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Location of the Plane of Best Average Definition With Low Contrast Resolution Patterns

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The plane of best average definition is located for each of several airplane-camera lenses using two types of low contrast test pattern and two emulsions. A low contrast pattern composed of dark lines on a light background and the reverse pattern consisting of light lines on a dark background are used. The results of measurement indicate that the position of the plane of best focus and the numerical magnitudes of the root mean product mean $\sqrt{R_\beta T_\beta}$ value of the resolving power are not significantly affected by this reversal of contrast In addition, the results obtained using low contrast targets are compared with those obtained with high contrast targets. Hence the position of the selected focal plane remains invariant although the values of the measured resolving power are substantially higher for the high contrast targets.

1. Introduction

In specifications dealing with airplane mapping cameras, great emphasis is placed upon the photographic resolving power of the lenses used in the camera. The method of measurement to be used in evaluating the resolving power is usually described in careful terms, with the type of test chart, the characteristics of the registering emulsion, the physical conditions of test, and the manner of reporting results all given in detail. A 1950 military specification, MIL–STD–150 [1] [1] attempted to establish standard practices in the evaluation of lens performance. A recent revision of this comprehensive specification, MIL–STD–150A [2] was issued in 1959. At the Washington meeting of the International Society of Photogrammetry in 1952, a specification dealing with the calibration of photogrammetric cameras was adopted for trial and discussion [3].

At the time the International Specification for the calibration of photogrammetric cameras was drawn, it was not possible to standardize on a single type of resolving power chart. Consequently several were listed as suitable for use; these include the three-line chart used by the U.S. Air Force [2], the Cobb two-line chart used in Great Britain and the annulus chart used in Canada [4]. These charts were of low contrast except that the three-line chart of the Air Force was provided in both high and low contrast versions. The three-line chart of the National Bureau of Standards [5] was not included as it has been available for only a few months prior to the drawing of the specification and its properties were not widely known.

In the eight years that have passed since the adoption of this specification, agreement on a single test chart has not yet developed. A few publications have appeared [6, 7] that permit an estimate of the differences likely to be found in comparing various types of charts.

Because of the differences that exist among the various test charts used in various laboratories, a study was initiated at the National Bureau of Standards in which the values of resolving power for the same group of lenses were determined for a variety of test charts, target contrasts, and emulsions. The results of this study should be useful in estimating the probable values of resolving power that would be obtained for a lens with a given type of chart when results are available for the same lens with a different type of chart.

This is the concluding portion of a three part investigation. The results for the first part dealing with various indices and methods used in locating the plane of best average definition have been reported in Photogrammetric Engineering [8]; the results for the second part which comprises results for lone-line, short-line, and annular charts are reported in J. Research NBS [9]. The results of the third part which deals with variations arising from differences in target contrast for two emulsions are reported in the present paper.

Measurements of photographic resolving power at the National Bureau of Standards are customarily made using a long-line three line high contrast test chart having dark lines on a light background with the images registered on a high contrast emulsion which has a higher resolving power than the emulsion commonly used in aerial photography. In many other calibration laboratories, the tendency is to use test charts having light lines on a dark background

[1] Figures in brackets indicate the literature references at the end of this paper.

with the images registered on a medium contrast emulsion with resolving power comparable to that being currently used in aerial photography.

In the present study, values are obtained for two emulsions and three targets of differing contrast. Results are given for four lenses of types commonly used in photogrammetric cameras.

2. Method of Measurement

2.1. Test Camera

The National Bureau of Standards precision lens testing camera [10] was used in making the negatives from which the values of resolving power are determined. Its construction and mode of operation simplify the process of evaluating the resolving power of a lens in a series of focal planes spaced at definite intervals along the optical axis. The precision lens testing camera is equipped with 10 collimators spaced at 5° intervals and spanning the range from 0° to 45°. Resolving power test charts placed in the focal plane of the collimators and imaged by the lens under test permit the study of quality of imagery for a series of focal planes of the test lens. By using one type of chart in 5 of the 10 collimators (designated the odd-numbered collimators) spaced at 10° intervals and another type in the remaining five collimators (designated the even-numbered collimators) it is possible by proper manipulation of the various controls to record the imagery of a lens under test on a single photographic plate for each of two types of chart in the same series of focal planes for the same angular separations, β, from the axis of the lens under test.

