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STUDY OF FOCUSING AID TECHNIQUES

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TABLE OF CONTENTS

LIST OF FIGURES

SECTION 1
INTRODUCTION

The study of focusing aid techniques was conducted to evaluate the performance and convenience of the split image, projection, and ground glass techniques used for focusing oscilloscope cameras. Specifically, the study was intended (1) to determine the usefulness of projection-type focusing aid devices now used on EG&G Type 3171 cameras, (2) to lead to recommendations for the most satisfactory device for use with the new LC-4 type camera, and (3) to evaluate the usefulness of such devices for production-line focusing of EG&G Type 850 cameras.

The study included a brief theoretical evaluation of each focusing method and a statistical determination of actual performance. The primary tests were made using a simulated oscilloscope trace to insure reproducibility. Comparisons of the results were made on a Tektronix oscilloscope to confirm validity of the trace simulation. Most of the tests were made with an LC-4 camera because the Nikon lens used in the LC-4 camera will be used in future 3171 cameras. A few experiments were conducted to confirm the correctness of applying the LC-4 camera results to unmodified 3171 cameras.

A special split image focusing aid developed at Lawrence Radiation Laboratory (LRL) for the LC-4 camera was used in the split image technique, and a type of focusing aid now commonly used with 3171 cameras was used in the projection technique. The ground glass technique was based on a method commonly used in optical work for critical focusing.

Data were accumulated for each focusing technique, for different operators, and under different conditions so that reasonable statistical validity could be obtained. In the basic experiment, the operator used a focusing aid to set the camera focus and repeatedly refocused the camera to achieve the best focus. The statistically analyzed results were then compared with focus criteria established for various films. In addition, the relative convenience of each technique was evaluated by the operators, and overall conclusions were drawn based on both the performance and the convenience of the techniques.

Section 2 includes a discussion of the techniques and criteria for acceptable focus. The experimental data are presented in Section 3. Section 4 contains a general comparison of techniques. Overall conclusions and recommendations are summarized in Section 5.

2.1 CRITERIA FOR FOCUS

In order to establish the criteria for adequate focus for a particular camera, it is necessary to consider the resolution of the lens and the film and the degrading effect on the resolution caused by axial motion of the lens from the position of best resolution. For any particular lens, fine-grained, high-resolution film will demand the best lens focus, but it is not necessary to require focusing accuracy capable of obtaining one hundred lines per mm resolution from a particular lens if the film used is limited to twenty to thirty lines per mm resolution.

During the development of the LC-4 camera, a series of tests was made of the optical characteristics of the Nikon f/1.2 lens used in the LC-4 camera and the Wray and Wollensak f/1.0 lenses used in the 3171 cameras. The results are summarized in EG&G Reports B-2911 and B-2912 and Technical Memo B-480.

The applicable results of these tests are plotted in Fig. 1 for the Nikon lens as used with Kodak microfile film and plates. The plot shows resolution at the center of the field as a function of lens displacement from best focus position for demagnifications between 3.8 and 4.2. Resolution versus depth of field as given in Equation 6 of NBS Circular 533 is also plotted on the graph for comparison.

The maximum resolving powers obtainable on typical films used with the Nikon lens are taken from EG&G Tech Memo B-480. These powers are plotted in Fig. 1. Comparison of the best obtainable resolution of the various films with the general trend of resolution degradation caused by defocusing allows establishment of approximate criteria for adequate focus (see Table 1).

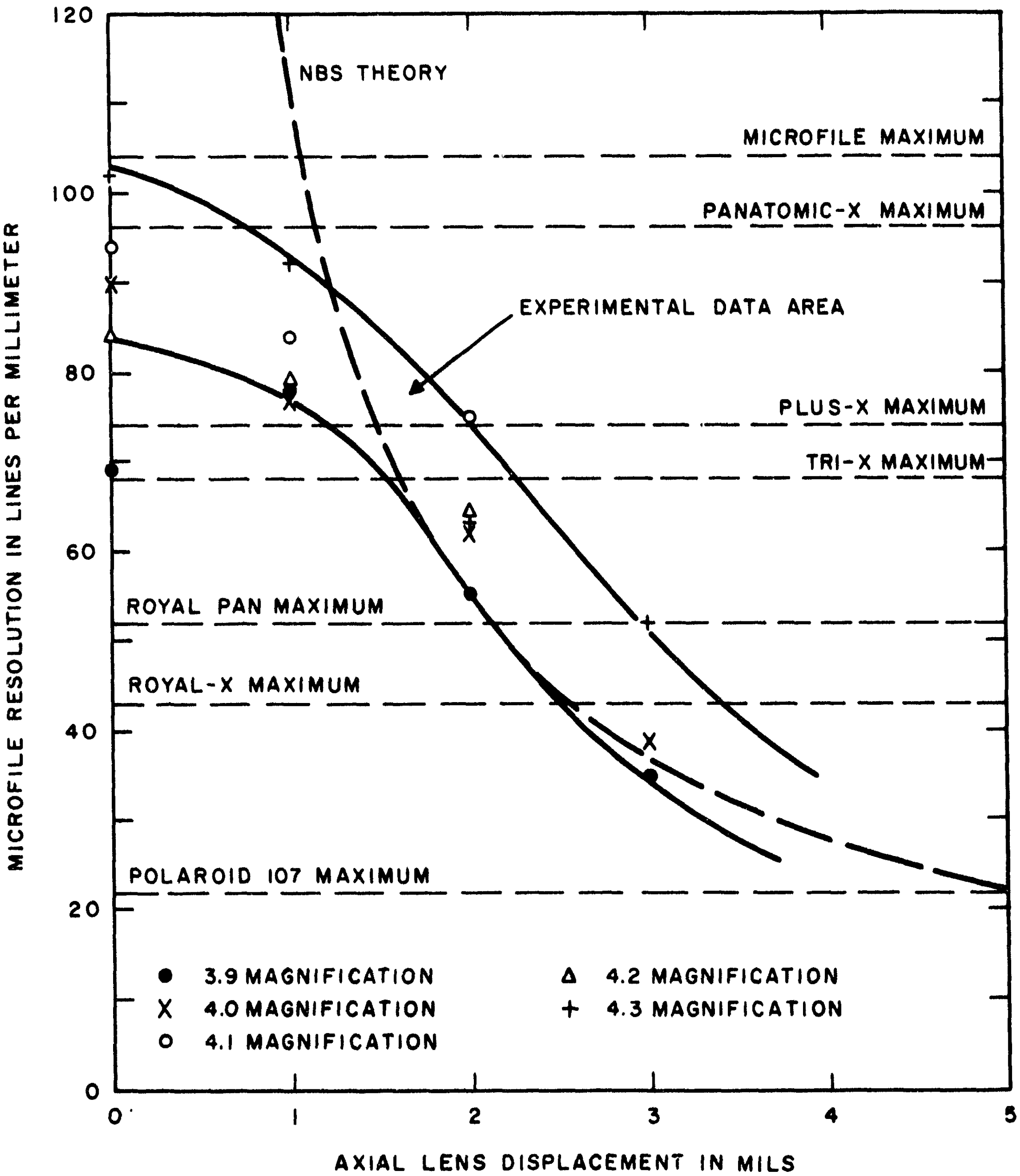


Fig. 1. Measured effect on resolution of LC-4 lens motion-related to maximum resolution of various films.

