RD&E CENTER

Technical Report

No. 13375

UNITY VISION BLOCK
WITH FOCAL PLANE

FINAL REPORT

CONTRACT NO. DAAE07-87-CR074

OCTOBER 1988

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A unity-magnification telescope with an intermediate focal plane has been designed to fit into the outer housing of a standard No. 6300790 tank vision block. This has a 29° field of view with an exit pupil of 16 mm, at an eye relief of 70 mm. A slide permits insertion of test cells in the intermediate focal plane for evaluating laser protection devices. The intensity of an incident laser beam is increased by a factor of 50,000 at the intermediate focal plane.

Two units have been built and tested. They show no degradation of normal vision over the entire focal plane.

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Two units have been built and tested. They show no degradation of normal vision over the entire focal plane.

2.0. INTRODUCTION AND OBJECTIVES

This is the final report of contract DAAE07-87-CR074 for the U.S. Army Tank Command. The objective of this contract was to develop a unity vision block with an intermediate focal plane, which is contained within the physical envelope of the standard 4 inch vision block number 6300790.

A dimensioned drawing of this vision block is shown in Figure 1. Laser light from anywhere in the field of view will be focused to a point in the intermediate focal plane and thus highly concentrated. This will permit testing various power-limiting concepts such as optical switches and nonlinear absorbers, which may not be sensitive enough to function in the direct laser beam, but would be effective in the high radiation density of a focused point.

The vision block is essentially a window 8 inches wide, 2 inches high and 4 inches thick. Because of refraction, this gives a very wide (almost 90°) horizontal field of view, with a wide aperture which permits binocular vision over much of the field. It is impossible to achieve all these features with an intermediate focal plane within the space limitations. The design problem then is to make an optimum tradeoff among field of view, aperture and image quality, consistent with conforming to the 4 inch vision block dimensions and intended use.

Originally, two quite different tradeoff selections were proposed, one being called a "full aperture system" and the other a "high-resolution system." The full aperture system functioned more like a window and would permit binocular viewing through the full 8 inch by 2 inch area of the vision block. This would be accomplished by plastic lenticular

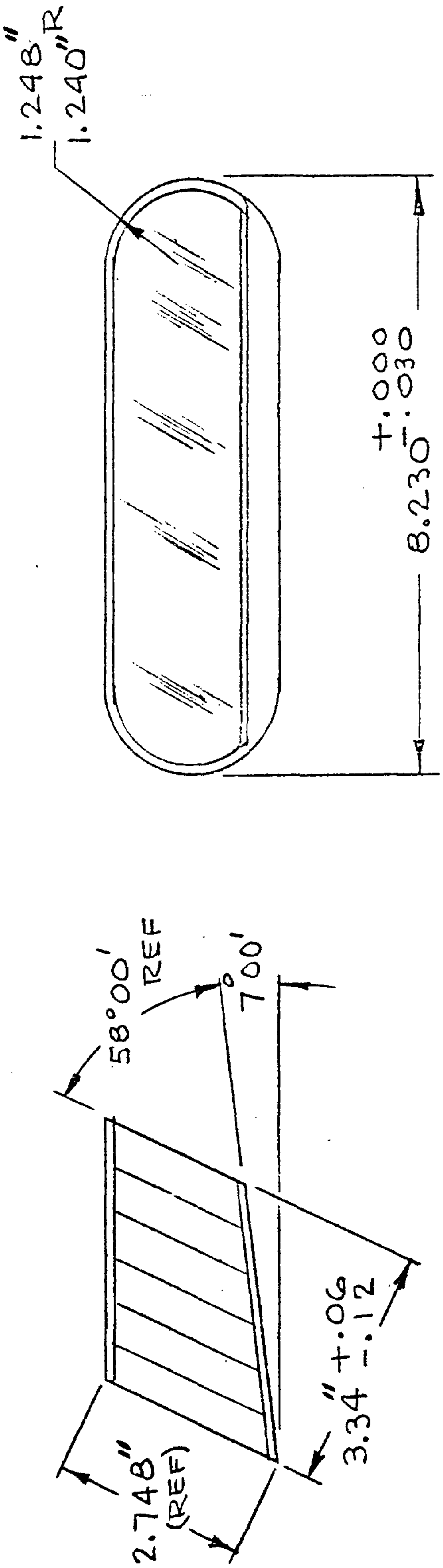


Figure 2-1. Block, Direct Vision No. 6300790

arrays made by injection molding. A disadvantage of such a system is that it would not be feasible to provide aberration correction in the plastic lens arrays and the image sharpness would suffer. This could reduce the effectiveness of the optical switch.

The high-resolution system would employ a single optical chain of glass elements in which a high degree of correction could be obtained and would produce a high-quality image. Its disadvantage is that, in order to fit within the prescribed envelope, the exit pupil must be much smaller than 8 inches by 2 inches and binocular vision is not possible.

The U.S. Army Tank-Automotive Command (TACOM) selected the high-resolution system as the most satisfactory for their requirements and no effort was expended on the full aperture system.

3.0. CONCLUSIONS

A design was developed having an intermediate focal plane which gave excellent imagery over a 40° field and which fit into the prescribed vision block envelope. A test slide is provided in the intermediate focal plane to permit insertion of non linear optical switches. Two such units were fabricated and tested. Test results confirmed the design.

4.0. RECOMMENDATIONS

These units highly concentrate collimated light from a laser beam in the intermediate focal plane. This will cause certain non-linear optical materials to become opaque whereas the intensity in the collimated beam would not be sufficient to do so. It is recommended that a number of test cells be made to fit into the slide provided at the intermediate focal plane, for holding these switching materials, many of which are liquid, and that tests then be made to determine their effectiveness for eye protection against lasers.

5.0. DISCUSSION

5.1. Optical Considerations

5.1.1. General

Figure 5-1 shows a simple unity telescope having an intermediate focal plane and defines some of the terms that will be

