1950

Field resolution tests with the Metrogon lens

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FIELD RESOLUTION TESTS WITH THE

METROGON LENS

BY

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A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

CIVIL ENGINEER

Rolla, Missouri

1950

Approved by E. W. Carlton
Professor of Civil Engineering

ACKNOWLEDGMENT

The writer wishes to express his appreciation to the following personnel of the Aerial Photographic Branch, Engineer Research and Development Laboratories, Wright-Patterson Air Force Base, Dayton, Ohio: To Mr. Eldon D. Sewell for his assistance in organization of the testing program and for his valuable criticisms in preparation of the manuscript; to Mr. George E. Whiting for his work in the photography of resolution targets and in the processing of film; and to Mrs. Phyllis Bonner for her assistance in evaluation of results and for typing. Acknowledgment for technical information and laboratory facilities also is made to Mr. Paul Pryor, Photo Physics Branch, Photographic Laboratory, Engineering Division, Air Material Command, Wright-Patterson Air Force Base.

CONTENTS

LIST OF ILLUSTRATIONS

"Field Resolution Tests with the Metrogon Lens"

A. INTRODUCTION

1. Tests of resolution have come to be accepted generally as a measure of the amount of information that can be obtained from a photographic system. Howlett[1] states that, "Resolution is the ability of a lens, in combination with a particular kind of device for detecting energy, to distinguish detail under certain specific conditions among which are the shape and contrast of the test target and the quality of the illumination". There are many methods of measuring the resolution of the lens only. Likewise, there are a number of methods for measuring the resolution of the sensitized material used in such tests. For the purpose of comparing or rating lenses or sensitized materials, most of the methods in present use are satisfactory. However, when it is desirable to measure the interpretable detail which can be obtained by a given lens-camera-film combination, the requirements are different. It then is no longer a question of how many lines per millimeter that a lens can resolve visually or on a fine-grained spectroscopic plate but, rather, how much information is obtainable by using a certain lens, with a given aerial film emulsion, at practical aperture settings. Furthermore, it is necessary to define the conditions under which the tests are conducted if the results are to be meaningful. The pertinent conditions which must be defined are: (a) the design, contrast, and illumination of the resolution target; (b) the type of tests--i.e., whether optical bench test, outdoor test with the camera mounted horizontally, aerial test, or others; (c) the method of processing the

1. Howlett, Dr. L. E. Photography for survey purposes. Photogrammetric Engineering, Vol. XIV, No. 3, September, 1948.

film; and (d) methods for reading and analyzing the resolution data.

2. Much research on optical resolution was done during the last war by groups in Great Britain, Canada, and this country. In this research, various types of targets were used, and resolutions were determined under varying conditions of photography. The Aerial Photographic Branch, Engineer Research and Development Laboratories, Wright-Patterson Air Force Base, Dayton, Ohio, recently has undertaken a program of resolution testing which has, as its primary object, the establishment of allowable resolution values (for various lens-film-camera combinations) to be used in the preparation of specifications for aerial mapping cameras. An attempt has been made, therefore, to eliminate as many variables as possible in the photography. Resolution targets, both line and annulus, were installed on the ground in a straight line normal to the camera axis and at a known distance from the lens. The targets were spaced along this straight line at given angles outward from the camera axis (See Fig. 1). With the camera in a horizontal position, exposures were made with the line of targets positioned across each diagonal of the format for the various combinations of shutter speed, aperture size, and filter type. It is apparent that this method eliminates factors found in actual flight photography, such as camera vibrations, relative motion of the aircraft with respect to the ground, differences in flight altitudes at the instant of exposure, atmospheric haze, etc. It is emphasized that these tests were conducted with a specific purpose in mind which called for this elimination of variables. The possibility of reaching satisfactory conclusions from normal photography taken in the air would be very unlikely,

TARGET LOCATION	
ANGLE (θ)	DIST. (D)
5°	35'
10°	70'
15°	107'
20°	146'
30°	231'
40°	336'

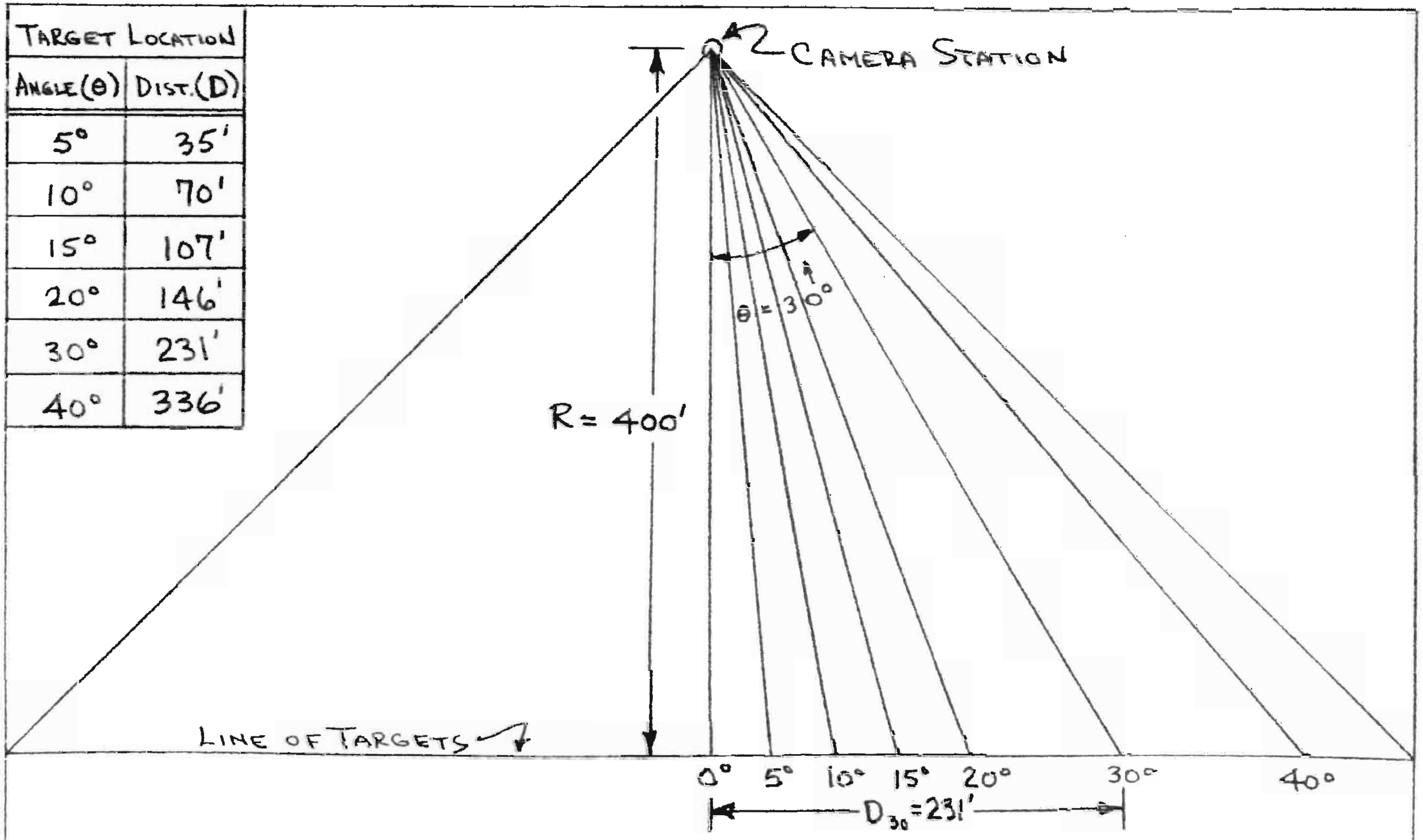

Fig. 1 - Camera Range for Resolution Photography.

since no two exposures ever would be obtained under the same photographic conditions. Later sections of this report will show that the conditions required for significant resolution tests, as described by Howlett[1] and others [2], have been fulfilled.

3. The first portion of this treatise is devoted to a compilation of general knowledge concerning photographic resolution testing--an explanation of certain optical terms; the drafting of resolution targets; methods for averaging resolution values, measured at various positions on the format, to obtain one over-all value for an exposure; and a description of the factors involved in conducting the photographic operations. In the second part of the paper, analyses of the results obtained from line-target resolutions are made with the purpose of determining those combinations of aperture, filter, and shutter speed which result in high photographic resolutions. This information will be of particular value to a person who is called upon to operate the camera, but whose knowledge of photography is limited. The final section includes a determination of that position of photographic focus in an aerial camera which produces best over-all definition. All phases of the resolution testing program described herein require no complex scientific equipment other than cameras for their execution. This system of testing produces adequate data and is sufficiently simple to warrant its consideration as a field method in which trained laboratory personnel, although desirable, are not essential for its accomplishment.

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1. Howlett, op. cit.

2. Pestrecov, Dr. K. Resolving Power of Photographic Lenses. Photogrammetric Engineering, Vol. XIII, No. 1, March, 1947.

B. RESOLUTION TARGETS.

4. Tests of resolution were accomplished at Wright Field on the range customarily used for the field calibration of aerial cameras. The clusters of targets were positioned along a straight line which was perpendicular to the line formed by the camera axis and at a distance of 400 feet from the camera station. The central target was installed at the intersection of the camera axis with the target line. Other targets were installed along this line on each side of the central target at angles of 5°, 10°, 15°, 20°, 30°, and 40° outward from the camera axis. The layout of the resolution target range, with pertinent dimensions, is shown in Figure 1. The distances from the central target, at which other targets were placed, were calculated by a simple trigonometric relationship in which the distance (D) is equal to the product of the distance (R) from the central target to the camera station and the tangent of the angle (θ) outward from the camera axis. For example, the desired distance along the line of targets to a point 30° from the central target is $D = R \tan \theta = 400 \times 0.57735 = 231'$.

5. Included within each target cluster was a line target of the standard Air Force, high-contrast type, having 22 target blocks whose sizes varied consecutively as the $\sqrt[6]{2}$. In Fig. 2 is illustrated the design of a typical target block in which the width of the white line is equal to the distance between adjacent black lines. This width is represented by A. The three vertical lines in the block are used in measuring tangential resolution, while the three horizontal lines provide a measurement of radial resolution. The displacement between the vertical and horizontal groups of lines is equal to twice the width of a line. The length of a line is equal to five times its width. The

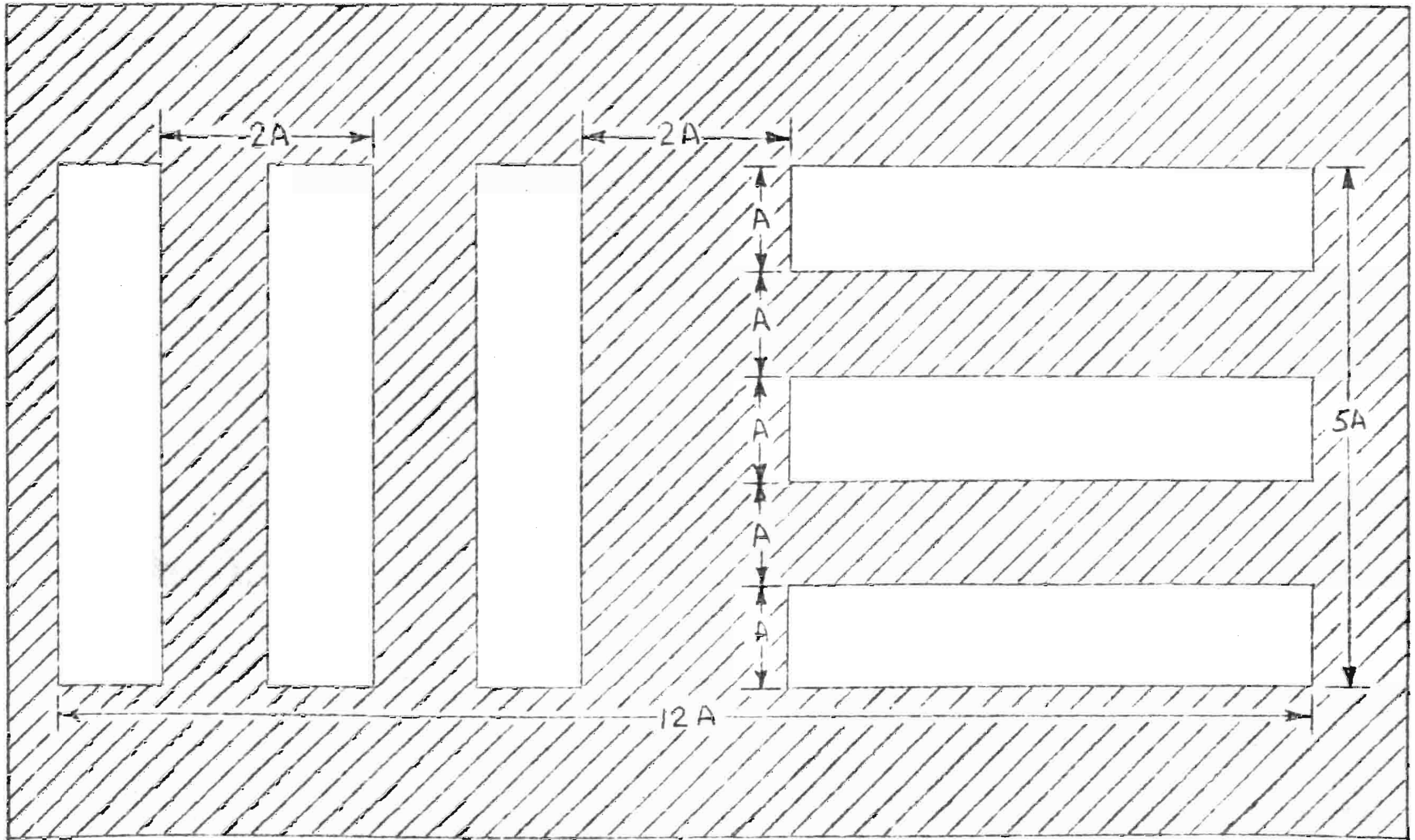


Fig. 2 - Dimensions for the Line-Target Block.

dimensions of a target block are 5A by 12A, while the distance from a block to the smaller block adjacent to it is 3A, in relative terms.

6. The various dimensions for the 22 line-target blocks are given in Table 1 (p. 63). Readings of resolution in column 2 are based on 10 lines per millimeter for target 1. At the central target, with a 400' distance from camera to target and a 153 mm. camera focal length, the photographic scale (S) is equal to 153/(400 x 12 x 25.4) = 1/796.8, expressed as a representative fraction. The reading of a line of resolution involves the distinguishing of separation between two target lines. Thus, a resolution line includes both the target line and the space between lines, or the distance in Table 1 and Fig. 2 represented by 2A. For readings of ten lines per millimeter on the photograph, one line should equal 0.1 mm. which is equivalent to the distance 2A, or A = 0.05 mm. The equivalent distance for A, to be drafted on the target, is 0.05 x 796.8 = 39.84 mm. (See column 4, Table 1).

7. The value of A for target 2 is calculated by dividing 39.84 by the $\sqrt[6]{2}$, or 1.12246, which gives a value of 35.50 mm. The number of lines per millimeter then is computed by multiplying 10 (lines per millimeter for target 1) by the $\sqrt[6]{2}$ to give a value of 11.23 lines per millimeter for target 2. Multiplying 11.23 by the $\sqrt[6]{2}$ gives 12.61 lines per millimeter in resolution obtainable on target 3. Values for other targets are determined in like manner. The complete line target is shown in Fig. 3. The resolution for any target position on a given negative is determined by running the eye down the row of target blocks, from large to small, and selecting the smallest block on which lines may be separated visually. For example, if target block 10 is the smallest one in which definition is apparent, then the resolution

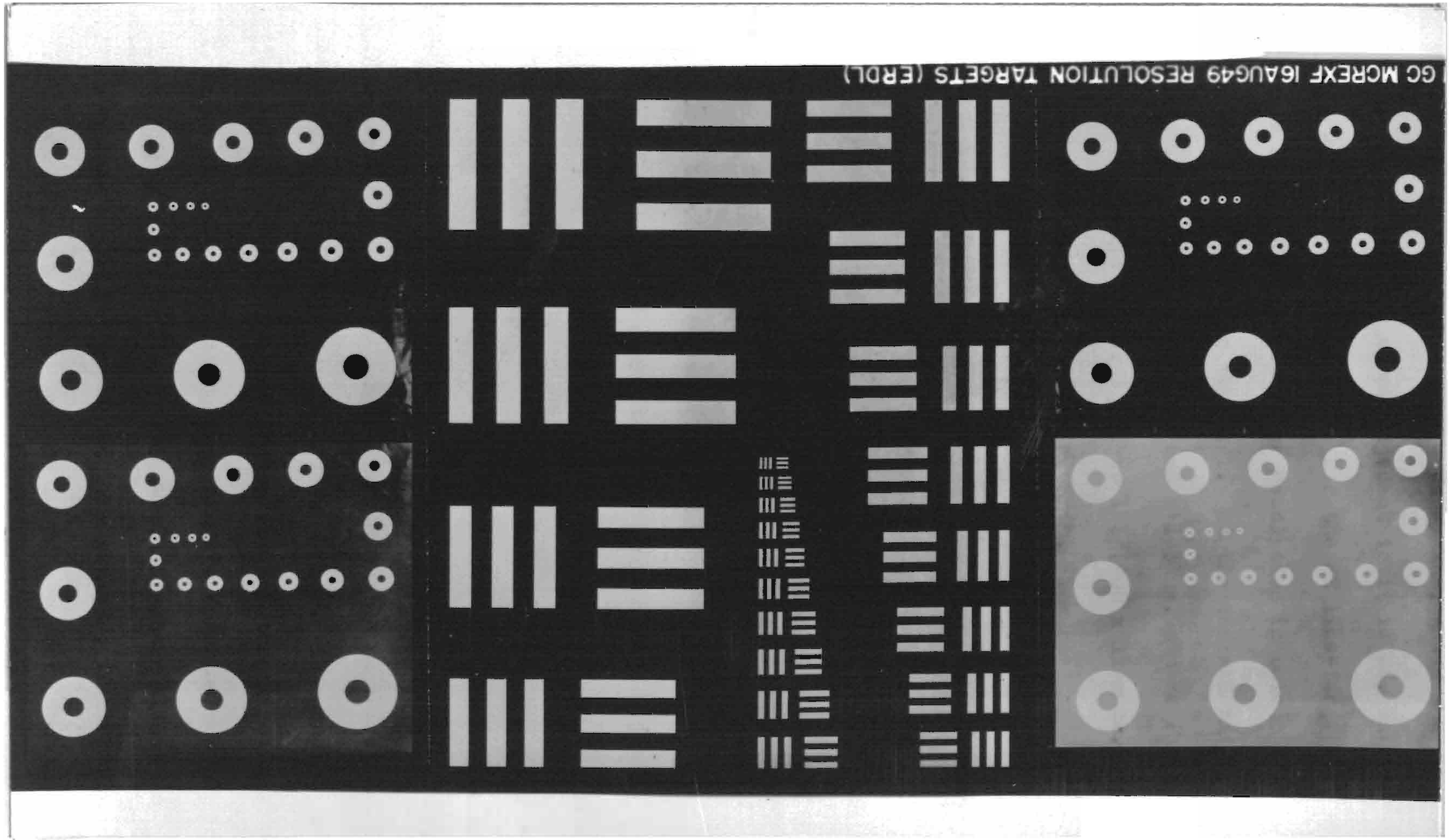


Fig. 3 - Line and Annulus Targets.

for that target is 28 lines per millimeter (See Table 1). The above process is accomplished separately for tangential and radial resolution.

8. Annulus targets are shown in Fig. 3. The annulus target is considered by some authorities to have advantages over the line target because it tends to give the resultant resolution by a single reading. In other words, it avoids the necessity of separating the readings of the radial and tangential resolutions and later of attempting to resolve them into a single resolution value. In construction, the central disk within the individual annulus is the same shade as the area surrounding the annulus. The annulus itself is white. The width of the annulus is exactly the same as the diameter of the central disk. In the targets used for these tests, the width of the annulus (measured radially) is equal to the width of the white line in the line-target block; that is, the sizes of annuli in the annulus targets vary by the $\sqrt[6]{2}$, in the same manner as the target blocks in the line targets. The reading of resolution values on the annulus target entails the selection of the smallest annulus in which the central target is distinguishable.

9. Four annulus targets of varying contrast were included in each target cluster. The target at the upper right in Fig. 3 has a brightness ratio of 36 to 1, that target at the upper left has a brightness ratio of 7.5 to 1, the brightness ratio for the lower left target is 4.5 to 1, and that for the lower right target is 2 to 1. The brightness ratio, which is measured with a reflecting densitometer, is the ratio of the density of a dark surface to that of a lighter surface. Since density is expressed as a logarithmic function, the white of the

annulus, which is used for a zero setting on the densitometer, becomes unity in the brightness ratio. Table 2 (p. 64) shows the results of densitometer tests on eight different contrasts of annulus targets. D_O represents the densitometer reading, set initially on the white of the first target, and then checked on each additional target. D_E is the corresponding densitometer reading of the target background. In the fourth column of Table 2 are listed the numerical differences between D_E and D_O. The fifth column contains anti-logs derived from the logarithms of column 4; these anti-logs are used to complete the brightness ratios of column 6.

10. The line targets, consisting of masonite sheets, 36" x 48" in size, first were sprayed with black paint; then the white blocks were painted on the black background, using a silk screen template. In the construction of the annulus targets, brass rings were machined from shim stock very accurately to the size of the various annuli in the target and were superimposed on a sheet of clear acetate. This sheet then was used as a negative from which contact prints were made. Different contrasts were achieved by varying the exposure time. Development was uniform for all targets. Finally, the developed prints were mounted on cardboard. Targets were installed on the target line using wooden frameworks which resembled football goal posts with an additional cross bar near the ground. In each cluster, the line target was attached at the middle of the frame to the two cross bars, and two of the annulus target sheets were tacked to the wooden uprights on each side of the line target. Care was taken that the surfaces of all targets were in the plane of the target line--i.e., with all targets in a straight line perpendicular to the axis of the camera.

C. CAMERAS USED IN RESOLUTION PHOTOGRAPHY.

11. Air Force K-17 Model aerial cameras were used in the ground photography of resolution targets. Two types of the K-17 Model were employed in the resolution tests--the K-17B, manufactured by the Fairchild Camera Corporation (Fig. 4), and the K-17C, manufactured by the Graflex Corporation (Fig. 5). Both types have a 6" focal length and a 9" x 9" format. Both also have lens aperture settings of f/6.3, f/8, f/11, f/16, and f/22. The K-17B has shutter speed settings of 1/50, 1/100, 1/200, and 1/300 second, while the shutter settings on the K-17C are 1/50, 1/100, 1/200, and 1/400 second. The K-17B can be operated manually as well as electrically, while the K-17C is operated by electricity only.

12. Four different combinations of filter were used on the camera during photography, as follows: (a) the normal yellow vignetting filter, (b) the yellow filter plus a 0.1 neutral density filter, (c) the yellow filter plus a 0.3 neutral density filter, and (d) the yellow filter plus a 0.6 neutral density filter. The Wratten neutral density filters were trimmed in the proper size to fit over the yellow filter and each was attached in contact with the filter surface by placing it under the metal confining rim. The various filter combinations were placed over the lens as required during the sequence of photographic operations.

13. The action of the various neutral density filters can be explained by a brief discussion of several sensitometric terms. Transmission of light refers to light passage through any medium--in this case, a filter. It is expressed by a ratio in which the denominator represents the intensity of light incident to a lens or filter, and the numerator denotes that portion of the light which passes through the

Fig. 4 - K17B Camera.

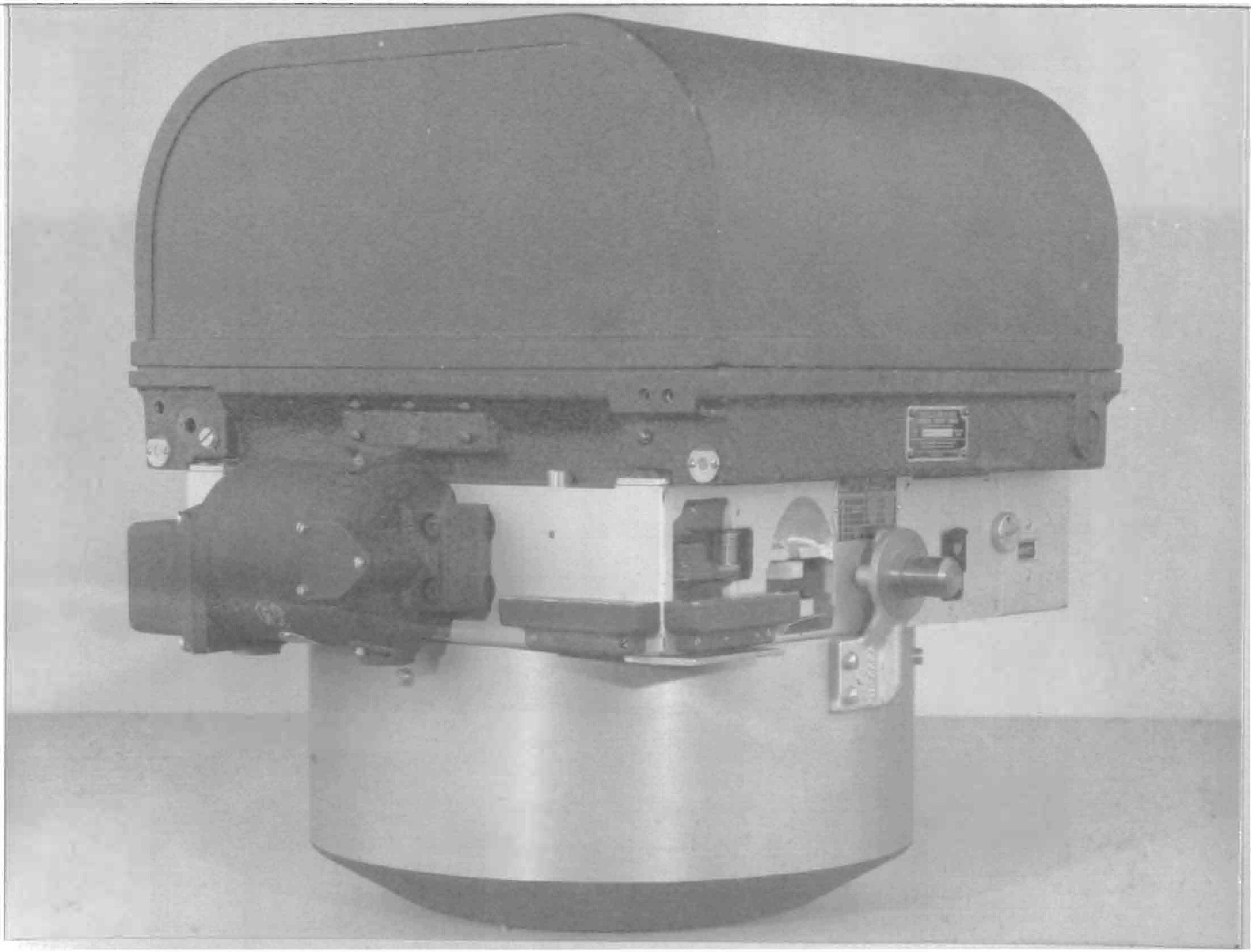


Fig. 5 - K17C Camera.

medium; the numerator is expressed as unity. Light transmission (T) also can be considered as a percentage value equal to its ratio fraction. Opacity (O) is the reciprocal of the transmission ratio. Density (D) of a medium, mathematically, is the logarithm to the base 10 of the opacity ($D = \log_{10} O$). Given D as 0.1, 0.3, and 0.6, it can be shown by the preceding equation that corresponding values of O become 1.25, 2.0, and 4.0, and $T_{0.1} = 4/5$, $T_{0.3} = 1/2$, and $T_{0.6} = 1/4$. This indicates that the 0.1 neutral density filter transmits 4/5 or 80% of the light onto the lens and yellow filter, the 0.3 neutral density filter transmits half of its incident light, and the 0.6 neutral density filter transmits only 25 percent of its light.

14. The action of the neutral density filters on light transmission has somewhat the same effect on the negative as increasing the shutter speed. Consider, for example, a shutter speed setting of 1/100 second on the camera with only the yellow filter in front of the lens. Introduction of the 0.1 neutral density filter in the path of the light rays will cause a decrease in the amount of light entering the cone which is equivalent to changing the shutter speed to a setting of 1/125 second (4/5 x 1/100). Likewise, the equivalent setting for the 0.3 neutral density filter becomes 1/200 second, and that for the 0.6 filter is 1/400 second. Hence, equivalent shutter speeds for any neutral density filter may be obtained merely by multiplying the initial shutter speed by the light transmission fraction of the filter.

15. One part of the original test program called for the determination of the best point of focus of the lens to give optimum over-all resolution. According to Howlett[1], "the plane of the best average photographic resolving power over a 9" x 9" picture area for this (the

1. Howlett, op. cit.

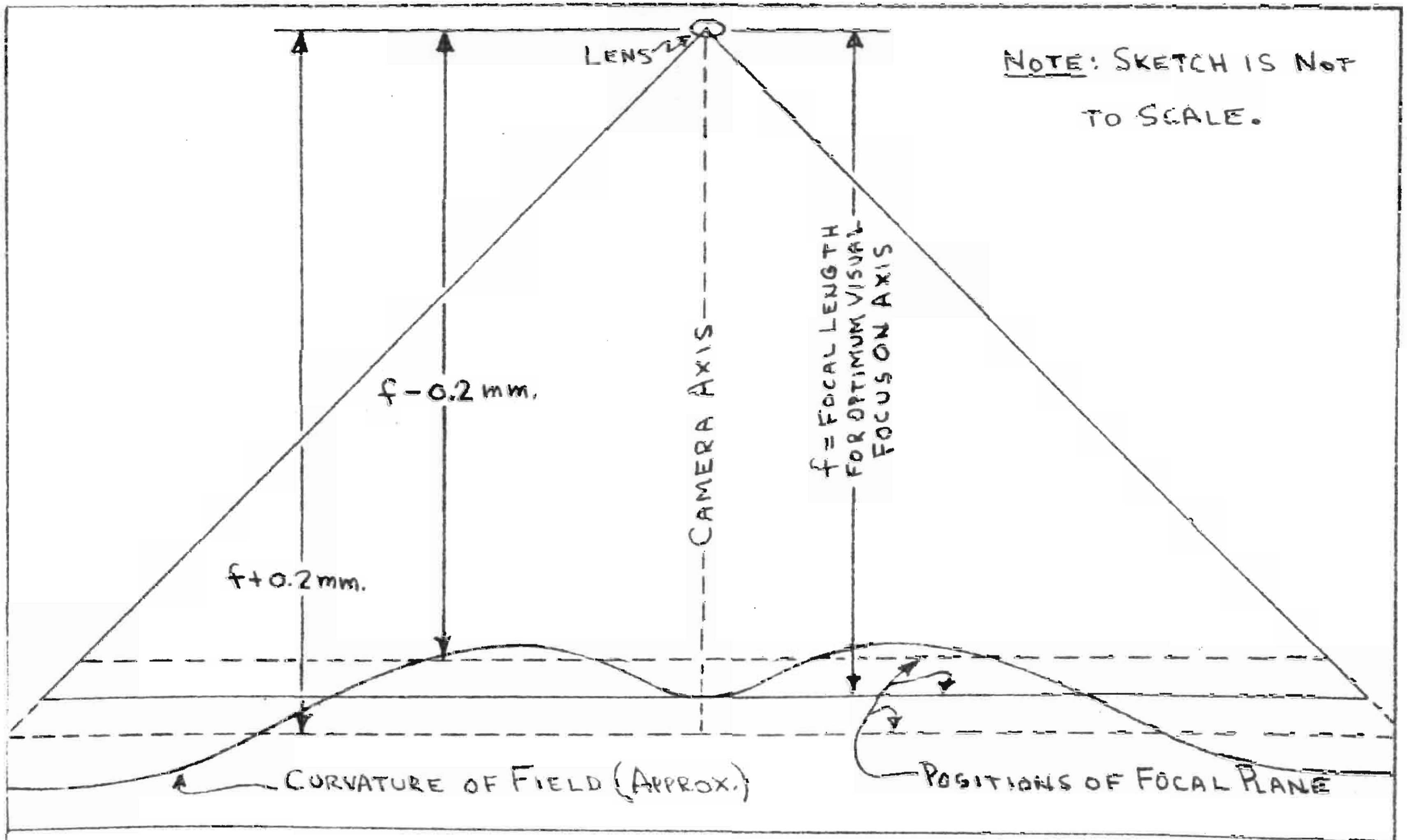


Fig. 6 - Three Positions of Focal Plane Used in Resolution Photography.

6" Metrogon) lens has been found to be 0.008" further from the lens than the axial position for best visual focus on the minimum fringe criterion". It was decided to accept, temporarily, this position of focus for one of the test cameras and to check the resolutions across the picture area against the resolutions across the picture area of another camera focussed on-axis. As a further check, a camera whose lens was moved 0.008" nearer the focal plane was exposed in the same manner as the others. Changes in focus of the cameras were accomplished by placing shims between camera cone and body or by removing shims from this position (See Fig. 6). The fact became apparent very quickly, on analysis of the results of this portion of the tests, that the three positions of focus in the cameras did not represent a sufficient range of distances along the optical axes. For this reason, determination of the best position of photographic focus was relegated to a later series of tests in which camera magazines with adjustable locating backs were used (See Section "R"). Tests with the three original cameras, however, show that high-resolution combinations of lens aperture, shutter speed, and filter are affected little by different positions of focus in the camera. In other words, a combination which produces the highest resolution for one focus position very probably will give the highest resolution for any other position of focus. Of course, the series of combinations still will reach maximum resolution at one certain position of focus along the optical axis.

D. RESOLUTION PHOTOGRAPHY.

16. Prior to photographing the resolution targets, each K-17 camera was carefully placed in a portable mount so that its lens was directly over the camera station, was adjusted so that the camera axis was

coincident with the line of sight to the central target, and was horizontalized by leveling. The camera also was rotated so that the line of targets was positioned along one of the diagonals of the format. With the yellow filter in position in front of the lens, an exposure then was made for each combination of aperture size and shutter speed. Since there are five aperture stops and four shutter speed settings on the K-17 camera, total exposures for any one filter combination equalled twenty. The yellow filter then was replaced with the combination of yellow filter and 0.1 neutral density filter, and another set of twenty exposures was taken. This procedure was followed with the two other filter combinations. Upon completion of the eighty exposures taken with the line of targets along one diagonal, the camera was rotated 90° so that the line of targets fell along the other diagonal, and another eighty exposures were made of the various aperture-speed-filter combinations.

17. Three cameras were taken through the above sequence of operations--160 exposures for each. One of the three was focussed on-axis, one camera was adjusted so that its camera focal length was 0.2 mm. (0.008") longer, and one camera was adjusted with its camera focal length 0.2 mm. shorter. The total number of exposures taken for use in resolution tests thus was 480.

18. Resolution photography was accomplished during the month of November, 1948, between 12 Noon and 3:30 P.M. on a clear day. Cameras were operated electrically from a 24-volt storage battery. Vacuum for the locating back of the camera was supplied by connection to the intake manifold of a 3/4-ton Dodge truck; this differential pressure was adjusted to maintain automatically a value of 4 inches of mercury

during the period of camera operation.