2.2. Test Charts

Three types of test chart are used in the present investigation. All three are based upon the NBS resolution chart of 1952 but differ in contrast between the lines and spaces. Each chart has the same range of sizes of the test object with the size proceeding in a geometric progression with $\sqrt[4]{2}$ (or 1.1892) as the common ratio. The same size test chart is used in the various collimators so that it is necessary to apply the "cos" and "$\cos^2$" corrections to images formed off-axis. The various types are described in the following section.

a. High Contrast Test Chart (HDL)

This is a composite chart based upon the NBS resolution test chart of 1952 which is described in detail in NBS Circular 533 [5]. It is a long-line three line chart with dark lines on a light background. The difference of log luminance between the dark lines and the light background exceeds 2.0.

b. Low Contrast Test Chart (LDL)

This chart is identical in all respects to that described in (a) except that the contrast is low between the dark lines and the light background. The difference of log luminance between the dark lines and the light background is 0.20 ±0.02.

c. Low Contrast Test Chart (LLD)

This chart is identical to that described in (b) except that the contrast is reversed, that is, the difference in log luminance between the light lines and the dark background is 0.20 ±0.02.

2.3. Test Negative

In making the test negative, the lens under test is initially so alined that its optical axis is parallel to and approximately coincident with the axis of the collimated beam emergent from the first collimator. The lens is adjusted along the bench to a location such that the collimated beam at 40° from the axis fills the front aperture of the lens under test as viewed through the lens at an inclination of 40° from the axis. The plate holder is adjusted to a position such that the front surface of the emulsion is in the plane of best visual axial focus for the central row of images to be registered on the plate. The plate holder is then moved to a position 1.05 mm nearer to the lens, where an exposure is made by illuminating the reticles in odd-numbered collimators, which thus records the imagery on the plate at 10° intervals for the range of angles from $\beta=0°$ to $\beta=40°$. This process is repeated with the plate moved 0.15 mm farther from the lens until 15 exposures have been made with the last for the plane 1.05 mm farther from the lens than the position of best visual axial focus. Between each exposure, the plate holder is also moved downward by an amount sufficient to avoid superposition of successive rows of images. The foregoing operation registers the imagery for the long-line high contrast patterns on the plate. The plate holder is then returned to its initial position for which the emulsion surface is 1.05 mm nearer to the lens than the plane of best visual axial focus; the plate is displaced sidewise in its holder approximately 12 mm; and the entire bench on which the camera is mounted is rotated on its pivot by 5° so that the axis of the lens is now parallel to and nearly coincident with the axis of the collimated beam emergent from the second collimator. The foregoing procedure is then repeated with the exception that exposures are made by illuminating the reticles in the even-numbered collimators, which again registers imagery on the plate at 10° intervals for the range of angles from $\beta=0°$ to $\beta=40°$. This process registers the imagery for the long-line low contrast patterns on the plate. The exposed plate is then processed to form the finished negative from which values of resolving power for tangential lines (T_β) and radial lines (R_β) are determined.

All exposures are made with the reticles illuminated by light from tungsten lamps with Wratten K–3 filters between the light source and test charts. Neutral filters are used to adjust the intensity of the light reaching the plate so that the final resulting optical density of each image on the negative is approximately the same for all values of β. The two types of photographic plates used in this work were Eastman Spectroscopic VF which has a fine grained panchromatic emulsion and Eastman Super Panchro Press, Type C. The plates were developed for 3 min. in D–19 developer at 68 °F.

2.4. Reading the Negative

The negative images were examined with a microscope using powers ranging from 30 to 50×. The criteria for considering a particular line pattern to be the finest resolved were that all coarser patterns were resolved and that the number of lines in a given pattern was the same as that of the corresponding pattern in the object.

3. Results of Measurements

The results of measurement on four wide-angle lenses are reported and analyzed in this study. Two lenses, designated Nos. 1 and 5, are essentially distortion-free; the other two, designated 7 and 8, have moderate amounts of distortion. Measurements of resolving power were made at 10° intervals from 0° to 40°.