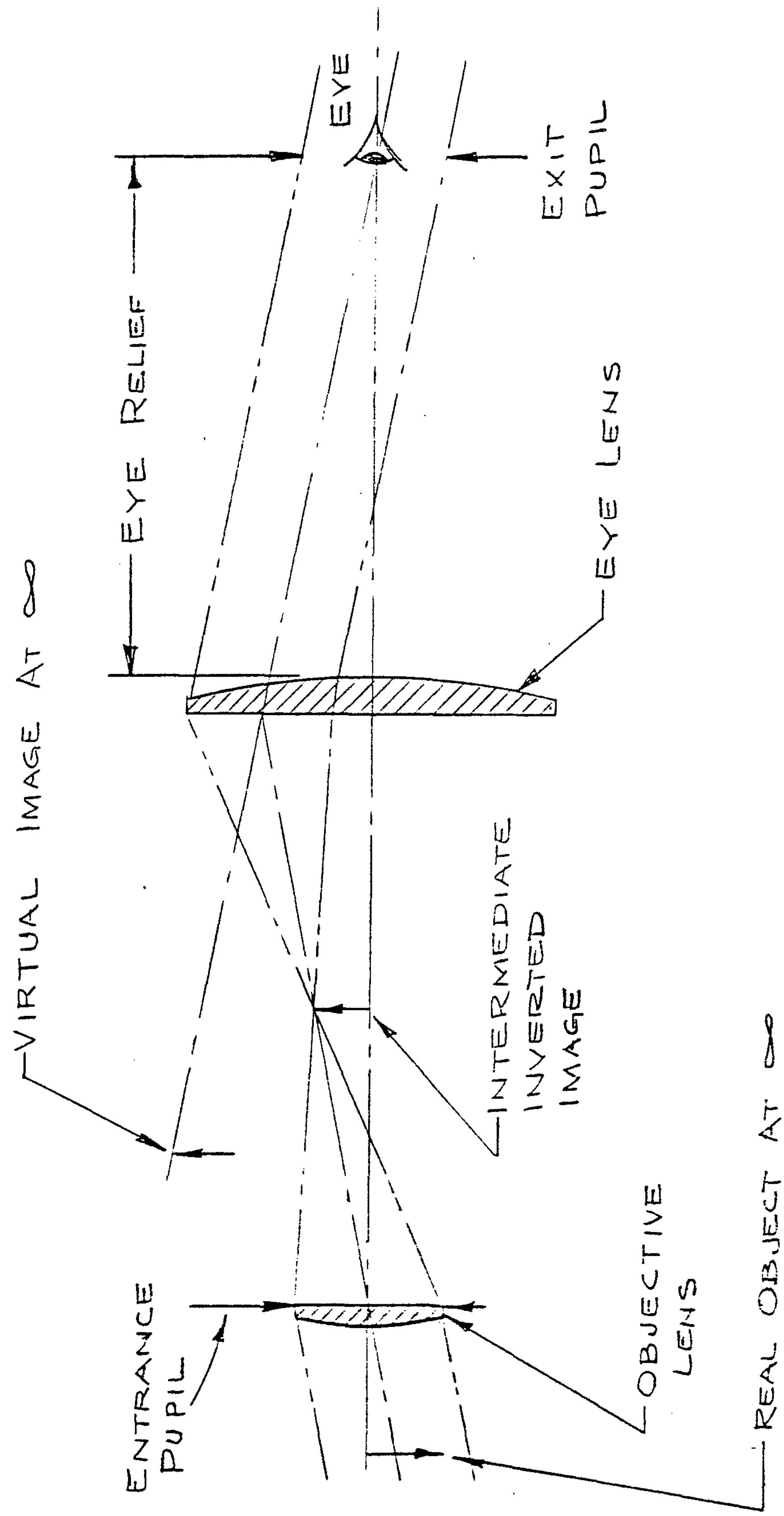


Figure 5-1. Simple Unity Telescope with Intermediate Focal Plane

used. The object at infinity is taken as an arrow pointing downward. The objective lens forms a real inverted image, while the eye lens converts this to a virtual image at infinity, still inverted (arrow pointing up). This figure illustrates the two main problems with such a system, namely, the inversion of the image, and the large size of the eye lens necessary to collect the light from the intermediate image.

The chief difficulty in the optical design was obtaining an erect unreverted (left-right correct) image to the eye. The conventional ways of doing this in terrestrial telescopes or binoculars are by means of an erecting lens, or a pair of porro prisms, but neither of these would fit in the vision block without severely restricting the aperture of the system. It is necessary at this point to clarify what is meant by the aperture. Strictly, the useful aperture is the pupil of the eye, which has a maximum diameter of about 7-mm when dark-adapted. In a unity telescope, the entrance pupil is equal to the exit pupil, therefore, the objective lens need only be 7 mm in diameter. However, this would require precise positioning of the eye to within the 7 mm exit pupil which would be an unacceptable restriction in a tank vision block. It was believed that the exit pupil should be at least 15 mm in diameter with a field of view of about 40°. This increases all dimensions of the system.

The distance between the eye lens and the exit pupil is called the eye relief. It is desirable to have this fairly long to prevent bumping against the eye lens when the tank jounces. This also requires enlargement of the system and these combined requirements rule out the erection lens, or porro prism solutions.

5.1.2. Image Erection

In order to make maximum use of the vision block envelope, two 90° folds of the optical path are necessary. These folding elements can be used for erecting the image, thus eliminating an erecting lens and shortening the optical path. However, care must be taken in the selection of the folding elements to ensure that the final image is both erect and unreverted. This has been accomplished with a penta prism and an Amici or roof prism. The penta prism has the property of reflecting the image <u>without</u> the left-right reversal that occurs in a plane mirror. The roof prism both reverts <u>and</u> inverts the image thus fully correcting the inversion-reversion caused by the objective lens.

5.1.3. Telecentric Condition

The other major design problem is the large diameter of the eye lens needed to get a large field of view as can be seen in Figure 5-1. This diameter can be reduced by using a field lens at the intermediate focal plane, however, this is where the optical switching devices to be tested are to be located Further, since the switching device will be in this focal plane, it is desirable that it be free of curvature, but a field lens produces field curvature. Therefore, instead of using a field lens, the system has been made "telecentric," which means that the central ray of each image point bundle be parallel to the optical axis. The telecentric condition is illustrated in Figure 5-2. Telecentricity is obtained by means of a stop located either at the front focal point of the objective lens or the back focal length of the eye lens. The front focal point of the objective lens falls within the penta prism as will be seen later and is inaccessible; therefore, the back focal point of the eye lens is used. In our case, the pupil of the eye itself serves as the telecen-tric stop.

Comparing Figures 5-1 and 5-2, it would seem that telecentricity reduces the required diameter of the eye lens for a given field of view, but enlarges the objective lens, since the latter is no longer the entrance pupil. This is desirable, since most efficient use of space occurs when both lenses are the same size.

It is important to note that positioning of the eye at the telecentric stop position is not critical. Deviations do not lose the image but merely degrade the telecentric condition which will merely cause some vignetting at the edges of the field of view.

5.2. Final Optical Design

The first design iteration employing the penta - Amici prism erection system and the telecentric condition resulted in the following characteristics.

- Field of View 40°
- Exit Pupil Diameter 16.0 mm
- Eye Relief 35 mm

This was a symmetrical system using the same objective and eye lens, each consisting of a doublet and singlet element.

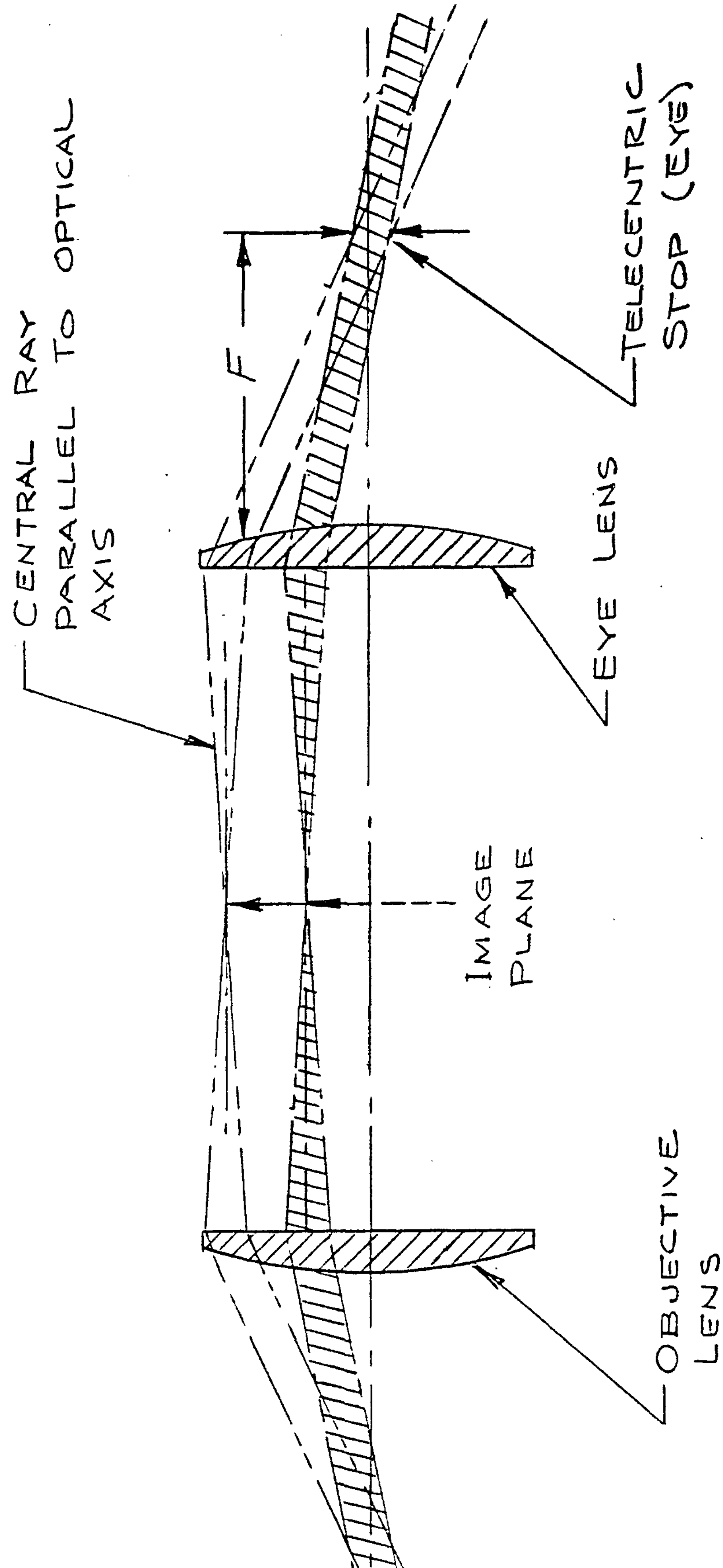


Figure 5-2. Telecentric Condition

TACOM felt that a considerably longer eye relief was desirable and requested that we see whether this could be achieved with some sacrifice of field of view. This was done by some enlargement of the eye lens and deviation from the perfect telecentric condition to give the following:

- Field of View 29°
- Exit Pupil Diameter 16 mm
- Eye Relief 70 mm

This configuration was approved by TACOM and is the one built. Figures 5-3 and 5-4 show top, side and face views of the final system to scale. The path of the extreme field rays are shown in Figure 5-3.