19. Kodak Aerographic Super XX Panchromatic film (Type 1A, Class L) was used in the above tests. Film was developed for 30 minutes in Army Type C developing solution; the Smith B-4 developing set was used for this purpose. An attempt was made to keep all elements of the developing process as uniform as possible for the various rolls of film in order to insure the elimination of variables in this part of the tests.

E. READING OF RESOLUTION VALUES.

20. All values of resolution were read over a light table directly from the negative. For this purpose, a Zeiss binocular viewer was used (See Fig. 7). Magnification of the viewer eyepieces was approximately 15.5. Resolution values were read by two persons. It was found that values of radial and tangential resolution on the line targets were identical in almost every case where readings on the same targets were tested by both operators. Readings of the annulus targets diverged somewhat, however, especially on those negatives in which the brightness ratio was low. An attempt was made to synchronize, as far as possible, the eye indices of the operators in order to minimize imagination effects. It is believed that any differences in reading of resolution values in these tests will be of a negligible nature. Readings on both types of target almost were identical for both observers on negatives with relatively high brightness ratios. Maximum differences on extremely dark or very light film were of the order of one target size on the line target values and two target sizes on the annulus readings. These types of negative provide the lowest resolution readings. For low resolution readings, the difference in lines per

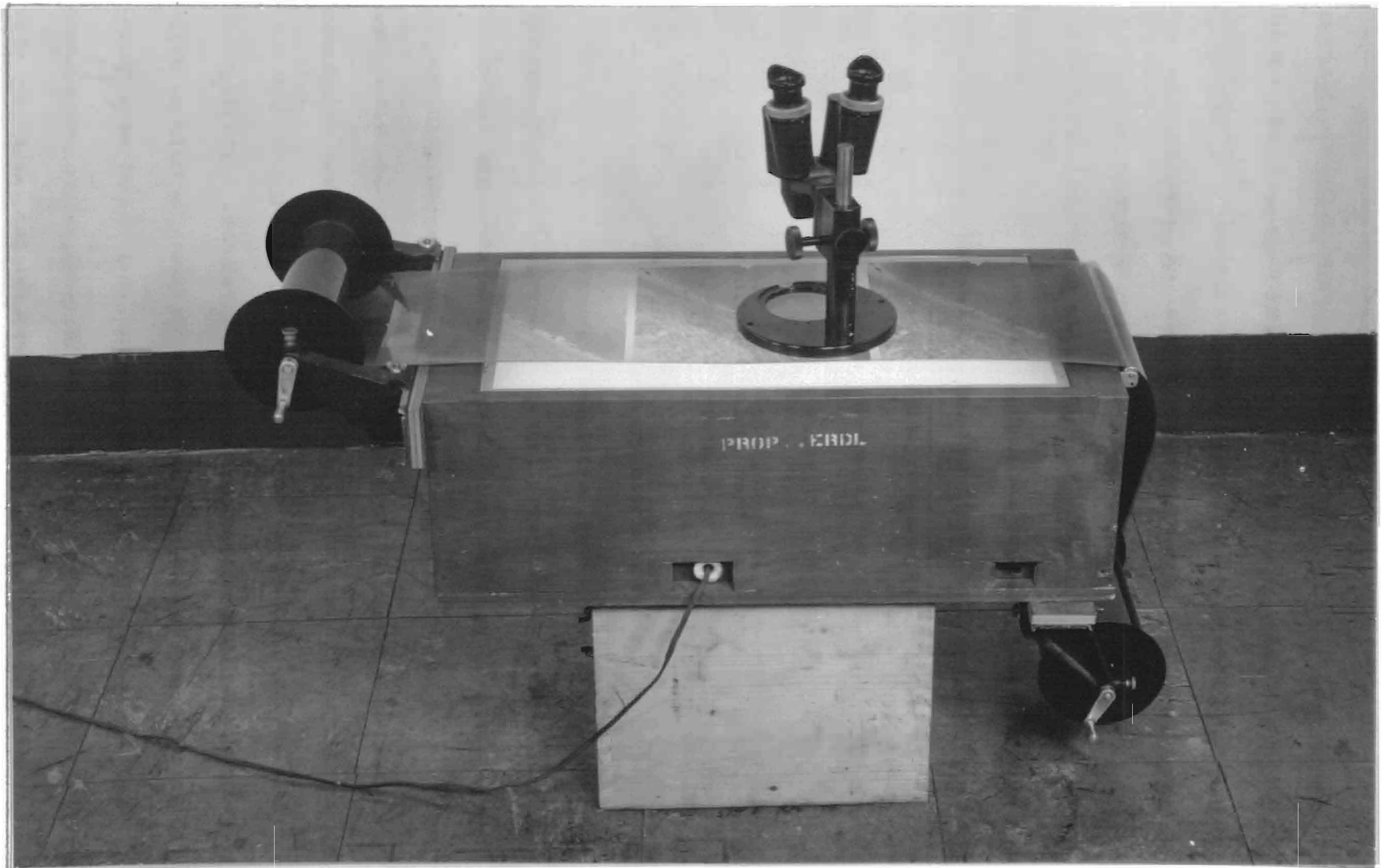


Fig. 7 - Zeiss Binocular Viewer.

millimeter between consecutive target-block or annulus sizes is correspondingly low (See Table 1); for example, between readings of 10 to 20 lines per millimeter over the first seven target sizes, the difference between any two consecutive targets is not more than two lines per millimeter, while for those targets with 20 to 40 lines per millimeter, these differences between consecutive targets are as much as four lines per millimeter. Furthermore, the greatest interest, for purposes of this study, lies in those settings of the camera which provide a good exposure with values of high resolution.

21. A voluminous amount of readings was made, of necessity, on each roll of film. With twenty different combinations of shutter speed and shutter aperture, and four combinations of filter, all of which were exposed over each of the two diagonals, the resulting exposures totaled 160 for each camera. On each exposure, there were thirteen clusters of targets (one at the center and six at varying angles on each side of the center). Each cluster of targets included a line target, which necessitated both radial and tangential readings, and four annulus targets of different contrasts. Six readings per group and thirteen groups of targets required 78 readings of resolution per exposure. The number of readings of resolution value, therefore, totalled 12,480 per camera and approximately 37,500 for the three cameras. It is felt that this amount of data should provide a comprehensive picture for the current tests.

F. AVERAGING OF LINE TARGETS.

22. After the reading of resolutions was completed, it was decided to analyze first the results obtained from the line targets. Consequently, an average resolution at the center and at each of the angles outward from the center was computed. No differentiation was made

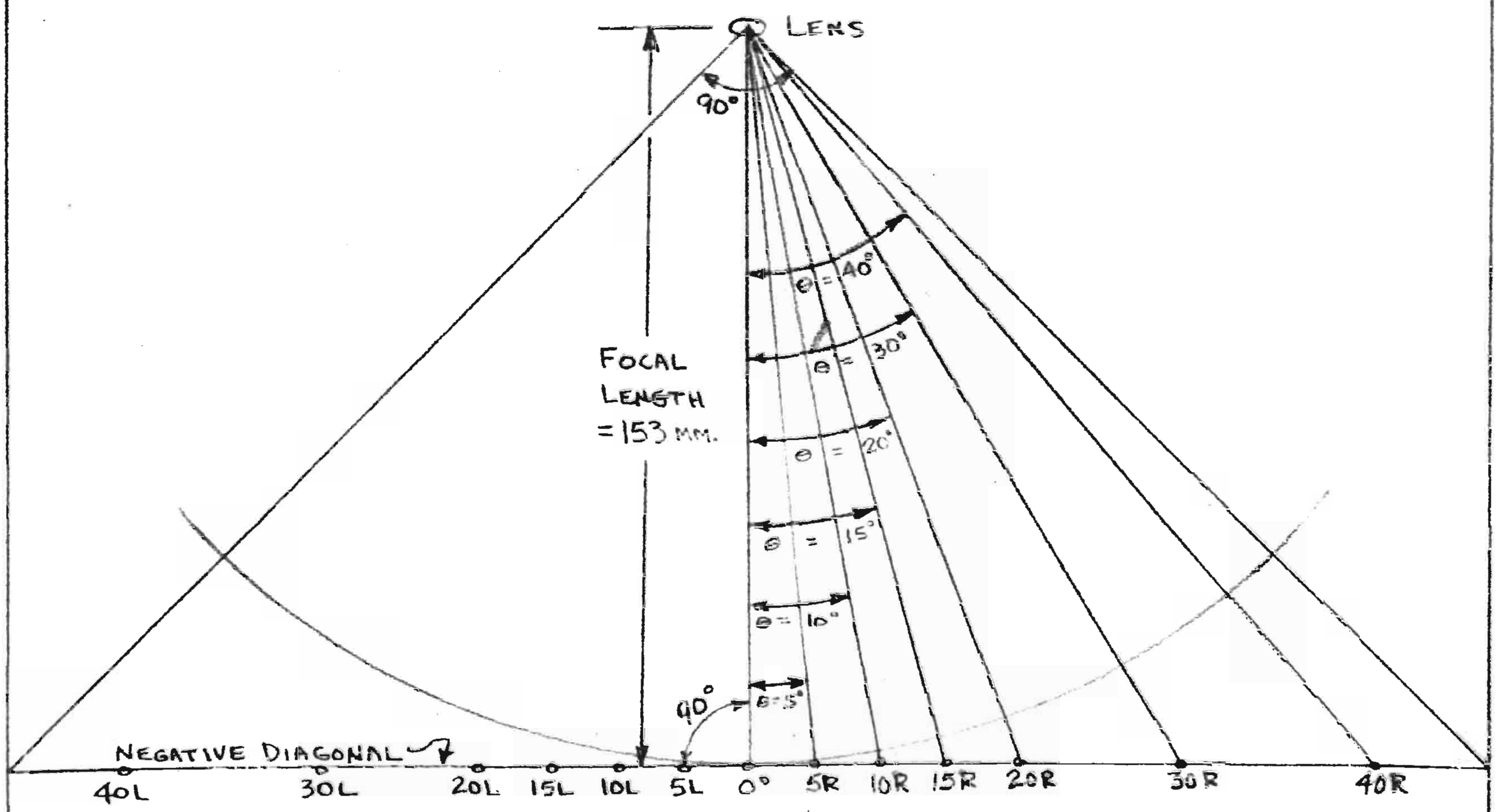
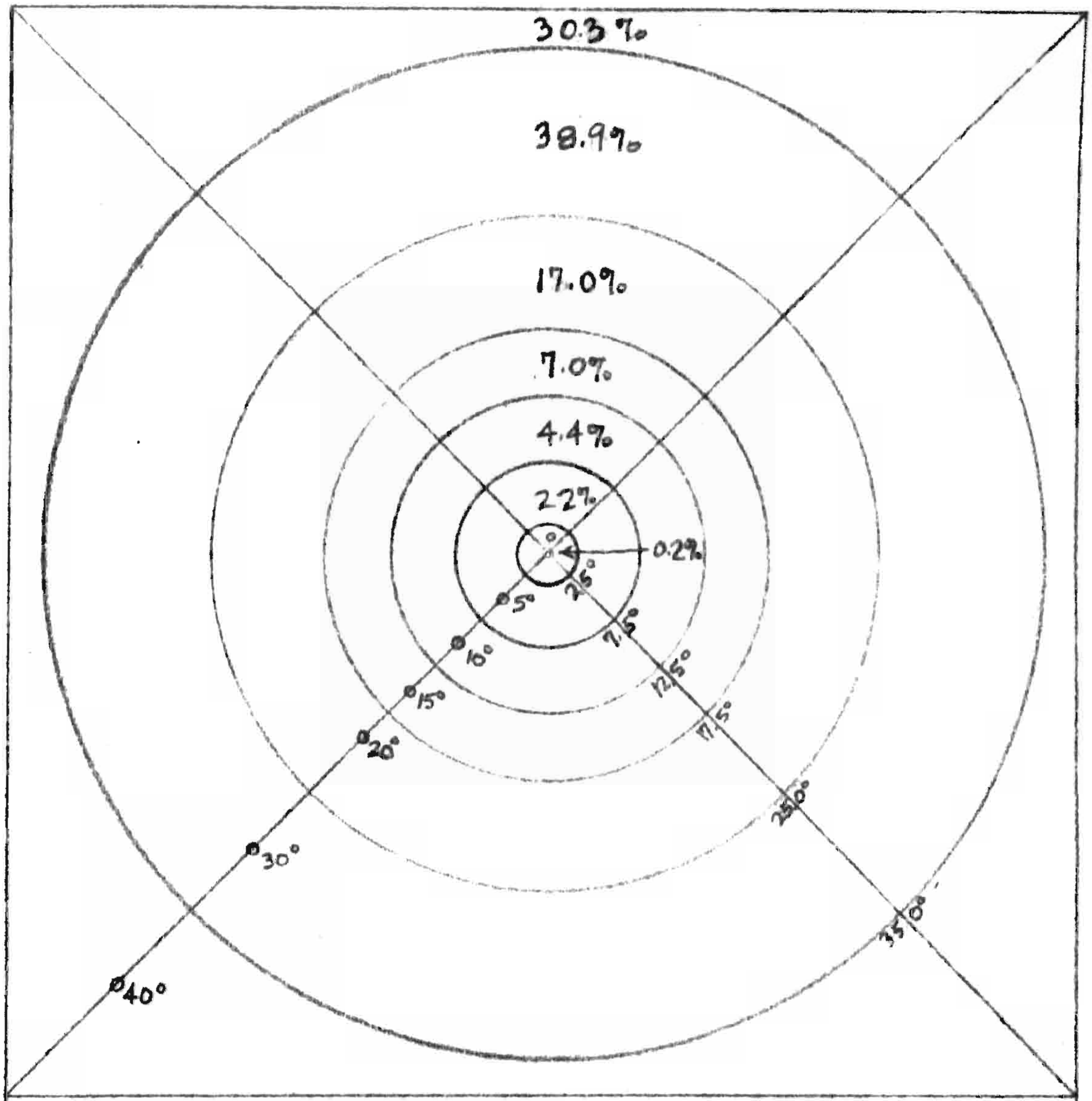


Fig. 8 - Distribution of Targets Along Photographic Diagonal.



SCALE OF PHOTOGRAPH REDUCED ONE-THIRD

FORMAT – 9" x 9"

TOTAL AREA – 81 SQ. IN.

FOCAL LENGTH – 6"

Fig. 9 - Annulus Diagram Showing Area-Weight Method for Averaging Resolutions.

initially between radial and tangential resolution, and resolutions for corresponding angles to the right and left of center were added together in the averaging process. Also included were corresponding values on the second diagonal. Thus, the final figures for each target angle represented averages of eight separate values, with the exception of that for the central target, which was an average of four values (See Table 3, p. 65).

23. The next objective was to determine a method, given average resolutions at 0°, 5°, 10°, 15°, 20°, 30°, and 40°, for reducing all values to a single resolution, for any filter-aperture-shutter speed combination, which would be truly representative of the conditions producing that resolution and could be used in comparison with resolutions for other combinations. It was decided to select a weighting of resolutions based on the areas of annuli whose limits for any particular target are defined by points halfway between it and adjacent targets (See Figs. 8 & 9). For example, the area pertinent to the target at 10° would be formed by an annulus whose lesser radius would reach 7 1/2° on the photo and whose greater radius would reach 12 1/2°. The calculated area of 3.6 square inches for this particular annulus represents 4.4% of the total of 81.0 square inches for the 9" x 9" photo. The value of 4.4%, multiplied by the resolution at 10°, gives a product which, when added to corresponding values for the other targets, provides a single, weighted average of resolution for the exposure (See Table 4, p. 71).

G. COMPUTATION OF RELATIVE LIGHT QUANTITIES.

24. In order to have a means for comparing the amount of light falling on the negative for the various aperture-speed-filter combina-

tions in the camera, a system was evolved which conceives of light flowing onto the negative through a given area of aperture for a certain length of time, much as water flows through a weir. Addition of the neutral density filters to the system lessens this flow of light by increasing the effective shutter speed. The system outlined herein is based on a unit quantity of light which flows through the lens for settings of 1/400 second in shutter speed and an f/22 aperture, and with the normal yellow filter in front of the lens. All other combinations of photographic conditions are expressed in relative numbers based on this fractional inch-second conception.

25. An explanation of the relationship in size between lens apertures, as denoted by the common "f" numbers, may be of value at this point. The aperture number (N) may be expressed as a ratio in which the focal length of the camera (F) is the numerator and the effective diameter of the shutter opening (d) is the denominator, or $N = F/d$. The focal length of all K-17 cameras used in these tests was 6". Then for an f/22 aperture, the diameter of aperture $= F/N = 6/22 = 0.27"$ and the area of the aperture, $A_{22} = d^2\pi/4 = 0.0729\pi/4$. This area represents a relative term of unity. Since the term, $\pi/4$, is a constant for all cases, we may consider, likewise, that the term, $d^2 = 0.0729$, also is unity for the f/22 aperture and that relative terms for other apertures may be based on the squares of their respective diameters. Thus, for an f/16 aperture, which has an effective diameter of $6/16 = 0.375"$, the square of its diameter becomes 0.141, which is approximately twice that of the f/22 aperture. It can be shown, by this method, that relative areas are 4 for the f/11 aperture, 8 for the f/8 aperture, and 16 for the f/5.5 aperture. This mathematical relationship does not exist with

the 6.3 aperture, whose relative area is 12.5 times that of the f/22 aperture (See Table 5, p. 72).

26. Relative numbers for shutter speeds are obtained by assuming a value of unity for the speed of 1/400 second. Since 1/200 second is twice as long a period of time, its relative number becomes 2. Other relative numbers for shutter speeds are 4 for 1/100 second, 8 for 1/50 second, and 1 1/2 for 1/300 second (See Table 5).

27. Relative light quantities are obtained for any combination of shutter speed and aperture by multiplying relative numbers, as shown in Table 5, to give an area-time product. These products are consolidated in Table 6, p. 72, to show light quantities for any combination encountered in these tests. Graph 1 (p. 99) further demonstrates the direct relationships involved in these light-quantity products. Relative numbers for apertures and shutter speeds are plotted against each other to present lines of constant light quantity. The effect of various filter combinations is shown in Table 7, p. 73, wherein light quantities are listed for each of the 100 separate combinations of shutter speed, lens aperture, and filter type. It is believed that this method of resolving all conditions of photography to the common denominator of light quantities on the negative will provide material for several interesting analyses of resolution.

H. TANGENTIAL AND RADIAL RESOLUTION.

28. The use of the line target in this series of resolution tests has introduced the subject of tangential and radial resolution. The standard Air Force, high-contrast target consists of target blocks which decrease consecutively in size by the $\sqrt[6]{2}$. Each target block includes three vertical lines and three horizontal lines. In ordinary

photography, radial, or sagittal, resolution refers to photographic definition which is measurable in a radial direction from the photo center, while tangential resolution may be measured from lines running in a direction perpendicular to the radial lines. A simpler conception may be illustrated by the figure of a wheel, in which the hub represents the photo center, the spokes represent radial lines, and the rim is analogous to a tangential line. With the images of targets appearing along the photographic diagonal, it easily is observable that the vertical lines in the target block will represent tangential lines, while the horizontal lines will measure radial resolution. Visual separation of each set of lines on the smallest possible target thus will provide the corresponding values of resolution in lines per millimeter.

29. The above conception of radial and tangential resolution is not applicable in the case of the aerial photograph. There still are two types of resolution--that measurable from lines within, or parallel to, the line of flight and that produced from lines perpendicular to the flight line. Differentiation between these two types of resolution on negatives exposed from a camera station in an airplane is much more important than a corresponding evaluation of radial and tangential resolution on a negative taken from a ground station camera. The motion of the airplane in flight imparts an image motion on the negative which tends to elongate the lines parallel to flight without obliterating them. This often results in a spurious resolution which is higher than normal. Those lines having perpendicularity to the line of flight, however, are fused together more rapidly, thereby producing values which are considerably lower than those for the resolution measurable in the line of flight. The differences between resolutions in flight and perpendicular to flight thus may total as much as 15 or 20 lines per

millimeter, most of which is directly chargeable to image motion. With the advent of image motion compensation features in the aerial mapping camera, these large differences will be minimized, and the smaller differences caused by lens aberrations then will represent a larger percentage of the total.

30. There are various methods currently used for obtaining a resultant resolution from the line targets. Consider the case of an ordinary photograph in which R is the radial and T is the tangential resolution. Let M be the mean of the two. The normal arithmetic average is half the sum of the radial and tangential resolutions and may be expressed as $M_A = 1/2\ (R+T)$. The geometric mean is the square root of the product of radial and tangential resolutions ($M_G = \sqrt{RT}$). The harmonic mean is expressed as a reciprocal which equals one-half the sum of the reciprocals of radial and tangential resolutions, or $1/M_H = 1/2\ (1/R + 1/T)$. Consider further the example of a negative on which a target resolves 30 lines per millimeter radially and 20 lines per millimeter tangentially. This condition would produce an arithmetic mean of 25, a geometric mean of 24.6, and a harmonic mean of 24 lines per millimeter. Hence, results of these common methods may be expressed in magnitude by the formula, $M_A > M_G > M_H$. Where differences between the two types of resolution are large, it has been advocated that a method be used in which the lower value is given the greater weight.

31. At least one Armed Forces unit is conducting resolution tests in which all six lines of the target block must separate visually before a resolution is recorded. This method assigns full value to the lowest of the two resolutions, a view which holds concurrence from other authorities in the field of resolution investigation. It is believed by the

writer that this method introduces a fallacious importance to the lower resolution. Tests of resolution at Muroc Air Base, in which cameras with, and without, image motion compensation were used, have disclosed a rather interesting fact. The negatives exposed in the camera equipped with image motion compensation produced resolutions of 20 lines per millimeter in directions both parallel to, and perpendicular to, the line of flight. From photography of the same area, exposed simultaneously by the camera without image motion compensation, were recorded resolutions in line of flight of 20 lines per millimeter and resolutions perpendicular to flight of 8 lines per millimeter. This indicates the apparent efficacy of the image motion compensation feature as far as resolution across flight is concerned. However, a visual examination of detail on each exposure shows little actual difference between the two in the amount of information received by the eyes. This phenomenon appears to indicate that the negative has not been affected to a great extent by a lessening of resolution in one direction. With a resolution of 20 lines per millimeter in one direction and 8 lines per millimeter in the other direction, the film can be rated for resolution in a number of ways: (a) it can be rated according to the highest resolution reading which, in this case, will be 20 lines per mm.; (b) it can be rated by using arithmetic, geometric, or harmonic means, which give resolutions of 11 to 14 lines per millimeter; or (c) it can be rated by the lowest resolution value which, in this instance, will be 8 lines per millimeter. The writer has found that, when examining a photograph for actual ground detail, the proper rating of the above photograph should be somewhere between 14 and 20 lines per millimeter rather than between 8 and 14 lines per millimeter. In other words, it is felt that high resolution in one direction identifies an object sufficiently to compensate, to a large degree, for the loss of resolution in the other direction.

32. All tests of resolution in this unit's program were conducted with the camera in a fixed position on the ground; hence, the effect of image motion is not a factor. Tangential and radial resolutions were recorded separately. Differences between tangential and radial resolution are caused primarily by various lens aberrations, chief of which is probably astigmatism. Other less important contributory causes might be localized flaws in the film, or personal errors in observation.

33. Initial listing of resolution in Table 3 made no separation of radial and tangential resolutions. In Table 8, p. 74, a number of frames have been extracted from the original data to show both types of resolution. Included therein are twenty combinations of filter, shutter speed, and aperture for each of the three positions of camera focus. Differences between radial and tangential resolution, for the various combinations, are shown in the right-hand column of Table 8. It can be noted that the average differences vary from approximately 1.5 to 3.5 lines per millimeter, depending on the camera, with an over-all average of 2.5 lines per millimeter. This value represents roughly one gradation in target block size and is not considered of sufficient significance by the writer to warrant any other form of mathematical handling than an ordinary arithmetic mean.

34. In Graph 2, p. 100, a curve is drawn which shows the average deviations between radial and tangential resolutions for each position of the target along the photographic diagonal. An overage of radial resolution is considered plus, while a minus value indicates a preponderance of tangential resolution, all values being expressed in lines per millimeter. Points along the curve were obtained by adding algebraically, for each target position, all differences between radial and

tangential resolution, then dividing by 60, the total number of filter-aperture-shutter speed combinations exposed in the three cameras. It can be seen that tangential resolution is higher than radial at 0°, 5°, and 10°, but that radial exceeds tangential along the remainder of the diagonal, with a maximum at 30°. Deviation from the axis of equality is indicative of the increased effects of astigmatism as the edge of the picture is approached.

35. It is interesting to note that the values of tangential and radial resolution diverge with a decrease in the size of lens opening. Average differences, in lines per millimeter, for various aperture sizes, as determined from Table 3, are as follows: (a) f/6.3 - 1.9; (b) f/8 - 2.0; (c) f/11 - 2.0; (d) f/16 - 2.4; and (e) f/22 - 3.7. These values have been used for the drawing of a curve (See Graph 3, p. 101) in which the average differences between radial and tangential resolutions are plotted against relative areas of aperture. For this purpose, the area of the f/22 aperture is taken as unity. Attention is directed to the fact that the curve varies little for the three largest apertures.

I. RELATION OF WEIGHTED-AVERAGE RESOLUTION TO RESOLUTION AT 30°.

36. Observable immediately in connection with the averaging of resolution values was the fact that the weighted-average resolution for any frame closely approximated that average resolution for the targets at an angle of 30° outward from the center of the photograph. The differences between the two values throughout the entire scope of the tests averaged about ±0.6 lines per millimeter (See Table 9, p. 77). The reason for this is apparent when consideration is given to the weight of 38.9% assigned to the 30° resolution in arriving at the over-all

weighted average. It seems reasonable to assume that a close approximation of resolution, based on the weighted annulus-area average, may be obtained, for this particular camera and lens, merely by measuring outward from the center of the negative a distance of 3.46" and reading the resolution on a single target. The distance of 3.46" represents the product of the tangent of 30° (0.57735) and the focal length of the camera (6").

37. Table 9 contains the amounts of variation between weighted-average resolutions and those at 30°, for all three cameras. Results of the original resolution tests parallel closely those of subsequent tests as far as similarity of these two values is concerned.

J. CORRELATION OF APERTURE, LIGHT QUANTITY, AND RESOLUTION DATA.

38. Section "G" of this report contains an explanation of the computation of relative light quantities for various combinations of aperture, shutter speed, and filter. The method outlined therein determines the amount of light flowing onto the negative through a certain aperture for a given length of time. Light quantities thus are expressed in relative numbers based on a unit quantity of light which flows through the lens for settings of 1/400 second in shutter speed and f/22 aperture, and with the normal yellow filter in front of the lens. The neutral density filters tend to decrease the amount of light in accordance with their density in a manner similar to increasing the shutter speed. Consider the combination of yellow plus 0.3 neutral density filter, an f/16 aperture, and a 1/50-second shutter speed. The 0.3 neutral density filter transmits only half of its incident light, thereby producing an equivalent shutter speed, in terms of the yellow filter, of 1/100 second. A shutter speed of 1/100 second allows 4 times as much light to pass as

a 1/400-second speed. The area of the f/16 aperture is twice that of the f/22 aperture. The product of the numbers 4 and 2 gives a value of 8, which is the relative light quantity of the above combination. In other words, 8 times as much light is allowed to flow onto the negative for the conditions listed in the example than is allowed by the combination of 1/400-second shutter speed, f/22 aperture, and yellow filter. The chief purpose of this system is to reduce all combinations of filter, aperture and shutter speed to one common medium, as an aid to the prediction of resolution.

39. Theoretically, any combinations of filter, aperture, and shutter speed which have the same relative light quantity numbers should produce about the same average resolutions. This theory will hold, in certain cases, but is not always true. For example, by reference to Table 3b it is noted that average resolutions for various combinations are listed as follows: (a) yellow filter, 1/200 second at f/11 - 22.7 lines/mm.; (b) yellow + 0.3 N.D. filter, 1/100 second at f/11 - 22.1 lines/mm.; (c) yellow + 0.6 N.D. filter, 1/50 second at f/11 - 22.9 lines/mm. These combinations, each of which has a relative number of 8, vary in average resolution by less than one line per millimeter. On the other hand, a combination of yellow + 0.1 N.D. filter, 1/100 second at f/22, produces an average resolution of 24.1 lines/mm., while the combination of yellow + 0.6 N.D. filter, 1/400 second at f/6.3, gives an average resolution of 16.6 lines/mm. Both of these combinations have relative light quantity numbers of 3. Although the fully opened lens has the highest theoretical resolution, its ability to produce high resolutions, in actuality, is not as great as for somewhat smaller aperture settings. The residual aberrations in a wide open lens and some

unfavorable characteristics of emulsions may reduce drastically resolving power. As the lens is stopped down, some of its aberrations become smaller, and its photographic resolving power may increase gradually until, at a certain stop, it approaches the theoretical value. This stop usually lies somewhere between f/8 and f/22.

40. The density of the negative appears to have an important bearing on photographic resolution. In general, a negative whose detail is pleasing to the eye on the light table will have a high average resolution. There is, of course, an occasional exception to this rule. Undoubtedly, the resolution will be lower on a negative which is very dark or on one which is extremely light, as far as brightness ratio is concerned. The light quantity data can be used as a medium for regulating the density of the negative to assure high resolutions. A cursory examination of this data discloses that all combinations having light quantities between 4 and 16, with the exception of several combinations which include both the f/6.3 aperture and the 0.6 neutral density filter, will produce resolutions from about 20 to 27 lines per millimeter. A further narrowing of this range shows that a light quantity of 8 represents an optimum value for selecting high-resolution combinations. Twenty-six combinations on the three cameras having a light quantity of 8 produce an average resolution of approximately 23 lines per millimeter. Table 10 (p. 78) contains values of resolution, based on aperture size, for various light quantities. From this data were drawn Graphs No. 4 (p. 102), which demonstrate the optimum resolution for the various apertures. Light quantities at which exposures were made are observable as abscissae on the graphs. Table 11 (p. 79) is a condensation of resolution and light quantity values for all investigated combinations of filter, aperture, and shutter speed at each of the three positions of focus.

K. COMBINATIONS OF APERTURE, FILTER, AND SHUTTER SPEED WHICH PRODUCE HIGH RESOLUTION.

41. As a matter of interest to the reader, those combinations of filter, aperture, and shutter speed on the three test cameras which produced average resolutions of 24 lines per millimeter or higher are listed in Table 12 (p. 82). The three highest individual combinations are as follows: (a) yellow + 0.3 N.D. filter, f/16 at 1/50 second - 27.0 lines/mm.; (b) yellow + 0.1 N.D. filter, f/16 at 1/50 second - 26.9 lines/mm.; and (c) yellow + 0.1 N.D. filter, f/22 at 1/50 second - 26.8 lines/mm. It is noticeable that the f/16 aperture is most prevalent among the 27 high-resolution combinations. Likewise, most of the combinations were exposed at a shutter speed of 1/50 second. The average light quantity for the 27 combinations was 8.5 units.

42. Table 13 (p. 83) was prepared by using the combinations listed in Table 12 as a nucleus. Over-all average resolutions were calculated from the average resolutions for various combinations on the three cameras. This method presents a more representative basis for final analysis of the filter, aperture, and shutter speed settings which produce highest photographic resolution. The right-hand column of Table 13 indicates the standing of the various combinations in the order of their high-resolution characteristics. Combinations were limited only to those having an average resolution of 21.8 lines per millimeter or higher; a total of 24 combinations are included in the table. The five highest combinations are as follows: (a) yellow + 0.3 N.D. filter, f/16 at 1/50 second - 25.30 lines/mm.; (b) yellow + 0.1 N.D. filter, f/22 at 1/50 second - 25.27 lines/mm.; (c) yellow + 0.1 N.D. filter, f/16 at 1/50 second - 24.9 lines/mm.; (d) yellow + 0.6 N.D. filter, f/16 at 1/50

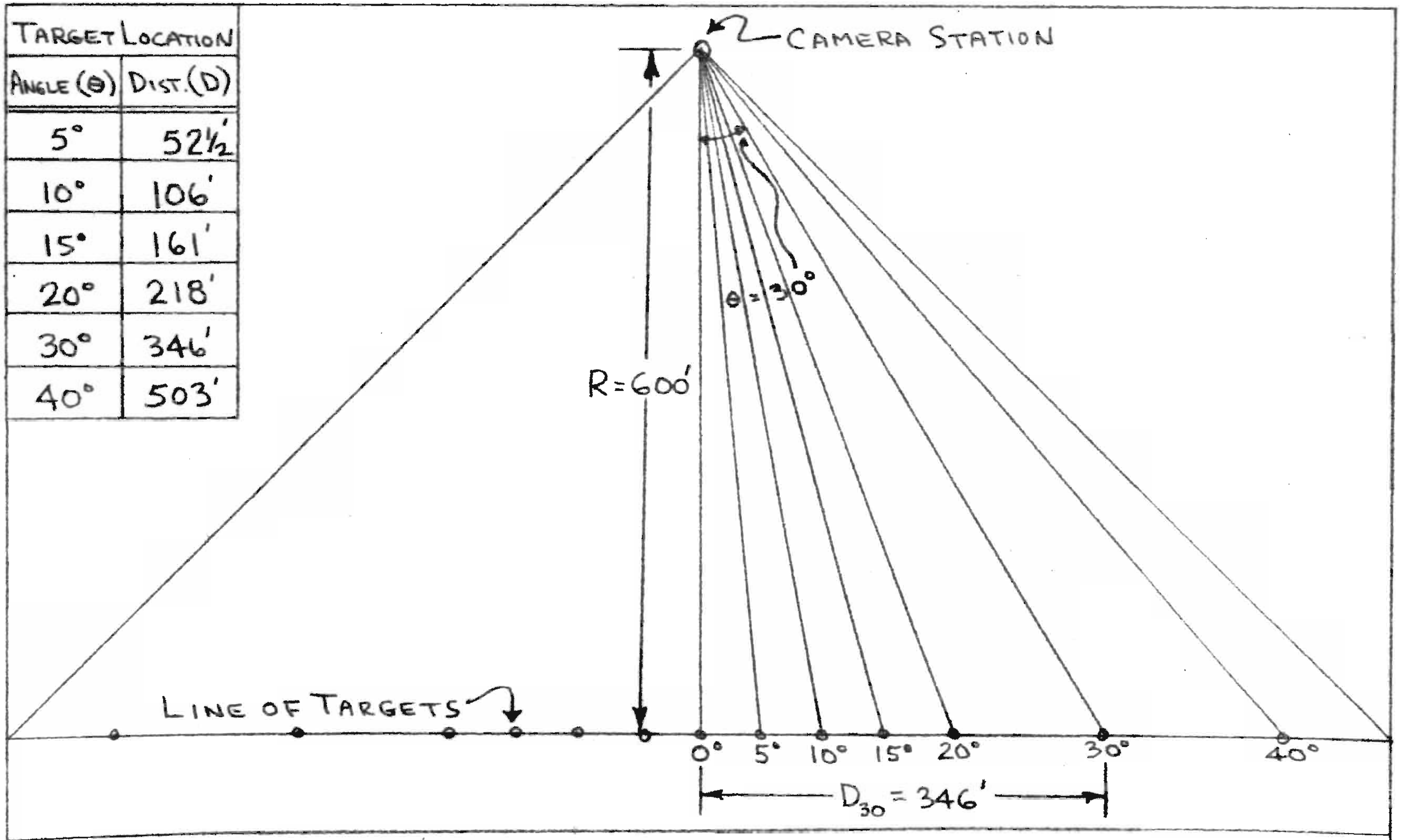
second - 24.5 lines/mm.; and (e) yellow filter, f/22 at 1/50 second - 24.3 lines/mm. An average light quantity of 8.3 units was calculated for the 24 combinations. Resolutions averaged highest with the f/16 aperture, with the 1/50-second shutter speed, and with the yellow + 0.1 N.D. filter combination, each being calculated individually.

