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RADC-TR-74-331
Final Technical Report
January 1975

COMPASS PREVIEW ADVANCED DESIGN AND VERIFICATION

Northrop Corporation/Electronics Division

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Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York 13441

COMPASS PREVIEW ADVANCED DESIGN AND VERIFICATION

This technical report has been reviewed and is approved for publication.

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The effort performed under this Advanced Design and Verification study was a logical continuation of the preliminary design to further validate and verify the design of the Viewing Module, the critical subsystem through which the imagery is displayed. The effort included the construction and testing of an optical mockup incorporating a Viewing Module and a stereo projection system fabricated to meet the optical design parameters of Compass Preview. Additionally, design studies were conducted to determine the feasibility and desirability
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of incorporating a low magnification viewing mode into the system to provide for full frame-width film viewing while retaining the annotation capability.

PREFACE

This program was initiated by Rome Air Development Center, Griffiss Air Force Base, New York. The advanced design and verification reported herein was performed by the Electronics Division, Northrop Corporation, 1 Research Park, Palos Verdes Peninsula, California, and Northrop's subcontractor, Redwitz Research Corporation, of Irvine, California, under Contract F30602-74-C-0322. The program manager for the design study was Mr. D. E. Zavodnik and the project engineer was Mr. W. G. Baker. The contract monitor for Rome Air Development Center was Lt. Ron Klotz. The contract was initiated in June 1974 and completed in August 1974.

ABSTRACT

A preliminary design of the Compass Preview System was completed in March 1974, under Contract F30602-73-C-0298. This design consists of a functional modular approach for an imagery viewer and supporting equipment, providing the capability to:

- View photographic and digital imagery in stereo or mono.
- Vary the magnification of imagery over a wide range.
- Electronically process imagery.
- Provide relative and absolute automated mensuration and target location determination with a direct readout.
- Automatically retrieve photo data base imagery for comparison viewing.
- Provide hard copies of displayed digital and film imagery with annotations.
- Adapt new technological advances without major redesign, because of the modular design approach.

The effort performed under this Advanced Design and Verification study was a logical continuation of the above preliminary design to further validate and verify the design of the Viewing Module, the critical subsystem through which the imagery is displayed. The effort included the construction and testing of an optical mockup incorporating a Viewing Module and a stereo projection system fabricated to meet the optical design parameters of Compass Preview. Additionally, design studies were conducted to determine the feasibility and desirability of incorporating a low magnification viewing mode into the system to provide for full frame-width film viewing while retaining the annotation capability.

EVALUATION

The Compass Preview Advanced Design results have verified the expected performance of the viewing module as reported in the Preliminary Design Study (RADC-TR-74-257). This effort is the last in a series of efforts to provide a sound technology base and minimize high risk areas prior to the fabrication of the prototype Compass Preview System.

The previous efforts have demonstrated the feasibility of a Compass Preview System which will support imagery exploitation organizations, initially at SAC/544 ARTW and in the future through the spectrum of other users. It will offer the flexibility to be molded into various operational units as well as adapting to the dynamic operational requirements and future collection systems. Additionally, the capabilities Compass Preview provides will insure imagery intelligence is derived in a time responsive manner.

Donald Klotz

Project Engineer
Imagery Applications Section

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SECTION 1

INTRODUCTION

This final report covers the work performed on Contract F30602-74-C-0322, Compass Preview Advanced Design and Verification. The work was performed by the Tactical Avionics Department of the Electronics Division, Northrop Corporation, with Redwitz Research Corporation as a major subcontractor. Additionally, Optical Research Associates, Inc., performed subcontract optical design studies for Redwitz Research Corporation. This work was performed under the direction of Rome Air Development Center, Griffiss Air Force Base, Rome, New York.

This contract was a logical continuation of the Compass Preview Design Study, and was performed to further validate and verify the preliminary design of the Viewing Module, as defined in:

RADC-TR-74-257

Compass Preview Design Study

Final Technical Report, March 1974

Volume 1, Technical Description and Trade-off Studies

The Viewing Module is an assembly consisting of a large Fresnel field lens and a diffuser assembly, whose function is to receive two properly aligned and projected high resolution stereo pair optical images, and transmit these images into two properly sized pupils located at the observer's eyes. In this manner, the observer can see large-screen stereo.

The objectives and work tasks to be performed under this contract were defined by RADC PR No. 1-4-4611, which is presented in its entirety in Exhibit 1-1 on the following page.

To satisfy the requirements of PR No. 1-4-4611, Northrop and its subcontractor, Redwitz Research, constructed a mockup duplicating the Compass Preview preliminary optical design and Viewing Module, capable of providing the two exit pupils at the representative magnifications; design studies and analyses were conducted to determine the optical and mechanical aspects and feasibility of incorporating the low magnification (2x to 5x) mode; and evaluation testing was performed using the mockup to verify the design parameters and human factors aspects.

The results of the analyses and the evaluation tests, and the conclusions and recommendations drawn therefrom, are presented in Section 2 of this report. The technical approaches taken to obtain these results are presented in Section 3. Additional detail supportive data is included in the Appendix. A summary of the most significant finding of the evaluation test, the Viewing Module effect on resolution, is shown in Figure 1-1, and a comparison of these results with the resolution capability of the Zoom 240 microstereoscope is shown in Figure 1-2 and Appendix E.

PR NO. I-4-4611

RESEARCH AND TECHNOLOGY WORK STATEMENT

1.0 Objective: The objective of this effort is the logical continuation of the Compass Preview Program. As with any sophisticated system there remains the task to verify and validate the design of the modules and subsystems by performance evaluation and to integrate the modules to evaluate the inter-module performance, human factors aspects and overall system design and performance.

2.0 Scope: N/A

3.0 Background: N/A

4.0 Tasks/Technical Requirements

4.1 The contractor shall conduct studies leading to the design finalization of the viewing module including study of human engineering and human factors aspects. This study shall include but not be limited to the following:

4.1.1 Performance evaluation of a two exit pupil viewing module conducted via a mockup suitably constructed so as not to deleteriously influence the test results and shall consider as a minimum:

4.1.1.1 The fresnel lens design requirement and shall verify that either a requirement exists for a variable diffusion capability or that a fixed diffusion capability is satisfactory to produce the requisite output resolution and pupil size with a 0.3 inch projection lens exit pupil.

4.1.1.2 Two magnifications to ascertain the axial, zonal, and edge resolution using at least a 600 line pairs/mm resolution target.

4.1.1.3 The effect that image size and the projection cone angle have on the diffuser.

4.1.2 Performance evaluation of direct viewing of imagery from 2x to 5x magnification shall be performed through the use of the system mockup (para. 4.1.1) and shall consider but not be limited to:

4.1.2.1 The analysis of the optical aspects of the requirement including the design option to install an adapter lens system to the projection module to provide an overview of large sections of film and to provide variable magnification below 5x in addition to the capability of extracting hardcopy reproductions with annotations.

4.1.2.2 Analysis of the mechanical aspects of the requirement including the impact of the adapter lens design option.

EXHIBIT 1-1

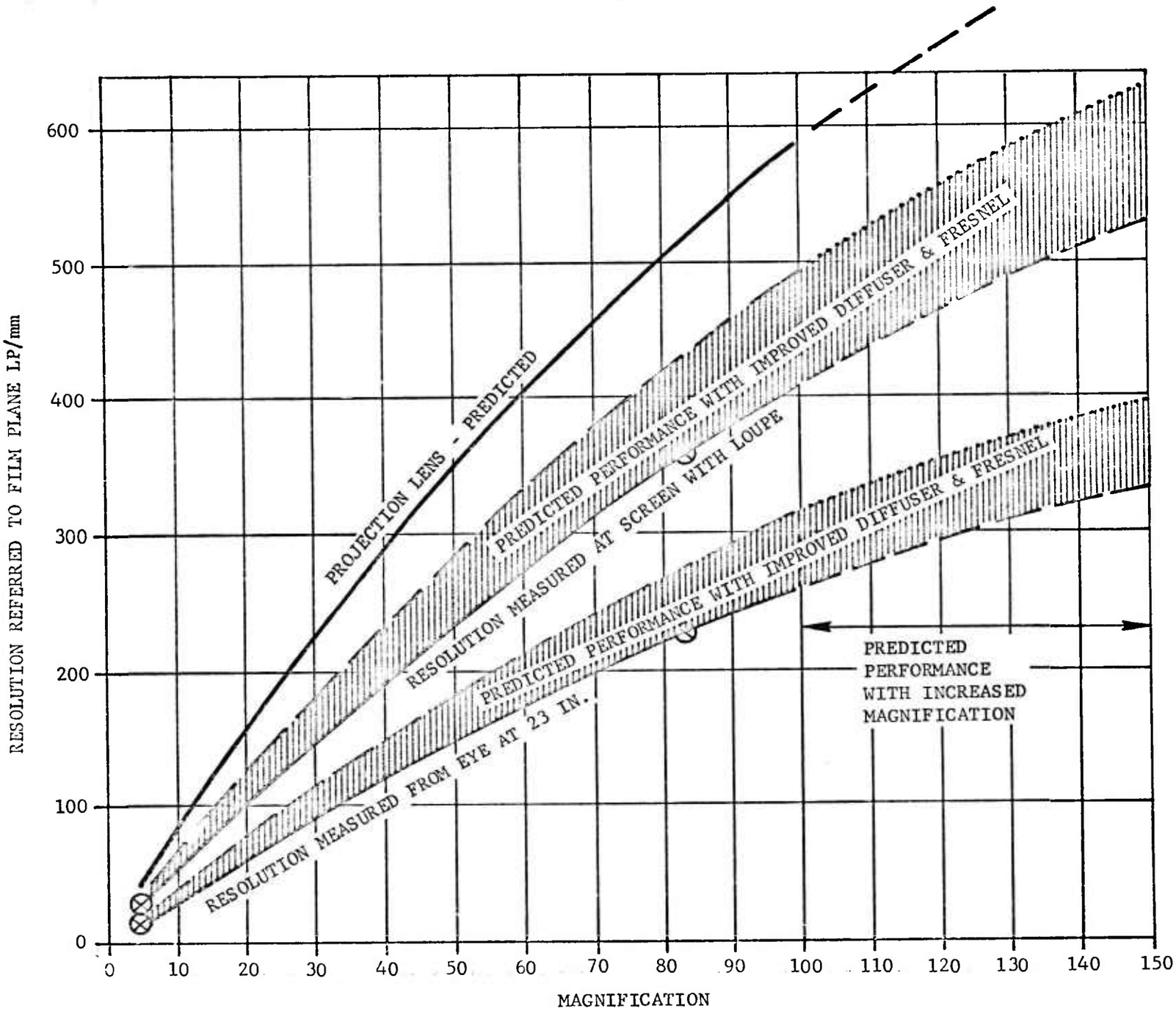

Figure 1-1. Compass Preview Resolution vs Magnification

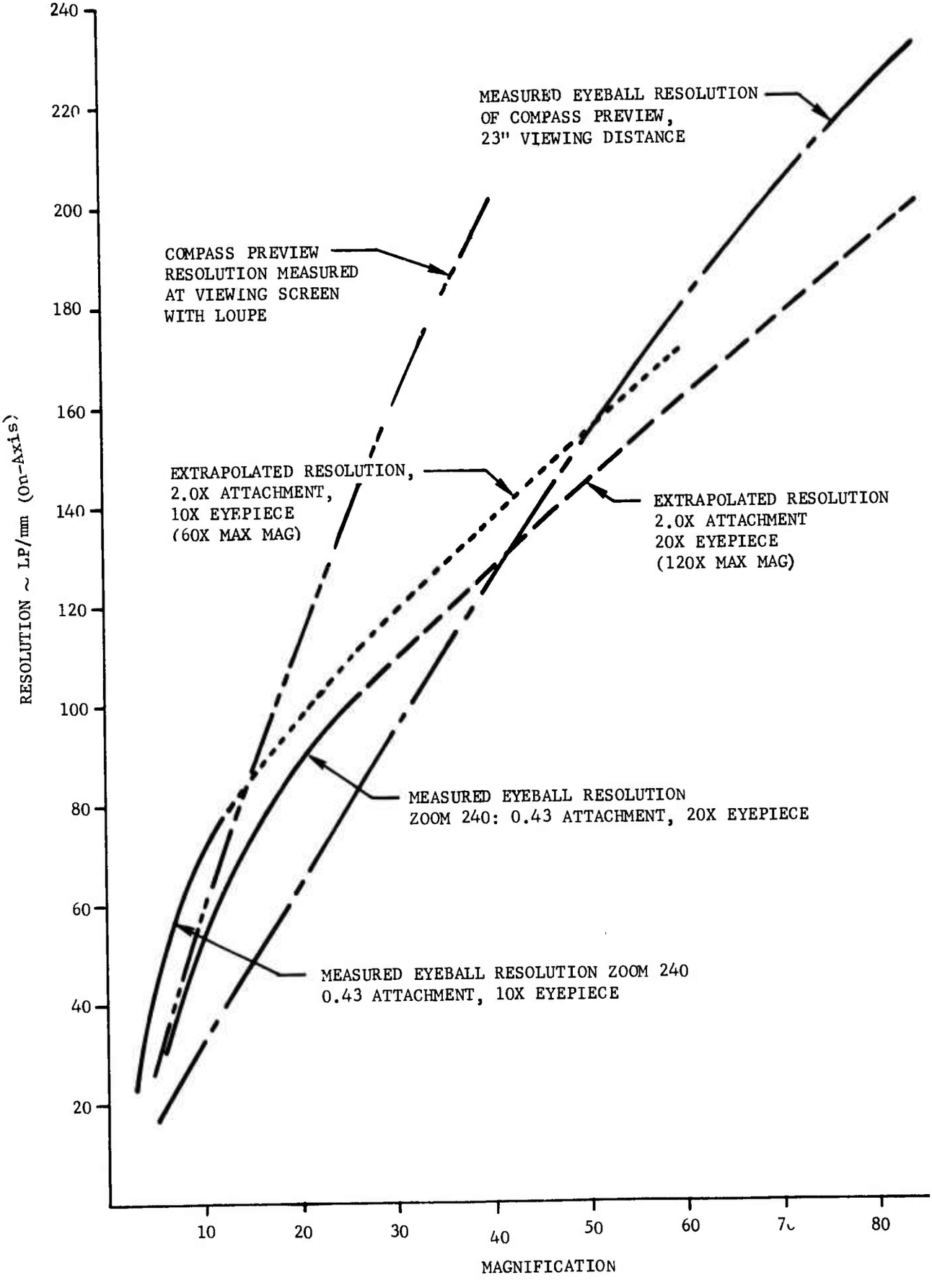

Figure 1-2. Compass Preview/Zoom 240 Comparative Results

The comparison of the Compass Preview viewing module and the Zoom 240 Microstereoscope in Figure 1-2 and Appendix E are for on-axis resolution only. It is important to note that resolution degradation off-axis is extreme for the Zoom 240 (as results indicate in RADC-TR-70-150) compared to the Compass Preview system (reference Appendix B, p10-11).

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SECTION 2

CONCLUSIONS

The technical approach for the Compass Preview Advanced Design and Verification was threefold:

a) A precision optical mockup, capable of closely duplicating the Compass Preview optical design parameters at discrete magnifications of 1.8X, 5X and 83X, was designed and constructed.

b) Design studies were conducted to ascertain the feasibility of incorporating a low magnification (2X) capability into the Compass Preview design.

c) Evaluation testing was conducted using the mockup to verify the design of the Viewing Module, and to evaluate the low magnification viewing mode.

This section presents the findings of the evaluation tests and the design studies, the conclusions reached therefrom, and recommendations as to the application of these conclusions to the Compass Preview preliminary design.

2.1 FINDINGS

The findings of this effort are subdivided into two categories:

a) Findings resulting from the evaluation test program.

b) Findings of the optical and mechanical design studies on the feasibility of incorporating the low magnification capability.

2.1.1 Evaluation Test Findings

Based on the evaluation tests, the following conclusions are reached by the contractor:

a) Need for Variable Diffusion: Two distinct levels of diffusion are required in Compass Preview. However, rather than have the two diffusers function as one for mono (2D) viewing and one for stereo (3D) viewing per the Compass Preview preliminary design, they will better serve as one diffuser for general purpose viewing (mono and stereo); and one for detailed viewing, as described in paragraph 2.1.1.1.

b) Viewing Module Resolution: The Viewing Module (Fresnel lens plus diffuser) evaluation shows that the human operator, seated at the proper

23-inch viewing distance, can expect to resolve between 3 and 3.5 line pairs per millimeter per power of magnification with improved Fresnel and diffuser. This resolution factor could be improved if desired by increasing the Compass Preview zoom lens response (modulation transfer function) by increasing its aperture; the maximum perceived resolution can be increased by increasing the zoom lens magnification, and/or by decreasing the 23" viewing distance (see Appendix C).

c) Effect of Image Size and Projection Cone Angle: The consensus of contractor personnel is that head motion and operator comfort factors while viewing Compass Previous in stereo is excellent compared to microstereoscope viewing for any prolonged period, and that the circular screen shape of 19.5-inch diagonal size is preferred. However, this finding will require more extensive evaluation by Air Force P.I.'s before a final determination is made. There appears to be no effect on the diffuser when the projection cone angle is changed.

d) Low Magnification (2X - 5X) Viewing: The low magnification viewing mode provides an excellent quick-scan look capability of the image. More detail can be seen and evaluated on the viewing module at 1.8X than can be seen with the unaided eye viewing the film directly. It is mechanically and optically feasible to incorporate this feature into the Compass Preview preliminary design.

The supporting data for the above findings is discussed in the following paragraphs. Additionally, all the 'raw' data sheets, completed by the observers per the test plan (Appendix A), are included in Appendix B.

2.1.1.1 Need for Variable Diffusion

To evaluate the diffusers, the Compass Preview mockup with Fresnel field lens and projection optics of 83X, 5X, and 1.8X were used to evaluate the two diffusers supplied by Redwitz Research Corporation.

- Diffuser #1, Redwitz number 2G-4-2064 (referred to as #2G on data sheets); this diffuser provides smaller pupils (less diffusion) and was intended for stereo viewing.

- Diffuser #2, Redwitz number 3G-6-2064 (referred to as #3G on data sheets); this diffuser provides larger pupils and was intended for mono viewing.

These diffusers were first evaluated subjectively with stereo pair imagery projected. The number 3G diffuser provides acceptable mono viewing and excellent stereo viewing. The number 2G diffuser provides marginal mono viewing and the stereo quality, while good, was not as comfortable to the viewer as was the viewing using the 3G diffuser. With the 2G, head motion is more restrictive and the apparent screen brightness is greater but more

variable with head motions. With both diffusers, minute color scintillations around diffuser granulations can be seen, but these are not objectionable and do not detract from viewing.

Next, the diffusers were tested for pupil size and brightness distribution, and photographed. The methods used are outlined in Section 3 and in Appendix C.

Figures 2-1 and 2-2 are the photos taken of the pupils at 5X projected magnification with the 2G diffuser in place and a reference grid in the pupils. Figures 2-3 and 2-4 are the pupils at 5X using the 3G diffuser. Figure 2-5 is the pupils of the Fresnel lens only (no diffuser). The source illumination at 5X was 225 watts.

Figures 2-6 and 2-7 are pupils at 83X projected magnification with the 2G diffuser; Figures 2-8 and 2-9 are at 83X with the 3G diffuser, and 2-10 is the Fresnel-only pupils at 83X. The source illumination used at 83X was reduced to 175 watts.

Photos of the pupils at 2X are nearly identical to those at 83X and 5X, and are included in Appendix B.

The 225-watt illumination setting at 5X, and the 175-watt setting at 83X appeared to viewers of imagery to give the "best" picture (subjectively) at these magnifications. Recording the pupils on film at these settings, and with identical camera settings, causes the photos of the 83X pupils to appear smaller than the 5X pupils. Due to the fact that pupil edges are not distinct, changing camera or illumination settings causes variations in the size of the photographed pupil. The human observers could tell no difference in pupil size at the two magnifications.

Figures 2-11, 2-12 and 2-13 are plots of the recorded brightness of the pupils and the source illumination at 83X, 5X, and 1.8X, respectively. These plots represent the fall-off in observed screen brightness one sees while looking at the center of the screen and moving the head laterally or vertically across the pupil. Screen "gain" data is also included on Figure 2-12. Figure 2-11 also includes a dual exit pupil plot of % brightness distribution for both diffusers.

Measurements of apparent screen brightness with the head fixed and the eye roving across the screen from a fixed position (angular scanning) could not be made with the equipment available for test. From a subjective standpoint, the screen brightness appears nearly constant to the viewer with the head stationary and scanning with eye motion only. It is more nearly constant with the 3G diffuser than with the 2G diffuser.

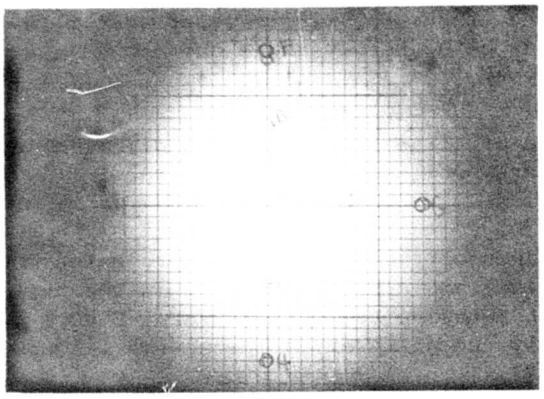

Figure 2-1. 5X, 2G Diffuser, Single Pupil

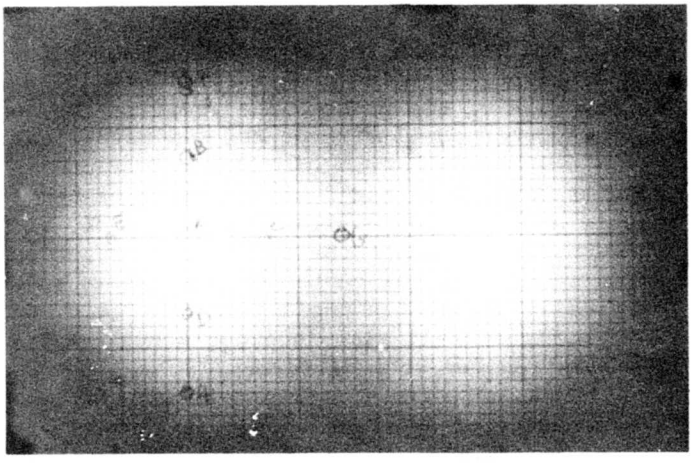

Figure 2-2. 5X, 2G Diffuser, Both Pupils

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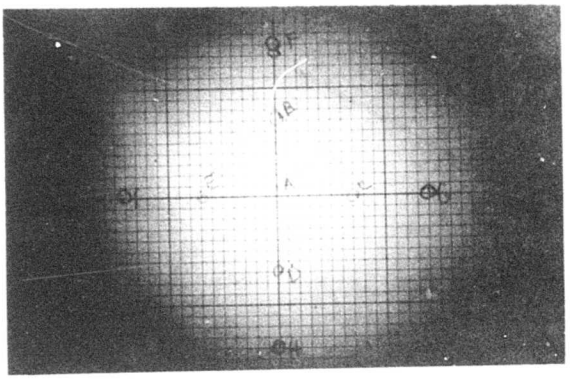

Figure 2-3.
5X, 3G Diffuser, Single Pupil

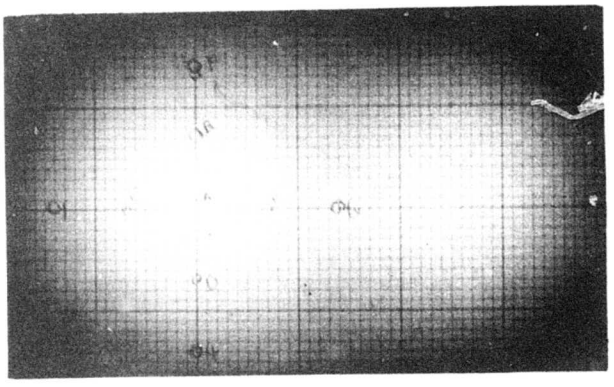

Figure 2-4.
5X, 3G Diffuser, Both Pupils

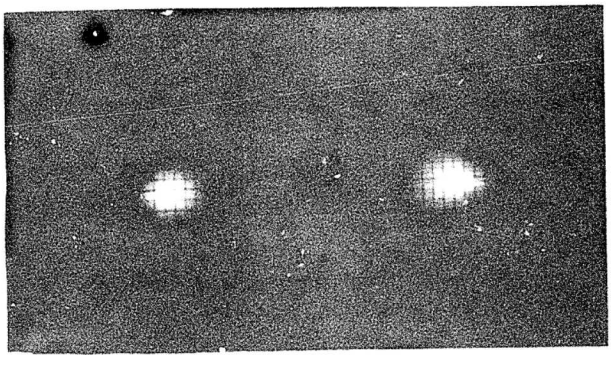

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Figure 2-5. 5X, Fresnel Lens Only

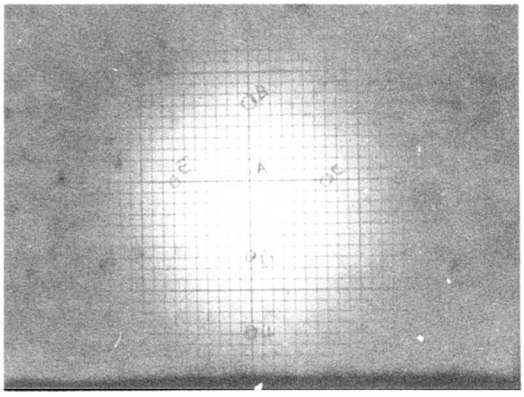

Figure 2-6. 84X, 2G Diffuser, Single Pupil

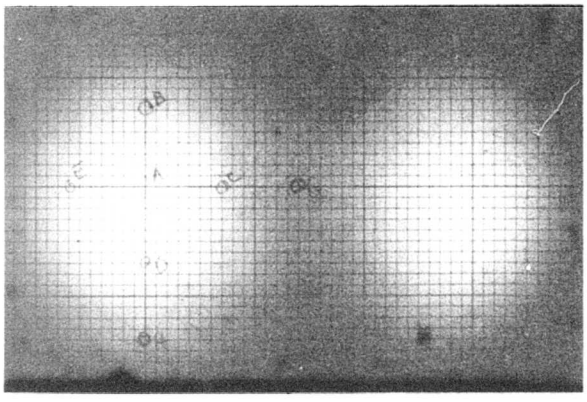

Figure 2-7. 84X, 2G Diffuser, Both Pupils

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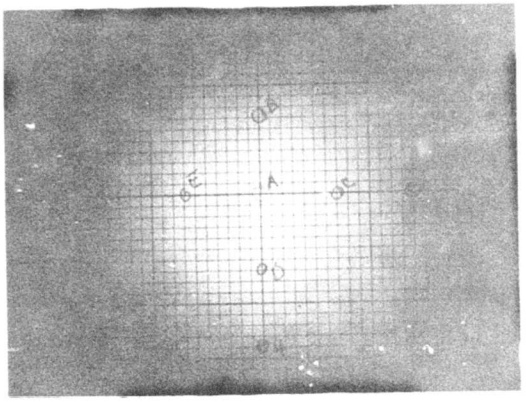

Figure 2-8.

84X, 3G Diffuser, Single Pupil

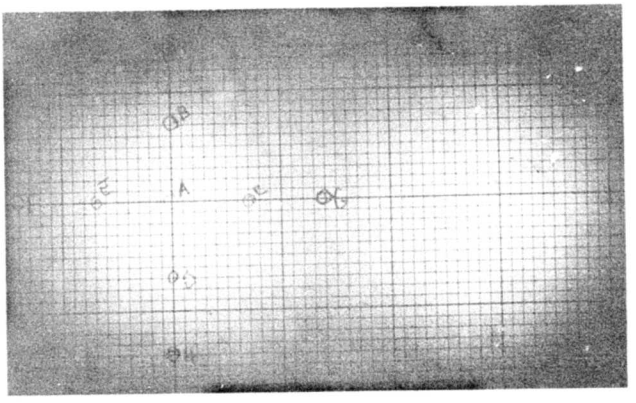

Figure 2-9.

