fig. 4. and Table 3.). The author has developed it for comparing aerial cameras with each other. The steps for TI_{30} are as follows:

1. The choice of the semidiagonal for MTF measurements.
2. MTF measurements of at least four field angles. The method used for MTF determinations can be chosen freely in wide limits.
3. Average MTF value for cycles/mm = 30 for every field angle.
4. TI_{30} is area weighted MTF of point 3.

The Transfer Index is only one number which describes the image quality of the lens and it is equally as useful as the AWAR.

Camera	1.	2.	3.	4.	5.	6.
r (mm)						
0	65	33	54	73	70	57
20	67	36	54	77	66	58
40	57	35	31	75	46	53
60	40	36	20	70	34	42
80	23	32	13	55	23	32
100	26	22	12	38	20	25
118	34	15	6	29	17	22
132	8	11	1	25	13	19
141	5	7	0	24	8	18

Table 1. Values of the MTFs (%) when cycles/mm = 30. The camera 4. is clearly the best. MTF values are averages of (R) and (T).

Camera	1.	2.	3.	4.	5.	6.
r (mm)						
0	1	0	-1	1	-1	-3
20	0	-4	5	-1	-7	11
40	-16	-7	-22	-3	-26	-1
60	-31	-6	-22	-4	-19	-9
80	-15	-6	-11	3	-9	-10
100	27	9	3	8	-4	12
118	30	11	3	8	5	13
132	-7	11	0	10	6	10
141	-9	9	0	11	3	5

Table 2. Values of the $MTF_{(R)} - MTF_{(T)}$ (%), an indicator for astigmatism when cycles/mm = 30. MTF values are averages of four semidiagonals.

Fig. 1. Different criterions for six aerial cameras.
 a) Optical RP (Determination from register films) of lenses (MTF = about 4 %).
 b) Thick lines: Curves for MTF = 10 %
 Thin lines : Curves for MTF = 30 %
 R = continued line
 T = dotted line

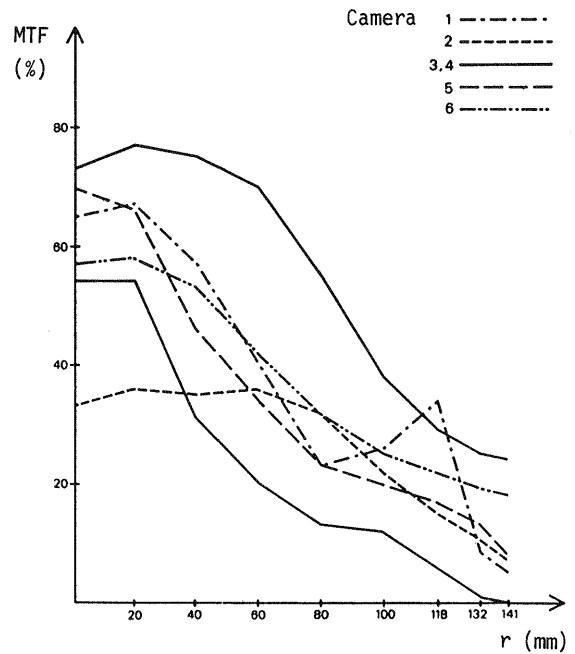
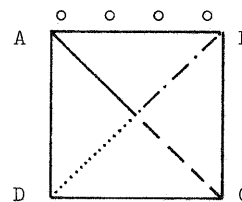


Fig. 4. Values of MTFs (%) when cycles/mm = 30.

Camera	1.	2.	3.	4.	5.	6.
TI_{30}	31	25	16	49	26	32

Table 3. TI_{30} (%) when cycles/mm = 30. Distribution between cameras is large.