43. Several pertinent facts may be gleaned from the foregoing tables. It seems apparent that the higher resolution values are produced by the smaller sizes of aperture in the camera, which is in line with findings from other sources. The f/16 aperture proves to be the optimum in this series of tests. With a small aperture, it becomes necessary to have a longer flow of light for a good exposure--hence, the fact that 1/50 second was found to be the best adjustment of shutter speed. High resolutions were recorded for all combinations of the normal yellow and neutral density filters. A better criterion for the use of the neutral density filters may be found by the photographer according to the varying conditions of actual operation. Data contained in Section "F" of this report have shown the advisability of selecting, for high resolution, a filter-aperture-shutter speed combination on the camera which carries a light quantity rating within the range of 4 to 16 units. The stated optimum light quantity rating of 8 units for highest resolution is confirmed by results of this section. It seems reasonable to suppose that, given normal conditions of illumination, the standard of photography with respect to photographic resolution could be maintained at a constant high level by adhering to the above principles in preparing the camera for operation.

L. DETERMINATION OF BEST PHOTOGRAPHIC FOCUS.

44. It is a generally known fact that the best focus for photographic definition in an aerial camera having a 6" Metrogon lens is at a position along the optical axis which is slightly farther from the lens than the axial position for best visual focus. The following sections of this report describe a series of tests which was made for the purpose of determining the position of best photographic focus in the camera. Definition on the photographic negative was measured in the same manner as for previous tests (resolution in lines per mm.). Movement of the focal plane along the optical axis was accomplished through the use of the type A-12 focusing magazine, in which the locating back can be moved away from, or toward, the lens through a range of ±0.100"; these movements are controlled by a focusing micrometer. The A-12 magazine is described more fully in Section "M".

45. Resolution tests for determination of focus position were performed in the same manner as described in Section "B"--that is, with the camera mounted horizontally and oriented so that images of resolution targets appeared at known positions along the diagonal of the photographic format. In this case, an object distance of 600 feet was used, instead of 400 feet, in order to reduce the correction for a finite distance. The positioning of targets along the diagonal is shown in Figure 10. Geodetic distances along the target line were calculated for any angular position by multiplying the object distance by the tangent of the angle for that particular position.



TARGET LOCATION	
ANGLE (θ)	DIST. (D)
5°	52½'
10°	106'
15°	161'
20°	218'
30°	346'
40°	503'

Fig. 10- Camera Range for Resolution Photography.

M. THE TYPE A-12 FOCUSING MAGAZINE.

46. This magazine, a modified type A-5, permits accurate changes in the focus of aircraft cameras. From an analysis of a series of photographs taken at each of several positions of the locating back is determined the position of the focal plane (plus or minus) which gives the sharpest definition of detail. The camera then can be focussed at that position which will give the optimum over-all photographic definition. Figure 11 shows the A-12 magazine, with particular reference to the micrometer mechanism which indicates position of locating back.

47. The locating back (vacuum back) in the magazine can be moved from its mean position in either direction along the optical axis by means of three cams actuated against spring-loaded studs, affixed permanently to the plate. The adjustment (cam actuation) is manual and can be accomplished either at the magazine or through a remote control. Accuracy is within ±0.002 of an inch. Figures 12 and 13 are two views showing the interior details of the A-12 magazine. The micrometer is graduated in thousandths of an inch. Positions of the locating back along the optical axis farther from the lens than the zero-position of the back are indicated on the plus-range of the micrometer; readings on the minus-range of the micrometer will be indicative of locating back positions which are closer to the camera lens.

48. Two separate corrections must be applied to the readings of the focusing magazine micrometer before these readings can be used in analysis. The first correction involves the determination of the actual visual focus for the particular camera-lens-magazine combination. It previously had been found, by measurement on a surface plate, that the graduations of the micrometers agreed closely with the corresponding

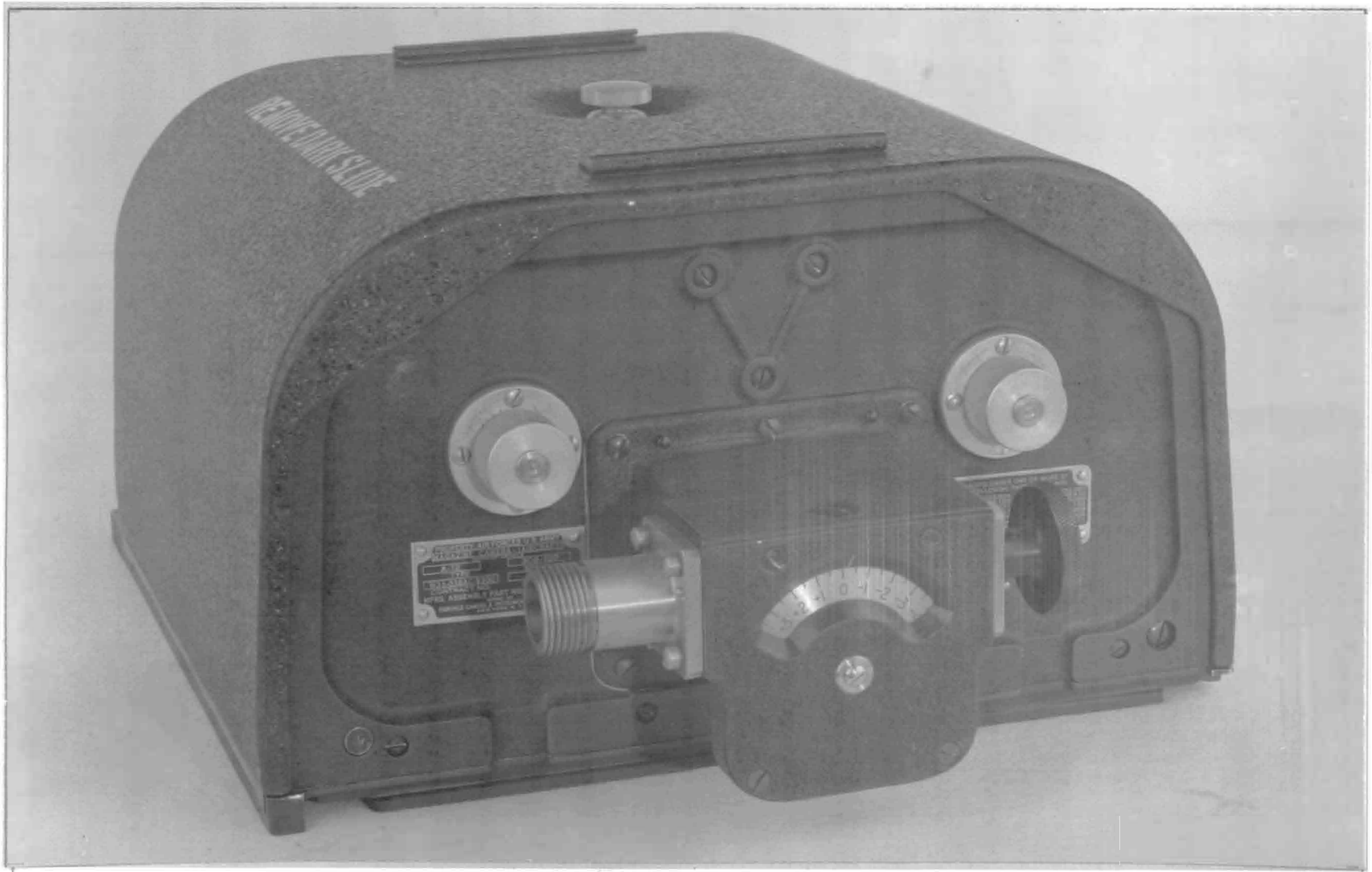


Fig. 11 - The Type A-12 Focusing Magazine.

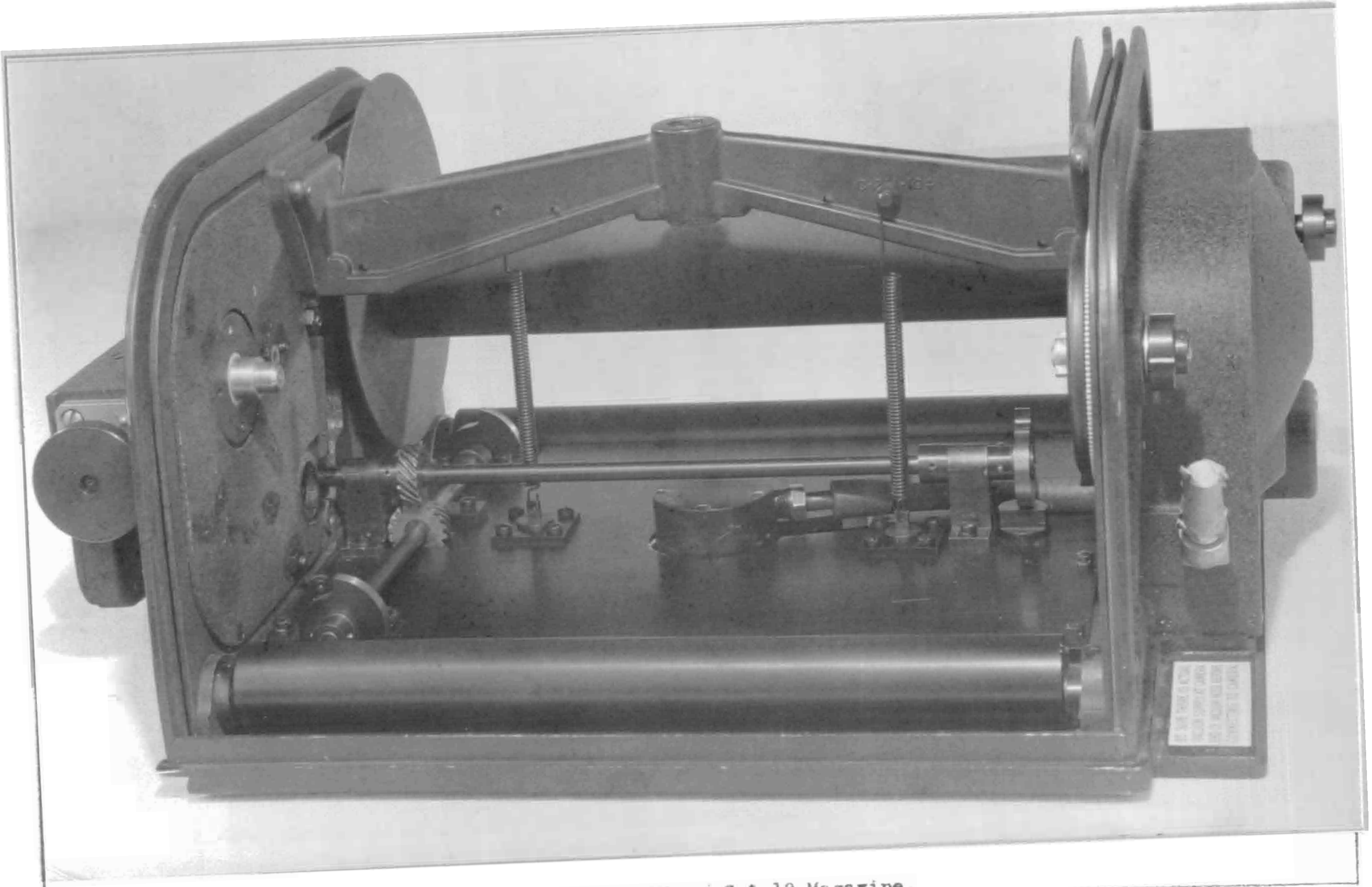


Fig. 12 - Side View of A-12 Magazine.

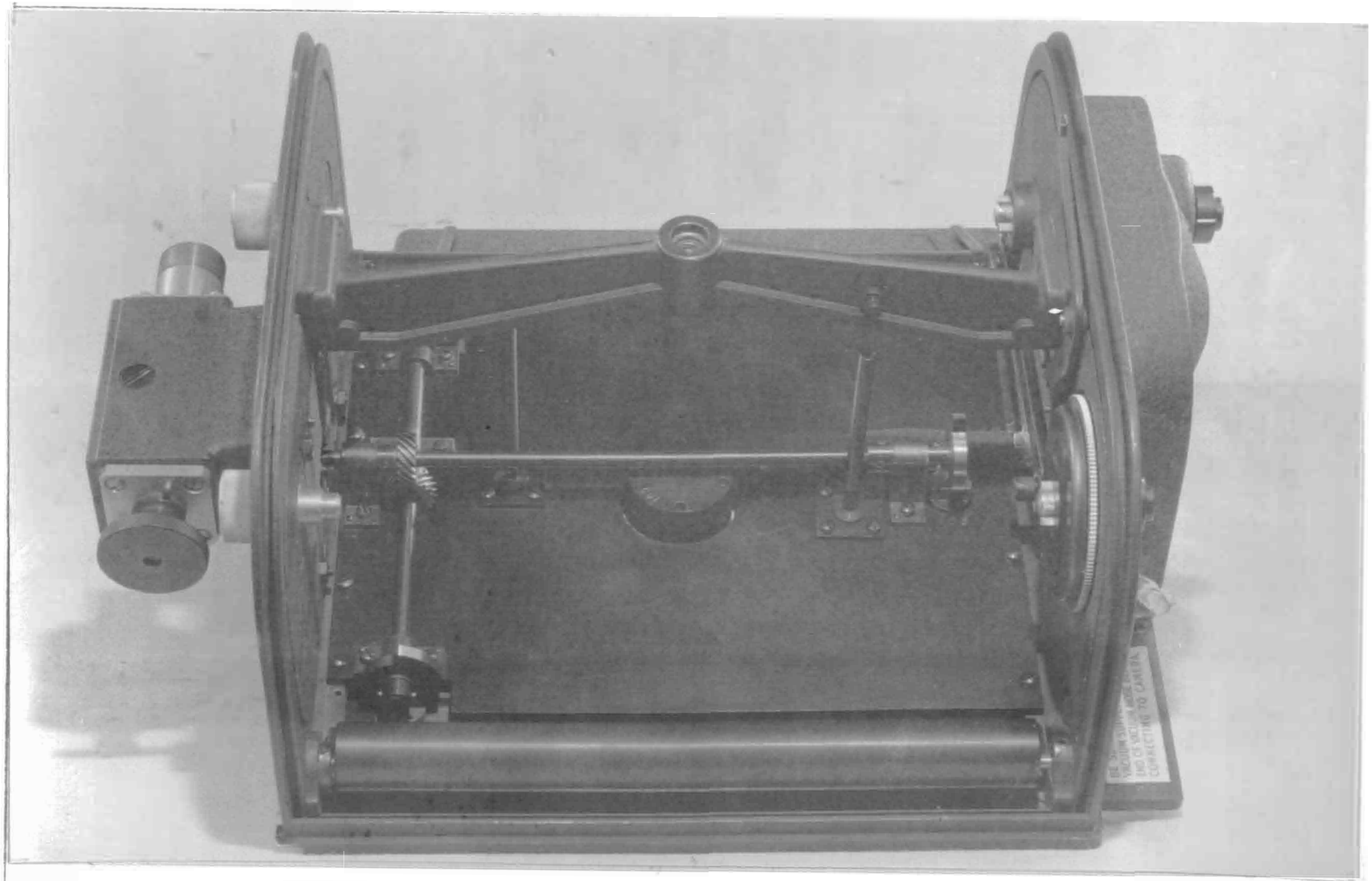
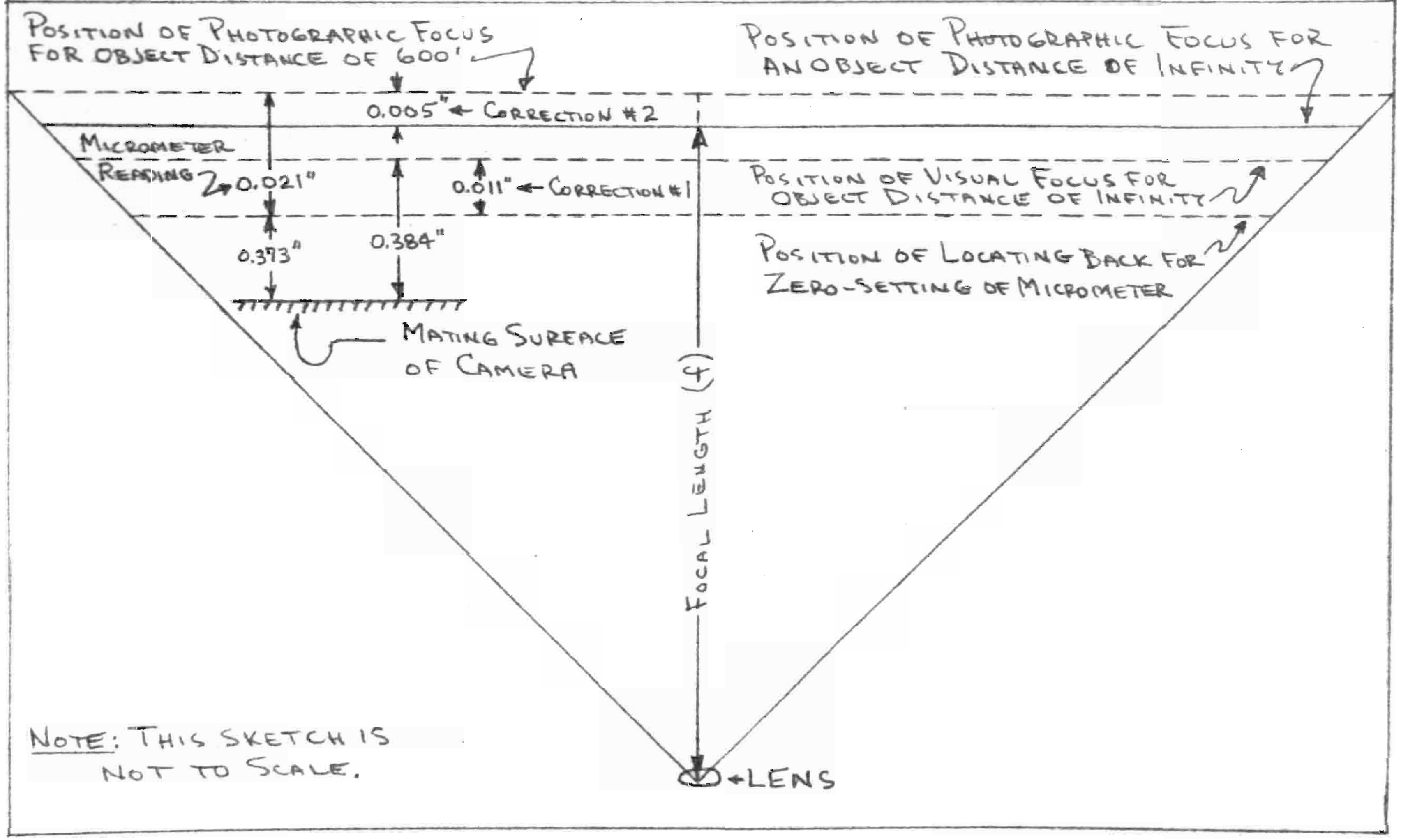


Fig. 13 - Type A-12 Magazine (View from Above)

movements of the vacuum backs in the magazines. The visual focus of the test camera was determined in the Optical Unit, Photo Physics Branch, Photographic Laboratory, Air Material Command. An optical bench method was used in which the camera was placed in a 14-foot collimator having a paraboloidal mirror, and the position of best on-axis focus was determined with a focal micrometer attached by a special jig to the mating surface of the camera. The average of six observations of the focal micrometer was -0.002". A check then was made to discover whether or not there was warpage in the focal micrometer plate. This was done by placing the plate across two bars of equal thickness resting on a surface plate and then focusing the micrometer on a third bar of the same thickness placed midway between the other two. The third bar was equipped with illumination for ease of observation. The zero-position of the focal micrometer was found to be 0.386" above the mating surface of the camera. The distance from the focal micrometer's zero-position to the plane of best on-axis visual focus (-0.002") then was applied to the above value of 0.386" to give 0.384", the distance from the mating surface of the camera to the position of best on-axis focus (See Fig. 14).

<u>49</u>. The next step in the procedure was the measurement of the distance from the mating surface to the surface of the locating back at the zero micrometer position in each of the two A-12 magazines used in the test. This distance measured 0.368" on Magazine No. 309-102 and 0.373" on Magazine No. 309-103. If 0.384", measured from the mating surface of the camera away from the lens, is the position of best on-axis focus for camera No. 44-190509, then the differences between this value and the above measured distances on the magazines will represent

Fig. 14 - Corrections in Readings of Focusing Micrometer on Magazine No. 309-103.



corrections to be applied to the micrometer readings. For Magazine No. 309-102, the correction will be +0.016", and for Magazine No. 309-103, this correction will amount to +0.011".

50. The position of visual focus obtained from the focusing micrometer is based on an object distance of infinity. Light rays coming from an infinite object, on passing through the lens, meet at a point whose distance from the lens is, by definition, the focal length (f) of the lens. Likewise, the image of an object placed at f-distance from the lens would come into focus at an infinite distance. Hence, the best position of visual focus for an object placed at some distance less than infinity would be at a point somewhat greater than the focal length of the lens. For this reason, a second correction must be applied to observations of the focusing micrometer to allow for the focus shift, since the object distance of resolution targets was only 600 feet. The correction to the focal length may be calculated quickly from the elemental Physics formula,

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \qquad (1)$$

in which u is the object distance, v is the distance from lens to point of focus, and f is the focal length. If the terms, u and v, are changed so that a value of f is included in each, as shown in Fig. 15, equation (1) becomes

$$\frac{1}{f+x} + \frac{1}{f+x'} = \frac{1}{f} \qquad (2)$$

Clearing fractions,

$$f(f+x') + f(f+x) = (f+x)(f+x')$$

reducing, and canceling,

$$f^2 = xx' \qquad (3)$$

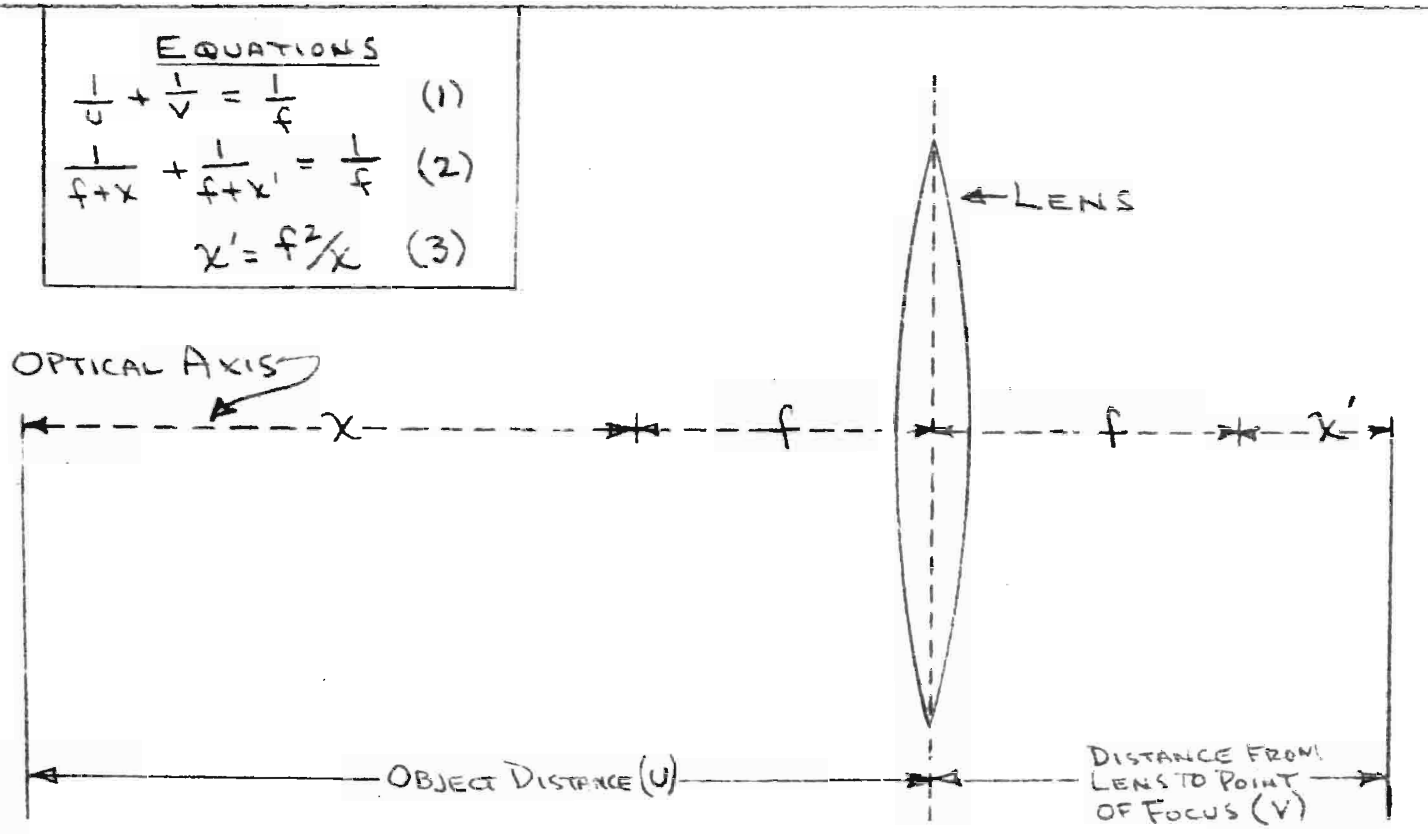


Fig. 15 - Relation of Object Distance to Position of Focus.

It can be seen that the term, x', represents the desired correction value. Then

$$x' = \frac{f^2}{x} = \frac{0.25 \times 12}{599.5} = 0.005"$$

This value of 0.005" will be added to the focal length but will be a subtractive correction on the micrometer readings (See Fig. 14).

51. The total correction to readings of the focusing micrometer will be 0.016 + 0.005 = +0.021" for Magazine No. 309-102, and will be 0.011 + 0.005 = +0.016" for Magazine No. 309-103. These total corrections will be used only as long as the magazines are operated with camera No. 44-190509. The actual position of the focal plane along the optical axis for best over-all definition finally is determined by subtracting the total correction from the numerical setting of the focusing micrometer at which maximum resolution is obtained.

N. COLLECTION OF DATA FOR DETERMINATION OF FOCUS POSITION.

52. Resolution photography was accomplished with four type K-17 aerial cameras. Initial tests were made with K-17C Camera No. 44-190509. The camera was placed in a specially constructed mount, set on a low platform, in such a position that its optical axis was level and its line of sight was in coincidence with the central target. In addition, the camera was rotated around its axis so that the line of targets on the negative fell along one diagonal of the format. This camera was equipped with the 6" Metrogon lens. The format of the type A-12 focusing magazine measures 8" x 9", the smaller dimension being along the direction of transport. Modification to this magazine limits its capacity to a 75-foot roll of film.

Fig. 16 - Resolution Targets Along Diagonal
(Yellow filter, f/16 aperture, 1/50 second.

53. A number of combinations of aperture, filter type, and shutter speed were exposed through a range in movement of focal plane from +0.030" to -0.030". An exposure was taken at each 0.0025-inch increment of distance throughout this range. This gave a total of 25 exposures for each aperture-filter-shutter speed combination. Fifteen different combinations were exposed in this manner. Most of the combinations selected were those having an aperture of f/6.3, since it seemed desirable to test the lens in its fully opened position. Other combinations were selected with respect to their ability for producing negatives of optimum density.

54. Kodak Aerographic Super XX Panchromatic film (Type 1A, Class L) was used in these tests. Film was developed for 10 minutes in Army Type C developing solution. An attempt was made to keep all elements of the developing process as uniform as possible for the various rolls of film in order to insure elimination of variables in this portion of the tests.

55. All values of resolution were read by an observer directly from the negative. The negative was placed on a light table and a Zeiss binocular viewer, having a magnification of approximately 16, was used, as before. Both tangential and radial resolutions were recorded for each of the 13 targets on each exposure. Thus, 650 observations were made on each camera combination, or approximately 10,000 for the 15 frames. A contact print from a representative exposure is shown in Figure 16.

56. Average resolutions at the center and at each of the angles outward from the center first were computed. No differentiation was made initially between radial and tangential resolution. Resolutions

for corresponding angles to the right and left of center were added together in the averaging process. Thus, final figures for each target angle represented averages of four separate values, with the exception of that for the central target, which was an average of two values (See Table 14, p. 84). In calculating average resolutions, it was noticed that resolution decreased rapidly on exposures photographed through the minus-range of the micrometer on the focusing magazine. Consequently, those values have been omitted in the tabulation of resolutions in Table 14. Also, the settings of the focusing micrometer have not yet been corrected for the discrepancies noted in Section "M".

57. The column at the extreme right in Table 14 presents an individual average resolution value for each frame, which has been weighted according to the area of the annulus whose limits, for any particular target, are defined by points halfway between that target and each adjacent target (See Fig. 9). Since the greater portion of photography used in the resolution program of this unit was taken with the A-5 magazine, which has a normal format of 9" x 9", the area calculations are based on a total of 81 square inches for the negative size. Resolution values with the A-12 magazine thus will be more in keeping with those observations already recorded.

O. CHARACTERISTIC RESOLUTION CURVES.

58. From a study of the data in Table 14, it can be deduced readily that the highest average resolutions are obtained on an exposure in which the resolution remains high as the edge of the photograph is approached. If curves are drawn in which the resolution is plotted against the angular position of the target at each position from the center of the negative to 40° outward from the center, this fact becomes

even more apparent. The graphs on pages 105 and 106 (No. 5) are drawn to show resolution curves for the five or six positions of focus which give maximum resolutions. Aperture and shutter speed are held constant, while the filter type is allowed to vary. The f/6.3 aperture was chosen in order to test the lens at its fully opened position. On each of the four filter combinations, the curve for maximum resolution is shown as a dotted line.

59. The curves in Graph 6 (p. 107) are selected and drawn in the same manner as those of Graph 5. In this case, however, combinations of aperture and shutter speed were selected which consistently give high resolution values. The combination of aperture, filter, and shutter speed which gives the highest average resolution does not necessarily produce high resolution values near the center of the photograph. However, if its values are high at 20°, 30°, and 40° outward from the center, then the average resolution must be high, since these three target positions provide approximately 86% of the weight, based on the annulus-area method of averaging (See Fig. 9). The positions of focus listed on these graphs were read directly from the focusing micrometer and represent uncorrected values.

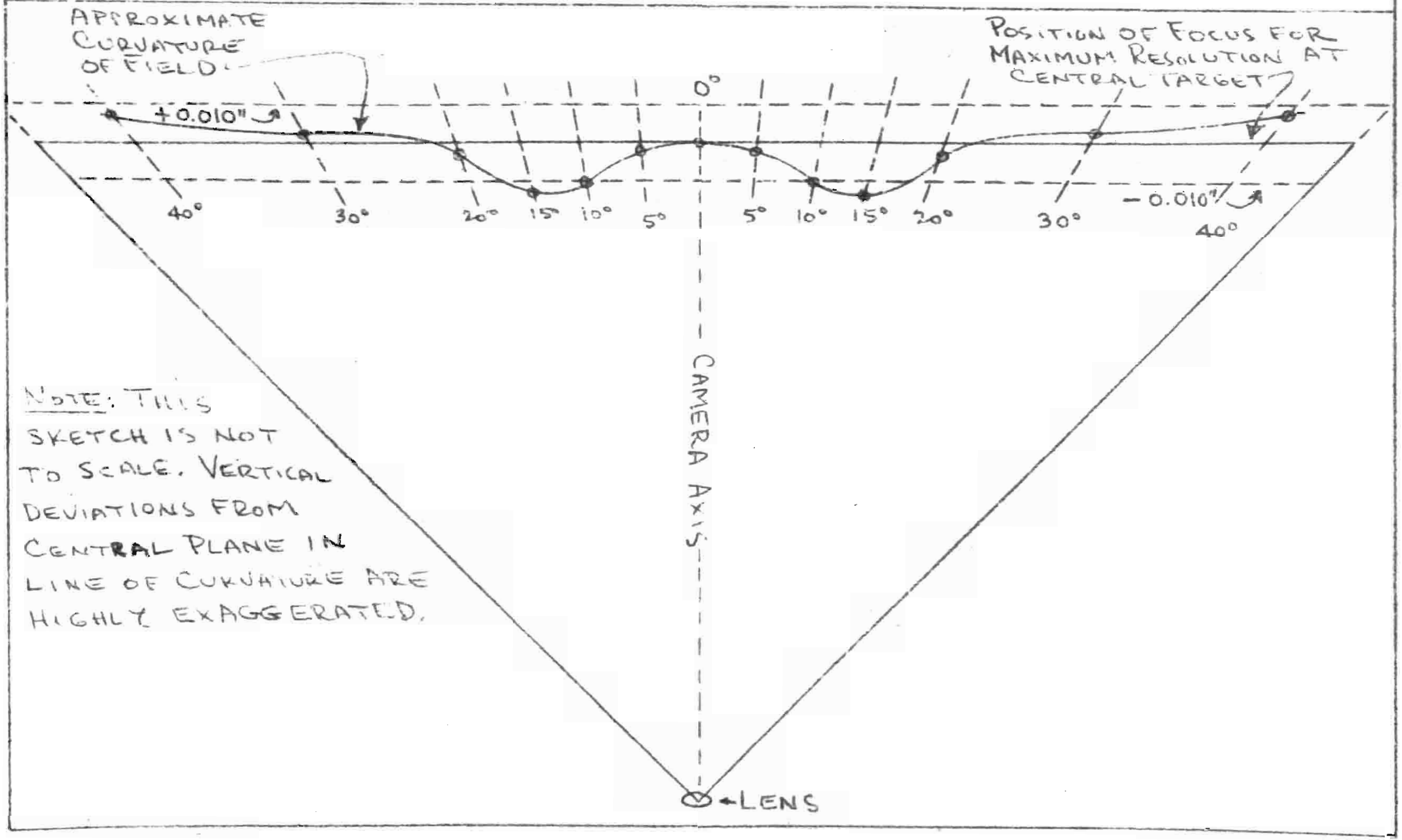
P. EFFECTS OF APERTURE, FILTER, AND SHUTTER SPEED ON CURVATURE OF FIELD.

60. The curvature of field for any lens may be traced approximately by noting the positions of focus at which maximum resolutions occur at each of the target positions along the photographic diagonal. For this purpose, the position of focus which produces the highest resolution in the center of the photograph (on-axis photographic focus) is

selected as the origin of the system and the divergences from this plane to points at which maximum resolutions occur at other targets along the diagonal are plotted either plus or minus, as the case may be. A graphical representation of such a curve is shown in Figure 17. Attention is directed to the fact that a minimum usually occurs at 10° or 15° outward from the center and that the positive field is most pronounced at 40°.