Figure 5-5 shows a set of system performance curves for off-axis ray bundles at 0.0°, 10.3° and 14.5°. The ordinate of all graphs is the angular deviation from the central ray in milliradians, while the abscissa is ray height in the exit pupil from -8 to +8 mm. The left-hand graph of each pair is for ray height variations in the plane of Figure 5-3 (meridional), while the right-hand graph is for ray heights normal to this plane (sagittal). The latter are always symmetrical and therefore only half is shown.

The day-adapted eye has a pupil diameter of about 3-mm. These curves show that the energy from a point source in this pupil will fall within 1 milliradian or 3.5 arc-minutes over the entire field. The ultimate resolution of a perfect human eye is usually taken as 1 arc-minute, although very few people have this visual acuity. Therefore, the degradation in imagery will not be objectionable or probably even detectable to most people. Optical tests on the final unit discussed in Section 5 confirm this.

The intermediate focal length is 71-mm. With a 16-mm entrance pupil and a 1-milliradian or 0.071 mm point-image blur, a laser beam will be concentrated in the intermediate focal plane by a factor of $(16/0.071)^2 = 50,000$.

A test cell will ultimately be placed at the intermediate focal plane and its thickness and refractive index will affect the location of the optical elements. TACOM specified that the cell would be 0.50 inch thick, constructed of BK-7 glass and be filled with materials having refractive indices ranging from 1.35 inches to 1.75 inches. This has been simulated in the design by two 0.25 inch thick glass plates, as shown in Figure 5-3 and a focusing adjustment has

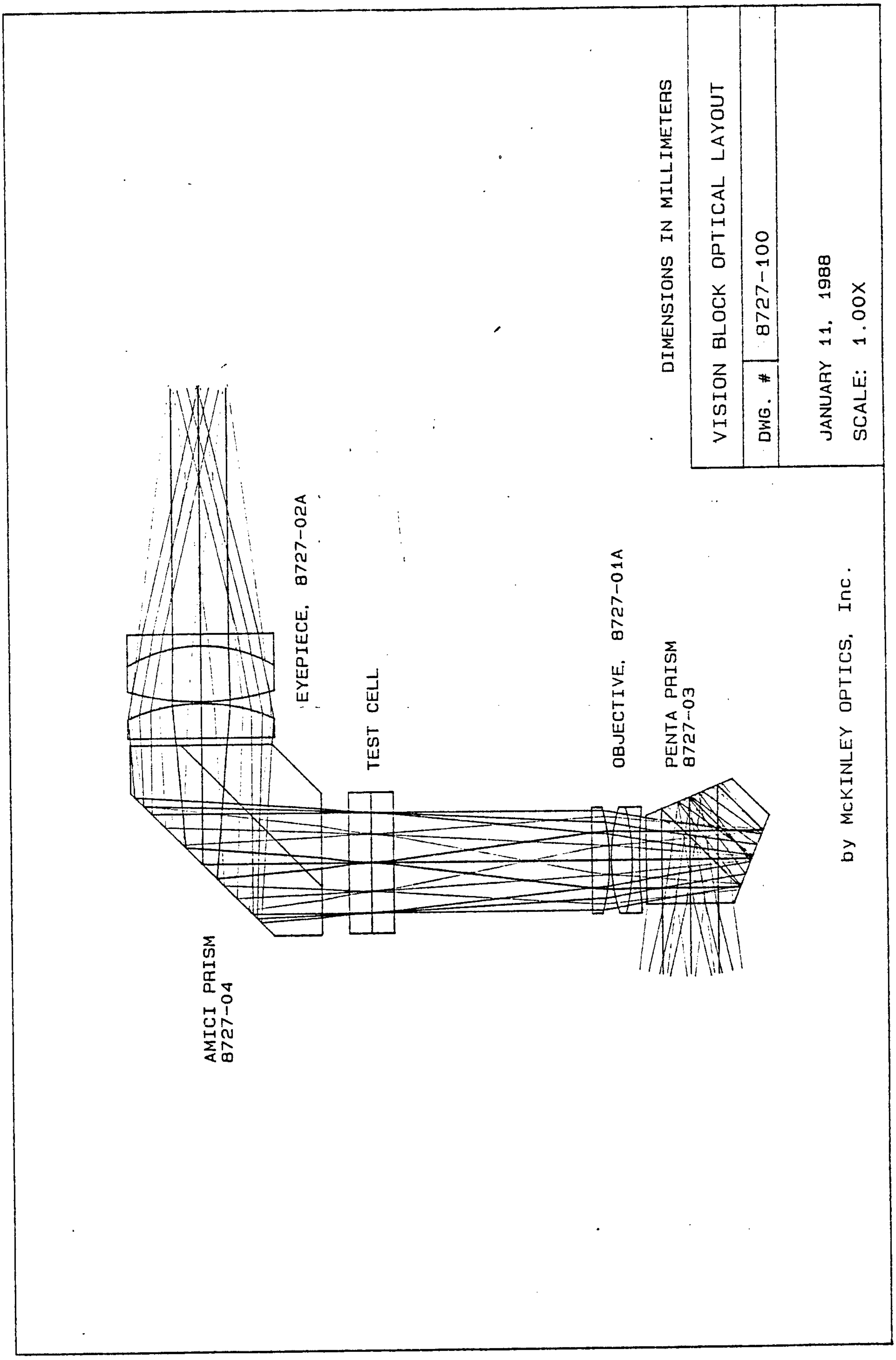


Figure 5-3. Vision Block Optical Layout (Top View)