The markings of MTF symmetry curves in Figs 2a-2f

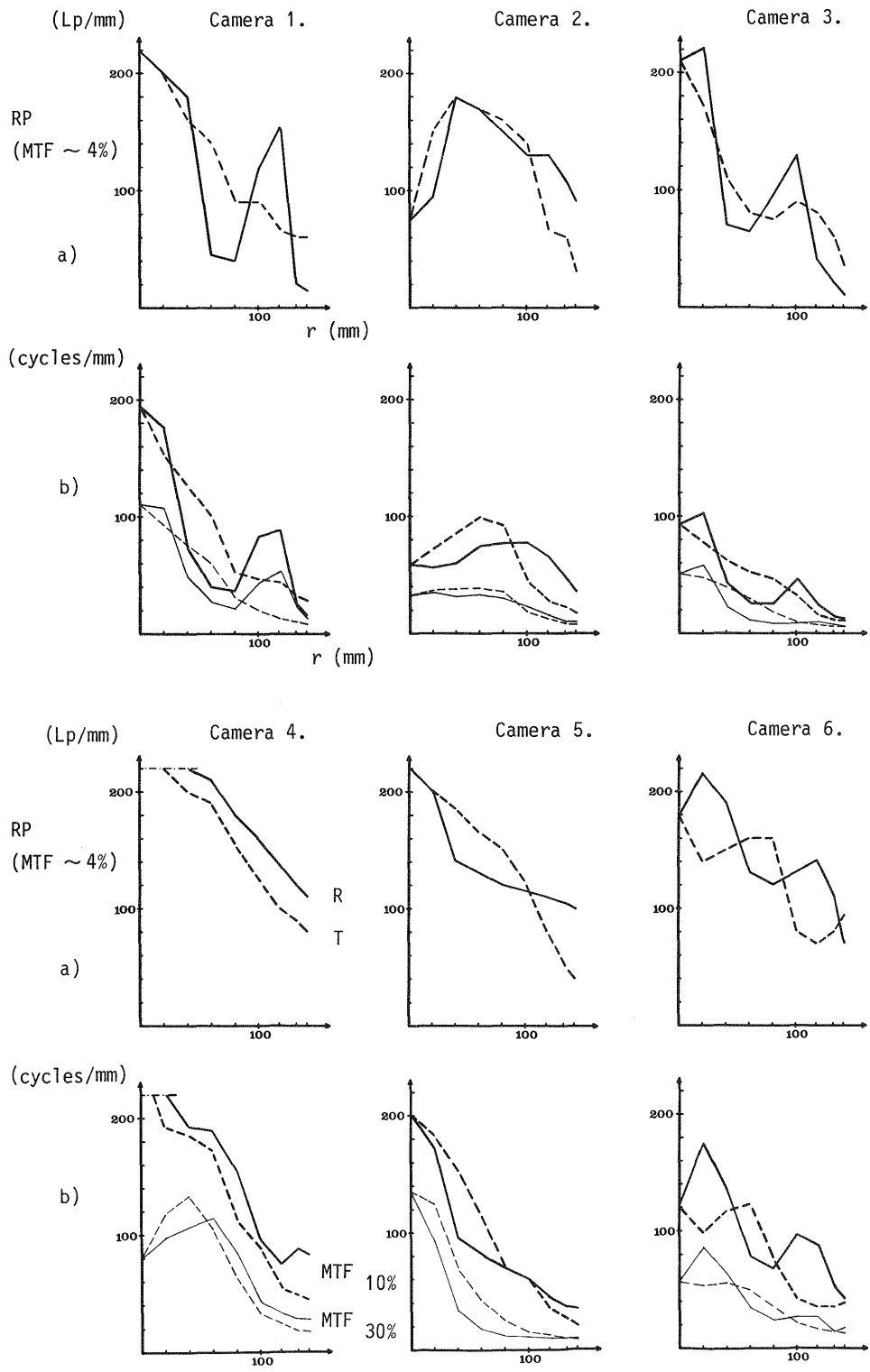


Fig. 1.