61. The expectation that the size of aperture would show a considerable effect on the curvature of field appears to have been confirmed by results of plotting an average curve for each setting of the aperture. Data for plotting these curves are contained in Table 15 (p. 89). Included in this table for each combination are the position of the locating back, indicated on the focusing micrometer, at which maximum resolution occurs at the center of the negative, and the differences between this position and the positions of maximum resolution for each of the other targets. For any particular graph, the origin is the same for all curves, regardless of the position of the central maximum resolution along the range of the focusing micrometer. A horizontal plane through the origin thus defines the on-axis position of photographic focus. At the bottom of Table 15 are shown a set of average values for each aperture stop. These values are used in the actual plotting of the curves of Graph 7 (p. 109). The curve for the f/6.3 aperture is plotted from an average of nine separate sets of data. Its configuration is approximately the same as other f/6.3 curves previously plotted. As the aperture size is decreased, the curves tend to flatten in shape. Results might be more conclusive if there were nine sets of data for each of the aperture settings, so that a closer average value could be calculated. However, it is the opinion of the writer that the final answer

Fig. 17 - Curvature of Field for the 6" Metrogon Lens.



still would not differ appreciably.

62. Next were plotted curvatures of field for the four different combinations of filter (See Graph 8, p. 110). An aperture of f/6.83 and a shutter speed of 1/50 second were maintained as constants. Although there are some irregularities, it is believed that the small differences in general outline probably are attributable to the reading of targets or to the photographic emulsion rather than to the varying densities of the filter combinations.

63. The curves in Graph 9 (p. 111) were plotted in order to discover what effect, if any, the speed of the shutter might have on the curvature of field. Four combinations of shutter speed are shown. The aperture of f/6.3 and the combination of yellow filter plus 0.1 neutral density filter are held constant for all shutter speeds. On examination of this diagram, it is obvious that all four curves have a similar configuration; hence, it can be assumed that the normal curvature of field is affected very little by changes in shutter speed.

Q. BEST POSITION OF FOCUS FOR OPTIMUM RESOLUTION.

64. The most important objective at this point in the report is the determination of the position of camera focus which will produce the highest definition of detail on the negative. Resolution data for 15 different combinations of aperture, filter, and shutter speed in camera No. 44-190509 were investigated, with this purpose in mind. The final results of the investigation have been placed, in condensed form, in Table 16 (p. 90). The maximum resolution for each combination is shown, as well as the position of the focal plane along the optical axis at which this resolution occurs. In the right-hand column of Table 16 are shown the corrected values of focal plane position, calculated in

accordance with the precepts outlined in Section "M". An arithmetic mean of the fifteen corrected values of focus position gives a distance of +0.0045" for optimum resolution. As previously defined, this is the distance through which the focal plane of the camera should be moved along its optical axis, in a direction away from the lens, starting from the axial position of best visual focus, in order to achieve greatest over-all definition of photographic detail. An average distance also was calculated by selecting, for each combination, a median position from the range of five or six consecutive positions of the locating back which gave the highest resolutions. From these median values is obtained an average distance of +0.004", which substantiates the original method.

65. In order to make a more accurate determination of the focal plane position, exposures of the resolution targets were made with three other cameras. For each camera, five different combinations of aperture and shutter speed were exposed through a range of -0.005" to +0.030" on the focusing micrometer. The five combinations of aperture and shutter speed included two with a setting of f/6.3 and three at f/16. Only the yellow filter was used with this photography. Results of these tests are contained in Table 17 (p. 91). The same two type A-12 magazines were used in this photography as were used in the earlier tests.

66. Attention is directed to the computation of a total correction to be applied to the readings on the focusing micrometer of each magazine. These figures are listed at the end of each camera's resolution values in Table 17. Total corrections are subtracted from readings of the focusing micrometer to give true positions of the focal

plane along the optical axis for best over-all resolution. Maximum values of resolution for each camera-aperture-shutter speed combination are listed in Table 18 (p. 97), along with corrected positions of the focal plane. Average focus positions for the three cameras were +0.004", +0.007", and +0.005". These values, along with those determined in the original tests and listed in Table 16, will give an average value of +0.005".

67. The position of the plane of best average photographic resolving power, for the 6" Metrogon lens, has been determined by others to be +0.008" farther from the lens than the axial position of best visual focus. Results of the foregoing tests with the A-12 magazine have indicated this value to be +0.005". The difference between these values is not very great when consideration is given to the fact that readings of focus positions with the focal micrometer may vary as much as 0.004" between several readings of an individual on any one camera and may vary somewhat more between readings of several individuals.

68. Tables 16 and 18 show that the positions of optimum focus for the cameras tested vary from zero correction along the optic axis to a correction of +0.0125", with an average of 0.005". Now, to demonstrate the actual effect of this focus shift, three curves were plotted for each of two filter-aperture-shutter speed combinations (See Graphs 10A and 10B, pp. 112 and 113). Target positions along the diagonal were plotted against resolution for three positions of the focal plane --(1) best on-axis visual focus, (2) position at +0.005", and (3) position at +0.010". In examining the graphs, it can be seen that the curves from 20° to 40° average about the same. Since this portion of the format represents over 86% of the total format area, it is obvious

that the resultant resolutions will be similar. The curves from 0° to 20° are dissimilar and no distinct pattern is indicated. In one instance the zero position gave resolutions higher than the +0.010" position and in the other case the +0.010" position gave higher resolutions. The +0.005" position gave resolutions between the other two in both instances.

69. Graphs 11a and 11b (pp. 114 and 115) show curves plotted for various aperture-shutter speed combinations with the shift of the locating back along the optical axis as the abscissa and the average resolution as the ordinate. The changes in resolution between the zero and +0.010" positions are very slight, but again there is a noticeable maximum at about the +0.005" position.

R. THE ANNULUS TARGET.

70. No effort has been made in this report to analyze in full the data collected during the initial tests which pertained to the annulus targets. However, from a superficial analysis, the following impressions were noted:

(a) On the negatives having the highest line target resolution, the annulus target resolution was approximately one-half as high.

(b) On the negatives having the highest annulus target resolution, the line target resolution was approximately the same.

(c) The maximum annulus target resolution values were found on very thin negatives whose average exposure was 1/400 second at f/16.

(d) In general, the higher the contrast in the four types of annulus target, the higher the resolution. However, the total spread usually was only five lines per millimeter.

71. It is the opinion of the persons who observed resolutions on both types of targets that the line targets could be read with greater ease and consistency than the annulus targets.

S. SUMMARY AND CONCLUSIONS.

72. The program of resolution tests outlined herein was accomplished by personnel of the Aerial Photographic Branch, Engineer Research and Development Laboratories, Wright-Patterson Air Force Base, with the chief purpose of securing information for the establishment of allowable resolution values (for various film-lens-camera combinations) to be used in the preparation of specifications for aerial mapping cameras.

73. Tests were conducted on the ground, using the type K-17 camera placed horizontally with its line of sight pointing toward a row of standard Air Force, high-contrast resolution targets, so arranged as to appear along the format diagonal with targets at known angular positions. This system eliminates a number of variables, such as differences in flight altitude, relative motion of camera with respect to the ground, atmospheric haze, etc., which are encountered in aerial photographic tests of resolution.

74. Three cameras having different positions of visual focus were used in the initial tests. Of primary concern, in this connection, was the question of whether or not the relative standing of average resolutions for various combinations would be changed to any extent by different positions of visual focus in the camera. The rather obvious fact that there should be no change was substantiated by subsequent analysis.

75. Readings of resolution values were performed by use of a 16-power Zeiss binocular viewer. A single average resolution for each exposure was calculated by a method in which percentage weights were assigned to resolution values according to the area of the annulus, whose radial limits, for a particular target, are defined by points halfway between the given target and each of its adjacent targets.

76. The average difference of about 2.5 lines per millimeter between radial and tangential resolution on the line target was not considered sufficiently significant to warrant more than an arithmetical average in arriving at a resultant value of resolution for any target. It was shown, however, that this difference becomes considerably greater on a negative exposed by an aerial camera from a plane in flight. The image motion on the film caused by forward movement of the airplane tends to elongate lines on the photograph which are parallel to the direction of flight, thereby producing a spurious increase in that form of resolution, while tending to decrease resolution measurable from lines running perpendicular to the line of flight.

77. The opinion was offered by the writer, based on his observation of photography exposed simultaneously by cameras with, and without, image motion compensation features, that perhaps more weight should be assigned to the higher value of the two types of resolution on an aerial photographic negative, since the amount of interpretable detail is contingent primarily on a high resolution in one dimension.

78. The effect of astigmatism in the lens is noted by an increase in the deviation between radial and tangential resolution on targets as the edge of the picture is approached. This divergence also is greater for smaller lens aperture settings, particularly for the f/16 and f/22 stops.

79. The individual weighted average resolution for any frame closely approximates the single value of resolution observable on the target at the angular position of 30° from the photographic center. This coincidence is inherent in the annulus-area method of averaging resolutions, in which the observations at 20°, 30°, and 40° receive approximately 86% of the total weight.

80. For purposes of analysis, all combinations of filter, aperture, and shutter speed were reduced to the common denominator of light quantity units, one such unit being equivalent to the amount of light flowing through an f/22 aperture for 1/400 second. A study of high-resolution combinations of camera adjustments indicates that the best resolutions are obtained by those whose light quantity ratings fall within a range of 4 to 16 units. The optimum value of light quantity for highest resolution was 8 units. This system provides a mathematical measure of negative density, a factor which has a very significant effect on resolution.

81. From a study of average values for high-resolution combinations of filter, aperture, and shutter speed, it was found that the optimum aperture for best resolution was f/16 and that the optimum shutter speed for that aperture was 1/50 second. The combination of yellow plus 0.1 neutral density filter appeared to produce slightly higher resolutions than other filter combinations.

82. A second series of tests was conducted to determine the best position of focus for producing the highest over-all resolution on a negative exposed in an aerial camera having a 6" Metrogon lens. The type A-12 focusing magazine, which permits accurate measurement of changes in the position of the locating back, was used in this photography. Movements of the locating back along the optical axis were

accomplished manually with a micrometer attachment on which the extent of such movements was directly measurable.

83. Corrections to be applied to readings of the focusing micrometer involved (a) the determination of the actual visual focus for the particular camera-lens-magazine combination, and (b) the determination of the best position of visual focus for an object distance of 600 feet (perpendicular distance from lens to target line).

84. Initially, fifteen different combinations of aperture, filter, and shutter speed were exposed through a range in movement of the focal plane from +0.030" to -0.030", an exposure being made at each 0.0025-inch increment throughout this distance. In addition, fifteen combinations on three other cameras were exposed through a range of +0.030" to -0.005", in order to provide a broader coverage in the testing program. Uniformity was maintained in all elements of the developing process.

85. The curvature of field in the lens may be traced approximately by selecting the position of the focal plane at which occurs maximum resolution at the center of the negative (the axial position of photographic focus) as the origin, then plotting target position against positions of focal plane for maximum resolution.

86. Variation in shutter speeds and in filter types produced little effect on the curvature of field. The effect of aperture size on the curvature of field, however, increases with the decrease in diameter of stop.

87. It was found that the plane of best average photographic resolving power for the lenses under consideration was at a distance of 0.005" farther from the lens than the axial position of best visual focus. The difference in average resolution between on-axis focus and focus at +0.010 inch is very little and seemingly unimportant. However,

the 0.005" position consistently gives higher resolution, however slight, so it seems wise to recognize this fact and to focus the camera accordingly.

88. It is hoped that the foregoing study may be of value in the achievement of higher photographic resolutions with aerial cameras having 6" Metrogon lenses. The photographer, although having the adjusted position of focus for high resolution on his camera, still must remember that his evaluation of photographic conditions existing at the time of exposure should be the final criterion in his selection of proper aperture and shutter speed.

APPENDIX "A"

TABLES

Table 1 - Data for Drafting of Resolution Targets.

Target Number	Lines per Millimeter	Target Block Dimensions (M.M.) 12A	A	2A	3A	5A
1	10	478.12	39.84	79.68	119.52	199.20
2	11	425.95	35.50	71.00	106.50	177.50
3	13	379.48	31.62	63.24	94.86	158.10
4	14	338.08	28.17	56.34	84.51	140.85
5	16	301.20	25.10	50.20	75.30	125.50
6	18	268.33	22.36	44.72	67.08	111.80
7	20	239.06	19.92	39.84	59.76	99.60
8	22	212.97	17.75	35.50	53.25	88.75
9	25	189.74	15.81	31.62	47.43	79.05
10	28	169.04	14.09	28.18	42.27	70.45
11	32	150.60	12.55	25.10	37.65	62.75
12	36	134.17	11.18	22.36	33.54	55.90
13	40	119.53	9.96	19.92	29.88	49.80
14	45	106.48	8.87	17.74	26.61	44.35
15	50	94.86	7.90	15.80	23.70	39.50
16	56	84.51	7.04	14.08	21.12	35.20
17	63	75.29	6.27	12.54	18.81	31.35
18	71	67.08	5.59	11.18	16.77	27.95
19	80	59.76	4.98	9.96	14.94	24.90
20	90	53.24	4.44	8.88	13.32	22.20
21	101	47.43	3.95	7.90	11.85	19.75
22	113	42.26	3.52	7.04	10.56	17.60

Table 2 - Brightness Ratios of Annulus Targets.

TARGET	D_0	D_E	DIFFERENCE	ANTI LOG	BRIGHTNESS RATIO
1 *	0	0.29	0.29	1.95	2:1
2	0.03	0.35	0.32	2.09	2:1
3 *	0.01	0.65	0.64	4.36	4.5:1
4	0.01	0.70	0.69	4.90	5:1
5 *	0.03	0.90	0.87	7.41	7.5:1
6	0.03	1.14	1.11	12.88	13:1
7	0.03	1.42	1.39	24.55	25:1
8 *	0.02	1.58	1.56	36.31	36:1

* SELECTED TARGETS

FORMULAE

$$D_0 = \log_{10} \frac{1}{R_0} = -\log_{10} R_0 \qquad \frac{R_0}{R_E} = \log_{10}^{-1}(D_E - D_0)$$

$$D_E = \log_{10} \frac{1}{R_E} = -\log_{10} R_E$$

Table 3a - Average Values of Resolutions for Line Targets.

K-17 B CAMERA No. 44-187315 FOCUS: OFF AXIS, -0.2 MM.

FILTER	SPEED	APERTURE	0°	5°	10°	15°	20°	30°	40°	AVE.
YELLOW	1/50	6.3	22	23	22.3	20	17.5	16.5	15.8	17.1
		8	23.5	24.3	21	19.5	18	16.5	16.5	17.3
		11	34	31	27.3	24.3	23	21.3	19	21.6
		16	34	29.3	28.3	25.8	25.8	23.5	21.3	23.7
		22	30	30	27.3	28	26.5	22.3	20.5	23.3
	1/100	6.3	25	25	23.5	20	18.5	17	16	17.6
		8	27	26.5	24.3	22	20	18	16	18.5
		11	30	31	26.5	24.3	23.3	20	17	20.5
		16	32	34	29	27.3	25	22.5	21	23.4
		22	28	29	27.3	25.8	25.8	21	17	21.4
	1/200	6.3	25	27.3	25	21.5	20	17	15.5	18.0
		8	32	29	25	23.5	21	18.5	17	19.4
		11	34	30.3	28.3	25	23.3	19.5	20	21.3
		16	34	37	31	27.5	29.3	23.3	22.5	25.0
		22	32	31	28.3	27.3	28.3	21.8	18.5	22.8
	1/300	6.3	25	27.3	24.3	23	21.3	18.5	15.5	18.8
		8	32	33	26.5	24.3	21.8	19	16.5	19.8
		11	34	34	27.3	25	25	22.5	18	22.2
		16	32	34	28.3	26.5	24.3	20	17.5	21.1
		22	23.5	25	24.3	21.8	21	18	15.5	18.5
YELLOW + 0.1 NEUTRAL DENSITY	1/50	6.3	26.5	25.8	24.3	21	18.5	17	14.8	17.4
		8	32	29	24.3	23.5	20.8	19	15	18.9
		11	28	29	29	26.5	23.3	21	18	21.4
		16	30	33	30	30	26.8	23	22	24.4
		22	34	35	33	33	30	26.5	22.5	26.8
	1/100	6.3	25	27.5	24.3	20.5	19	17.5	15.3	17.8
		8	30	33	25.8	23.5	22	19.5	16.3	19.8
		11	32	35	28	27.5	25	21	18.5	22.0
		16	32	34	31	29.3	29.3	22.5	20.8	24.3
		22	30	31	31	27.3	26.5	23	20.5	23.7
	1/200	6.3	32	31	24.3	23.8	21.5	18	16	19.0
		8	34	28	27.3	24.5	22.5	19	16.5	19.8
		11	36	34	34	26.5	24.3	22.8	18	22.6
		16	36	34	34	33	28.5	22.8	19.5	24.2
		22	23.5	22.8	21	20.5	19	15.5	11.8	15.7
	1/300	6.3	32	29	26.5	23	22.5	20	16.3	20.0
		8	36	35	29.3	25.8	23.3	22.5	16.8	21.7
		11	34	33	29	26.5	24.5	20.3	17	21.1
		16	28	29	24.3	22.5	23	19	15.8	19.4
		22	21	23	21	17.5	19.5	14.8	12	15.4

Table 3a - (Cont.)

K-17B CAMERA No. 44-187315 FOCUS: OFF AXIS, -0.2 MM.

FILTER	SPEED	APERTURE	0°	5°	10°	15°	20°	30°	40°	AVE.
YELLOW + 0.3 NEUTRAL DENSITY	1/50	6.3	26.5	25.8	23	20.5	19	18.5	19.5	19.4
		8	32	29	24.3	21.8	20.8	19.8	20.5	20.7
		11	36	33	31	25	23.3	20.8	21	22.3
		16	34	35	35	28	26	23.8	23.8	25.2
		22	36	35	34	31	28.3	25.8	20	25.4
	1/100	6.3	32	28.3	25.8	21.8	20	18.3	19	19.6
		8	32	28.3	27.3	23.8	21.3	19	20	20.6
		11	34	32	28	24.3	25	20.8	21.5	22.6
		16	30	30	25.8	23.5	22.5	19.5	18.5	20.5
		22	26.5	25.8	22	20	20.5	17	13.8	17.3
	1/200	6.3	26.5	28	23.8	20.8	21.3	18	19	19.6
		8	36	34	26.5	23.3	21.3	20	19	20.8
		11	36	36	30.3	28.5	23.3	20	19	21.7
		16	34	31	28	24.3	23	20.5	20	21.6
		22	25	23.5	21.8	21	19.5	17	13.8	17.1
	1/300	6.3	36	31	23.5	23	21.5	18.3	18.5	19.8
		8	34	31	27.5	21.3	21.3	18	17.5	19.4
		11	28	27.3	23.5	22.3	19.8	17.3	15.5	18.0
		16	23.5	25	21.5	18.5	16.5	14.8	11.8	15.0
		22	12	13	11.3	11.5	11	9.5	—	—
YELLOW + 0.6 NEUTRAL DENSITY	1/50	6.3	32	26.8	23.5	22.5	20.3	17	16.5	18.3
		8	30	29	24.3	24.5	23.3	22.5	19.5	22.1
		11	42.5	36	36	32	25.8	23	22.3	24.8
		16	38	36	36	30.3	26.8	26.5	21	25.8
		22	34	29	26.5	24.3	22.8	21	16.5	20.6
	1/100	6.3	30	28.5	22	21	19	17.5	14	17.4
		8	28	34	25	22.3	21.8	17.5	14.8	18.5
		11	28	29.3	25.8	22.8	20.5	18.5	15	18.7
		16	21	22.8	19	18	17.5	13	10	13.7
		22	17	14.5	13.3	13.5	12.5	11	9.5	11.2
	1/200	6.3	34	30	23.3	21	19.5	17	14	17.4
		8	28	34	25.8	22.5	19.5	17.5	15.5	18.3
		11	34	29	26.5	24.3	20	19	15.8	19.2
		16	25	26.5	21.8	20	19.5	17.5	11.5	16.6
		22	13.5	13	11.5	11.3	9.5	—	—	—
	1/300	6.3	30	27.3	21	20.3	18.5	14	10	14.6
		8	28.5	26.5	21.3	20.3	17.5	12.3	9.5	13.6
		11	19	20	17.5	14.5	13.3	9.8	8.5	10.9
		16	10.5	9.3	—	—	—	—	—	—
		22	—	—	—	—	—	—	—	—

Table 3b - Average Values of Resolutions for Line Targets.

K-17C CAMERA No. 44-190629 FOCUS: ON AXIS

FILTER	SPEED	APERTURE	0°	5°	10°	15°	20°	30°	40°	AVE.
YELLOW	1/50	6.3	14	14	13	12.5	12	10	9.5	10.6
		8	20	20	20	20	19	16.5	15	17.0
		11	22.5	22.5	22.5	23	22	19	17.5	19.6
		16	29.5	26.5	28	28	27	22	19.5	22.9
		22	32	31	29.5	28.5	26.5	23	19.5	23.4
	1/100	6.3	21	21.5	20	19.5	18	15	15	16.2
		8	23	23	22	21.5	20.5	18	17	18.7
		11	26	25.5	25	25	24.5	20	18	20.9
		16	29	30	29	28.5	26	24	19	23.5
		22	35	33.5	29.5	30	27.5	25	19.5	24.5
	1/200	6.3	23	23.5	23	22	21.5	18.5	16	18.8
		8	24	24.5	25.5	24	22.5	19.5	18	20.3
		11	29	28	27	28	26	21.5	20	22.7
		16	29	29	29	28	28.5	23	19	23.5
		22	29	28	27	26	25	21	17	21.3
	1/400	6.3	24	25	23	23	21	19	16.5	19.2
		8	27	28	26.5	25.5	23.5	20	18	20.9
		11	28.5	27	27.5	28	26	21.5	19	22.4
		16	29	29	26	26.5	25.5	21	16.5	21.2
		22	23	22.5	21	19	19	14	10	14.5
YELLOW + 0.1 NEUTRAL DENSITY	1/50	6.3	21	21	20.5	20	18	15	12.5	15.5
		8	23	21.5	22	20	19.5	17	15	17.4
		11	23.5	24.5	25.5	26.5	25	21	17	21.1
		16	33	28	28.5	29	28	23	19	23.4
		22	32	32.5	31.5	29	30	25	21	25.4
	1/100	6.3	20.5	20	21.5	20	19.5	15.5	14	16.4
		8	24	24	24.5	22	22.5	18	15	18.6
		11	25	24.5	26.5	27	26	22	19	22.4
		16	28	29	28	30	28.5	24.5	18.5	24.0
		22	32	31	30	30.5	28	24	19	24.1
	1/200	6.3	25	24	24.5	23	21	18.5	16	18.9
		8	25	26.5	27	26	23	19.5	17.5	20.4
		11	26.5	27	28	28	25	22	18	22.1
		16	32	29.5	28	29.5	27	23	18	23.0
		22	30	31	26	26	25.5	19.5	16	20.5
	1/400	6.3	24	24	24	24	21	18	16.5	18.9
		8	24	24	25.5	24	23	20	16	19.9
		11	26	27.5	26	27	25	21	16.5	21.1
		16	27.5	26	25.5	25	24	20.5	15	20.1
		22	21.5	21	19.5	19	17.5	13	9.5	13.6

Table 3b - (Cont.)

K-17C CAMERA No. 44-190629 FOCUS: ON AXIS.

FILTER	SPEED	APERTURE	0°	5°	10°	15°	20°	30°	40°	AVE.
YELLOW + 0.3 NEUTRAL DENSITY	1/50	6.3	20	21	20	20	19	17	14	16.9
		8	24	23	23.5	23.5	21	17.5	15.5	18.3
		11	24	24	24.5	24.5	24	20.5	16	20.3
		16	30	27	28	28.5	30	23	19	23.7
		22	30.5	30	26	26	25.5	22	17.5	21.9
	1/100	6.3	20.5	21	21	20	20	18	16.5	18.2
		8	25	22	23	23	23	19	16	19.3
		11	27	26	27.5	26.5	26	22	18	22.1
		16	28.5	29	28	27.5	27.5	23	18	22.9
		22	31	30	26	27	26.5	22.5	17	22.2
	1/200	6.3	23	23	23	21	21.5	18	15.5	18.4
		8	25	25.5	25.5	24.5	23	20	17	20.3
		11	26.5	25.5	27.5	29	25.5	22	17	21.9
		16	27	27	25	26	27	21	18	21.8
		22	21	21.5	20	19.5	19	14.5	10.5	14.8
	1/400	6.3	26.5	25.5	25.5	25.5	24	18	15.5	19.3
		8	27	24.5	25.5	24.5	23.5	20	16	20.1
		11	23.5	24	24	26	25	20.5	12.5	19.5
		16	21	21.5	20	20	20	14	10	14.7
		22	12	11.5	11	10.5	—	—	—	—
YELLOW + 0.6 NEUTRAL DENSITY	1/50	6.3	24	24.5	25	22.5	20.5	19	19.5	20.0
		8	24	25.5	23	24	22	18.5	17	19.4
		11	26.5	27	28	29	25.5	22	20	22.9
		16	28.5	27	30	28	25.5	23	19.5	23.1
		22	31	31.5	30	30	27.5	21.5	18	22.7
	1/100	6.3	25	24.5	24.5	23	21	18	18.5	19.5
		8	26	27	26	25.5	22.5	20	19	20.9
		11	26.5	27.5	27	26	27	21	19	22.2
		16	30	30	31	28	28	21	18	22.4
		22	25	24.5	22.5	21	20.5	16	10.5	15.9
	1/200	6.3	26	25	24	23	22	18	17	19.2
		8	27	26.5	25	24	24	20	17	20.4
		11	26.5	27	25.5	25.5	24	19.5	16	20.1
		16	23	22	21	21	19.5	15.5	12	15.9
		22	11	12	11	10.5	10	—	—	—
	1/400	6.3	24	26	24	22	21	16	12	16.6
		8	24	24.5	23	21	20	16.5	11.5	16.4
		11	21	21.5	20.5	21	19	11.5	9.5	13.7
		16	11	11.5	11	10.5	10	—	—	—
		22	—	—	—	—	—	—	—	—

Table 3c - Average Values of Resolutions for Line Targets.

K-17C CAMERA No 44-190620 FOCUS: OFF AXIS, +0.2 MM.

FILTER	SPEED	APERTURE	0°	5°	10°	15°	20°	30°	40°	AVE.
YELLOW	1/50	6.3	23.5	22	22.5	22.3	19.8	15.5	14.3	16.8
		8	22.5	23.6	23.4	22.3	20.8	19	15.4	18.7
		11	23	23.1	24.3	26.4	23.3	19.6	15.5	19.8
		16	32	34.5	35	32	30.3	25.1	18	25.0
		22	33	33	34.5	31.5	30.6	26.5	20.3	26.2
	1/100	6.3	20	21.1	21.4	21	20	17.8	15	17.8
		8	25.3	27.1	27.1	22.9	23.9	20.1	17	20.5
		11	31.3	31.8	31.9	31.6	31.8	24.5	17.8	24.7
		16	31	34	32.5	29.8	28.1	23.8	19.8	24.2
		22	33	33	32.3	28.5	31.3	24.1	19.9	24.9
	1/200	6.3	30	30.1	28.1	25.4	23	20	16.5	20.4
		8	23	23	24	25.8	22.6	19.5	15.9	19.7
		11	27.5	30.5	27.1	27.5	25	22.1	17.3	21.9
		16	27.3	28.8	28.1	27	27.5	22.1	16.3	22.0
		22	29.5	26.9	26.1	23.4	23	19.4	14.1	19.2
	1/400	6.3	25.8	25.4	25.4	23.5	22.8	19.8	15.5	19.6
		8	27.5	28.3	26.1	26.5	24.6	20	15	20.2
		11	26.5	30.5	27.9	27.1	26.1	22.1	17.3	22.1
		16	28.3	25.8	25.4	24.3	23.8	19.8	13	19.1
		22	19.8	20.3	17.8	17.3	18.5	13	10	13.7
YELLOW + 0.1 NEUTRAL DENSITY	1/50	6.3	20.5	21.4	22.1	20.9	20	18	13.4	17.4
		8	27.3	24.6	25.5	28.3	24.1	20.8	17.6	21.2
		11	27.5	28.8	32	27.8	28.8	25.3	19.3	24.6
		16	32	32	34	31	33	28.3	19.3	26.9
		22	31.3	29.6	29.5	29	26.4	23.8	19.1	23.6
	1/100	6.3	21	23.1	22.3	21.8	20.3	18.3	15.4	18.3
		8	24.3	25.1	24.6	23.9	21.8	19.3	17.5	19.9
		11	38	32.5	36.5	32.5	30.3	24.8	20.3	25.6
		16	31	30.8	28.9	27.9	27.9	21.6	18.4	22.7
		22	34	31	28.3	28.3	26.8	21.8	17.5	22.3
	1/200	6.3	25	24	24	23.4	20.5	19	15.1	18.7
		8	27.8	25.6	29.6	24.5	24.4	19.3	16.3	20.2
		11	31.3	28.4	29.4	25.8	25.5	22.4	18	22.3
		16	31	25.5	30.5	28.8	29.1	22.1	17.5	22.8
		22	26.5	28.3	26.1	25.1	24.8	20.3	14.5	20.1
	1/400	6.3	27.3	27.5	25.6	26	23.8	19.4	15.3	19.8
		8	27.3	25.3	26.9	24.6	23.6	21.8	17.5	21.3
		11	32.3	30.3	28.1	26.8	26.3	21.1	17.8	21.9
		16	24.5	26.5	25.3	24.3	22.3	19	13.6	18.7
		22	22.3	21.6	19.5	20	19.8	14.1	10.3	14.7

Table 30 - (Cont.)

K-17C CAMERA NO. 44-190620 FOCUS: OFF AXIS, +0.2 MM.

FILTER	SPEED	APERTURE	0°	5°	10°	15°	20°	30°	40°	AVE.
YELLOW + 0.3 NEUTRAL DENSITY	1/50	6.3	25	24	23.8	24	21.5	19.5	15.8	19.3
		8	30	32.5	29.6	30.1	28.4	23.5	18.8	23.9
		11	32	31	33	32.5	31.1	24.1	17.8	24.5
		16	32	36	37	32	32	28	19.5	27.0
		22	31	33.5	32	27.3	27	23	18.8	23.4
	1/100	6.3	25	27.6	24.6	23.9	22.5	20	16.6	20.0
		8	27.8	29.8	29.8	28.4	25.4	21	17.5	21.8
		11	32	30.6	30.1	30	30.6	24.1	18.3	24.3
		16	31.3	32.1	32	28.1	27.8	24.9	17.3	23.8
		22	30.3	31.6	27.8	27.9	27.3	21.8	17	22.2
	1/200	6.3	23	23	24.8	22.9	22.3	19	15.4	19.1
		8	27	30.6	28.8	24.6	22.6	20	16.1	20.2
		11	26.8	29.3	27.5	27.8	26.3	20.6	14.6	20.8
		16	29.3	29.4	26.1	23.6	22.8	19.3	13.4	18.9
		22	20.8	19.8	16.5	17.6	16.3	12	9.6	12.8
	1/400	6.3	26.5	25.3	27.8	25.3	21.9	20.6	14.1	19.6
		8	33	34	29.5	26.3	22.9	20	14.9	20.1
		11	27.5	27.9	25	22.9	21.6	19.5	11.5	18.1
		16	16	16	14.8	15.3	13.5	11.3	9.5	11.7
		22	12.3	12.4	11.8	11.1	10.1	—	—	—
YELLOW + 0.6 NEUTRAL DENSITY	1/50	6.3	27.3	28.6	28.3	27	24.6	20.4	16.3	20.9
		8	27.5	27.3	29.8	25.8	24.8	21.3	18.6	21.9
		11	29.3	32.1	33.5	31	27	24.5	19.1	24.3
		16	36	33.6	33.1	30.8	28.6	25.1	18.8	24.7
		22	31	33	31.5	29.3	26.6	22	17.3	22.5
	1/100	6.3	26.5	26.6	29	26.6	25.6	20	16.5	20.9
		8	27.3	28.3	30.1	27.8	26.6	21.4	17.1	22.0
		11	32	35.5	34	32.5	27.8	24.6	18.5	24.5
		16	26.5	29.1	26.3	24.3	24.3	19	14	19.3
		22	25	26.9	24.3	22.8	23	18	12.4	18.0
	1/200	6.3	28	29.1	26.5	25	23.6	19.5	14.1	19.5
		8	30	28.3	26.9	25	23.5	19.3	14.5	19.5
		11	26.5	29.1	27.5	25.8	22.3	19	11.3	18.3
		16	21.8	21.6	19.3	18.5	17.5	13.3	9.4	13.7
		22	12.3	11.8	11.3	10.4	10.1	9.4	—	—
	1/400	6.3	24.3	24	22.5	21.5	20.8	16	10.1	15.9
		8	24.3	23.1	23.3	21.6	19.3	14	9.8	14.8
		11	19	18.8	18.5	18.5	16.3	11.6	9	12.6
		16	11	11.9	11	10.9	9.8	—	—	—
		22	—	—	—	—	—	—	—	—

Table 4 - Computation of Average Resolutions by Area-Weight Method.

Angle from Center (θ)	tan θ	Dist. from Center (r)"	Areas in Sq. In. (A)		Area Weights
			Circle	Annulus	
			81.00		
40°	0.83910	5.03		24.52	30.3 %
35°		4.24	56.48		
30°	0.57735	3.46		31.50	38.9 %
25°		2.82	24.98		
20°	0.36397	2.18		13.76	17.0 %
17½°		1.89	11.22		
15°	0.26795	1.61		5.66	7.0 %
12½°		1.33	5.56		
10°	0.17633	1.06		3.60	4.4 %
7½°		0.79	1.96		
5°	0.08749	0.52		1.75	2.2 %
2½°		0.26	0.21		
0°				0.21	0.2 %
Totals				81.0	100 %

RELATIVE NUMBER	APERTURE	SHUTTER SPEED
1	f:22	1/400
1 1/2		1/300
2	f:16	1/200
4	f:11	1/100
8	f:8	1/50
12 1/2	f:6.3	

Table 5 - Relative Numbers for Aperture and Shutter Speed.

PRODUCTS	1/400	1/300	1/200	1/100	1/50
f:22	1	1 1/2	2	4	8
f:16	2	3	4	8	16
f:11	4	6	8	16	32
f:8	8	12	16	32	64
f:6.3	12 1/2	18 1/2	25	50	100

Table 6 - Light-Quantity Products for Various Aperture-Shutter Speed Combinations.

Table 7 - Light Quantities for All Combinations of Filter, Aperture, and Shutter Speed.

SHUTTER SPEED	APERTURE	YELLOW FILTER	YELLOW + 0.1 N.D.F.	YELLOW + 0.3 N.D.F.	YELLOW + 0.6 N.D.F.
	6.3	100	80	50	25
	8	64	51	32	16
1/50	11	32	26	16	8
	16	16	13	8	4
	22	8	6½	4	2
	6.3	50	40	25	12½
	8	32	26	16	8
1/100	11	16	13	8	4
	16	8	6½	4	2
	22	4	3	2	1
	6.3	25	20	12½	6
	8	16	13	8	4
1/200	11	8	6½	4	2
	16	4	3	2	1
	22	2	1½	1	½
	6.3	18½	15	9	4½
	8	12	10	6	3
1/300	11	6	5	3	1½
	16	3	2½	1½	¾
	22	1½	1¼	¾	⅜
	6.3	12½	10	6	3
	8	8	6½	4	2
1/400	11	4	3	2	1
	16	2	1½	1	½
	22	1	¾	½	¼

Table 8(a) - Average Values of Radial and Tangential Resolution.