Table 1. Tolerance in axial lens deviation from position of highest resolution.

Film Type	Tolerance (inch)
Microfile	±0.0005
Panatomic-X	±0.0005
Plus-X	±0.001
Tri-X	±0.001
Royal Pan	±0.002
Royal-X Pan	±0.0025
Polaroid 107	±0.004

2.2 SPLIT IMAGE FOCUSING AID

The split image focusing aid, as designed at LRL, is shown schematically in Fig. 2 and in the photographs of Fig. 3. The prism assembly is made up of two wedge-type prisms cut from a single Bausch and Lomb PR-5-250 prism. Each prism deviates the light path by approximately 14°.

In use, the prism assembly position is adjusted so that the point of intersection of the two prisms lies exactly in the film plane of the camera. The intersection is marked by a deposited metal line across the faces of both individual prisms. If the camera is properly focused, the oscilloscope trace image lies at the prism surface and is undeviated as seen by the observer. If the image is inside or outside of the correct focus position, the observer will see a displacement of the image caused by the deviation of the prism. The portion of the image seen through one prism will be displaced in the opposite direction from the portion seen through the other prism. If a horizontal trace is observed on the oscilloscope, then the observer will see an image made up of two separated line segments. Correct focus is obtained when the camera is adjusted to bring the two line segments together.

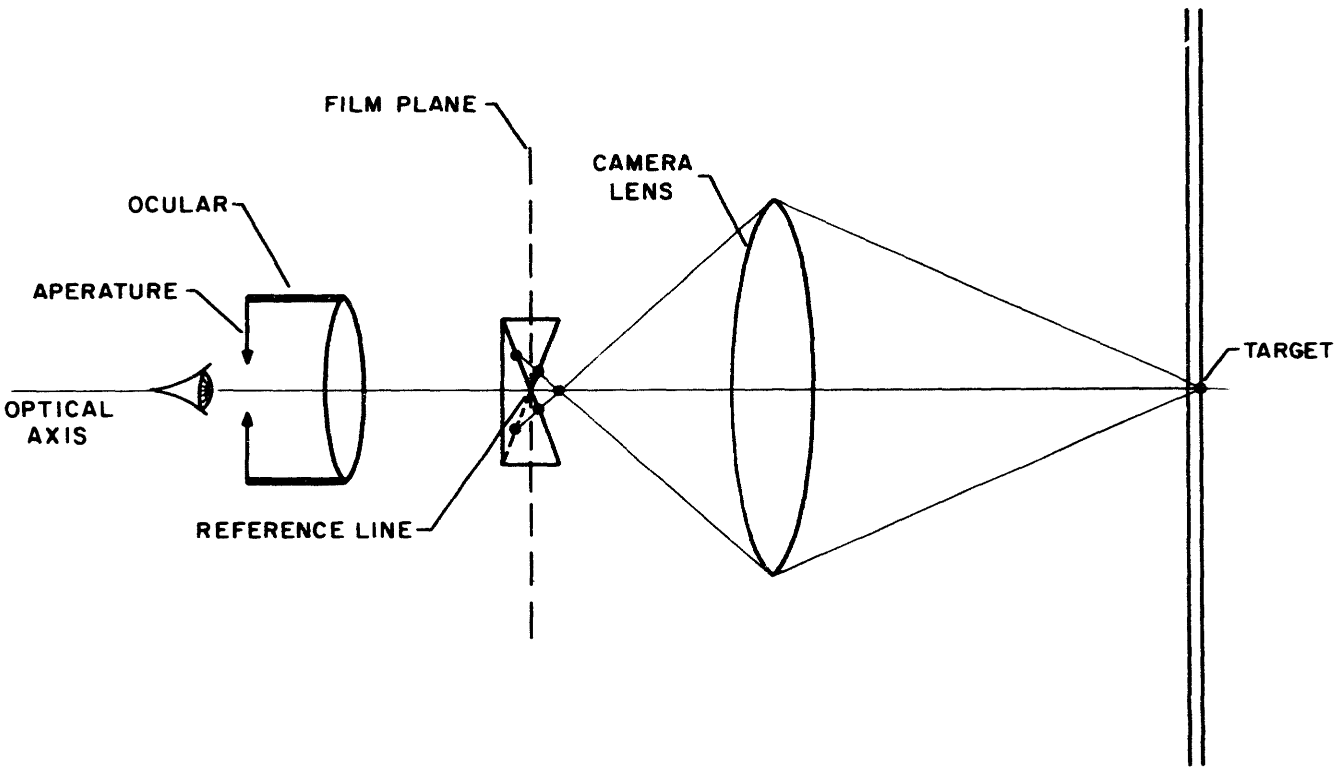


Fig. 2. Optical arrangement of split image focusing aid.

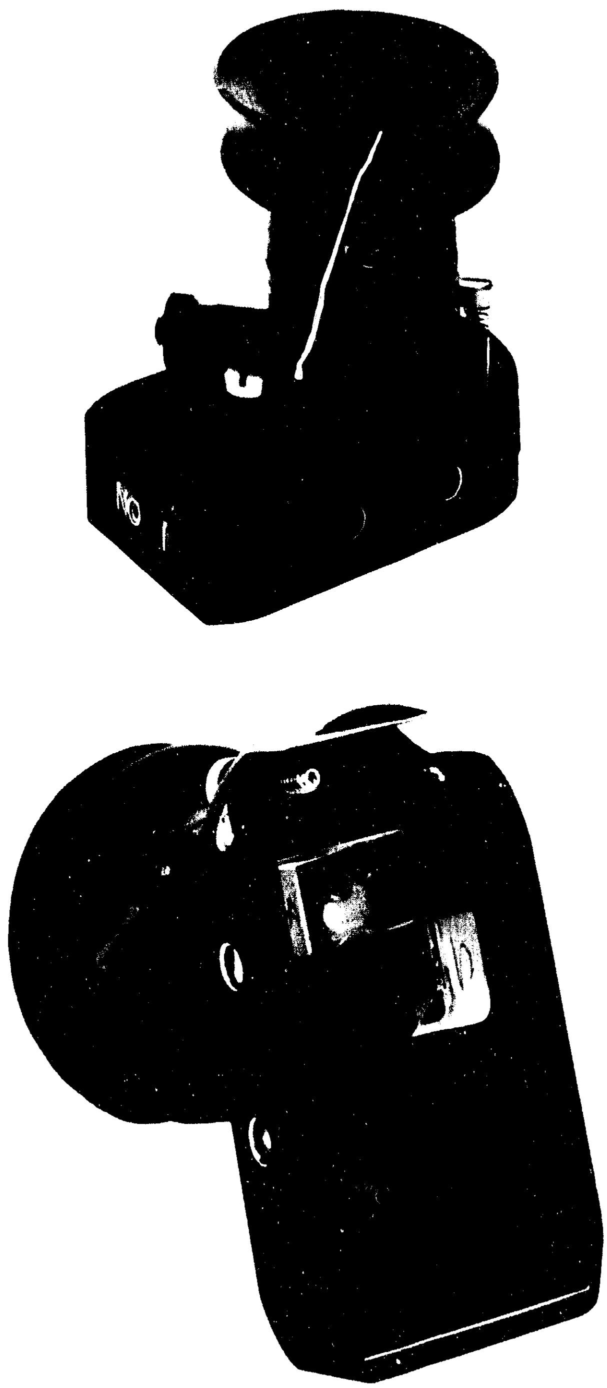


Fig. 3. Split image focusing aid.