Negatives were made with both VF and SP emulsions for each of three target contrasts for each of the four lenses. The measured equivalent focal length for the plane of best visual axial focus was the same for each emulsion and each type of target pattern. The maximum range of change in measured equivalent focal length did not exceed ±0.02 mm for a given type of lens.

The results of measurement are shown graphically in figures 1 and 2. The values of the geometric mean resolving power $\sqrt{R_\beta T_\beta}$ are shown plotted against the separation, Δf, from the plane of best visual axial focus. Positive values of Δf denote positions of the image plane farther from the lens than the plane of best visual axial focus. In figure 1, values of $\sqrt{R_\beta T_\beta}$ obtained with VF emulsion are shown for values of β ranging from 0° to 40°. The lowest frame in each column shows values of the root mean product mean [8] $\sqrt{\overline{R_\beta T_\beta}}$ versus Δf. The curves, numbered 1, show the results obtained with the high contrast target having dark lines on a light background. The curves, marked 2, show the results for the low contrast target having dark lines on a light background. The curves, marked 3, show results for the low contrast targets having light lines on a dark background. In figure 2, comparable results are shown for the same four lenses using SP emulsion.

Values of $\sqrt{R_\beta T_\beta}$ are shown in these graphs as this quantity is of primary interest in evaluating the image forming qualities of a lens intended for use in an airplane mapping camera. In two earlier papers [8, 9], values of R_β and T_β are shown for lens No. 1.

4. Location of the Plane of Best Average Definition

The plane of best average definition was located for each set of conditions by the maximum value of the index $\sqrt{\overline{R_\beta T_\beta}}$. The plane so located is likely to be slightly farther from the lens than that located by graphical analysis [8]. For the purposes of the present paper, the use of the maximum of $\sqrt{\overline{R_\beta T_\beta}}$ is satisfactory. The values of the index $\sqrt{\overline{R_\beta T_\beta}}$ for the range of Δf extending from 0.45 mm nearer to the lens to 0.30 mm farther from the lens than the plane of best visual axial definition is shown in table 1 for the four lenses for all of the various conditions. The values listed are the averages for several runs ranging from 1 to 6. The total number of runs for the high contrast target is equal to the sum of the runs for the two low contrast targets. This occurs because a single negative always contains a record of the imagery for the high contrast target and for one of the two low contrast targets. In table 1 the underlined value of the index in each column is the maximum for the indicated set of conditions.

5. Comparison of Results Obtained With the Three Charts

The principal points to be considered in the analysis of the results of measurement are possible differences in the location of the focal plane for the various conditions, the reduction in average resolving power that may result from such differences, relative magnitudes of average resolving power for the two emulsions and effects of contrast. These are discussed in the present section.

5.1. Relative Positions of Focal Plane

The relative positions of the focal plane for the various conditions are indicated for the four lenses in table 1. The displacements for each of the contrasts and emulsions from the focal plane of best average definition for the high contrast target using VF emulsion of the corresponding planes are shown in table 2. It is clear from this table, that differences in contrast of target have little or no effect upon the location of the focal plane of best average definition for either emulsion. Only in the case of the low contrast target having light lines on a dark background (LLD) used with SP emulsion is there any indication of a possible effect on the location of the focal plane and even in this instance the apparent shift may be a result of random error.

On the average, the plane of best average definition for the various contrasts appear to be 0.15 mm nearer to the lens for the SP emulsion than is the corresponding plane for VF emulsion. This difference is small and may be real. However, it would be unlikely to present serious cause for concern in the locating of the plane of best average definition. It is likely that the average plane selected using VF emulsion will be satisfactory if this plane be used for photography with SP emulsion. Likewise the plane selected using SP emulsion would be reasonably satisfactory for photography with VF emulsion.