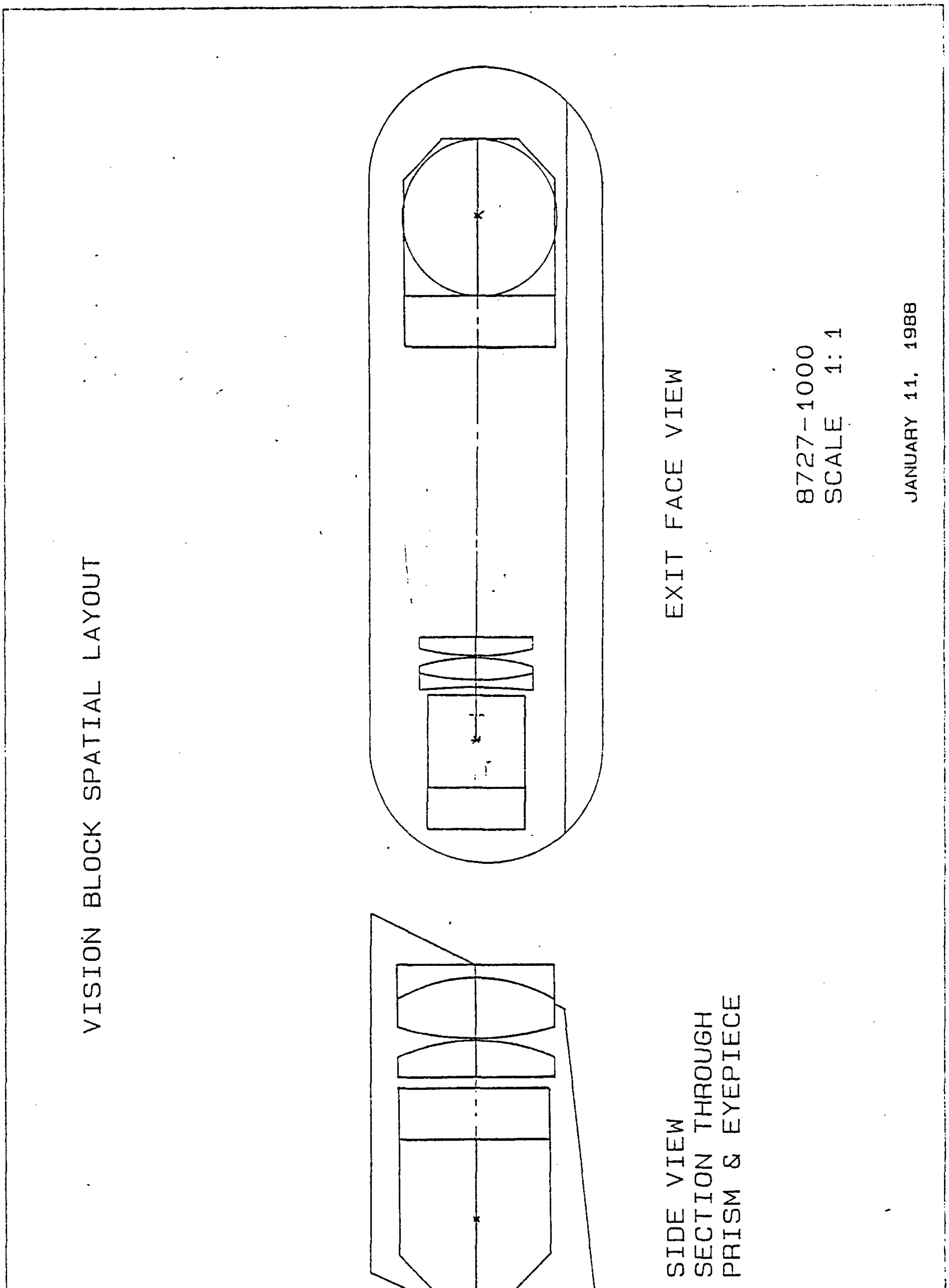


Figure 5-4. Vision Block Optical Layout (Face and Side Views)

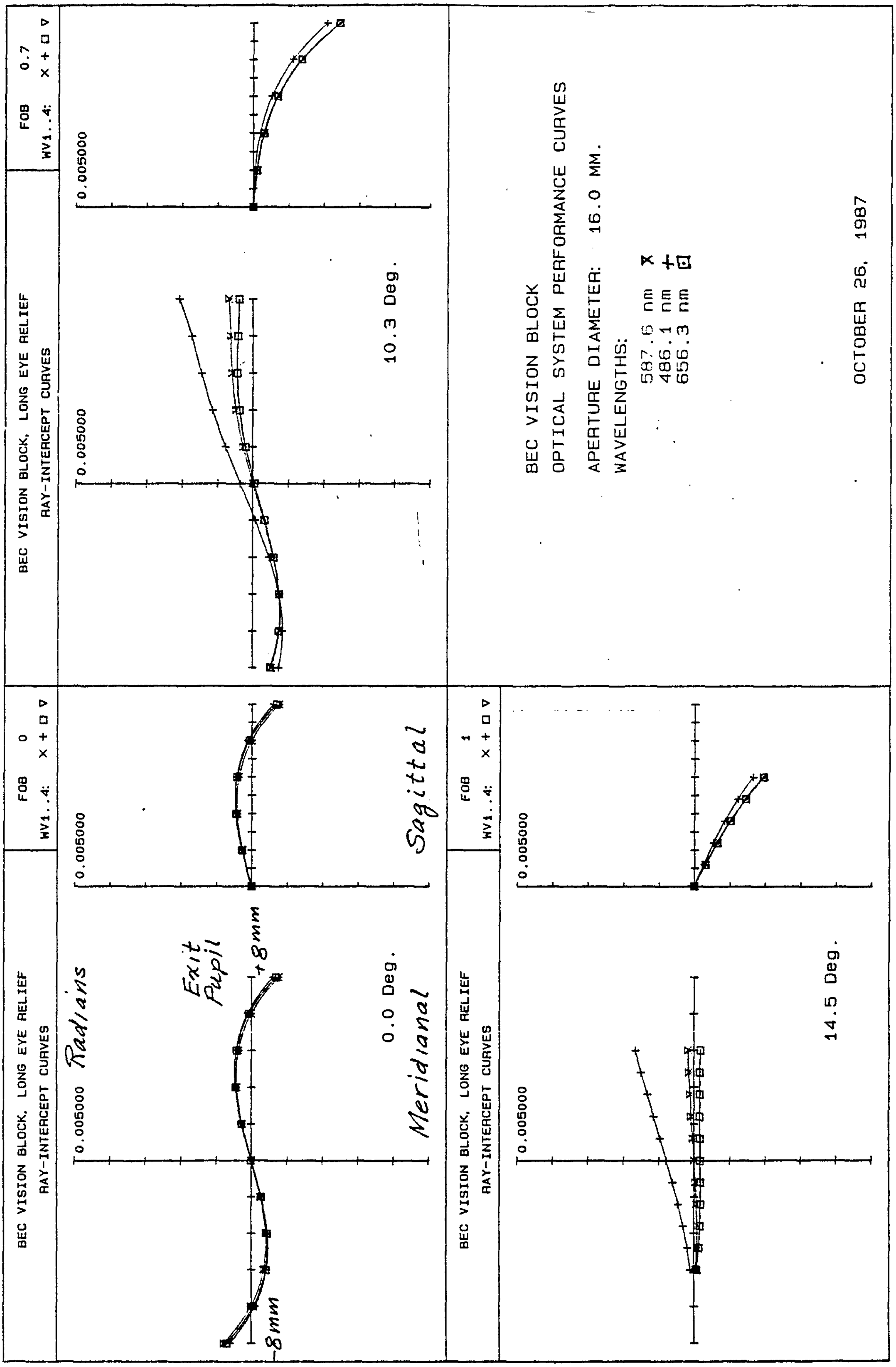


Figure 5-5. Optical System Performance Curves

been provided to accommodate the index variation. Figures 5-6 to 5-9 show detailed drawings of all the optical elements. The axial spacings of the elements are listed below:

- Penta Prism to Objective Lens 2.00 mm
- Objective Lens to Test Cell 56.54 mm
- Test Cell Thickness 12.70 mm
- Test Cell to Amici Prism 7.81 mm
- Amici Prism to Eye Lens 2.00 mm

5.3. Mechanical Packaging and Fabrication

The optical system described in Section 3.4 was packaged in the casing (Part No. 6300790-1) of the No. 6300790 Direct Vision Block. These casings were purchased from Vision Block Company of Melbourne, Florida, which manufactures these vision blocks.

A mounting base for all elements is screwed to the bottom of the casing on the inside. This base directly holds the eye lens and the Amici prism. A set of ways on this base permits the test cell to be inserted from the eyepiece side or rear face of the vision block. A test cell holder is provided which slides into these ways.

The penta prism and objective lens are mounted on a separate plate which slides on the baseplate in the direction of the test cell for focusing, and is locked into position by an Allen screw in a slot. A plate with an aperture for the penta prism fits over the front of the vision block and prevents any extraneous light from entering the system.

Figure 5-10 is a photograph of the vision block assembly, while Figure 5-11 shows the unit with the casing removed. A complete set of drawings including an assembly drawing and details of all parts have been provided separately.

5.4. Testing

The units were tested visually for resolution and field of view and gave very satisfactory results. This is a subjective opinion, however, and in order to make a more quantitative evaluation, photographs were made of resolution charts both in the far field and in the focal plane.