The apparent deviation (d) at the image plane will be proportional to the tangent of the prism deviation angle and the displacement of the image from correct focus (y). In the present focusing aid, the displacement of each image is:

$$d = y \tan 14^{\circ} = y\ 0.249.$$

In the tests, the camera gave a demagnification of approximately 4.33, so the apparent deviation of each image in terms of oscilloscope face dimensions is:

$$d_{scope} = 4.33\ y\ 0.249 = 1.10\ y.$$

For a horizontal line, the apparent separation of the two lines (in terms of oscilloscope face dimensions) is therefore:

$$s = 2.20\ y.$$

With the 15-mm focal length ocular, the apparent angular line separation of the two lines, as seen by the observer, is approximately:

$$\alpha = 2.8\,y \text{ minutes of angle,}$$

where y is lens displacement in thousandths of an inch.
Assuming a best visual resolution of one minute of angle, this relation indicates an approximate best focus accuracy of about 0.00035 in.

If the horizontal line on the oscilloscope face is 0.010 in. thick, a focus displacement (y) of 0.0005 in. will cause an apparent separation of the two halves of the image by

$$s = 2.20\ (0.0005) = 0.0011 \text{ in.}$$

This is about one-tenth of the thickness of the line and should just be detectable if the line has sharp edges.

For maximum image deviation, the prism deviation should be as great as possible within the limits of the lens cone angle. The present 14^{o} deviation prisms have a deviation as large as can be used with the Nikon f/1.2 lens at a nominal demagnification of 4.0.

2.3 PROJECTION FOCUSING AID

The film plane projection focusing aid (PH-2), shown in Figs. 4 and 5, uses a line-type resolution target placed in the camera film plane. The target is diffusely illuminated from behind, and the camera lens projects an enlarged image of the target on the oscilloscope face. The operator views the image through the camera viewing port and adjusts the focus until the line pattern appears sharp. Line targets presently used are standard NBS resolution charts (opaque lines on a clear background). During the tests it was noted that much better results were obtained by using targets with clear lines on an opaque background; consequently, this type of target was used throughout the remaining tests.

During the evaluation it was noted that the images formed by the standard battery-operated focusing aid were excessively dim and hard to see. Additional measurements were therefore made with a higher intensity illuminator behind the diffuser.

To establish the theoretical limitations of the projection focusing aid, an experiment was conducted to determine the limit of visual acuity for a well-illuminated NBS target at the 11-1/2 in. eye-to-screen distance required by the 3171-type camera. A typical limit of 8.66 l/mm (just resolvable at the scope face) was established based on the average of the eight observers. This limit corresponds to about 1.35 minutes of arc per line pair, which is in reasonable agreement with the commonly accepted value of 1 minute of arc.

If the observer could visually resolve to 8.66 l/mm at the screen,

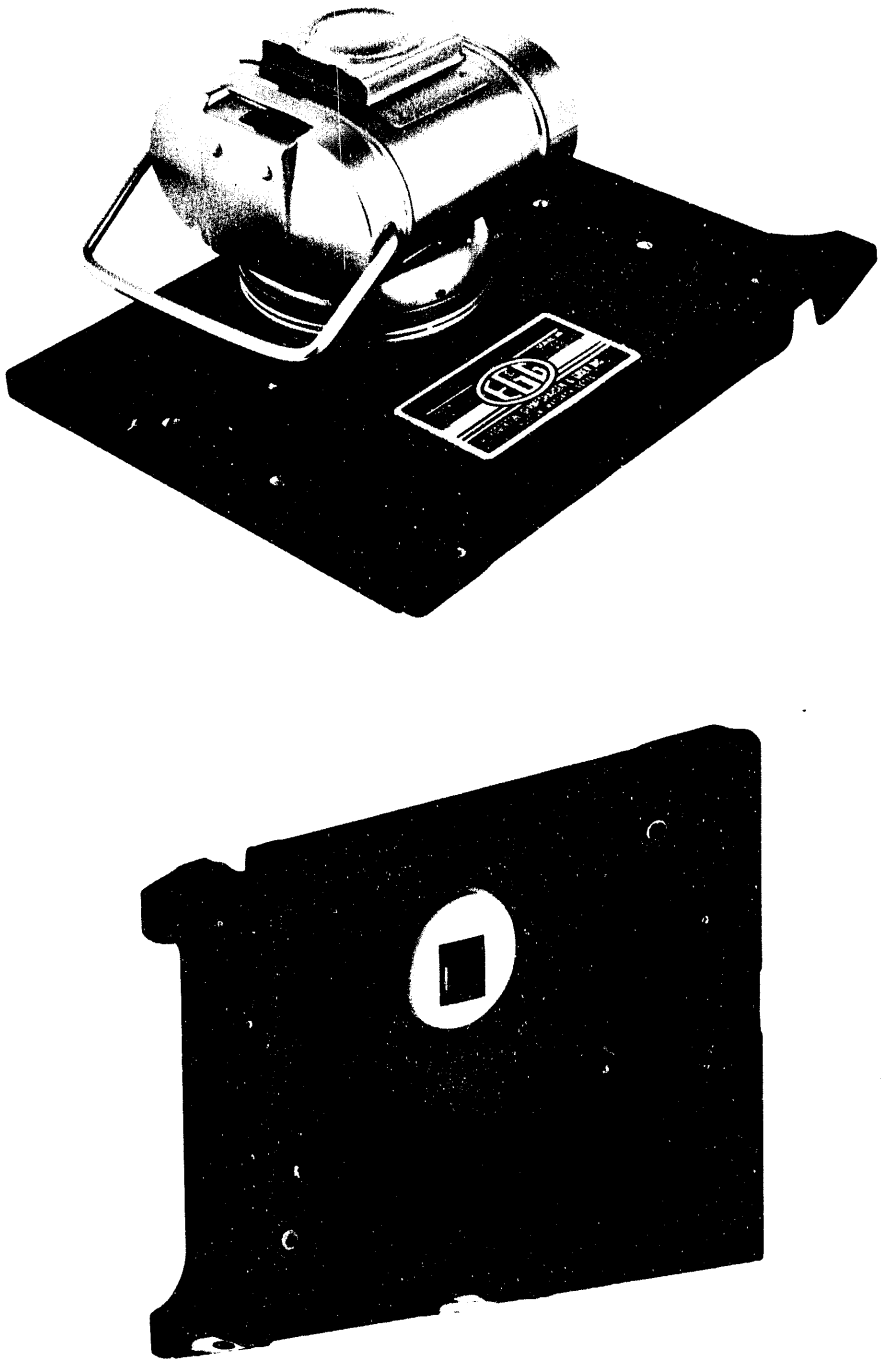


Fig. 4. Projection focusing aid.