84X, 3G Diffuser, Both Pupils

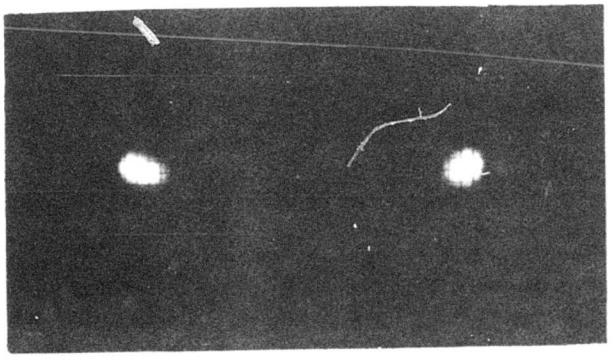

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Figure 2-10. 84X, Fresnel Lens Only

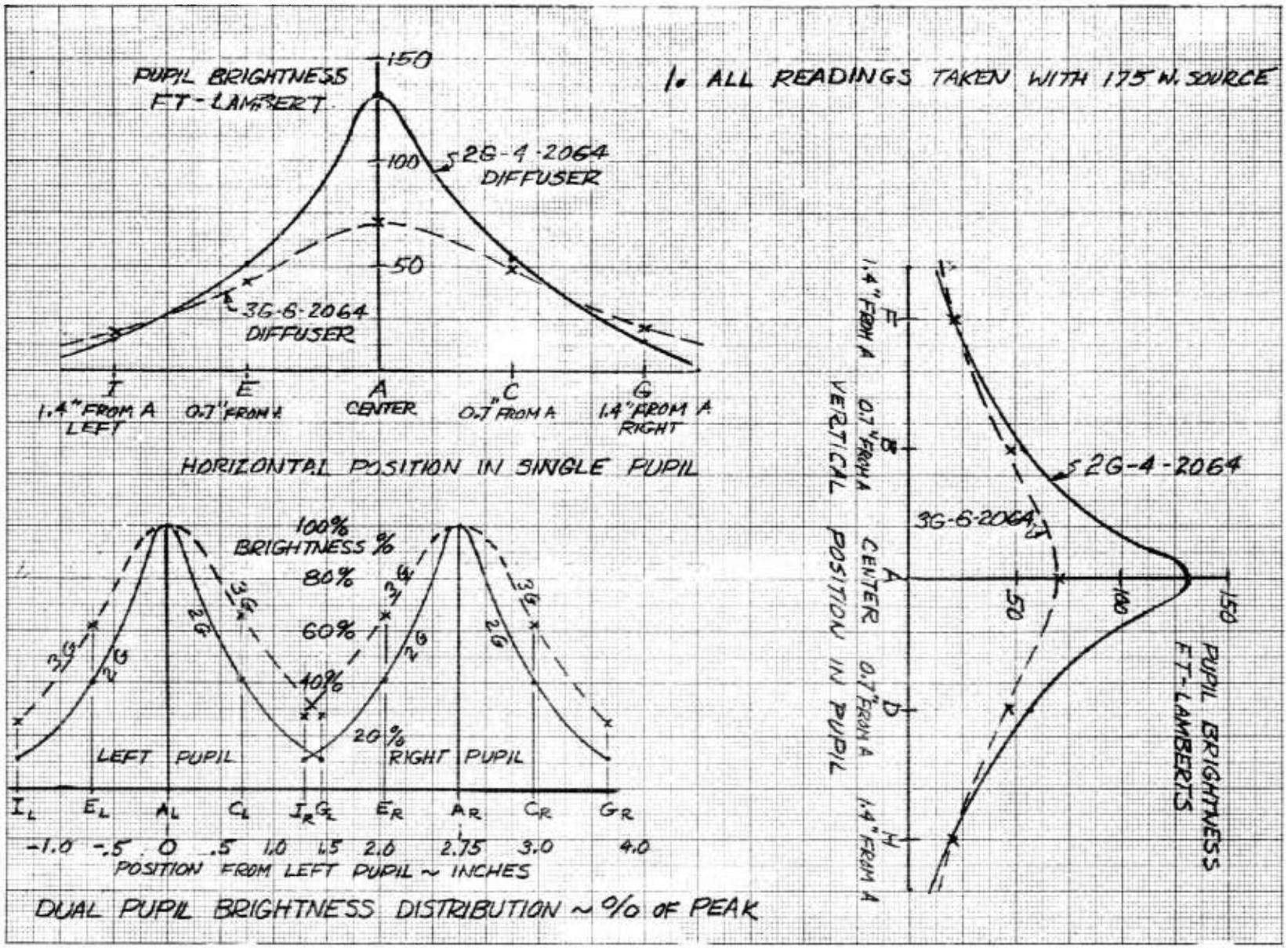

Figure 2-11. Pupil Brightness Distribution, 83X

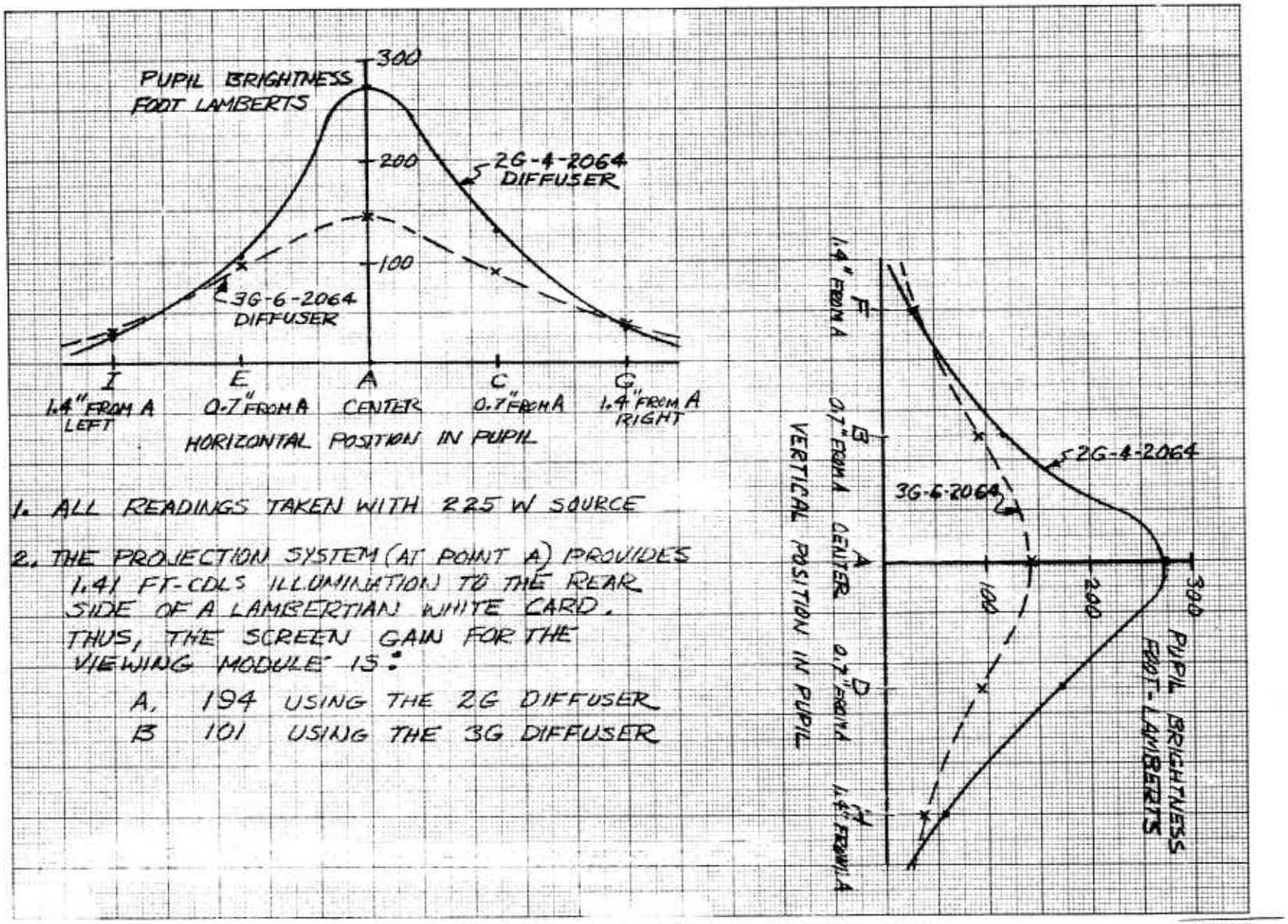

Figure 2-12. Pupil Brightness Distribution, 5X

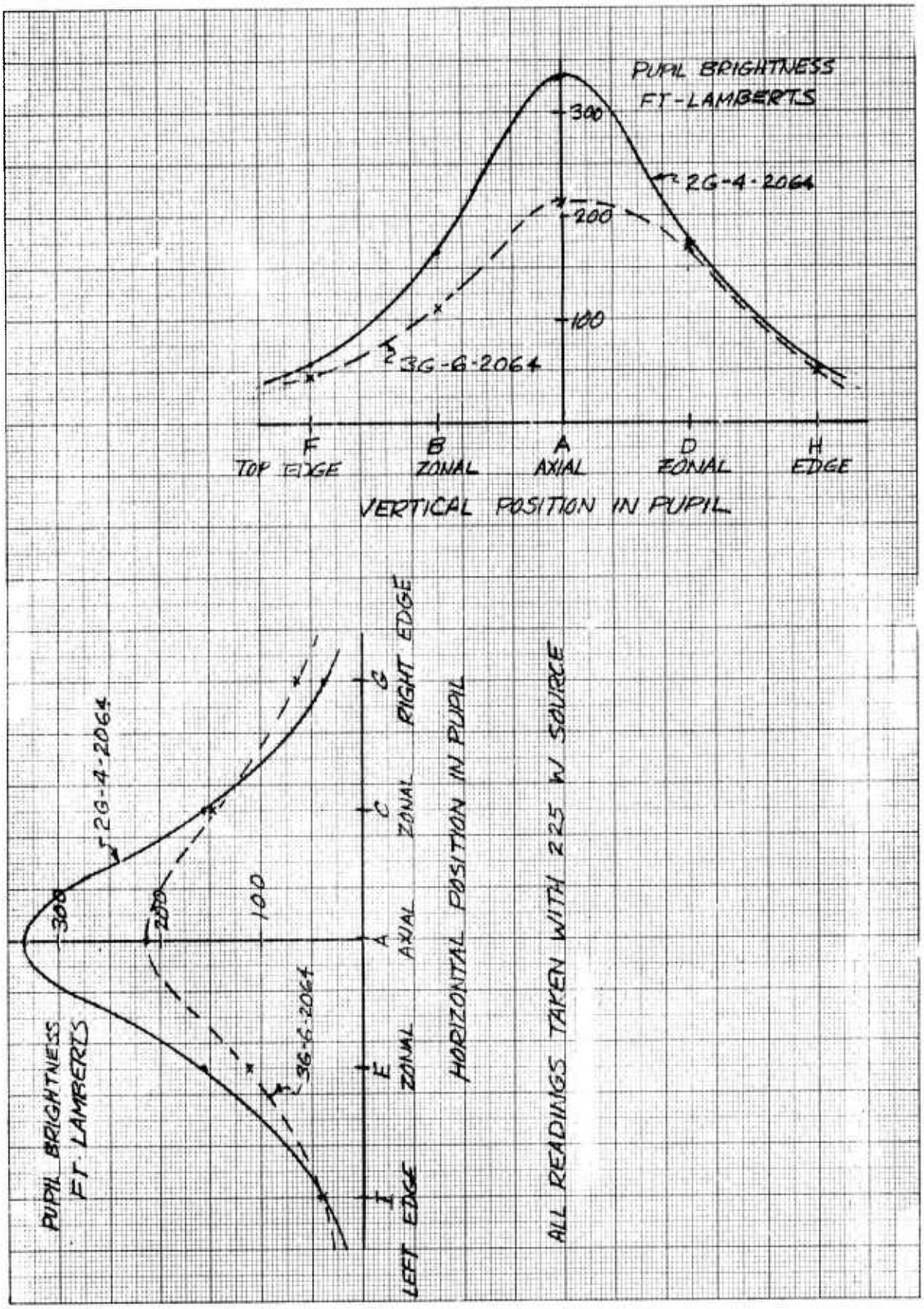

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Figure 2-13. Pupil Brightness Distribution, 2X

The third test involving diffuser performance involved resolution testing (discussed in detail in Paragraph 2.1.1.2). From this test it was determined that the greater the diffusion, the greater the effect on optical resolution.

This fact, coupled with the earlier finding that the best mono diffuser also provides the most comfortable stereo viewing, leads to the stated conclusion that one diffuser can be used for both mono and stereo viewing in general, but that when an object is to be minutely examined for detail, a second diffuser designed for high resolution, rather than large pupil size, should be used.

Further, the "general viewing" diffuser should provide a slightly larger pupil size than that provided by the tested 3G-6-2064 diffuser, and the "high resolution" diffuser can provide a smaller pupil if it could provide a significant corresponding increase in resolution.

2.1.1.2 Viewing Module Resolution

To evaluate the optical resolution effects, precision USAF 1951 resolution test patterns were placed in the film gates of the mockup. The following test patterns were used:

a) For 83X testing, an ITEK XTRG 302.112A high contrast (>20:1) target, from 16 to 912 lp/mm (group 4-1 to 9-6) was used.

b) For 5X and 2X testing, an ITEK STR 702.112 high contrast target, from 1 lp/mm to 228 lp/mm (group 0-1 to 7-6) was used.

The resolution readings were taken at nine locations (one axial, four zonal, and four edge) over the viewing screen. For each location, resolution on the complete viewing module was read by three observers viewing the screen in proper position. Then the same reading was taken using a low power (12X) telescope. Then, still using the telescope in the pupil, the diffuser was removed and resolution again read, and then the Fresnel was removed and the direct projected resolution read. In this manner the resolution contribution of each element was determined.

Figure 2-14 is a plot of the resolutions taken at 83X, in lp/mm at the film plane. Curve A is the resolution read by eye on the viewing module assembly, curve B is the resolution read by telescope on the viewing module, curve C is the resolution with the diffuser removed (Fresnel in place), and curve D is the resolution with the Fresnel removed (projected resolution to the viewing module).

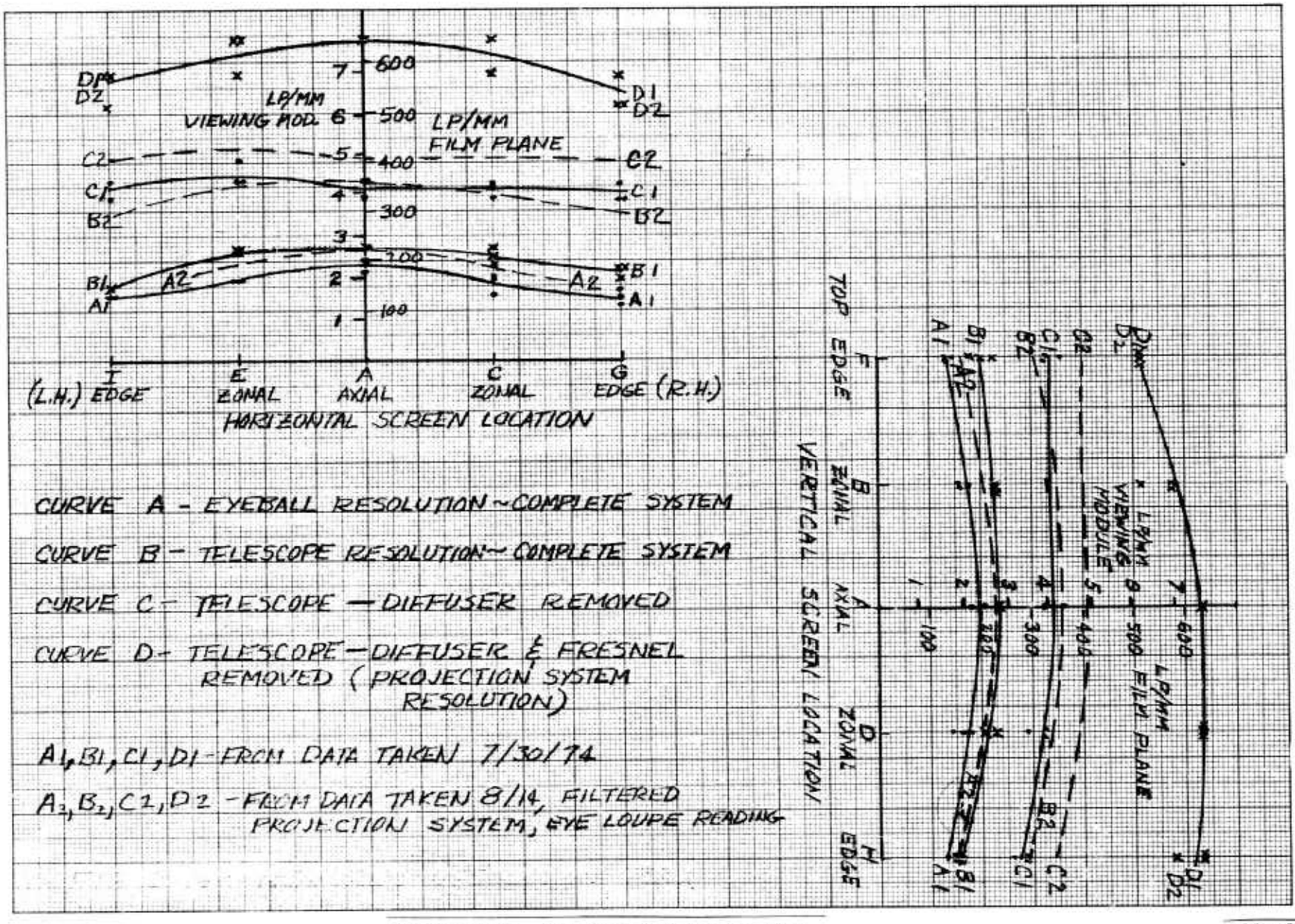

Figure 2-14. Measured Resolution, 83X

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Note that curve D essentially is the measured resolution of the commercial projection lens used. Manufacturer's performance data was not available for these lenses at the time of purchase, but supplier experience indicated they were the best available and had near diffraction limited performance, which was confirmed by these tests.

A comparison of Figures 2-14 and 2-15 with Figures 2-11 and 2-12 shows that the resolution performance degrades only minimally (≈15%) from axial readings to edge readings, while the illumination level falls rapidly from axial to edge location (≈600%), indication that resolution performance is not a direct function of illumination level or distribution.

A review of the data shown in curves A1, B1, C1 and D1 (data sheet dated 7-30-74, reproduced as page B-10 of Appendix B) was at some variance with previous performance data. A review of the system indicated that reducing the screen illumination by varying input voltage to the source was not the optimum method, and the axial readings were repeated using neutral density filters and a blue cut-off filter to lower screen illumination. These readings were taken with a 7X eye loupe at the Viewing Module, and are shown as the improved curves A2, B2, C2 and D2, on Figure 2-14.

Figure 2-15 is a similar plot of the measured resolutions taken at 5X.

As a result of this data, an additional test was conducted to remove all effects from the projectors. For this test, the 1 to 228 lp/mm target was first viewed by observers at the Compass Preview 23-inch viewing distance; it was then placed on the back side of the Fresnel field lens and read, and then on the back side of the diffuser and read, and finally on the back side of the Fresnel/diffuser assembly and read, with all readings taken by eyeball at 23-inch viewing distance. The results are presented in Table 2-1.

TABLE 2-1. TEST RESULTS, 23-INCH VIEWING DISTANCE

		Group (2 observers)	lp/mm
1.	Target STR 702.111 alone	2-2, 2-3	4.7 avg
2.	Target behind Fresnel	2-1, 2-1	4.0 avg
3.	Target behind diffuser 3G	1-6, 1-6	3.56 avg
4.	Target behind diffuser 2G	2-1, 1-6	3.80 avg
5.	Target behind diffuser and Fresnel	1-5, 1-5	3.17 avg

The above test represents an unachievable ideal situation; i.e., an image projected up to the viewing module with no loss of modulation (contrast).

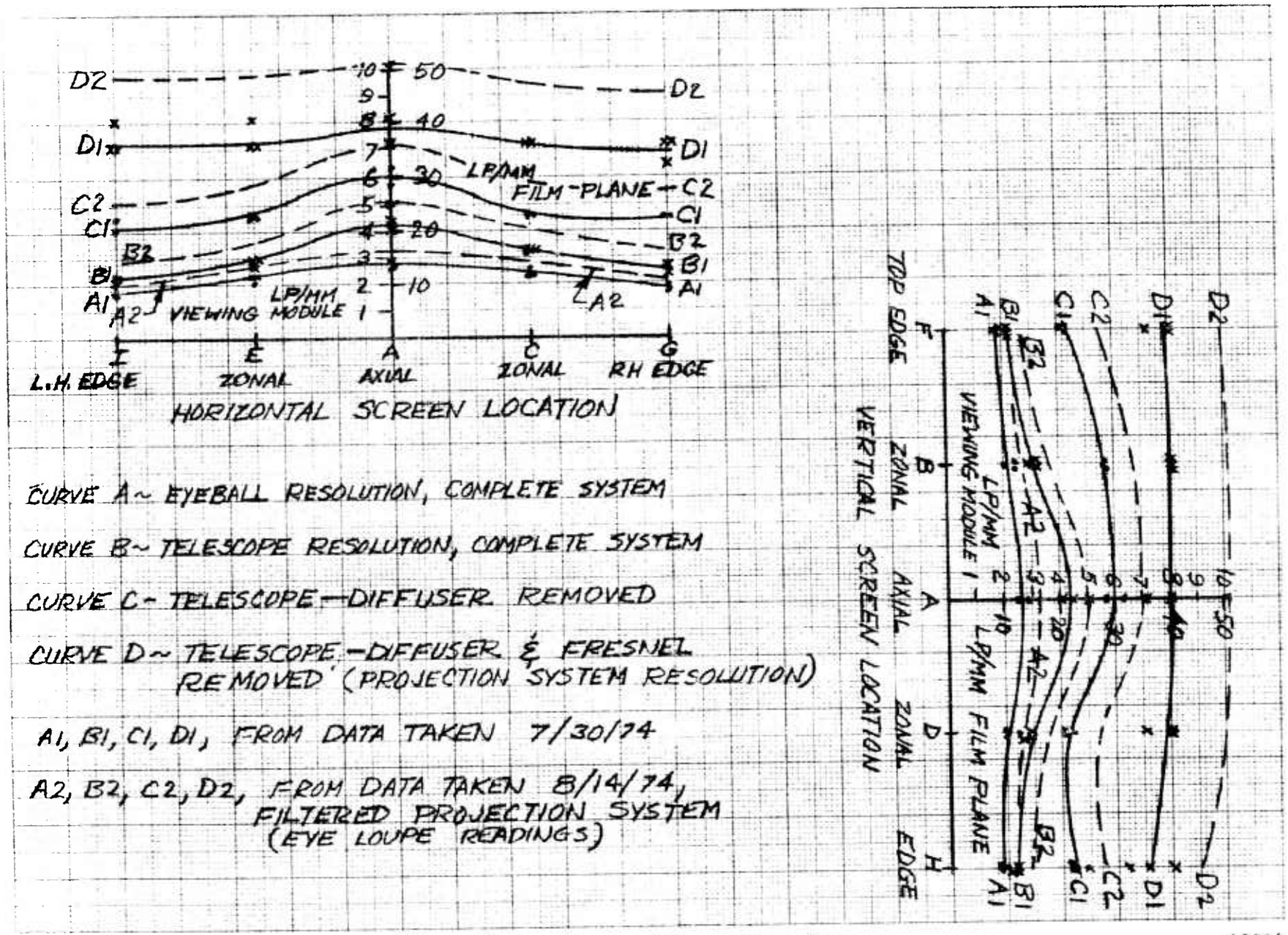

Figure 2-15. Measured Resolution, 5X

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Item 1 (viewing of the target alone) is of particular interest. The commonly accepted value for resolution of the human eye is one arc-minute. Using that value (sin one arc-min = 0.00029), the eye at 23.25 inches (590.55mm) should resolve 590.55 x 0.00029 = 0.171 mm or $\frac{1}{0.171} = 5.85$ lp/mm (100% contrast). Yet, the average of two tested observers, with 20/17 and 20/18 vision respectively, is that they can resolve 4.7 lp/mm, not 5.85 lp/mm, using a 100% contrast target viewed from 23.25 inches.

Note from Figures 2-14 and 2-15 that the resolution of the mockup projection system is 645 lp/mm at 83X, or over 7 lp/mm at the screen, and that this performance closely matches that calculated for the Compass Preview zoom lens (6 lp/mm at the screen).

Note that with limiting resolutions of the eye, Fresnel and diffuser as measured above, the measured system (eye) resolution was 2.8 line pairs/mm at 83X, and 3.2 lp/mm at 5X. It is estimated that after optimization of the Fresnel and diffuser, and utilizing the present zoom lens design, the system screen resolution can approach 5.0 lp/mm, which relates to an eye resolution of greater than 3.0 lp/mm, when viewed at a 23-inch viewing distance. An analysis of eye performance viewing the projected imagery is presented in Appendix C.

During resolution testing using the telescope for readings of "Fresnel only" resolution, it was noted that the grooves of the Fresnel lens tend to confuse resolution readings with the telescope. This fact leads to the question whether the selection of 150 grooves/inch for the Compass Preview Fresnel lens is an optimum. In order to examine the Fresnel spacing effect on resolution for this application, several other Fresnel lenses from the contractor's laboratory were fitted to the mockup and tested. These lenses provided groove densities of 48 grooves/inch (3 lenses), 125 grooves/inch (2 lenses) and 300 grooves/inch (1 lens). Tests were taken at the axial location only for these lenses, and the results are shown in Figure 2-16. They were also read with the grooves toward the projector (as designed) and with the grooves toward the operator. The conclusions from this test are:

a) The density of 125 grooves/inch is best of those tested.

b) Performance is slightly better in some cases with grooves toward the operator.

c) There is considerable spread of performance of Fresnel lenses of the same groove density. This could be caused by:

   1) Different f/numbers (focal lengths)
   2) Material from which lens is made
   3) Manufacturing method, or quality.

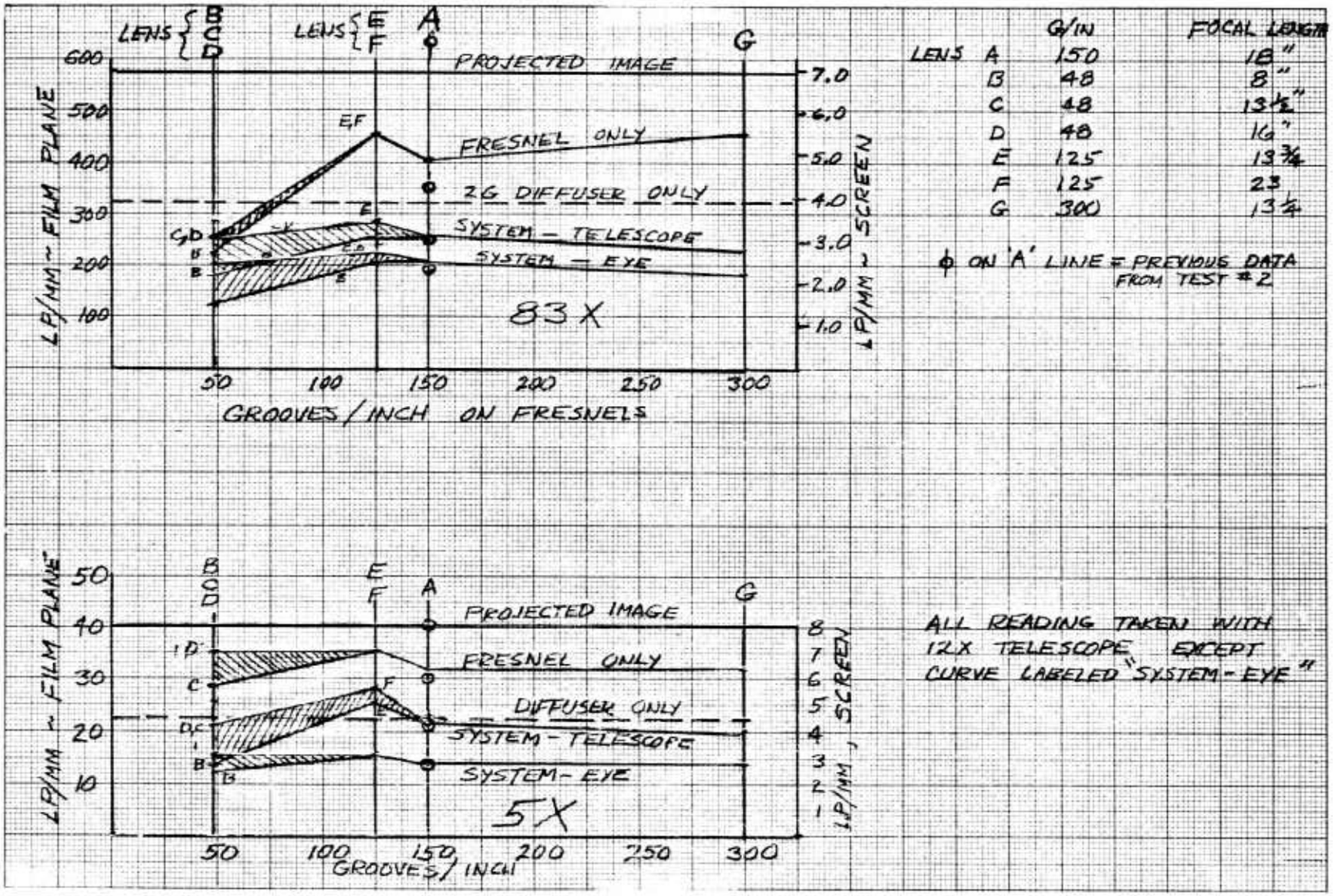

Figure 2-16. Effect of Fresnel Groove Density

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Additionally, a series of tests were conducted using a 7X eye loupe at the viewing module, instead of the 12X telescope located approximately 4 feet from the Viewing Module, to determine if the telescope method of reading used for the measurements had itself limited or distorted the readings. These results are shown in Table 2-2 (for point A axial readings only), and show that readings with the loupe are better because the image magnification presented to the eye with a 7X loupe at 1" viewing distance is greater than that presented by the 12X telescope at 48" viewing distance. Resolution measurement methods are shown in Figure 2-17.