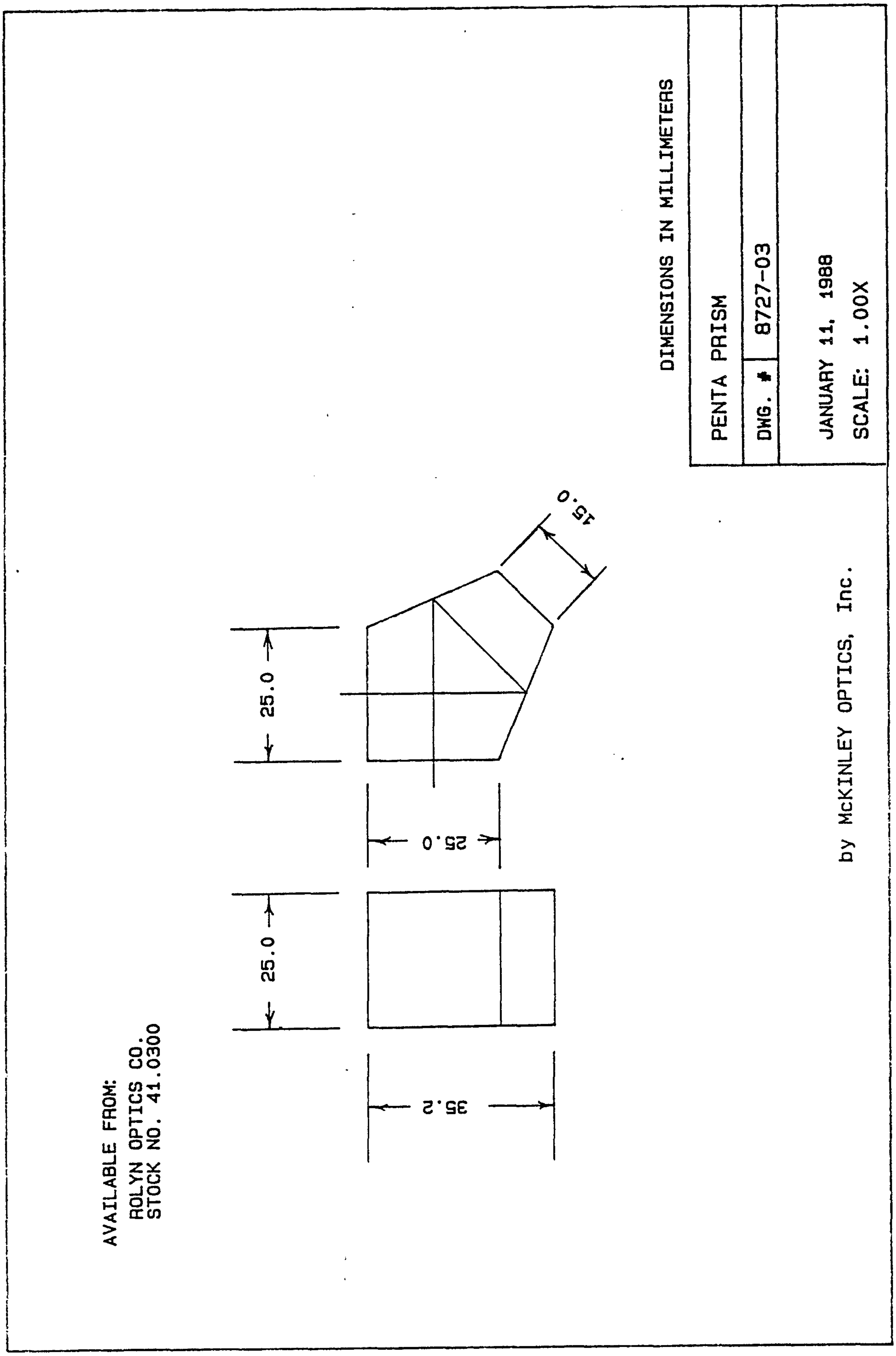


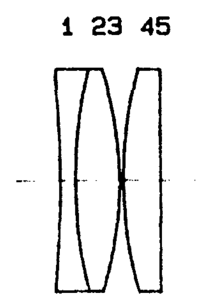
Figure 5-6. Penta Prism

E.F.L. = 63.01
B.F.L. = 61.00

SURF #	RADIUS	CNTR THK	GLASS
1	149.880 CV	2.00	SF8
2	61.869 CV/CX	6.00	BAK1
3	50.213 CX	0.50	AIR
4	55.433 CX	5.00	BAK1
5	PLANO	B.F.L.	AIR

DIAMETER: 30.00, +0/-.04
CLEAR AP: 29.0

ANTI-REFL COAT GLASS/AIR SURFs
PER MIL-C-675A



DIMENSIONS IN MILLIMETERS

OBJECTIVE LENS	
DWG. #	8727-01A
JANUARY 11, 1988	
SCALE: 1.00X	

Figure 5-7. Objective Lens

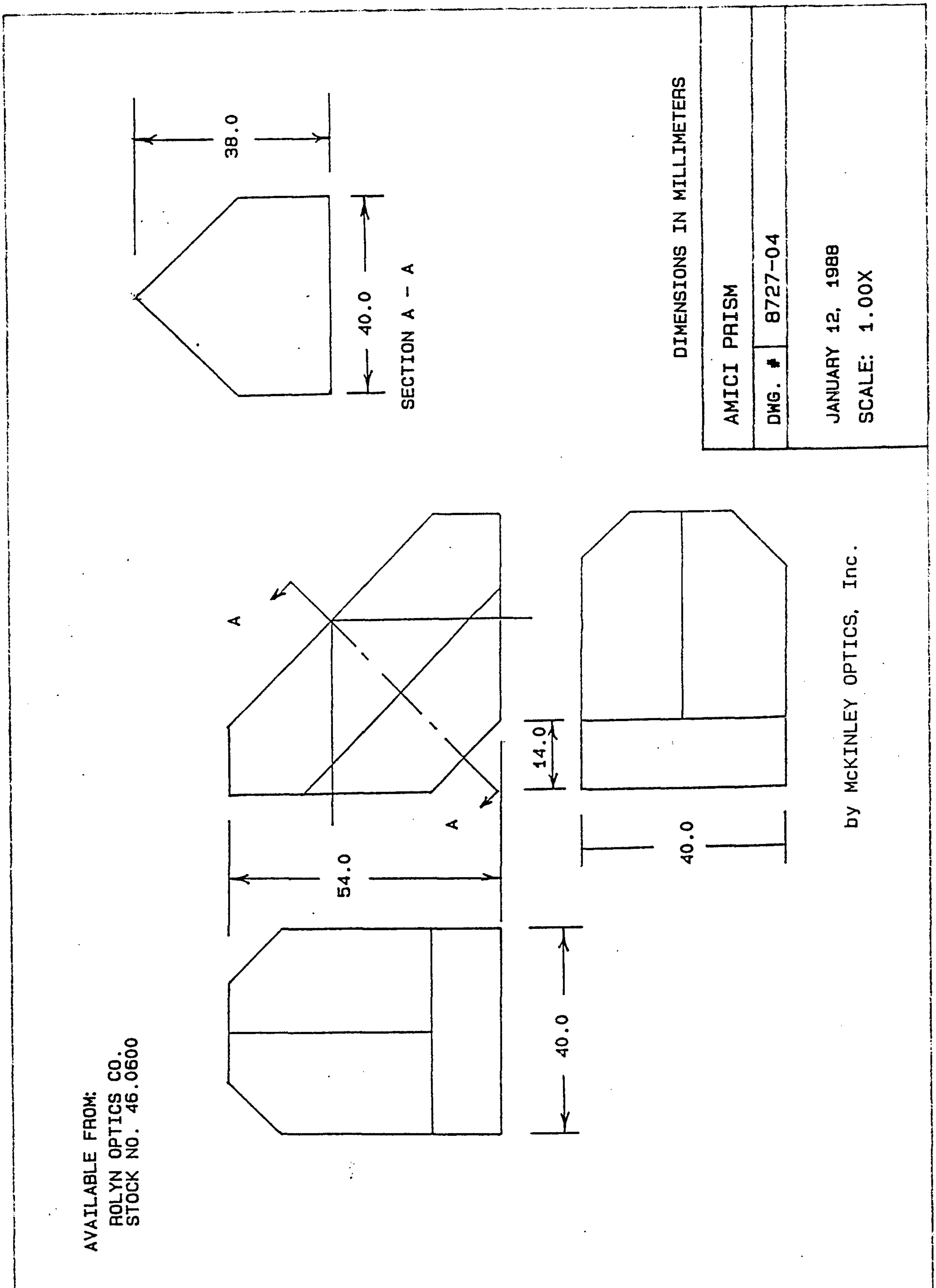


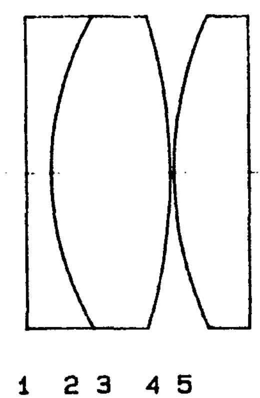
Figure 5-8. Amici Prism

E.F.L. = 62.40
B.F.L. = 58.20

SURF #	RADIUS	CNTR THK	GLASS
1	614.000 CV	3.0	SF8
2	41.503 CV/CX	16.00	BAK1
3	73.622 CX	0.50	AIR
4	50.213 CX	10.00	BAK1
5	PLANO	B.F.L.	AIR