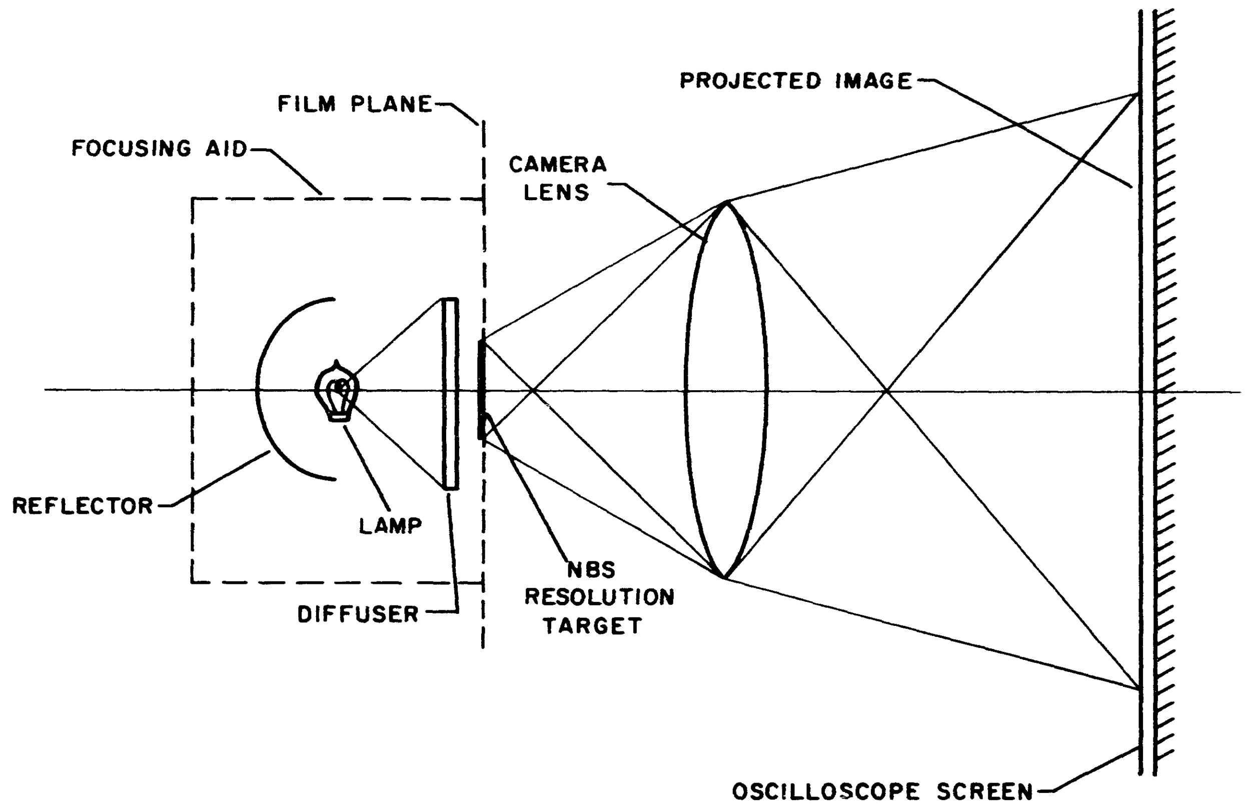


Fig. 5. Optical arrangement of the film plane projection focusing aid.

this would correspond to 34.6 l/mm at the film (for a 4:1 camera demagnification). By the criteria of Fig. 1, this would imply a focusing accuracy of about ±0.003 inch.

2.4 GROUND GLASS FOCUSING

The ground glass focusing tests were performed by placing a finely etched glass surface at the camera film plane and examining the image with a 20-power microscope. The camera focus was adjusted until the sharpest possible image was obtained. This is a standard technique which requires careful attention to the focus of the eye to prevent viewing of an aerial image rather than an image which is actually on the ground glass surface.

Because of the difficulty attendant in proper eye focusing, the ground glass method was included for comparison as a standard optical laboratory technique rather than as a field technique.

2.5 TEST TARGET

To avoid the variability of an actual oscilloscope trace, most of the tests were conducted with a simulated trace produced by a special test target as shown in Fig. 6. The basic line was produced by diffuse back illumination of 0.002 in. wide clear lines on an opaque aluminized surface. The center horizontal line was used for all tests. A piece of vellum paper (0.002 in. thick) was placed over the grid lines to diffuse the image slightly and to simulate a phosphor surface for the projection focusing test. A cover glass was placed over the vellum paper to hold it in place and to simulate the glass of an oscilloscope faceplate.

The target assembly was placed in a test jig which was suitable for mounting both the LC-4 and 3171 cameras.

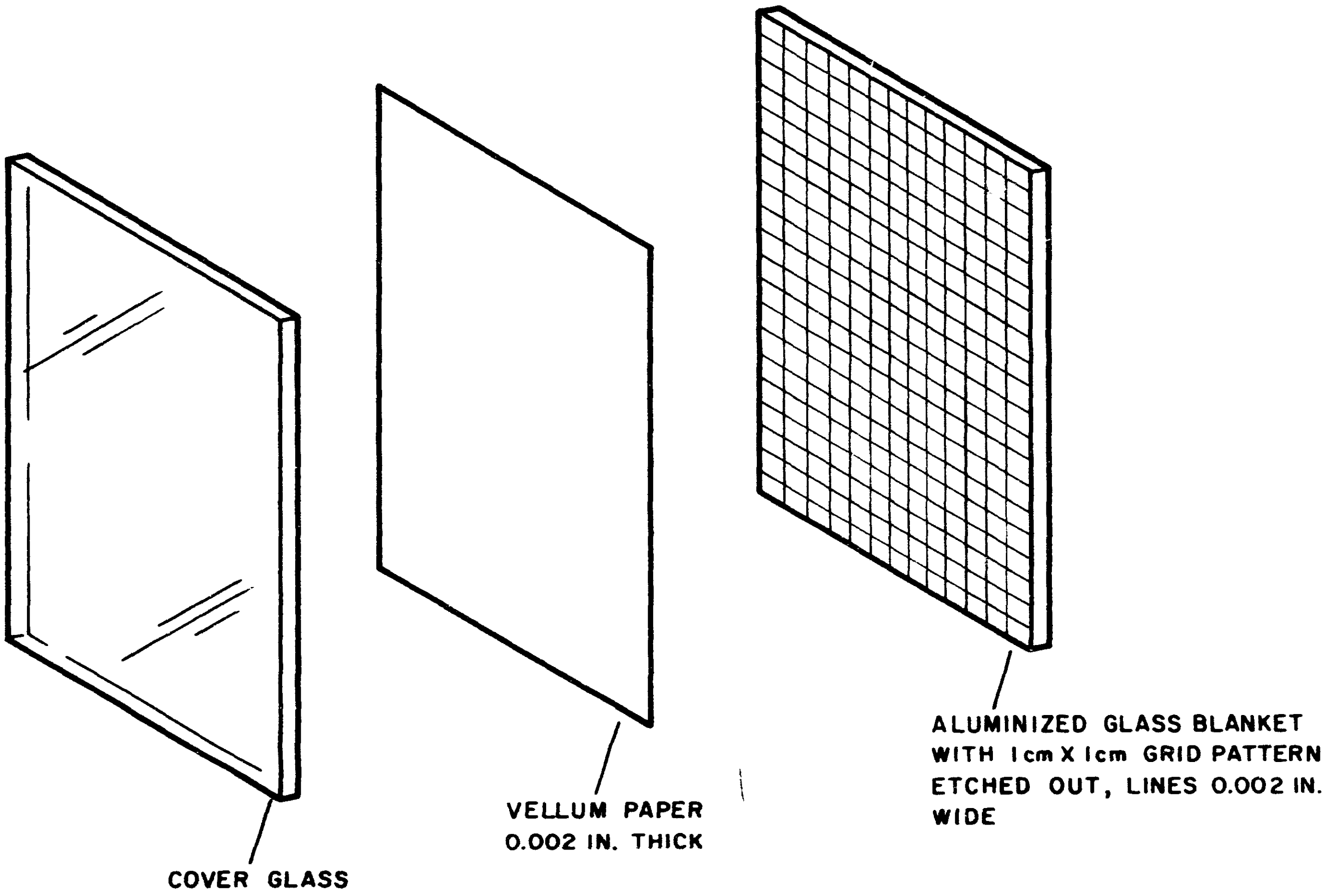


Fig. 6. Focusing test target assembly.

