AFAMRL-TR-81-133

DESIGN OF A CATADIOPTRIC VCASS HELMET-MOUNTED DISPLAY

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AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICES

TECHNICAL REVIEW AND APPROVAL

AFAMRL-TR-81-133

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

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Air Force Aerospace Medical Research Laboratory

AIR FORCE/56780/15 December 1981 — ...

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A new wide-angle, dual-eye, helmet-mounted display has been designed. Two images combine, with a 15° central field overlap, to provide a panoramic display 102° wide by 45° tall, with a resolution of approximately 1000 TV lines per eye. The image-generating device is a miniature 18-mm CRT. The optics, which are symmetrical for both eyes, comprise partially reflective plastic reflectors, five small glass lens elements, and a 2:1 fiber optic magnifier. A 12-mm exit pupil is obtained with enough eye relief to permit the user to wear glasses, with an interpupillary adjustment of 58 to 73 mm. Total weight

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20. ABSTRACT (continued)

of the device, not including the Air Force flight helmet type HGU-2A/P upon which it is mounted, is less than 3 pounds.

SUMMARY

This report describes the designing process and final design of a new wide-angle, helmet-mounted dual-eye display being developed as part of the Visually Coupled Airborne Systems Simulator (VCASS) program. The VCASS is being designed as an engineering research tool to investigate advanced control/display techniques for current and future operational aircraft. The system incorporates unique visually coupled system components (head/eye position/orientation systems and miniature helmet-mounted displays) to synthesize a visual sphere of real-time simulated flight environments based upon head and/or eye look angle that is used to update imagery on a helmet-mounted display system. Measurement/control functions are inherent capabilities as well. The optical system design was evaluated from the perspective of its potential use in either ground based or airborne environments.

The new design differs from previous designs in two ways: It has a much wider visual angle, 102 degrees, and it uses the principle of image tangency to form a visual panorama. Whereas conventional binocular displays provide image redundancy and reinforcement, the panoramic concept relies on more complex psychophysical factors. Thus, the results vary from observer to observer and also may depend on the state of training of an individual observer. However, it is apparent that only by this technique can such a wide-angle display be obtained in practice. Ideally the instrument must be fabricated and tested to determine the full validity of its usefulness. No prototype has been constructed.

The final design is the result of extreme compromises with the original design goals. Any other solution to the immediate problem of a relatively high-efficiency dual-eye display would require major reconsideration of boundary constraints, such as the constraint that the display be used within the confines of a canopy.

The display, if constructed, would weigh less than 3 pounds, not counting the helmet to which it would be attached. It is adjustable from 58 to 73 mm in interpupillary distance (IPD) and allows the user to wear eyeglasses. It yields a panoramic field-of-view 102 degrees wide by 45 degrees tall, provides approximately 1000 TV lines (TVL) resolution per eye, and provides a 12 mm exit pupil. The design is nominally free from chromatic aberration and geometric distortion. To provide rapid access to constructional details, a complete, reduced size, drawing set has been attached as an appendix.

PREFACE

The research described in this report was accomplished with funds supplied by the Air Force Aerospace Medical Research Laboratory (AFAMRL), Human Engineering Division, Visual Display Systems Branch and the Air Force Human Resources Laboratory (AFHRL), Advanced Systems Division, Simulation Techniques Branch, as part of AFAMRL Project 7184-20-07. The unique concept described herein attempted the development of a two-eye, wide field-of-view helmet-mounted display capable of providing a stereoscopic presentation as part of the advanced Visually Coupled Airborne Systems Simulator development program, conceived by Mr. Dean F. Kocian, AFAMRL project engineer. Dr. H. Lee Task, AFAMRL and Dr. Douglas Anderson, AFHRL both provided valuable consultation throughout the duration of this effort.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. DESIGN FACTORS 1

2.1. Helmet 1
2.2. Image generator 1
2.3. Head and eye position sensing 4
2.4. Optical specifications 4
2.5. Perspective distortion 5
2.6. Weight and center of gravity 8

3. DESIGN DEVELOPMENT 8

3.1. Mechanical layouts and models 8
3.2. Optical design 9
3.3. Human factors engineering 12

4. FINAL DESIGN 15

4.1. Layout 15
4.2. Optical design 15
4.3. Image quality 17
4.4. Materials 23
4.5. Adjustments on the prototype 23
4.6. General comments 25

5. FABRICATION RISK 25

5.1. Aspherics 25
5.2. Plastics 25

6. CONCLUSION AND RECOMMENDATION 26

6.1. Conclusion 26
6.2. Recommendation 26

APPENDIX. MECHANICAL DRAWINGS FOR A CATADIOPTRIC VCASS HELMET-MOUNTED DISPLAY 27

SELECTED BIBLIOGRAPHY 58

LIST OF ILLUSTRATIONS

Figure		Page
1	Preliminary layout of top-insertion, side-mounted optics	2
2	Perspective distortion, illustrated by viewing square images projected in the forward direction	6
3	Experimental apparatus to study perspective distortion in panoramic/stereoscopic display	7
4	Two design candidates, drawn to same scale, that were considered and rejected	11
5	Vignetting in the right eye's field of view	16
6	On-axis MTF (optics above)	19
7	MTF at top of image (optics alone)	20
8	MTF at side of image (optics alone)	21
9	MTF at corner of image (optics alone)	22

1. INTRODUCTION

Our proposal of December 1977, in response to solicitation No. F33615-78-R-0152, explained our initial thoughts regarding the design of a wide-angle display. During the course of the project, our theoretical projections were confirmed, especially with regard to the difficulty of obtaining high MTF over a wide-angle field. However, due to lack of detailed layouts at the time of the proposal, we had underestimated the extremely difficult problem of folding the reflected beam so as to obtain both a good form factor and freedom from obstructions in the field of view. In the end, it became apparent that no ideal solution exists. Indeed, we came close to concluding that no acceptable solution would be found.

2. DESIGN FACTORS

2.1. Helmet. The display is to be mounted on an extra large Air Force flight helmet, type HGU-2A/P (see Figure 1). Since a single size of helmet must be adapted to all wearers (see sizing data in Table 1), various methods of adjustment were considered. It was decided that front-to-back adjustment would be made by adding selected thicknesses of quickly detachable padding to the front and back of the helmet. Vertical adjustment would be made by using an adjustable air bladder placed between the top of the head and the top of the helmet.

The helmet can be modified to reduce its weight or provide counterweight distribution.

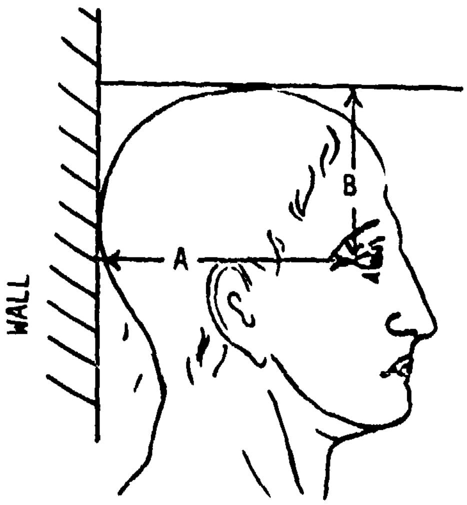
The oxygen mask normally used with the helmet is not required at present, but the VCASS design appears reasonably compatible with it.

2.2. Image generator. The image generator is a miniature 18-mm

Figure 1. Preliminary layout of top-insertion, side-mounted optics.

Table 1. Head Sizing Data for Air Force Pilot Population

Percentile	Dimension A, inches	Dimension B, inches
1	6.4	4.0
5	6.6	4.2
50	7.0	4.7
95	7.4	5.2
99	7.6	5.4
Standard deviation	0.26	0.30



Dimension A:
Ectocanthus to wall

Dimension B:
Ectocanthus to top of head

(Courtesy USAF AMRL/HEA, Dean Kocian)

cathode ray tube (CRT) capable of up to 1800 TVL at 150 foot-lamberts or up to 1000 foot-lamberts with reduced image quality. Size and weight of the image generator are a consideration. In this design they were minimized by using the AMRL VCS 6-2 CRT (Ferranti Model CR 3136), but new developments in CRT technology may provide even better alternatives.

2.3 Head and eye position sensing. Our proposal took exception to the requirements for methods of sensing head and eye position. These are not discussed here.

2.4 Optical specifications.

2.4.1. Field of view. The field of view is 45.6° x 58.5° per eye; the views overlap 15° for a panorama 102° wide.

2.4.2. Exit pupil. The exit pupil is 12 mm in diameter without vignetting except for an occluded section of the field of view, as will be shown in a later illustration (Figure 5).

2.4.3. Eye relief. The design provides approximately 55 mm distance to a 45° semitransparent beamsplitter. This is sufficient to accommodate most eyeglasses.

2.4.4. IPD. The interpupillary distance is adjustable from 58 to 73 mm. Each eye channel is separately adjustable.

2.4.5. Collimation. Dipvergence is 15 arc minutes, divergence 40 arc minutes, convergence 25 arc minutes.

2.4.6. Transmission. See-through transmission is 10%. Probable CRT transmission is 6%, based on design for broad-band (for example, beam penetration) phosphors. Special coatings for monochrome phosphor would permit up to 15% CRT transmission.

2.4.7. D ,tortion. Aberrational distortion is nominally 0±1%. Perspect: _ ons may be compensated electronically.

2.4.8. Co.or correction. Color correction is achromatic from 486 to 656 nm, with less than 1 arc minute of axial color and less than 3 arc minutes lateral co..r.

2.4.9. MTF. The MTF exceeds the original goal at all field angles, for both monochrome and broad spectrum phosphors. The performance and goals are shown in Figures 6 through 9 (paragraph 4.3). (The MTF presented is solely for the optics and does not include the fiber optics and CRT.)

2.5. Perspective distortion. "Keystone" or "wide angle" distortion arises when images are viewed from a center of persp..tive or along a line of sight not agreeing with the original cent. or optical axis of the image-forming optics. Although this effect is zero in binocular instruments with the eyes looking straight ahead, it does arise when the eyes pivot in their sockets. In our panoramic display, based on nearly tangent imagery, the optical axes diverge from the forward direction by 19°. This causes a distortion of considerable magnitude, and in a sense that is rarely seen in actual life. Figure 2 shows the predicted panorama for two slightly overlapping squares The panorama does not look like a simple rectangle; rather, the two images are inclined and converge in some forward line. To determine how the eyes would deal with this illusion, we constructed the simple apparatus shown in Figure 3. Two wide-angle Erfle eyepieces, with apparent fields of about 70°, are tilted 19° and view nondistorted identical transparencies directly at the focus and perpendicular to the optical axes of the eyepieces. The

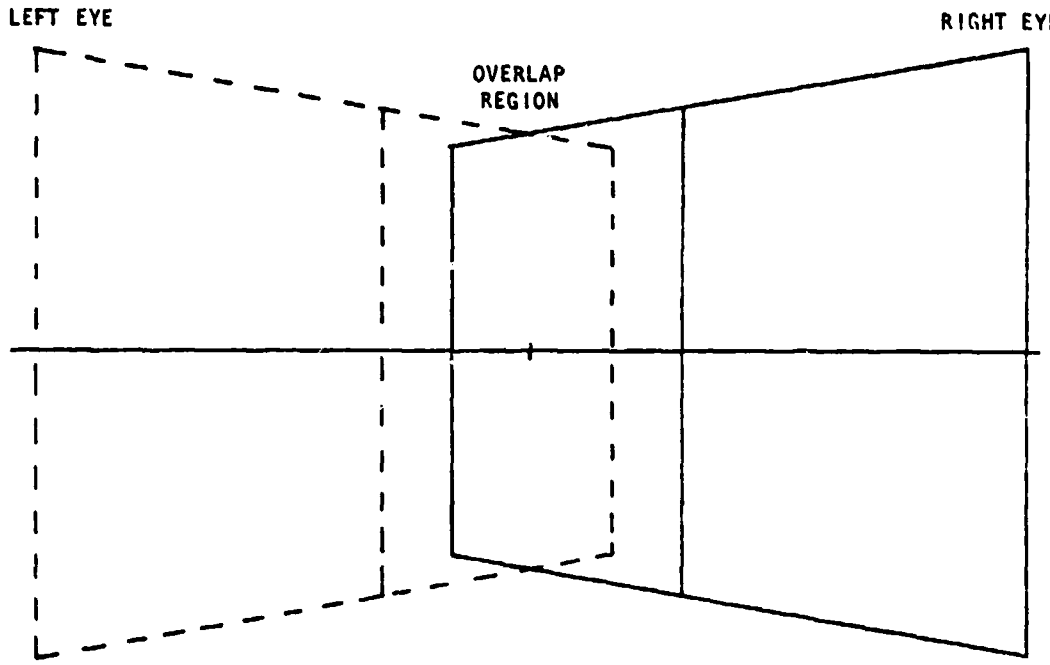


Figure 2. Perspective distortion, illustrated by viewing square images projected in the forward direction.