DIAMETER: 42.00, +0/-.04
CLEAR AP: 41.0

ANTI-REFL COAT GLASS/AIR SURFs
PER MIL-C-675A



DIMENSIONS IN MILLIMETERS

EYEPIECE SYSTEM	
DWG. #	8727-02A
JANUARY 11, 1988	
SCALE: 1.00X	

by McKINLEY OPTICS, Inc.

Figure 5-9. Eyepiece System

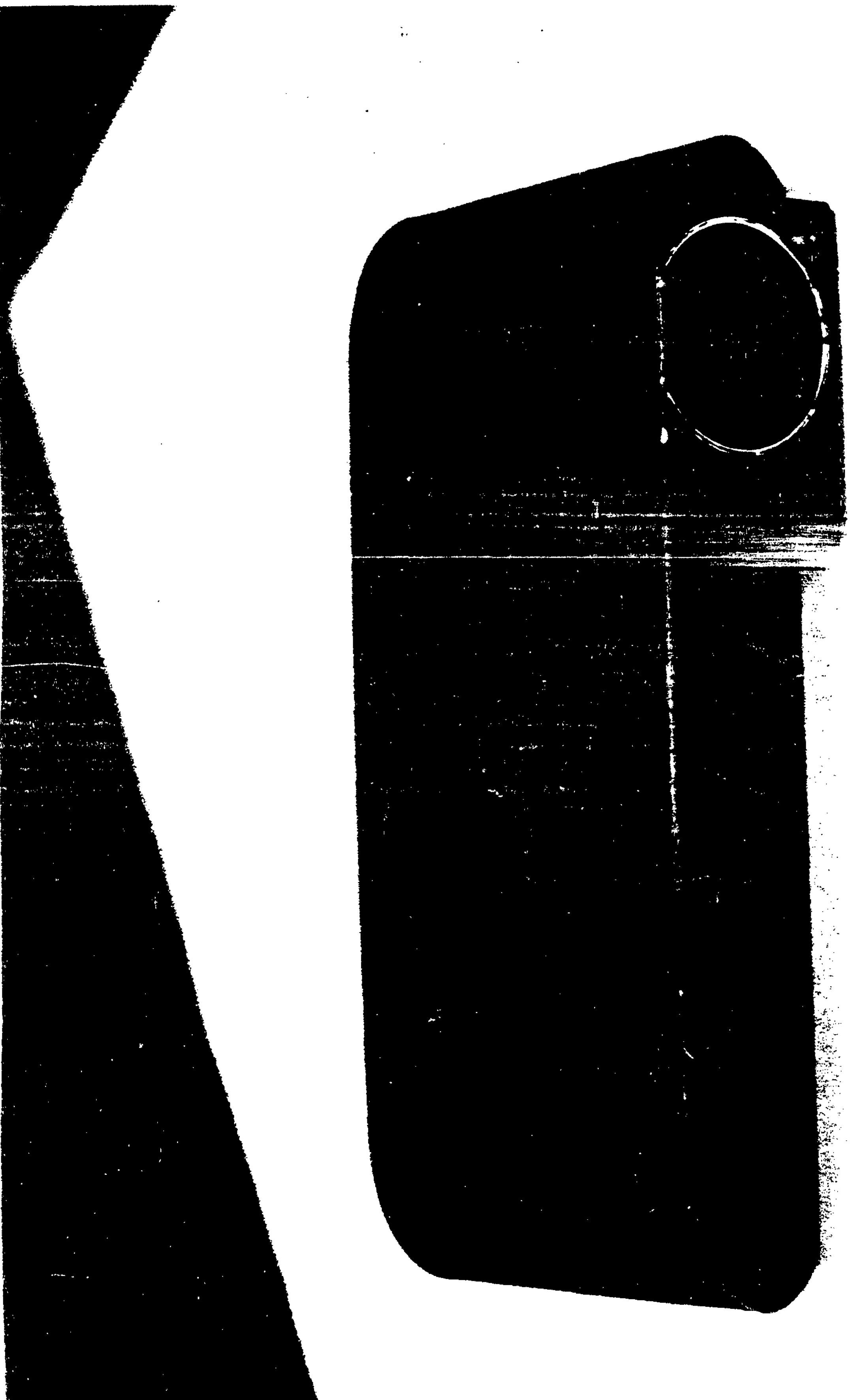


Figure 5-10. Photograph of Vision Block Assembly

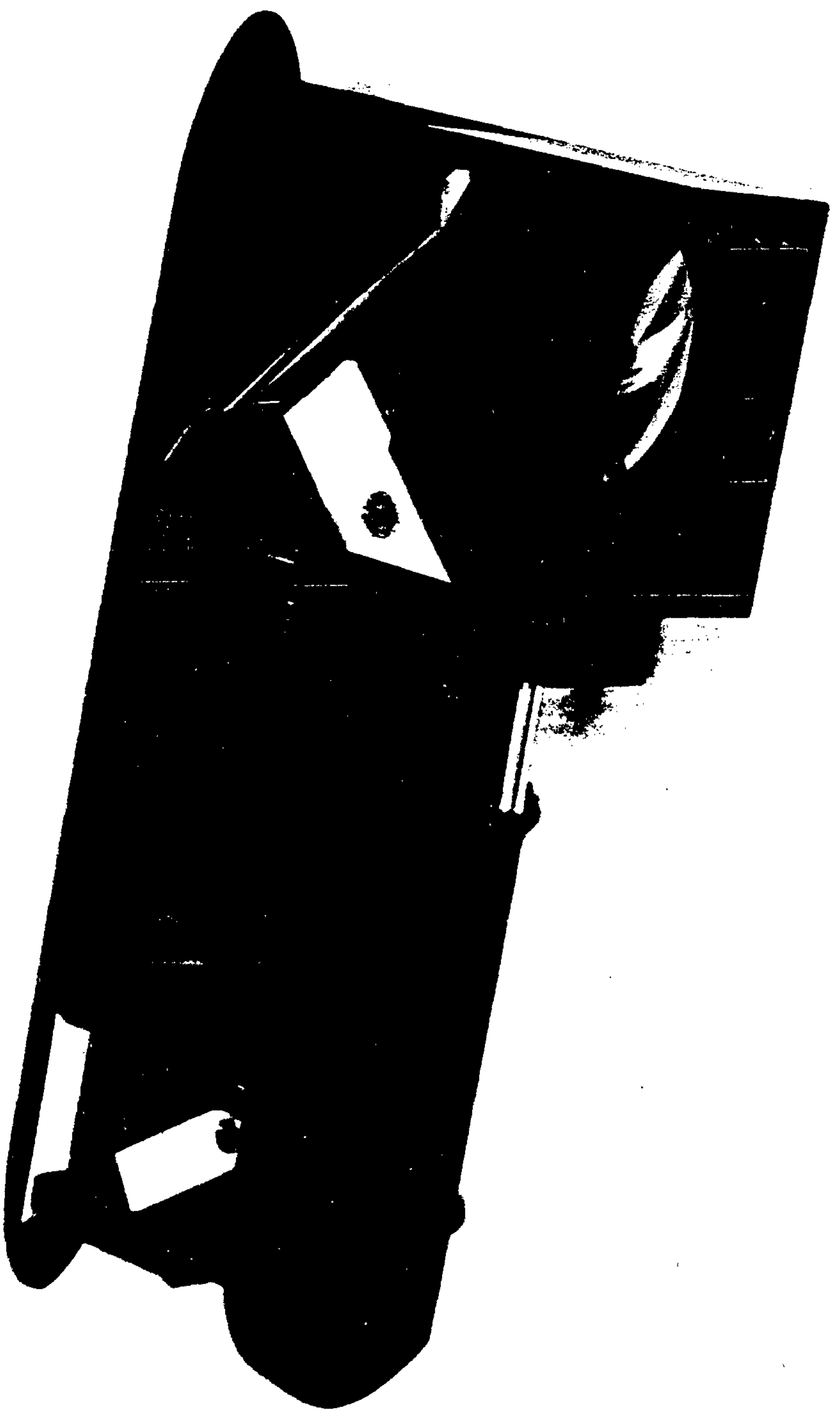


Figure 5-11. Photograph with Casing Removed

The resolution was evaluated by means of the USAF 1951 resolution test target. This consists of groups of horizontal and vertical 3-bar patterns of decreasing spacing. A group is comprised of six elements where each element consists of two bar patterns of three lines each, at right angles to each other. The elements of each group have decreasing line spacings in the step ratio of the 6^{th} root of 2. Thus the number of line pairs per mm doubles at every 7^{th} element, which starts a new group. The line pairs per mm are given in Table 5-1 for all the elements of each group. The "bar width" or "bar spacing" is the reciprocal of the "line pairs per mm."

Two resolution patterns were used. The first was a large wall chart on which were printed a number of USAF 1971 Resolution Targets at different locations and in different colors. These targets contained Groups -2 to 3, Group 4 being too small to be useful in the far field.

The second was a thin glass reticle on which one USAF target was photographically reproduced, consisting of Groups 1 to 7. This was for use in evaluating the resolution in the intermediate focal plane. It was sandwiched between two 0.25 inch thick glass plates in the test cell slide.

Figure 5-12 shows a photograph of the resolution chart taken through the vision block, while Figure 5-13 shows a similar photograph with the reticle resolution target in the intermediate focal plane. The distance to the chart was 9 ft. (2743 mm), while the focal length of the objective lens is 71 mm, therefore, the image of the wall chart in the intermediate focal plane was reduced by a factor of 2743/71 = 38.6. Since each successive element in the USAF 1971 pattern is reduced by $2^{(1/6)}$, a reduction of 38.6 is a shift of n elements where $2^{(n/6)} = 38.6$ and n = 31.6 or 5 groups plus 1.6 elements. For example, Element 1 of Group -2 of the wall chart should appear the same size as element 2 or 3 of Group +3 of the reticle pattern. Inspection of Figure 5-13 shows this to be the case.

The maximum resolution of the human eye is about 1 arc minute or 0.0003 radians. At 9 ft. (2743 mm), this is 0.80 mm or 1.6 mm/line pair, which is 0.625 line pairs/mm. This is Group -1, Element 3 of the wall chart. Shifting 31 elements, it corresponds to Group 4, Element 4 of the reticle pattern. We see that these are just barely discernable in Figures 5-12 and 5-13. This shows that the vision block does not degrade the image seen by the eye. This experimentally confirms the optical performance calculated and shown in Figure 5-5.