5.2. Reduction in Resolving Power From the Maximum

If the differences in the relative location of the focal plane are regarded as genuine, it is instructive to determine the magnitude of the effect of these differences on resolving power under the various

Table 1. *Variation of $\sqrt{R_\beta T_\beta}$ with separation, Δf, from the plane of best visual axial focus for four lenses*

Values of $\sqrt{R_\beta T_\beta}$ in lines per millimeter are given for two emulsions and three target contrasts. The columns, designated HDL, show values obtained with a high contrast target having dark lines on a light background. The columns, designated LDL, show values for a low contrast target having dark lines on a light background. The columns, designated LLD, show values obtained with a low contrast target having light lines on a dark background. The maximum values of $\sqrt{R_\beta T_\beta}$ are underlined. The number of test negatives used in each set of determinations is shown in the row marked n.

	Values of $\sqrt{R_\beta T_\beta}$ for lens No. 1 obtained with emulsion					
	VF			SP		
n	2	1	1	3	1	2
Δf	HDL	LDL	LLD	HDL	LDL	LLD
mm						
−0.45	39.3	27.2	25.2	20.0	14.6	13.5
−.30	42.0	28.9	27.8	22.2	15.3	13.8
−.15	46.4	31.3	28.3	22.9	15.4	13.7
.00	48.6	32.4	28.7	21.8	14.9	13.5
.15	48.4	29.3	26.6	19.4	12.7	11.8
.30	38.6	23.2	23.2	15.6	11.1	10.4

	Values of $\sqrt{R_\beta T_\beta}$ for lens No. 5 obtained with emulsion					
	VF			SP		
n	3	2	1	6	3	3
Δf	HDL	LDL	LLD	HDL	LDL	LLD
mm						
−0.45	30.1	22.2	22.3	19.8	14.4	13.1
−.30	34.6	26.0	24.8	21.8	15.1	14.5
.15	39.8	27.6	27.2	23.4	15.6	14.1
.00	42.2	28.8	27.2	22.8	15.2	13.8
.15	42.1	26.8	28.3	21.4	13.5	12.6
.30	36.6	23.0	23.4	17.6	11.7	10.8

	Values of $\sqrt{R_\beta T_\beta}$ for lens No. 7 obtained with emulsion					
	VF			SP		
n	4	2	2	2	1	1
Δf	HDL	LDL	LLD	HDL	LDL	LLD
mm						
−0.45	42.6	31.6	29.6	24.6	16.1	14.3
−.30	46.5	33.0	29.8	24.8	16.4	14.3
−.15	48.1	33.0	30.0	24.5	16.2	14.0
.00	46.8	32.3	29.2	23.6	16.2	13.9
.15	43.4	27.2	27.4	21.5	13.9	12.4
.30	36.5	24.2	23.4	17.9	12.8	11.1

	Values of $\sqrt{R_\beta T_\beta}$ for lens No. 8 obtained with emulsion					
	VF			SP		
n	3	1	2	2	1	1
Δf	HDL	LDL	LLD	HDL	LDL	LLD
mm						
−0.45	34.5	28.0	24.2	21.4	13.3	13.2
−.30	36.7	28.3	26.6	21.5	13.3	13.2
−.15	37.4	28.8	26.4	21.7	13.7	12.9
.00	38.9	27.8	25.9	21.0	13.4	12.5
.15	37.4	25.5	24.4	18.8	11.7	11.6
.30	33.2	23.2	21.6	17.2	10.8	10.9

Table 2. *Location of the focal plane of best average definition with respect to that obtained for a high contrast target using VF emulsion for four lenses*

Results are given for VF and SP emulsion and for two types of low contrast target. The symbols in the colmn heading are defined in table 1. A negative value of Δf indicates a position of a selected focal plane nearer to the lens than that selected for the high contrast target using VF emulsion. The focal plane of best average definition is determined by the maximum value of $\sqrt{R_\beta T_\beta}$.

Lens	Separations, Δf, in millimeters from plane of best average definition obtained with high contrast target for emulsion					
	VF			SP		
	HDL	LDL	LLD	HDL	LDL	LLD
1	0.00	0.00	0.00	−0.15	−0.15	−0.30
5	.00	.00	.15	−.15	−.15	−.30
7	.00	.00	.00	−.15	−.15	−.15
8	.00	−.15	−.30	−.15	−.15	−.30
Average	0.00	−0.04	−0.04	−0.15	−0.15	−0.26

Table 3. *Effect on average resolving power, $\sqrt{R_\beta T_\beta}$ for various contrast targets produced by using focal plane of best average definition obtained with VF emulsion for the high contrast target*

Values of the reduction from the maximum are given in percent for four lenses using VF and SP emulsions for one high and two low contrast targets. The meanings of the symbols heading the columns are as given in the caption of table 1.