Misc. Data	Filter	Aperture	Shutter Speed	Type of Resolution	0°	5°	10°	15°	20°	30°	40°	Ave.	Diffs. Between R.&T.
Camera No. 44-187315 -0.2 MM. Off Axis Average Diff. Between R.&T. - 3.4	Yellow	f/22	1/50	T	32	32	28	28	25	21	19	22.1	+2.3
				R	28	28	26.5	28	28	23.5	22	24.4	
		f/16	1/100	T	32	32	30	28	23.5	20	20	21.9	+2.9
				R	32	36	28	26.5	26.5	25	22	24.8	
		f/11	1/200	T	32	30.5	26.5	23.5	20	17	19	19.3	+4.0
				R	36	30	30	26.5	26.5	22	21	23.3	
		f/8	1/200	T	36	30	23.5	22	20	17	15	17.9	+3.0
				R	28	28	26.5	25	22	20	19	20.9	
		f/6.3	1/300	T	25	26.5	23.5	21	19	16	14	16.8	+4.0
				R	25	28	25	25	23.5	21	17	20.8	
	Yellow +0.1 N.D.	f/22	1/50	T	36	36	36	34	28	25	20	25.4	+2.9
				R	32	34	30	32	32	28	25	28.3	
		f/16	1/100	T	28	32	30	26.5	26.5	20	18	21.7	+5.1
				R	36	36	32	32	32	25	23.5	26.8	
		f/11	1/200	T	36	36	34	25	22	19	16	20.1	+5.0
				R	36	32	34	28	26.5	26.5	20	25.1	
		f/8	1/200	T	36	28	26.5	22.5	20	17	14	17.7	+4.2
				R	32	28	28	26.5	25	21	19	21.9	
		f/6.3	1/300	T	32	28	25	21	20	18	13.5	17.7	+4.6
				R	32	30	28	25	25	22	19	22.3	
	Yellow +0.3 N.D.	f/22	1/50	T	36	34	36	30	26.5	23.5	18	23.6	+3.6
				R	36	36	32	32	30	28	22	27.2	
		f/16	1/100	T	28	30	26.5	23.5	20	18	18	19.4	+2.2
				R	32	30	25	23.5	25	21	19	21.6	
		f/11	1/200	T	36	36	28.5	25	20	18	17	19.4	+4.5
				R	36	36	32	32	26.5	22	21	23.9	
		f/8	1/200	T	36	36	25	20	19	18	18	19.1	+3.4
				R	36	32	28	26.5	23.5	22	20	22.5	
		f/6.3	1/300	T	36	30	23.5	21	18	15.5	18	17.8	+3.9
				R	36	32	23.5	25	25	21	19	21.7	
	Yellow +0.6 N.D.	f/22	1/50	T	32	30	26.5	18	22	20	15	19.2	+2.4
				R	36	28	26.5	25	23.5	22	18	21.6	
		f/16	1/100	T	22	22	18	18	16	12.5	10	13.2	+1.0
				R	20	23.5	20	18	19	13.5	10	14.2	
		f/11	1/200	T	36	28	25	23.5	18	17	14.5	17.5	+3.3
				R	32	30	28	25	22	21	17	20.8	
		f/8	1/200	T	36	30	25	20	18	15	14	16.4	+3.8
				R	36	32	26.5	25	21	20	17	20.2	
		f/6.3	1/300	T	32	26.5	20	18	16	13	10	13.6	+2.1
				R	28	28	22	22.5	21	15	10	15.7	

Table 8(b) - Average Values of Radial and Tangential Resolution.

Misc. Data	Filter	Aperture	Shutter Speed	Type of Resolution	Resolution Values 0°	5°	10°	15°	20°	30°	40°	Ave.	Diffs. Between R&T
Camera No. 44-190629 On Axis Focus Average Difference Between R&T - 1.6	Yellow	f/22	1/50	T	28	26.5	30	26.5	22	19	15	19.5	+5.1
				R	25	26.5	26.5	28	28	25	21	24.6	
		f/16	1/100	T	28	28	26.5	26.5	23.5	21	18	21.3	0
				R	25	25	25	25	25	21	18	21.3	
		f/11	1/200	T	28	28	25	28	25	21	18	21.6	−0.7
				R	28	25	23.5	25	23.5	20	19	20.9	
		f/8	1/200	T	25	25	28	22	21	19	17	19.5	−1.0
				R	20	22	23.5	22	21	18	16	18.5	
		f/6.3	1/400	T	25	25	23.5	22	20	17	17	18.3	+0.3
				R	25	25	21	21	20	19	16	18.6	
	Yellow + 0.1 N.D.	f/22	1/50	T	32	34	32	28	32	22.5	19	24.1	+3.2
				R	28	30	30	28	32	26.5	25	27.3	
		f/16	1/100	T	28	30	30	30	27	23.5	16	22.7	+2.2
				R	28	28	28	30	26.5	26.5	20	24.9	
		f/11	1/200	T	28	28	30	28	25	22	17	21.9	+0.9
				R	28	26.5	26.5	26.5	25	23.5	19	22.8	
		f/8	1/200	T	22	28	27	25	21	18	15.5	18.9	+1.9
				R	25	26.5	25	26.5	23.5	20	18	20.8	
		f/6.3	1/400	T	25	23.5	24	23.5	20	16	15.5	17.6	+0.9
				R	25	25	25	25	21	17	16	18.5	
	Yellow + 0.3 N.D.	f/22	1/50	T	36	32	26.5	28	26.5	21	15	21.1	+4.0
				R	36	32	30	30	26.5	25	22	25.1	
		f/16	1/100	T	32	32	32	28	28	22	17	21.8	+1.5
				R	25	28	26.5	26.5	28	23.5	19	23.3	
		f/11	1/200	T	28	26.5	28	32	26.5	23.5	16	22.6	−0.7
				R	25	25	26.5	28	25	22.5	17	21.9	
		f/8	1/200	T	25	26.5	23.5	23.5	20	19	15	18.6	+1.3
				R	22	23.5	25	25	23.5	20	15	19.7	
		f/6.3	1/400	T	25	26.5	26.5	25	23.5	18	16	19.4	−1.5
				R	28	25	25	26.5	23.5	14	16	17.9	
	Yellow + 0.6 N.D.	f/22	1/50	T	32	32	30	32	25	21	17	21.9	+2.8
				R	28	32	30	32	32	23.5	19	24.7	
		f/16	1/100	T	28	30.5	32	30	26.5	22	18	22.8	−0.4
				R	28	28.5	30	28	28.5	21	18	22.4	
		f/11	1/200	T	28	28	30	26.5	28	21	17	21.9	−1.8
				R	28	26.5	26.5	25	25	20	15	20.1	
		f/8	1/200	T	28	26.5	26.5	25	25	20	17	20.7	+0.7
				R	28	28	26.5	25	26.5	21	17	21.4	
		f/6.3	1/400	T	25	28	25	22.5	21	15	12.5	16.5	−0.2
				R	25	28	22	22	21	16	11	16.3	

Table 8(c) - Average Values of Radial and Tangential Resolution.

Misc. Data	Filter	Aperture	Shutter Speed		Resolution Values 0°	5°	10°	15°	20°	30°	40°	Ave.	Diffs. Between R&T
Camera No. 44-190620; +0.2 MM. Off Axis; Average Diff. Between R&T = 2.2	Yellow	f/22	1/50	T	28	34	30	30	26.5	21	17	22.0	+5.9
				R	32	32	34	30	28	32	21	27.9	
		f/16	1/100	T	28	30	32	26.5	26.5	21	16	21.5	+7.0
				R	32	34	30	26.5	32	28	22.5	28.5	
		f/11	1/200	T	28	32	28.5	28	22	20	17	20.6	+2.3
				R	32	32	28.5	30.5	26.5	22.5	18	22.9	
		f/8	1/200	T	20	21	22	23.5	21	17	17	18.4	0
				R	22	22.5	21	21	22.5	19	14	18.4	
		f/6.3	1/400	T	25	23.5	25	22	21	19	15	18.7	+1.4
				R	28	26.5	25	25	25	20	15	20.1	
	Yellow + 0.1 N.D.	f/22	1/50	T	28	30	28	28	23.5	20	17	20.8	+2.6
				R	25	28	28	30	25	23.5	20	23.4	
		f/16	1/100	T	32	32	26.5	26.5	26.5	19	17	20.8	-2.4
				R	16	19	19	19	19	19	17	18.4	
		f/11	1/200	T	25	28	27	25	25	20	18	21.1	+0.5
				R	32	26.5	28.5	23.5	22.5	22.5	18	21.6	
		f/8	1/200	T	32	25	28.5	20	22.5	18	15	18.6	+2.9
				R	32	28	28	25	25	21	18	21.5	
		f/6.3	1/400	T	25	22	22	22	21	16	15	17.4	+0.4
				R	20	22	22	22	21	18	14	17.8	
	Yellow + 0.3 N.D.	f/22	1/50	T	32	32	30	26.5	25	21	16	21.2	+4.3
				R	32	34	32	26.5	30	26.5	20	25.5	
		f/16	1/100	T	32	36	34	28	28	22.5	16	22.7	+0.9
				R	25	28.5	32	26.5	26.5	25	18	23.6	
		f/11	1/200	T	25	26.5	28.5	26.5	26.5	20	14	20.3	+0.1
				R	32	26.5	26.5	26.5	28.5	20	13.5	20.4	
		f/8	1/200	T	32	32	30	25	21	21	16	20.4	+0.9
				R	32	30	28.5	26.5	25	21	16.5	21.3	
		f/6.3	1/400	T	32	30	28.5	26.5	21	20	14	19.4	+3.3
				R	32	30	28	30	26.5	23.5	16.5	22.7	
	Yellow + 0.6 N.D.	f/22	1/50	T	28	34	30	25	25	18	15	19.7	+4.8
				R	32	32	32	30	28	25	19	24.5	
		f/16	1/100	T	25	28.5	26.5	25	22	17	13.5	18.0	+3.6
				R	25	30	28.5	26.5	26.5	21	17	21.6	
		f/11	1/200	T	28	26.5	26.5	23.5	20	18	12	17.5	+0.9
				R	22	28	25	25	22	20	11	18.4	
		f/8	1/200	T	22	26.5	28	26.5	23.5	19	15	19.6	+0.5
				R	28	26.5	26.5	25	25	20	15	20.1	
		f/6.3	1/400	T	25	28.5	23.5	22	21	15	10	15.7	+0.1
				R	25	22	22	21	19	17	10	15.8	

Table 9 - Relation Between Weighted-Average Resolution and Resolution at 30°.

Shutter Speed	Aperture	* K17B Camera No. 44-187315 Focus, -0.2 mm. Off Axis				K17C Camera No. 44-190629 Focus, On Axis				K17C Camera No. 44-190620 Focus, +0.2 mm. Off Axis			
		Filter				Filter				Filter			
		Yellow	Y+0.1	Y+0.3	Y+0.6	Yellow	Y+0.1	Y+0.3	Y+0.6	Yellow	Y+0.1	Y+0.3	Y+0.6
1/50	6.3	+0.6	+0.4	+0.9	+1.3	+0.6	+0.5	-0.1	+1.0	+1.3	-0.6	-0.2	+0.5
	8	+0.8	-0.1	+0.9	-0.4	+0.5	+0.4	+0.8	+0.9	-0.3	+0.4	+0.4	+0.6
	11	+0.3	+0.4	+1.5	+1.8	+0.6	+0.1	-0.2	+0.9	+0.2	-0.7	+0.4	-0.2
	16	+0.2	+1.4	+1.4	-0.7	+0.9	+0.4	+0.7	+0.1	-0.1	-1.4	-1.0	-0.4
	22	+1.0	+0.3	-0.4	-0.4	+0.4	+0.4	-0.1	+1.2	-0.3	-0.2	+0.4	+0.5
1/100	6.3	+0.6	+0.3	+1.3	-0.1	+1.2	+0.9	+0.2	+1.5	0	0	0	+0.9
	8	+0.5	+0.3	+1.6	+1.0	+0.7	+0.6	+0.3	+0.9	+0.4	+0.6	+0.7	+0.6
	11	+0.5	+1.0	+1.8	+0.2	+0.9	+0.4	+0.1	+1.2	+0.2	+0.8	+0.2	-0.1
	16	+0.9	+1.8	+1.0	+0.7	-0.5	-0.5	-0.1	+1.4	+0.4	+1.1	-1.1	+0.3
	22	+0.4	+0.7	+0.3	——	-0.5	+0.1	-0.3	-0.1	+0.8	+0.5	+0.4	0
1/200	6.3	+1.0	+1.0	+1.6	+0.4	+0.3	+0.4	+0.4	+1.2	+0.4	-0.3	+0.1	0
	8	+0.9	+0.8	+0.8	+0.8	+0.8	+0.9	+0.3	+0.4	+0.2	+0.9	+0.2	+0.2
	11	+1.8	-0.2	+1.7	+0.2	+1.2	+0.1	-0.1	+0.6	-0.2	-0.1	+0.2	-0.7
	16	+1.7	+1.4	+1.1	-1.1	+0.5	0	+0.8	+0.4	-0.1	+0.7	-0.4	+0.4
	22	+1.0	+0.2	+0.1	——	+0.3	+1.0	+0.3	——	-0.2	-0.2	+0.8	——
1/300* or 1/400	6.3	+0.3	0	+1.5	+0.6	+0.2	+0.9	+1.3	+0.6	-0.2	+0.4	-1.0	-0.1
	8	+0.8	-0.8	+1.4	+1.3	+0.9	-0.1	+0.1	-0.1	+0.2	-0.5	+0.1	+0.8
	11	-0.3	+0.8	+0.7	+1.1	+0.9	+0.1	-1.0	+1.7	0	+0.8	-1.4	+1.0
	16	+1.1	+0.4	+0.2	——	+0.2	-0.4	+0.7	——	-0.7	-0.3	+0.4	——
	22	+0.5	+0.6	——	——	+0.5	+0.6	——	——	+0.7	+0.6	——	——
Averages		±0.76	±0.65	±1.06	±0.76	±0.63	±0.44	±0.42	±0.84	±0.35	±0.56	±0.49	±0.43

Table 10 - Average Resolution, by Aperture, for Given Light Quantity Values.

LIGHT QUANTITIES	CAMERA No. 44-187315 −0.2 MM. OFF AXIS					CAMERA No. 44-190629 ON AXIS					CAMERA No. 44-190620 +0.2 MM. OFF AXIS				
	APERTURE					APERTURE					APERTURE				
	6.3	8	11	16	22	6.3	8	11	16	22	6.3	8	11	16	22
100	17.1					10.1					16.8				
80	17.4					15.4					17.3				
64		17.3					16.9					18.7			
51		18.8					17.3					21.2			
50	18.5					16.9					18.5				
40	17.8					16.4					18.2				
32		18.7	21.6				18.4	19.5				22.1	19.7		
26		19.8	21.4				18.5	21.1				19.8	24.5		
25	18.6					19.0					20.4				
20	18.9					18.8					18.7				
18½	18.8														
16		20.7	21.4	23.7			20.0	20.5	22.8			21.1	24.5	24.9	
15	20.0														
13		19.8	22.0	24.3			20.4	23.3	23.4			20.2	25.5	26.8	
12½	18.5					18.9					19.8				
12		19.7													
10		21.7				18.9					19.8				
9	19.8														
8		19.6	22.9	24.3	23.2		20.6	22.5	23.5	23.3		20.7	23.4	25.5	26.1
6½			22.6	24.2	26.8		19.8	22.0	23.9	25.3		21.2	22.2	22.6	23.5
6	17.3	19.4	22.2			19.2					19.5				
5			21.1												
4½	14.6														
4		18.3	20.2	23.7	23.3		20.2	22.1	23.1	23.1		19.8	22.4	23.4	24.1
3		13.6	18.0	22.7	23.6	16.6		21.0	22.9	24.0	15.8		21.9	22.7	23.2
2½				19.4											
2			19.1	17.6	20.2		16.3	19.7	22.0	22.4		14.7	18.1	18.9	21.2
1½			10.9	14.9	17.1				20.0	20.4				18.7	20.0
1¼					15.4										
1				16.5	12.1			13.1	15.2	15.0					14.8
3/4										13.2					14.7
1/2															
3/8															

Table 11(a) - Resolution and Light Quantity Values for Various Combinations of Camera, Filter, Aperture, and Shutter Speed.

−0.2 MM. OFF AXIS		YELLOW FILTER		YELLOW + 0.1 N.D. FILTER		YELLOW + 0.3 N.D. FILTER		YELLOW + 0.6 N.D. FILTER	
APERTURE	SHUTTER SPEED	LIGHT QUANTITY	RESOLUTION	LIGHT QUANTITY	RESOLUTION	LIGHT QUANTITY	RESOLUTION	LIGHT QUANTITY	RESOLUTION
f/6.3	1/50	100	17.1	80	17.4	50	19.4	25	18.3
	1/100	50	17.6	40	17.8	25	19.6	12½	17.4
	1/200	25	17.9	20	18.9	12½	19.6	6	17.3
	1/300	18½	18.8	15	20.0	9	19.8	4½	14.6
f/8	1/50	64	17.3	51	18.8	32	20.8	16	22.1
	1/100	32	18.5	26	19.8	16	20.6	8	18.4
	1/200	16	19.3	13	19.8	8	20.8	4	18.3
	1/300	12	19.7	10	21.7	6	19.4	3	13.6
f/11	1/50	32	21.6	26	21.4	16	22.3	8	24.8
	1/100	16	20.4	13	22.0	8	22.6	4	18.6
	1/200	8	21.3	6½	22.6	4	21.7	2	19.1
	1/300	6	22.2	5	21.1	3	18.0	1½	10.9
f/16	1/50	16	23.7	13	24.3	8	25.2	4	25.7
	1/100	8	23.3	6½	24.2	4	20.5	2	13.6
	1/200	4	25.0	3	24.2	2	21.6	1	16.5
	1/300	3	21.1	2½	19.4	1½	14.9	¾	—
f/22	1/50	8	23.2	6½	26.8	4	25.3	2	20.6
	1/100	4	21.3	3	23.6	2	17.2	1	—
	1/200	2	22.7	1½	15.7	1	17.1	½	—
	1/300	1½	18.4	1¼	15.4	¾	—	3/8	—

Table 11(b) - Resolution and Light Quantity Values for Various Combinations of Camera, Filter, Aperture, and Shutter Speed.

On-Axis Focus		Yellow Filter		Yellow + 0.1 N.D. Filter		Yellow + 0.3 N.D. Filter		Yellow + 0.6 N.D. Filter	
Aperture	Shutter Speed	Light Quantity	Resolution	Light Quantity	Resolution	Light Quantity	Resolution	Light Quantity	Resolution
f/6.3	1/50	100	10.1	80	15.4	50	17.5	25	20.0
	1/100	50	16.2	40	16.4	25	18.2	12½	19.4
	1/200	25	18.8	20	18.8	12½	18.3	6	19.1
	1/400	12½	19.1	10	18.9	6	19.2	3	16.6
f/8	1/50	64	16.9	51	17.3	32	18.3	16	19.4
	1/100	32	18.6	26	18.5	16	19.3	8	20.9
	1/200	16	20.2	13	20.4	8	20.2	4	20.4
	1/400	8	20.8	6½	19.8	4	20.0	2	16.3
f/11	1/50	32	19.5	26	21.1	16	20.2	8	22.8
	1/100	16	20.8	13	22.3	8	22.1	4	22.1
	1/200	8	22.6	6½	22.0	4	21.8	2	20.0
	1/400	4	22.3	3	21.0	2	19.3	1	13.1
f/16	1/50	16	22.8	13	23.4	8	23.6	4	23.1
	1/100	8	23.4	6½	23.9	4	22.8	2	22.4
	1/200	4	23.4	3	22.9	2	21.7	1	15.8
	1/400	2	21.1	1½	20.0	1	14.6	½	—
f/22	1/50	8	23.3	6½	25.3	4	21.8	2	22.6
	1/100	4	24.4	3	24.0	2	22.1	1	15.9
	1/200	2	21.2	1½	20.4	1	14.7	½	—
	1/400	1	14.4	¾	13.2	½	—	¼	—

Table 11(c) - Resolution and Light Quantity Values for Various Combinations of Camera, Filter, Aperture, and Shutter Speed.

+0.2 MM. OFF AXIS		Yellow Filter		Yellow + 0.1 N.D. Filter		Yellow + 0.3 N.D. Filter		Yellow + 0.6 N.D. Filter	
Aperture	Shutter Speed	Light Quantity	Resolution	Light Quantity	Resolution	Light Quantity	Resolution	Light Quantity	Resolution
f/6.3	1/50	100	16.8	80	17.3	50	19.3	25	20.8
	1/100	50	17.7	40	18.2	25	20.0	12½	20.8
	1/200	25	20.4	20	18.7	12½	19.0	6	19.4
	1/400	12½	19.6	10	19.8	6	19.5	3	15.8
f/8	1/50	64	18.7	51	21.2	32	23.8	16	21.9
	1/100	32	20.4	26	19.8	16	21.7	8	21.9
	1/200	16	19.6	13	20.2	8	20.2	4	19.4
	1/400	8	20.1	6½	21.2	4	20.1	2	14.7
f/11	1/50	32	19.7	26	24.5	16	24.4	8	24.2
	1/100	16	24.6	13	25.5	8	24.2	4	24.4
	1/200	8	21.9	6½	22.2	4	20.7	2	18.2
	1/400	4	22.0	3	21.9	2	18.0	1	12.5
f/16	1/50	16	24.9	13	26.8	8	26.8	4	24.7
	1/100	8	24.1	6½	22.6	4	23.7	2	19.2
	1/200	4	21.9	3	22.7	2	18.6	1	13.6
	1/400	2	19.0	1½	18.7	1	11.6	½	—
f/22	1/50	8	26.1	6½	23.5	4	23.3	2	22.5
	1/100	4	24.9	3	22.2	2	22.1	1	17.9
	1/200	2	19.1	1½	20.0	1	12.7	½	—
	1/400	1	13.7	¾	14.7	½	—	¼	—

Table 12 - Individual High-Resolution Combinations.

Focus Position	Filter	Aperture	Shutter Speed	Resolutions							
				0°	5°	10°	15°	20°	30°	40°	Ave.
−0.2 mm. Off Axis	Yellow	f/16	1/200	34	37	31	27.5	29.3	23.3	22.5	25.0
	Y+0.1	"	1/50	30	33	30	30	26.8	23	22	24,4
	"	f/22	"	34	35	33	33	30	26.5	22.5	26.8
	"	f/16	1/100	32	34	31	29.3	29.3	22.5	20.8	24.3
	"	"	1/200	36	34	34	33	28.5	22.8	19.5	24.2
	Y+0.3	"	1/50	34	35	35	28	26	23.8	23.8	25.2
	"	f/22	"	36	35	34	31	28.3	25.8	20	25.4
	Y+0.6	f/11	"	42.5	36	36	32	25.8	23	22.3	24.8
	"	f/16	"	38	36	36	30.3	26.8	26.5	21	25.8
On Axis	Yellow	f/22	1/100	35	33.5	29.5	30	27.5	25	19.5	24.5
	Y+0.1	"	1/50	32	32.5	31.5	29	30	25	21	25.4
	"	f/16	1/100	28	29	28	30	28.5	24.5	18.5	24.0
	"	f/22	"	32	31	30	30.5	28	24	19	24.1
+0.2 mm. Off Axis	Yellow	f/16	1/50	32	34.5	35	32	30.3	25.1	18	25.0
	"	f/22	"	33	33	34.5	31.5	30.6	26.5	20.3	26.2
	"	f/11	1/100	31.3	31.8	31.9	31.6	31.8	24.5	17.8	24.7
	"	f/16	"	31	34	32.5	29.8	28.1	23.8	19.3	24.2
	"	f/22	"	33	33	32.3	28.5	31.3	24.1	19.9	24.9
	Y+0.1	f/11	1/50	27.5	28.8	32	27.8	28.8	25.3	19.3	24.6
	"	f/16	"	32	32	34	31	33	28.3	19.3	26.9
	"	f/11	1/100	38	32.5	36.5	32.5	30.3	24.8	20.3	25.6
	Y+0.3	"	1/50	32	31	33	32.5	31.1	24.1	17.8	24.5
	"	f/16	"	32	36	37	32	32	28	19.5	27.0
	"	f/11	1/100	32	30.6	30.1	30	30.6	24.1	18.3	24.3
	Y+0.6	"	1/50	29.3	32.1	33.5	31	27	24.5	19.1	24.3
	"	f/16	"	36	33.6	33.1	30.8	28.6	25.1	18.8	24.7
	"	f/11	1/100	32	35.5	34	32.5	27.8	24.6	18.5	24.5

Table 16 - Average Resolutions for 24 Combinations of Filter, Aperture, and Shutter Speed Producing Highest Resolution.

Filter	Aperture	Shutter Speed	Average Resolutions (Lines/mm.)				Standing
			Focus, -0.2mm off	Focus, on axis	Focus, +0.2mm off	Over-all Average	
Yellow	f/11	1/100	20.5	20.9	24.7	22.0	20
	f/11	1/200	21.3	22.7	21.9	21.97	21
	f/16	1/50	23.7	22.9	25.0	23.9	7
	f/16	1/100	23.4	23.5	24.2	23.7	8
	f/16	1/200	25.0	23.5	22.0	23.5	12
	f/22	1/50	23.3	23.4	26.2	24.3	5
	f/22	1/100	21.4	24.5	24.9	23.6	10
Yellow + 0.1 N.D.	f/11	1/50	21.4	21.1	24.6	22.4	17
	f/11	1/100	22.0	22.4	25.6	23.3	14
	f/11	1/200	22.6	22.1	22.3	22.3	19
	f/16	1/50	24.4	23.4	26.9	24.9	3
	f/16	1/100	24.3	24.0	22.7	23.67	9
	f/16	1/200	24.2	23.0	22.8	23.3	14
	f/22	1/50	26.8	25.4	23.6	25.27	2
	f/22	1/100	23.7	24.1	22.3	23.4	13
Yellow + 0.3 N.D.	f/11	1/50	22.3	20.3	24.5	22.4	17
	f/11	1/100	22.6	22.1	24.3	23.0	16
	f/16	1/50	25.2	23.7	27.0	25.3	1
	f/16	1/100	20.5	22.9	22.2	21.87	23
	f/22	1/50	25.4	21.9	23.4	23.57	11
Yellow + 0.6 N.D.	f/11	1/50	24.8	22.9	24.3	24.0	6
	f/11	1/100	18.7	22.2	24.5	21.8	24
	f/16	1/50	25.8	23.1	24.7	24.5	4
	f/22	1/50	20.6	22.7	22.5	21.9	22

Table 14(a) - Average Resolution Values for Line Targets.

MAGAZINE No. 309-102 CORRECTION TO FOCUS (+0.021")

FILTER	APERTURE	SHUTTER SPEED	FOCUS	0°	5°	10°	15°	20°	30°	40°	AVE.
YELLOW	f/6.3	1/50	+.0300"	24	22.5	22	19.5	20	20	19	19.8
			+.0275	22.5	22.5	21.5	21.8	20.3	19.5	18	19.4
			+.0250	27	27.8	24.3	22	21.8	20.3	17	20.0
			+.0225	28.5	26.3	22.8	21.5	20	19	17.5	19.2
			+.0200	27	27.8	24.8	24.5	20.8	19.5	16.5	19.6
			+.0175	28.5	29.3	27	24.3	21.5	19	17	19.8
			+.0150	27	27	24.8	23	23.3	19	16	19.5
			+.0125	25.5	27	25.5	22	22	18.5	17	19.4
			+.0100	22.5	22.5	24.8	23.3	20.5	18.5	17	19.1
			+.0075	24	23.3	24	24.8	22.8	19	17	19.8
			+.0050	21	22.5	22.5	21.3	20	17	16	17.9
			+.0025	18	21	21.3	22	20.8	17.5	16	18.2
			0	19	20	20.3	19	20	16	15	16.9
YELLOW	f/11	1/50	+.0300"	31.5	30	28.5	27.8	25.8	25	21.3	24.5
			+.0275	31.5	32.3	28.8	27.8	24.3	24.3	20.3	23.7
			+.0250	30	29.3	28.5	27	28.5	25	20.3	24.6
			+.0225	33	30.8	28.5	26.3	27	24.8	19.5	24.0
			+.0200	30	30	27	27.8	27	24.8	19.5	24.0
			+.0175	31.5	30.8	80	27.8	26.3	24.8	20.3	24.3
			+.0150	30	28.5	30.8	29.5	26.3	24	18.5	23.4
			+.0125	28.5	30	30	27.8	27.8	22.8	18	23.0
			+.0100	30	29.3	29.3	27	29.3	22.8	17	22.9
			+.0075	28.5	27.8	29.3	29.3	27	22.3	18	22.7
			+.0050	28.5	30	27	27.8	26.3	21.3	17	21.8
			+.0025	28.5	27.8	27	26.3	26.3	21.3	17	21.6
			0	27	27	29.3	28.5	26.3	20.5	16.5	21.4
YELLOW	f/16	1/50	+.0300"	35	35	35.3	32.8	30	26.3	21	26.4
			+.0275	35	32.5	32.3	30.8	30	25.5	20.5	25.6
			+.0250	33.5	35	33.3	31.5	31.5	27	22.8	27.3
			+.0225	35	35	33.3	34.3	30.8	27	22	27.1
			+.0200	35	30.8	30	31	28.5	27.8	20.8	26.2
			+.0175	35	32.3	31.5	31.8	29.3	27	20.8	26.2
			+.0150	33	31.5	32.5	30.8	30	26.3	19.5	25.6
			+.0125	33	31.5	32.3	30.8	28.5	23.8	20	24.5
			+.0100	33	33.3	32.3	29.3	27.8	24.3	19.3	24.3
			+.0075	31.5	35	33	30	29.3	24.3	18.8	24.5
			+.0050	30	30.8	32.3	30	29.3	24.8	18.5	24.5
			+.0025	31.5	29.3	30.8	30.8	29.3	23.3	18	23.7
			0	30	29.3	31.5	29.3	29.3	24.3	16.5	23.6

Table 14(b) - Average Resolution Values for Line Targets.

MAGAZINE No. 309-102 CORRECTION TO FOCUS (+0.021")

FILTER	APERTURE	SHUTTER SPEED	FOCUS	0°	5°	10°	15°	20°	30°	40°	AVE.
YELLOW	f/6.3	1/400	+.0300"	27	24	21.3	22	21.8	21.3	17	20.2
			+.0275	27	26.3	24	22.8	22.8	21.5	16	20.4
			+.0250	27	27.8	25.5	23.5	23	20.5	17.5	20.62
			+.0225	30	27.8	26.3	25	24.5	20.8	15.5	20.5
			+.0200	28.5	30	24.8	27	24.3	20.3	16	20.57
			+.0175	27	27.8	27	25	23.5	19.5	15.5	19.9
			+.0150	28.5	26.3	27	25.5	23.5	19.5	15.5	19.9
			+.0125	28.5	26.3	25.5	24	22	20.5	15	19.7
			+.0100	25.5	27	27.8	24.8	22.8	18.5	15	19.2
			+.0075	24	26.3	26.3	24.8	22.8	18.5	15.5	19.3
			+.0050	24	24	24.8	24	22.8	18.5	14.5	18.8
			+.0025	27	24	24.8	23.5	21.3	17.5	15	18.3
			0	24	22.8	22.8	22.8	21.8	15.5	14	17.1
YELLOW + 0.1 NEUTRAL DENSITY	f/6.3	1/50	+.0300"	DEFECTIVE EXPOSURE							—
			+.0275	22.5	24	19.8	19	19.8	18.8	15	18.0
			+.0250	24	23.3	21.8	20.3	21	19.3	14.5	18.4
			+.0225	28.5	25.5	22	18.5	21	17.5	15	17.8
			+.0200	27	27	24	22.3	19.5	18	14.5	18.0
			+.0175	27	24.8	24.8	21.3	20.3	18	14	17.9
			+.0150	27	27.8	24	20.3	19.5	17.5	14.5	17.7
			+.0125	25.5	26.3	24.8	20.8	20	17	14.5	17.6
			+.0100	24	25.5	25.5	20.8	19.5	17	14	17.4
			+.0075	22.5	22.5	24	20.8	19.8	17.5	14	17.5
			+.0050	21.5	24	24.8	21.3	20.8	17	14.5	17.7
			+.0025	18	20.5	22.8	20.3	19	17	14	17.0
			0	19	20.8	20.8	21.3	20.3	15	14	16.4
YELLOW + 0.1 NEUTRAL DENSITY	f/16	1/50	+.0300	33	32.3	30.8	30.3	27.8	24.5	16.5	23.5
			+.0275	33	33.3	31.5	30.8	28.5	24.5	16.5	23.7
			+.0250	33	33	30	30	28.5	25.8	16	23.9
			+.0225	33.5	32.3	30.8	29.3	30	24.5	15.5	23.5
			+.0200	33	32.3	32.5	28.5	27.8	24.8	15.5	23.3
			+.0175	30	34.3	32.5	30	28.5	24.5	14.5	23.1
			+.0150	30	31.5	31.5	30.3	27.8	24	14	22.6
			+.0125	30	30	31.5	29.3	29.3	23	14	22.3
			+.0100	28.5	30	30	29.3	29.3	23.3	13.5	22.2
			+.0075	31.5	29.3	30.8	27.8	26.3	23	14	21.7
			+.0050	30	30	30	29.3	25.5	23	13.5	21.5
			+.0025	27	26.3	29.3	29.3	26.3	23	13	21.3
			0	25.5	26.3	28.5	28.5	26.3	22.3	13	21.0

Table 14(c) - Average Resolution Values for Line Targets.

MAGAZINE NO. 309-103 CORRECTION TO FOCUS (+0.016")

FILTER	APERTURE	SHUTTER SPEED	FOCUS	0°	5°	10°	15°	20°	30°	40°	AVE.
YELLOW + 0.1 NEUTRAL DENSITY	f/6.3	1/100	+.0300"	21	22	18	17	18	18	14.5	17.0
			+.0275	22.5	22.5	19.3	18.5	17	18.5	14	17.0
			+.0250	22.5	21.3	21	17.5	19.3	18.3	14	17.3
			+.0225	25.5	24	20.3	19	20	18	14	17.4
			+.0200	24	25.5	22.5	20	19.8	19	13.5	17.85
			+.0175	25.5	26.3	24	18.5	18.5	18	14	17.4
			+.0150	24	27	22	21	19.8	17.5	13	17.2
			+.0125	25.5	24	23.3	20.5	21.5	18	13.5	17.79
			+.0100	24	22.5	23.3	20.3	19.8	17	13	16.9
			+.0075	22.5	23.3	26.3	21.3	18.5	16.5	—	—
			+.0050	20.5	21.5	20.8	19.3	19.3	16	—	—
			+.0025	19	18.5	19	18.5	17	15.5	—	—
			0	18	19.5	19.5	19	18	—	—	—
YELLOW + 0.1 NEUTRAL DENSITY	f/6.3	1/200	+.0300"	24	21.5	20.3	18.5	18	19	14.5	17.6
			+.0275	24	22	18.5	18.5	18	17	14	16.6
			+.0250	24	24	19.8	19.5	20.5	20	13	18.0
			+.0225	28.5	25.5	21.5	21.3	20	18	14	17.7
			+.0200	24	26.3	22	21.3	18.5	17.5	—	—
			+.0175	28.5	27.8	24	20	19.8	18.5	—	—
			+.0150	27	26.3	25.5	21.5	20.5	17.5	—	—
			+.0125	25.5	26.3	23.3	21	19	18	—	—
			+.0100	27	26.3	25.5	19.5	19.3	17	—	—
			+.0075	22.5	24.8	25.5	22	19.8	17	—	—
			+.0050	24	25.5	26.3	19.8	19.5	17	—	—
			+.0025	22.5	23.3	24.8	20	20	16.5	—	—
			0	21.5	20.8	22.8	21	18.5	16	—	—
YELLOW + 0.1 NEUTRAL DENSITY	f/6.3	1/400	+.0300"	22.5	24	19.3	19.3	18.8	18.8	14	17.5
			+.0275	24	24	20.5	18.8	19.5	18.8	13.5	17.5
			+.0250	25.5	26.3	24.3	20.5	19	19.5	14	18.2
			+.0225	28.5	28.5	25	20.5	20.5	20	13.5	18.6
			+.0200	30	27.8	24	21	20.5	18.3	13	17.7
			+.0175	28.5	28.5	25.5	22.5	23.3	19.3	13	18.8
			+.0150	27	28.5	25.5	20.8	20.5	17.5	—	—
			+.0125	28.5	27.8	23.3	22.3	21	18	—	—
			+.0100	27	25.5	27	23	21	17	—	—
			+.0075	22.5	23.5	24.8	20.8	21.5	17	—	—
			+.0050	21.5	22	25.5	22.8	20.3	17	—	—
			+.0025	22.5	24	23.3	21	20.8	16.5	—	—
			0	20.5	22.8	23.3	19.5	19.5	17	—	—

Table 14(d) - Average Resolution Values for Line Targets.