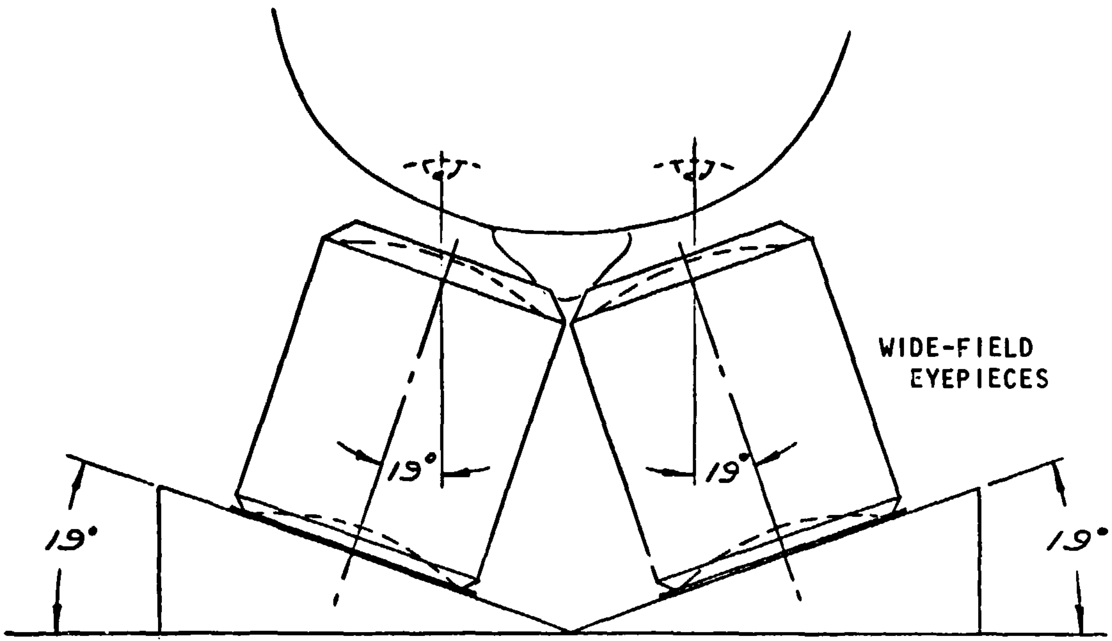


Figure 3. Experimental apparatus to study perspective distortion in panoramic/stereoscopic display.

eyes look straight down, and thus are inclined at 19° to the optical axes of the apparatus. Using this setup, we found that we could usually fuse the imagery in the central field and that the panoramic field of view appeared "nondistorted" until we searched to recognize the detail indicated in Figure 2. We did not measure eyestrain, nor use complex images. While most observers found the result satisfactory, not all did. The outcome of our informal experiment was the belief that many observers--not all--would achieve the desired result with the proposed VCASS display. The question of dynamic imagery was not examined.

2.6. Weight and center of gravity. The display weighs about 3 pounds, and by studied effort this could be reduced to about 2½ pounds. The center of gravity has been kept low and as close to the helmet as possible. Its exact location has not been computed, but it might be estimated to within an inch by examination of Figure 1 and the element drawings included in the appendix.

3. DESIGN DEVELOPMENT

3.1. Mechanical layouts and models. Mr. C. John Edwards, our first mechanical designer (who unfortunately had to leave the project before its completion), greatly advanced our appreciation of packaging problems by making detailed layouts and then full-size wearable models. On the basis of his work, we learned that simple side mounting of the CRTs would not be possible. Because of the divergence of the optical axes and because of the maximum angle in the horizontal direction, the insertion of relay optics would have created an unacceptable obscuration of the field. This led to the conclusion that only top-insertion optics would be possible.

The idea of rabbit-ear mounting of the CRTs was rejected because it would be inconsistent with use in a canopy-covered simulator. This is most unfortunate from our standpoint, for it would have instantly resolved the packaging problems that troubled us down to the last hours of the contract. One of these problems was to find a way of folding the light beam so as to lower the height of the CRTs. Our first line of attack was to solicit aid from the manufacturers of fiber optics. We sought both a 2:1 magnifier and a right-angle fold. Obtaining the 2:1 magnifier was simple; obtaining a right-angle fold was very difficult. Only Dr. Walter Siegmund, American Optical Company, was responsive to our request. He provided us with some experimental fiber optic folds that showed great promise. We were concerned, however, that it might take too long for further refinement, and that combining two separate fiber optic units would result in too much additional light loss.

We finally achieved a compromise folding arrangement, which might be termed an elevated side-mounted CRT configuration. As will be explained later (paragraph 4.2), this involved permitting an obstruction in the upper corners of the field of view. However, in exchange for this loss, we eliminated all developmental uncertainties in the optical component chain and we obtained a surely higher MTF and assured higher transmission by eliminating the additional fiber optic. The final mechanical design represents the best compromise available to us at the time of this writing.

3.2. Optical design. The Government had excluded from our consideration the use of holographic optical elements and laser beam scanners.

Consideration of the required field angles quickly led us to reject simple refractors. This left us with some type of catadioptric optical system. Because of the extreme angles of view, tilted-component high-efficiency reflector designs were ruled out. Of the remaining "on-axis" catadioptrics, we elected to deal with an extension of conventional beam-splitter-type art. We early discussed the difficulty of obtaining the extreme field angles required by the RFP and were granted an exception. Our design activity, particularly with respect to packaging, proved the sensibility of our modesty with regard to field angle.

Although the original specification called out the narrow P43 spectrum, which is sensibly monochromatic in the green, later discussion led us to design for a wider spectrum so as to permit use with "beam penetration phosphors," red-green imagery that imposed a stricter requirement for achromatization with a consequent increase in lens complexity.

Two designs are shown in Figure 4. In the upper figure is the design we obtained when we tried to use only spherical optics with a particular prismatic lens fold. The lower figure, drawn to the same scale, shows the simplest possible design we could achieve by allowing a nonachromatic image and a curved CRT faceplate. Our final optical design is an achromatized, modified form of the lower design; the curved faceplate was eliminated by using a field-flattening single lens element.

In the course of this project, three different computer programs were used to compute at least five separate optical designs. The David Grey program was used to explore all-spherical and aspheric designs. The Code V program was used for curved and flat-field designs with and without distortion. The final design, computed with the ACCOS IV program, was derived

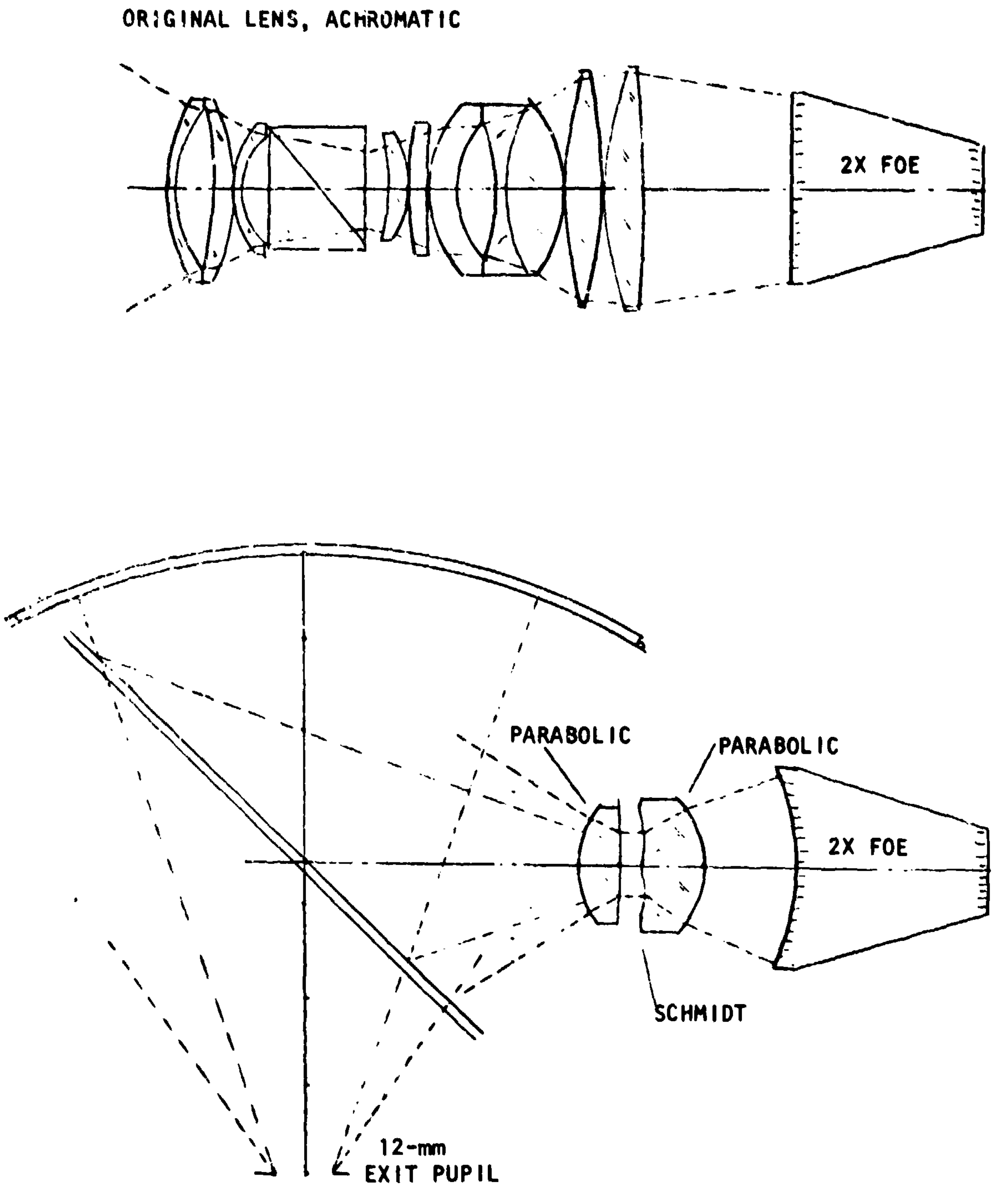


Figure 4. Two design candidates, drawn to same scale, that were considered and rejected. Upper lens has all-spherical optics; lower lens is nonachromatic with curved fiber optics faceplate.

by modifying one of the Code V designs to accommodate very stringent and difficult boundary constraints. The MTF was computed with the ACCOS-IV program; it is geometrical only, both monochromatic and polychromatic. Although we had analyzed the effects of decentered pupil location on some intermediate designs, we did not have time or resources to compute for decentered pupils on the final design.

3.3. Human factors engineering. In human factors engineering, relevant information about human characteristics and behavior are applied systematically to the design of the system. The objectives are to enhance the effectiveness of human-machine interfaces. The human factors engineer participates in planning, designing, and building devices. He considers questions of feasibility and of positive and negative aspects of human usage, and evaluates available choices especially when these are related to interface problems. Choices having technical impact he evalutes jointly with the optical, mechanical, and electrical designer. The human factors engineer gives to the other workers a sense of perspective; he reminds them that the objective is to produce a design that probably won't be perfect but that will be the best compromise available within the time and resources at their disposal. The human factors engineering of this design project included the following considerations:

3.3.1. Eyeglasses. It was decided early in the program that the design should permit the user to wear eyeglasses if desired, and no objection was found.

3.3.2. Slide-up and flip-up mechanisms. Original objectives to provide simple slide-up and flip-up mechanisms were discarded in the design development stages. Problems with compactness and weight reduction made it impracticable to provide the full range of safety and convenience features originally envisioned.

3.3.3. Binocular overlap. The problems of binocular overlap were considered. The purpose of binocular overlap in this display is to merge the two images. If the images were simply tangent, vagaries of the separate eyes would present them as not always tangent, with disturbing illusion. The 15° image overlap was thought to be sufficient for merging the images. Because the overlap area is intended mainly for smoothing one image into another, requirements for collimation may be less stringent than for a true binocular optical system.

3.3.4. Obstructions in field of view. Obstructions in the field of view are distracting; whether they greatly interfere with task performance is not known. It is true that some distractions can be ignored, but it is not true that ignoring them is sufficient in every case. They may conceal useful information. In some instances, as with the rear view mirror in an automobile, they create a hazard by concealing an important part of the forward field of vision. It is good practice to minimize the size of obstructions, and if they are in harmless locations they should be made inconspicuous by suitable choice of color, shape, or texture.