Lens	Reduction in % of $\sqrt{R_\beta T_\beta}$ from its maximum for					
	VF emulsion			SP emulsion		
	HDL	LDL	LLD	HDL	LDL	LLD
1	0.0	0.0	0.0	4.8	3.2	2.2
5	.0	.0	3.9	2.6	2.6	4.8
7	.0	.0	0.0	1.2	1.2	2.1
8	.0	3.5	2.6	3.2	2.2	5.3

conditions. For example, one may select the focal plane of best average definition for high contrast targets with VF emulsion and then use this focal plane for photography under all conditions of contrast for both emulsions. This has been done and the effects on resolving power for the other conditions are shown in table 3. From this table it is clear that for 3 of the 4 lenses, there is no reduction in resolving power when using VF emulsion for the low contrast target having dark lines on a light background (LDL) while there is a 3.5 percent loss in the case of lens No. 4. For the low contrast target having light lines on a dark background, the change is zero for two lenses and reductions of 3.9 and 2.6 percent are shown for the other two. When SP emulsion is used, reductions in resolving power ranging from 1.2 to 5.3 percent occur, with the reduction under 3 percent in 7 of 12 instances. One can expect a 3 percent variation in the magnitude of $\sqrt{R_\beta T_\beta}$ on the basis of observational error, hence in only five of the twelve cases is the reduction in resolving power in excess of the probable observational error.

If the plane of best average definition for the high contrast target using SP emulsion is taken as a reference plane, values of the reductions in resolving power can be determined for the other condition.

The values of these reductions are shown in table 4. For this condition, the reduction is zero for the low contrast target (LDL) with SP emulsion. For the VF emulsion, the reduction is under 3 percent in 5 of 12 cases and does not exceed 5.6 percent for any of the remainder.

5.3. Relative Magnitude of the Resolving Power

From figures 1 and 2, it is apparent that the resolving power for VF emulsion is higher than that for SP emulsion for all values of β ranging from 0° to 40°. It is moreover clear that this is true for all three conditions of contrast. It is not possible to determine a numerical value of the ratio of the resolving powers that would be invariant for all values of β and all values of Δf. Accordingly, average values of the ratios based upon the values of $\sqrt{R_\beta T_\beta}$ shown in table 1 have been determined for each lens and are shown in table 5. In table 5, the ratios of average resolving power for the two emulsions and three contrasts with respect to the average resolving power for the high contrast target obtained with SP emulsions for four lenses. From the average values of the ratios given in this table, an estimate can be made of the probable value of other ratios that are of interest. For example, values of resolving power obtained with the low contrast target are approximately two-thirds of that obtained with the high contrast target for either of the two emulsions.

TABLE 4. *Effect on average resolving power, $\sqrt{R_\beta T_\beta}$ for various contrast targets produced by using focal plane of best average definition obtained with SP emulsion for the high contrast target*

Values of the reduction from the maximum are given in percent for four lenses using VF and SP emulsions for one high and two low contrast targets. The meanings of the symbols heading the columns are as given in the caption of table 1

Lens	Reduction in % of $\sqrt{R_\beta T_\beta}$ from its maximum for					
	VF emulsion			SP emulsion		
	HDL	LDL	LLD	HDL	LDL	LLD
1	4.5	3.4	1.4	0.0	0.0	0.7
5	5.6	4.2	3.9	.0	.0	2.8
7	3.3	0.0	0.7	.0	.0	0.0
8	3.8	.0	.8	.0	.0	2.3

TABLE 5. *Ratios of average resolving powers for two emulsions and three targets of various contrasts*

Ratios are given showing the relative magnitude of the average resolving power obtained under specified conditions to that obtained with a high contrast target on SP emulsion. Values are given for four lenses, using two emulsions and three contrasts. Values of the averages are given together with the average probable error $\overline{PE}_s$ of a single determination. The meanings of the symbols heading the columns are as given in the caption of table 1.