TABLE 2-2 TEST RESULTS, USING 7X EYE LOUPE

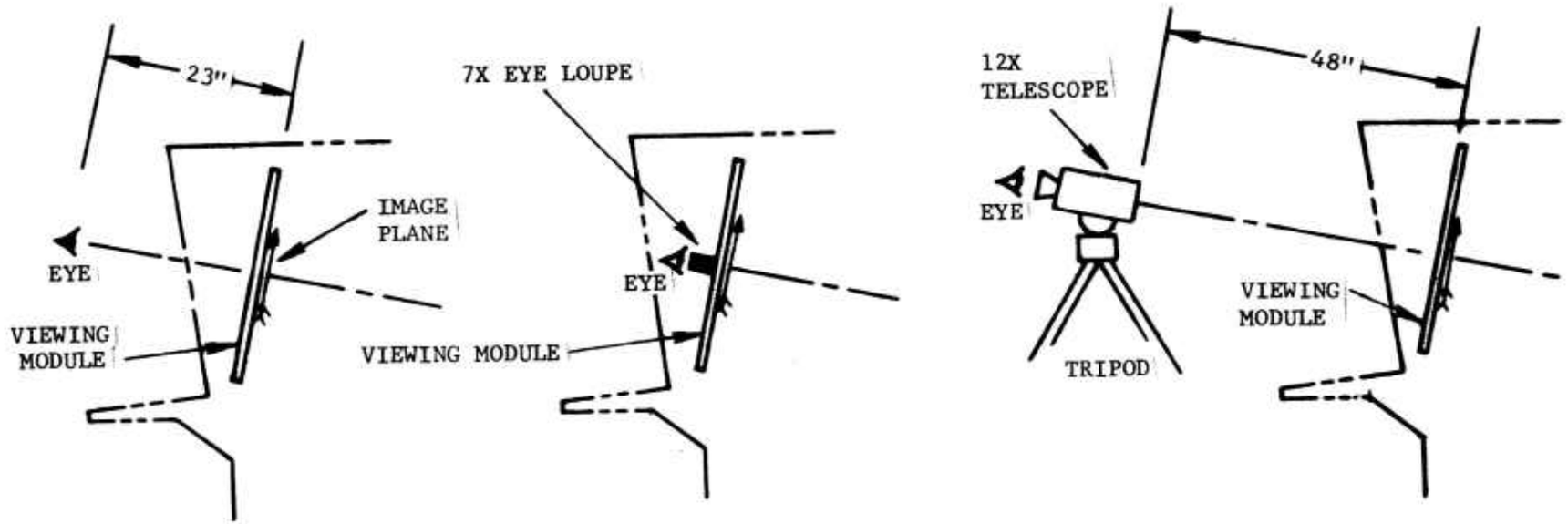
	Max Reading - Telescope*		Max Reading - Loupe**	
Magnification	83X	5X	83X	5X
Aerial Image (Projected)	7.8	7.8	7.8	10.1
Aerial Plus Fresnel	4.2	6.2	4.9	7.1
Aerial, Fresnel, Plus Diffuser	2.8	4.2	4.3	5.1

*From above test of different diffusers - Appendix B, Test No. 1, Pages 1 & 2.
**Taken after adding neutral density and blue filters to reduce illumination level.

All of the resolution tests conducted lead to the conclusion that the Compass Preview Viewing Module can be improved by optimizing the Fresnel lens design for groove density, manufacturing method, and material; and optimizing the high-resolution diffuser for better resolution with the resultant smaller pupil.

A Viewing Module with these improvements could present up to 5.0 lp/mm at the Viewing Module and 3.5 lp/mm to the unaided eye at the proper 23-inch viewing distance, or 350 lp/mm of film resolution at 100X, using the currently designed zoom projection lens.

To further improve the performance of the unaided eye, it would be necessary to improve the resolution of the projected image to the Viewing Module by increasing the magnification range, or by increasing the exit pupil (aperture) of the zoom lens, or by decreasing the 23" operator viewing distance (see Appendix C).



A. "EYEBALL" READINGS

B. LOUPE READINGS

C. TELESCOPE READINGS

43102

Figure 2-17. Schematic Representation ~ Resolution Measurement Methods

2.1.1.3 Effect of Image Size and Projection Cone Angle

To evaluate this effect, both on diffuser performance and as a human factor effect on the observers, various sized masks were used to limit the viewing screen size and shape, and thereby limit the cone angle.

No effect of cone angle on diffuser performance could be noted. The effect of screen size on the observer is largely subjective. With the design size large screen (22.5 inches square with clipped corners), seeing into the corners from the nominal eye position is difficult. Most observers found it uncomfortable to hold their heads fixed and swivel the eyeballs 31° to reach the very corner; instead they would turn their heads, which necessitated repositioning the head to stay within the stereo pupils.

Interestingly, several observers prefer a round, rather than square, screen shape. This preference could become stronger for Compass Preview when the ability to rotate the image (which could not be done on the mockup) is incorporated. With image rotation capability, an object visible in the corner of a square screen would, of course, disappear with a few degrees of rotation. This is a finding of contractor personnel only, and a more extensive evaluation by Air Force photo interpreters is required in this area.

2.1.1.4 Low Magnification Viewing Evaluation

In addition to measuring pupils and resolutions (see data sheets, Appendix B), a subjective evaluation of image quality and appearance, versus viewing the film directly with the unaided eye, was made. The image on the Viewing Module is easier to evaluate and shows more detail than direct viewing with the unaided eye. For example, a row of 12 parked light aircraft can be consistently counted accurately at 1.8X, whereas the count made from the direct view of the film was 10 or 11, depending on the particular viewer. The fact that, at 1.8X, the full image does not fill the viewing screen does not detract from the presentation, and was not even noticed by some observers.

2.1.2 Low Magnification Optical and Mechanical Study Results

To determine the feasibility and impact on the Compass Preview preliminary design of adding the Low Magnification Viewing Mode (2X to 5X), Redwitz Research Corp., in conjunction with Optical Research Associates, analyzed the optical and mechanical effects of adding auxiliary "flip-in" optics to the system, and of providing proper illumination over the increased area of the film being viewed. The complete results of this study are included in Appendix D.

In summary, the results are:

a) It is optically feasible and practical to add an adapter lens set to the existing Compass Preview zoom lens to provide a low magnification viewing range from 2X to 5.4X. The lens set consists of one element located between the flip mirror and the zoom lens objective, and one element located between the zoom objective and first moving lens element.

b) It is also mechanically feasible and practical to add these lenses to the system. An electric motor drive mechanism will index the lenses in and out of the optical path for low and high range viewing of imagery.

c) At the 2X magnification, the entire 9.0-inch x 9.0-inch frame can be viewed (with corners "clipped" on an 11.4-inch diameter circle), and this will be presented as an 18.0-inch x 18.0-inch format (with corners clipped at 22.8-inch diameter) on the Viewing Module.

d) The low magnification mode is completely compatible with all other Compass Preview capabilities and operating modes, including the abilities to annotate, mensurate, and prepare hard copies of imagery at 2X.

2.2 RECOMMENDATIONS

As a result of the evaluation tests and studies conducted under this program, the following are recommended for incorporation into the Compass Preview preliminary design and/or further study:

a) Two diffusers should be incorporated into Compass Preview, one to be used in a general viewing mode, and one to be used in a high detail mode.

b) Continued refinement of the optical properties of both the diffusers and the Fresnel field lens is warranted to achieve the full potential of the design.

c) Preliminary indications are that a smaller (19.5-inch diameter) circular screen is preferred for viewing by the evaluation personnel. However, it is recommended that as many viewers as possible, particularly photo interpreters, concur with this finding before any design changes are incorporated into Compass Preview.

d) The contractor evaluation of the low magnification (2X to 5X) viewing capability is that it is both feasible and desirable to incorporate this feature into the Compass Preview preliminary design.

SECTION 3

TECHNICAL APPROACH

The technical approach for the Compass Preview Advanced Design and Verification effort included the construction of an optical mockup, design studies of low magnification viewing, and evaluation testing utilizing the mockup.

3.1 COMPASS PREVIEW MOCKUP

The Compass Preview mockup consists of two basic sections or subassemblies:

a) The console assembly, including the viewing module (Fresnel field lens and diffuser), and control panel. The console physical and optical parameters have been made to duplicate the Compass Preview preliminary design (ref. Compass Preview Design Study Final Technical Report, Vol. I, RADC-TR-74-257, March 1974) as nearly as possible.

b) The optical projection system, including stereo pair projection lenses, film and target holders, and illuminators, made to duplicate the Compass Preview preliminary design at three discrete magnifications.

The console assembly is mounted in a wall between two rooms, so that observers are located in one light-controlled room and the optical elements are located in an adjacent dark room, projecting images to the back of the viewing module.

3.1.1 Console Assembly

The console assembly (Figure 3-1) is physically the size and shape of the Compass Preview preliminary design, and mounts the viewing module and dummy control panel in proper relationship to the observer. Additionally, an electrically powered operator's chair provides fore and aft, up and down, and tilt adjustments to properly position the observer's eyes in the exit pupil.

The viewing module mounted in the console was fabricated to meet the preliminary optical design of Compass Preview, including the Fresnel field lens and test diffusers fabricated and supplied by Redwitz Research Corp.

The Fresnel field lens was fabricated by Optical Sciences Group, San Rafael, California, to the requirements of Redwitz Research drawing number 721513, to the following parameters:

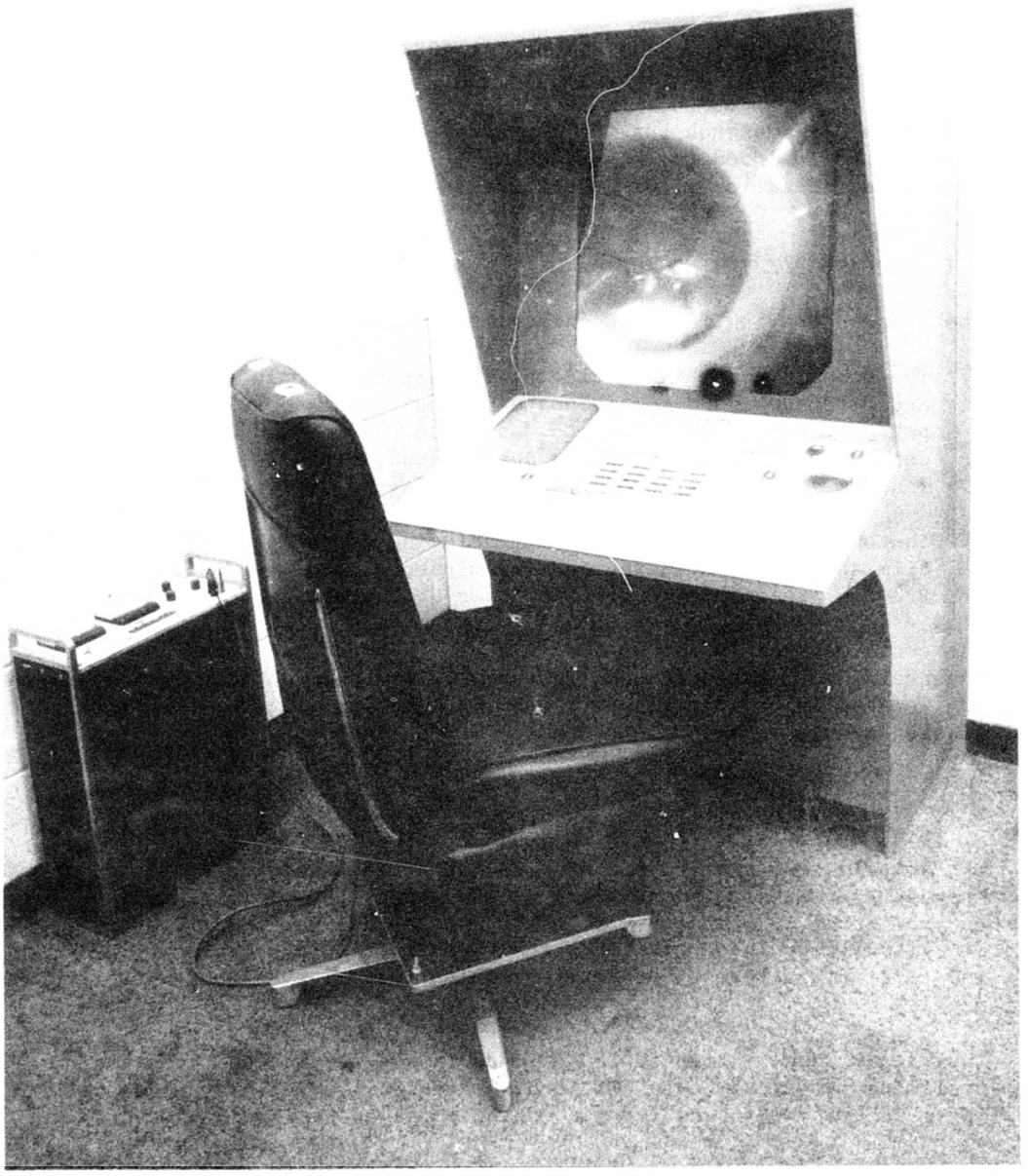


Figure 3-1. Mockup Console

Size	22.5 x 22.5 inches, with the corners trimmed to 28-inch diameter
Focal Length	18.0 inches
Relative Aperture	F/0.64 (over 28-inch area)
Nominal Viewing Distance	23.25 inches
Nominal Viewing Angle	64°
Grooves/Inch	150

The diffusers furnished by Redwitz Research are identified as:

Number 1. Redwitz Part No. 2G-4-2064.
This diffuser was designed for stereo viewing

Number 2. Redwitz Part No. 3G-6-2064
This diffuser was designed for mono viewing

These elements were mounted in the console, with 1.0" space between the back of the Fresnel and the diffuser, providing the proper geometry and optical pupil locations in accordance with the preliminary design.

Additionally, a full-sized artist's rendering of the control panel (Figure 3-2) showing the multifunction mode control panel, alphanumerics and graphics input panel, manual control elements, and the 8 x 10-inch direct view textual display, was installed in the proper location on the console. The purpose of this panel is to obtain preliminary human factors information as to control placement, size and shape, readability, etc.

3.1.2 Optical Bench Assembly

In order to project two channels of imagery for stereo onto the viewing module, and to provide rapid changing of the magnification of the imagery, an optical bench assembly was fabricated for the mockup (Figure 3-3).

The optical bench assembly consists of a heavy aluminum bedplate, mounted to the floor at the proper projection angle, and two commercial (Ealing Corp.) optical rail assemblies, mounted on the bedplate with respect to each other to provide the proper stereo pair viewing angle. The optical elements (projection lenses, film holders, condenser lenses and light sources) mount to the rails using Ealing Corp. base assemblies, and can be rapidly repositioned for magnification changes. The base assembly for the film holders incorporates X and Y screw adjustments for centering and superimposing imagery.

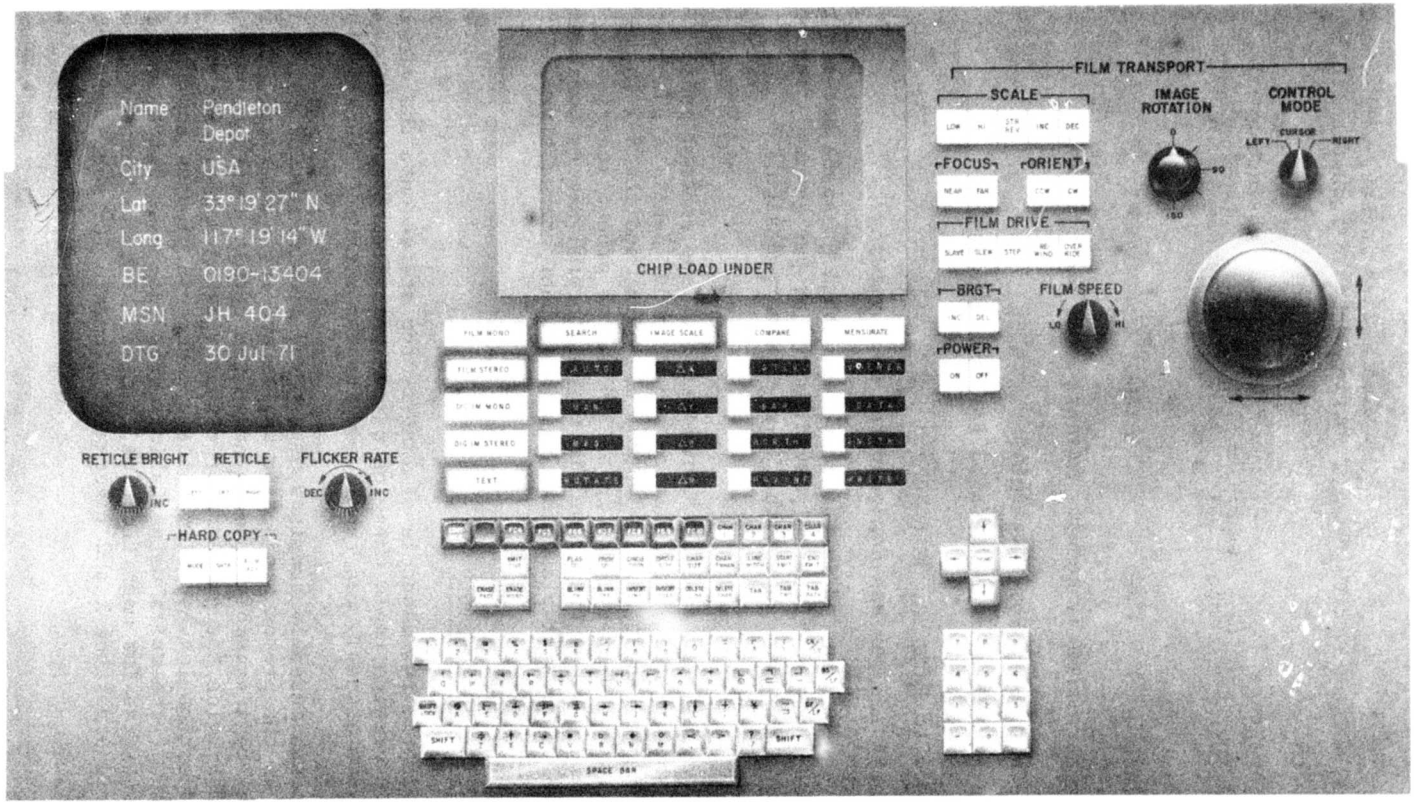


Figure 3-2. Mockup Control Panel

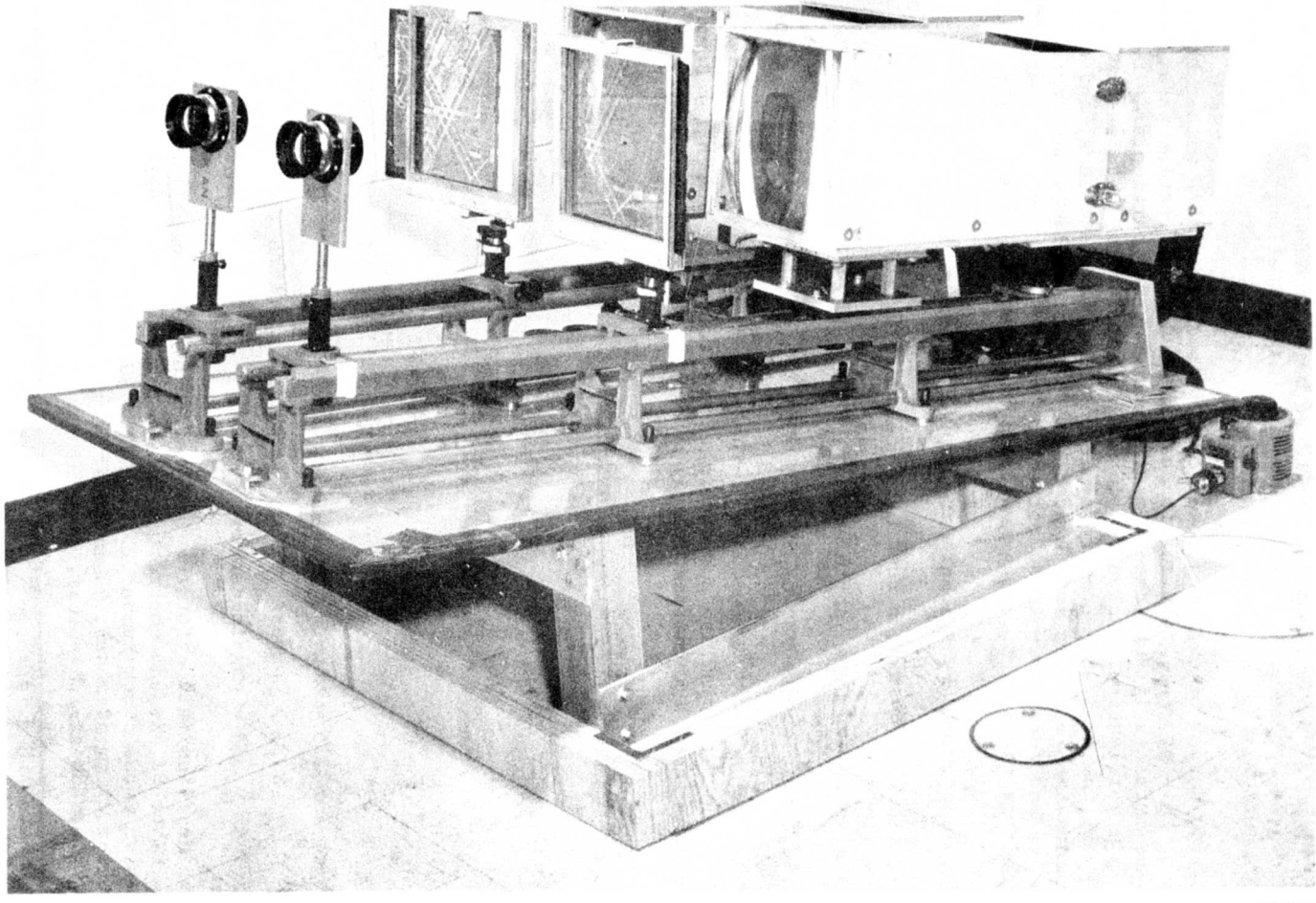


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Figure 3-3. Optical Bench Assembly

In selecting projection lenses for the mockup, it was the original intent to provide magnifications of 100X, 5X, and 2X, and to provide exact simulation of the Compass Preview zoom lens at these magnifications. This simulation includes the parameters of field coverage, magnification, exit pupil size, and resolution.

A detailed survey of existing commercial lenses, available within the time frame of this program, resulted in changing the magnification parameter in order to more nearly duplicate the other parameters, particularly resolution at high magnification. Actual performance (resolution) data was not available for any of the available commercial lenses, but manufacturers' and suppliers' statements such as "this lens approaches diffraction limit performance", were relied on and were shown to be correct by our tests. The final magnifications selected for the mockup, using available high-quality lenses, are:

a) 83.5X, provided by a Schnieder Corp. 25mm, F/1.4 lens.

b) 5X, provided by a Schnieder Corp. 355mm, F/9 lens.

c) 1.8X, provided by a Schnieder Corp. 762mm, F/12.5 lens.

The film format covered at 83.5X is 0.335 inch (diagonal); at 5X it is 5.6 inches (diagonal), and at 1.8X it is 11.4 inches (diagonal).

For reference, to simulate and duplicate the zoom lens design for Compass Preview at discrete magnifications, the following equations apply:

$$\text{Effective Focal Length (EFL)} = \frac{83.25}{1 + M}$$

$$\text{f/no.} = \frac{\text{EFL}}{0.3}$$

$$\text{Object Distance (lens-to-film)} = \frac{83.25}{M}$$

$$\text{Film Format (inches)} = \frac{28.0^{*}}{M}$$ (except for the 1.8X magnification, which does not fill the viewing screen)

where: 83.25 = Compass Preview throw distance

0.3 = Compass Preview numerical aperture

M = magnification

To provide illumination for the image plane over the magnification range from 1.8X to 83.5X, the contractor designed a condenser system consisting of a Rolyn Corp. stock number 25.0100 lens (270mm square), an Optical Industries 250mm diameter, 450mm focal length lens, and a Sylvania DCB lamp (300 watts at 120 volts).

*This compares to a factor of $\frac{8.03}{M}$ for the Zoom 240 microstereoscope; providing field-of-view improvement factors of 3.49 (lineal dimensions) and 12 (area coverage), for Compass Preview over the Zoom 240.

The geometry and relative positions for the optical elements at each magnification are shown in Figure 3-4. The overall optical geometry of the mockup is shown in Figure 3-5.

3.2 LOW MAGNIFICATION STUDIES

The low magnification optical and mechanical studies were conducted by Redwitz Research Corp., and its subcontractor, Optical Research Associates.

Since the optical design options are severely constrained by the geometry and mechanical considerations of the Compass Preview preliminary design, the study approach involved a coordinated, iterative design effort to provide a feasible opto-mechanical design. Several areas where auxiliary lenses could be mechanically added, along with their retractive mechanisms, were explored to determine the diameters and thicknesses available to the lens designer. These areas included the space between the film and the flip mirror, the space between the flip mirror and the zoom lens objective, and the space within the zoom assembly between the objective and the first movable element. Once the general location, approach, and size were agreed upon, the optical design was pursued using computer analysis techniques.

The results of the optical and mechanical studies are presented in Appendix D.

In addition to these studies, low magnification viewing (1.8X to 5.0X) was also evaluated using the mockup to view imagery. Results of this evaluation are included in Section 2 of this report and in Appendix C.

3.3 EVALUATION TEST PROGRAM

The purpose of the evaluation test program was to quantitatively and qualitatively determine the effects of the Compass Preview Viewing Module on the projected optical image, and to provide necessary data so as to optimize the design parameters for the Viewing Module. It was also a purpose of this test program to evalute the low magnification viewing mode and certain human factors, including viewing cone angle and preliminary control panel layout and placement.

To perform this evaluation, the contractor prepared a test plan detailing three types of evaluation testing:

Test 1 - Determine diffuser characteristics (pupil size, brightness distribution) at 83.5X, 5X, and 1.8X magnification.

Test 2 - Determine resolution effects of the diffuser and Fresnel field lens at 83.5X, 5X, and 1.8X magnification.

Test 3 - Determine the effects of projection cone angle, including operator preference for various screen sizes, allowable head motion, and physical comfort.