SECTION 3
EXPERIMENTAL DATA

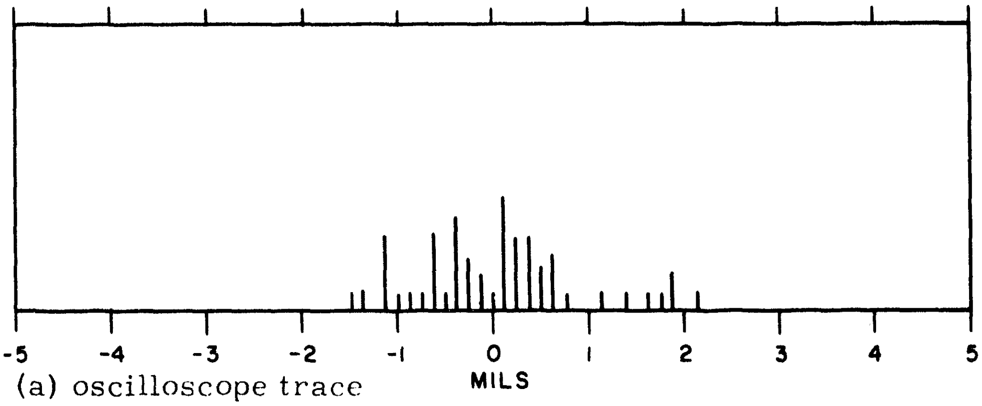
The experimental data obtained under each set of conditions are presented in two forms. One form is based on the performance of the individual operator; the second form illustrates the overall distribution of readings. The focus parameter used is the axial deviation of the lens in units of 0.001 in. as calculated from the camera focus dial reading. The performance of the individual operator is evaluated by the standard and maximum deviations of his readings referenced to a zero point. The zero point is based on the mean of all operator readings taken with that particular setup. The second form is a plot of each reading as a deviation from the same zero point, combining the data taken by all operators. Time limitations on the scope of this study prevented detailed comparison with the setting for best photographic focus, but it seems reasonable to assume that any of the focusing aids can be adjusted to give correct photographic focus.

3.1 PRELIMINARY USE OF THE SPLIT IMAGE FOCUSING AID

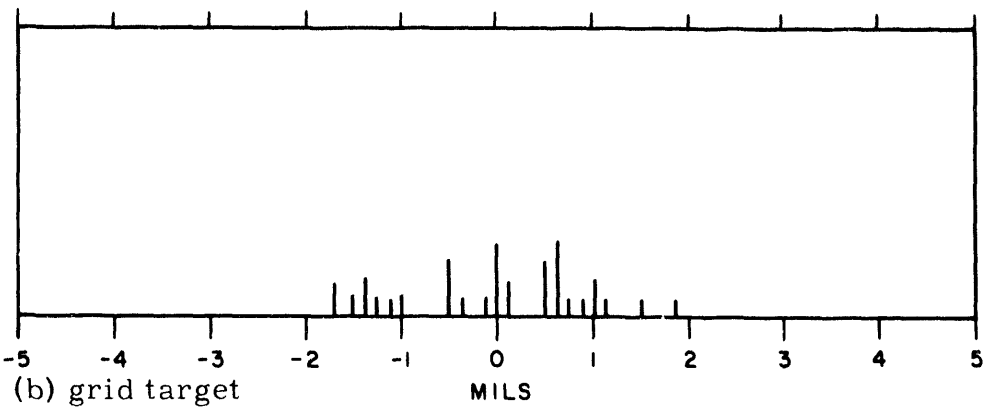
Since the split image focusing aid is a newly developed device, it was considered necessary to perform preliminary tests to study operating procedures and locate possible problem areas. The combined results of these preliminary tests are illustrated in Fig. 7.

The top set of data shows the reading deviations obtained using a well-focused Tektronix oscilloscope. The middle set shows a similar run made with the test target. Four operators were used in each case. From these tests there appeared to be no significant difference in focusing for the grid line target as compared to the well-focused oscilloscope trace. To avoid the variability of the oscilloscope trace, the grid line test target was used for the remainder of the measurements.

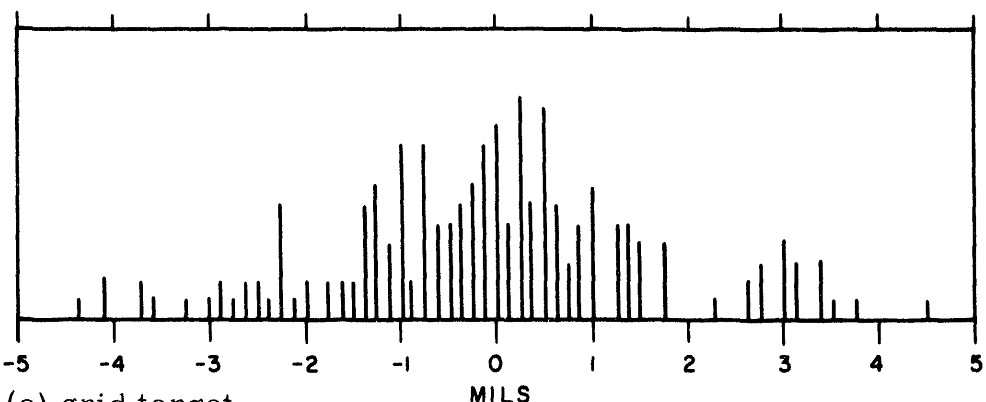
The third set of measurements illustrated in Fig. 7 shows the reading deviations obtained using the grid line target in a large scale



(a) oscilloscope trace



(b) grid target



(c) grid target

Fig. 7. Preliminary tests of LC-4 split image focusing aid.

experiment in which nineteen operators each made approximately ten focus settings. Each operator followed the same procedure and used the reference cross hair in the focusing aid for the vertical location of the focus point. The procedure was as follows:

1. The ocular of the focusing aid was adjusted by the operator while the aid was attached to the camera and while the oscilloscope screen was illuminated through the viewing point. (The aid remained on the camera throughout the experiment so as to avoid errors in reading because of possible misalignment of the aid when it was reinstalled on the camera.)

2. Since the focusing aid was permanently attached to the camera, the reference cross hair on the prisms and the test target line were in the same relative position to each other throughout the experiment. The operator aligned the split image by turning the camera focusing dial to bring down the right side of the image to the focus point. This procedure eliminated the effect of any residual backlash in the camera.