3.3.5. Brightness and color disparities. Brightness and color disparities are brought up in the RFP. We feel that our type of display minimizes these effects. The optics for the left and right eyes are duplicates save for slight mirror image changes. Modern coating technology ensures that the two optical channels will match in color and transmission to within a few percent. Even if they did not match, it is known that when a binocular system is properly focused and collimated, the human eyes quickly adjust to moderately dissimilar color and brightness. An extreme example is found in anaglyphic stereo; our panoramic display has more than a little in common with anaglyphs, and it is reasonable to say that a person who cannot fuse anaglyphic stereo will probably have difficulty with the panoramic VCASS display.

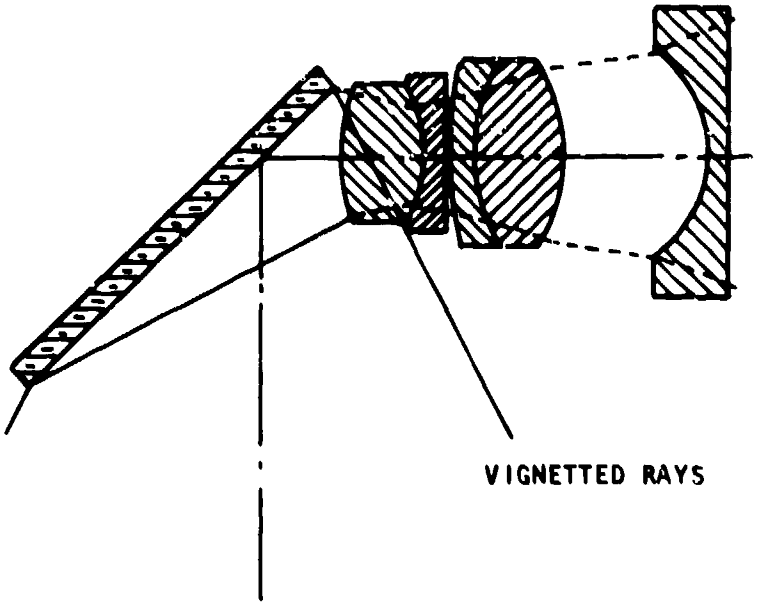
3.3.6. Distortion. The subject of distortion was brought up many times in our discussions with the Government. We believe that distortion in itself can be adapted to if it is consistent over a period of time so that the person learns how to accommodate for it. Of course, if the simulator must be used without a warmup or training period, adaptation will be difficult and greater effort must be assigned to distortion reduction.

3.3.7. Mental processing of the panoramic image data. There are several possible results of feeding two information streams into the separate eyes. Within fairly broad limits, the two images will be fused through the information-processing efforts of the central nervous system. If the images are too unalike, however, they will not fuse and some perceptual effects may occur. First, there will be a rapid switching of attention back and forth between images; this is known as binocular rivalry. Or, some unpredictable noncomposite image (some research indicates "sparkle" can occur) may result instead of a simple panorama. Note that the panorama results only when the visual system cooperates in placing the images side by side to form one wide image. If the user has a dominant eye, there is no reason to think a panorama will necessarily occur, as the image presented to the weaker eye may simply be neglected. It appears impossible to generalize the effects that will occur for all observers; we expect the display may not be acceptable to some users.

4. FINAL DESIGN

4.1. Layout. The full set of engineering drawings is reduced in size and included as an appendix to this report to show how the individual elements are assembled and the whole attached to the helmet. In addition, an overall view is provided by Figure 1, which is an artist's rendering of the final design concept.

4.2. Optical design. The final design incorporates three reflections: from the spherical plastic shell, from the flat beamsplitter, and from the top full reflector mirror. Earlier, we had intended to employ only two reflections and to make use of a right-angle fiber optic fold to obtain good placement of the CRTs. However, such a design caused the CRTs to be more than an inch higher than in the final design. Furthermore, and probably more important, no manufacturer could guarantee us a right-angle fiber optic fold. American Optical Company's Dr. Walter Siegmund provided some prototype fiber optics of great promise, but because we wanted to be prepared to fabricate a prototype rapidly upon completion of the engineering drawings, we decided to reject fiber optics because of potential scheduling problems. An alternative solution was to use a third mirror and to redesign the optical elements to obtain minimum vignetting. However, we were unable to obtain a design that did not obscure part of the field of view. As shown in Figure 5, the projected angle of view is simply so large that it is virtually impossible to force the insertion optics to stand clear of the optical beams. Further design refinement might minimize this effect, but we did not have time



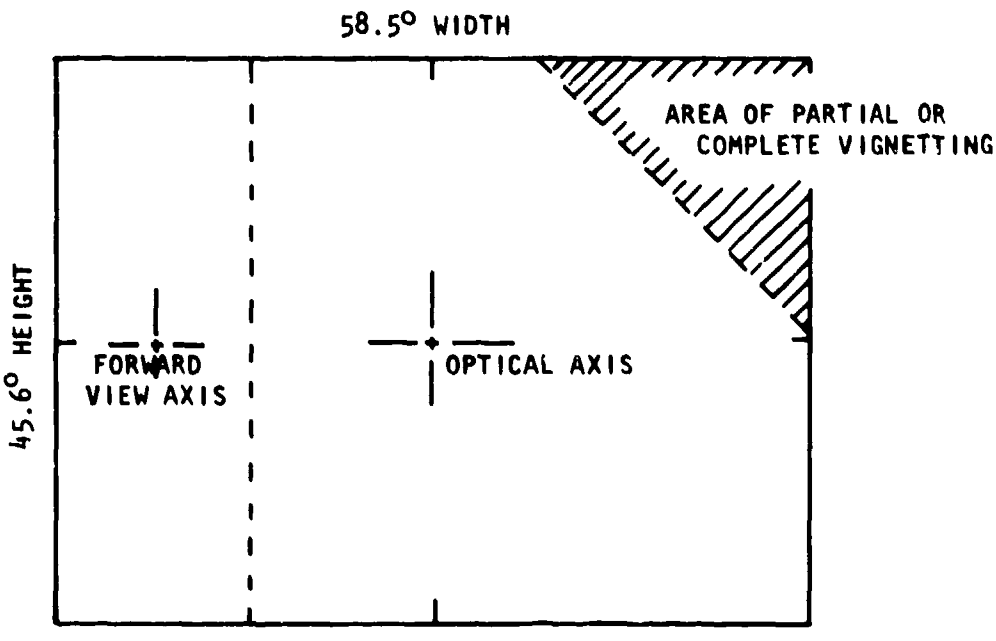


Figure 5. Vignetting in the right eye's field of view.

to study this conjecture.

Individual lens element drawings with recommended tolerances are included in the drawings in the appendix. Three aspheric surfaces are required. Only the fabrication of the aspherics poses an unusual task. Auxiliary test optics might possibly be designed to facilitate the optician's task, but it would be presumptuous to define such tests at this time.

Some readers with optical analysis capability may wish to re-analyze our optical design. Table 2 provides a nominal unfolded definition of the optics. For analysis, it may be assumed vignetting is zero, the aperture stop is the eye, and the semi-angular field is 35°.

4.3. Image quality. Computation shows that distortion for the centered eye is less than 0.1% over the entire field of view. That is, nominally the design is free from distortion. Fabrication problems and mechanical distortions of the plastic components will produce some image distortion, but it was impracticable to predict the magnitude of this distortion. It has been suggested that, should it prove excessive, thin glass components might be used instead of the plastic. Of course, such a solution is unattractive because of weight and safety. One purpose of prototype construction would be to learn about these problems with plastic.

We have computed the geometrical sine wave response, both for green monochrome images and for broad color spectrum images, for a 7-mm-diameter centered exit pupil. Figures 6 through 9 show the MTF on axis and at the side, top, and corner of the CRT image. The nominal MTF greatly exceeds the design goal at all field angles. This surfeit of quality is desirable

Table 2. Lens Identification--Final VCASS Optical Design 8/79

WAVELENGTHS

5.87600E-01	4.86100E-01	6.56300E-01	4.35800E-01	7.68200E-01

BASIC SYSTEM DATA

SURF	CURVATURE	RADIUS	KAPPA	THICKNESS
0	0.	INFINITE	0.	1.0000000E+10
1	0.	INFINITE	0.	0.
2	0.	INFINITE	0.	1.2700000E+02
3	-7.1262123E-03	-1.40327[illegible]+02	0.	-6.3500000E+01
4	0.	INFINI[illegible]	0.	8.7300000E+01
5	4.0950041E-02	2.4420000E+01	-1.156600E+00	1.1079000E+01
6	-5.8823529E-02	-1.7000000E+01	0.	2.5400000E+00
7	3.7561507E-03	2.6623000E+02	-1.000000E+00	5.0800000E-01
8	1.5304327E-02	6.5341000E+01	0.	4.0320000E+00
9	3.754459[illegible]E-02	2.6635000E+01	0.	1.1809000E+01
10	-4.3540732E-02	-2.2967000E+01	-1.156600E+00	1.8673000E+01
11	-5.6179775E-02	-1.7800000E+01	0.	2.5400000E+00
12	0.	INFINITE	0.	-2.4390526E-04
13	0.	INFINITE	0.	0.
14	0.	INFINITE	0.	0.

GLASSES

SURF	N1	N2	N3	N4	N5	DELN
0	AIR					
1	AIR					
2	AIR					
3	REFLECTOR					
4	REFLECTOR					
5	1.620409	1.627560	1.617272	1.633128	1.613657	.010289
6	1.620037	1.632088	1.615031	1.642024	1.609566	.017057
7	AIR					
8	1.805175	1.827760	1.796087	1.847069	1.786445	.031673
9	1.620409	1.627560	1.617272	1.633128	1.613667	.010289
10	AIR					
11	1.516798	1.522379	1.514322	1.526689	1.511437	.008057
12	1.516798	1.522379	1.514322	1.526689	1.511437	.008057
13	1.516798	1.522379	1.514322	1.526689	1.511437	.008057

ASPHERIC SURFACE DATA

SURF	D	E	F	G
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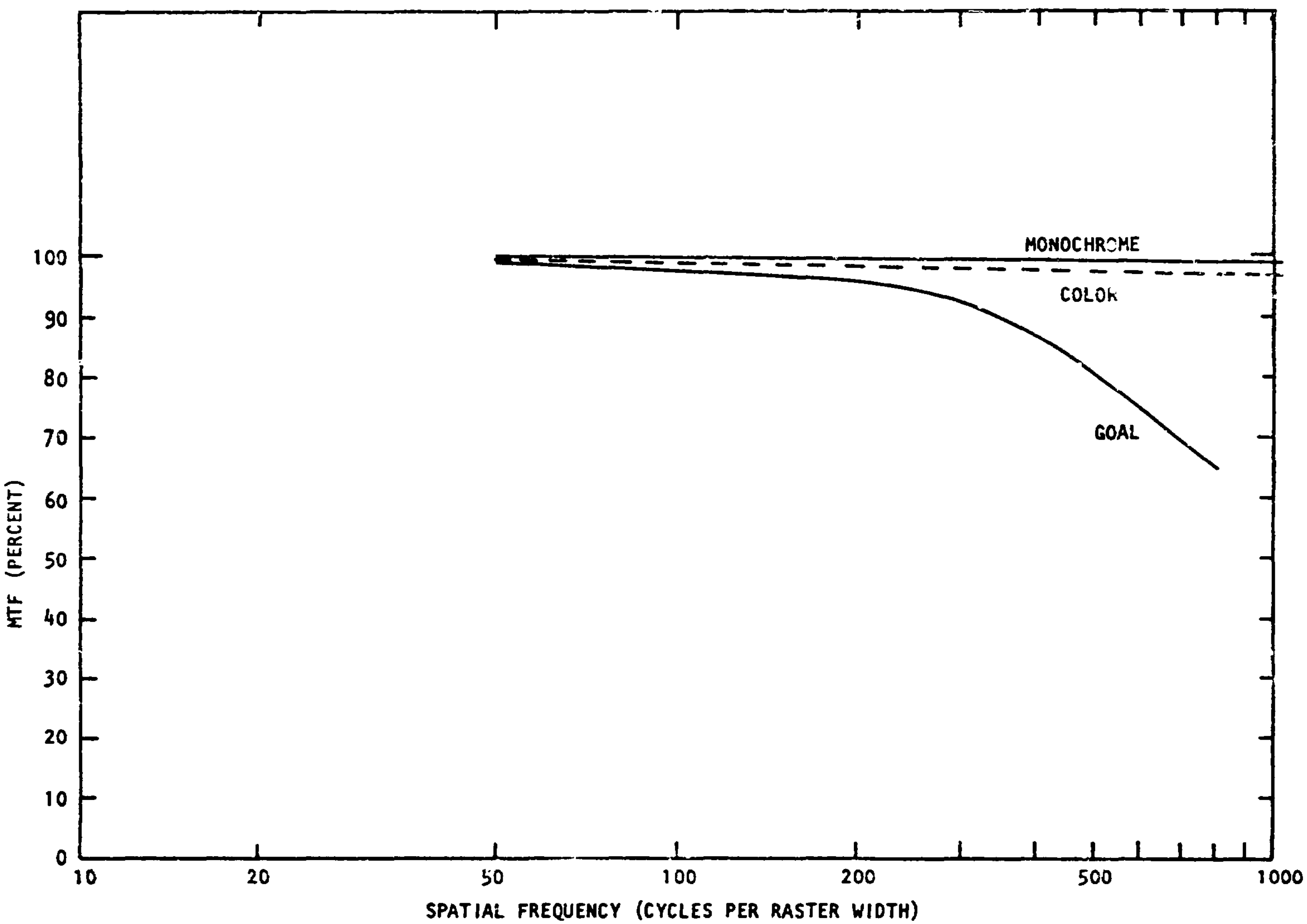


Figure 6. On-axis MTF (optics above).