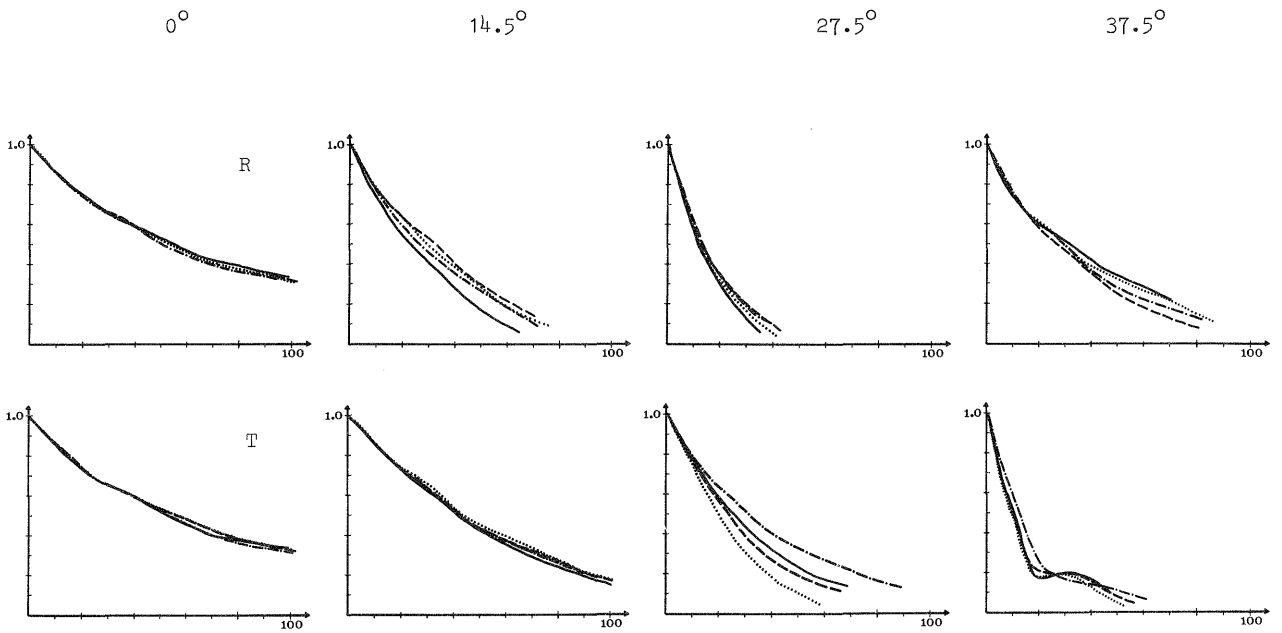


Fig. 2a. MTF symmetry of the camera 1.