MAGAZINE 309-102 CORRECTION TO FOCUS (+0.021")

FILTER	APERTURE	SHUTTER SPEED	FOCUS	0°	5°	10°	15°	20°	30°	40°	AVE.
YELLOW + 0.1 NEUTRAL DENSITY	f/22	1/50	+.0300"	30	33.5	30.8	28.5	26.3	23	17	22.7
			+.0275	33	30	29.3	29.3	27	22.3	17	22.5
			+.0250	31.5	29.3	28.5	27.8	26.3	22.5	17	22.3
			+.0225	30	30.8	29.3	29.3	26.3	23	14.5	21.9
			+.0200	33	29.3	30.8	24.8	26.3	21.8	15.5	21.4
			+.0175	30	28.5	27.8	26.3	26.3	20	15.5	20.7
			+.0150	30	29.3	27	27.8	27	21	15	21.1
			+.0125	30	27.8	25.5	26.3	24.3	20.5	15	20.3
			+.0100	31.5	29.3	27.8	27	24.3	20.8	14.5	20.4
			+.0075	27	26.3	24.8	24	24.8	19.8	15	19.9
			+.0050	25.5	27	27	24.8	24	20.8	14.5	20.1
			+.0025	30	29.3	28.5	28.5	25.5	19.5	15	20.4
			0	30	27	27.8	26.3	27	19	14	19.9
YELLOW + 0.1 NEUTRAL DENSITY	f/8	1/400	+.0300"	27	22.8	21.8	19.3	20	19	14.5	18.05
			+.0275	28.5	24.3	23	18.8	19.5	18	13.5	17.3
			+.0250	30	27	23.5	20.5	20	18.8	13	17.8
			+.0225	28.5	27.8	24.3	20.8	20.8	18.8	13	18.0
			+.0200	25.5	28.5	25.8	22.5	21	18.5	13	18.09
			+.0175	28.5	27.8	27.8	24	22.2	17.5	—	—
			+.0150	25.5	26.3	25.5	22.3	20.3	17	—	—
			+.0125	30	26.3	27.8	22.3	21	17.5	—	—
			+.0100	27	27	25.5	20.3	21	17	—	—
			+.0075	28.5	25.5	25.5	20	20.3	17	—	—
			+.0050	27	25.5	25.5	21.5	20.8	16.5	—	—
			+.0025	21.5	22.5	24	18	20.8	14.5	—	—
			0	20	21.3	23.3	19.5	18	14.5	—	—
YELLOW + 0.3 NEUTRAL DENSITY	f/6.3	1/50	+.0300"	DE	FECT	IVE	EX	POSU	RE.		—
			+.0275	27	26.3	22	22.3	21	20	17.5	19.8
			+.0250	28.5	27	24.5	23.8	23	19.8	18	20.5
			+.0225	28.5	26.3	24.8	23.5	20.8	19.8	17	19.8
			+.0200	28.5	30	25.5	23	21.8	19.3	16.5	19.7
			+.0175	27	27.8	27.8	22.8	21.5	19.8	17	20.0
			+.0150	23.5	27	25.5	23.5	22.8	18	16.5	19.3
			+.0125	27	27.8	27	21.5	21.5	19	16.5	19.4
			+.0100	27	25.5	26.3	24.8	21.5	18.8	16.5	19.5
			+.0075	24	25.5	27	25.5	21.3	18.5	16	19.2
			+.0050	22.5	24	25.5	24.8	22	18.5	15.5	19.1
			+.0025	27	21.8	24.8	21.8	21.8	17.5	16.5	18.7
			0	20	20.8	21.5	22.5	20	17	16	17.9

Table 14 (e) - Average Resolution Values for Line Targets.

MAGAZINE No. 309-103 CORRECTION TO FOCUS (+0.016")

FILTER	APERTURE	SHUTTER SPEED	FOCUS	0°	5°	10°	15°	20°	30°	40°	AVE
YELLOW + 0.3 NEUTRAL DENSITY	f/8	1/200	+.0300"	17	17	16.5	17	16	16	14	15.9
			+.0275	19	18	18	16.5	17.5	18	14	16.6
			+.0250	22.5	20.8	20.3	19	19.3	18	14.5	17.4
			+.0225	25.5	23	20.3	19.8	18	17.5	14	16.9
			+.0200	25.5	24.8	20.8	19	18.5	17	13.5	16.7
			+.0175	30	27	25.5	20.5	21	18	13.5	17.9
			+.0150	25.5	27.8	25.5	21	19.3	17	13.5	17.2
			+.0125	28.5	26.3	25.5	21	21.5	17	14	17.7
			+.0100	28.5	25.5	26.3	21.3	21.5	17	13.5	17.6
			+.0075	28.5	26.3	28.5	21.3	20.8	—	—	—
			+.0050	28.5	26.3	24.8	21.3	20.8	16.5	—	—
			+.0025	25.5	22.8	24	20.8	21	—	—	—
			0	22.5	24.8	22.5	19.8	20.3	15.5	—	—
YELLOW + 0.6 NEUTRAL DENSITY	f/6.3	1/50	+.0300"	21.5	21	19.3	17.5	18	16.5	18	17.5
			+.0275	21	20.3	20.3	20.3	18.5	17.3	16.5	17.7
			+.0250	22.5	22	19.8	20.3	20	17.8	17	18.3
			+.0225	24	24	21	21.5	20.3	17.5	17	18.4
			+.0200	28.5	26.3	23.5	19.5	20	18	16	18.3
			+.0175	31.5	27	27	22.3	22.5	16.5	18	19.1
			+.0150	30	27.8	26.3	23.5	22	17.5	16.5	19.0
			+.0125	27	28.5	27.8	24.3	21	16.5	16.5	18.6
			+.0100	30	28.5	26.3	24	20.8	16.5	15.5	18.2
			+.0075	30	32.3	29.3	25.5	22	17	16	19.0
			+.0050	28.5	27	27.8	23.5	21.3	16.5	15	18.1
			+.0025	27	25.5	26.3	22.8	22	17	15	18.3
			0	25.5	24.8	25.5	24	19.5	17.5	16	18.4
YELLOW + 0.6 NEUTRAL DENSITY	f/6.3	1/100	+.0300	21.5	19.3	17.5	18	18.3	18.3	17	17.9
			+.0275	21	20	18	19.3	18.3	17	16.5	17.3
			+.0250	22.5	21.5	21.5	21	18.3	18.8	16	18.2
			+.0225	27	24.8	21.5	21.5	18.5	18	16	18.0
			+.0200	31.5	23.5	23	20.5	19.8	17	15	17.6
			+.0175	25.5	26.3	22.3	20.5	19	16.5	15.5	17.4
			+.0150	27	25.5	23.5	21.5	19.8	17.8	15	18.0
			+.0125	30	27.8	24.8	21.5	19	16	14.5	17.1
			+.0100	27	28.5	26.3	21.3	21.5	16.5	14	17.6
			+.0075	28.5	27.8	27.8	23.3	21.5	16	14	17.6
			+.0050	28.5	27.8	26.3	22.3	20	15.5	14.5	17.2
			+.0025	22.5	25.5	25.5	22.8	20.3	15.5	14	17.0
			0	24	24	27	21.8	20.3	17	14	17.6

Table 15 - Data for Plotting Curvatures of Field with Respect to Various Apertures.

Aperture	Shutter Speed	Filter	Vernier Pos. for Max. Res. at Center	Deviations from Central Axis of Field Curvature					
				5°	10°	15°	20°	30°	40°
f/6.3	1/50	Yellow	+0.0200	−0.0025	−0.0025	−0.0125	−0.0050	+0.0050	+0.0100
"	1/400	"	+0.0225	−0.0025	−0.0125	−0.0025	0	+0.0050	+0.0025
"	1/50	Y+0.1	+0.0225	−0.0075	−0.0125	−0.0025	+0.0013	+0.0025	+0.0025
"	1/100	"	+0.0175	−0.0025	−0.0100	−0.0100	−0.0050	+0.0025	+0.0125
"	1/200	"	+0.0200	−0.0025	−0.0150	−0.0125	0	+0.0050	+0.0100
"	1/400	"	+0.0200	−0.0013	−0.0100	−0.0100	−0.0025	+0.0025	+0.0075
"	1/50	Y+0.3	+0.0200	0	−0.0025	−0.0125	+0.0050	+0.0075	+0.0050
"	1/50	Y+0.6	+0.0175	−0.0100	−0.0100	−0.0100	0	+0.0025	+0.0063
"	1/100	"	+0.0200	−0.0100	−0.0125	−0.0125	−0.0113	+0.0050	+0.0100
f/8	1/400	Y+0.1	+0.0188	+0.0013	−0.0038	+0.0013	−0.0013	+0.0113	+0.0113
"	1/200	Y+0.3	+0.0175	−0.0025	−0.0100	−0.0100	−0.0063	+0.0050	+0.0075
f/11	1/50	Yellow	+0.0225	+0.0050	−0.0075	−0.0150	−0.0125	+0.0050	+0.0075
f/16	1/50	Yellow	+0.0225	+0.0025	+0.0075	0	+0.0025	−0.0025	+0.0025
"	1/50	Y+0.1	+0.0225	−0.0050	−0.0038	+0.0050	0	+0.0025	+0.0063
f/22	1/50	Y+0.1	+0.0238	+0.0063	+0.0013	+0.0013	−0.0025	+0.0025	+0.0038
	Average Deviations for Various Apertures								
f/6.3	—	—	+0.0200	−0.0043	−0.0097	−0.0094	−0.0019	+0.0042	+0.0074
f/8	—	—	+0.0181	−0.0006	−0.0069	−0.0044	−0.0039	+0.0081	+0.0094
f/11	—	—	+0.0225	+0.0050	−0.0075	−0.0150	−0.0125	+0.0050	+0.0075
f/16	—	—	+0.0225	−0.0013	+0.0019	+0.0025	+0.0013	0	+0.0044
f/22	—	—	+0.0238	+0.0063	+0.0013	+0.0013	−0.0025	+0.0025	+0.0038

Table 16 - Positions of Focus for Optimum Resolution in Camera No. 44-190509.

Magazine	Filter	Aperture	Shutter Speed (Sec.)	Maximum Resolution (Lines/mm.)	Total Correction (In.)	Position of Focus for Optimum Resolution (In.)	
						Uncorrected	Corrected
Type A-12 No. 309-102	Yellow	f/6.3	1/50	20.0	0.021	+0.025	+0.004
	"	f/11	1/50	24.6	0.021	+0.025	+0.004
	"	f/16	1/50	27.3	0.021	+0.025	+0.004
	"	f/6.3	1/400	20.6	0.021	+0.025	+0.004
	Y+0.1 N.D.	f/6.3	1/50	18.4	0.021	+0.025	+0.004
	"	f/16	1/50	23.9	0.021	+0.025	+0.004
	"	f/22	1/50	22.7	0.021	+0.030	+0.009
	"	f/8	1/400	18.1	0.021	+0.020	-0.001
	Y+0.3 N.D.	f/6.3	1/50	20.5	0.021	+0.025	+0.004
	Average Corrected Position of Focus					—	+0.004
Type A-12 No. 309-103	Y+0.1 N.D.	f/6.3	1/100	17.8	0.016	+0.020	+0.004
	"	f/6.3	1/200	18.0	0.016	+0.025	+0.009
	"	f/6.3	1/400	18.8	0.016	+0.018	+0.002
	Y+0.3 N.D.	f/8	1/200	17.9	0.016	+0.018	+0.002
	Y+0.6 N.D.	f/6.3	1/50	19.1	0.016	+0.018	+0.002
	"	f/6.3	1/100	18.2	0.016	+0.025	+0.009
	Average Corrected Position of Focus					—	+0.005

Table IVa - Average Resolution Values for Various Cameras.

Camera	Magazine	Aperture	Shutter Speed	Focal Plane Position (Uncorr.)	Resolutions 0°	5°	10°	15°	20°	30°	40°	Ave.
K-17B No. 44-187367	Type A-12 No. 309-103	f/16	1/50	+.0300	21.5	19.5	19	16	16	16	18.3	16.9
				+.0275	21	19	18.5	17	15.5	16	19.3	17.2
				+.0250	21.5	19.5	20.3	18	16	16	19	17.3
				+.0225	24	23.3	20.3	20.5	17	16.5	18.5	17.8
				+.0200	22.5	22.3	20.5	19	17.8	16	18.5	17.6
				+.0175	28.5	25.5	22.5	20.8	20	18.3	18.8	19.3
				+.0150	25.5	24.3	22.5	20.5	18.8	16.5	16	17.5
				+.0125	22.5	23.3	22.5	19.3	19	16.5	17.3	17.8
				+.0100	27	25.5	24	22.8	19.3	19.3	18.8	19.8
				+.0075	25.5	26.3	24	21.3	20.5	20	17	19.6
				+.0050	30	31.8	27.8	25	23.3	20.8	18.5	21.4 *
				+.0025	24	23.3	22.5	23.5	21	19.8	19	20.2
				Axis	22	23.3	22	22.3	20.5	18.5	17	18.9
				-.0025	22	23.8	22.5	21.3	20.5	19	16.5	18.9
				-.0050	25.5	24.8	22.5	22.3	21	19	16.8	19.2
		f/16	1/100	+.0300	21	20.8	18.5	16.5	16	16.5	17.8	16.8
				+.0275	20	20.3	18	17	15	16	16.5	16.2
				+.0250	24	21.8	18.5	19.3	16.5	16.5	17.5	17.2
				+.0225	25.5	21.8	20.8	19	16.5	16.5	19.5	17.9
				+.0200	27	23.3	21.5	19.8	18	17	17.8	18.0
				+.0175	22.5	22.8	21.5	20.5	17.5	17.5	17	17.9
				+.0150	28.5	26.3	23	22.3	20.8	18.8	18.3	19.6
				+.0125	24	23.3	22.8	19.3	17.5	17	17	17.7
				+.0100	28.5	26.3	23.5	22.5	19.8	18.3	18	19.2
				+.0075	30.5	27.8	24.8	23.3	21	19.3	17.5	19.8
				+.0050	27	30.8	28.5	26.3	22.3	21	20	21.8
				+.0025	25.5	30	24	24.5	22	20.8	19.5	21.2
				Axis	24	29.3	27	23.5	22.5	20.3	20	21.3
				-.0025	27	29.3	30	26.3	26.5	22.5	20	23.2 *
				-.0050	27	27.8	25.5	24.8	22.8	21	18	21.0
		f/6.3	1/100	+.0300	—	—	—	—	—	—	16.5	—
				+.0275	—	—	—	—	—	—	16	—
				+.0250	—	—	—	—	—	—	17	—
				+.0225	14	—	—	—	—	15	16	—
				+.0200	14	14	—	—	—	14.5	16	—
				+.0175	16	15	15	14	14	15	15.5	14.9
				+.0150	15	15	15	14.5	14.5	15.5	15	15.1
				+.0125	19	18.5	16	15.5	15.5	16.5	15.5	16.0
				+.0100	20	18.5	17	15.5	15	15.5	16	15.7
				+.0075	21.5	19	18	16.5	15.5	16.5	15	16.0
				+.0050	20	19.5	18	17	16.5	16.5	15	16.2
				+.0025	19	20.5	18	17.5	16.5	16.5	15	16.3
				Axis	22.5	24	19.5	18.5	18.5	17	16	17.3 *
				-.0025	22.5	21.3	20	18	17	16	15.5	16.5
				-.0050	24	22.8	20.8	18.5	17.5	17.5	15	17.1

Table 17a - (Cont.)

Camera	Magazine	Aperture	Shutter Speed	Focal Plane Position (Uncorr)	Resolutions 0°	5°	10°	15°	20°	30°	40°	Ave.
K-17B No. 44-187367	Type A-12 No. 309-103	f/6.3	1/200	+.0300	—	—	—	—	—	—	—	—
				+.0275	15	—	—	—	—	—	—	—
				+.0250	—	—	—	—	—	—	—	—
				+.0225	17	18.5	18	15	14.5	16	16	15.8
				+.0200	18	18	16.5	14	14	15.5	16.5	15.5
				+.0175	18	17	16	16	14.5	16	16	15.8
				+.0150	19	17.5	16	15.5	15	16	15	15.5
				+.0125	19	17	18	16	16.5	17	16.5	16.7
				+.0100	21	19.5	19	17.5	16.5	16	15.5	16.3
				+.0075	24	24	19.5	18	18.5	17	16	17.3 *
				+.0050	21.5	21	19.3	18	16.5	16.5	15.5	16.5
				+.0025	21.5	21.3	20.5	17.5	17	16.5	16	17.0
				Axis	27	25.5	22	19.8	17	16.5	16	17.1
				-.0025	24	21.5	19.8	18.5	18	17.5	15	17.0
				-.0050	22	21.5	21	19.3	17.5	16	15	16.5
		f/16	1/200	+.0300	21	20	18.5	17.5	15.5	16	15.5	16.1
				+.0275	22.5	20.8	18.5	17	16	15.5	17.5	16.6
				+.0250	21.5	19.5	18.5	17	15.5	16	16	16.2
				+.0225	24	27.8	22.5	19.5	18.5	17	17.5	18.1
				+.0200	27	24	20.5	21	18.5	19	18.3	19.0
				+.0175	25.5	22.5	22.3	18.5	18	17	16.5	17.5
				+.0150	28.5	26.3	22.5	21	19.3	17	16.5	18.0
				+.0125	28.5	28.5	23.5	22.5	20	18.8	17	19.2
				+.0100	31.5	27	25.5	25	21.8	19.5	17	20.0
				+.0075	31.5	32.5	28.5	24	22.5	20.8	18.5	21.2 *
				+.0050	28.5	27.8	25.5	22.8	21.8	20	17.5	20.2
				+.0025	28.5	27.8	26.3	22.8	22	20	16.5	19.9
				Axis	30	29.3	30	24.8	22.5	18	16.5	19.6
				-.0025	27	27.8	27	24.8	22.3	20	17.8	20.6
				-.0050	30	28.5	26.3	26.3	23	20	18	20.8

* Maximum Values of Resolution

Calculation of Corrections

Zero Position of Focal Micrometer - - - - - - - - - - - - - -	+0.386"
Distance to Plane of Visual Focus - - - - - - - - - - - - - -	-0.018
Position of Best On-Axis Focus (Camera) - - - - - - - - - -	+0.368
Distance from Mating Surface of Magazine to Focal Plane -	-0.373
Correction #1 -	-0.005
Correction #2 -	+0.005
Total Correction - - - - - - - -	0

Table 17b - Average Resolution Values for Various Cameras.

Camera	Magazine	Aperture	Shutter Speed	Focal Plane Position (Uncorr.)	Resolutions 0°	5°	10°	15°	20°	30°	40°	Ave.	
K-17B No. 42-54857	Type A-12 No. 309-102	f/16	1/50	+.0300	19	19	18.5	18.5	18.5	19.8	20.5	19.6	
				+.0275	18	17.5	17	18	17	18.3	17	17.6	
				+.0250	16	16	17	16	16.5	17	17	16.8	
				+.0225	16	16.5	17	17	16.5	17	16.5	16.8	
				+.0200	17	16.5	16.5	16	16.5	17	15.5	16.4	
				+.0175	20.5	21.3	19.8	19.5	18	19	16	18.1	
				+.0150	18.5	17	17	17	17	17	16	16.7	
				+.0125	31.5	29.3	27.8	27.8	25.5	24.8	21.8	24.46	
				+.0100	31.5	28.5	28.5	28.5	25.5	24.8	20.3	24.1	
				+.0075	30	27	27.8	27.8	24.8	22.3	18	22.2	
				+.0050	31.5	30	27	27	25.5	23	17.5	22.4	
				+.0025	33.5	32.3	31.5	30	29.3	24.8	18.5	24.50	*
				Axis	27	30	30.8	29.3	25	23.3	18.5	23.0	
				-.0025	30	32.5	30	27.8	24.8	24	18	23.0	
				-.0050	31.5	31.5	29.3	30	26.3	24	17	23.1	
		f/16	1/100	+.0300	20	19.5	18.5	18	17.5	21.5	21.8	20.5	
				+.0275	20	20.8	19.5	19	18	21.5	22.3	20.9	
				+.0250	22.5	22.8	20.5	19.8	19	20.5	20.5	20.2	
				+.0225	24	23.3	21.3	20.8	20.3	24.5	22	22.6	
				+.0200	25.5	26.3	23.3	22.5	21.8	24.3	20.5	22.6	
				+.0175	28.5	26.3	25.5	24	22.5	23.8	21.8	23.1	
				+.0150	30	24	26.3	25.5	24	23.3	21.3	23.1	
				+.0125	30	30.3	27.8	26.3	24.3	24.5	20.8	23.8	
				+.0100	31.5	29.3	27.8	27	25.5	25.5	19.3	23.92	*
				+.0075	33	31.5	28.5	26.3	25.5	24.8	20	23.90	
				+.0050	31.5	28.5	28.5	27	26.3	22.8	19.3	23.0	
				+.0025	31.5	32.3	30.8	27.8	24.8	25	19	23.8	
				Axis	36	33.3	30.8	30	27	23.5	18	23.4	
				-.0025	31.5	30.8	28.5	28.5	28.5	24	18	23.6	
				-.0050	31.5	33.3	30.8	29.3	26.3	23.5	17.5	23.1	
		f/6.3	1/100	+.0300	—	—	—	—	—	17.5	16	—	
				+.0275	—	—	—	—	—	18	17	—	
				+.0250	—	—	—	—	—	17	17	—	
				+.0225	14	—	—	14	14.5	18.3	16	—	
				+.0200	13	14.5	14	14	15.5	18.8	16	16.6	
				+.0175	16	14.5	15.5	16	16.5	19.3	16	17.3	
				+.0150	18	16.5	16	17.5	17.5	19.3	17	18.0	
				+.0125	18	17.5	18	17	17.5	21	17.3	18.8	*
				+.0100	19	21.5	20.8	20.3	19	18.5	16	18.1	
				+.0075	24	22	21.3	20.3	19.8	17.5	16	17.8	
				+.0050	25.5	25.5	23.3	22.8	20.5	17.5	15.5	18.2	
				+.0025	30	24.8	21.5	22.3	20.5	17.5	15.5	18.1	
				Axis	30	24	23.5	21.5	19.8	18	14.5	17.8	
				-.0025	28.5	26.3	27	21.3	19.5	19	15	18.6	
				-.0050	30	27	24.8	22.5	21.5	18.8	14	18.5	

Table IVb - (Cont.)

Camera	Magazine	Aperture	Shutter Speed	Focal Plane Position (Uncorr.)	Resolutions 0°	5°	10°	15°	20°	30°	40°	Ave.
K-17B No. 42-54857	Type A-12 No. 309-102	f/6.3	1/200	+.0300"	—	—	—	—	—	17	16	—
				+.0275	—	—	—	—	—	17	16	—
				+.0250	—	—	14	14	14.5	16.5	16	—
				+.0225	—	—	—	14	14.5	17.5	16.5	—
				+.0200	14	13.5	15	14	16	17.5	15.5	16.2
				+.0175	15	15	15.5	15.5	16.5	18	16	16.8
				+.0150	17	16.5	17	16.5	18	19.5	15.5	17.6
				+.0125	18	17	17.5	17.5	17.5	17.5	15	16.7
				+.0100	18	19	18	17.5	18	19	15.5	17.6
				+.0075	20	20	19	18.5	21	18.8	15.5	18.2 *
				+.0050	21.5	22.5	20	19	19	17	15	17.1
				+.0025	25.5	24	22.3	21	20	16.5	14.5	17.2
				Axis	24	24	23.3	20.8	20.8	18	14.5	18.0
				-.0025	27	26.3	22	20.3	20.5	18	14	17.8
				-.0050	25.5	24	22.5	22	18.5	16.5	14	16.9
		f/16	1/200	+.0300	18	18	17.5	18	16.5	19.8	19.3	18.6
				+.0275	19	19	18	18.5	17.5	19.3	18	18.5
				+.0250	20	20.3	18	18	19	20.3	18.8	19.4
				+.0225	21	20	19.5	19.5	19.5	21.3	17.5	19.6
				+.0200	19	19.5	20.3	19.5	18.5	21.3	17.5	19.5
				+.0175	24	21.8	22	20.3	19.8	21.8	18.8	20.4
				+.0150	28.5	26.3	23.3	22.5	22.8	22.3	17	20.9
				+.0125	25.5	24.8	26.3	23.5	22	23.8	17.5	21.7
				+.0100	28.5	27	25.5	22.5	22	21	17	20.4
				+.0075	30	28.5	26.3	24.8	24.3	21.3	16.5	21.0
				+.0050	30	26.3	27	24	23	22	15.5	20.7
				+.0025	28.5	27.8	27.8	26.3	24	23.5	16.5	22.0 *
				Axis	30	27	25.5	23.8	23	22	16	20.6
				-.0025	31.5	25.5	27.8	27	24.8	20.3	14.5	20.2
				-.0050	27	27	26.3	25.5	24.8	23	14	21.0

* Maximum Values of Resolution

<u>Calculation of Corrections</u>

Zero Position of Focal Micrometer - - - - - - - - - - - - - -	+0.386
Distance to Plane of Visual Focus - - - - - - - - - - - - - -	-0.023
Position of Best On-Axis Focus (Camera - - - - - - - - - -	+0.363
Distance from Mating Surface of Magazine - - - - - - - -	[illegible]
to Focal Plane -	-0.368
Correction #1 -	-0.005
Correction #2 -	+0.005
Total Correction - - - - - - - -	0

Table 17c - Average Resolution Values for Various Cameras.

Camera	Magazine	Aperture	Shutter Speed	Focal Plane Position (Uncorr.)	Resolutions 0°	5°	10°	15°	20°	30°	40°	Ave.
K-17B No. 42-44995	Type A-12 No. 309-102	f/16	1/50	+.0300	28.5	24.8	22.8	22	18.8	17	16	17.8
				+.0275	30	28.5	25.5	22.3	20	18.8	17.5	19.4
				+.0250	25.5	22.8	28.3	19.8	17.5	17	16	17.4
				+.0225	24	21.3	21.5	21.3	18.8	18.5	15.5	18.0
				+.0200	24	23.3	25.5	21.3	20	18	16	18.4
				+.0175	27	27	24.8	22	20.3	17.5	15	18.1
				+.0150	27	24.8	24	22	20.8	18.8	16.5	19.0
				+.0125	27	24.8	24	22.8	20.8	19	18	19.6
				+.0100	22.5	24	26.3	22.8	18.5	17	15	17.6
				+.0075	28.5	27.8	25.5	24.8	22.3	20.5	19.8	21.3 *
				+.0050	27	24	28.5	22.8	23	18.5	17	19.7
				+.0025	25.5	22.5	23.3	22.5	20	17.5	16.5	18.4
				Axis	25.5	23.3	24	24.8	22.3	17.5	15.5	18.7
				-.0025	24	23.3	25.5	24.8	21.5	19.3	16	19.4
				-.0050	22.5	21.8	25.5	24	21.5	18.5	18	19.6
		f/16	1/100	+.0300	27	23.3	22.5	19	17	16	15	16.5
				+.0275	21	20.3	19.5	18.5	15	14	14	14.9
				+.0250	28.5	24	24	21.8	19.3	15.5	18.3	18.0
				+.0225	28.5	27.8	27	20.8	19.3	17.5	17	18.6
				+.0200	28.5	25.5	23.5	20.5	18.5	16	14.5	16.8
				+.0175	24	22	20	19.5	16.5	16.5	14.5	16.4
				+.0150	27	25.5	23.5	19.8	18.5	15.5	14	16.5
				+.0125	27	24.8	23.3	22.3	20.5	18.3	16	18.7 *
				+.0100	25.5	25.5	21	20.5	19	16.5	15.5	17.3
				+.0075	27	24.8	24.8	23.3	21	17.5	16	18.5
				+.0050	20.5	19.8	20.5	18.5	16.5	15	13.5	15.4
				+.0025	20	18.5	18.5	18.5	18	18.3	15	17.3
				Axis	20	21.5	20.8	20	19	16	13	15.7
				-.0025	20.5	22.8	21.8	21.5	18	16.5	14	16.7
				-.0050	19	20.5	20.3	20	18.5	16.5	15.5	17.0
		f/6.3	1/100	+.0300	15	—	—	—	—	—	14.5	—
				+.0275	14	14	—	—	—	—	—	—
				+.0250	15	15	—	—	—	—	—	—
				+.0225	15	14.5	14.5	—	—	—	—	—
				+.0200	16	16	16	—	—	—	—	—
				+.0175	16	16.5	15.5	—	—	—	—	—
				+.0150	20	20.8	16	14.5	13.5	14	14	15.1
				+.0125	20	21.3	19.5	17.8	16.5	15.5	14.5	15.8
				+.0100	17	16.5	16	14.5	13.5	14	14	14.1
				+.0075	17	18	16.5	15	15	13.5	13	13.9
				+.0050	22.5	22.5	20.3	19	17	16	14	16.1 *
				+.0025	20	18.5	19	16.5	16	14.5	14	15.0
				Axis	20	20	19.5	17	17	15	14	15.5
				-.0025	18	18.5	17.5	16.5	15.5	14	13.5	14.5
				-.0050	20	19	18	18	16	16	14	15.8

Table 17c - (Cont.)