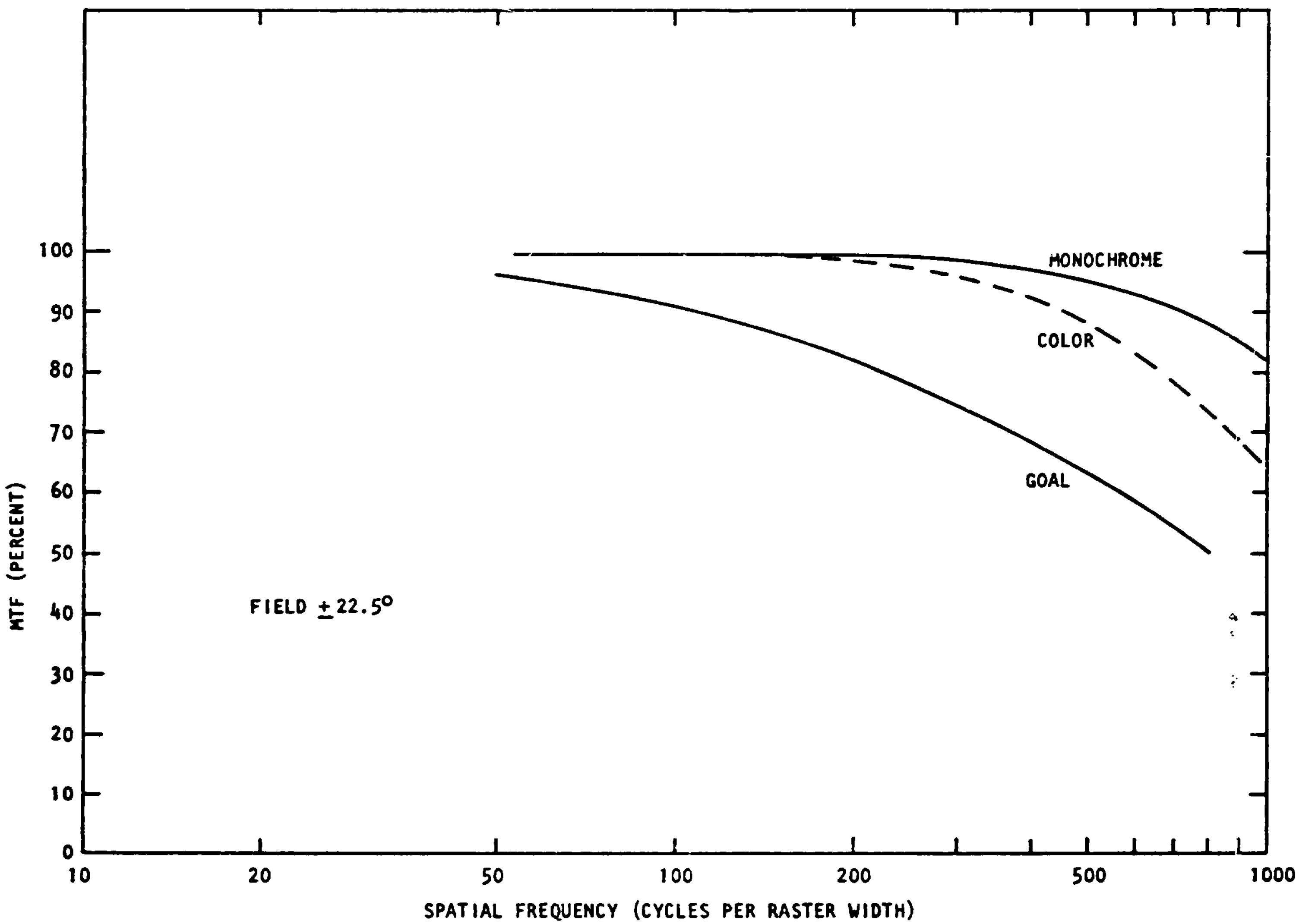


Figure 7. MTF at top of image (optics alone).

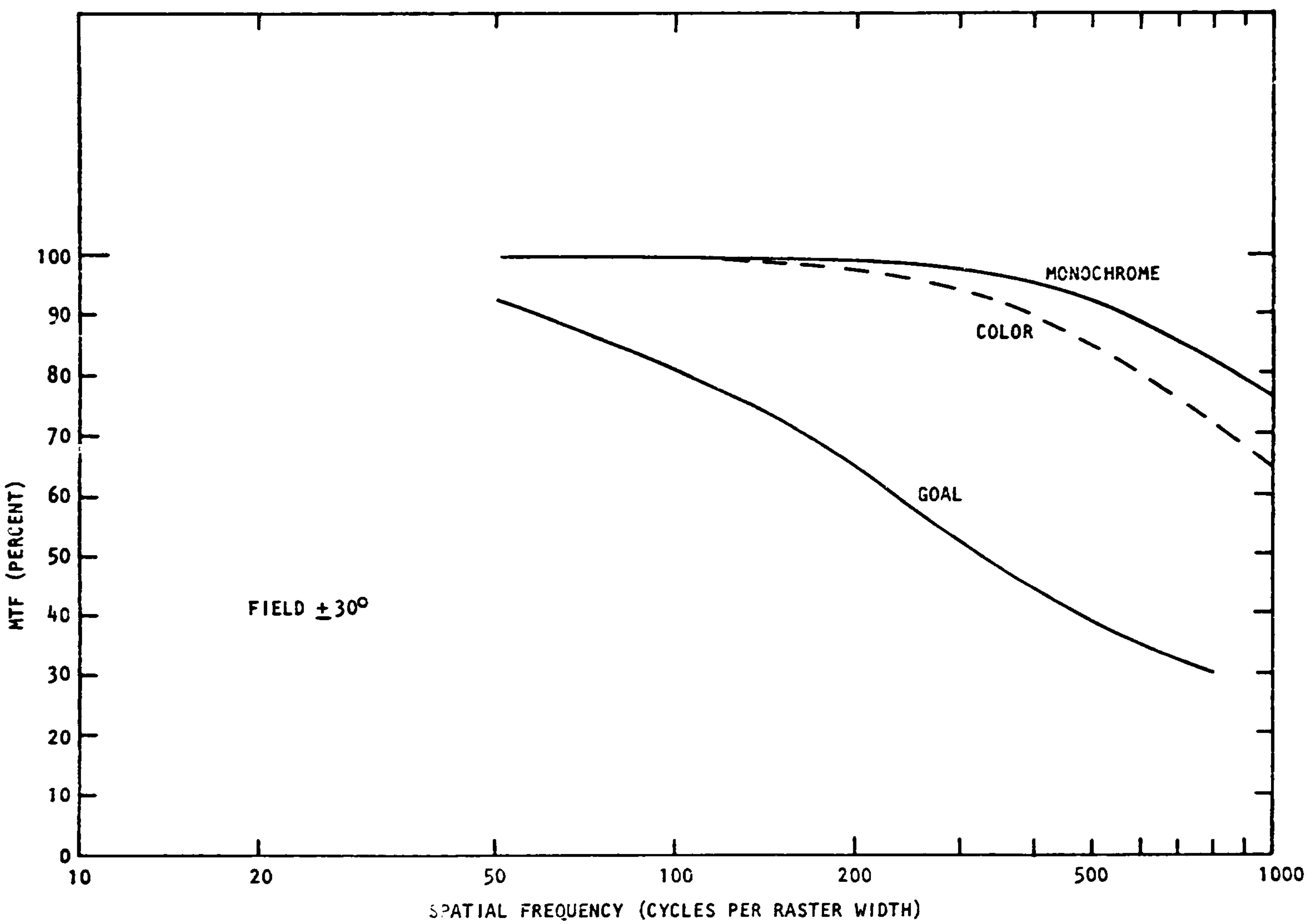


Figure 8. MTF at side of image (optics alone).

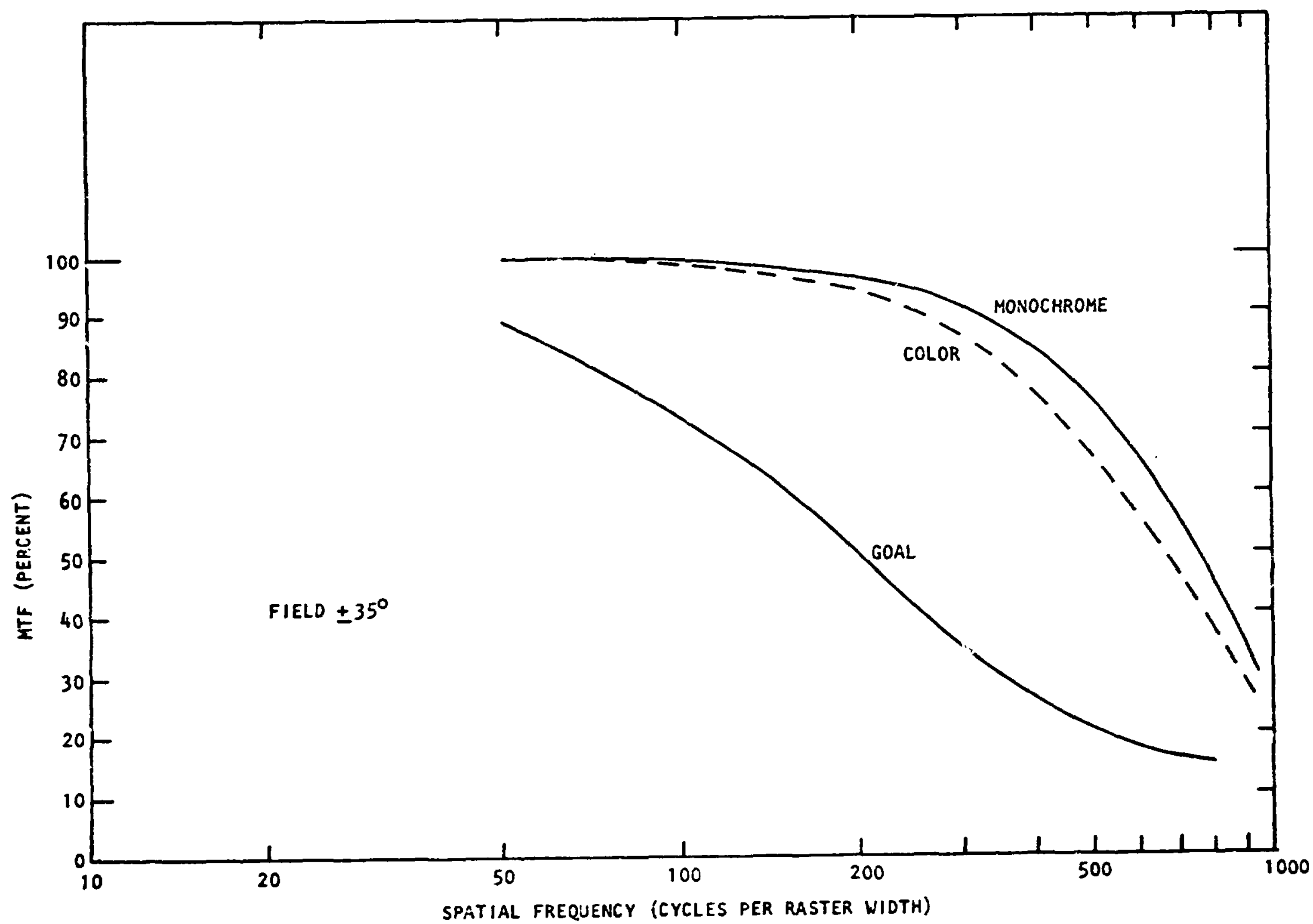


Figure 9. MTF at corner of image (optics alone).

and would be consumed by imperfect aspheric lens surfaces and inevitable deterioration of plastic reflectors.