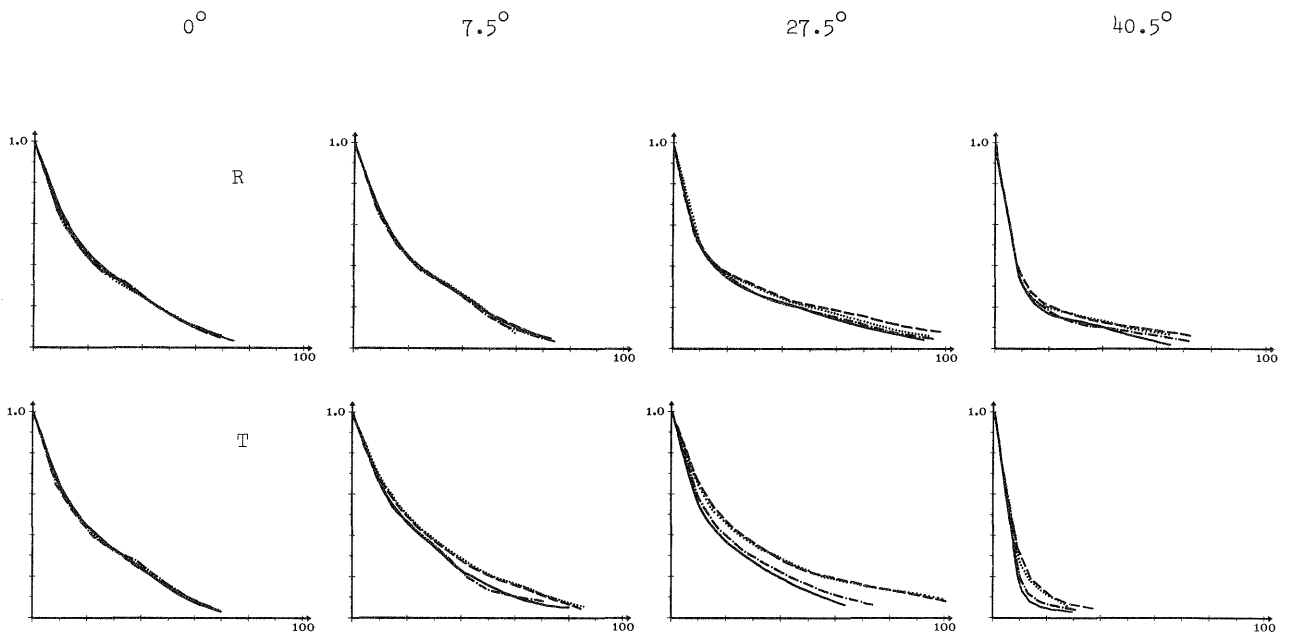


Fig. 2b. MTF symmetry of the camera 2.

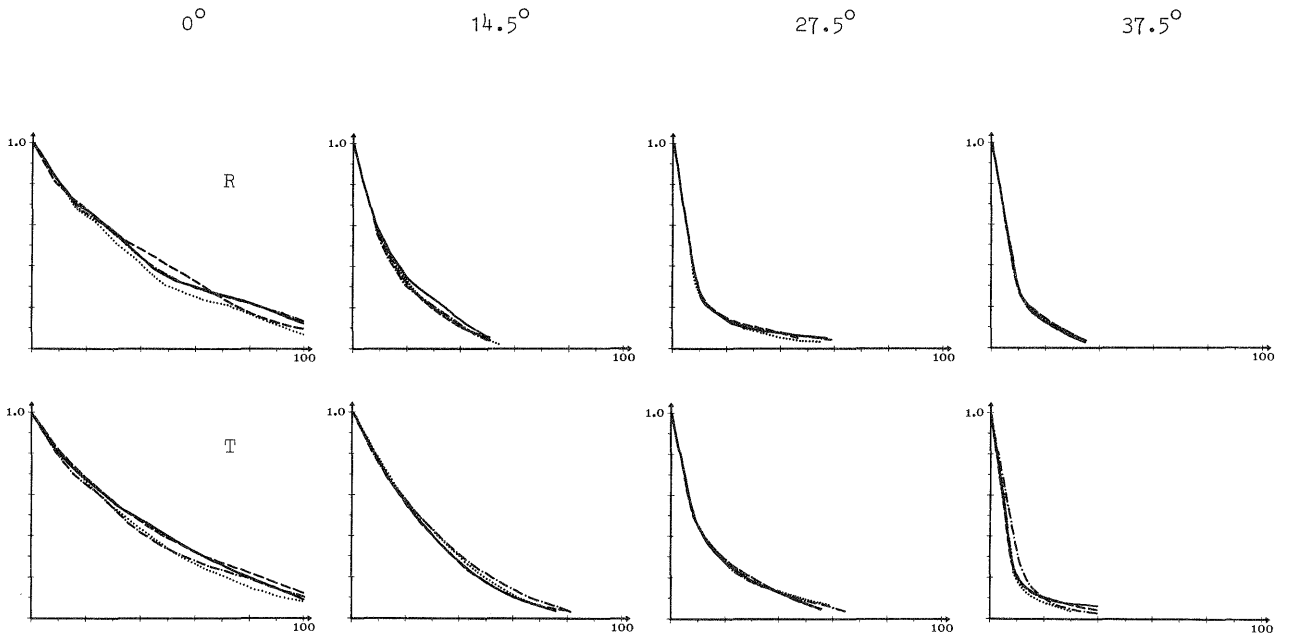


Fig. 2c. MTF symmetry of the camera 3.