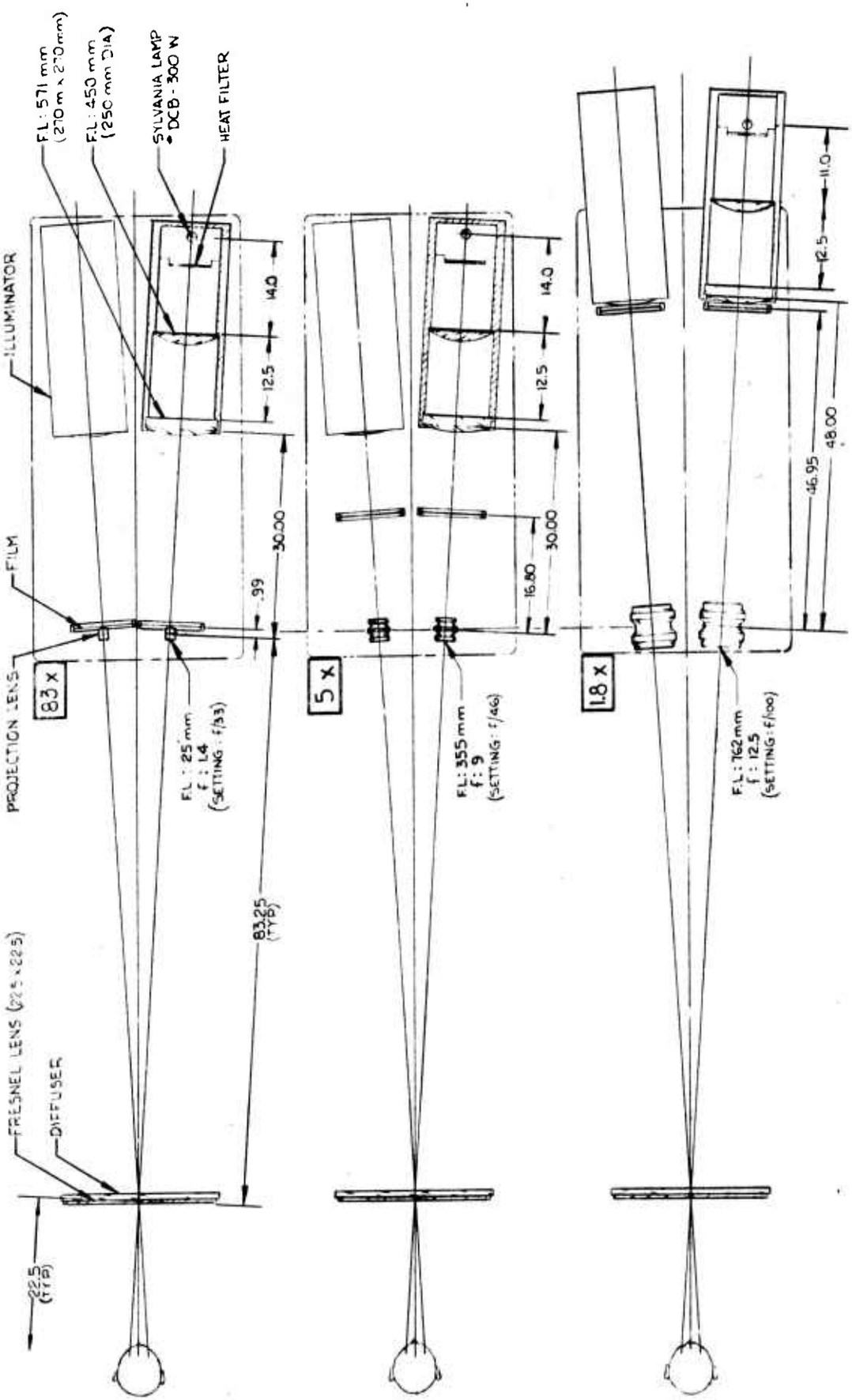

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Figure 3-4. System Layout

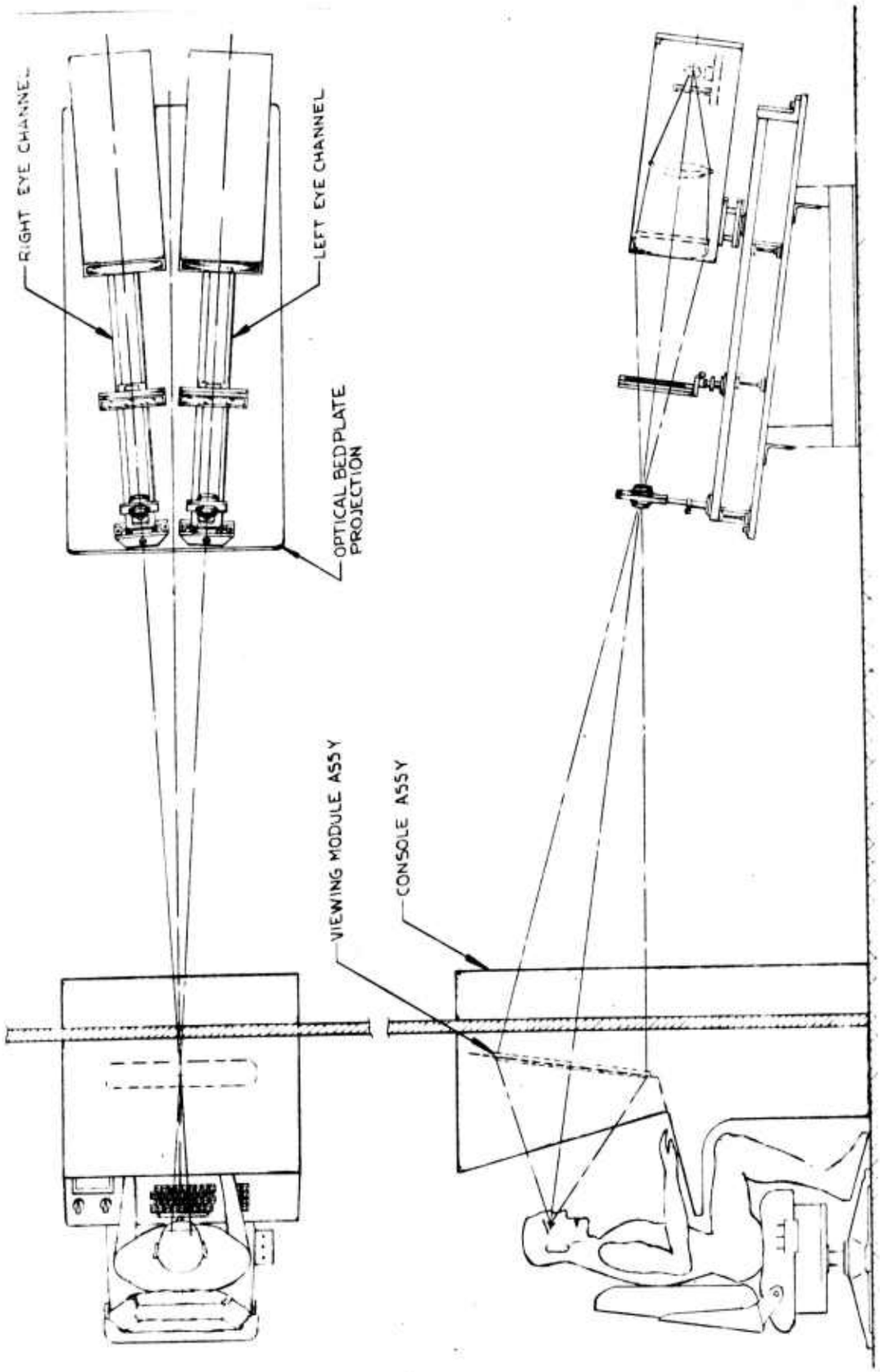

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Figure 3-5. Mockup, Stereo Geometry

The detailed evaluation test procedure is included as Appendix A of this report. This test procedure was followed in conducting the evaluation. The data sheets completed by observers during the evaluation are included as Appendix B. The conclusions drawn from the evaluation are presented in Section 2.

Test No. 1 was conducted using the Fresnel lens, diffusers supplied by Redwitz Research, and the mockup optics. All brightness measurements were taken with a Pritchard Spectra Photometer, Model 1980.

For taking brightness measurements of the exit pupil, the left eye channel of the optics was used. A grid, consisting of heavy black lines at 1.0-inch spacing and fine black lines at 0.1-inch spacing, was erected at the exit pupil. The measurement points were marked directly on the grid, and the photometer, located 4 feet from the grid and using a 2-arc-minute field of view (thus measuring a 0.73mm diameter circle at the exit pupil), was focused on the point. The grid was then removed and the measurement taken. This process was repeated for each of the 9 measurement points, and for each diffuser at each magnification. Additionally, for each diffuser and magnification, a 4 x 5-inch view camera was used to photograph the exit pupils with the grid in place.

Test No. 2 was conducted to determine the resolution effects of the diffuser, Fresnel lens, and the combination of both. For this test, a precision ITEK USAF 1951 Resolution test pattern was placed in the film plane of the mockup. A low power (12X) telescope mounted on a tripod located 48" from the viewing module and used to read all resolution measurements (except as noted on the data sheets) to remove, as much as possible, individual eye effects and measure the resolution actually presented.

For each measurement location, the resolution was first read with the diffuser and Fresnel in place, then the diffuser was removed and resolution read, and then the Fresnel removed and the resolution of the aerial image read. Thus, the basic resolution of the projected image is known, and the effect on this resolution provided by the Fresnel and the diffuser, both individually and together, is known.

These measurements were taken at all nine specified locations at 83.5X and 5X magnifications, and axially only at 1.8X.

Test No. 3 was primarily a qualitative (subjective) type of test to determine operator preference as to screen size (cone angle), image appearance with the different diffusers, and comfort factors while viewing stereo. Additionally, allowable head motion (while retaining stereo fusion) was measured.

APPENDIX A

EVALUATION TEST PLAN

INTRODUCTION

The purpose of this test program is to quantitatively and qualitatively determine the effects of the Compass Preview Viewing Module (Fresnel field lens with diffusers) on the projected optical image, and to provide necessary data so as to optimize the design parameters for the viewing module. The parameters to be tested include:

a) The size, shape, and brightness distribution of the exit pupil (at the observer's eye) created by the Fresnel lens and different diffusers, at different magnifications.

b) The effect of the Fresnel/diffuser Viewing Module on overall system resolution (axial, zonal, and edge).

c) The effect that image size and cone angle have on the diffuser.

d) Performance evaluation of low magnification (2X to 5X) viewing.

A separate test procedure is provided for each test, and each procedure contains the following information:

Scope

Applicable Documents

Test Requirements

Evaluation Criteria

Test Reports

STANDARD TEST CONDITIONS

1) All tests will be conducted at the Northrop Electronics Division facilities at 1 Research Park, Palos Verdes Peninsula, California.

2) All tests will be conducted utilizing the Compass Preview mockup.

3) Ambient illumination at the observer's station will be 10 to 20 foot-candles.

4) The viewing distance from the observer's eye to the Viewing Module will be approximately 23 inches.

5) The visual performance of each observer will be determined and recorded prior to acceptance testing. Observers who normally wear eyeglasses will wear them during testing.

6) The test conductor will be present during all tests to record data, give instructions, and in general ensure the proper conduct of each test.

7) Test will be conducted at normal laboratory temperature, pressure, and humidity.

TEST NO. 1

DIFFUSER CHARACTERISTICS

1. SCOPE

The purpose of this test is to determine the characteristics of various diffusers (in conjunction with the Fresnel field lens) at different magnifications to define the design characteristics for the diffuser and to determine whether variable or fixed diffuser parameters are required for Compass Preview.

2. APPLICABLE DOCUMENTS

RADC Contract No. F30602-74-C-0322, paragraphs 4.1.1.1 and 4.1.2.1.

3. TEST REQUIREMENTS

a) General

With constant illumination at the film plane of the mockup (without film imagery), measure and record size, shape, and illumination distribution of exit pupils created by Fresnel field lens only, and by the combination of Fresnel lens and each test diffuser combination at 1.8X, 5X, and 83X magnification.

b) Test Equipment

1) Compass Preview mockup with 1.8X, 5X and 83X projection lens for each stereo channel.

2) Test Diffusers furnished by Redwitz Research Corporation.

3) Tripod and 6" x 8" glass plate and reference grid, to be mounted at the observer's normal eye position, to allow visible presentation of exit pupils.

4) Camera and tripod for photographing exit pupils presented on the glass plate.

5) Calibrated laboratory spot meter with 1 mm^2 maximum aperture, for measurement of illumination distribution within the exit pupil, and measurement of illumination distribution at the Viewing Module.

6) Data Recording Sheets.

c) Test Conditions

Standard test conditions, except that ambient illumination may be lowered during direct observation and photographing of pupils.

d) Test Procedure

1) Install 1.8X projection lenses in both stereo channels of the mockup. Position film gate and illumination sources in proper location. Remove all diffusers from Viewing Module.

2) Measure and record illumination distribution at the back side of the Viewing Module using spot meter (minimum of 9 readings are required for axial, zonal, and edge illumination of the back of the Viewing Module).

3) Erect 6" x 8" glass with reference grid at the observer's eye position, perpendicular to the Viewing Module optical centerline. Erect camera behind the plate to photograph the exit pupils projected onto the plate and grid.

4) Turn on both illumination sources, check positioning of 6" x 8" plate visually, measure diameter of pupils projected onto the plate, photograph the pupils (with reference grid). Record camera settings (f/number, exposure, film type).

5) Measure pupil brightness with spot meter with Fresnel lens only; pupils should be too small to measure distribution within the pupil. Record.

6) Place diffuser #1 in mockup behind Fresnel lens and repeat steps (4) and (5).

7) Replace diffuser #1 with #2 in mockup and repeat (4) and (5).

8) Repeat steps (4) and (5) with both diffusers in place, and/or any other diffusers to be tested. (Note: Use only one illumination source when testing diffuser designed for mono viewing.)

9) Install 5X projection lens in mockup, reposition film gate and illumination source to 5X location, and repeat steps (2) thrcugh (9) at 5X magnification.

10) Install 83X projection lens, configure mockup optics for 83X, and repeat steps (2) through (9).

4. EVALUATION CRITERIA

a) General

Proper pupils for stereo viewing should be optimally 2.5 inches in diameter, and should have a nearly even illumination distribution. Proper pupil size for mono viewing (single channel) should be a minimum of 4.0 inches in diameter.

b) Stereo Pupils

If a single diffuser provides approximately a 2.5-inch diameter pupil at all magnifications, then it is determined that fixed diffusion is satisfactory at all magnifications for stereo-film viewing. If not, then "variable" diffusion is required for Compass Preview; i.e., the diffuser must be automatically changed in the Viewing Module, as a function of the magnification selected for viewing.

c) Mono Pupils

The same is true for mono viewing, except that the criterion is a 4.0-inch diameter (minimum) pupil.

d) Illumination Distribution

The shape of the illumination distribution curve across the pupil should be approximately the same as the shape of the illumination curve across the back of the Viewing Module, except that the diffuser should attenuate variations such as hot spots. If hot spots are created by the Viewing Module, it would indicate either that the diffusion characteristics of the diffuser are not homogeneous across its face, or that optical distortions are present in the Fresnel field lens. In either case, the cause will be determined.

5. TEST REPORTS

The test report will include measurements of Viewing Module (back side) illumination levels, photographs, and measurements of each pupil generated with various diffusers and at various magnifications, recorded on data sheets. Conclusions drawn from these tests are presented in the Final Report.

TEST NO. 2

VIEWING MODULE RESOLUTION EFFECT

1. SCOPE

The purpose of this test is to determine the effect on system limiting resolution introduced by the Viewing Module. This will be determined by measuring the optical projection resolution with the Viewing Module removed, then measuring resolution with the Fresnel lens and diffuser(s) (selected as a result of Test No. 1) in place.

2. APPLICABLE DOCUMENTS

RADC Contract No. F30502-74-C-0322, paragraphs 4.1.1.1, 4.1.1.2, 4.1.1.3, 4.1.2.1.

3. TEST REQUIREMENTS

a) General

With proper illumination and with the 16-912 LP/MM target(s) in the film gate(s), three different observers will measure and record axial, zonal, and edge resolution of the optical projection system only, optical projection plus Fresnel, and optical projection and Fresnel, plus diffuser combinations at 1.8X, 5X, and 83X magnification.

b) Test Equipment

1) Compass Preview mockup with 1.8X, 5X, and 83X projection lenses.

2) Itek XTRG 302.112A Resolving Power Test Targets, 16-912 LP/MM, positive, high contrast.

3) Viewing Module diffusers deemed acceptable as result of Test No. 1.

4) Low power telescope, stand, and hardware to allow placement of microscope in viewing position when the Viewing Module is removed.

5) Data Sheets.

c) Test Conditions

1) Standard test conditions.

2) Three observers with current eye test data.

d) Test Procedure

1) Install 83X projection lenses, configure optics for 83X, install Itek resolution target in film gate, and focus images on back side of Viewing Module with test target images on the optical centerline.

2) Remove Viewing Module (Fresnel and diffuser). Erect telescope on stand for direct viewing of spatial image at the Viewing Module location.

3) Each observer to measure and record limiting resolution as read from the target. This is to be done at nine locations (one axial, four zonal, and four edge locations) within the viewing area. Note: for each location the position of the target within the film gate must be changed (with the X-Y adjusting screws) so that the target image appears at the proper location.

4) Remove the telescope and stand, replace the Fresnel lens (only).

5) Repeat step (3), using the telescope to measure resolution at all nine locations.

6) Install the diffuser determined best for the magnification being tested (from Test No. 1), and repeat step (5).

7) Configure the mockup optics for 5X viewing.

8) Repeat steps (2) through (6) at 5X, all nine locations.

9) Configure the mockup optics for 1.8X viewing.

10) Repeat steps (2) through (6) at 1.8X, axial readings only.

11) At 83X magnification, read and record the axial resolution only, using all available diffusers (individually). If one of the previously rejected diffusers appears superior in resolution performance to the accepted (from Test No. 1) diffuser, measure and record the zonal and edge resolutions also for a complete comparison.

4. EVALUATION CRITERIA

The Viewing Module (Fresnel/diffuser combination) should not cause more than one pattern degradation of the optical limiting resolution (i.e., if the limiting resolution without the Viewing Module is read as group 8, element 6, then the resolution with the best configuration Viewing Module in place shall be at least group 8, element 5, etc.), as an average of the three viewers' readings.*

*The resolution test results presented herein did not meet the above criteria. This is because this criteria was incorrectly established, based on incomplete knowledge of the resolution effects (MTF) of the Viewing Module components.

7. TEST REPORTS

The test report will include all resolution measurements taken and the configuration of the mockup during each reading, recorded on the data sheets. Conclusions drawn from these tests are presented in the Final Report.

TEST NO. 3

EFFECT OF IMAGE SIZE AND PROJECTION CONE ANGLE

1. SCOPE

The purpose of this test is to determine the effects of the projection cone angle on the diffuser, operator preference for various viewing screen sizes and shapes, and the allowable operator head motion and comfort while viewing stereo imagery.

2. APPLICABLE DOCUMENTS

RADC Contract No. F30602-74-C-0322, paragraph 4.1.1.3.

3. TEST REQUIREMENTS

a) General

The projection cone angle and Viewing Module shape will be varied by placing different masks over the Viewing Module aperture to reduce the cone angle of the light reaching the observer's exit pupil. The exit pupils generated with the various masks in place will be photographed and compared with those pupils generated in Test No. 1.

Stereo pair imagery will be installed in the film gates, and three observers will acnieve stereo fusion and indicate their preferences as to the size and shape of the Viewing Module. Additionally, the physical head motions allowed for each observer to maintain stereo fusion will be measured.

b) Test Equipment

1) Compass Preview mockup with 1.8X, 5X and 83X projection lenses.

2) Selected diffusers for each magnification.

3) Stereo pair imagery transparencies (9" x 9")

4) Viewing Module masks:

No. 1 - 22.5" diameter circular cutout
No. 2 - 19.5" x 19.5" square, with round corners
No. 3 - 19.5" diameter circular
No. 4 - 16.5" x 16.5" square, with round corners
No. 5 - 16.5" diameter circular

5) Tripod and 6" x 8" diffuser plate with grid (as used in Test No. 1).

6) Tripod and camera (used in Test No. 1).

7) Tripod with horizontally mounted arm (to provide reference point at observer's head for measurement of head motions).

8) Data Recording Sheets.

c) Test Conditions

1) Standard test conditions.

2) Three observers with current eye test data.

d) Test Procedure

1) Configure mockup for 5X magnification (film gates empty), Fresnel and "best" diffuser in place.

2) Erect 6" x 8" glass diffuser with grid at operator's eye position, perpendicular to the optical line of sight. Set up camera in position to photograph the pupils generated on the plate.

3) Install the 22.5" circular mask, turn on illumination sources, photograph the resultant pupils. Repeat with each mask (5 total).

4) Remove 6" x 8" glass diffuser, tripod, and camera setup. Install stereo pair transparencies in film gates, align for stereo viewing.

5) Observer No. 1 to view the stereo imagery using each mask (as well as no masks). Record observer's comments and preferences as to shape and size of Viewing Module. Measure and record his allowable head motion while maintaining stereo fusion.

6) Repeat step (5) with observer No. 2.

7) Repeat step (5) with observer No. 3.

8) At the discretion of the test director, any or all of the above steps may be repeated using a different magnification.

4. EVALUATION CRITERIA

Not applicable. This is largely a subjective test to determine operator preference and comfort.

5. TEST REPORTS

The test report will include photographs of pupils generated through the various masks, measurements of allowable head motions, and observer preferences and comments recorded on data sheets. Conclusions drawn from these tests are included in the Final Report.

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APPENDIX B

EVALUATION TEST DATA SHEETS

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TEST NO. 1 - DIFFUSER CHARACTERISTICS

OBSERVER W. BAKER, G. SINGLETON DATE 7/25/74

1. Magnification 5X

2. Diffuser in Place
No. 2G-4-2064
#1 - STEREO

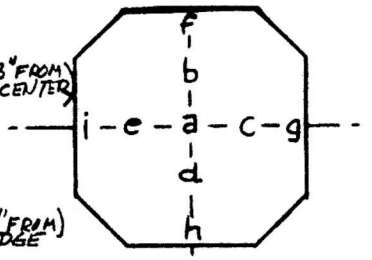
3. Source Illum. Level
225 Watts

90 V ON VARIAC

4. Brightness at Viewing Module, ft-lamberts

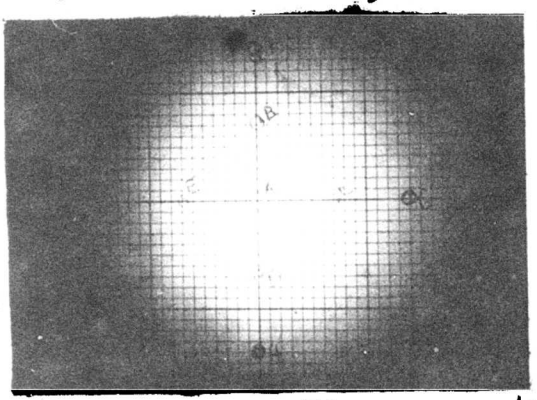
a 37.2×10^3 (axial)
b 18.5×10^3 (zonal) (3" FROM CENTER)
c 18.4×10^3 (zonal)
d 20.1×10^3 (zonal)
e 20.1×10^3 (zonal)
f 27.5×10^3 (edge) (5" FROM EDGE)
g 25.7×10^3 (edge)
h NOT TAKEN (edge)
i 23×10^3 (edge)

(20° MIN APERTURE ON PRITCHARD)



Measurement Locations looking at front of viewer

5. Exit pupils, Grid Scale 1", 0.1"



Film type #52 F/No f/16 Shutter 1/4 SEC
POLAROID

6. Brightness of pupil location, ft-lamberts

a 274 (axial)
b 113 (zonal)
c 130 (zonal)
d 172 (zonal)
e 104 (zonal)
f 31 (edge)
g 34 (edge)
h 58 (edge)
i 25 (edge)

NOTE 1

7. Comments:
1. PRITCHARD 'SPECTRA' PHOTOMETER MODEL 1980 — 4 FT FROM PUPIL, 2 ARC MIN FOV, USED FOR MEASUREMENTS.
2. PUPILS 22 1/2" FROM LENS
3. POINT 'A' LOCATED AS MAX INTENSITY POINT
4. THIS DIFFUSER GOOD STEREO, UNACCEPTABLE MONO.

TEST NO. 1 - DIFFUSER CHARACTERISTICS

OBSERVER W. BAKER, G. SINGLETON DATE 7/25/74

1. Magnification 5X

2. Diffuser in Place

No. 3G-6-2064 (#2 - MONO)

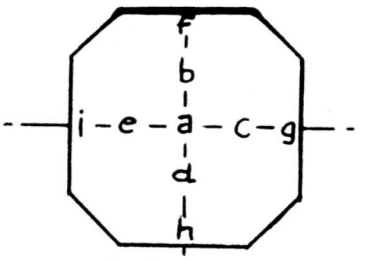
3. Source Illum. Level

225 Watts

90V ON VARIAC

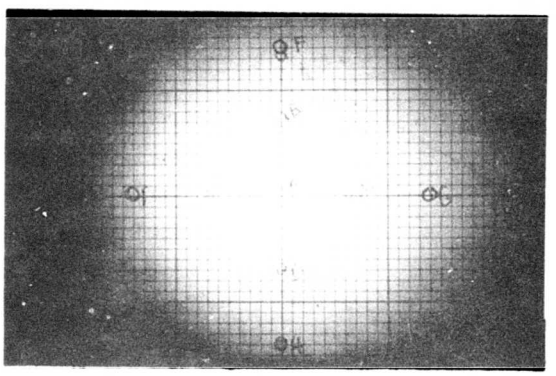
4. Brightness at Viewing Module, ft-lamberts

a 37.2×10^3 (axial)
b 18.5×10^3 (zonal)
c 18.4×10^3 (zonal)
d 20.1×10^3 (zonal)
e 20.1×10^3 (zonal)
f 27.5×10^3 (edge)
g 25.7×10^3 (edge)
h NOT TAKEN (edge)
i 23×10^3 (edge)



Measurement Locations looking at front of viewer

5. Exit pupils, Grid Scale 1", 0.1"



Film type 52 POLAROID F/No F/16 Shutter 1/4 SEC

6. Brightness of pupil location, ft-lamberts

a 143.6 (axial)
b 90.7 (zonal)
c 90.6 (zonal)
d 92.8 (zonal)
e 97.7 (zonal)
f 31.6 (edge)
g 34.9 (edge)
h 35.1 (edge)
i 34.2 (edge)

7. Comments: MODEL 1980

1, PRITCHARD SPECTRA PHOTOMETER - 4 FT FROM PUPILS - 2 MIN F.O.V.

2, PUPILS 22 1/2" FROM LENS

3, THIS PUPIL SIZE GIVES VERY GOOD STEREO, MARGINAL MONO

4, OBSERVER'S LEFT EYE CHANNEL MEASURED.

TEST NO. 1 - DIFFUSER CHARACTERISTICS

OBSERVER W. BAKER, G. SINGELTON DATE 7/25/74

1. Magnification 5X

2. Diffuser in Place
No. NONE — (FRESNEL ONLY)

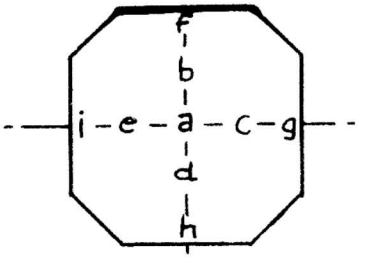
3. Source Illum. Level
100 Watts

(40 V ON VARIAC)

4. Brightness at Viewing Module, ft-lamberts

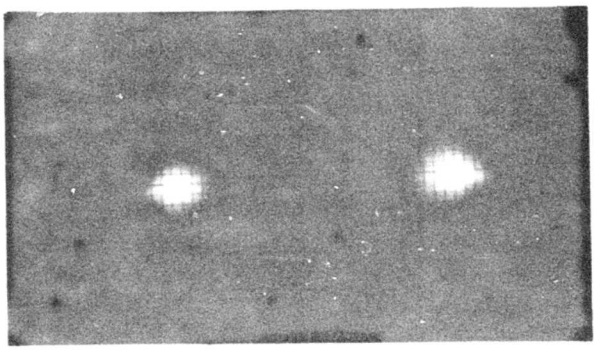
a _____(axial)
b _____(zonal)
c _____(zonal)
d _____(zonal)
e _____(zonal)
f _____(edge)
g _____(edge)
h _____(edge)
i _____(edge)

SAME AS PAGES 1 & 2



Measurement Locations looking at front of viewer

5. Exit pupils, Grid Scale 1", 0.1"



Film type #52 POLAROID F/No F/16 Shutter 1/4 SEC.