4.4. Materials. The design calls for no metallic components except for the skin of the CRT. This is to minimize problems with electromagnetic head position sensors. Plastic is used extensively. Although plastic is aesthetically pleasing, we are uneasy about the shape stability of a plastic design. Fortunately, acrylic is the best understood plastic, and a large body of experimental knowledge is available. Other materials are a mixed blessing. For example, the superb machining properties of Deldrin made it a logical choice for the lens cell, but it has an extremely high coefficient of expansion. We wish to advise that a large number of mechanical compromises have been made, and the outcome rests with tests of a prototype.

4.5. Adjustments on the prototype. No prototype has been commissioned as of this writing, and it appears that none will be. However, the following discussion explains our plans to adjust such a prototype. It should not be taken as the only possible scheme, nor is it necessarily complete. Some feedback after working the prototype would doubtless reveal omissions and suggest improvements. Of the adjustments described below, tilt and centration adjustments are provided so that nominal alignment can be achieved in laboratory assembly. We expect that only focus and IPD will need to be set individually by the user, and these adjustments may be performed without tools. The remaining adjustments require a screwdriver and are made at the top of each optical assembly. We believe the assemblies to be readily accessible and the adjustments to be easily performed.

The optical systems for left and right eyes are mirror images of each other, so operation for one eye is the same as for the other; the following discussion pertains to both eyes.

4.5.1. Focus control. A simple, locking sliding lever system that travels up to 120° is provided for focus. The design was laid out to provide large focus change with minimum motion. Adjustment range is ±4 diopters. Coarse adjustment can be obtained during initial alignment if required.

4.5.2. IPD. Interpupillary distance is adjusted by moving the left and right stages until the pointer on each indicates the desired IPD (ranging from 58 to 73 mm). The setting can be locked.

4.5.3. Vidicon. The housing containing the vidicon is rotatable by hand so that the images can be individually leveled. A split-ring retainer has its locking screw loosened for adjustment, then tightened after completion. We expect this adjustment to be needed only infrequently. However, should it be needed more often, it would not be difficult to provide finger-actuated locking screws.

4.5.4. Folding flat mirror. This mirror is adjusted with three screws and need be adjusted only during assembly.

4.5.5. Spherical beam combiner. This is a see-through plastic element that combines the CRT images with the see-through images. It is adjusted with two screws, and adjustment will generally be made in the laboratory. Adjustment of the spherical beam combiner is intended mainly to affect image collimation.

4.5.6. Flat beamsplitter. One screw presently adjusts the tilt of the flat beamsplitter. In principle, adjustments on the spherical beam combiner make further adjustments unnecessary; experience with the prototype may show otherwise. The main purpose of adjusting the flat beamsplitter is to center the exit pupil onto the eye. It is instructive to know that a relayed CRT image focuses on the surface of this beamsplitter; this accounts for its relatively small effect on image collimation.

4.6. General comments. The supporting struts of the semireflectors are likely to be visible in the peripheral field but are far enough outside the direct field of vision that we expect a wearer will quickly adjust to their presence. The construction materials consist largely of plastic. The clear and partially coated acrylic and the opaque black structural members are expected to blend aesthetically, so even as a prototype the display should have a neat and finished appearance.

5. FABRICATION RISK

5.1. Aspherics. The relay lens employs three aspheric surfaces that may be difficult to fabricate because of their small size. However, lenses of this type have been fabricated by optical specialty houses, and we believe their fabrication at the Optical Sciences Center is an acceptable risk.

5.2. Plastics. The spherical beam combiner and the flat beam splitter are tentatively scheduled to be made from heat-formed acrylic sheet. Such sheet has an intrinsic tendency to return to the as-cast shape, which is usually flat. Plastic does not behave like glass, and it is difficult to polish. Guidance from the plastics industry would be solicited before we embarked on the prototype fabrication of these elements. As a backup, these elements can be made from thin sheet glass.

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion. The design described in this report represents the culmination of an extensive and frustrating exploration of potential candidates. Obtaining an acceptable form factor proved to be the problem, for we learned that, with a three-aspheric optical design, we could fairly easily achieve low distortion and high MTF. The restriction that the display had to be used within the confines of a canopy-covered simulator turned a trivial packaging problem, with rabbit ears, into an almost insurmountable engineering problem. The final solution employed available technology at the expense of some field obscuration, to avoid the uncertainties and weight/transmission/resolution limitations of developing a right-angle fiber optic fold.

6.2. Recommendation. There are a number of technical and psychophysical questions that cannot be resolved effectively and with certainty unless the prototype is fabricated. To our knowledge, there is only an insignificant body of experience with wide-angle dual-eye panoramic displays, yet it is apparent that the future development of many wide-angle visually coupled optical systems is likely to be based on this new concept. We feel that fabrication of a prototype would supply necessary experimental evidence for specifying future wide-angle displays, and we recommend that the Government proceed along these lines.

APPENDIX

MECHANICAL DRAWINGS FOR A CATADIOFTRIC

VCASS HELMET-MOUNTED DISPLAY

DWG. NO.	TITLE
0501-01	ELEMENT A
0501-02	ELEMENT B
0501-03	DOUBLET AB ASSEMBLY
0501-04	ELEMENT C
0501-05	ELEMENT D
0501-06	DOUBLET CD ASSEMBLY
0501-07	ELEMENT E
0501-08	BEAMSPLITTER
[illegible]-09	FACEPLATE
0501-10	LEFT FOLDING FLAT
0501-11	RIGHT FOLDING FLAT
0501-12	VCASS LAYOUT
[illegible]-13	CRT HOUSING ASSEMBLY
[illegible]-14	PART 20
[illegible]-15	PART 21
0501-16	PART 22
0501-17	PART 23
0501-18	PART 24 - LENS CELL
0501-19	PART 25 - FOCUSSING KNOB
0501-20	PARTS 26 & 27
0501-21	PARTS 14 & 15 - CRT ASSEMBLY CLAMP BASE
0501-22	PARTS 16 & 17 - MAIN STRUT

DWG. NO.	TITLE
0501-23	PART 18 - SLIDE PLATE
0501-24	PART 19 - CRT [illegible]
0501-25	PART 28 - VERTIC[illegible]
0501-26	PART 29 - VERTICAL TILT ADJUSTING BRACKET
0501-27	PARTS 30 & 31 - FACEPLATE & STANDARD SPACERS
0501-28	PARTS 32 & 33 - FACEPLATE & BEAMSPLITTER HINGES
0501-29	PARTS 22 & 23 - MANTLE
0501-30	DRAWING LIST

REV.	DESCRIPTION	DATE	BY

FINAL ASSEMBLY | NEXT ASSEMBLY

TOLERANCES UNLESS NOTED: DECIMAL PLACES; MILLIMETER ±; ANGULAR ±

OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA

DESCRIPTION: DWG. LIST

TITLE: VCASS

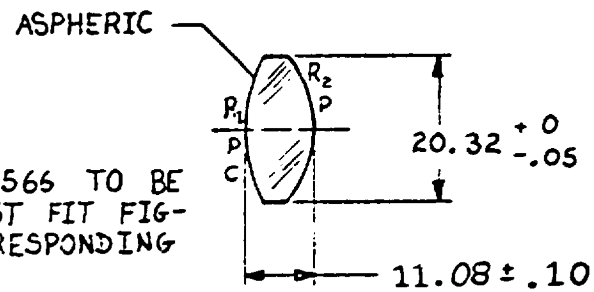
SCALE:

DRAWN BY: DV — DATE: 7/31/79

DWG. NUMBER: 0501-30

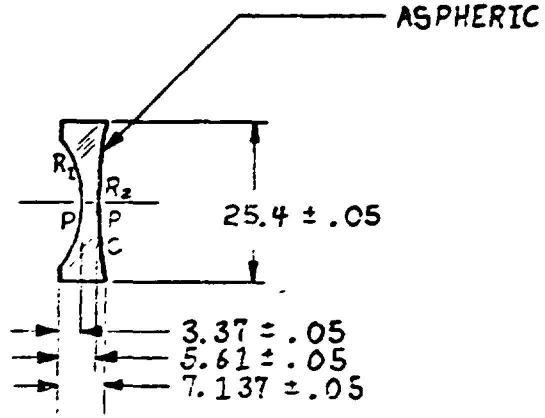
TEST PLATE RADIUS	±	COSMETIC	T.P. FIT	CLEAR APERTURE
R_1 = ASPHERIC 1	CX	60-40	–	18.0
R_2 = 17.00 ± .02	CX	60-40	5-1	15.0

1. MATERIAL
   - TYPE: SCHOTT SK2 (607567)
   - VARIETY:
   - N_d = 1.6074 ± .001
   - V_d = 56.7 ± 0.5
   - GRADE: A
   - SPECIAL:
2. CENTERING
   - 4 MINUTES MECHANICAL WEDGE
   - ____ MINUTES DIA. IMAGE RUNOUT
   - ____ MM (IN.) DIA. IMAGE RUNOUT
   - WITH ELEMENT ____ RUNNING TRUE ON SURFACE ____.
3. SPECIAL NOTES ASPHERIC R = 24.42, K = -1.1566 TO BE TESTED IN NULL TEST SUCH THAT BEST FIT FIGURE IS ACCURATE TO 1 λ WITH CORRESPONDING VERTEX RADIUS ACCURATE TO ±0.05
4. DIMENSIONS IN MM (__)
5. TEST PLATE (T.P.) FIT: RINGS OF POWER-FRINGES OF IRREG.
6. ELEMENT IN ACCORDANCE WITH MIL-O-13830
7. CEMENT IN ACCORDANCE WITH MIL-A-3920
8. CHAMFER EDGES .1-.5 X 45°
9. POLISH SURFACES MARKED "P"; OTHER FINE GRIND.
10. COAT SURFACES MARKED "C" PER DWG 0501-10
11. ASPHERIC CENTERED ON POWER AXIS WITHIN .10



DATE 05/01/79	SCALE FULL	DRAWN BY DV	APPROVED BY [illegible]
TITLE ELEMENT A			
PROJECT VCASS		DRAWING NO. 0501-01	REV

TEST PLATE RADIUS	±	COSMETIC	T.P. FIT	CLEAR APERTURE
R_1 = 17.00 ± .02	CC	60-40	5-1	15.0
R_2 = ASPHERIC 2	CC	60-40	-	16.5



1. MATERIAL
   TYPE: SCHOTT F2 (620364)
   VARIETY:
   N_d = 1.6200 ± .001
   V_d = 36.4 ± 0.3
   GRADE: A
   SPECIAL:

2. CENTERING
   4 MINUTES MECHANICAL WEDGE
   ____ MINUTES DIA. IMAGE RUNOUT
   ____ MM (IN.) DIA. IMAGE RUNOUT
   WITH ELEMENT ____ RUNNING TRUE ON SURFACE ____.

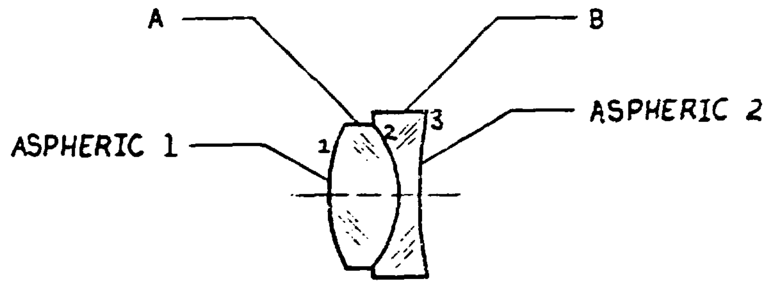
3. SPECIAL NOTES ASPHERIC SAG $X = Y^2(3.756 \times 10^{-3}) + Y^4(2.505 \times 10^{-5}) + Y^6(1.406 \times 10^{-8}) + Y^8(-1.318 \times 10^{-10})$
   THE OPTICAL SURFACE SHALL BE ASPHERIZED TO AN ACCURACY CONFORMING TO THIS EQUATION WITHIN ONE WAVE OF NON-SPHERICAL WAVEFRONT, AND WITHIN 5 WAVES OF POWER.

4. DIMENSIONS IN MM (__)
5. TEST PLATE (TP) FIT: RINGS OF POWER-FRINGES OF IRREG.
6. ELEMENT IN ACCORDANCE WITH MIL-O-13830
7. CEMENT IN ACCORDANCE WITH MIL-A-3920
8. CHAMFER EDGES .1-.5 x 45°
9. POLISH SURFACES MARKED "P"; OTHER FINE GRIND.
10. COAT SURFACES MARKED "C" PER DWG 0501-10
11. ASPHERIC CENTERED ON POWER AXIS WITHIN 0.10

DATE	SCALE	DRAWN BY	APPROVED BY
05/01/79	FULL	DV	RAB 5/1/79
TITLE: ELEMENT B			
PROJECT: VCASS		DRAWING NO.: 0501-02	

TEST PLATE RADIUS	±	COSMETIC	T.P. FIT	CLEAR APERTURE
R_1 =				
R_2 =				

1. MATERIAL
   TYPE:
   VARIETY:
   N_d =
   V_d =
   GRADE:
   SPECIAL:



2. CENTERING
   4 MINUTES MECHANICAL WEDGE *
   ____ MINUTES DIA. IMAGE RUNOUT
   ___ __ MM (IN.) DIA. IMAGE RUNOUT
   WITH ELEMENT B RUNNING TRUE ON SURFACE 3.