Lens	Ratios of average resolving powers for					
	VF emulsion			SP emulsion		
	HDL	LDL	LLD	HDL	LDL	LLD
1	2.17	1.42	1.32	1.00	0.69	0.63
5	1.77	1.22	1.21	1.00	.67	.62
7	1.93	1.32	1.24	1.00	.67	.59
8	1.80	1.33	1.23	1.00	.63	.63
Average	1.92	1.32	1.25	1.00	0.66	0.62
$\overline{PE}_s$ (%)	±6.9	±4.0	±2.8		±2.6	±2.1

5.4. Effect of Reversed Contrast

In many specifications that require measurements of resolving power of lenses with low contrast targets, it is stipulated that the test chart shall consist of light lines on a dark background. This is so specified because of the belief that the use of a target having dark lines on a light background will result in lower measured values of resolving power than would be found with a target of opposite contrast because of the effect of veiling glare [3]. In figures 1 and 2, the curves marked 2 show values of $\sqrt{R_\beta T_\beta}$ as a function of Δf for the low contrast target having dark lines on a light background; the curves marked 3 show values of $\sqrt{R_\beta T_\beta}$ as a fraction of Δf for a low contrast target having light lines on a dark background. It is noteworthy that in most instances, the curve marked 2 lies slightly above the curve marked 3. Even if one ascribes the difference to experimental error, it is improbable that such error could reduce all of the observed values of curve 2 below those for curve 3. From these results, it is clear that the values of resolving power obtained using targets having dark lines on a light background are not lower than those obtained using targets having light lines on a dark background when the difference in log luminance between line and background is 0.2.

It seems probable, therefore, that when resolving power tests are made using transparent charts located in the focal plane of collimators, the use of light lines on a dark background will not, in general, yield higher values of the resolving power than will the use of dark lines on a light background. In this case, the values of resolving power are not noticeably reduced by the effect of veiling glare. Although veiling glare may affect the values of resolving power on the axis which may be the case for lens No. 5 in figure 2, it is not likely to do so for extra-axial imagery. The effect of veiling glare possibly would be more pronounced in using resolution targets on a range rather than in collimators which may account for the prevalence of the specification of targets having light lines on a dark background.

6. Conclusion

In this study, the effect of contrast upon choice of a focal plane has been investigated using four lenses, two target contrasts, and two emulsions. Analysis of the results of measurement leads to the following conclusions.

(1) For either of the two emulsions used, the choice of focal plane of best average definition is not affected by differences in contrast between lines and background in the target.

(2) When a lens images targets where the difference in log luminance between lines and background equals 0.20, the values of measured resolving power are not significantly affected by reversal of target contrast. In other words, low contrast targets with either dark lines on a light background or light lines on a dark background will yield substantially the same measured values of average resolving power for a given lens.