Figure 8 illustrates the performance of each operator relative to the mean of the readings for all operators for the third set of measurements. The solid bar portion represents one standard deviation on each side of the mean for the particular operator, while the extreme limits of readings are shown by vertical tic marks. The actual number of readings is noted for each operator.

As can be seen from this plot, some operators had significantly more difficulty in performing repeatable focus than others and, in some cases, the mean established by the individual operator was well displaced from the overall mean. It is considered that this resulted from two causes:

1. The ocular was not properly focused.

2. The criteria for what was considered to be the focus point were not the same for all operators, since the sharpness of

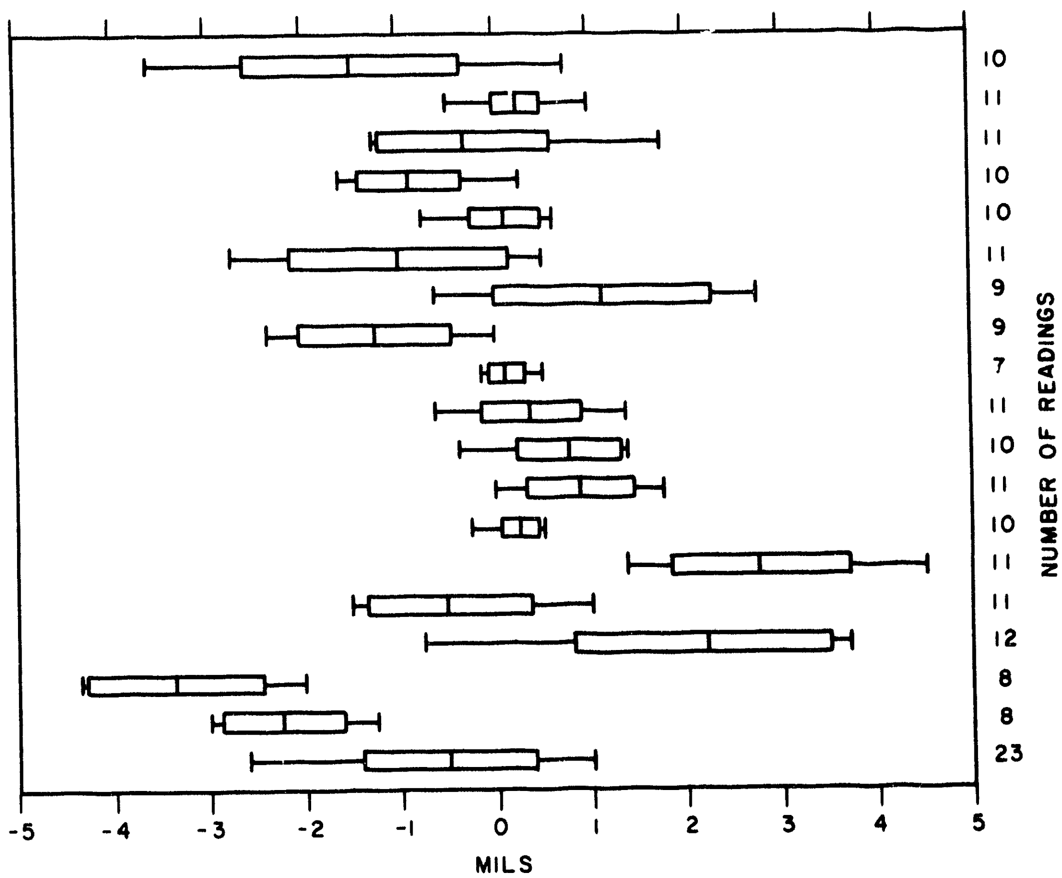


Fig. 8. Operator performance (split image focusing-grid target).

one-half of the image was not the same as that of the other half.

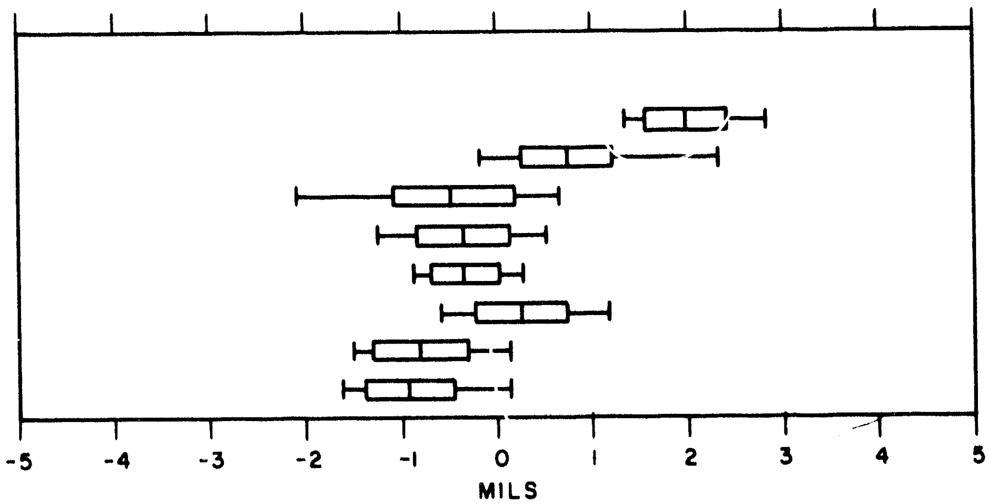
Problem 2 was investigated, and it was found that in order to obtain sharp focus of both halves of the image, it was necessary to place the grid line well above the prism reference cross hair. This indicates that the reference cross hair line is not at the exact point where the prisms are of equal thickness. The test target position was readjusted for the remaining experiments, and increased attention was given to ocular focusing.

3.2 SPLIT IMAGE FOCUSING, CONTROL EXPERIMENT

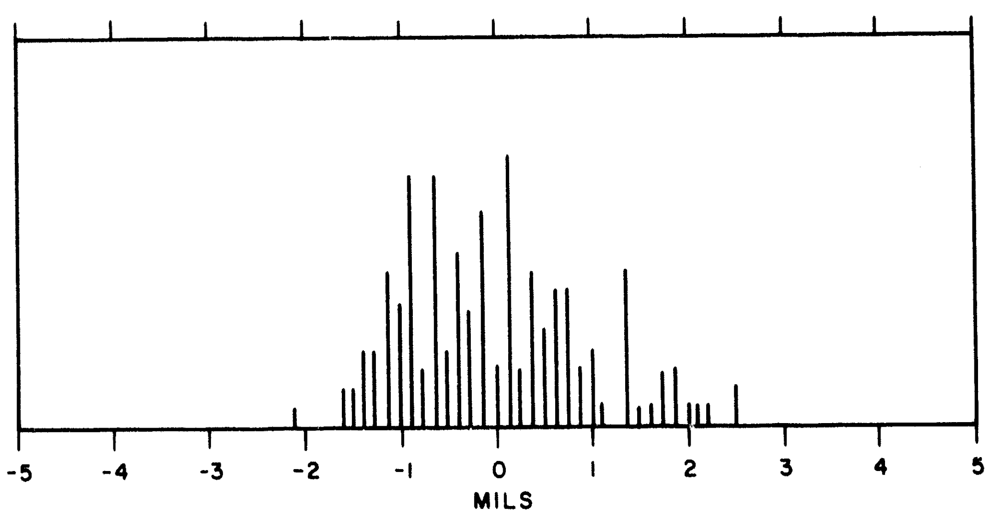
By applying the experience obtained in the preliminary tests to a control experiment, it was possible to establish the reading deviation that should be expected with the present focusing aid configuration when used under optimum conditions. Twenty readings were taken by each of eight operators. Figure 9 illustrates both the overall distribution of readings and the performance of the individual operators. The standard deviation of the individual operators for this experiment did not vary significantly in magnitude from operator to operator, which indicates that the ability of the individual operator was not a significant factor. These data will be used to evaluate the expected optimum performance of the split image focusing aid.