3. SPECIAL NOTES * ASPHERIC 1 AND ASPHERIC 2 SHALL EACH BE CENTERED TO THE FINAL POWER AXIS WITHIN ±.15 MM.

4. DIMENSIONS IN MM (__)
5. TEST PLATE (T P) FIT: RINGS OF POWER-FRINGES OF IRREG.
6. ELEMENT IN ACCORDANCE WITH MIL-O-13830
7. CEMENT IN ACCORDANCE WITH MIL-A-3920
8. CHAMFER EDGES _____ X 45°
9. POLISH SURFACES MARKED "P"; OTHER FINE GRIND.
10. COAT SURFACES MARKED "C" PER

DATE	SCALE	DRAWN BY	APPROVED BY
05/01/79	FULL	DV	[illegible] 5/5/79
TITLE DOUBLET AB ASSEMBLY			
PROJECT VCASS		DRAWING NO. 0501-03	REV

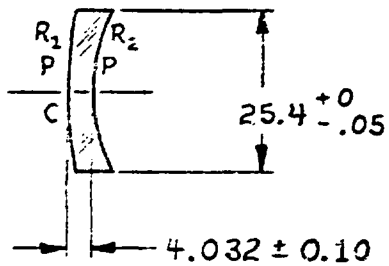
TEST PLATE RADIUS	±	COSMETIC	T.P. FIT	CLEAR APERTURE
R_1 = 65.341 ±0.07	CX	60-40	5-1	17.0
R_2 = 26.635 ±0.03	CC	60-40	5-1	19.0

1. MATERIAL
   TYPE: SCHOTT SF6 (805254)
   VARIETY:
   N_d = 1.8052 ±.0015
   V_d = 25.4 ± 0.3
   GRADE: A
   SPECIAL:

2. CENTERING
   4 MINUTES MECHANICAL WEDGE
   ____ MINUTES DIA. IMAGE RUNOUT
   ____ MM (IN.) DIA. IMAGE RUNOUT
   WITH ELEMENT ____ RUNNING TRUE ON SURFACE ____.

3. SPECIAL NOTES

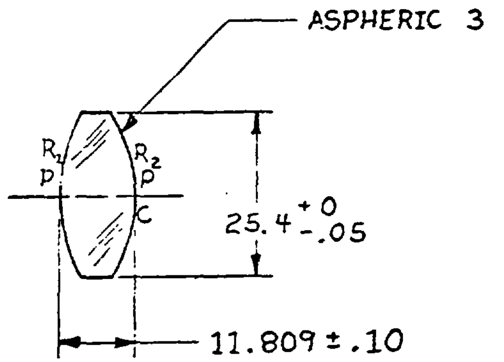
4. DIMENSIONS IN MM ( )
5. TEST PLATE (T.P.) FIT: RINGS OF POWER-FRINGES OF IRREG.
6. ELEMENT IN ACCORDANCE WITH MIL-O-13830
7. CEMENT IN ACCORDANCE WITH MIL-A-3920
8. CHAMFER EDGES .1-.5 X 45°
9. POLISH SURFACES MARKED "P"; OTHER FINE GRIND.
10. COAT SURFACES MARKED "C" PER DWG 0501-10



DATE 05/01/79	SCALE FULL	DRAWN BY DV	APPROVED BY 5/5/79
TITLE ELEMENT C			
PROJECT VCASS		DRAWING NO 0501-04	REV

FORM NO FAB 1977

TEST PLATE RADIUS	±	COSMETIC	T.P. FIT	CLEAR APERTURE
R_1 = 26.635 ± 0.03	CX	60-40	5-1	19.0
R_2 = ASPHERIC 3	CX	60-40	-	23.0



1. MATERIAL
   TYPE: SCHOTT SK2 (607567)
   VARIETY:
   N_d = 1.6074 ± .001
   V_d = 56.7 ± 0.5
   GRADE: A
   SPECIAL:

2. CENTERING
   4 MINUTES MECHANICAL WEDGE
   ____ MINUTES DIA. IMAGE RUNOUT
   ____ MM (IN.) DIA. IMAGE RUNOUT
   WITH ELEMENT ____ RUNNING TRUE ON SURFACE ____.

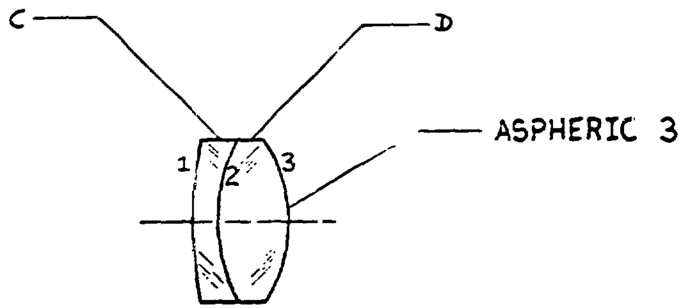
3. SPECIAL NOTES ASPHERIC R_2 = 22.967, K = -1.1566 TO BE TESTED IN NULL TEST SUCH THAT BEST FIT FIGURE IS ACCURATE TO 1 λ WITH CORRESPONDING VERTEX RADIUS ACCURATE TO ± 0.05.

4. DIMENSIONS IN MM (___)
5. TEST PLATE (TP) FIT: RINGS OF POWER-FRINGES OF IRREG.
6. ELEMENT IN ACCORDANCE WITH MIL-O-13830
7. CEMENT IN ACCORDANCE WITH MIL-A-3920
8. CHAMFER EDGES .1-.5 X 45°
9. POLISH SURFACES MARKED "P"; OTHER FINE GRIND.
10. COAT SURFACES MARKED "C" PER DWG 0501-10

DATE	SCALE	DRAWN BY	APPROVED BY
05/01/79	FULL	DV	[illegible] 5/15/79
TITLE ELEMENT D			
PROJECT VCASS		DRAWING NO. 0501-05	REV

FORM NO. 2-3 1977

TEST PLATE RADIUS	±	COSMETIC	T.P. FIT	CLEAR APERTURE
R_1 =				
R_2 =				



1. MATERIAL
   TYPE:
   VARIETY:
   N_d =
   V_d =
   GRADE:
   SPECIAL:

2. CENTERING
   4 MINUTES MECHANICAL WEDGE *
   ___ MINUTES DIA. IMAGE RUNOUT
   ___ MM (IN.) DIA. IMAGE RUNOUT
   WITH ELEMENT ___ RUNNING TRUE ON SURFACE ___.

3. SPECIAL NOTES *ASPHERIC 3 SHOULD BE CENTERED TO THE FINAL POWER AXIS WITHIN ± 0.15 MM.

4. DIMENSIONS IN ___ (___)
5. TEST PLATE (T.P.) FIT: RINGS OF POWER-FRINGES OF IRREG.
6. ELEMENT IN ACCORDANCE WITH MIL-O-13830
7. CEMENT IN ACCORDANCE WITH MIL-A-3920
8. CHAMFER EDGES ___ X 45°
9. POLISH SURFACES MARKED "P"; OTHER FINE GRIND.
10. COAT SURFACES MARKED "C" PER

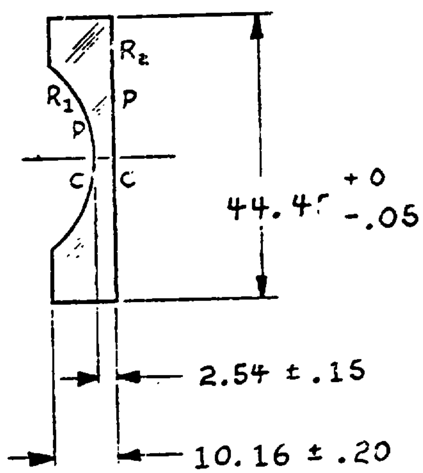
DATE 05/01/79	SCALE FULL	DRAWN BY DV	APPROVED BY [illegible] -/-/79
TITLE DOUBLET CD ASSEMBLY			
PROJECT VCASS		DRAWING NO. 0501-06	

FORM NO. [illegible] 1977

TEST PLATE RADIUS	±	COSMETIC	T.P. FIT	CLEAR APERTURE
R_1 = 17.8 ± 0.04	CC	20-10	10-2	28.0
R_2 = PLANO	-	20-10	10-2	39.0

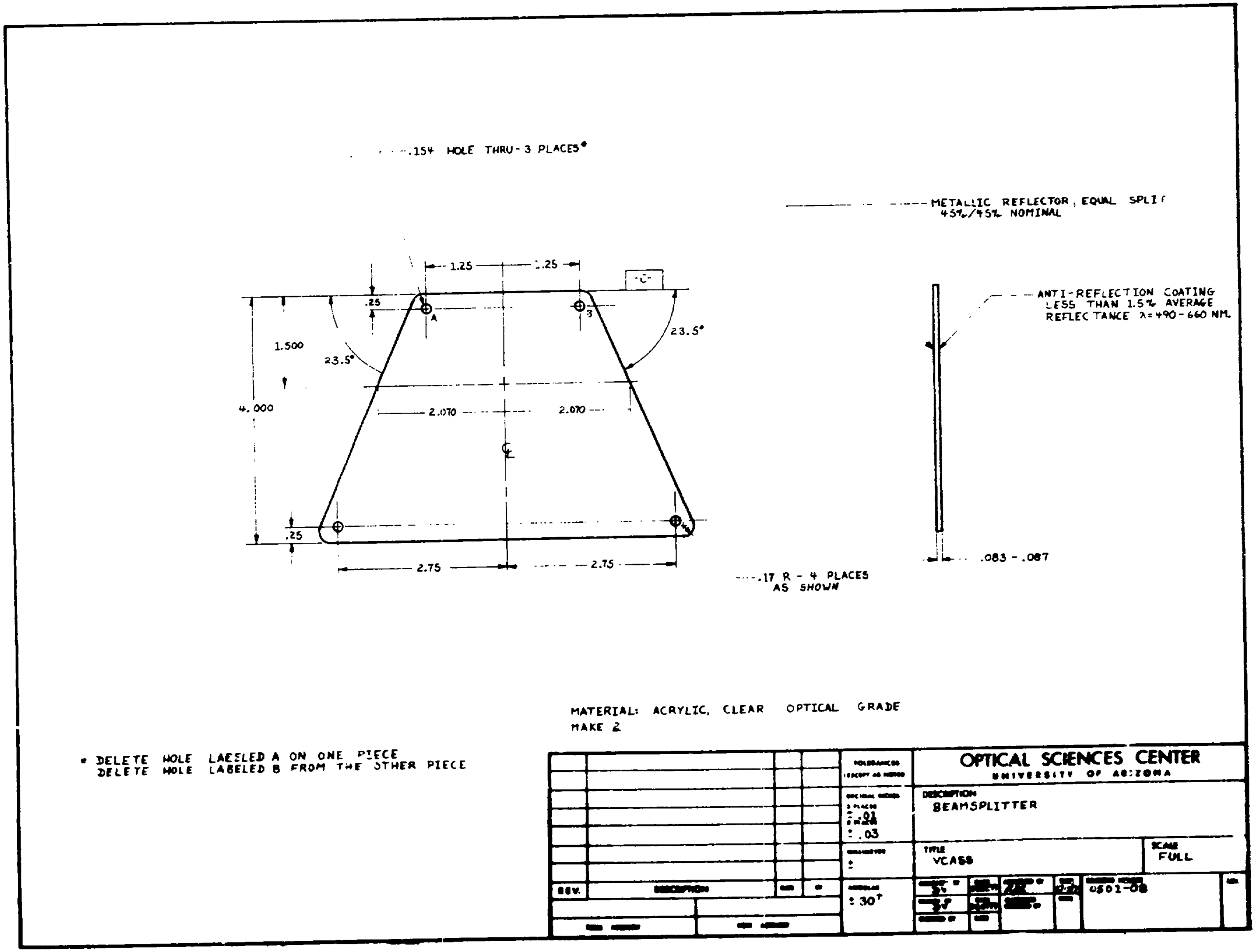
1. MATERIAL
   TYPE: SCHOTT BK7 (517642)
   VARIETY:
   N_d = 1.5168 ± .001
   V_d = 64.2 ± 0.6
   GRADE: A
   SPECIAL: NO VISIBLE BUBBLES OR FLAWS; RETICLE QUALITY
2. CENTERING
   3 MINUTES MECHANICAL WEDGE
   ___ MINUTES DIA. IMAGE RUNOUT
   ___ MM (IN.) DIA. IMAGE RUNOUT
   WITH ELEMENT ___ RUNNING TRUE ON SURFACE ___.
3. SPECIAL NOTES