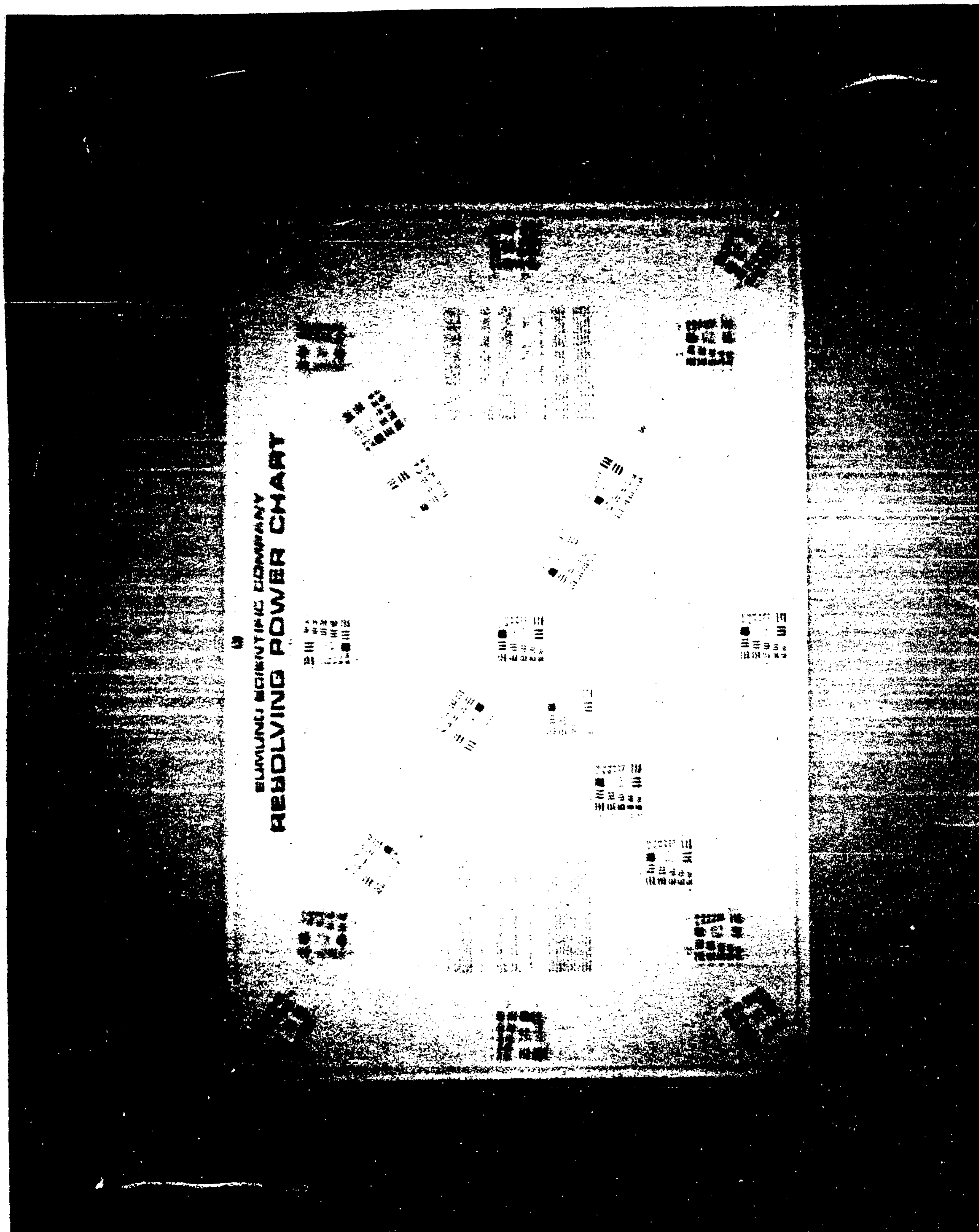


Figure 5-12. Photograph of Resolution Chart Through Vision Block

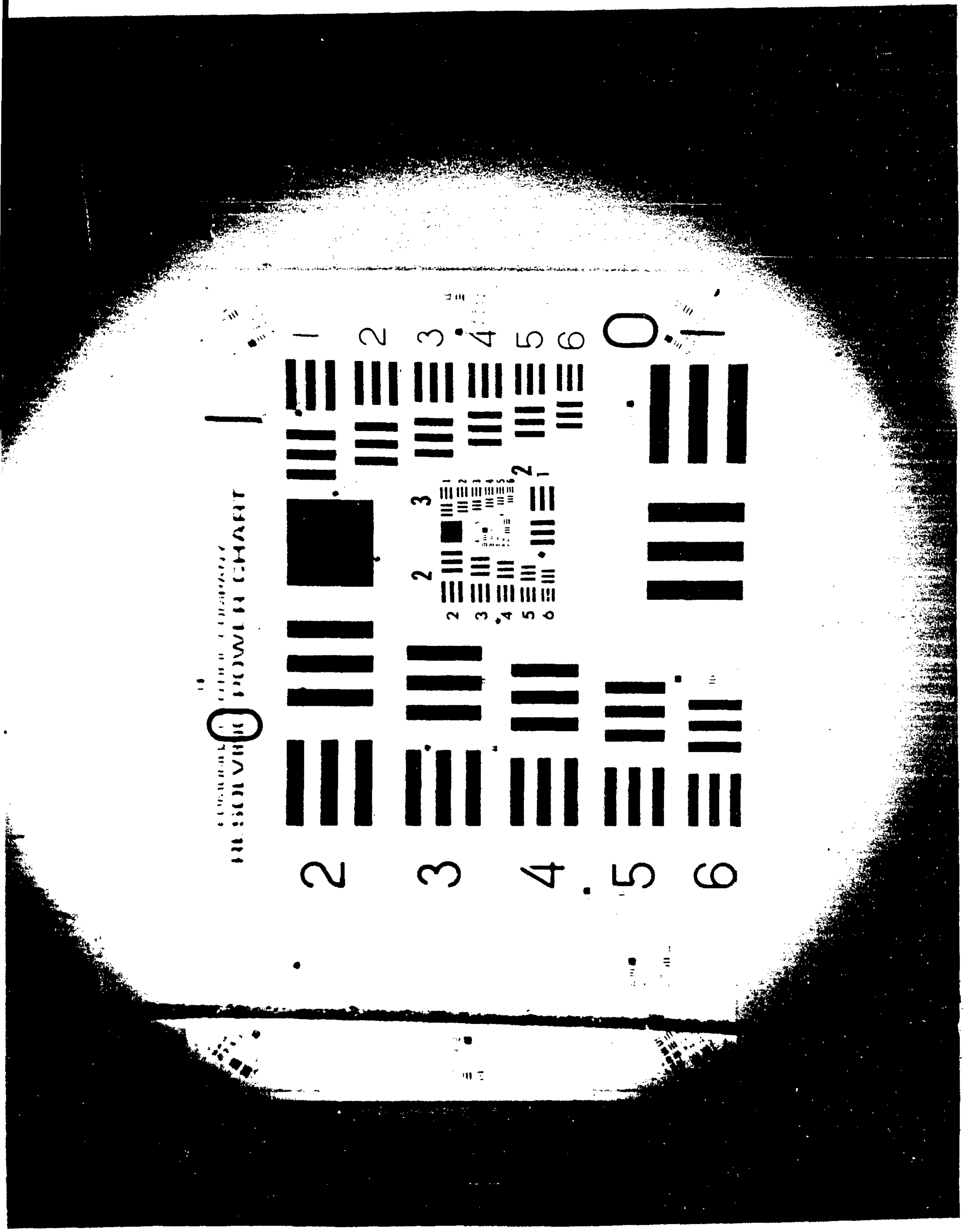


Figure 5-13. Photograph of Resolution Chart with Resolution Reticle in Focal Plane

Table 5-1. U.S.A.F. 1971 Resolution Test Target

Element No.	Line Pairs Per mm						
	Group No.						
	-2	-1	0	1	2	3	4
1	0.250	0.500	1.00	2.00	4.00	8.00	16.0
2	0.281	0.561	1.12	2.24	4.49	8.98	17.95
3	0.315	0.629	1.26	2.52	5.04	10.1	20.16
4	0.354	0.707	1.41	2.83	5.66	11.3	22.63
5	0.397	0.794	1.59	3.17	6.35	12.7	25.39
6	0.445	0.891	1.78	3.56	7.13	14.3	28.51

The field of view cannot be measured accurately from the film because of a mismatch of exit pupil of the vision block with the entrance pupil of the camera, however, visual measurements confirmed the predicted 29^{o} field.