3.3 PROJECTION FOCUSING AID

The projection focusing aid technique was used in a controlled test setup similar to that for the split image focusing aid. Eight operators were employed, each of whom was to take twenty readings. Seven operators used an NBS resolution target having clear lines on an opaque background. One operator also used a target having opaque lines on a clear background. Six operators used the standard PH-2 focusing aid, and two



(a) Operator performance.



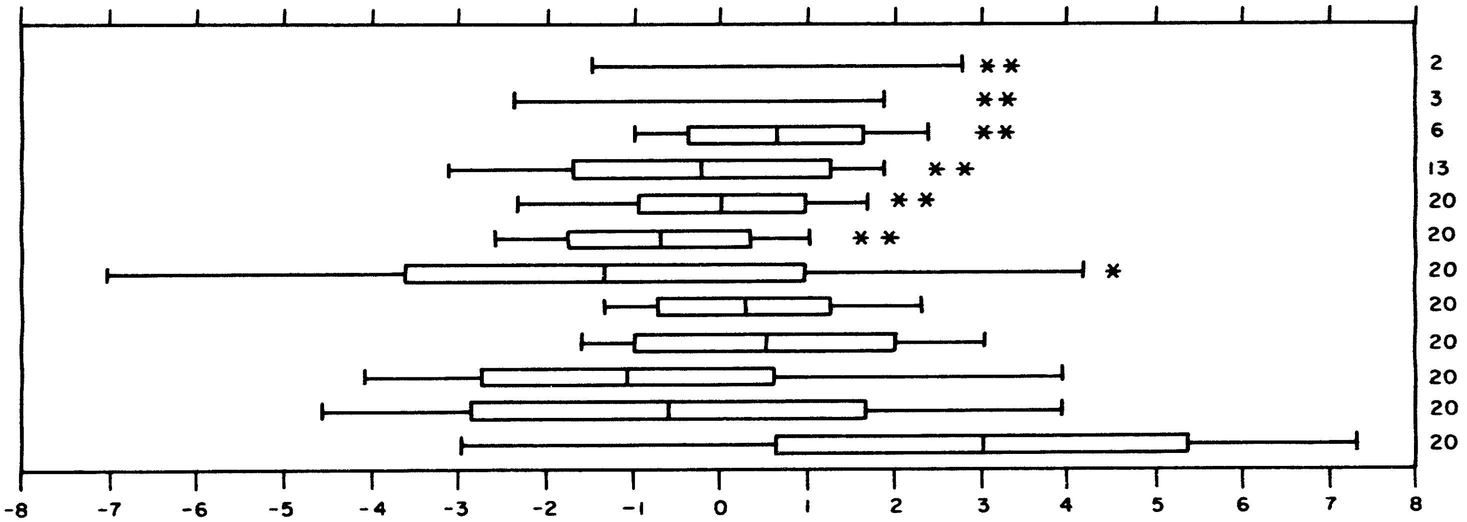
(b) Total distribution.

Fig. 9. Control run (split image focusing-grid target)

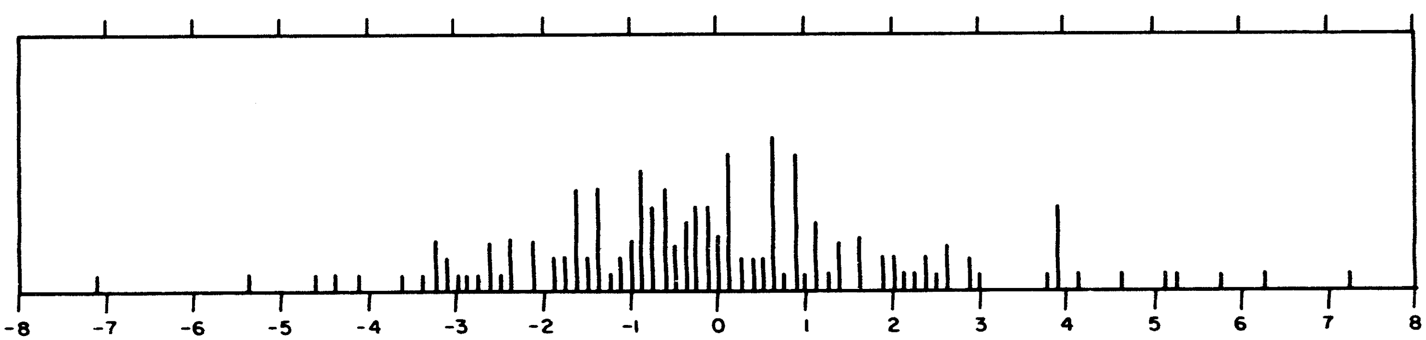
operators used a high intensity source with the same projection target. The results of this test for both the performance of the individual operator and the overall distribution are illustrated in Fig. 10.

3.4 GROUND GLASS FOCUSING

Focusing data obtained with the conventional ground glass technique have been included for comparison. During the experiment, a piece of finely etched glass was used at the camera film position. The operator examined the image through a 20-power microscope while the camera was adjusted for best apparent focus. Focusing by this method is dependent upon operator skill and experience. The results of this test for both the performance of the individual operator and the overall distribution are illustrated in Fig. 11.

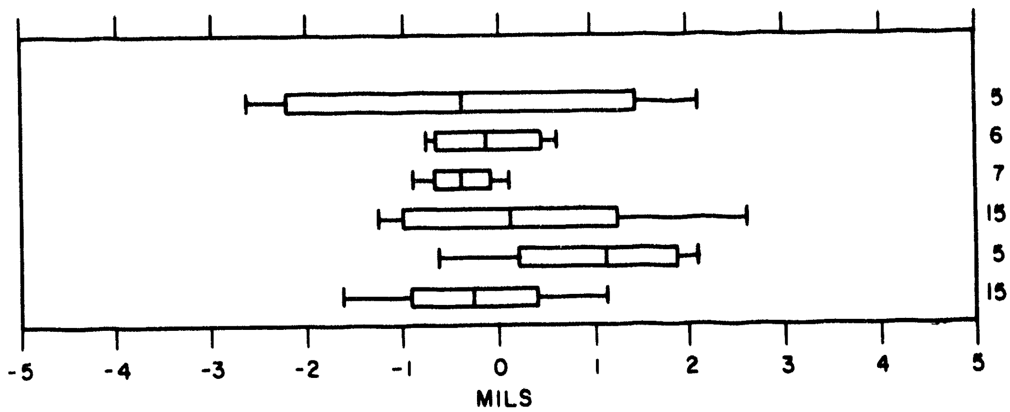


(a) Operator performance.