6. Brightness of pupil location, ft-lamberts

a _____(axial)
b _____(zonal)
c _____(zonal)
d _____(zonal)
e _____(zonal)
f _____(edge)
g _____(edge)
h _____(edge)
i _____(edge)

NOT APPLICABLE

7. Comments:

TEST NO. 1 - DIFFUSER CHARACTERISTICS PAGE 4

OBSERVER W. BAKER, G. SINGLETON DATE 7/26

1. Magnification 83.5 X

2. Diffuser in Place
No. 2G-4-2064
#1 (STEREO)

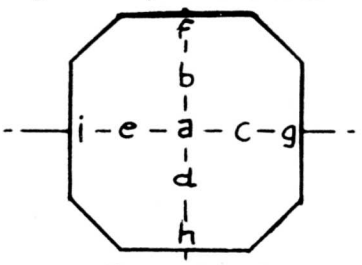
3. Source Illum. Level
175 Watts

70 VOLTS (VARIAC)

4. Brightness at Viewing Module, ft-lamberts

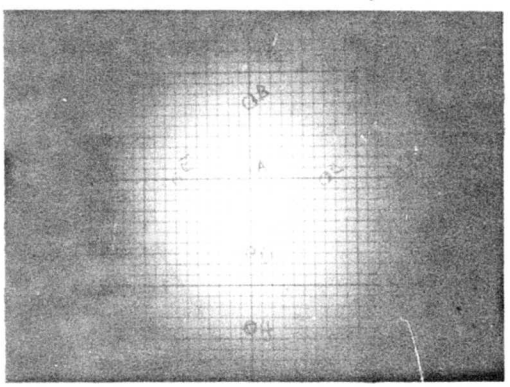
a 7.8×10^3 (axial)
b 6.7×10^3 (zonal)
c 5.6×10^3 (zonal)
d 7.1×10^3 (zonal)
e 7.2×10^3 (zonal)
f 5.2×10^3 (edge)
g 6.7×10^3 (edge)
h NOT TAKEN (edge)
i 7.1×10^3 (edge)

20 MIN FOV ON PRITCHARD.



Measurement Locations looking at front of viewer

5. Exit pupils, Grid Scale 1.0", 0.1"



Film type 52 POLAROID F/No F/16 Shutter 1/4 SEC

6. Brightness of pupil location, ft-lamberts

a 130.4 (axial)
b 60 (zonal)
c 53 (zonal)
d 65 (zonal)
e 52 (zonal)
f 21 (edge)
g 14 (edge)
h 21 (edge)
i 15 (edge)

7. Comments:
1. PRITCHARD SPECTRA PHOTOMETER MODEL 1980 - 4 FT FROM PUPILS - 2 MIN FOV
2. PUPILS 22 1/2" FROM LENS

TEST NO. 1 - DIFFUSER CHARACTERISTICS

OBSERVER W, BAKER, G, SINGLETON DATE 7/26/74

1. Magnification 8X

2. Diffuser in Place
No. 3 G-6-2064 #2

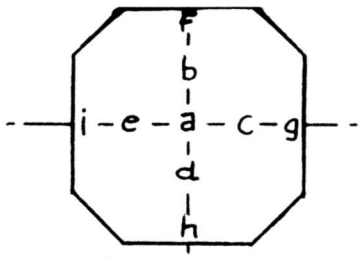
3. Source Illum. Level
175 Watts

70 V ON VARIAC

4. Brightness at Viewing Module, ft-lamberts

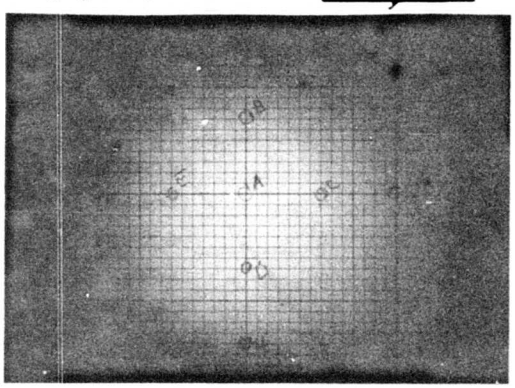
a 7.8×10^{3} (axial)
b 6.7×10^{3} (zonal)
c 5.6×10^{3} (zonal)
d 7.1×10^{3} (zonal)
e 7.2×10^{3} (zonal)
f 5.2×10^{3} (edge)
g 6.7×10^{3} (edge)
h NOT TAKEN (edge)
i 7.1×10^{3} (edge)

20° FOV ON PRITCHARD



Measurement Locations looking at front of viewer

5. Exit pupils, Grid Scale 1.0", 0.1"



Film type 52 F/No F/16 Shutter 1/4 SEC
POLAROID

6. Brightness of pupil location, ft-lamberts

a 71 (axial)
b 45 (zonal)
c 47 (zonal)
d 46 (zonal)
e 44 (zonal)
f 18 (edge)
g 20 (edge)
h 18 (edge)
i 18 (edge)

7. Comments: MODEL 1980
1. PRITCHARD SPECTRA PHOTOMETER, 4 FT FROM PUPILS, 2° FOV
2, PUPILS 22½" FROM LENS,

TEST NO. 1 - DIFFUSER CHARACTERISTICS PAGE 6

OBSERVER W. BAKER, G. SINGLETON DATE 7/26/74

1. Magnification 83 X

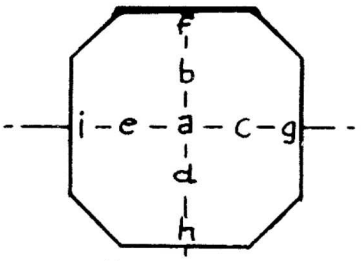
2. Diffuser in Place
No. NONE (FRESNEL ONLY)

3. Source Illum. Level
75 Watts

30 V ON VARIAC

4. Brightness at Viewing Module, ft-lamberts

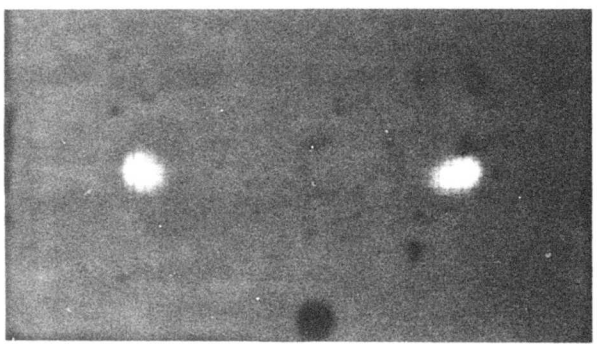
a _____(axial)
b _____(zonal)
c _____(zonal)
d _____(zonal)
e _____(zonal)
f _____(edge)
g _____(edge)
h _____(edge)
i _____(edge)



Measurement Locations looking at front of viewer

SAME AS PAGES 5 & 6

5. Exit pupils, Grid Scale _____



Film type 52 F/No F/16 Shutter 1/4 SEC
POLAROID

6. Brightness of pupil location, ft-lamberts

a _____(axial)
b _____(zonal)
c _____(zonal)
d _____(zonal)
e _____(zonal)
f _____(edge)
g _____(edge)
h _____(edge)
i _____(edge)

NOT APPLICABLE

7. Comments:

TEST NO. 1 - DIFFUSER CHARACTERISTICS PAGE 7

OBSERVER W TRAKER DATE 8/12/76

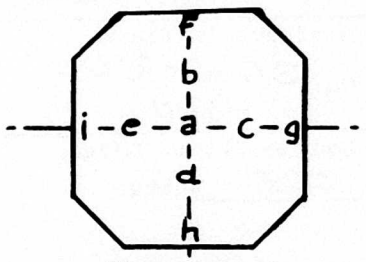
1. Magnification 2 X

2. Diffuser in Place
No. 2G-4-2064
STEREO

3. Source Illum. Level
225 W Watts
90 V ON VARIAC

4. Brightness at Viewing Module, ft-lamberts

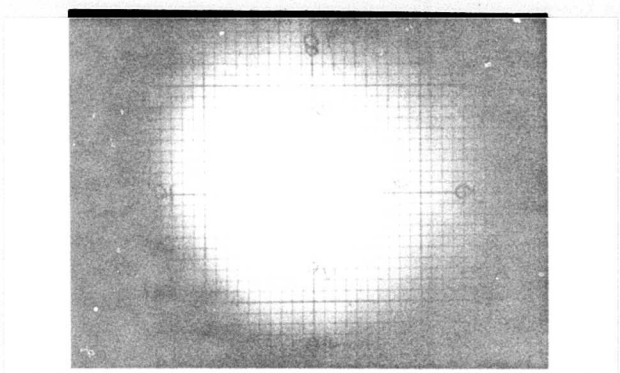
a 27×10^3 (axial)
b 8×10^3 (zonal)
c 11×10^3 (zonal)
d 8×10^3 (zonal)
e 9×10^3 (zonal)
f 5×10^3 (edge)
g 7×10^3 (edge)
h 2×10^3 (edge)
i 5×10^3 (edge)



Measurement Locations looking at front of viewer

FOR THESE READINGS NOTE: LAMP ILLUM RED TO 112 W TO AVOID SATURATION

5. Exit pupils, Grid Scale 1", 0.1"



Film type #52 F/No F/16 Shutter 1/4 SEC
POLAROID

6. Brightness of pupil location, ft-lamberts

a 335 (axial)
b 165 (zonal)
c 156 (zonal)
d 176 (zonal)
e 155 (zonal)
f 56 (edge)
g 38 (edge)
h 55 (edge)
i 41 (edge)

7. Comments: Note; at 2X projector does not fill 22.5 x 22.5 screen - fills illum area of 17" x 17" with corners clipped to 21" diagonal. (≅ 300 IN² illuminated @ 2X vs 500 IN² illum @ 5X & larger. Thus, the same watts are distributed over a smaller area, leading to much higher illumination levels that at 5x & larger.

42897

TEST NO. 1 - DIFFUSER CHARACTERISTICS PAGE 8

OBSERVER W BAKER DATE 8/12/74

1. Magnification 2X

2. Diffuser in Place
No. 3G-6-2064
MONO

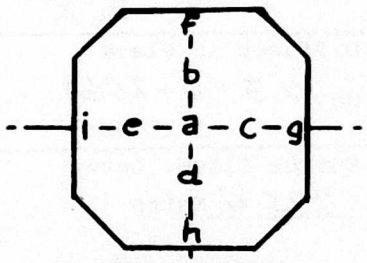
3. Source Illum. Level
225 Watts

90 VOLTS ON VARIAC

4. Brightness at Viewing Module, ft-lamberts

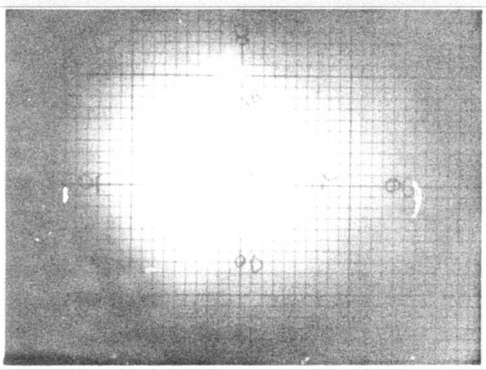
a _____(axial)
b _____(zonal)
c _____(zonal)
d _____(zonal)
e _____(zonal)
f _____(edge)
g _____(edge)
h _____(edge)
i _____(edge)

SAME AS P. 7



Measurement Locations looking at front of viewer

5. Exit pupils, Grid Scale 1", 0.1"



Film type 52 POLAROID F/No F/16 Shutter 1/4 SEC

6. Brightness of pupil location, ft-lamberts

a 213 (axial)
b 109 (zonal)
c 146 (zonal)
d 173 (zonal)
e 111 (zonal)
f 43 (edge)
g 65 (edge)
h 42 (edge)
i 41 (edge)

7. Comments:

Note: at 2X projector does not fill 22.5 x 22.5 view screen — illuminated area is 17" x 17", with corners clipped on 21" diagonal.

42898

TEST NO. 1 - DIFFUSER CHARACTERISTICS

OBSERVER W Baker DATE 8/12/74

1. Magnification 2X

2. Diffuser in Place
No. - NONE
FRESNEL ONLY

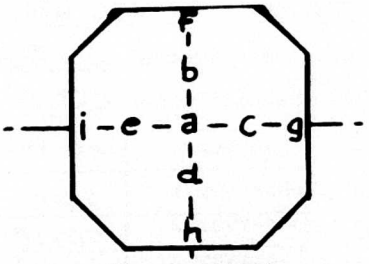
3. Source Illum. Level
75 Watts

30 V ON VARIAC

4. Brightness at Viewing Module, ft-lamberts

a _____(axial)
b _____(zonal)
c _____(zonal)
d _____(zonal)
e _____(zonal)
f _____(edge)
g _____(edge)
h _____(edge)
i _____(edge)

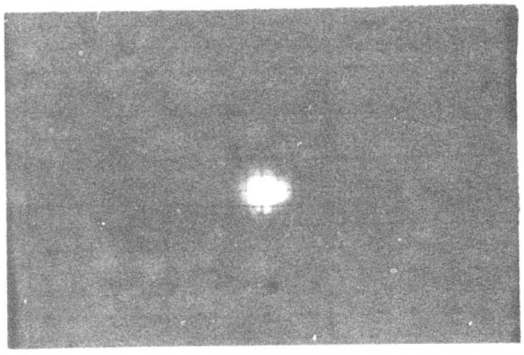
N/A



Measurement Locations looking at front of viewer

SAME AS P. 7

5. Exit pupils, Grid Scale _____



Film type 52 F/No F/16 Shutter 1/4 SEC
POLAROID

6. Brightness of pupil location, ft-lamberts

a _____(axial)
b _____(zonal)
c _____(zonal)
d _____(zonal)
e _____(zonal)
f _____(edge)
g _____(edge)
h _____(edge)
i _____(edge)

N/A

7. Comments:

42899

TEST NO. 2 - VIEWING MODULE RESOLUTION

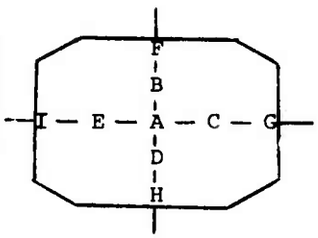
PAGE 1

1. Test Director W Baker 7/30/74

2. Magnification 83.5 X

3.

	Observers:	Left Eye	Rt. Eye	ST ACQ	Date Tested
W. G	Observer 1	20/17	20/17	9	7/15/74
G S	Observer 2	20/18	20/18	6	7/15/74
G D	Observer 3	20/22	20/22	7	7/15/74



Measurement Locations

4. Measurements: SOURCE ILLUM → 100W (40V) 125W (50V) 200W (80V) ← VARIAC SETTING

Location	Observer	Proj. Only	Proj. + Fresnel	Proj. Fresnel + "Best" Diffuser 2G	EYEBALL READING Other	3 G DIFFUSER (AXIAL ONLY)	
A (Axial)	1	9-3	8-3	7-6	7-5	7-6	} in ½ group less than 2G
	2	9-3	8-4	7-6	7-4	7-6	
	3	9-3	8-3	7-6	7-4	7-6	
B (Zonal)	1	9-1	8-3	7-6	7-4		
	2	9-2	8-3	7-6	7-3		
	3	9-1	8-3	7-6	7-3		
C (Zonal)	1	9-2	8-4	7-5	7-3		
	2	AM 9-3	8-4	7-4	7-3		
	3	9-2	8-3	7-6	7-1		
D (Zonal)	1	9-3	8-2	7-6	7-4		
	2	9-3	8-3	7-5	7-3		
	3	9-3	8-3	7-6	7-2		
E (Zonal)	1	9-3	8-5	7-6	7-4		
	2	AM 9-3	8-5	7-6	7-3		
	3	9-2	8-4	7-6	7-3		
F (Edge)	1	9-1	8-4	7-6	7-3		
	2	9-1	8-4	7-5	7-1		
	3	9-1	8-3	7-6	7-1		
G (Edge)	1	9-1	8-3	7-4	7-2		
	2	9-1	8-4	7-3	8-6		
	3	9-2	8-3	7-4	7-1		
H (Edge)	1	9-3	8-1	7-2	7-2		
	2	AM 9-3	8-2	7-2	7-2		
	3	9-2	8-2	7-2	7-1		
I (Edge)	1	9-2	*	*	*		
	2	9-2	8-3	7-1	7-1		
	3	9-1	8-4	7-2	7-1		

5. 5X RESOLUTION (AXIAL ONLY)(REF)

A (AXIAL)	1	5-2	4-6	4-4	3-6	
	2	5-2	5-1	4-5	3-6	
	3	5-3	4-6	4-3	3-5	

6. 1.8X RESOLUTION (AXIAL ONLY)

A (AXIAL	1	3-5	3-1	2-5	2-2	
	2					
	3					

(W Baker

* OPERATOR MISSING

1. DATA TAKEN USING L.H. SYSTEM (OP. LHS)
2. POSITIONED TARGET AT 45°

TEST NO. 2 - VIEWING MODULE RESOLUTION

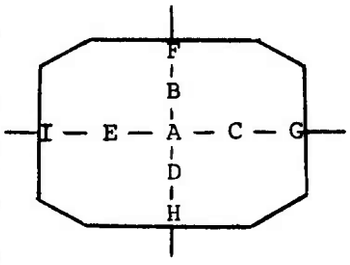
1. Test Director W Baker 7/31/74

2. Magnification 5 X

3.

Observers:	Left Eye	Rt. Eye	ST ACQ	Date Tested
W, G, Observer 1	20/17	20/17	9	7/15/74
G, S, Observer 2	20/18	20/18	6	7/15/74
G, D, Observer 3	20/22	20/22	7	7/15/74

FINISHED 8/1-74



Measurement Locations

4. Measurements:

40V 50V. 80V

Location	Observer	Proj. Only	Proj. + Fresnel	Proj. Fresnel + "Best" Diffuser	EYEBALL READING Other	
8th A (Axial)	1	5-2	4-6	4-4	3-6	
	2	5-2	5-1	4-5	3-6	
	3	5-3	4-6	4-3	3-5	
7th B (Zonal)	1	5-3	4-6	4-1	3-5	
	2	5-3	4-6	4-1	3-5	
	3	5-3	4-6	3-6	3-4	
3rd C (Zonal)	1	5-2	4-4	4-1	3-5	
	2	5-2	4-4	4-1	3-4	
	3	5-2	4-4	4-1	3-4	
2nd D (Zonal)	1	5-3	4-3	3-6	3-5	
	2	5-3	4-3	3-5	3-3	
	3	5-2	4-4	3-6	3-3	
5th E (Zonal)	1	5-3	4-4	3-6	3-4	
	2	5-3	4-4	3-5	3-4	
	3	5-2	4-4	3-6	3-3	
F (Edge)	1	5-1	4-4	3-4	3-2	
	2	5-2	4-4	3-4	3-2	
	3	5-2	4-3	3-4	3-1	
4th G (Edge)	1	5-2	4-4	3-5	3-2	
	2	5-2	4-4	3-4	3-2	
	3	5-1	4-4	3-5	3-1	
1st H (Edge)	1	5-3	4-5	3-4	3-3	
	2	5-2	4-4	3-3	3-2	
	3	5-1	4-4	3-4	3-2	
6th I (Edge)	1	5-3	*	*	*	
	2	5-2	4-4	3-3	3-2	
	3	5-2	4-3	3-4	3-1	

* OPERATOR MISSING

EXTRA TEST ~ DIFFERENT FRESNELS

TEST NO. 2 - VIEWING MODULE RESOLUTION — PAGE 1

A

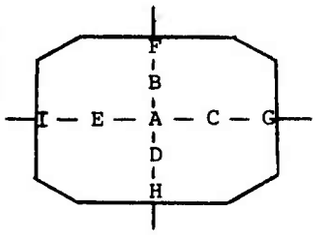
1. Test Director W. BAKER

2. Magnification 83 X

3.

Observers:	Left Eye	Rt. Eye	ST ACQ	Date Tested
Observer 1				
Observer 2				
Observer 3				

W Baker



Measurement Locations

4. Measurements:

TELESCOPE READINGS

GROOVES PER INCH	LENS USED	FOCAL LENGTH	Observer	Proj. Only	Proj. + Fresnel		Proj. Fresnel + "Best" Diffuser 2G		EYEBALL READING Other		
C/P LENS	150 A (~~Duplicate~~)	18"	1	9-2	8-4	8-5	7-6	8-1	7-4	7-5	HALO ≅ 20" DIA
			2								
			3								
FOCAL LENGTH AND SHORT -	48 B 8" (~~Bonnell~~)		1	9-2	7-6	7-6	7-4	7-4	7-1	7-1	
			2								
			3								
LESS — TRANS	48 C 13½ (~~Bonnell~~)		1	9-2	7-6	8-1	7-6	8-1	7-3	7-5	LOW XMISSION - G, IN OR OUT
			2								
			3								
	48 D 16 (~~Bonnell~~)		1	9-2	8-1	8-1	8-1	8-1.	7-4	7-5	
			2								
			3								
	125 E 13¾ (~~Bonnell~~)		1	9-2	8-5	8-6	8-1	8-2	7-5	7-6	
			2								
			3								
	125 F 23 (~~Edge~~)		1	9-2	8-5	8-6	7-6	8-1	7-4	7-5	
			2								
			3								
	300 G 13¾ (~~Edge~~)		1	9-2	8-5	8-6	7-6	7-6	7-4	7-4	
			2								
			3								
	H (Edge)		1								
			2								
			3								
	I (Edge)		1								
			2								
			3								

GROOVES TOWARDS PROJECTOR — OBSERVER — GROOVES TOWARDS PROJECTOR — OBSERVER — GR IN — GROOVES OUT

THIS TEST RUN TO DETERMINE RELATIVE PROP OF DIFFERENT FRESNEL LENSES - PARTICULARLY TO DETERMINE EFFECT OF NO. OF GROOVES/IN ON PERCEIVED RESOLUTION.

groove effect very pronounced using telescope, no diff.

A - groove not resolvable with diffuser

B } grooves vis, width diff
D } pronounced without

E } grooves not vis with diff
F

G

2G Diff only - NO LENS 8-2 } TO 8-3

EXTRA TEST ~ DIFFERENT FRESNELS

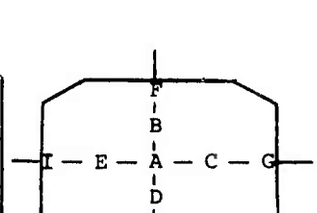
TEST NO. 2A - VIEWING MODULE RESOLUTION

1. Test Director W. BAKER

2. Magnification 5X

3.

Observers:	Left Eye	Rt. Eye	ST ACQ	Date Tested
WBaker Observer 1				
Observer 2				
Observer 3				



Measurement Locations

4. Measurements: TELESCOPE READINGS.

LENS USED: ~~Location~~	Observer	Proj. Only	Proj. + Fresnel		Proj. Fresnel + "Best" Diffuser		EYEBALL READING Other		
LENS 150 A 18 (~~Axial~~)	1	5-3	5-1	5-1	4-4	4-3	3-6	3-6	HALO-10.5 WITH GROOVES OUT
	2	7X LOUPE							
	3								
LENS 48 B 8 (~~Zonal~~)	1		*	*	3-6	4-2	3-6	3-6	
	2	5-3 LOUPE 7X							
	3								
LENS 48 C 13 1/2 (~~Zonal~~)	1		4-5	4-6	4-4	4-4	3-6	4-1	
	2								
	3								
LENS 48 D 16 (~~Zonal~~)	1		5-2	5-2	4-4	4-4	4-1	3-6	
	2		(5-3 LOUPE)						
	3								
LENS 125 E 13 3/4 (~~Zonal~~)	1		5-2	5-1	4-5	4-5	4-1	3-6	
	2				(4-5 LOUPE)	(4-6 LOUPE)			
	3								
LENS 125 F 23 (~~Zonal~~)	1		5-2	5-2	4-6	4-6	4-1	4-1	
	2								
	3								
LENS 300 G 13 1/4 (~~Zonal~~)	1		4-6	5-1	4-3	4-3	3-6	3-6	
	2								
	3								
H (~~Edge~~)	1								
	2								
	3		GROOVES: IN	OUT	IN	OUT	IN	OUT	
I (~~Edge~~)	1								
	2								
	3								

Telescope reading - 4-4, I = DIFF ONLY

* Groove effect ~~pronounced~~ [illegible] - ~~not~~ better with diffuser.

TEST NO. 3 - IMAGE SIZE, PROJECTION CONE ANGLE

OBSERVER G E SINGLETON DATE 8-1-74 PAGE 1

1. Observer's Comments:

5X STEREO

NO MASK	1. CORNERS HAVE CHROMATIC ABERATIONS 2. LARGE AREA IS NICE BUT REQUIRES A LOT OF EYE MOVEMENT
MASK 1	(attach exit pupil photo to back of sheet) EASY TO SCAN
MASK 2	(attach exit pupil photo to back of sheet) 1. SMALL SIZE CAUSES YOU TO FOCUS YOUR ATTENTION BETTER 2. YOU WANT TO MOVE YOUR HEAD LESS
MASK 3	(attach exit pupil photo to back of sheet) SAME AS 2
MASK 4	(attach exit pupil photo to back of sheet) SAME AS 2 3. LESS DISTORTION
MASK 5	(attach exit pupil photo to back of sheet) Same as 2, 3, 4, 4. all the stereo area is good stereo.

2. Preferred Configuration #1 - large round

3. Head Motion while Maintaining Stereo

1) Fore and Aft 10 - 11 inches (INSIDE) DARKENING AT EDGES (OUTSIDE) TO CHROMATIC CHANGE

2) Side to Side 3 3/4 - 4 1/4 inches beginning of loss of stereo AT EDGES

3) Up and Down 4 - 5" inches AT 50% BRIGHTNESS

NOTE: PUPIL SIZE & SHAPE NOT AFFECTED BY MASKS - PUPILS ARE AS SHOWN IN TEST #1 FOR 5X MAGNIFICATION. PHOTOS WERE NOT INCLUDED FOR THIS TEST THEREFORE.

TEST NO. 3 - IMAGE SIZE, PROJECTION CONE ANGLE

OBSERVER G.D. BENEDETTO DATE 8-1-74 PAGE 2

1. Observer's Comments:

NO MASK	
MASK 1	(attach exit pupil photo to back of sheet) ○ EASY TO SEE AT PERIPHERY. (THAN SQUARE)
MASK 2	(attach exit pupil photo to back of sheet) EASY TO SEE BECAUSE SIZE (SMALLER) - NOT AS GOOD AS #1, TO AT EDGES
MASK 3	(attach exit pupil photo to back of sheet) (*) ○ SIMILAR TO Nº 1 - MORE UNIFORMITY OF PICTURE BECAUSE OF SMALLER SIZE
MASK 4	(attach exit pupil photo to back of sheet) BETTER THAN #2, BECAUSE SMALLER, PICTURE IS SHARPER (LESS DISTORTION AT EDGES)
MASK 5	(attach exit pupil photo to back of sheet) ○ SIMILAR TO #1 & #3, (MAY BE TOO SMALL)?.

2. Preferred Configuration MASK #3

3. Head Motion while Maintaining Stereo

1) Fore and Aft 12½" TO 13½" inches DARKENING AT EDGES INSIDE TO CHROMATIC CHANGE OUTSIDE

2) Side to Side 4" TO 4½" inches (LOSS STEREO AT EDGES)

3) Up and Down 5" TO 6" inches FOR ∞ 50% BRIGHTNESS (STEREO STILL GOOD)

DATA SHEET

RESOLUTION VALUES FOR STANDARD USAF 1951 RESOLUTION TEST PATTERN (CYCLES PER MILLIMETER)

ELEMENTS	GROUPS -2	-1	0	1	2	3	4	5	6	7	8	9
1	0.250	0.500	1.00	2.00	4.00	8.00	16.0	32.0	64.0	128	256	512
2	0.281	0.561	1.12	2.24	4.49	8.98	17.9	35.9	71.8	143	287	575
3	0.315	0.629	1.26	2.52	5.04	10.1	20.1	40.3	80.6	161	323	645
4	0.354	0.707	1.41	2.83	5.66	11.3	22.6	45.3	90.5	181	362	724
5	0.397	0.794	1.59	3.17	6.35	12.7	25.4	50.8	101	203	406	813
6	0.445	0.891	1.78	3.56	7.13	14.3	28.5	57.0	114	228	456	912

APPENDIX C

VIEWER ANALYSIS

OF COMPASS PREVIEW RESOLUTION

COMPASS PREVIEW RESOLUTION

SUMMARY

Calculations are presented to show a predicted resolution of approximately 2.75 line pairs/mm at the screen when viewed from the normal viewing distance with the lens at 100X magnification. This is based on measured data for the diffuser and Fresnel lens, and calculated data for the zoom lens. Film with infinite resolution capability is assumed. This can be compared to a value in the region of 3.5 to 4.3 line pairs/mm computed for a diffraction-limited lens with infinite resolution diffuser and Fresnel. The range of values comes about because of the range of values published for the capability of the eye.

CALCULATIONS

In predicting the performance of any system, it is desirable to have a standard of reference; it is important to know how good it could possibly be. In optics the diffraction-limited lens is this standard. Its performance cannot be exceeded by a real lens. The on-axis modulation transfer function [MTF(ν)] of a diffraction-limited lens is given in Reference 1* as:

$$\text{MTF}\ (\nu) = \frac{2}{\pi}\ (\phi - \cos\phi \sin\phi) \qquad (1)$$

where:

$\phi = \lambda\nu\ (\text{f/no})$

λ = wavelength of light

ν = spatial frequency in consistent units

f/no = "f" number of lens

The f/number of the zoom lens at 100X is given in Reference 3* as 2.62. A curve showing the calculated MTF (ν) for $\lambda = 0.555\ \mu$m is presented in Figure C-1.

In order to relate the values to the screen, the calculated spatial frequencies were divided by 100 -- the magnification of the lens. The MTF (ν) is related to targets whose contrast varies in a sinusoidal fashion. The performance with resolution patterns which are alternate black and white bands is more accurately predicted by the square wave transfer function [S(ν)].

*References given page C-5.

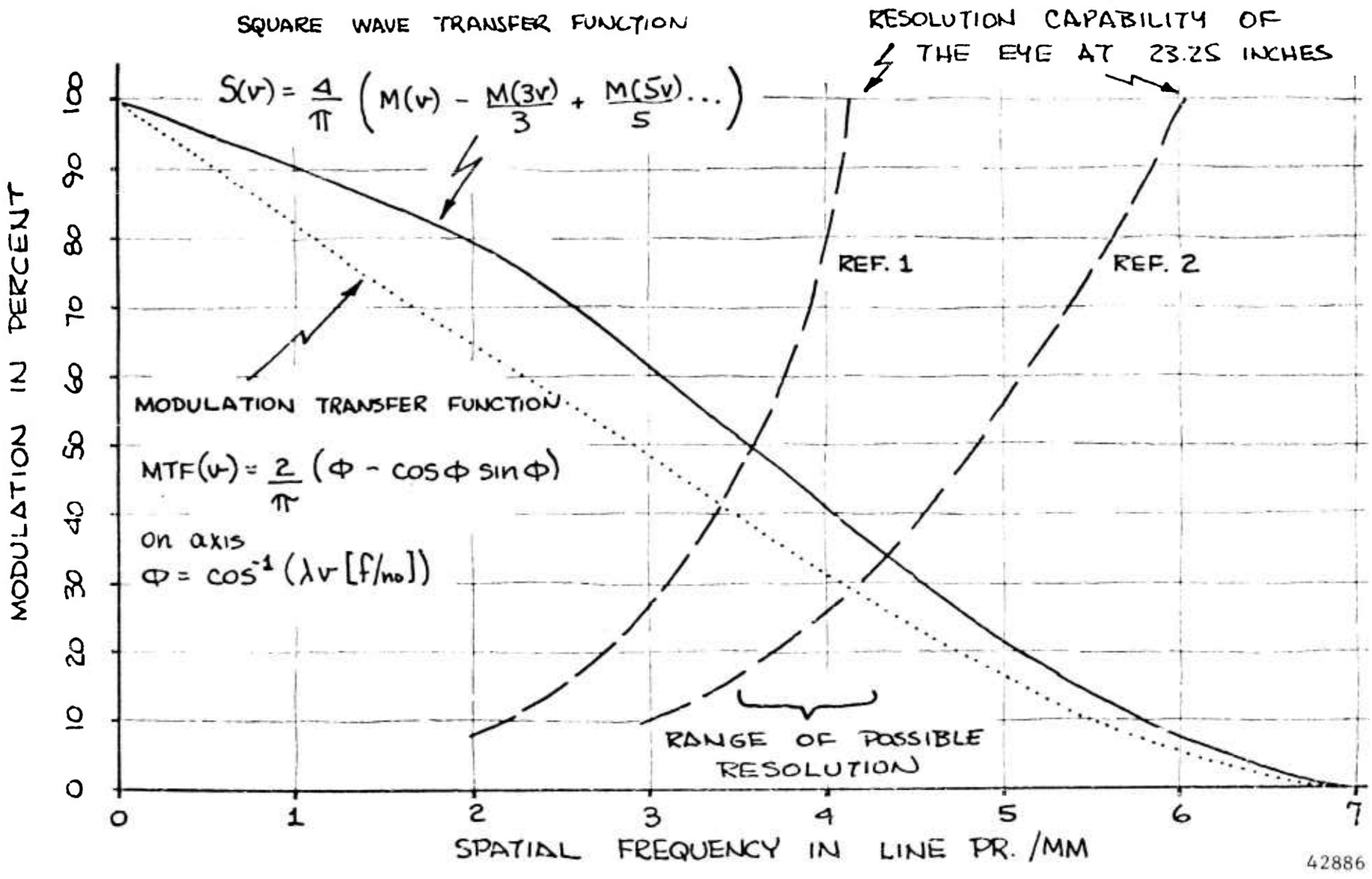


Figure C-1. Theoretical Resolution for a Projected Image from a Diffraction-Limited Lens (F/2.62)

This is related to the MTF (ν) by the following from Reference 1.

$$S(\nu) = 4\left|M(\nu) - \frac{M(3\nu)}{3} + \frac{M(5\nu)}{5} \cdots\right| \qquad (2)$$

where: $M(\nu)$ = MTF (ν)

This curve is also presented in Figure C-1. To determine the overall resolution when viewed by the eye, the resolution capability of the eye must be considered. Two curves for the eye are shown from References 1 & 2. Actually the resolution capability is a function of several things other than contrast, such as the relative brightness of the image and the surrounding area. The basic eye data are given in line pairs per arc-minute. These are converted to line pairs per mm as follows:

$$\frac{1 \text{ line pr}}{\widehat{\text{min}}} \times \frac{60 \text{ min}}{\text{degree}} \times \frac{57.3 \text{ degrees}}{\text{radian}} \times \frac{1.0 \text{ radian}}{23.25 \times 25.4 \text{ mm @ } 23.25 \text{ in}} = \frac{5.82 \text{ lp}}{\text{mm}}$$

The maximum performance, then, would be predicted by the intersection of the eye curve with the lens curve. This predicts a possible resolution in the range of 3.5 to 4.3 line pairs/mm depending on which eye curve is used for a diffraction-limited lens with a diffuser and Fresnel with infinite resolution.