Camera	Magazine	Aperture	Shutter Speed	Focal Plane Position (Uncorr.)	0°	5°	10°	15°	20°	30°	40°	Ave.
K-17B No. 42-44995	Type A-12 No. 309-102	f/6.3	1/200	+.0300	16	16	16	15	14.5	14.5	15	14.8
				+.0275	17	17	15.5	14.5	14.5	15	15	15.0
				+.0250	20	17.5	17	15.5	15	15	14.5	15.0
				+.0225	22.5	17.5	18.5	16	15	15.5	13.5	15.0
				+.0200	19	20.8	18	15.5	15.5	14.5	13	14.6
				+.0175	27	22.8	20.5	18.5	17.5	16.5	16	17.0
				+.0150	25.5	22.5	19.5	19.3	18	16	14.5	16.4
				+.0125	21.5	20.8	18.5	16.5	15.5	15	13	14.9
				+.0100	22.5	21.3	19.5	17.5	16	14.5	14	15.2
				+.0075	21	24.3	21.5	19.8	17	16	13.5	16.1
				+.0050	27	26.3	21.5	21.8	19.8	17	16	17.9 *
				+.0025	25.5	23.3	21.3	19	17	16	13.5	16
				Axis	20	22.5	19.5	19	17	17	15.5	16.9
				-.0025	22.5	23.5	20.8	19	18	15.5	14.5	16.3
				-.0050	20	22	20	19.8	17.5	16.5	15	16.7
		f/16	1/200	+.0300	27	22.5	18.5	18	16	15	14	15.4
				+.0275	25.5	23.3	21.8	20.5	17	16	14	16.3
				+.0250	25.5	22.5	19.5	20.3	18.5	16	15	16.7
				+.0225	25.5	24	22	20.8	18	17	15	17.2
				+.0200	25.5	23.3	21.5	19.5	18.5	17	15	17.2
				+.0175	27	24	24.8	22.5	19	19.3	16.5	19.0 *
				+.0150	24	24.8	23.5	22.3	18.8	17	14.5	17.5
				+.0125	25.5	22.5	24	19	18.5	16.5	14	16.7
				+.0100	21	21.3	18.5	19	17	15.5	14	15.8
				+.0075	27	22.8	23.3	20.8	19	17.5	14	17.3
				+.0050	25.5	24.8	22.8	23.3	19.8	17.5	13.5	17.5
				+.0025	23	23.5	22.3	22	19.8	16.5	13.5	17.0
				Axis	20.5	21.5	22.3	21	19.3	16.5	13	16.6
				-.0025	22.5	22.3	22.8	20	19.8	16	13.5	16.5
				-.0050	21.5	20.3	18.5	20	18.5	16	13	16.0

* Maximum Values of Resolution

Calculation of Corrections

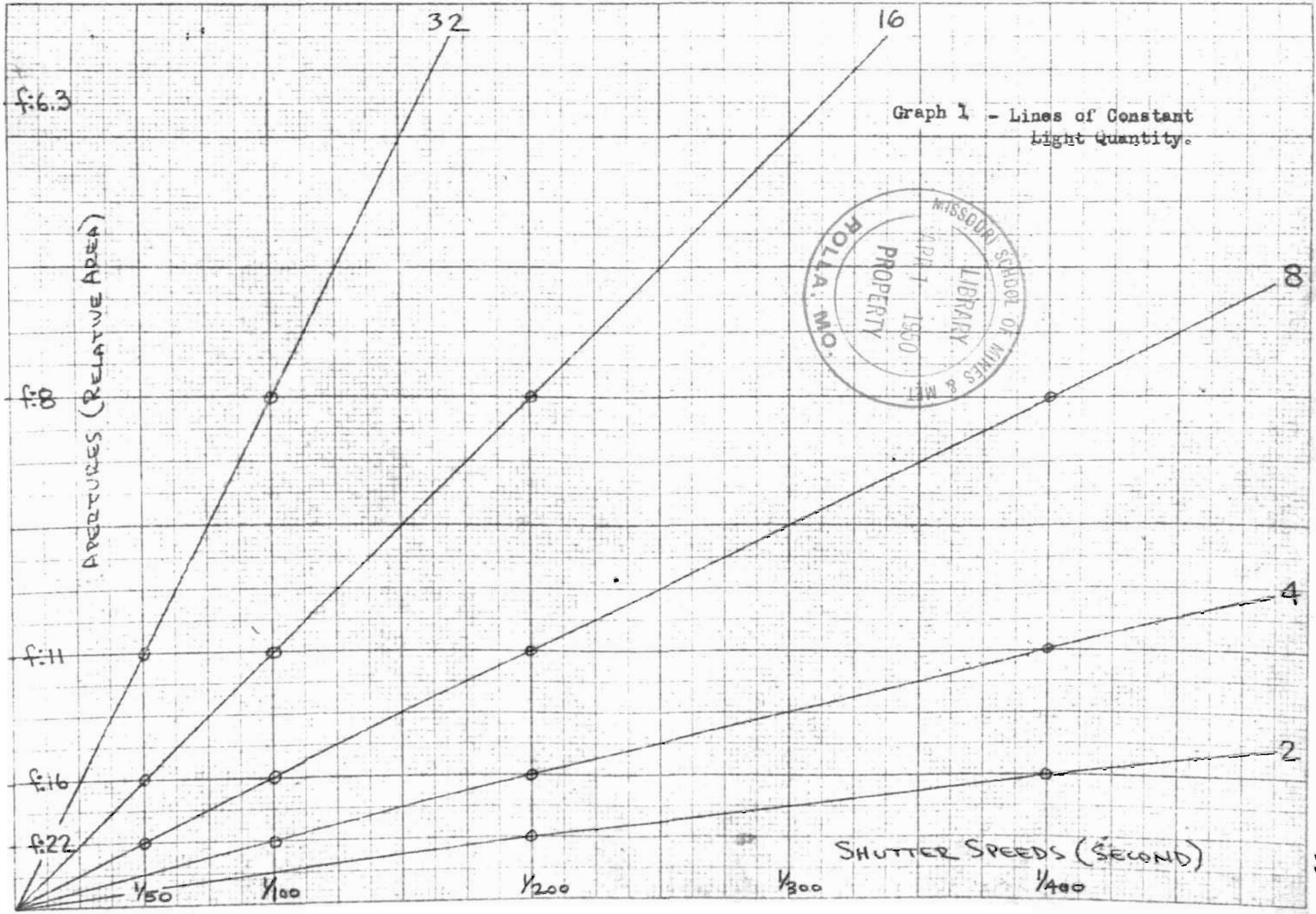
Zero Position of Focal Micrometer - - - - - - - - - - - - -	+0.386
Distance to Plane of Visual Focus - - - - - - - - - - - - -	-0.018
Position of Best On-Axis Focus (Camera) - - - - - - - - - -	+0.368
Distance from Mating Surface of Magazine to Focal Plane -	-0.368
Correction #1 -	0
Correction #2 -	+0.005
Total Correction - - - - - - - -	+0.005

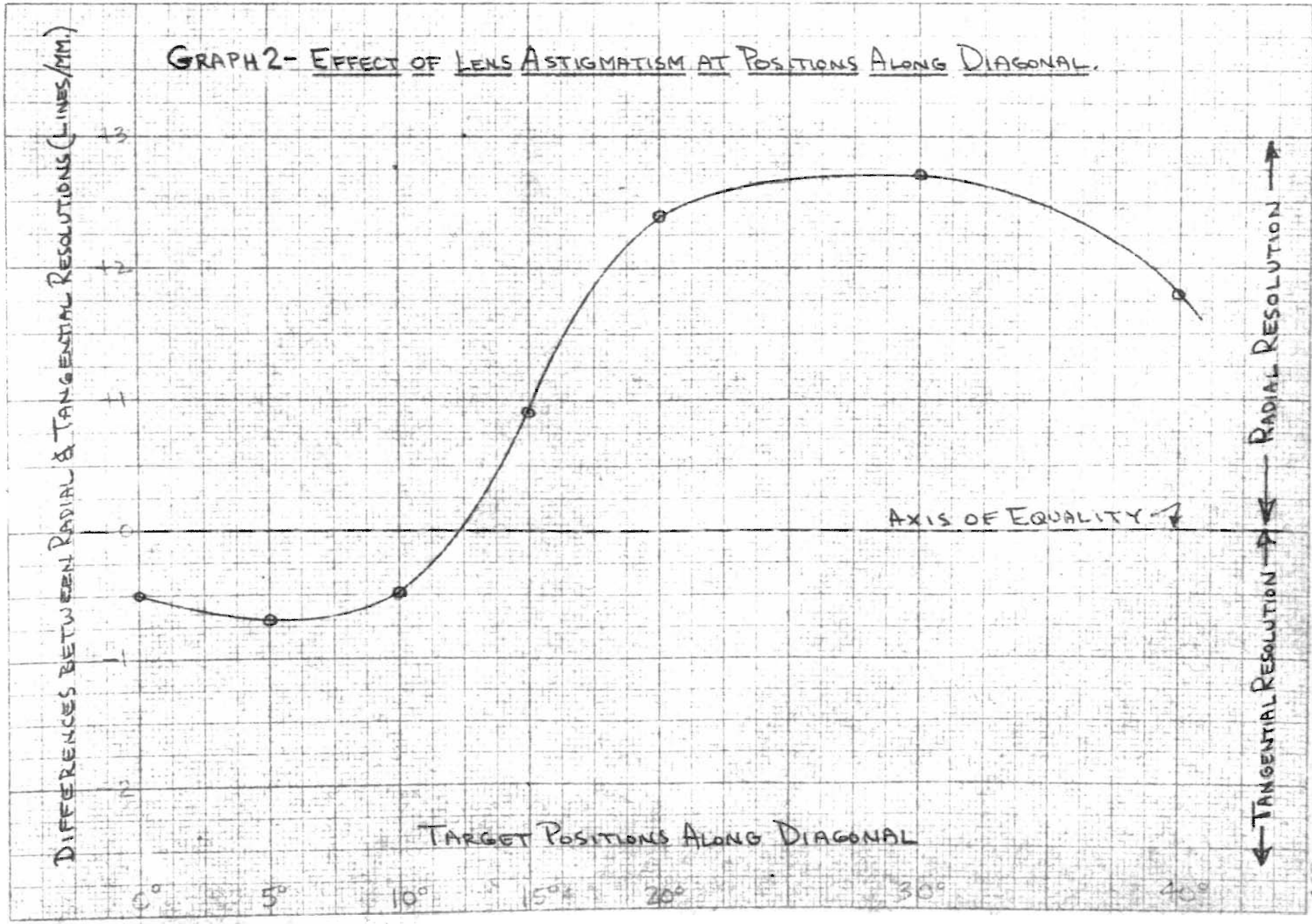
Table 18 - Positions of Focus for Optimum Resolution in Various Cameras.

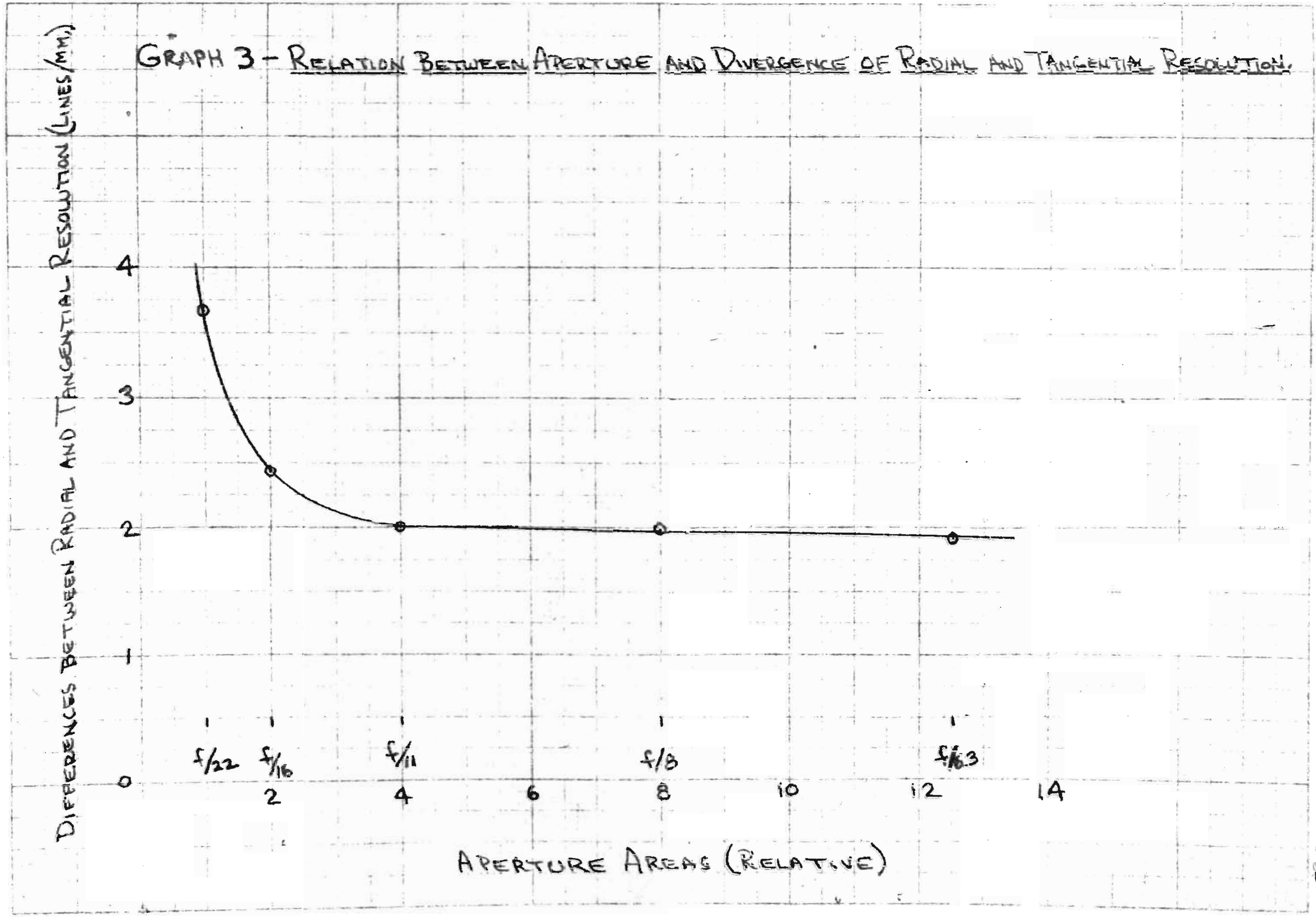
Camera	Magazine	Aperture	Shutter Speed (Sec.)	Maximum Resolution (Lines/mm)	Total Correction	Position of Focus for Optimum Resolution	
						Uncorrected	Corrected
No. 44-187367	No. 309-103	f/16	1/50	21.4	0	+0.0050"	+0.0050"
		f/16	1/100	23.2	0	-0.0025"	-0.0025"
		f/6.3	1/100	17.3	0	Axis	Axis
		f/6.3	1/200	17.3	0	+0.0075"	+0.0075"
		f/16	1/200	21.2	0	+0.0075"	+0.0075"
			Average Focus Position -				+0.004"
No. 42-54857	No. 309-102	f/16	1/50	24.5	0	+0.0025"	+0.0025"
		f/16	1/100	23.9	0	+0.0100"	+0.0100"
		f/6.3	1/100	18.8	0	+0.0125"	+0.0125"
		f/6.3	1/200	18.2	0	+0.0075"	+0.0075"
		f/16	1/200	22.0	0	+0.0025"	+0.0025"
			Average Focus Position -				+0.007"
No. 42-44995	No. 309-102	f/16	1/50	21.3	0.005"	+0.0075"	+0.0025"
		f/16	1/100	18.7	0.005"	+0.0125"	+0.0075"
		f/6.3	1/100	16.1	0.005"	+0.0050"	Axis
		f/6.3	1/200	17.9	0.005"	+0.0050"	Axis
		f/16	1/200	19.0	0.005"	+0.0175"	+0.0125"
			Average Focus Position -				+0.005"

APPENDIX "B"

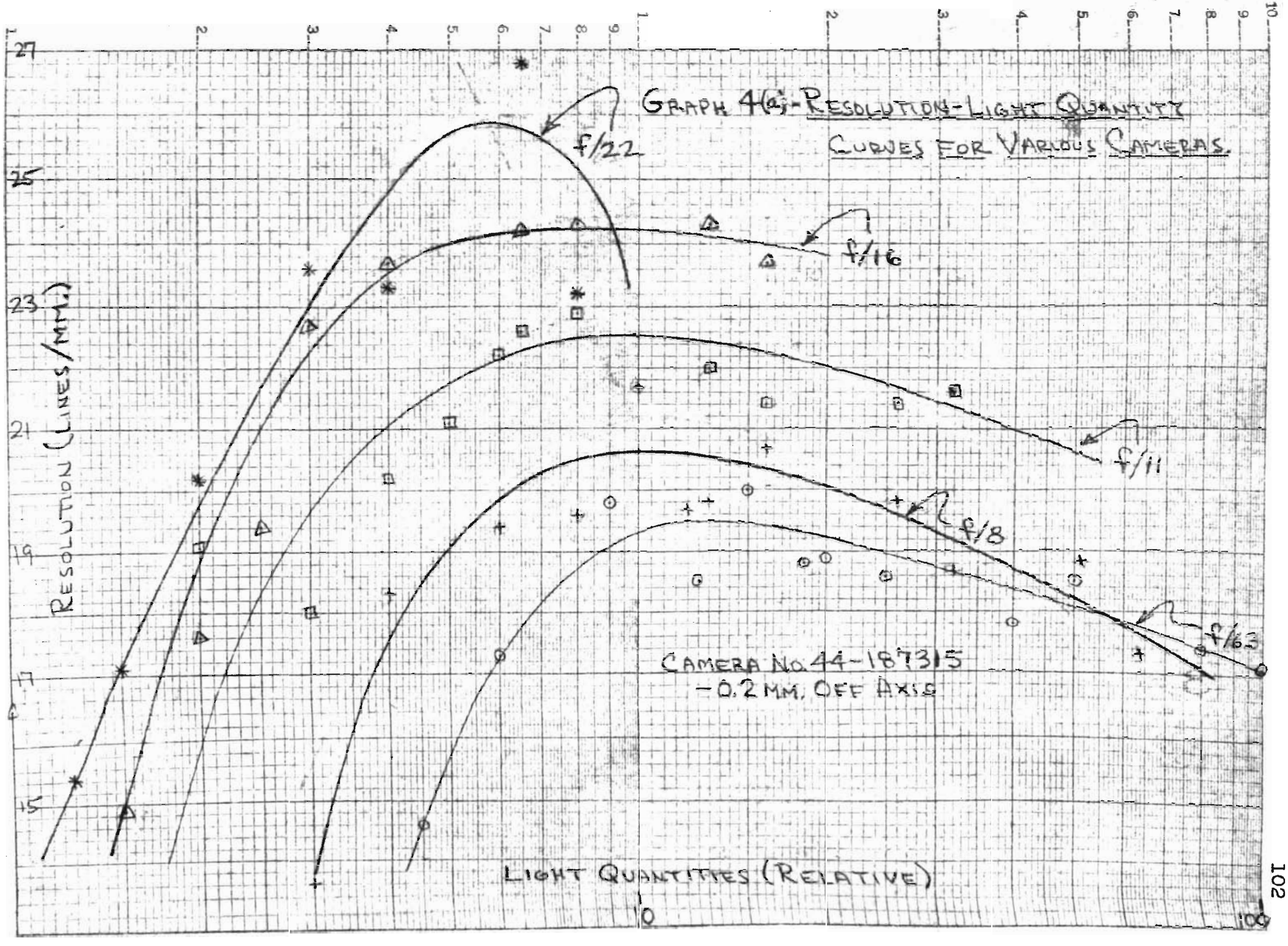
GRAPHS


Graph 1 - Lines of Constant Light Quantity.
32
16
8
4
2
f:6.3
f:8
f:11
f:16
f:22
APERTURES (RELATIVE AREA)
SHUTTER SPEEDS (SECOND)
1/50
1/100
1/200
1/300
1/400

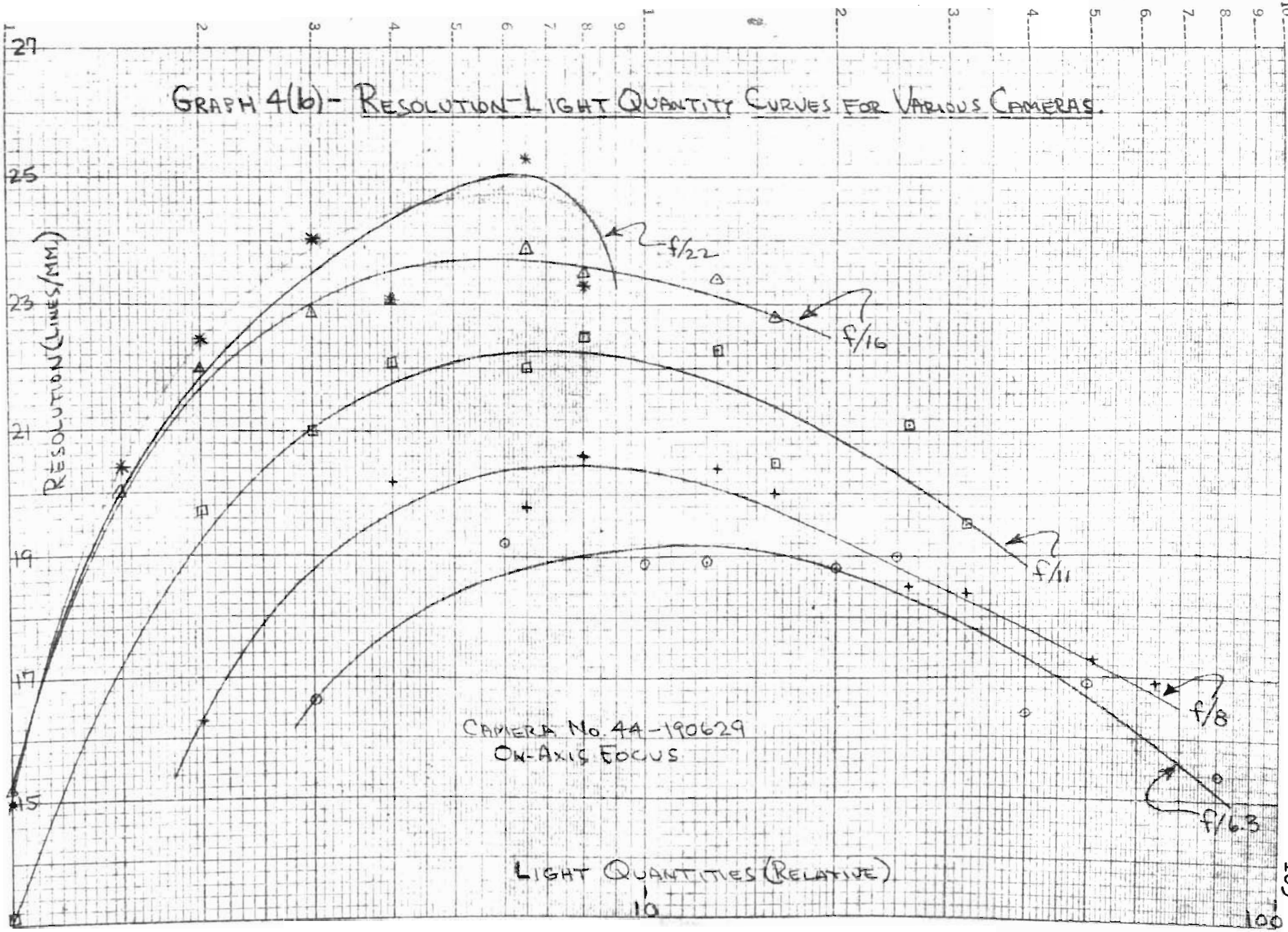

GRAPH 2- EFFECT OF LENS ASTIGMATISM AT POSITIONS ALONG DIAGONAL.
DIFFERENCES BETWEEN RADIAL & TANGENTIAL RESOLUTIONS (LINES/MM.)
+3
+2
+1
0
-1
AXIS OF EQUALITY
RADIAL RESOLUTION
TANGENTIAL RESOLUTION
TARGET POSITIONS ALONG DIAGONAL
0°
5°
10°
15°
20°
30°
40°



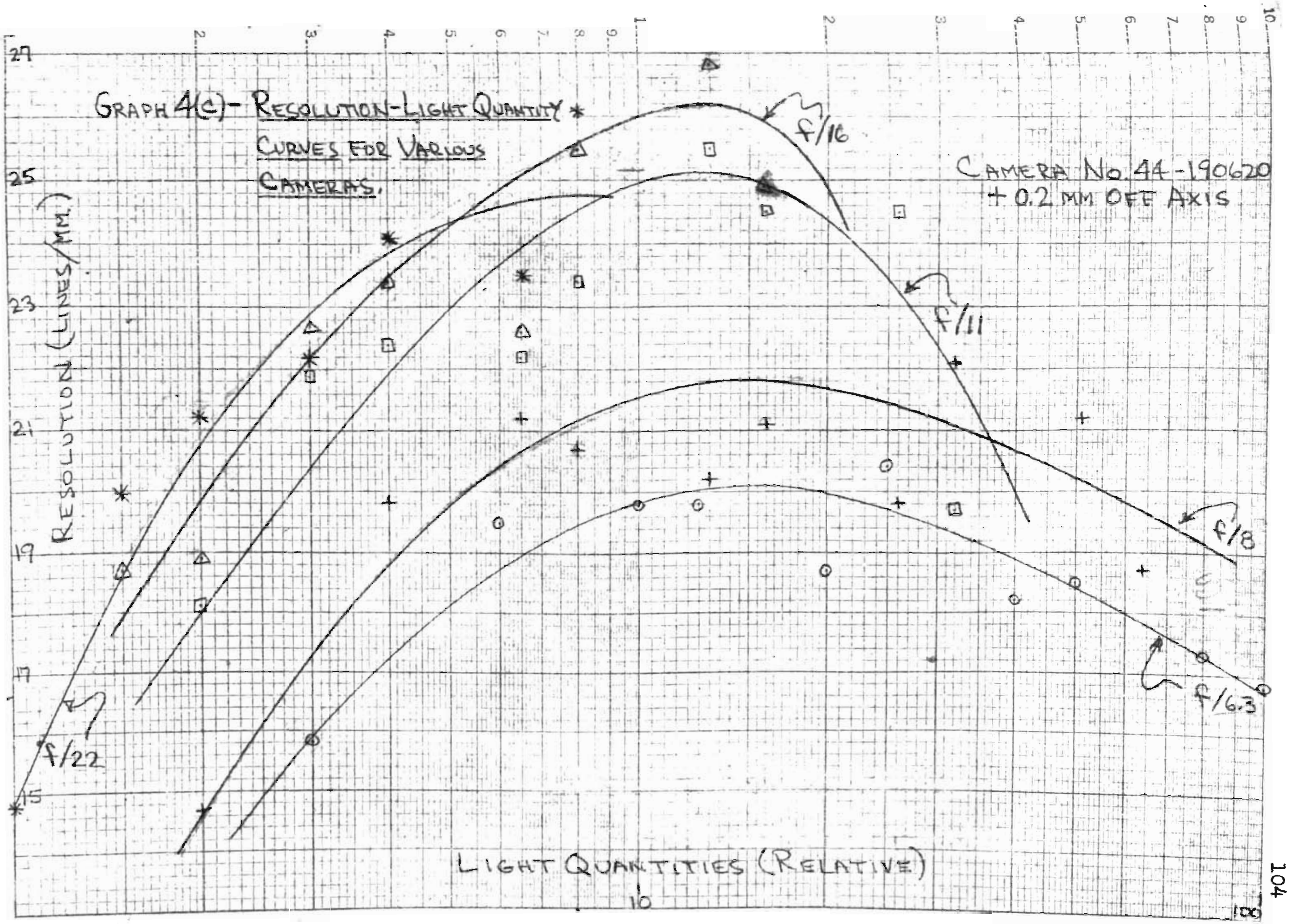
Graph 3 - Relation Between Aperture and Divergence of Radial and Tangential Resolution.
Differences Between Radial and Tangential Resolution (Lines/mm.)
4
3
2
1
0
f/22
f/16
f/11
f/8
f/6.3
2
4
6
8
10
12
14
Aperture Areas (Relative)



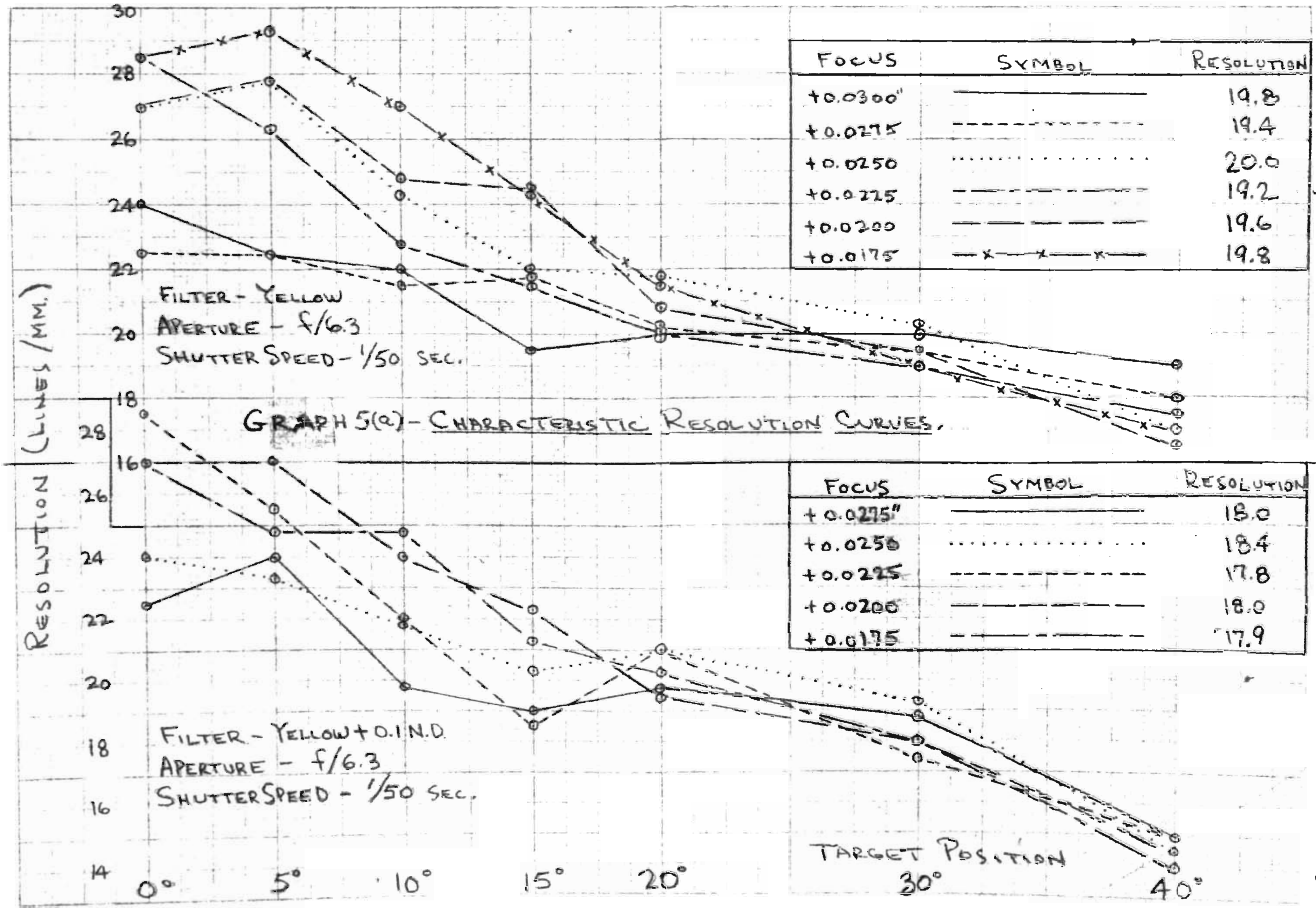
GRAPH 4(a) - RESOLUTION-LIGHT QUANTITY CURVES FOR VARIOUS CAMERAS.
f/22
f/16
f/11
f/8
f/6.3
CAMERA No. 44-187315
-0.2 MM. OFF AXIS
RESOLUTION (LINES/MM.)
LIGHT QUANTITIES (RELATIVE)



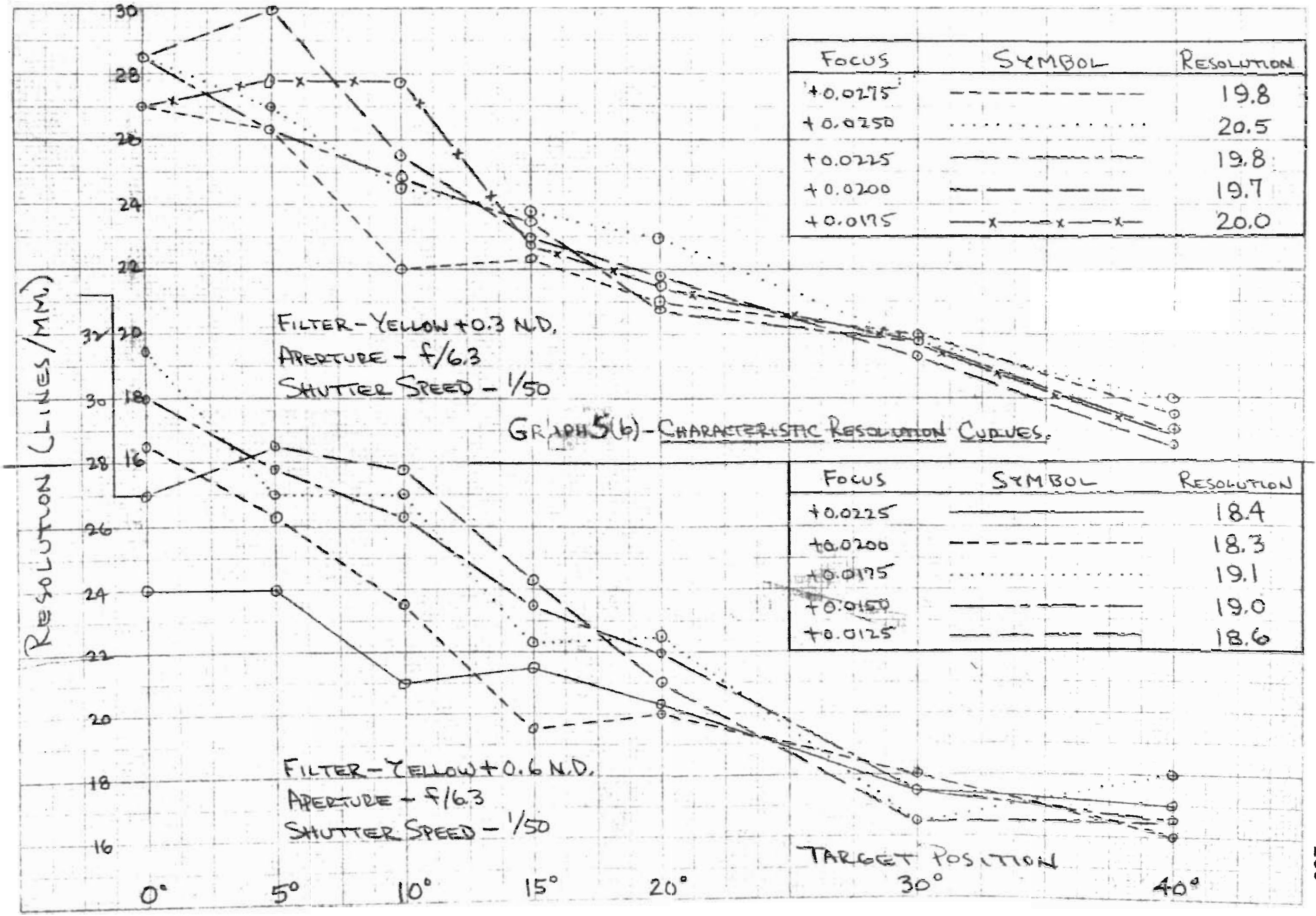
GRAPH 4(b)- RESOLUTION-LIGHT QUANTITY CURVES FOR VARIOUS CAMERAS.
RESOLUTION (LINES/MM.)
27
25
23
21
19
17
15
f/22
f/16
f/11
f/8
f/6.3
CAMERA No. 44-190629
ON-AXIS FOCUS
LIGHT QUANTITIES (RELATIVE)
10
100



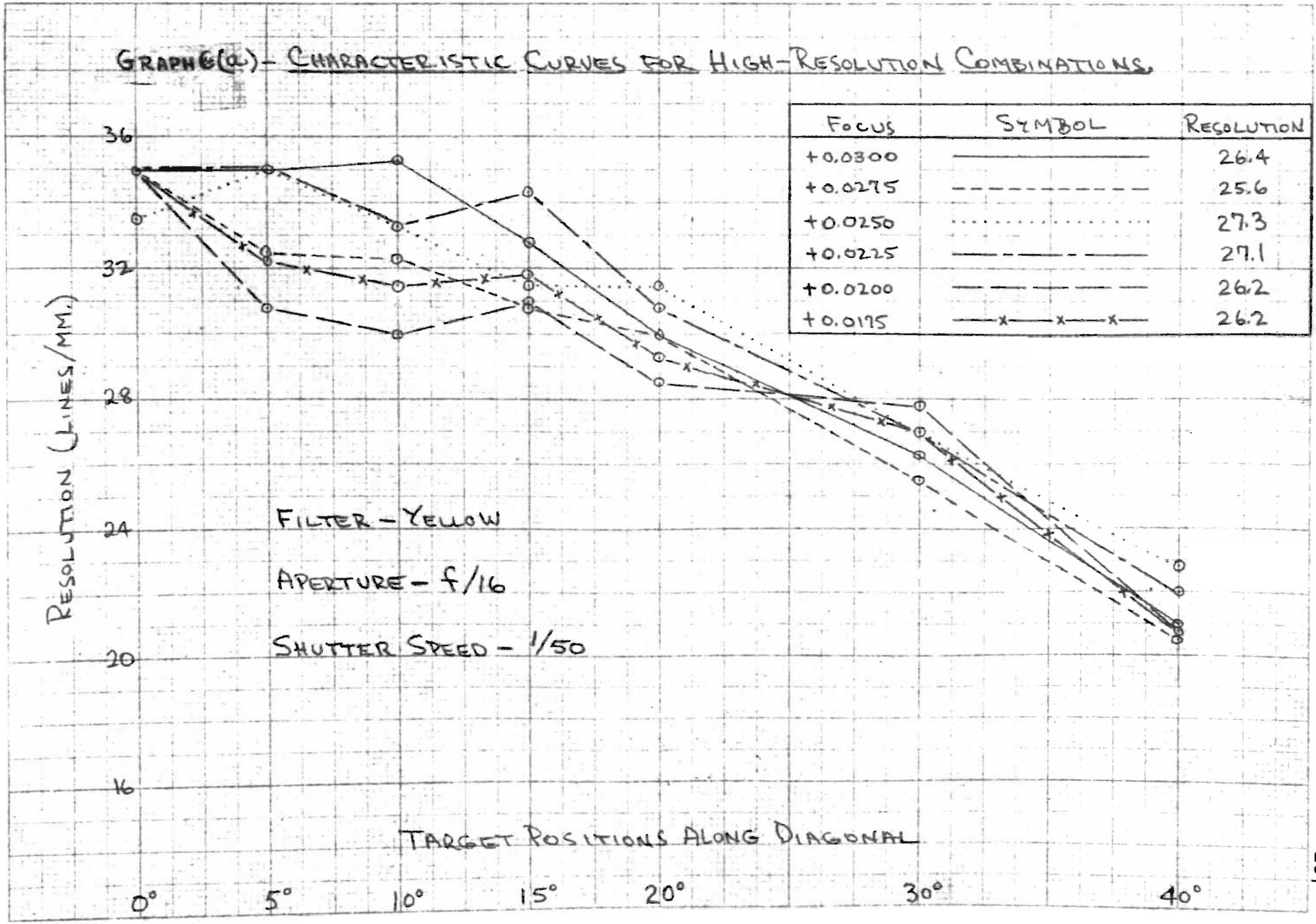
Graph 4(c) - Resolution-Light Quantity Curves for Various Cameras.
Camera No. 44-190620
+ 0.2 mm off Axis
Resolution (Lines/mm.)
Light Quantities (Relative)
f/16
f/11
f/8
f/6.3
f/22
27
25
23
21
19
17
15
1
10
100



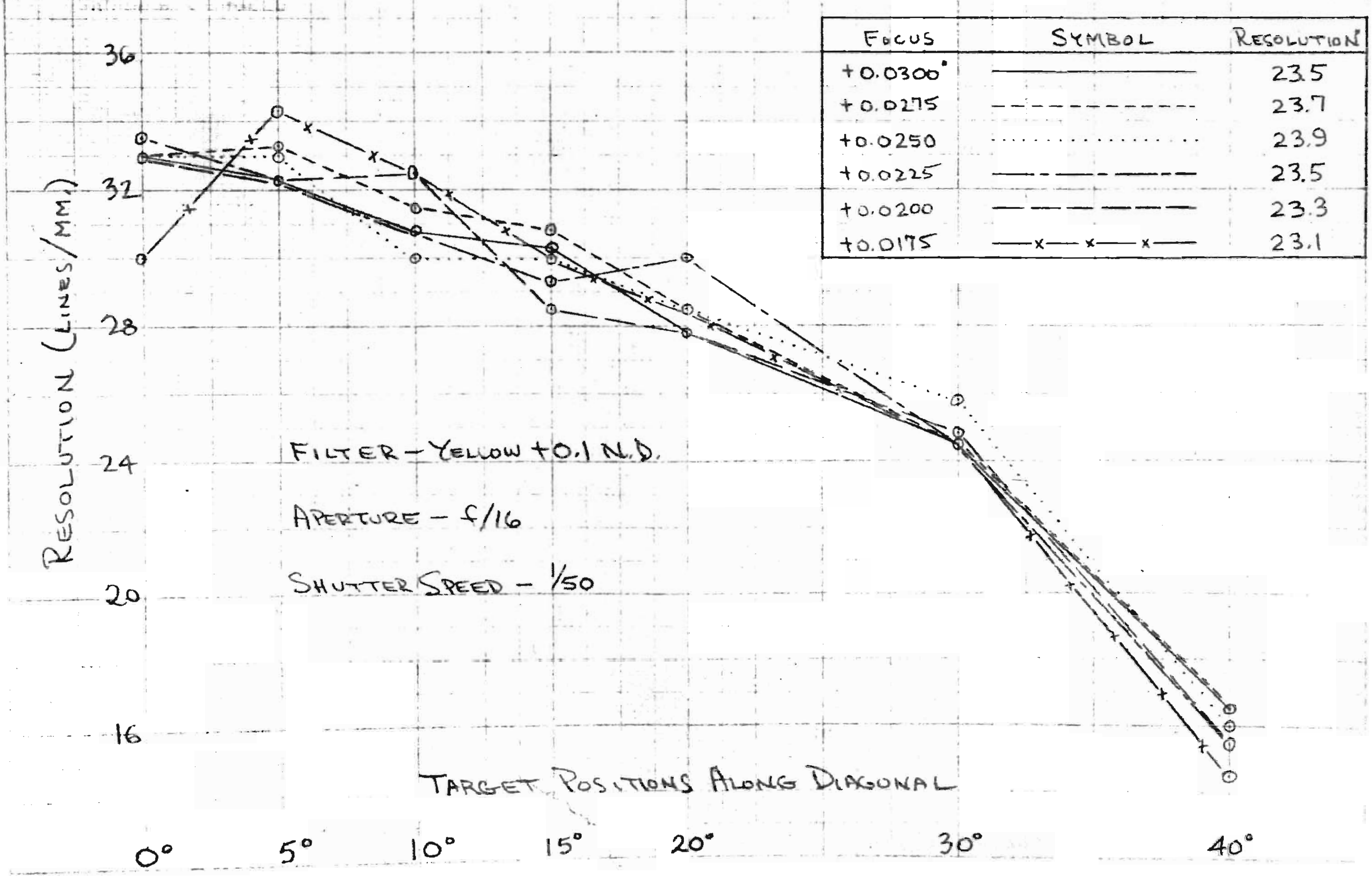
GRAPH 5(a) - CHARACTERISTIC RESOLUTION CURVES.