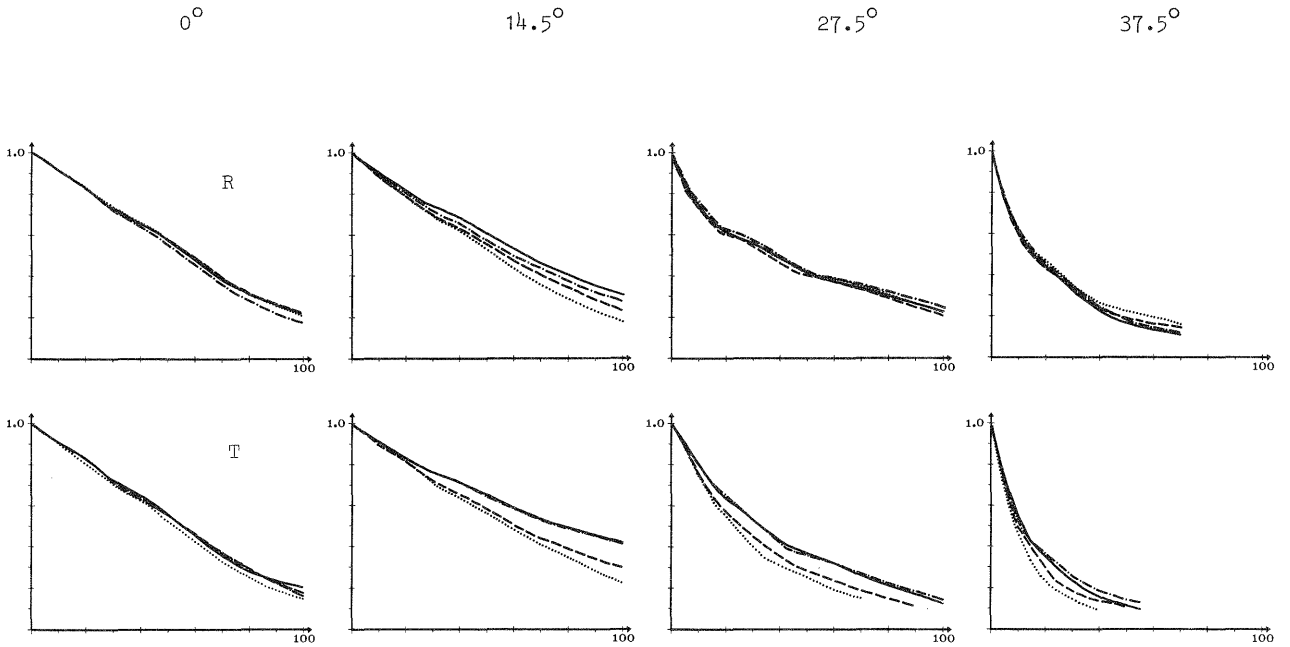


Fig. 2d. MTF symmetry of the camera 4.