To predict the performance of the actual system, calculated data are combined with measured data. First, the calculated zoom lens performance is shown in Figure C-2. It was obtained from Reference 3. Next the resolution capability of the observer's eyes was determined by viewing a resolution chart at 23.25 inches. A value of 4.7 lp/mm was obtained. This is shown as point E on Figure C-2. This is between the values determined from References 1 and 2. From this point a curve was constructed by scaling the curve from Reference 1. This is shown in Figure C-2.

To measure the degradation due to the Fresnel alone, the resolution target was viewed through the Fresnel at the 23.25-inch viewing distance. A value of 4.0 lp/mm was measured. This is plotted as point "F" in Figure C-2. An estimate of the MTF curve over a narrow region was made by drawing a line through point "F" and the (0 lp/mm; 100%) point of the graph. This is shown as line "A".

To measure the degradation due to the diffuser alone, the resolution target was viewed through the diffuser at the 23.25-inch viewing distance. A value of 3.80 lp/mm was measured. This is plotted as point "B". The estimate of the MTF curve was determined in the same fashion as for the diffuser. This is shown as curve "B".

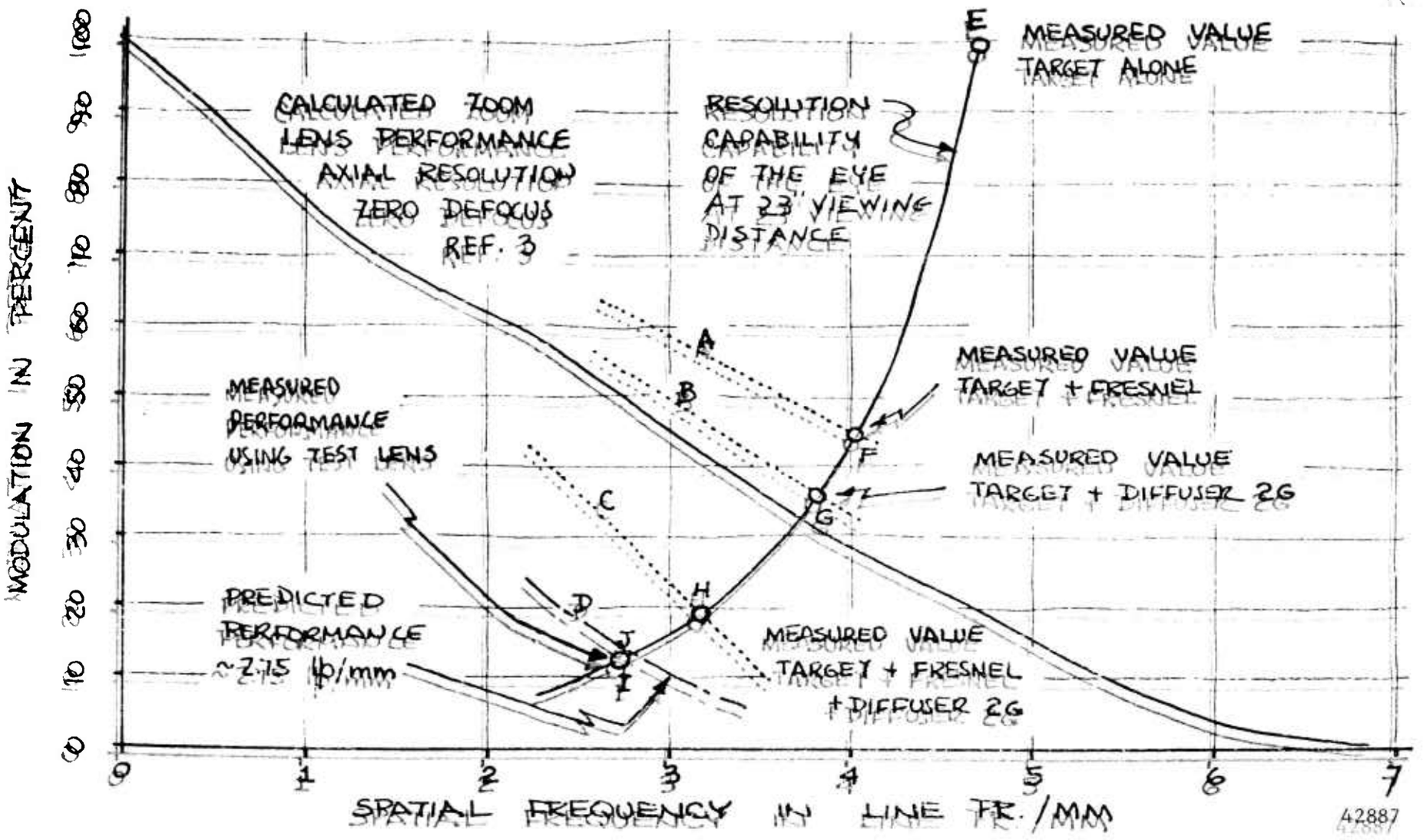


Figure C-2. Determination of Predicted Resolution of Total Viewing System

Next, the degradation due to the combination of the Fresnel and the diffuser was determined. The resolution was measured to be 3.17 lp/mm. This is shown as point "H". Line "C" is the estimate of the MTF curve. To check on the validity of the process, curve "C" should be the product of curves "A" and "B". At 3 lp/mm:

A = 58%

B = 49%

A x B = 28%

This is close to the experimentally determined value of 24% for "C" at 3 lp/mm.

The overall system response curve can be estimated by taking the product of the lens curve and curve "C". This is shown as curve "D". The intersection of this curve with the eye curve at "J" is the predicted resolution, approximately 2.75 lp/mm.

As a cross-check, this value can be compared with the value of 2.7 lp/mm measured with a test lens as shown at "I".

To estimate the performance improvement possible by decreasing the eye distance from 23.25 inches to 16 inches, the analysis shown on Figure C-3 was performed. The lens MTF and the system MTF curves are the same as in Figure C-2. So, also, is the eye curve for 23.25 inches. If the eye is moved to 16 inches the linear eye resolution for a given angular resolution will improve by a factor of $\frac{23.25}{16.00}$. This curve is shown. The predicted system resolution with the eye at 16 inches will be the intersection of the 16 inch eye curve with the system MTF curve. This is shown. The resolution, then, will be improved from approximately 275 lp/mm to 340 lp/mm (film plane resolution at 100X magnification as read by an unaided eye at 16" viewing distance).

REFERENCES

1. Smith: Modern Optical Engineering

2. Human Engineering Design Guide for Image Interpretation Equipment

3. Compass Preview Design Study, Final Technical Report, RADC TR-74-257

RESOLUTION IMPROVEMENT BY MOVING EYE POSITION FROM 23.25 IN. TO 16 IN.

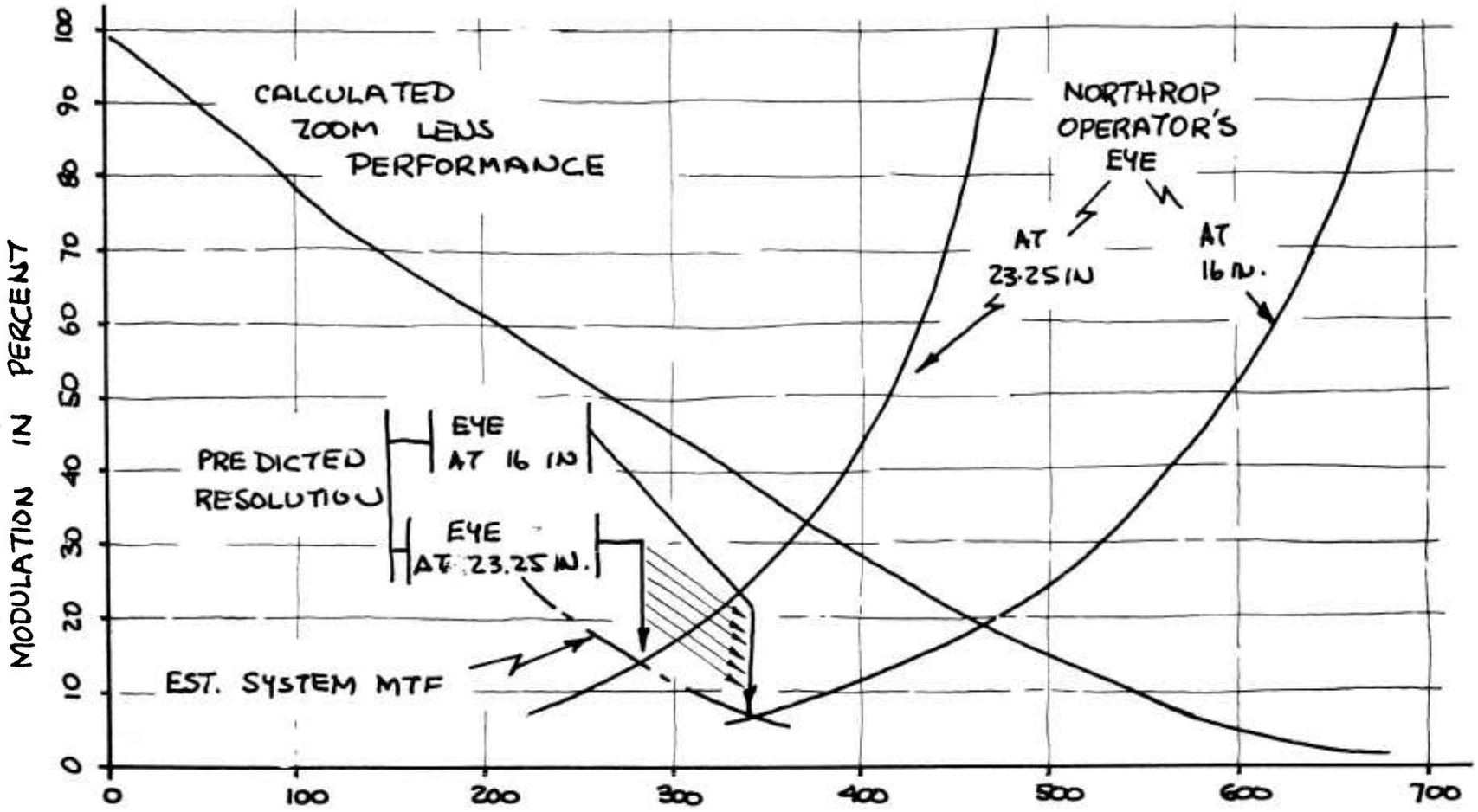


Figure C-3. Spatial Frequency in Line PR/MM at Film Plane - 100X Magnification

APPENDIX D

LOW MAGNIFICATION STUDIES

APPENDIX D

LOW MAGNIFICATION STUDIES

One of the features desired in Compass Preview is the ability to view relatively large segments of the film. This is to permit deployment of Compass Preview in a manual search mode in addition to the regular processor-controlled search modes. The term processor-controlled search is defined as those operations in which the machine searches for and displays the appropriate imagery. This mode implies ready access to a large data base, since without such data and the ability to program work orders, not much automation is possible.

There are, however, occasions when even with an extensive data base, it is necessary or desirable to perform manual searches. Of course, if the data base becomes inaccessible for reasons of logistics or equipment malfunction, a manual search mode becomes the only way to continue operations. There are, therefore, some compelling reasons why Compass Preview System should also be an effective system when manual search methods are called for.

In addition to facilitating the manual search capability, there are other reasons why a low magnification capability is highly desirable. This relates mainly to the tradeoff between magnification and field of view. The basic Compass Preview optical zoom system covers a 4.5-inch x 4.5-inch field with clipped corners which just fills the 22.5-inch viewing area at 5X magnification, resulting in a relationship of $\frac{22.5}{M}$ for the x or y (rectangular) dimensions and $\frac{28}{M}$ for the diagonal dimension (to fill the 28.0" diagonal of the Viewing Module). Although the 4.5-inch field is quite adequate for most situations, particularly small-scale imagery, there are cases where a larger field is highly desirable.

One additional factor which bears on the subject of low magnification relates to the hard copy capability. Although the hard copy subsystem of Compass Preview is not dedicated to the production of reference chips, it may well turn out to be used for limited chip production. (In most cases chips will be cut from the film.) In the event that the hard copy device will be used for chipping, it will be desirable to produce a copy at close to a one-to-one magnification. Since the Compass Preview projection optical system is an integral part of the hard copy capability, the desirability of a very low magnification capability is again manifested.

The need for low magnification was determined by the foregoing considerations. This demonstrates that considerable versatility may be gained by the introduction of a low magnification range. Design of the low magnification feature had to consider, among other things, the state of the Compass Preview development. The work done previously had resulted in a versatile device which still retained an inherent simplicity and functionality. It was determined that the addition of a low range should not compromise any of the existing functional capabilities or result in unreasonable complexity.

The latter was not an easy objective in view of the fact that the Compass Preview system is tightly packaged and has little unused internal space. Also, the multiple modes of operation had to be considered. The low magnification feature should be usable not only in the film projection mode but also in the chip projection mode, as well as the video and hard copy modes. An evaluation of the various possibilities indicated that some type of adapter lens or lenses added to the basic lens would be a logical approach.

Placing an adapter lens in front of another lens to gain a larger field with reduced magnification is a well-proven technique. Many cameras are designed to use wide angle auxiliary or adapter lenses for close work. Usually, however, the adapter and its mating lens are designed as a pair; therefore, the basic design can be tuned to work with the adapter. In the case of Compass Preview, however, the basic lens design had already been completed. Since the performance of this design is nearly diffraction limited, to touch the basic design would be at the risk of impairing its performance. So an added requirement imposed on the designer of the wide-angle adapter was to avoid any impairment of the basic 5X to 100X zoom performance.

In order to explore the mechanical alternatives that would influence the optical design, several possible concepts were laid out. A brief review of the physical configuration within the bounds where an adapter lens might be placed shows the alternatives. There are three possible locations for an adapter lens or lenses:

a) Between the film plane and the flip mirror

b) Between the flip mirror and the first stationary zoom lens element

c) Inside the zoom lens (this presupposes that the zoom travel can be restricted).

There are, of course, combinations of the foregoing which must also be considered if the optical design dictates this.

The first alternative (i.e., a lens between the flip mirror and the film plane) is not a good choice from the optical designer's viewpoint. The reason is that as a lens is moved closer to the object of image plane it becomes less effective as a magnifier. The ability of the lens to magnify, or rather demagnify, as is the case here, becomes zero when both are in the same plane. Since it was determined earlier that a 2X or less magnification was desired, the power of the adapter lens must be 0.4 to change the 5X magnification to 2X. This means that the lens should be nearly in the same location as the flip mirror. As an exploratory effort a hypothetical lens was placed between the film and the flip mirror. This required cutting down the length of the flip mirror, which would probably result in some loss of field in the transverse film or "Y" direction.

Mechanically, the foregoing concept is feasible. Since the area inside the door could be utilized, the adapter lenses could be mounted on a slide or slides as shown. Figure D-1 illustrates in schematic form the general idea. In use, the lenses are inserted between the film and the flip mirror. Out of use they retract into the door well. To have a 2X capability in both of the flip mirror positions would actually require four adapter lenses, two above and two below the flip mirrors. A trade study indicated that four lenses were more desirable than a mechanism for moving these into the upper or lower position. Since these lenses would be relatively large and heavy, making them from plastic was considered. A preliminary assessment of the optical problems associated with this concept ruled out continuation of the effort, at least as a solution by itself.

An auxiliary lens placed in front of the zoom, between the flip mirror and the first stationary lens, was next considered. An adapter lens as shown in Figure D-2 is obviously far enough from the object plane so that it can have the requisite power. Therefore, optically it may be quite feasible to go this route. One advantage of this lens location is that only two lenses are required, since each lens serves in both positions of the flip mirror.

The mechanism for introducing or removing a lens between the zoom and the flip mirror is not simple, as can be seen from Figure D-3 (drawing 721517). The main problem is the severe lack of space. This requires that the lens be translated from the stowed location and rotated to its functional position. The flip mirror doing the transition has to be in the position shown in Figure D-2 to avoid interference. Interlocks would have to be provided to prevent introducing the adapter lens if the flip mirror was in the wrong position; or, as an alternative, the whole sequence would have to be automated to the point where all the operator need do is actuate a single control. This can be done, although at the expense of some increased complexity.

Since it was not certain that the single lens shown in Figure D-2 could be designed to the required performance, additional configurations were developed. These configurations assume that lenses both before and after the flip mirrors will be required as shown in Figures D-4 and D-5. These concepts are by far the most complex and costly, therefore the least desirable; however, the concept does demonstrate that, if necessary, a considerable number of additional optical elements could be introduced ahead of the zoom lens.

Figure D-4 is actually a combination of the concepts illustrated in Figures D-1 and D-2. As before, the large elements (a) near the film plane are retracted into the door space when not in use. The smaller element (b) retracts to a position above and slightly to the rear of the zoom lens. Insertion of the smaller element (b) requires that the filp mirror be in the appropriate position.

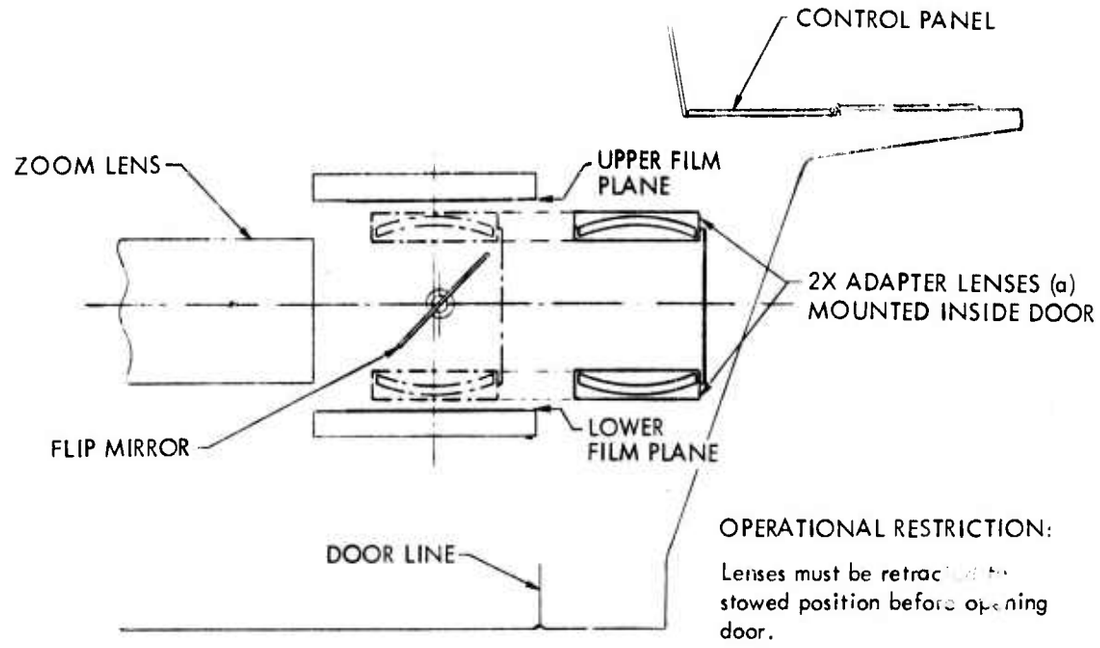


Figure D-1. Lenses Between Film Plane and Flip Mirror

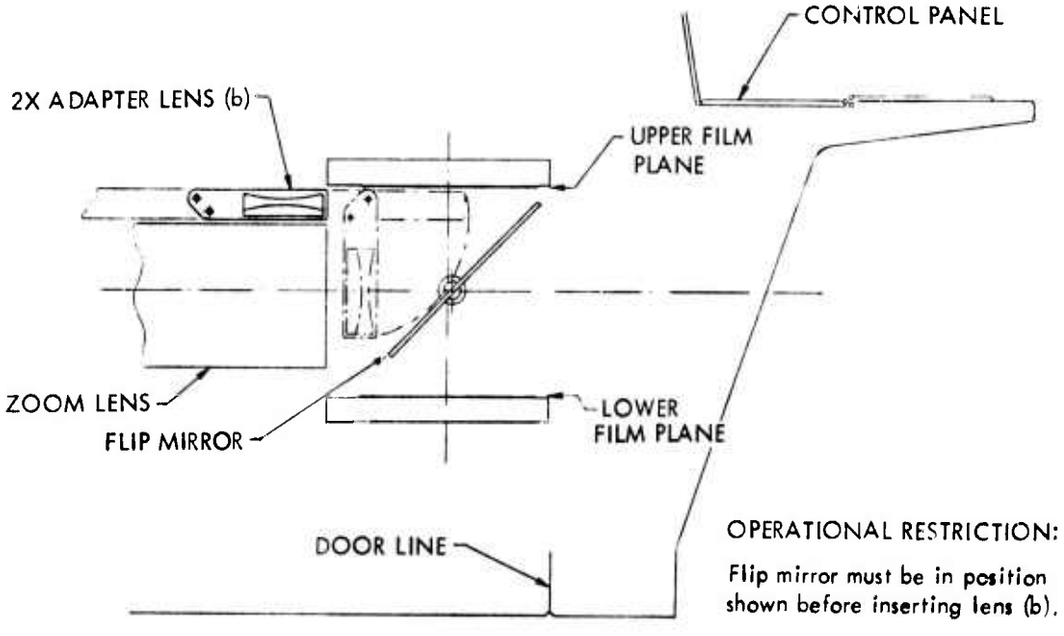


Figure D-2. Adapter Lens Between Flip Mirror and First Stationary Zoom Lens

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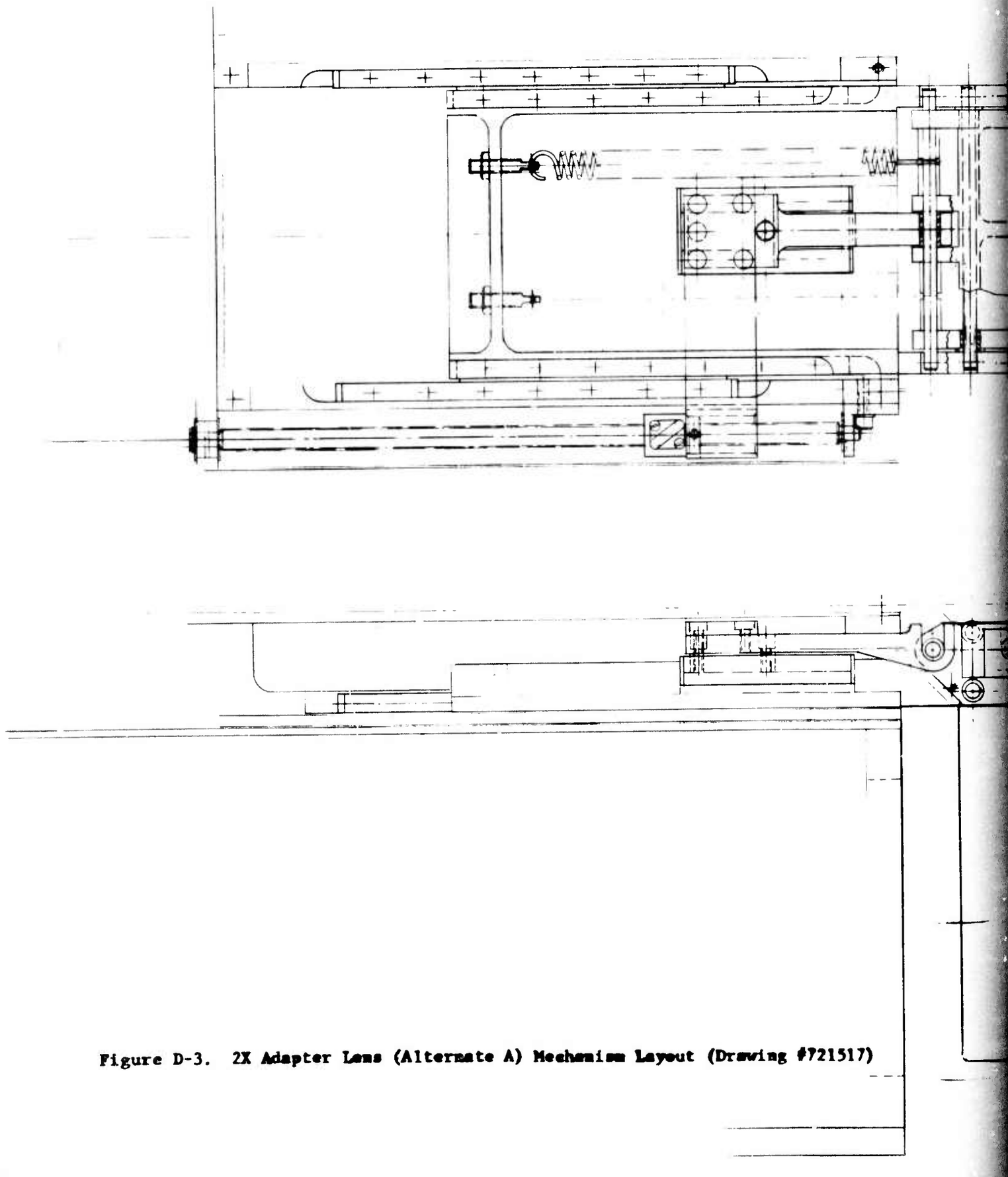
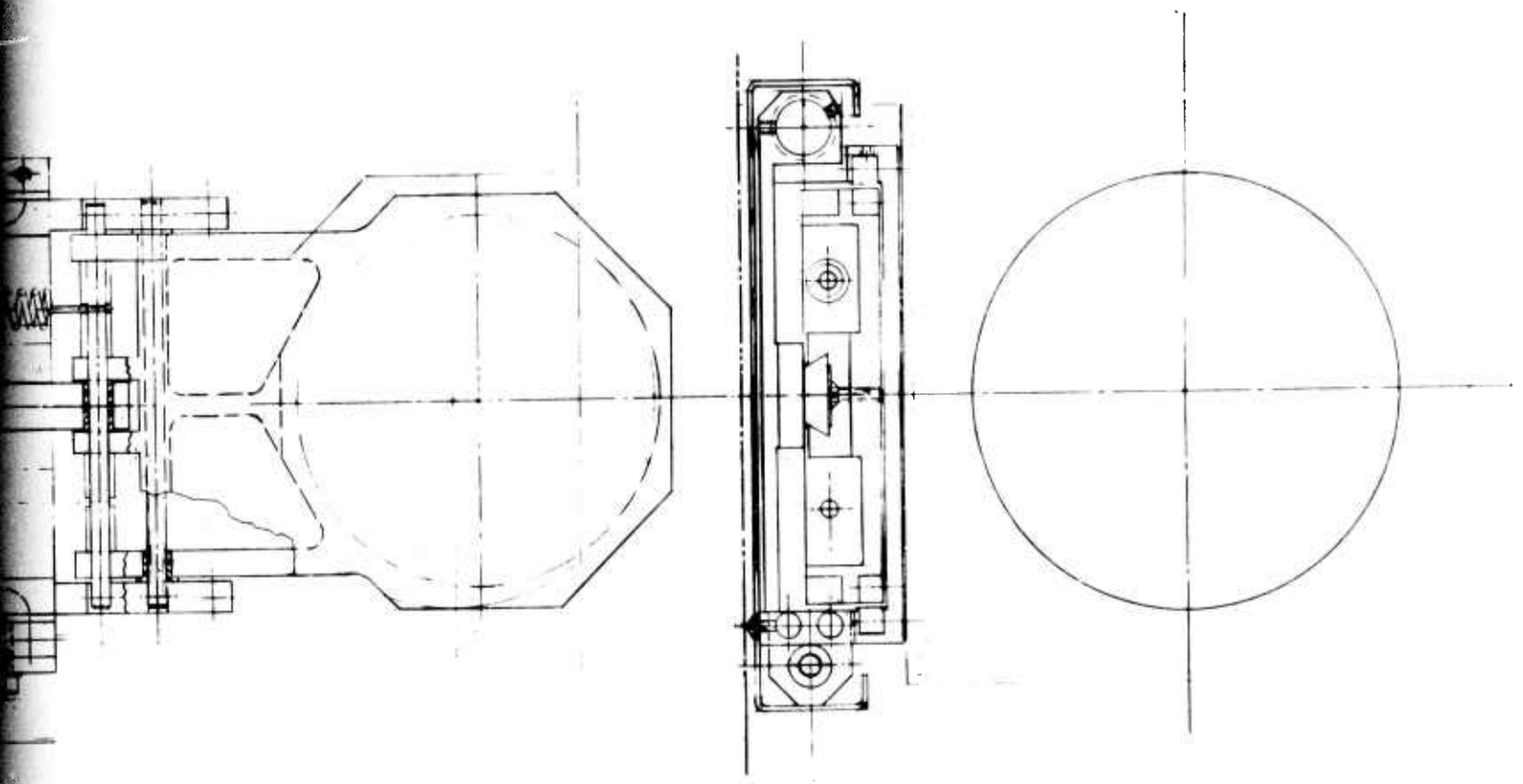
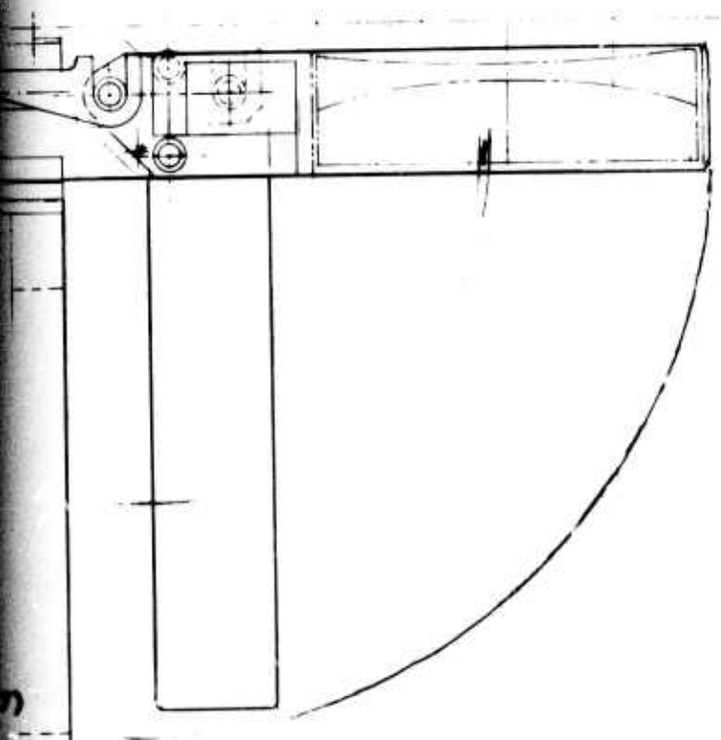