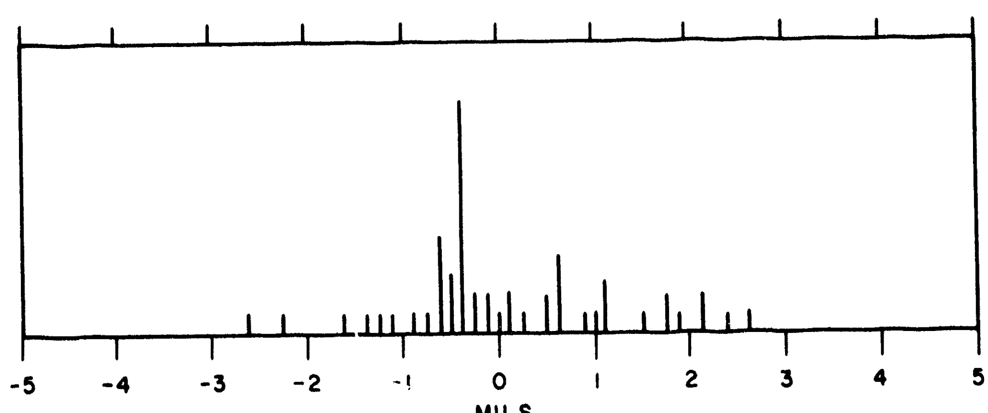


(b) Total distribution.

Fig. 10. Control run—projection focusing aid.



(a) Operator performance.



(b) Total distribution.

Fig. 11. Ground glass focusing technique.

SECTION 4
SUMMARY OF RESULTS

4.1 MEASUREMENT PRECISION

The data presented in Section 3 were examined in general terms to establish the degree of precision that could be associated with each focusing technique. The results of the analysis are presented in Table 2.

The data used for the split image focusing technique were based on the final control run presented in Para. 3.2, since these data are considered to be most representative of data obtained by experienced operators.

The data for the projection technique are divided into two categories. In the first category are the results obtained using the standard PH-2 focusing arrangement modified by use of transparent lines on an opaque background; in the second are the results obtained using a high intensity light source with the same projection target.

Examination of Table 2 shows that the performance of the split image and the ground glass techniques are essentially similar. Individual operators seem to have a smaller deviation from their individual mean reading with the split image technique, but the overall performance with a large number of operators shows similar standard deviations of ±0.001 in. and extreme deviations of ±0.0025 in. for both techniques. Either technique can, therefore, probably be relied upon to provide focus within about 0.002 in. for a single setting of a randomly selected operator. If the operator makes a number of settings and uses the mean of these settings, the focus will probably be within ±0.0015 in. of the correct value— a performance satisfactory for use with Royal Pan, Royal-X Pan and Polaroid types of film.

Comparison with the projection technique shows that the high intensity projection case will give a slightly poorer result in standard deviation (0.0015 in.) but similar extreme limits of ±0.0025 in. It appears that the high intensity technique can probably be relied upon to insure

Table 2. Performance summary.

Type of Focusing Aid	Typical Performance (deviations in inches)					
	Combined settings of all operators about the combined mean		Settings of one typical individual operator about his own mean		Deviations in means of each individual from the combined mean	
	std. dev.	extreme	std. dev.	extreme	std. dev.	extreme
Split image focusing aid	±0.001	±0.0025	±0.0005	±0.001	±0.0008	±0.0015
Projection focusing aid (transparent lines, PH-2 light source)	±0.0025	±0.0055	±0.002	±0.004	±0.0015	±0.002
Projection focusing aid (transparent lines, high intensity light source)	±0.0015	±0.0025	±0.0013	±0.002	±0.0007	±0.001
Ground glass focusing	±0.001	±0.0025	±0.001	±0.0015	±0.0005	±0.0015

correct focus within about 0.0025 in., a slightly poorer performance than the split image or ground glass techniques but adequate for Royal-X Pan film.

The ordinary intensity projection method (clear lines on an opaque background) seems to give a typical standard deviation of ±0.0025 in. and an extreme spread of 0.0055 in. for all operators combined. This technique is considered to insure adequate focus (within about ±0.004 in.) for Polaroid film.

The (now standard) projection method with opaque lines on a clear background was tried in only one set of twenty readings, but its performance was such that it can probably guarantee focus only within ±0.005 in. or greater. This is inadequate even for Polaroid film.

4.2 EASE OF OPERATION

An estimate of the ease of operation of each focusing technique was made from operator comments. In general, the operators felt that the split image focusing aid was much easier to use than either the projection or the ground glass techniques. The standard projection aid was most difficult to use because of visual difficulty in seeing the projected target on the oscilloscope face. The projection device with the opaque lines on a clear background (the standard target) was particularly difficult to use. The high intensity projection aid seemed to cause significantly less visual strain than the standard illumination system.

The operators felt most confident of their settings with the split image device and least confident with the standard projection aid.

4.3 MECHANICAL PROBLEMS

The LRL prototype split image device was noted during the tests to have some minor mechanical problems. These included difficulty in mounting the device on the camera, insecure mounting, and interference with the camera back-plate casting. These deficiencies, however, could be corrected relatively easily. Use of the device on the 3171 camera, however, will require a complete redesign as well as a camera modification to hold the focusing aid.

The PH-2 projection focusing aid, as normally used on the 3171 camera, showed much more serious mechanical problems:

1. PH-2 light source intensity too low to provide sufficient contrast for focusing;
2. PH-2 light source flickers--changing contrast of image makes focusing difficult;
3. Operators couldn't get close enough to image to see clearly the high resolution line pairs; and
4. The target plane in the focusing aid is not at the same distance from the camera back face as is the film in a normal holder.

These problems are so serious that a complete mechanical and optical redesign will be necessary for satisfactory use on the 3171 camera.

SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

Ground glass focusing was used in the experiment only to provide reference control to the other two techniques, since although this technique produces high quality results, it is considered that ground glass focusing is too dependent upon operator skill and provides no separation between oscilloscope trace focus and camera focus. Therefore, the recommendations pertain only to the split image and the projection techniques. In a comparison of the normal PH-2 projection focusing aid and the LRL split image focusing aid used in the experiment, the split image focusing aid provided much greater focusing accuracy and was significantly easier to use as a focusing aid. If an improved high intensity version of the projection focusing aid is designed, the split image focusing aid will provide only slightly better focusing repeatability but will still provide greater operator convenience.

The main operational drawback of the projection technique is the difficulty in seeing the resolution target at the large distance between the operator's eye and the projected image. The main operational drawback of the split image technique is that a trace on the oscilloscope is required for focusing.

The projection focusing aid is significantly less complicated and less expensive to fabricate as compared to the split image focusing aid. Estimates of $50 versus $100 have been made for production quantities.

The split image device also serves as a trace-viewing device which can be used in setting oscilloscope focus.

In the proposed improved configurations, both of the focusing aids provide focusing capability for medium to low resolution film. High resolution films will still require a series of photographic exposures to determine the best focus point.

The split image device should be useful in making initial focus settings during production of fixed-focus 850-type cameras. Final focus, however, will still have to be determined photographically.

It is considered that each type of focusing aid has its own particular advantages for a given application and that the optimum design configuration of both aids should be pursued. The aid selected for use with the camera should be determined by the application.

It is therefore recommended that prototypes of both an improved high intensity projection aid and a mechanically improved split image aid be fabricated for the LC-4 camera. In addition, a prototype of each type should be fabricated for the 3171 series of cameras. A final selection of the optimum type can then be made by field evaluation of the prototypes.

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