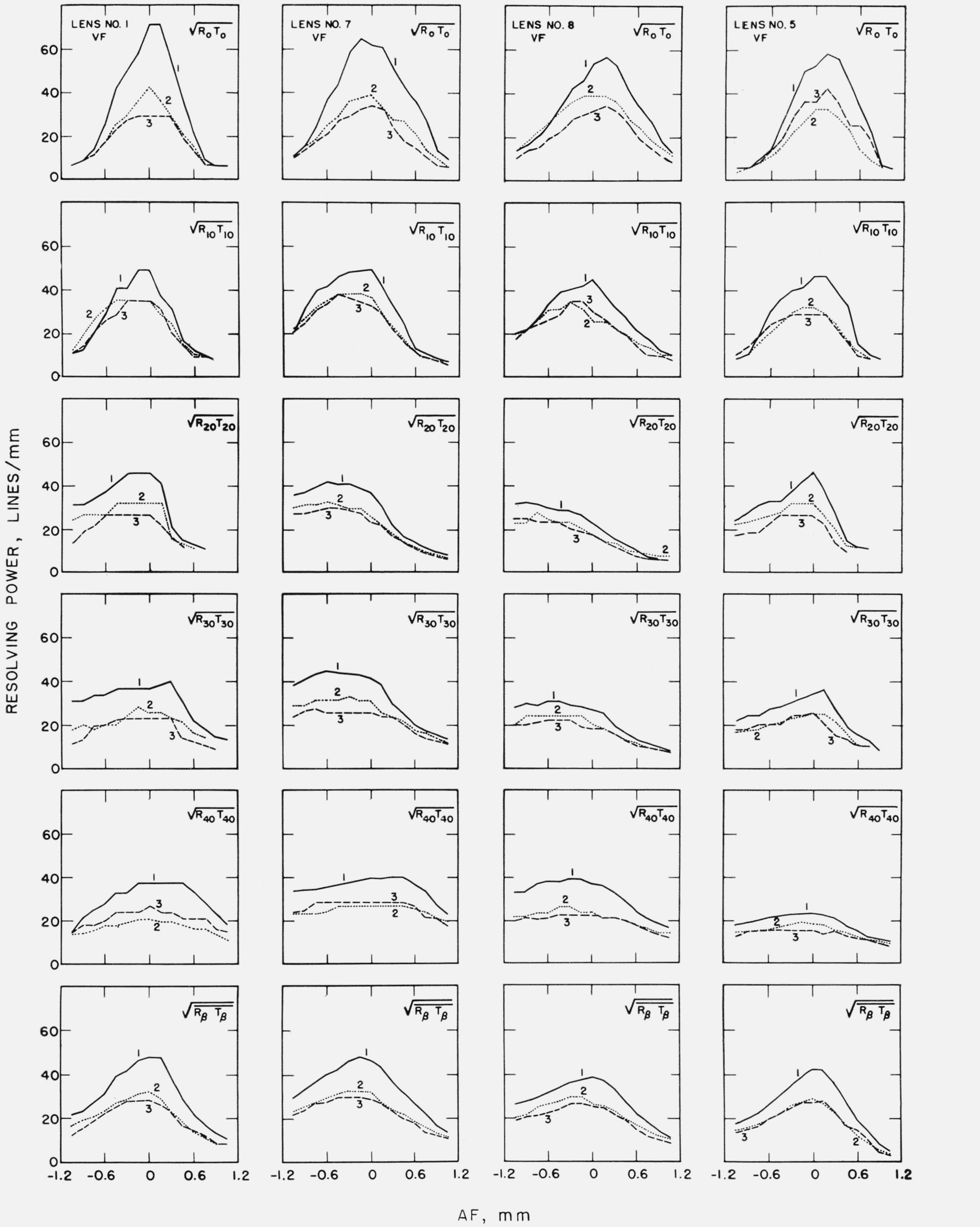

FIGURE 1. *Average resolving powers versus position of the image plane for four lenses with VF emulsion.*

Values of the average resolving power $\sqrt{R_\beta\ T_\beta}$ are shown at 10° intervals from 0° to 40°. The lowest box in each column shows values of $\sqrt{\overline{R_\beta\ T_\beta}}$. Curve 1 shows the result obtained with a high contrast target having dark lines on a light background with contrast between lines and background greater than 2.0 on a density scale. Curve 2 shows the results for a low contrast target (0.2 difference of log luminance between lines and background), having dark lines on a light background. Curve 3 shows results obtained for a low contrast target (0.2 difference of log luminance between lines and background) but having light lines on a dark background. The zero of abscissas marks the position of best visual axial focus, and positive values of Δf indicate positions farther from the lens.