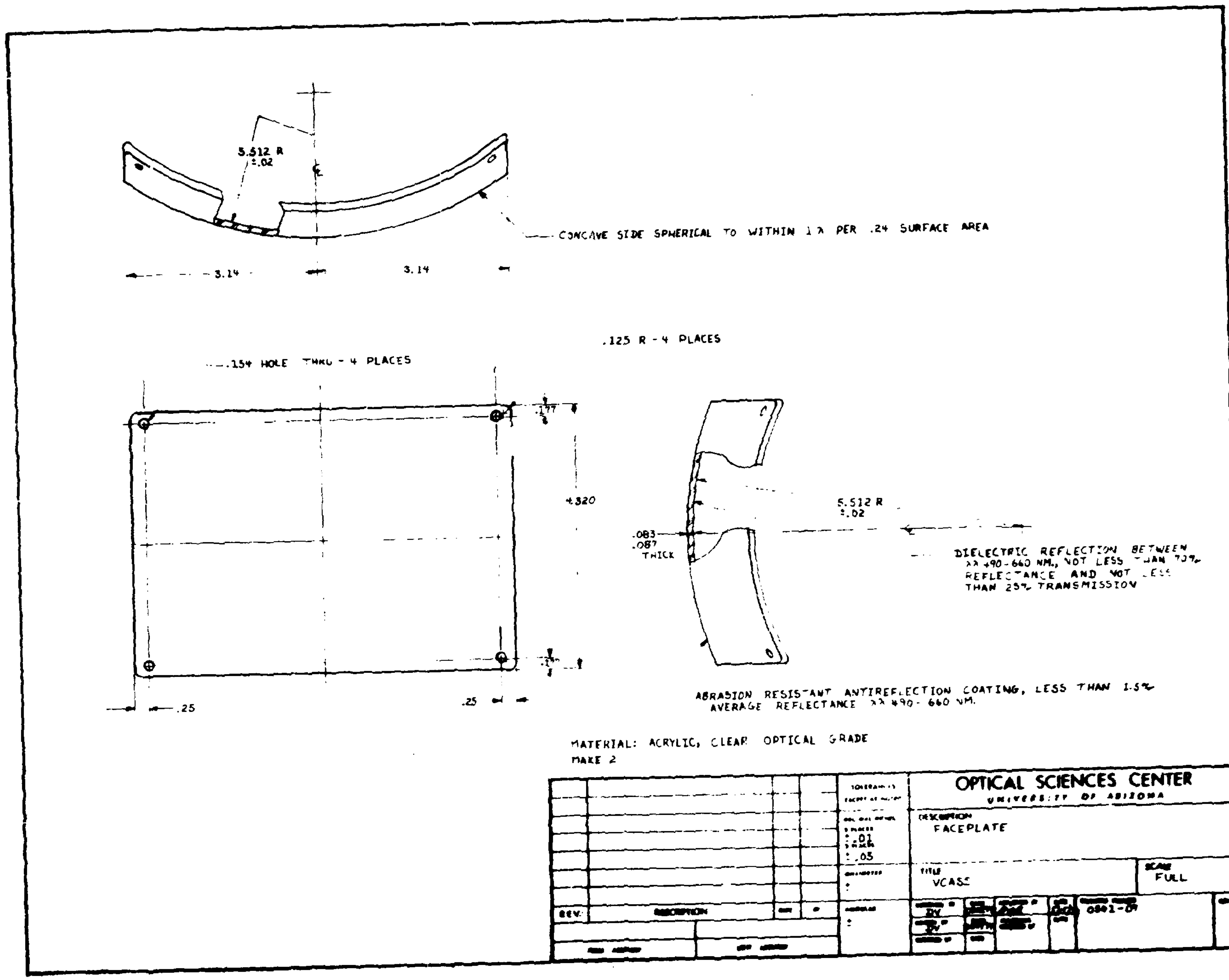
4. DIMENSIONS IN MM (___)
5. TEST PLATE (T.P.) FIT: RINGS OF POWER-FRINGES OF IRREG.
6. ELEMENT IN ACCORDANCE WITH MIL-O-13830
7. CEMENT IN ACCORDANCE WITH MIL-A-3920
8. CHAMFER EDGES ±1-.5 x 45°
9. POLISH SURFACES MARKED "P"; OTHER FINE GRIND.
10. COAT SURFACES MARKED "C" PER DWG 0501-10

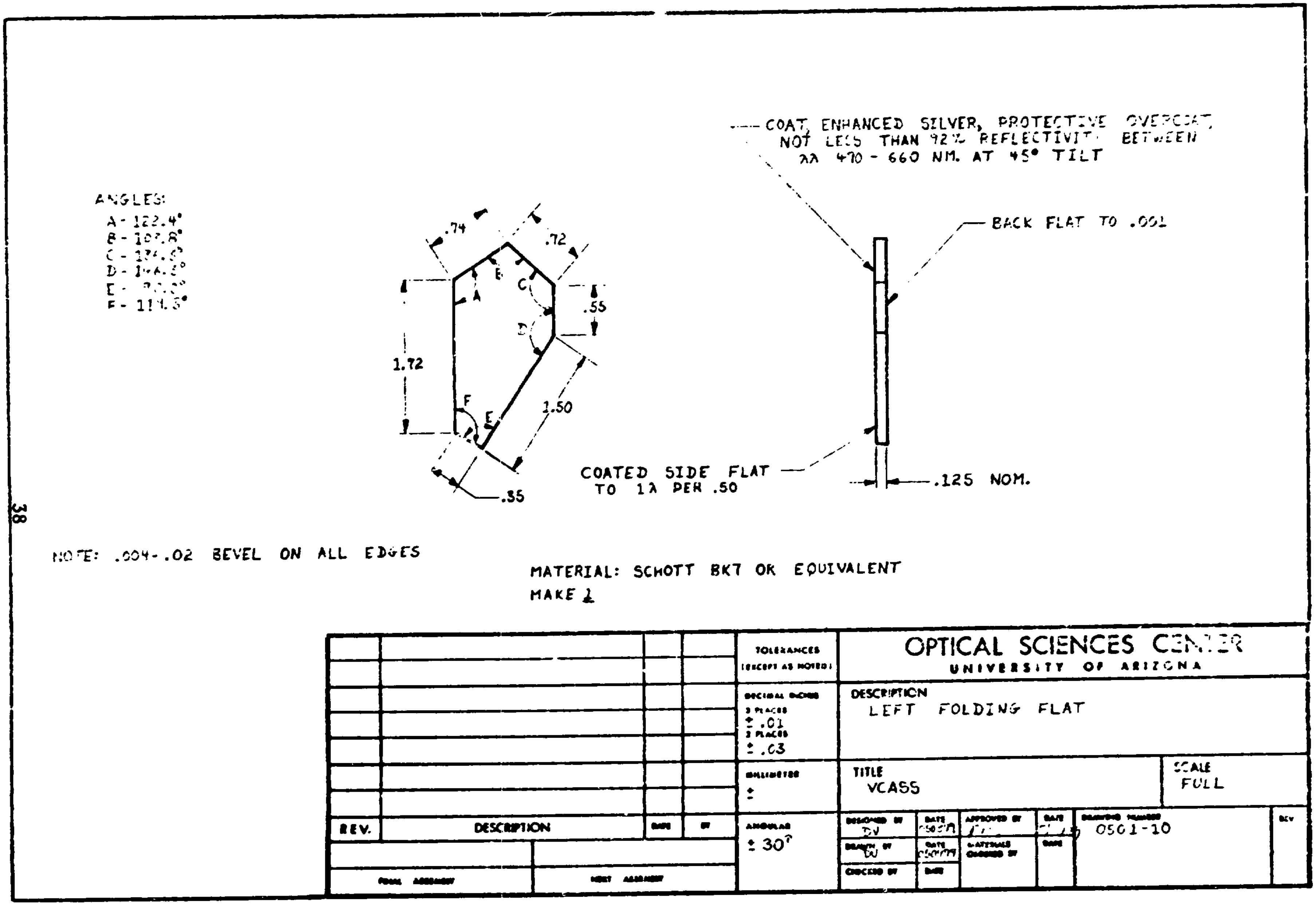


DATE	SCALE	DRAWN BY	APPROVED BY
05/01/79	FULL	DV	[illegible] 5/-/79
TITLE ELEMENT E			
PROJECT VCASS		DRAWING NO 0501-07	REV

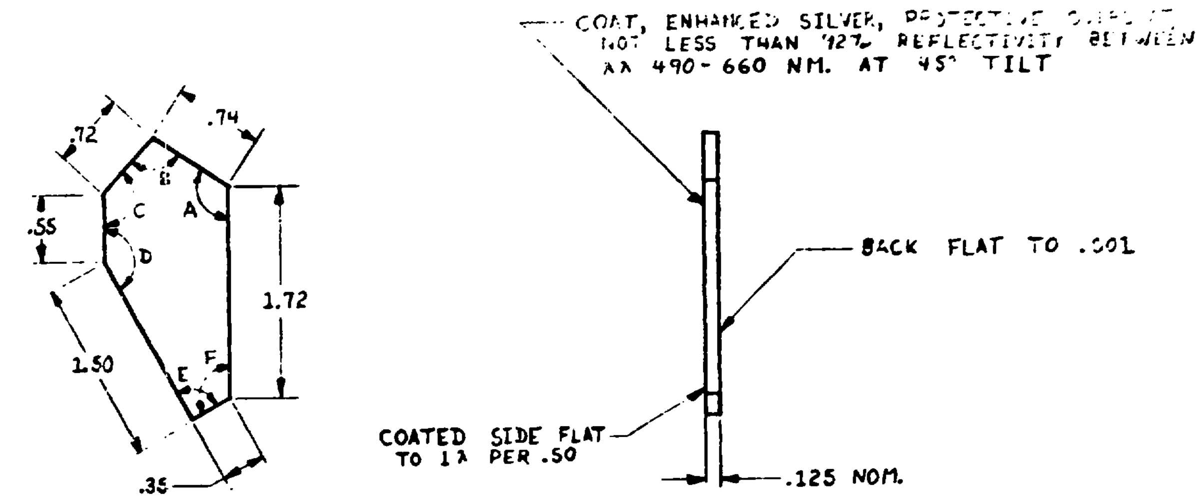
FORM NO. 2AB 1977


.154 HOLE THRU - 3 PLACES*
METALLIC REFLECTOR, EQUAL SPLIT
45%/45% NOMINAL
1.25
1.25
.25
A
3
23.5°
23.5°
1.500
4.000
2.070
2.070
.25
2.75
2.75
-C-
ANTI-REFLECTION COATING
LESS THAN 1.5% AVERAGE
REFLECTANCE λ=490-660 NM.
.083 - .087
.17 R - 4 PLACES
AS SHOWN
MATERIAL: ACRYLIC, CLEAR OPTICAL GRADE
MAKE 2
* DELETE HOLE LABELED A ON ONE PIECE
DELETE HOLE LABELED B FROM THE OTHER PIECE
OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA
DESCRIPTION
BEAMSPLITTER
TITLE
VCASS
SCALE
FULL
±.01
±.03
±30'
0501-08
REV.
DESCRIPTION


5.512 R ±.02
CONCAVE SIDE SPHERICAL TO WITHIN 1 λ PER .24 SURFACE AREA
3.14
3.14
.125 R - 4 PLACES
.154 HOLE THRU - 4 PLACES
4.320
.25
.25
5.512 R ±.02
.083
.087
THICK
DIELECTRIC REFLECTION BETWEEN λλ 490-660 NM., NOT LESS THAN 73% REFLECTANCE AND NOT LESS THAN 25% TRANSMISSION
ABRASION RESISTANT ANTIREFLECTION COATING, LESS THAN 1.5% AVERAGE REFLECTANCE λλ 490-660 NM.
MATERIAL: ACRYLIC, CLEAR OPTICAL GRADE
MAKE 2
OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA
DESCRIPTION
FACEPLATE
±.01
±.05
TITLE
VCASS
SCALE
FULL
REV.
DESCRIPTION
0801-07


COAT ENHANCED SILVER, PROTECTIVE OVERCOAT, NOT LESS THAN 92% REFLECTIVITY BETWEEN λλ 470 - 660 NM. AT 45° TILT
BACK FLAT TO .001
COATED SIDE FLAT TO 1λ PER .50
.125 NOM.
ANGLES:
A - 122.4°
.74
.72
.55
1.72
1.50
.35
NOTE: .004-.02 BEVEL ON ALL EDGES
MATERIAL: SCHOTT BK7 OR EQUIVALENT
MAKE 1
OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA
TOLERANCES (EXCEPT AS NOTED)
DECIMAL INCHES
2 PLACES ± .01
3 PLACES ± .03
MILLIMETERS ±
ANGULAR ± 30'
DESCRIPTION
LEFT FOLDING FLAT
TITLE
VCASS
SCALE
FULL
DRAWING NUMBER
0501-10
REV.
DESCRIPTION
DATE
BY
FINAL ASSEMBLY
NEXT ASSEMBLY
DESIGNED BY
DRAWN BY
CHECKED BY
APPROVED BY
MATERIALS CHECKED BY
DATE