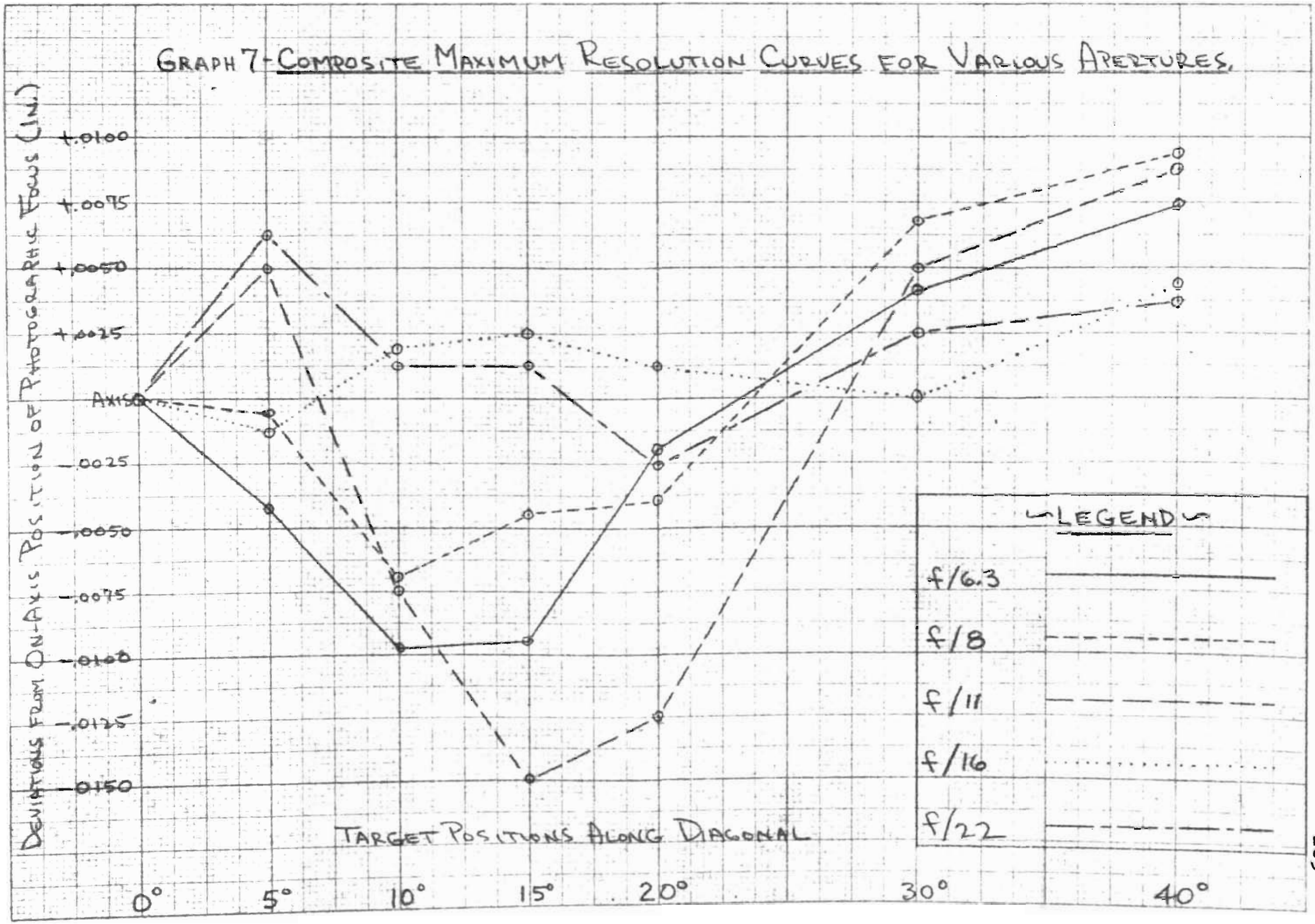


GRAPH 5(b) - CHARACTERISTIC RESOLUTION CURVES.

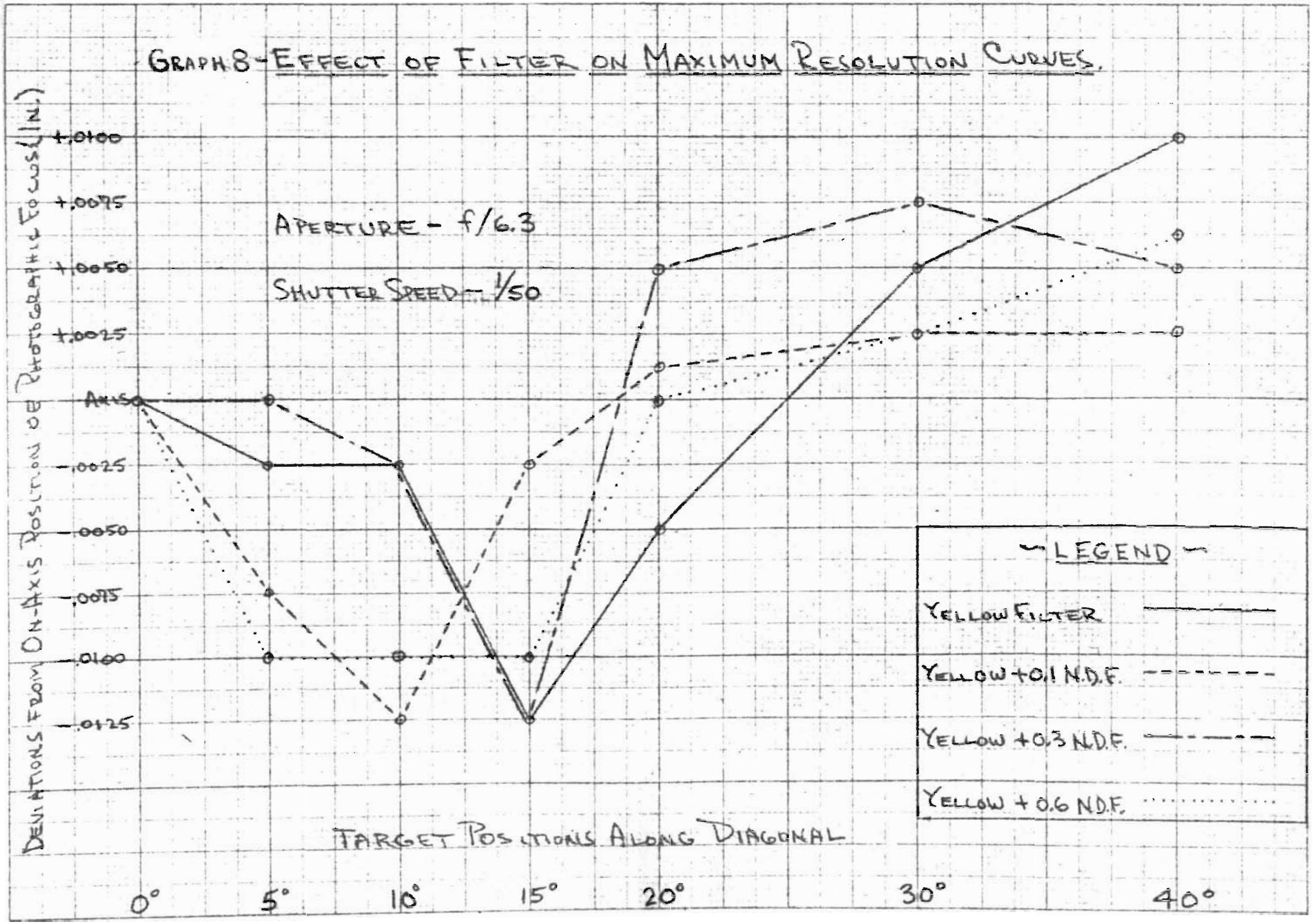

GRAPH 6(a) – CHARACTERISTIC CURVES FOR HIGH-RESOLUTION COMBINATIONS.
FOCUS | SYMBOL | RESOLUTION
+0.0300 | 26.4
+0.0275 | 25.6
+0.0250 | 27.3
+0.0225 | 27.1
+0.0200 | 26.2
+0.0175 | 26.2
FILTER – YELLOW
APERTURE – f/16
SHUTTER SPEED – 1/50
RESOLUTION (LINES/MM.)
36
32
28
24
20
16
TARGET POSITIONS ALONG DIAGONAL
0°
5°
10°
15°
20°
30°
40°

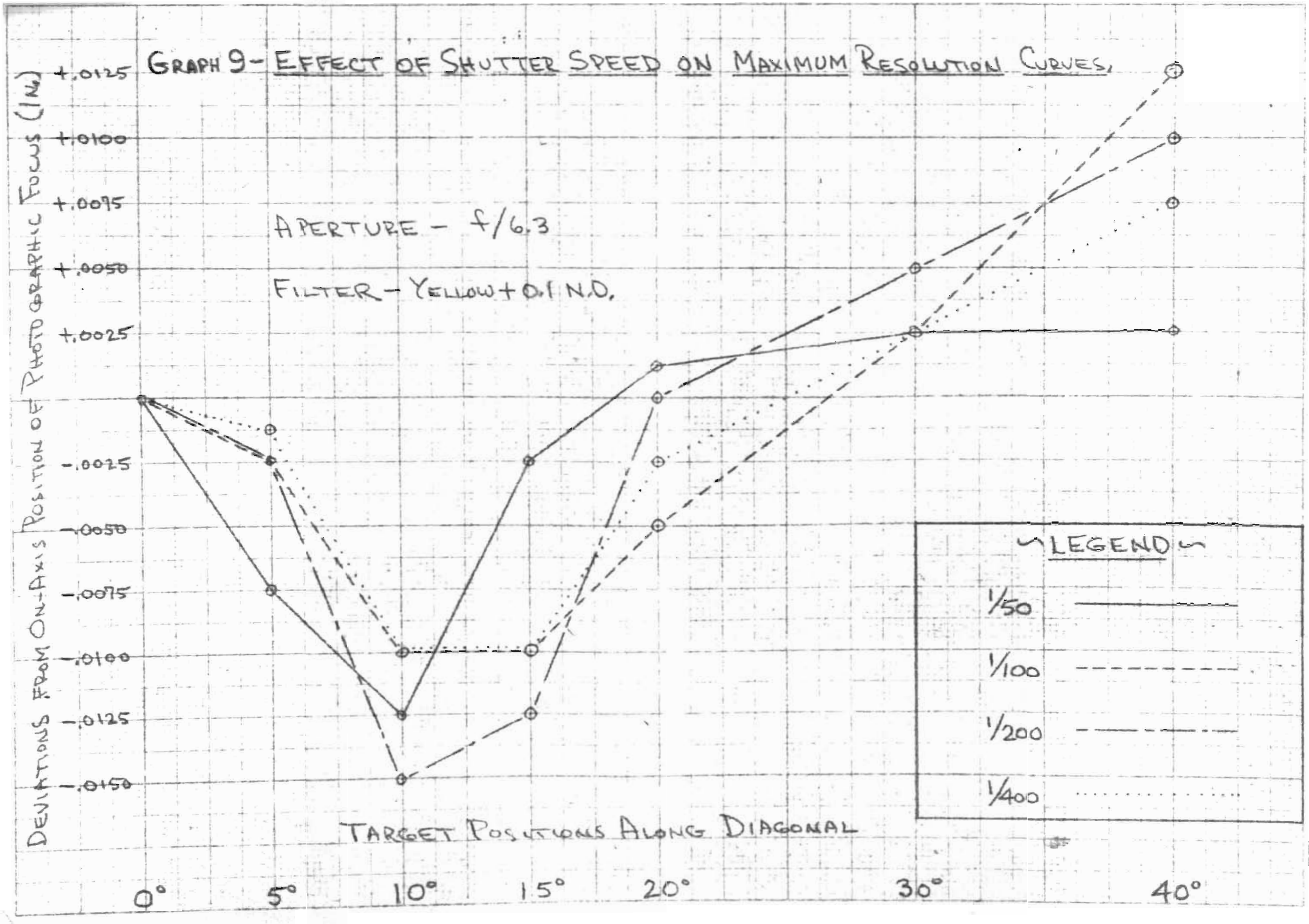
GRAPH 6(b) - CHARACTERISTIC CURVES FOR HIGH-RESOLUTION COMBINATIONS.





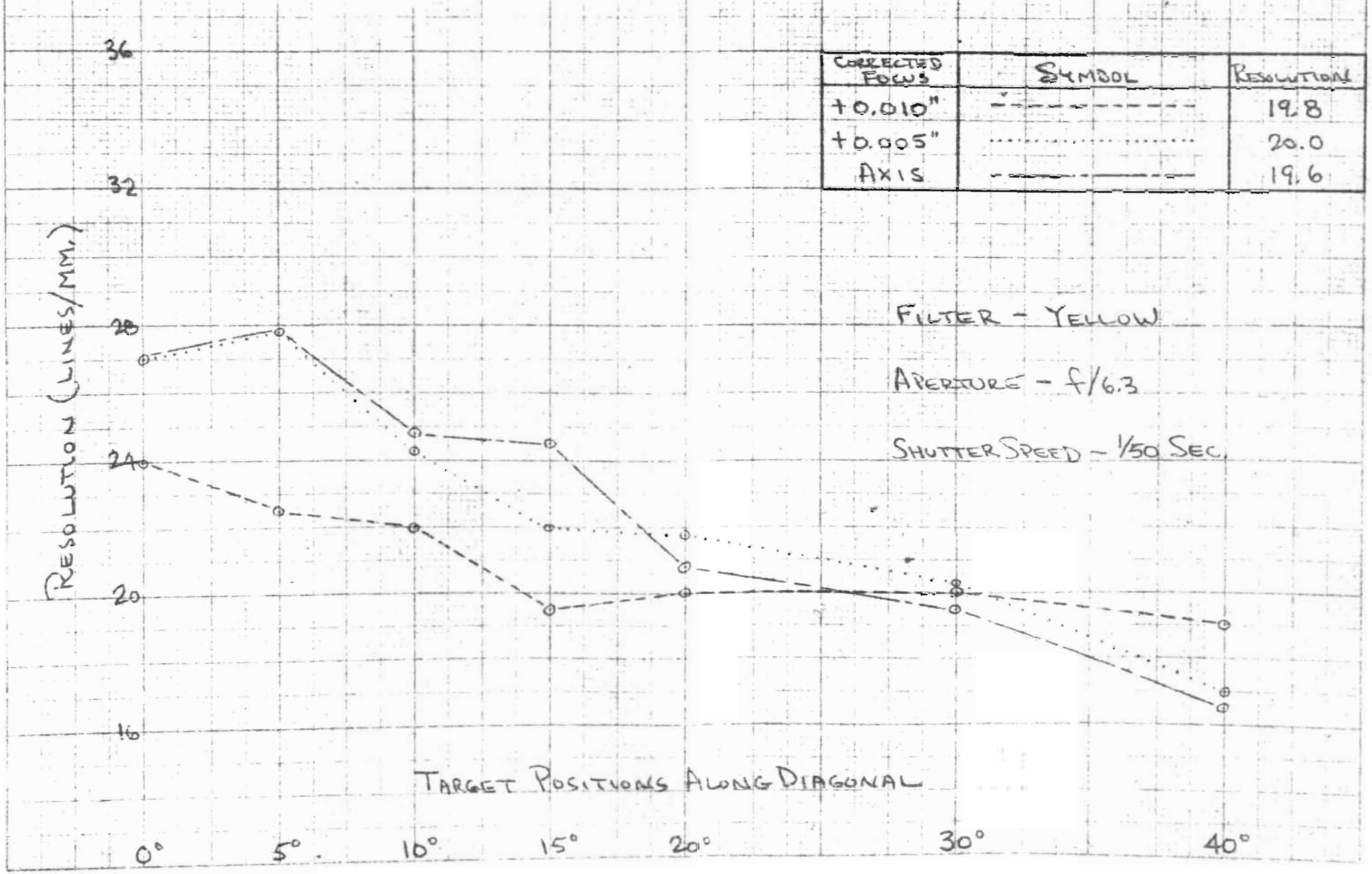
GRAPH 7 - COMPOSITE MAXIMUM RESOLUTION CURVES FOR VARIOUS APERTURES.

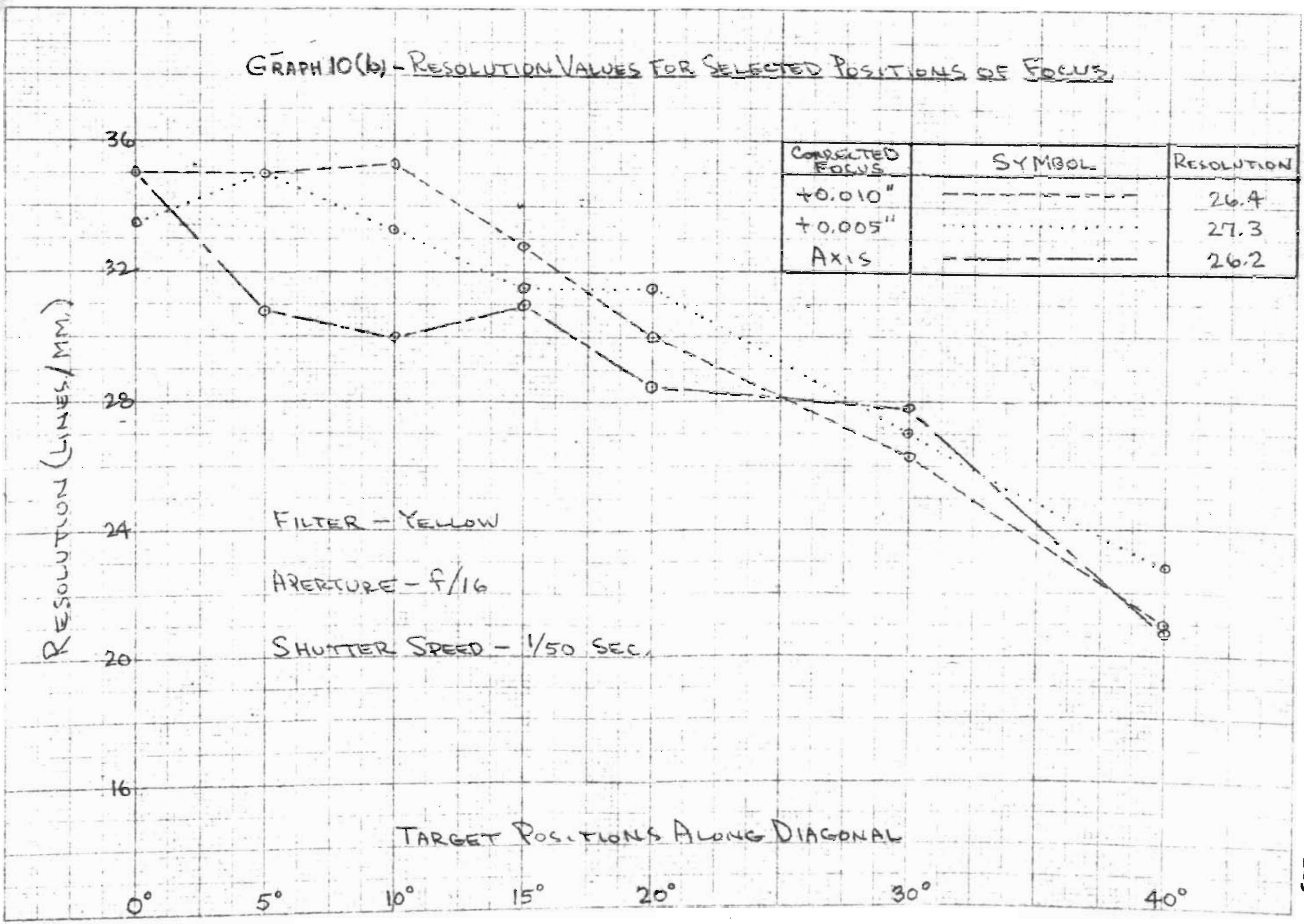

Graph 8 - Effect of Filter on Maximum Resolution Curves.
Aperture - f/6.3
Shutter Speed - 1/50
Deviations from On-Axis Position of Photographic Focus (In.)
+.0100
+.0075
+.0050
+.0025
Axis
-.0025
-.0050
-.0075
-.0100
-.0125
Target Positions Along Diagonal
0°
5°
10°
15°
20°
30°
40°
~ LEGEND ~
Yellow Filter
Yellow + 0.1 N.D.F.
Yellow + 0.3 N.D.F.
Yellow + 0.6 N.D.F.



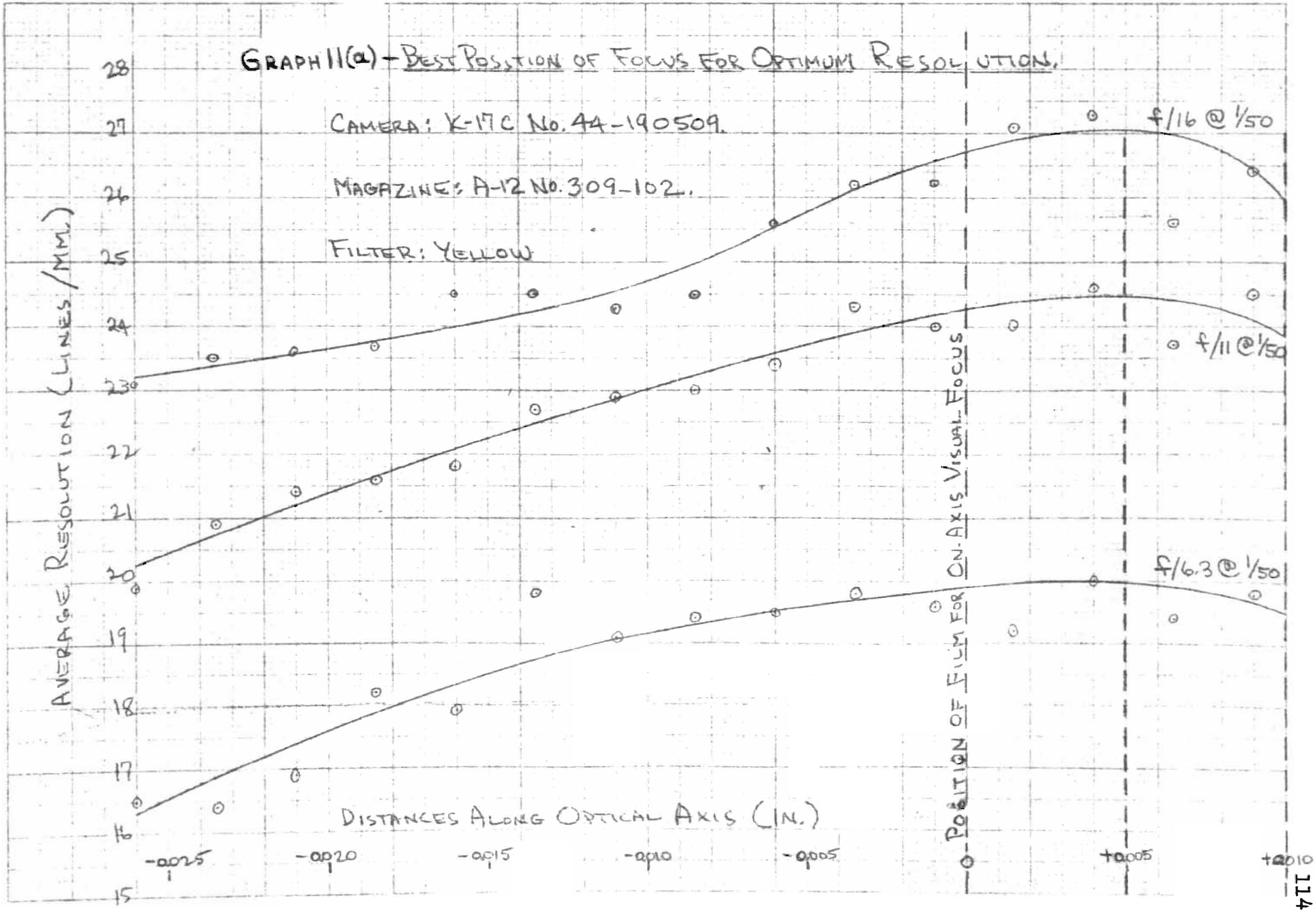
GRAPH 9 - EFFECT OF SHUTTER SPEED ON MAXIMUM RESOLUTION CURVES.
APERTURE - f/6.3
FILTER - YELLOW + 0.1 N.D.
DEVIATIONS FROM ON-AXIS POSITION OF PHOTOGRAPHIC FOCUS (IN.)
+.0125
+.0100
+.0075
+.0050
+.0025
-.0025
-.0050
-.0075
-.0100
-.0125
-.0150
TARGET POSITIONS ALONG DIAGONAL
0°
5°
10°
15°
20°
30°
40°
LEGEND
1/50
1/100
1/200
1/400

GRAPH 10(a) - RESOLUTION VALUES FOR SELECTED POSITIONS OF FOCUS.

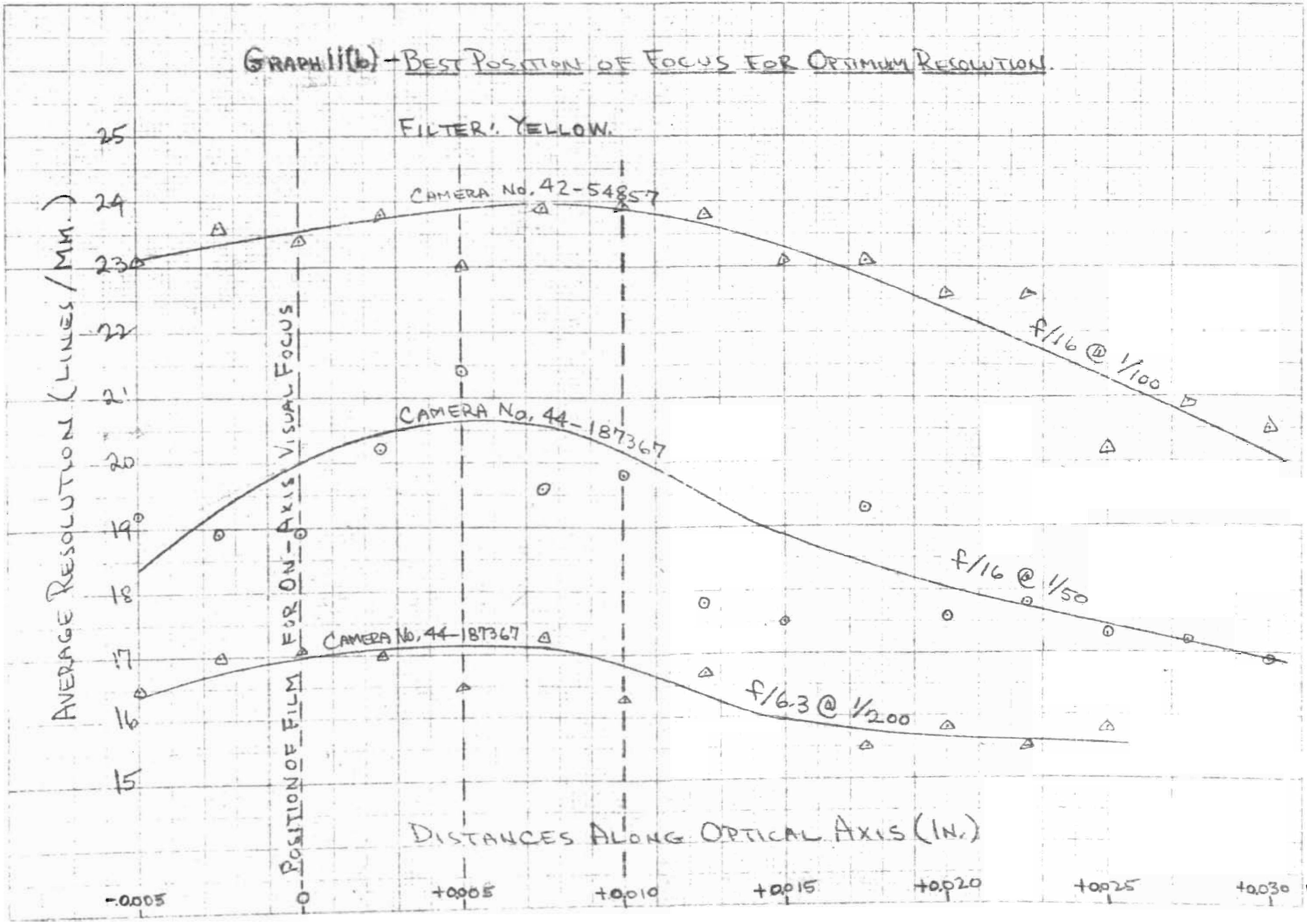




Graph 10(b) – Resolution Values for Selected Positions of Focus.



GRAPH II(a) - BEST POSITION OF FOCUS FOR OPTIMUM RESOLUTION.
CAMERA: K-17C No. 44-190509.
MAGAZINE: A-12 No. 309-102.
FILTER: YELLOW
f/16 @ 1/50
f/11 @ 1/50
f/6.3 @ 1/50
AVERAGE RESOLUTION (LINES/MM.)
POSITION OF FILM FOR ON-AXIS VISUAL FOCUS
DISTANCES ALONG OPTICAL AXIS (IN.)
28
27
26
25
24
23
22
21
20
19
18
17
16
15
-0.025
-0.020
-0.015
-0.010
-0.005
0
+0.005
+0.010



GRAPH II(b) - BEST POSITION OF FOCUS FOR OPTIMUM RESOLUTION.
FILTER: YELLOW.
CAMERA No. 42-54857
f/16 @ 1/100
CAMERA No. 44-187367
f/16 @ 1/50
CAMERA No. 44-187367
f/6.3 @ 1/200
POSITION OF FILM FOR ON-AXIS VISUAL FOCUS
AVERAGE RESOLUTION (LINES/MM.)
25
24
23
22
21
20
19
18
17
16
15
DISTANCES ALONG OPTICAL AXIS (IN.)
-0.005
0
+0.005
+0.010
+0.015
+0.020
+0.025
+0.030

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2. Pestrecov, Dr. K. Resolving power of photographic lenses. Photogrammetric Engineering, Vol. XIII, No. 1, March, 1947, pp. 64-85.

VITA

Robert Greig Livingston was born on May 17, 1914, at DeCamp, Mo., the son of Dr. and Mrs. Archibald A. Livingston. His early education was received in the public schools of Jefferson and St. Louis Counties, Missouri. He entered the Missouri School of Mines and Metallurgy in 1935, and graduated in May, 1939, with a Bachelor of Science degree in Civil Engineering.

Upon graduation, he accepted employment with the St. Louis Southwestern Railway Company. For almost two years, he worked under the division engineer of the railroad at Pine Bluff, Ark.

Early in 1941, he entered active military service as a second lieutenant with the 30th Engineer Topographic Battalion, at Fort Belvoir, Va. In the course of the next two years with this unit he became one of the company commanders.

He then activated and took overseas Headquarters Company, 660th Engineer Topographic Battalion. For the next 2 1/2 years, he was engaged in mapping operations with this unit in the European Theater, and finally was separated from the Army after five years of service.

Shortly after his return from overseas, he entered Missouri School of Mines for graduate work in Photogrammetry; he received his Master of Science degree in Civil Engineering in June, 1947.

He immediately entered Iowa State College for an additional year of graduate work. During this time, he assumed part-time teaching duty in the Department of Civil Engineering.

In June, 1948, he accepted a position for the summer term as Instructor of Photogrammetry in the College of Aeronautics, University of Southern California.

Upon completion of this work, he entered government service with the Corps of Engineers as a research photogrammetrist and assistant branch chief in the Aerial Photographic Branch, Engineer Research and Development Laboratories, Wright-Patterson Air Force Base, Dayton, Ohio.