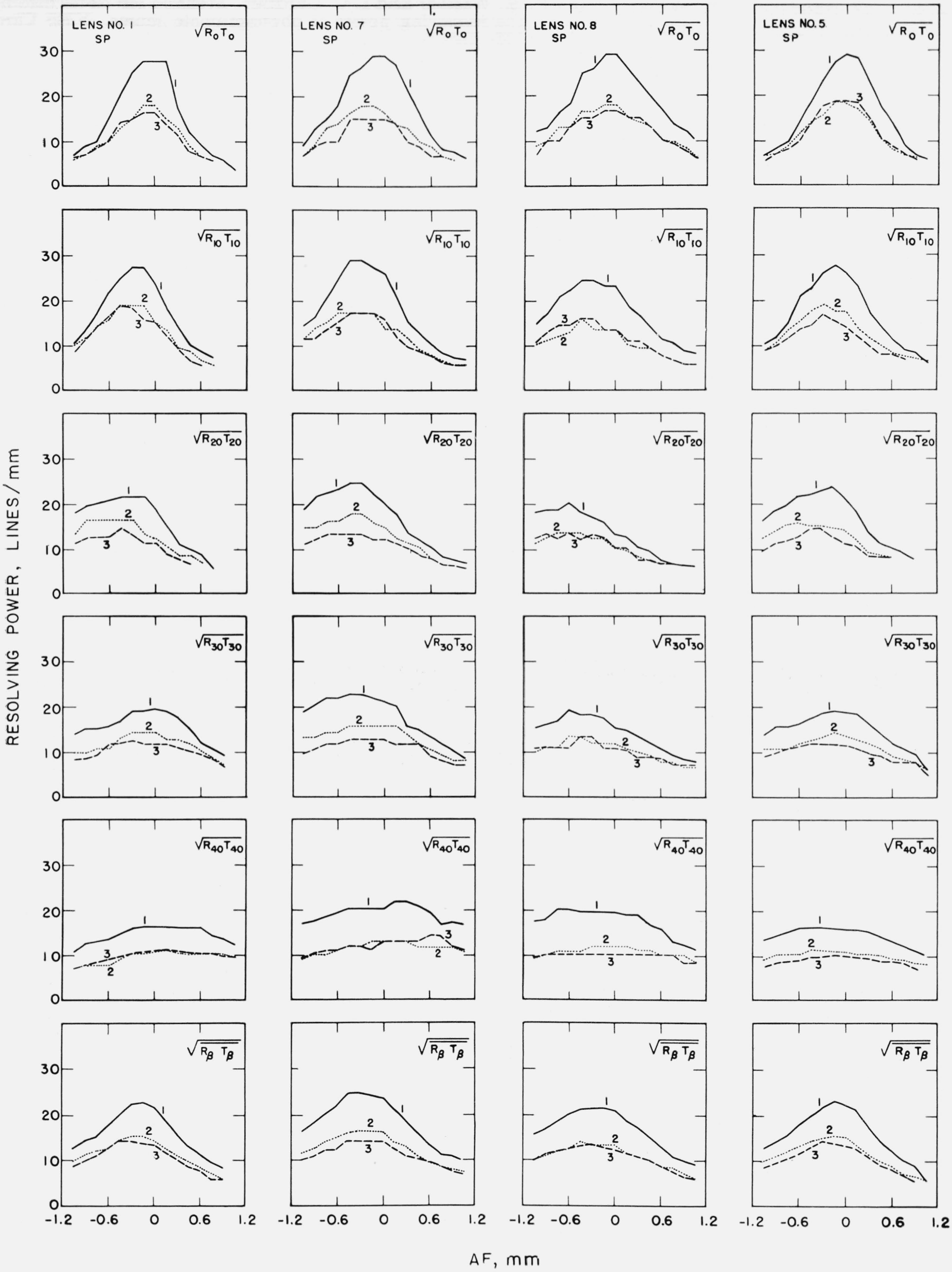

FIGURE 2. *Average resolving power versus position of the image plane for four lenses with SP emulsion.*

Values of the average resolving power $\sqrt{R_\beta T_\beta}$ are shown at 10° intervals from 0° to 40°. The lowest box in each column shows values of $\sqrt{\overline{R_\beta T_\beta}}$. Curve 1 shows the results obtained with a high contrast target having dark lines on a light background with contrast between lines and background greater than 2.0 on a density scale. Curve 2 shows the results for a low contrast target (0.2 difference of log luminance between lines and background), having dark lines on a light background. Curve 3 shows results obtained for a low contrast target (0.2 difference of log luminance between lines and background) but having light lines on a dark background. The zero of abscissas marks the position of best visual axial focus, and positive values of Δf indicate positions farther from the lens.

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