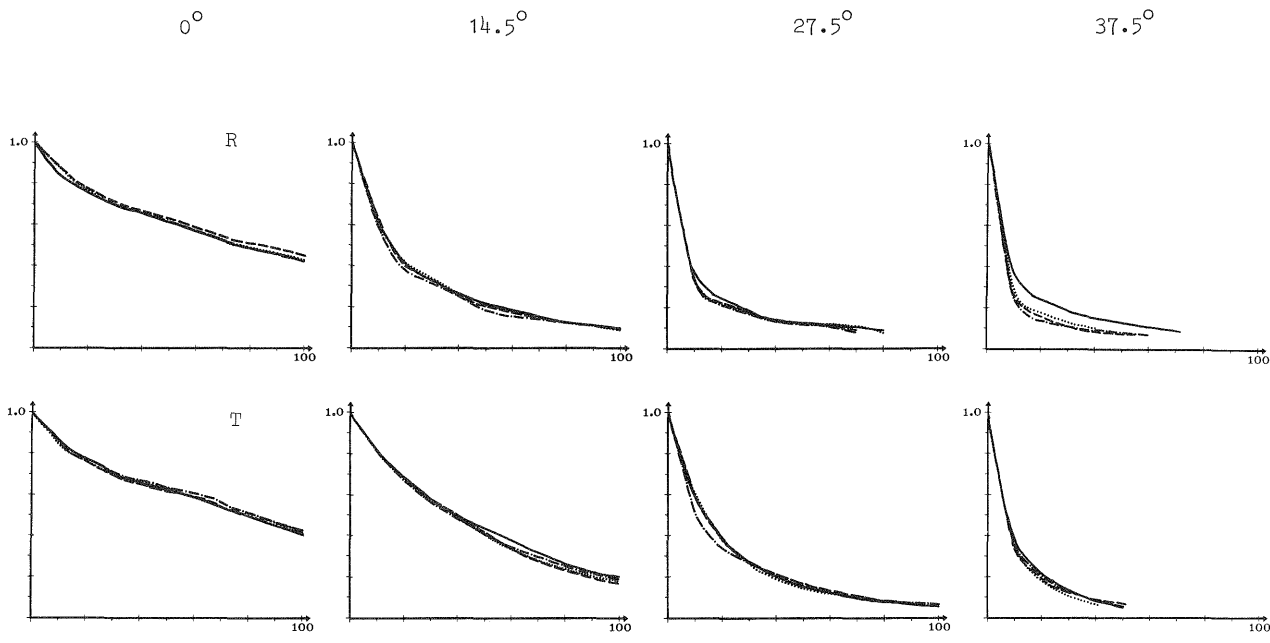


Fig. 2e. MTF symmetry of the camera 5.

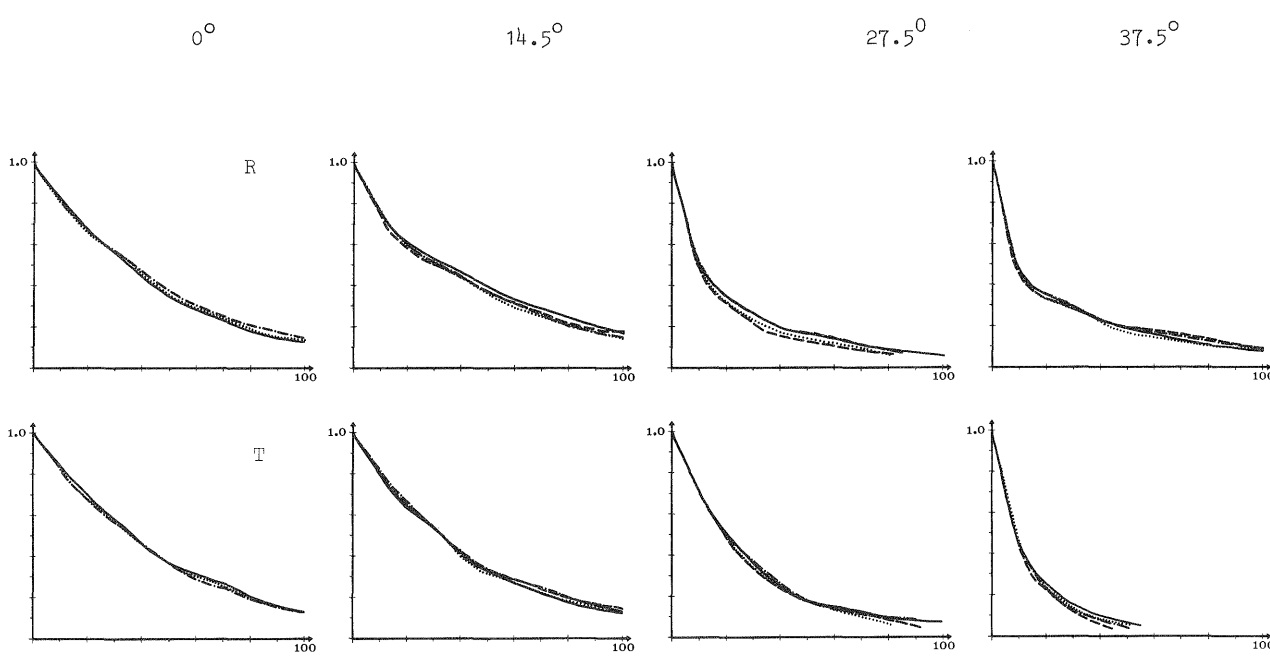


Fig. 2f. MTF symmetry of the camera 6.

5 CONCLUSION

According to the MTF measurements of six aerial wide-angle cameras of different types it can be verified:

- 1) It is advantageous to use MTF as one indicator for lens quality in connection with aerial camera calibration. An MTF measurement is more objective than that of the RP and the measurements are possible to be automatized.
- 2) Symmetry of the MTF of aerial cameras seems to be good, especially in new cameras.
- 3) Because of the good MTF symmetry, a criterion based on MTF can be developed were 16 MTF measurements are needed.
- 4) Image quality differences between different aerial camera types are rather large according to the AWAMs measured for cameras.

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