Figure D-3. 2X Adapter Lens (Alternate A) Mechanism Layout (Drawing #721517)





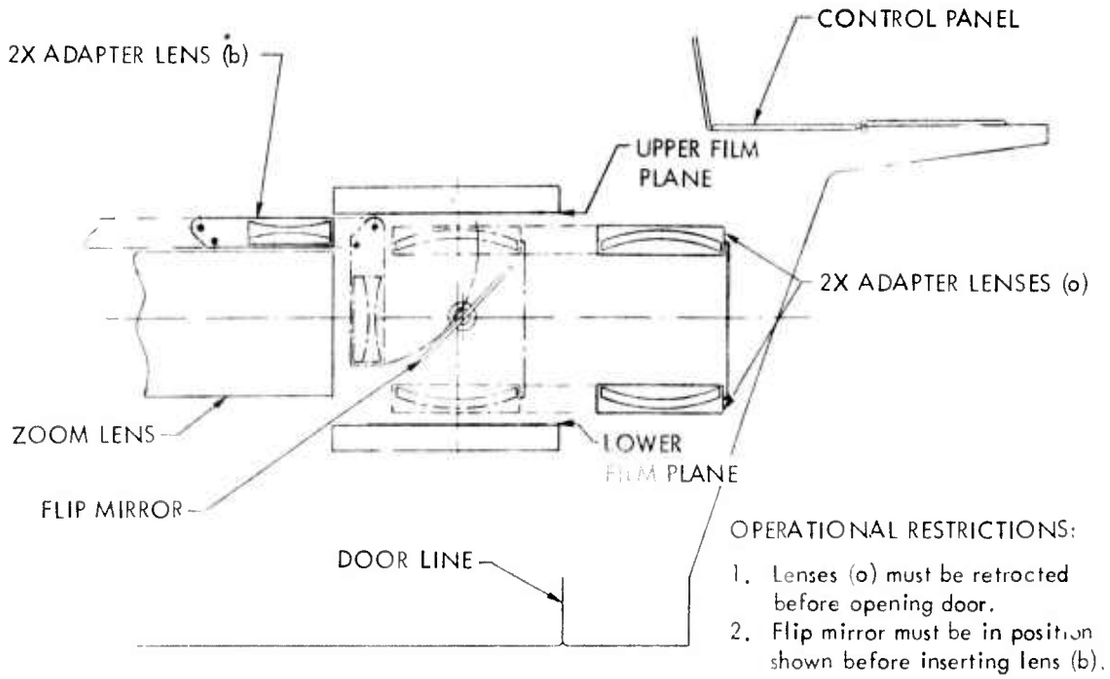


Figure D-4. Combination of Concepts Shown in Figures D-1 and D-2

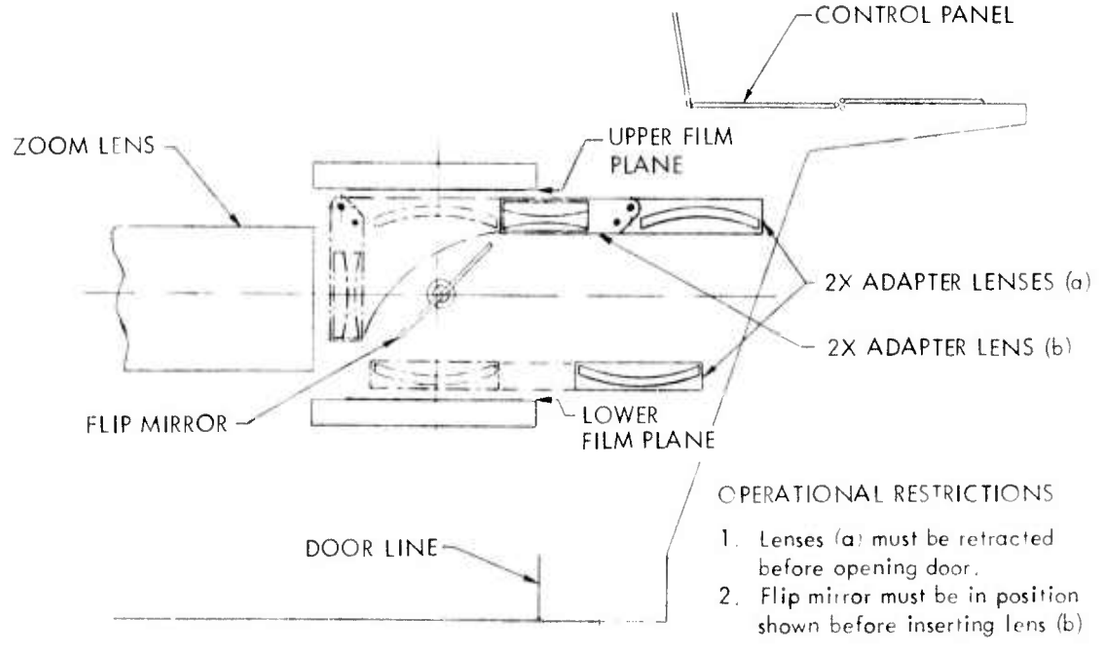


Figure D-5. Alternate Mechanization of Dual Adapter Lens Configuration

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Figure D-5 shows an alternate means for mechanizing a dual adapter lens configuration. In this case the upper large lens (a) carries with it the smaller auxiliary lens (b). As the two lenses move into position, lens (b) pivots as well as translates until it is in its position between the flip mirror and the zoom lens.

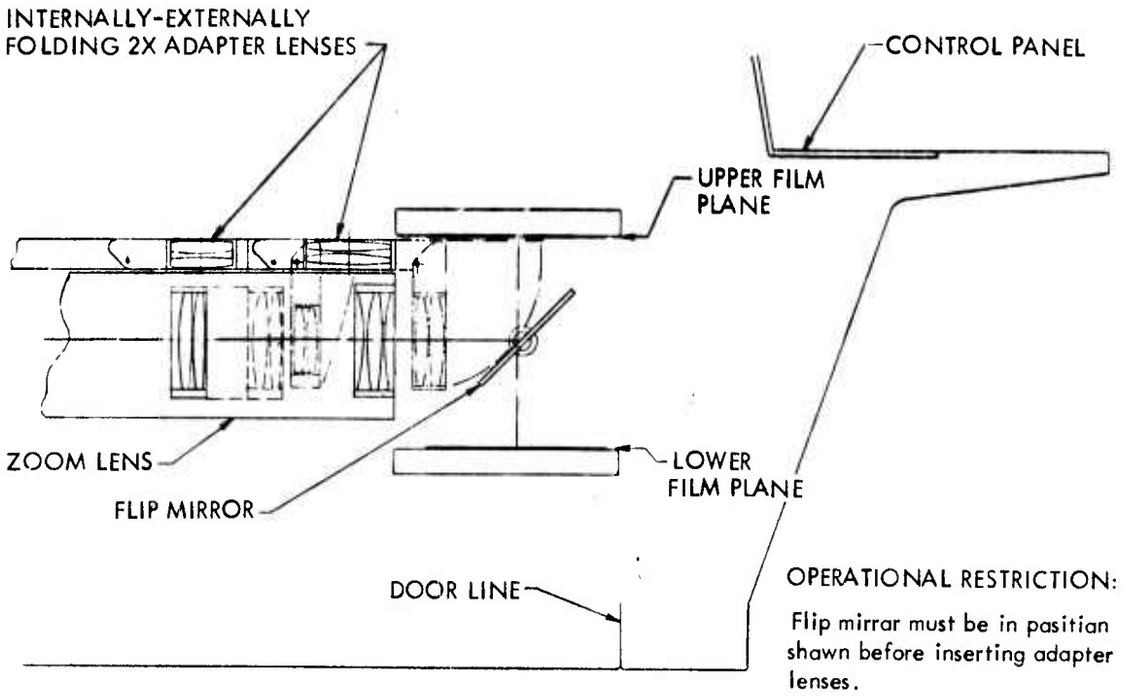
Both the configurations shown in Figures D-4 and D-5 require two of the smaller elements (b) and four of the larger elements (a). Also, undesirable complex precision mechanisms are involved along with considerable electrical gear to provide all the necessary actuators, interlocks and control sequences.

After a review of the various alternatives, it was determined that the single lens adapter as illustrated in Figure D-2 was in the direction of the most acceptable solution. This was based on the design aspects as well as operational considerations.

One of the inherent limitations of this approach is the number of lens elements that can be added. It is restricted by the space available between the zoom lens and the flip mirror. Because of this, some thought was given to possible locations of additional elements. One possibility was to utilize some of the space taken by the zoom travel. Since, in the low magnification range, the zoom lens needs to go no further than from 2X to 5X, only a small part of the 20:1 zoom range is used. This leaves some open space between the stationary and the moving elements in the lens. Fortunately, the first moving element is furthest from the first stationary element when the zoom module is in the low end of the range. Therefore, space behind the first fixed element could be utilized to introduce additional lenses inside the zoom module to augment those on the outside. This concept is shown in Figure D-6. When the auxiliary lens is in place, the zoom module travel is restricted by interlocks. When the auxiliary lens is swung out of the way, the full zoom travel is available.

The concept shown in Figure D-6 still has the mechanical drawbacks (flip mirror interference and complexity) attributed to the Figure D-2 concept. The next approach sought to substantially minimize the mechanical complexity. If the external lens could be eliminated entirely, much could be gained. From the preliminary optical studies, the feasibility of using only the internal lens was a reasonable possibility. This concept is depicted in Figure D-7. This would be the most satisfactory mechanical approach, since it places all additional elements inside the zoom module. Attempts to develop an optical solution based on this concept did not yield a system with sufficient performance. With some reluctance it was decided to review the Figure D-6 concept and to see if the following criteria could be reasonably met:

a) Incorporate simple mechanical motions and therefore simple mechanisms for introducing or retracting the lenses.



Auxiliary Lenses Inside Zoom Module to Augment Those Outside

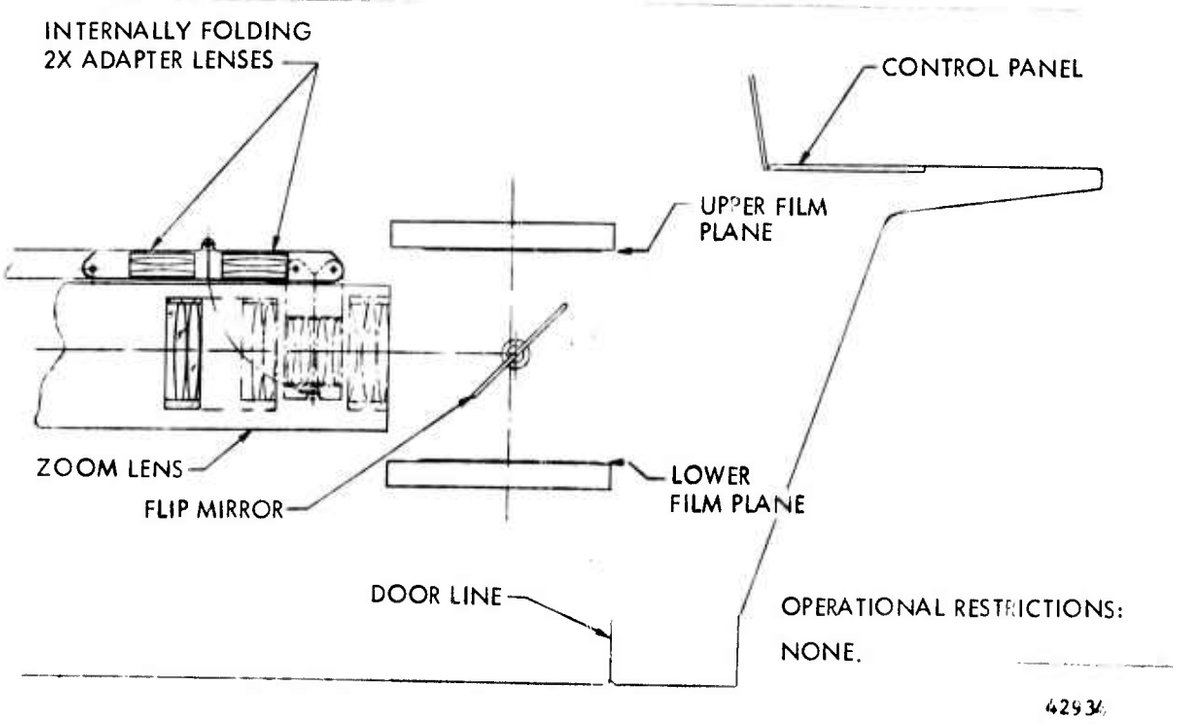


Figure D-7. All Additional Lenses Inside Zoom Module

b) Avoid the need to preposition the flip mirror before inserting the 2X adapter.

c) Strive to make the transition from high to low range or vice versa as rapid as possible.

d) With the adapter lenses removed, the zoom lens should revert to its basic configuration; therefore the performance through the 5X to 100X range should in no way be impaired.

A concept meeting the above criteria should find user acceptance. The transition should also be natural transition; i.e., the magnification would be dropping at the time the low power adapter is introduced. This can be done because the zoom module has to move to the low position to clear the area for the auxiliary lens.

One of the more significant points mentioned above is that of transition time. A major annoyance in the viewing process is the down time during magnification change. With a zoom lens this, of course, is avoided. However, in the case of incremental magnification changes (such as a range change), there is an unavoidable period of time when the image disappears from the Viewing Module. This period of time always seems longer to the observer than it really is. If the range change is only an occasional event, then a lengthy transition time is a nuisance but still tolerable. If, however, the changeover is frequent, and it appears likely that in some cases it will be, then a prolonged transition time becomes an operational impediment affecting the efficiency of the viewing process. It is, therefore, not only desirable but necessary to make the transition as fast as possible and the least noticeable (absence of noise, vibration, image shake, etc.).

DETAILED OPTICAL DESIGN

The most desirable configuration is depicted in Figure D-7 with all the adapter lenses inside the zoom module. It became apparent soon after this approach was started that a successful solution was not forthcoming. The substantial power required of these elements (because of their location) introduced unwanted aberrations. To achieve the 2X to 5X range the effective focal length of the first zoom element must change from about 12 inches (for the 5X to 100X range) to about 30 inches (for the 2X to 5X range). Since the physical space available is only about 12 inches, it is necessary to employ a telephoto lens construction. However, this is not an ordinary telephoto lens because the flip mirror seriously limits the space where additional elements can be located. Consequently, it becomes a fine tradeoff requiring the selection of elements of sufficient power that could be located in the available spaces and would still provide satisfactory imagery.

The first successful approach employed three groups of elements, two inside and one outside the zoom module, similar to Figure D-6 but with the addition

of one internal element. It became apparent during the detailed evaluation of this approach that the second internal element was contributing very little to the performance. As a result the next solution attempted was with the second internal element removed. The change in performance was negligible. Since this element only complicates the required insertion mechanism, it was gladly deleted in the interests of simplification. The final optical configuration is shown in Figure D-8.

The design of the low range adapter utilizes a small amount of astigmatism in order to get the tangential field flat. Unavoidably this results in a little radial distortion; however, the system balance is optimized. The radial distortion in the corner is 6% or less depending on the magnification. Table D-1 shows the distortion values at the various field positions and at two magnifications.

TABLE D-1. DISTORTION VALUES FOR LOW RANGE ADAPTER

Magnification	Axis	Zone	Corner
5X	0.0%	0.17%	0.35%
2X	0.0%	2.81%	6.00%

This distortion would affect the accuracy of rapid mensuration (i.e., mensuration performed by a "roving" cursor), but not precise mensuration where all measurements are made by driving the film under the central reference cursor. If this distortion (6% at the corner) provides too large a rapid mensuration error, the error can be removed by adding a distortion compensation term in the rapid mensuration program.

Figure D-9 provides a graphic presentation of what 6% distortion really looks like. It can be seen that it takes a critical observer to detect some deviation from a perfectly straight line.

The field positions at which the distortion values were calculated are axial, zonal or 0.7 full field and at the corner or full field. The field covered by the adapter lens at the 2X position is 11.40* inches in diameter. This will nicely cover a 9.5-inch format with only a slight cutoff in the corners. The way in which a 9.5-inch format would appear, projected at 2X on the Compass Preview Viewing Module, is shown in Figure D-10.

The resolution that the 2.5X adapter will provide is summarized in Table D-2. All values are in line pairs/mm and the field positions are as described previously. "R" refers to the radial resolving power and "T" is the tangential. Shown is the square wave MTF and 5% has been used as the cutoff frequency.

Since at 2X the image does not fill the viewing screen, the previously stated $\frac{28}{M}$ ratio does not apply.

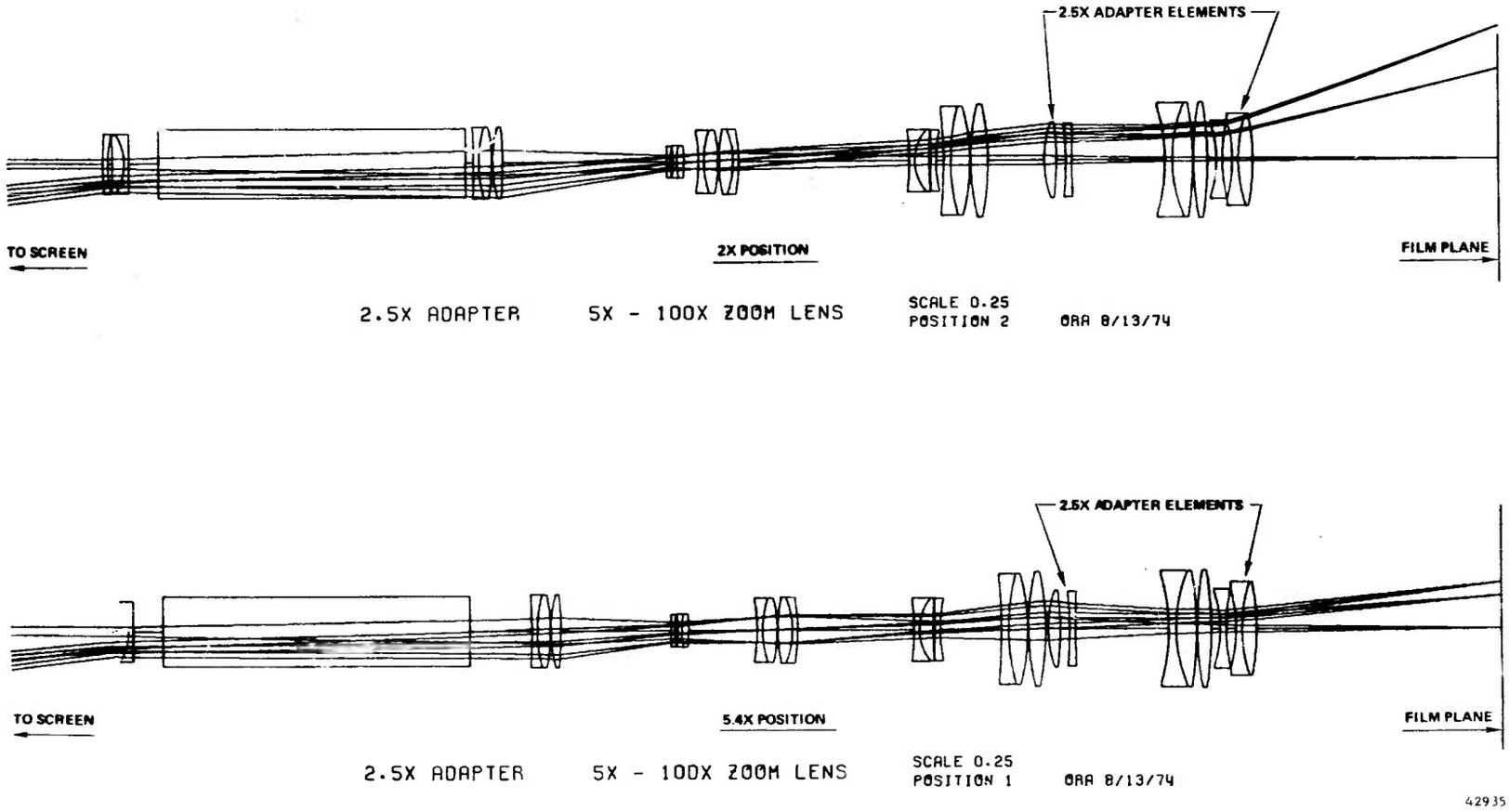


Figure D-8. Optical Configuration of 2.5X Adapter

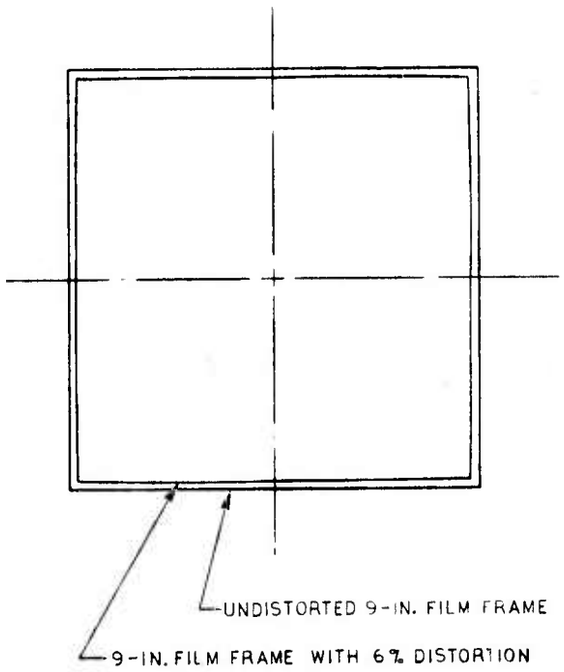


Figure D-9. Undistorted vs 6% Distorted Film Frame

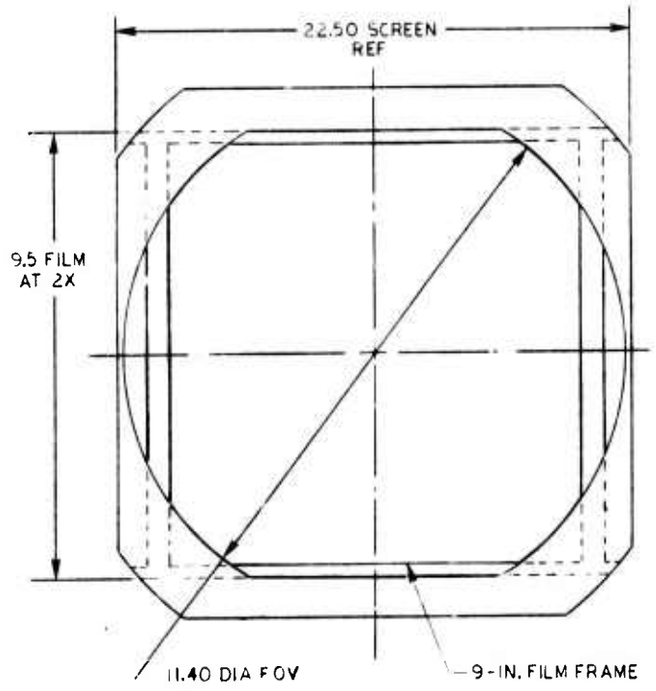


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Figure D-10. Appearance of 9.5-Inch Format Projected at 2X on Viewing Module

TABLE D-2. RESOLUTION VALUES FOR LOW RANGE ADAPTER

Magnification	Axis	Zone		Corner	
		R	T	R	T
5X	>7.0	>7.0	>7.0	3.2	6.8
2X	9.0	8.0	7.5	2.0	6.0

The detailed performance analysis of the low range adapter is provided in the following computer printouts (Table D-3).

DETAILED MECHANICAL DESIGN

With the optical design objectives reasonably well satisfied, it next became necessary to establish the specific mechanical configuration. The objectives were outlined earlier and these became the criteria used to evaluate the various mechanization alternatives. From the optical standpoint, a general scheme as shown in Figure D-6 was required. The major operational shortcoming of this scheme was the need to place the flip mirror in a particular position before the front adapter lens could be inserted.

It is entirely possible (at the expense of some added complexity) to automate the flip mirror positioning/lens insertion sequence. However, in the interest of simplification it was decided to look for other ways which might achieve the same result. One such way is to insert the lens in a manner which does not interfere with the flip mirror regardless of its position. To implement this line of reasoning, the first step involved reducing the length of the flip mirror to its minimum. Although the field of view with the adapter is 11.4 inches in diameter, it is not necessary to display a field greater than 9.5 inches wide, the width of the widest film. Therefore, in the direction of the film width, the mirror may serve to restrict the field.

Layouts of the reduced mirror size, based on the 9.5 transverse field, showed a substantial increase in clearance between the zoom lens and the edge of the mirror. At the same time other methods for inserting the lens between the mirror were investigated. One method, which proved feasible, entailed pivoting the lens somewhat like a pendulum. The details of this are shown in Figure D-11 (drawing 721518). The drive for inserting the lens is a small dc gearhead motor driving through a worm and gear. The entire assembly bolts to the front face of the zoom module as shown.