The USAF test target patterns printed on the test chart are in different colors (red, blue and yellow) and at different locations over the field. There are no significant differences among them which shows that chromatic aberration, and off-axis aberrations are insignificant. Figure 5-14 shows a scene through the vision block and it will be seen that image sharpness is maintained over the entire field.

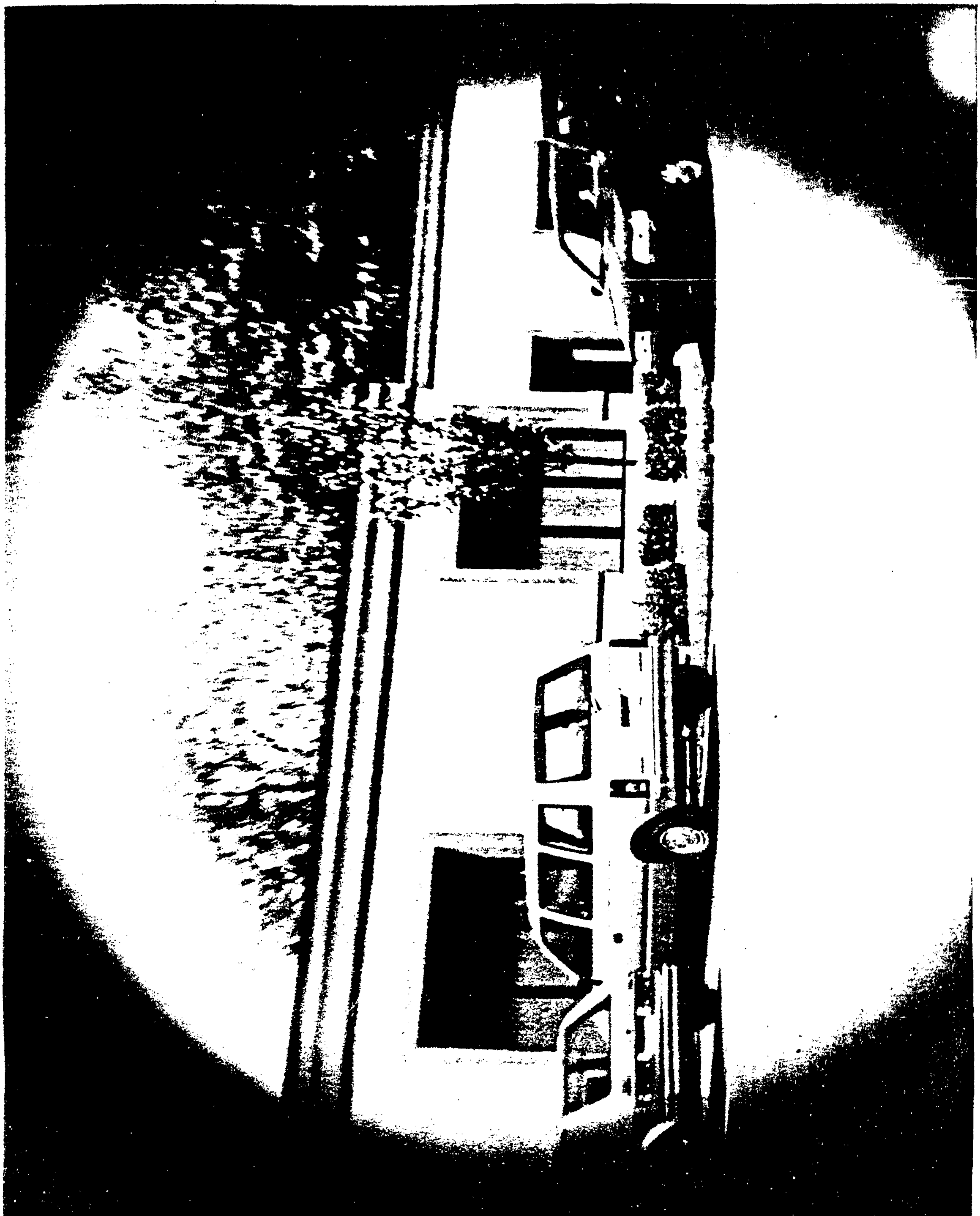


Figure 5-14. Photograph of Scene Through Vision Block

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EDO CORPORATION
BARNES ENGINEERING DIVISION

Judith D. Fazekas

Judith D. Fazekas
Contracts Administrator

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