TABLE D-3. PERFORMANCE ANALYSIS OF 2.5X ADAPTER

POSITION 1 DIFFRACTION SOW CRA 8/13/74

2.5X ADAPTER 5X - 100X ZOOM LENS RDW-ATT-002

FIELD POSITION = 0.00 Y MAX. (0.00 DEGREES)
RELATIVE ILLUMINATION =100.0 PER CENT
DISTORTION = 0.00 PER CENT

WAVELENGTH	WEIGHT
648.1 NM	13
603.9 NM	58
562.7 NM	90
523.4 NM	44
476.9 NM	5

DIFFRACTION LIMIT			FOCUS POSITION									
F/NO	OBSCURED		-.01000		-.00500		-.00000		.00500		.01000	
/MM34.72	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN
	.999	.999	.999		.999		.999		.999		.999	
2	.968	.968	.967		.967		.967		.967		.966	
4	.936	.938	.926		.925		.923		.922		.920	
6	.904	.904	.861		.856		.851		.846		.839	
8	.869	.869	.783		.775		.765		.755		.745	
10	.833	.832	.693		.682		.670		.656		.642	
12	.816	.812	.622		.608		.593		.577		.559	
14	.795	.792	.565		.549		.532		.515		.496	
16	.760	.761	.514		.498		.481		.463		.444	
18	.708	.711	.461		.445		.428		.411		.393	
20	.650	.654	.409		.394		.379		.362		.345	
22	.592	.595	.363		.349		.334		.319		.303	
24	.535	.536	.320		.307		.294		.280		.266	
26	.479	.482	.285		.273		.261		.249		.236	
28	.425	.428	.252		.242		.231		.220		.209	
30	.373	.378	.225		.216		.206		.196		.186	
32	.322	.329	.197		.189		.181		.173		.164	
34	.274	.281	.172		.165		.158		.151		.144	

TABLE D-3. (Continued)

POSITION 1 DIFFRACTION SOU OPA 8/13/74

2.5X ADAPTER 5X - 100X ZOOM LENS RDW-ATT-002

FIELD POSITION = .71 Y MAX. (5.41 DEGREES)
RELATIVE ILLUMINATION = 95.9 PER CENT
DISTORTION = .17 PER CENT

WAVELENGTH	WEIGHT
648.1 NM	13
603.9 NM	58
562.7 NM	90
523.4 NM	44
476.9 NM	5

	DIFFRACTION LIMIT		FOCUS POSITION									
	F/NO	OBSCURED	-.01000		-.00500		-.00000		.00500		.01000	
L/MM	34.72	RAD TAN	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN
	.999	.999 .999	.999	.999	.999	.999	.999	.999	.999	.999	.999	.999
2	.968	.967 .967	.964	.966	.965	.966	.965	.966	.965	.966	.965	.966
4	.936	.933 .933	.908	.924	.910	.924	.912	.926	.914	.924	.916	.923
6	.904	.900 .899	.821	.865	.827	.864	.833	.864	.839	.863	.844	.861
8	.869	.863 .859	.725	.785	.735	.785	.745	.788	.754	.782	.762	.779
10	.833	.831 .827	.623	.708	.637	.708	.650	.707	.662	.704	.673	.700
12	.816	.813 .809	.548	.650	.565	.649	.581	.647	.595	.644	.609	.640
14	.795	.791 .788	.494	.599	.512	.598	.529	.595	.545	.591	.560	.586
16	.760	.756 .750	.453	.548	.471	.547	.488	.544	.503	.540	.518	.534
18	.708	.702 .696	.407	.490	.424	.488	.440	.485	.455	.481	.468	.475
20	.650	.642 .635	.362	.435	.377	.433	.392	.430	.406	.426	.419	.421
22	.592	.585 .577	.326	.389	.341	.387	.354	.384	.367	.380	.379	.375
24	.535	.529 .521	.295	.348	.308	.346	.320	.343	.332	.338	.342	.333
26	.479	.473 .465	.266	.309	.278	.307	.289	.303	.299	.300	.308	.295
28	.425	.416 .409	.239	.271	.249	.269	.259	.266	.268	.262	.276	.258
30	.373	.365 .358	.218	.239	.227	.237	.235	.234	.243	.230	.249	.226
32	.322	.314 .307	.196	.207	.204	.204	.211	.202	.217	.199	.222	.195
34	.274	.268 .260	.178	.178	.184	.176	.189	.173	.194	.170	.198	.167

TABLE D-3. (Continued)

POSITION 1 DIFFRACTION SOW ORA 8/13/74

2.5X ADAPTER 5X - 100X ZOOM LENS RDW-ATT-002

FIELD POSITION = 1.00 Y MAX. (7.63 DEGREES)
RELATIVE ILLUMINATION = 93.8 PER CENT
DISTORTION = .35 PER CENT

WAVELENGTH	WEIGHT
648.1 NM	13
603.9 NM	58
562.7 NM	90
523.4 NM	44
479.9 NM	5

	DIFFRACTION LIMIT		FOCUS POSITION									
	F/NO	OBSCURED	-.01000		-.00500		-.00000		.00500		.01000	
/MM	34.72	RAD TAN	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN
	.999	.999 .999	.999	.999	.999	.999	.999	.999	.999	.999	.999	.999
2	.968	.968 .966	.955	.964	.956	.964	.956	.964	.957	.964	.958	.964
4	.936	.936 .931	.788	.903	.797	.904	.805	.905	.813	.905	.821	.905
6	.904	.906 .897	.537	.802	.555	.804	.572	.805	.588	.807	.605	.808
8	.869	.870 .855	.340	.693	.361	.696	.382	.699	.402	.701	.423	.703
10	.833	.838 .826	.197	.606	.216	.610	.236	.612	.255	.614	.275	.614
12	.816	.821 .810	.107	.528	.123	.530	.140	.532	.157	.533	.176	.533
14	.795	.797 .787	.054	.452	.067	.455	.082	.456	.097	.457	.114	.457
16	.760	.760 .747	.034	.385	.046	.387	.058	.388	.072	.389	.086	.389
18	.708	.707 .687	.025	.322	.035	.324	.045	.325	.057	.325	.069	.325
20	.650	.646 .625	.018	.268	.025	.269	.034	.270	.044	.270	.055	.270
22	.592	.589 .568	.015	.222	.022	.223	.029	.224	.038	.225	.047	.225
24	.535	.532 .510	.014	.181	.019	.182	.026	.184	.033	.185	.042	.185
26	.479	.475 .453	.012	.143	.017	.146	.023	.147	.030	.149	.037	.151
28	.425	.418 .395	.009	.111	.014	.114	.020	.116	.026	.118	.033	.120
30	.373	.366 .343	.011	.084	.015	.087	.021	.090	.027	.092	.034	.095
32	.322	.314 .291	.011	.061	.016	.064	.022	.067	.028	.070	.034	.072
34	.274	.267 .244	.017	.044	.022	.047	.027	.049	.033	.052	.039	.054

TABLE D-3. (Continued)

POSITION 2 DIFFRACTION SOW CPA 8/13/74

2.5X ADAPTER 5X - 100X ZOOM LENS PDW-ATT-002

FIELD POSITION = 0.00 Y MAX. (0.00 DEGREES)
RELATIVE ILLUMINATION =100.0 PER CENT
DISTORTION = 0.00 PER CENT

WAVELENGTH	WEIGHT
649.1 NM	13
603.9 NM	58
562.7 NM	90
523.4 NM	44
476.9 NM	5

	DIFFRACTION LIMIT F/NO /MM86.07		OBSCURED		FOCUS POSITION -.02000		-.01000		-.00000		.01000		.02000	
		RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN	
	.999	.999		.999		.999		.999		.999		.999		
1	.960	.960		.960		.960		.960		.960		.960		
2	.920	.919		.917		.917		.917		.916		.916		
3	.881	.880		.875		.874		.874		.873		.872		
4	.834	.835		.820		.819		.817		.814		.812		
5	.813	.814		.790		.787		.783		.780		.776		
6	.782	.783		.752		.749		.745		.740		.736		
7	.727	.726		.693		.689		.685		.680		.675		
8	.655	.652		.619		.615		.611		.607		.602		
9	.583	.582		.551		.548		.544		.540		.535		
10	.513	.513		.485		.482		.478		.475		.471		
11	.445	.444		.420		.418		.415		.412		.408		
12	.379	.375		.356		.354		.352		.349		.346		
13	.317	.313		.299		.298		.296		.294		.292		
14	.258	.252		.242		.241		.240		.239		.238		
15	.202	.199		.192		.192		.191		.190		.190		
16	.151	.146		.142		.141		.141		.141		.140		
17	.106	.103		.101		.101		.101		.101		.100		
18	.067	.061		.060		.060		.060		.060		.060		
19	.036	.036		.035		.035		.035		.035		.035		
20	.016	.011		.011		.011		.011		.011		.011		
21	.006	.006		.006		.006		.006		.006		.006		

TABLE D-3. (Continued)

POSITION 2 · DIFFRACTION SOL OPA 8/13/74

2.5X /D/PTER 5X - 100X ZOOM LENS RDW-ATT-002

FIELD POSITION = .71 Y MAX. (5.36 DEGREES)
RELATIVE ILLUMINATION = 85.2 PER CENT
DISTORTION = 2.81 PER CENT

WAVELENGTH	WEIGHT
648.1 NM.	13
503.9 NM	58
587.7 NM	90
523.4 NM	44
476.9 NM	5

	DIFFRACTION LIMIT		FOCUS POSITION									
	F/NO	DESIRED	-.02000		-.01000		-.00000		.01000		.02000	
L/MM	86.07	RAD TAN	RAD	TAN	RAD	TAN	RAL	TAN	RAD	TAN	RAD	TAN
	.990	.990 .990	.999	.999	.999	.999	.999	.999	.999	.999	.999	.999
1	.960	.958 .955	.952	.954	.952	.954	.952	.954	.952	.953	.952	.953
2	.920	.914 .908	.859	.894	.860	.893	.862	.893	.863	.893	.865	.892
3	.881	.869 .863	.720	.782	.724	.781	.728	.779	.731	.777	.735	.776
4	.834	.828 .822	.554	.681	.561	.676	.567	.676	.573	.673	.579	.669
5	.813	.805 .800	.434	.599	.442	.596	.450	.592	.457	.588	.465	.584
6	.782	.763 .756	.353	.515	.361	.511	.369	.508	.377	.503	.385	.499
7	.727	.691 .679	.283	.441	.290	.437	.298	.433	.306	.429	.313	.425
8	.655	.611 .598	.227	.381	.234	.378	.241	.374	.248	.371	.255	.367
9	.583	.537 .523	.192	.333	.198	.331	.205	.328	.211	.325	.217	.322
10	.513	.463 .447	.166	.288	.171	.286	.177	.284	.182	.282	.187	.280
11	.445	.392 .376	.148	.244	.152	.242	.157	.241	.161	.239	.165	.237
12	.379	.322 .306	.130	.197	.134	.196	.137	.195	.141	.194	.144	.192
13	.317	.259 .241	.118	.153	.121	.153	.124	.152	.126	.151	.129	.150
14	.256	.197 .179	.101	.110	.103	.110	.104	.109	.106	.108	.108	.108
15	.202	.144 .127	.084	.074	.085	.074	.086	.074	.088	.073	.089	.073
16	.151	.091 .077	.058	.044	.058	.044	.059	.043	.060	.043	.060	.043
17	.106	.057 .045	.042	.024	.042	.024	.042	.024	.042	.024	.043	.024
18	.067	.024 .014	.017	.010	.018	.010	.018	.010	.018	.010	.018	.010
19	.036	.013 .007	.011	.005	.011	.005	.011	.005	.011	.005	.011	.005
20	.016	.001 .001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
21	.006	.001 .000	.001	.000	.001	.000	.001	.000	.001	.000	.001	.000

TABLE D-3. (Concluded)

POSITION 2 DIFFRACTION SOW ORA 8/13/74

2.5X ADAPTER 5X - 100X ZOOM LENS RDW-ATT-002

FIELD POSITION = 1.00 Y MAX. (7.55 DEGREES)
RELATIVE ILLUMINATION = 72.7 PER CENT
DISTORTION = 6.00 PER CENT

WAVELENGTH	WEIGHT
648.1 NM	13
603.9 NM	58
562.7 NM	90
523.4 NM	44
476.9 NM	5

	DIFFRACTION LIMIT		FOCUS POSITION									
	F/NO	OBSCURED	-.02000		-.01000		-.00000		.01000		.02000	
L/MM	86.07	RAD TAN	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN	RAD	TAN
		.999 .999	.999	.999	.999	.999	.999	.999	.999	.999	.999	.999
1		.960 .953 .953	.918	.944	.919	.943	.919	.943	.920	.943	.920	.942
2		.920 .906 .906	.600	.817	.603	.814	.607	.812	.611	.810	.615	.807
3		.881 .854 .850	.268	.638	.273	.633	.278	.628	.283	.623	.288	.617
4		.834 .822 .819	.052	.488	.056	.480	.060	.473	.064	.465	.068	.457
5		.813 .791 .787	.046	.359	.043	.351	.040	.343	.038	.335	.035	.327
6		.782 .730 .723	.064	.251	.062	.244	.061	.236	.059	.229	.057	.222
7		.727 .645 .638	.062	.176	.061	.170	.060	.165	.059	.159	.058	.153
8		.655 .560 .553	.053	.138	.053	.133	.052	.129	.052	.124	.051	.120
9		.583 .481 .471	.040	.119	.040	.116	.040	.112	.040	.109	.039	.105
10		.513 .401 .389	.031	.101	.030	.098	.030	.095	.030	.093	.029	.090
11		.445 .328 .316	.017	.077	.017	.076	.016	.074	.016	.072	.015	.071
12		.379 .254 .243	.006	.053	.005	.052	.005	.052	.004	.051	.004	.050
13		.317 .192 .181	.011	.038	.012	.038	.012	.038	.013	.037	.013	.037
14		.258 .130 .118	.018	.023	.019	.023	.019	.023	.020	.023	.020	.023
15		.202 .083 .073	.025	.014	.026	.014	.026	.014	.026	.014	.027	.015
16		.151 .037 .032	.013	.015	.013	.015	.013	.016	.013	.016	.013	.016
17		.106 .019 .014	.012	.011	.013	.011	.013	.011	.013	.011	.013	.011
18		.067 .001 .001	.000	.001	.000	.001	.000	.001	.000	.001	.000	.001
19		.036 .001 ?	.000	?	.000	?	.000	?	.000	?	.000	?
20		.016 0.000 ?	0.000	?	0.000	?	0.000	?	0.000	?	0.000	?
21		.006 0.000 ?	0.000	?	0.000	?	0.000	?	0.000	?	0.000	?

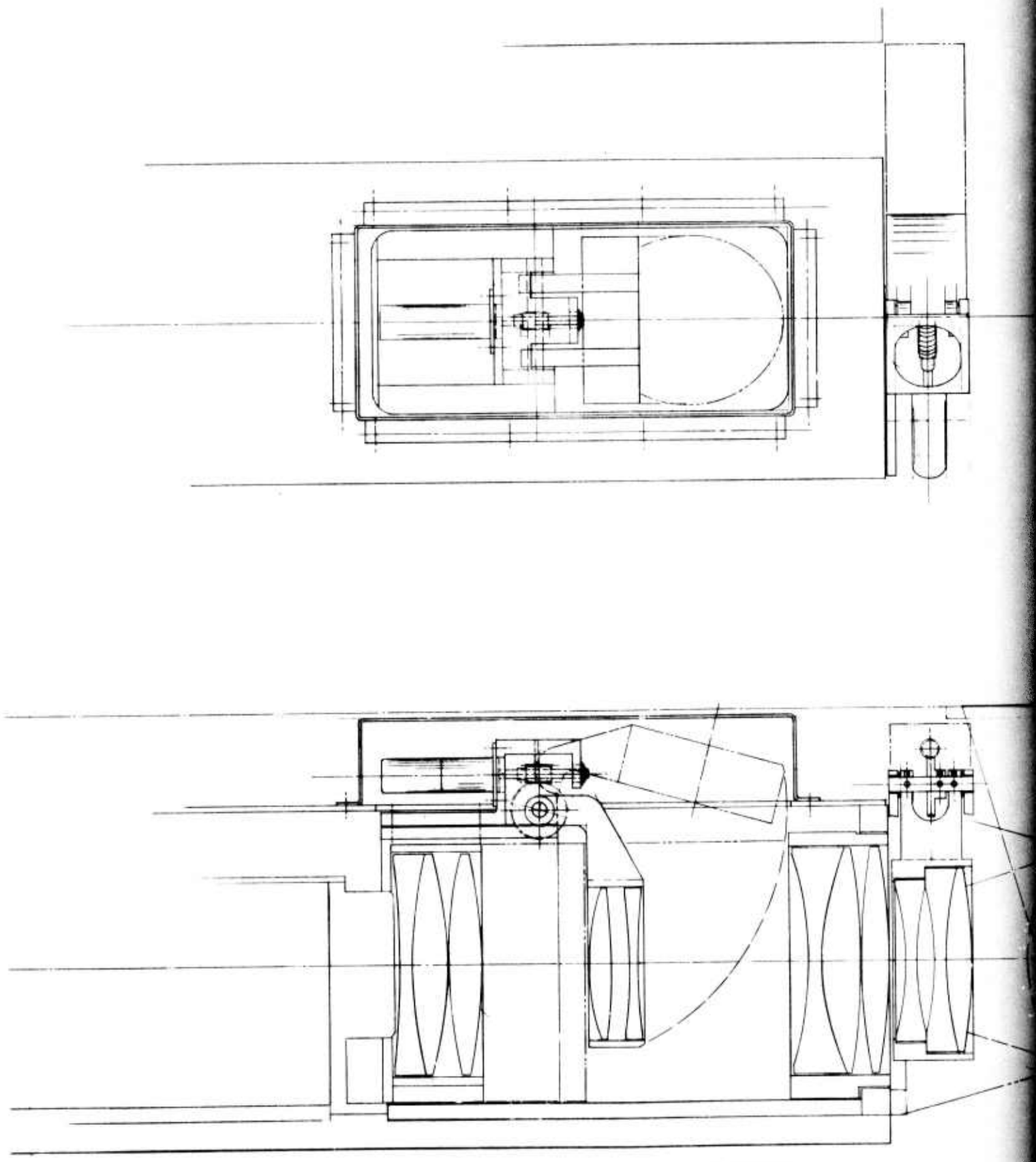
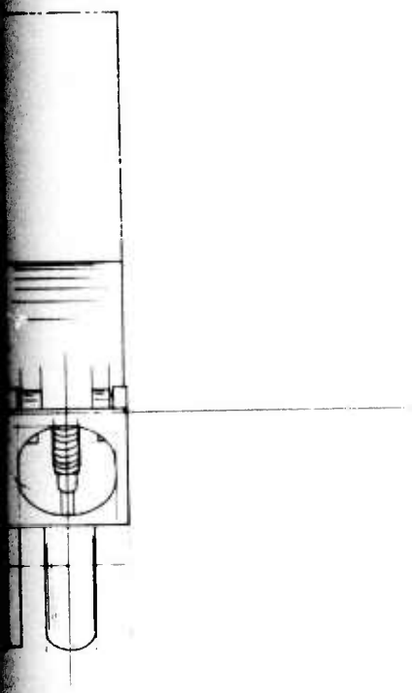
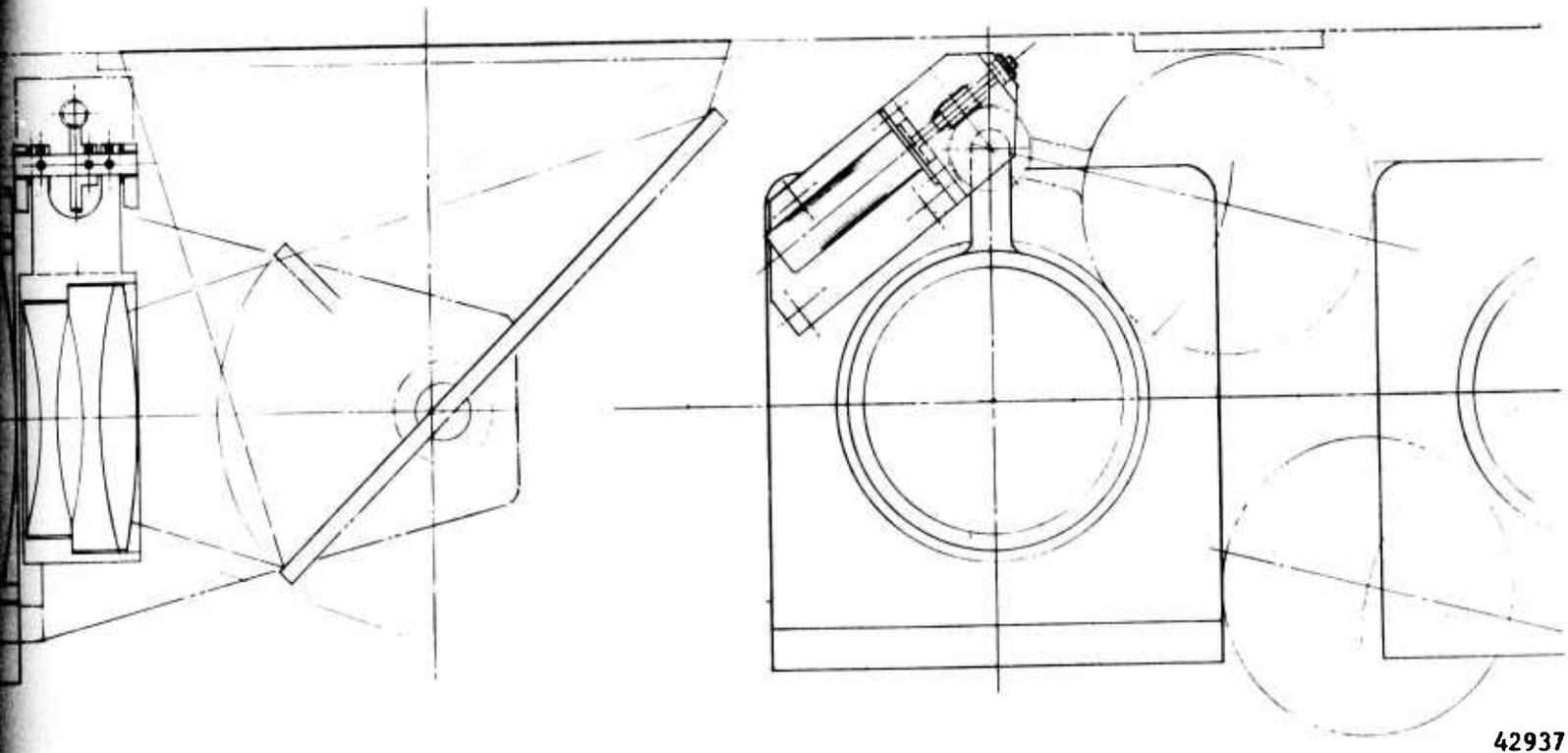


Figure D-11. 2X Adapter Lens Mechanism Layout (Drawing #721518)





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The second adapter lens is inside the zoom module. This lens is pivoted from above and swings in or out as shown in Figure D-11. The motor and drive mechanism is the same as for the front lens. Thought was given to mechanically linking the two lens drives together. This is possible; however, it appears to be substantially more complex than the concept shown.

In summary it can be stated that the low range adapter concept is feasible. This assumes that the problem of illuminating the 9.5-inch format can be solved by reasonable means. The adapter should provide the following features:

a) An extended low magnification range of 2X to 5.4X.

b) Viewing the full 9.5-inch format except for the very corners as shown in Figure D-10.

c) Transition from low range to high or vice versa in approximately 3 seconds.

d) Capability of inserting adapter lenses when flip mirror is in either position.

e) Capability of full performance of the 5X to 100X zoom module with adapter lenses removed.

f) Availability of all previous operational modes in the low or high range.

APPENDIX E

COMPASS PREVIEW/ZOOM 240 MICROSTEREOSCOPE COMPARATIVE TESTS

As part of this contract Northrop was furnished with a Richards MIM-33710-M Light Table and a Bausch and Lomb Zoom 240 Microstereoscope (Ser No. 654TF) equipped with 10X eyepieces and 0.43X stereo attachments. Since the basic pod zoom magnification of this instrument is .7X to 3.0X, the total test range available with the 10X eyepiece and the 0.43X stereo attachment is 3X to 12.9X. Additionally, the instrument was tested using contractor-owned 20X Bausch & Lomb eyepieces from a lab microscope, which provide a test range of 6X to 25.8X. These tests were conducted using the same ITEK 1951 USAF 3-bar resolution test targets that were used in making all Compass Preview resolution measurements, and the results are shown in Table E-1, and a plot of these results as compared to Compass Preview results is presented in Figure E-1.

Additionally, the contractor resolution measurements of the B&L Zoom 240 were compared with measurements taken by the Optical Sciences Center of the University of Arizona as reported in RADC-TR-70-150.

Since the contractor (Northrop) did not have the full range of B&L eyepieces and stereo attachments available, only two points of direct comparison can be made with the RADC-TR-150 data, as follows:

Magnification	Northrop	RADC-TR-70-150
6X (34 mm field)	45.8 cycles/mm	75 cycles/mm
12X (17 mm field)	76.3 cycles/mm	125 cycles/mm

The differences in these results can be explained as follows:

1) Measurement Technique:

Northrop used human operators viewing directly through the Zoom 240 eyepieces at the target mounted on the light table.

The University of Arizona measurement technique is fully reported in RADC-TR-70-150. Briefly, it involved the use of secondary optics to magnify and re-focus the Zoom 240 image through a pinhole and onto a photodetector using an S-1 photocathode. The output of the detection system was recorded on strip charts.

Quantifying the differences of these two test methods would require a lengthy test program, and involve test equipment not provided under this contract. However, the eye measurements will certainly show lower resolution than electronic measurements, depending on the image modulation and eye response to that modulation. As reported in RADC-TR-70-150 "unfortunately, the effect of the retina on the image modulation is much more difficult to predict since there are many variables which can influence the SWR and Sq WR of the eye".

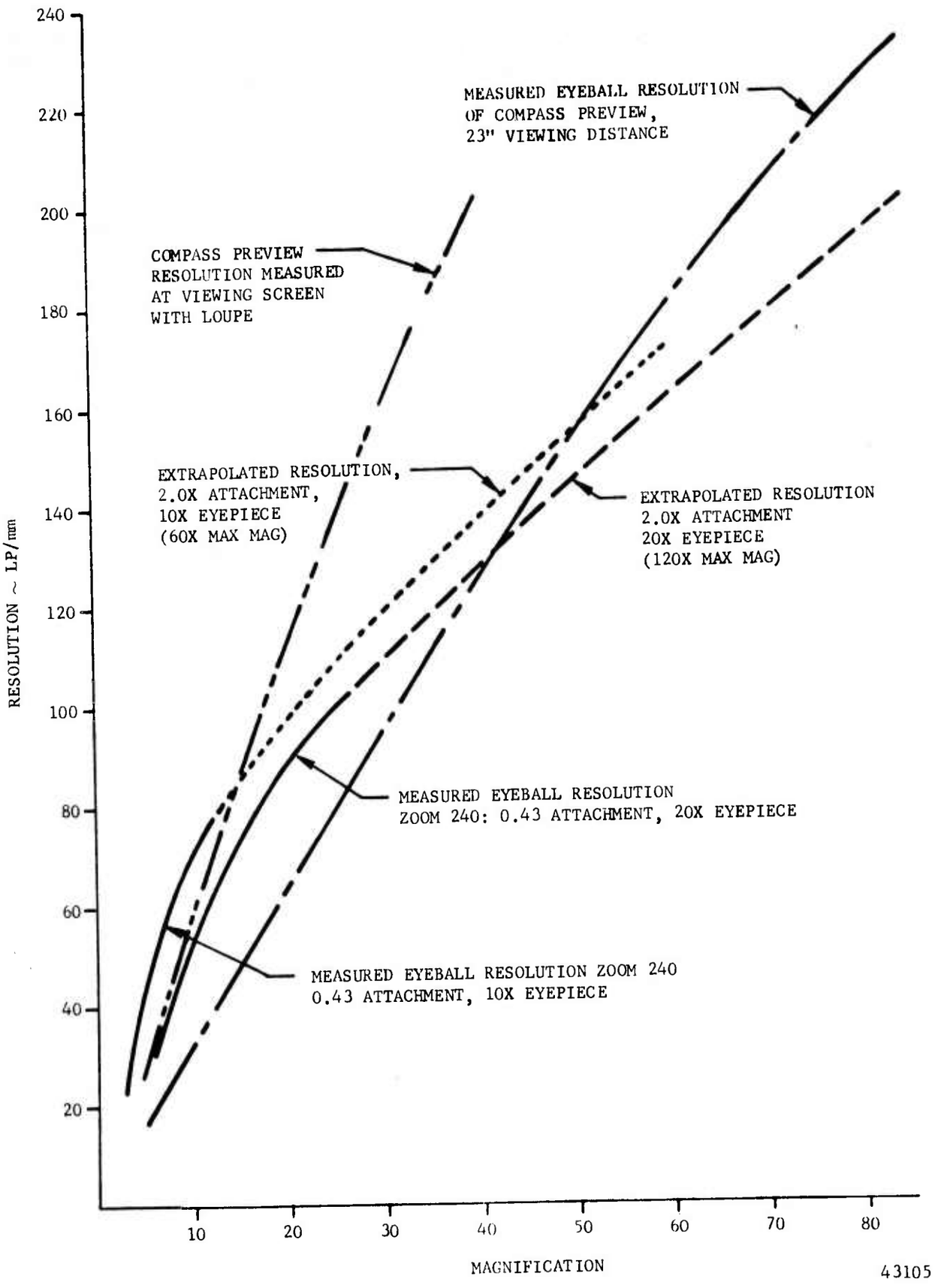

Figure E-1. Compass Preview/Zoom 240 Comparative Results

TABLE E-1. RESOLUTION MEASUREMENTS - ZOOM 240 USING 1951 USAF 3-BAR RESOLUTION TEST TARGET

	Line Pairs per mm (.43X Stereo Lens Attachment)	
Magnification	10X Eyepiece	20X Eyepiece
3	23.5	
4	32.1	
5	39.0	
6	45.8	30.9
7	51.5	36.0
8	60.7	39.0
9	62.8	43.8
10	70.5	49.2
11	72.8	53.4
12	76.3	57.8
13	78.9	64.9
14		70.5
15		70.5
16		76.3
17		76.3
18		83.3
19		83.3
20		88.8
21		91.7
22		96.4
23		96.4
24		96.4
25		99.7
26		103.0

2. Test Target Used:

Northrop used the 1951 USAF 3-bar resolution test target, wherein the observer must be able to see 3 horizontal and 3 vertical bars (3 cycles each).

The University of Arizona used a 15 bar (cycle) target, with vertical bars only.

Both are square wave (not sine wave) targets, of high contrast.

Arguments are presented in RADC-TR-70-150 that a minimum of 7 cycles are required in the test target to effectively approximate a square wave train of infinite extent. If true, the contractor use of the USAF 3-bar target has somewhat degraded the resolution results (both for Compass Preview and the Zoom 240). Further, in use of the 3-bar target, the requirement that the operator be able to "see" both the horizontal and the vertical bars leads to more conservative resolution measurements. For nearly every contractor reading, one to two groups of higher resolution could be reported if vertical bars only were read.

3. The Instrument Used:

The contractor had available only one B&L Zoom 240 for test, and no precise method of determining whether or not that particular instrument (serial number 654 TF) performs to the manufacturer's, or government, specifications.

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Source AFSCR 23-50, 11 May 70