ANGLES:
A - 122.4°
B - 103.8°
C - 136.3°
D - 146.3°
E - 70.0°
F - 117.3°



NOTE: .004-.02 BEVEL ON ALL EDGES

MATERIAL: SCHOTT BK7 OR EQUIVALENT
MAKE 1

REV.	DESCRIPTION	DATE	BY	
FINAL ASSEMBLY	NEXT ASSEMBLY			

TOLERANCES (EXCEPT AS NOTED)
DECIMAL INCHES
2 PLACES ± .01
3 PLACES ± .03
MILLIMETERS ±
ANGULAR ± 30'

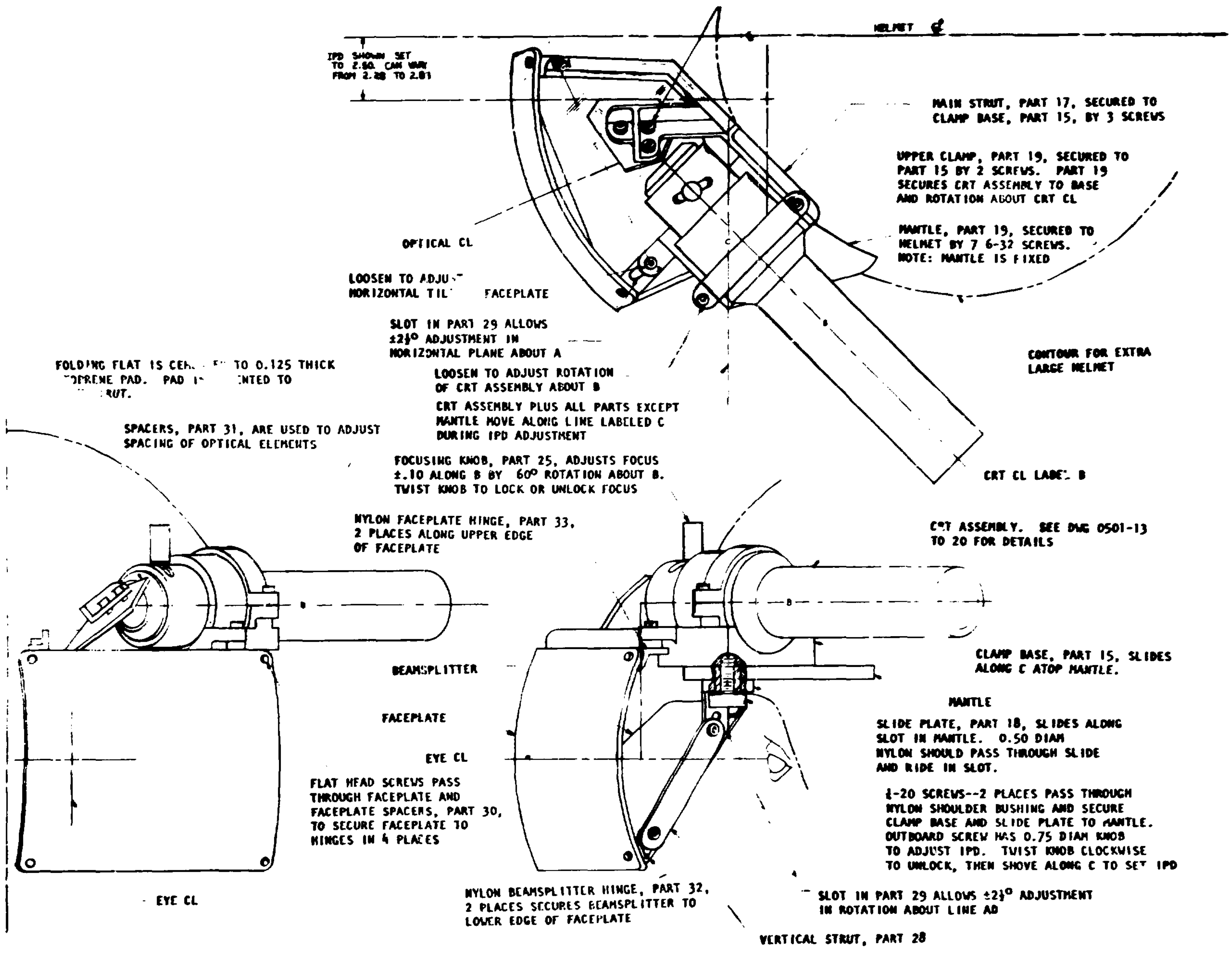
OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA

DESCRIPTION
RIGHT FOLDING FLAT

TITLE
VCASS

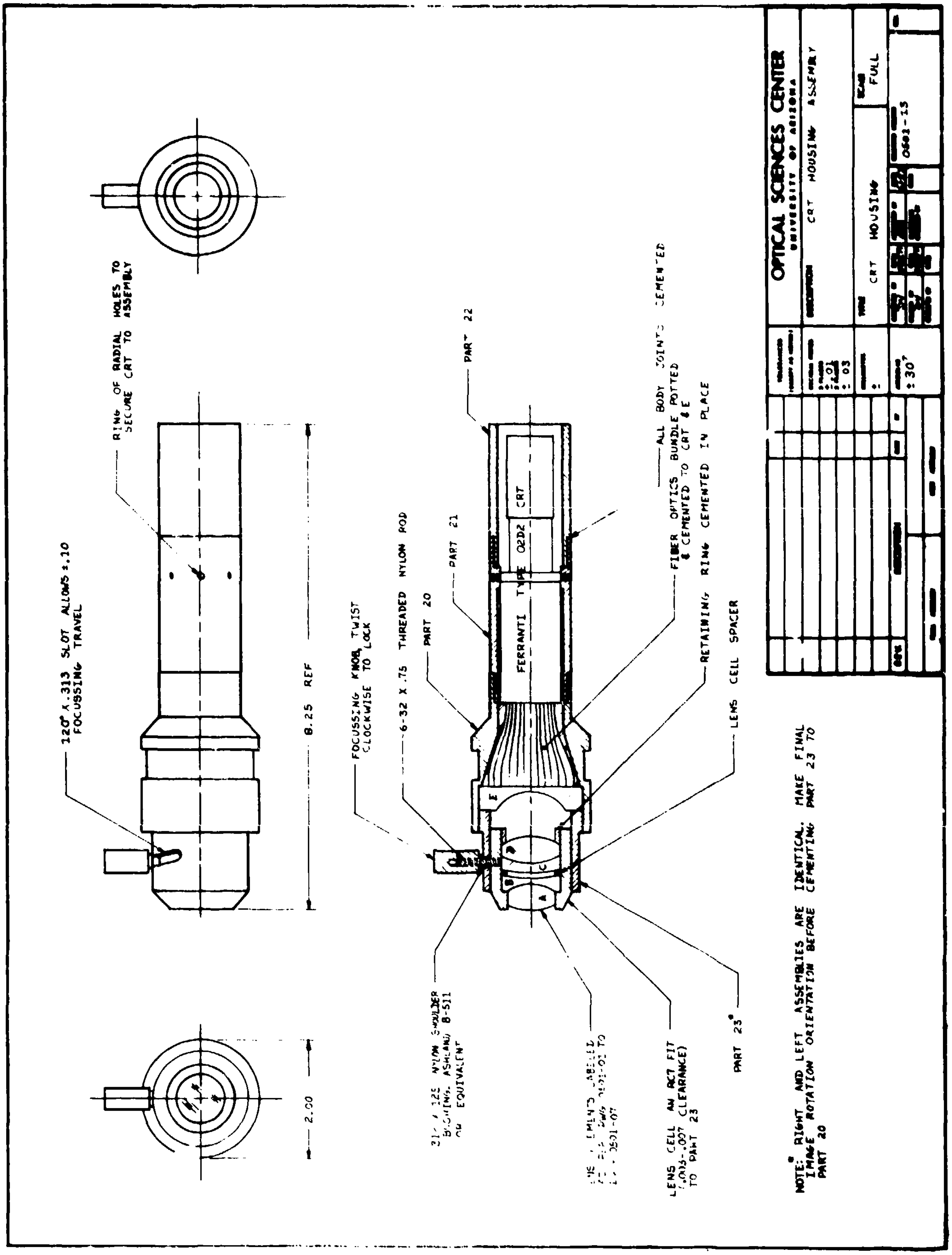
SCALE
FULL

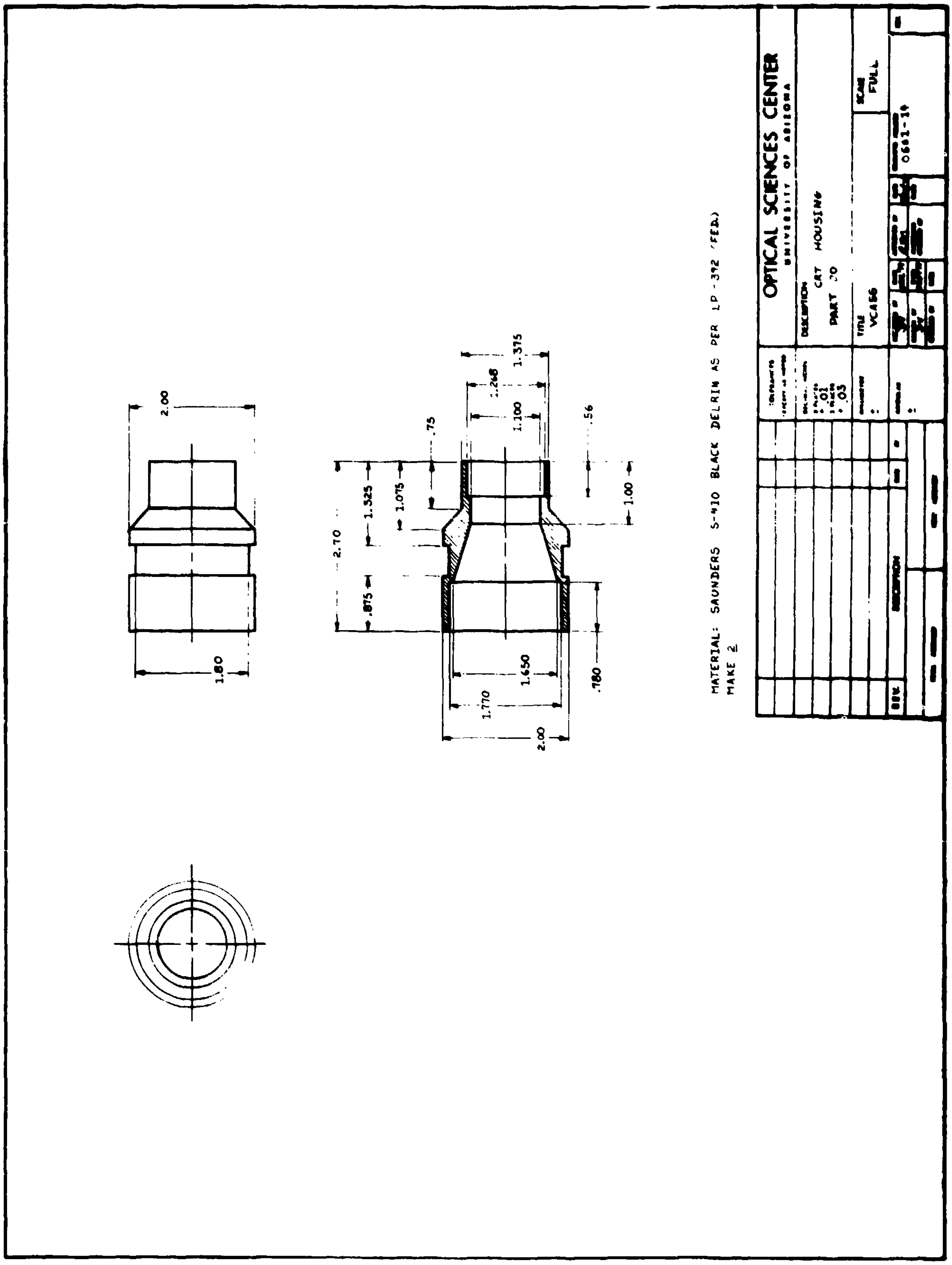
DESIGNED BY	DATE	APPROVED BY		DRAWING NUMBER	REV
DV	05-25-77		1	0551-11	
DRAWN BY	DATE	MATERIALS CHECKED BY	DATE		
DJ					
CHECKED BY	DATE				

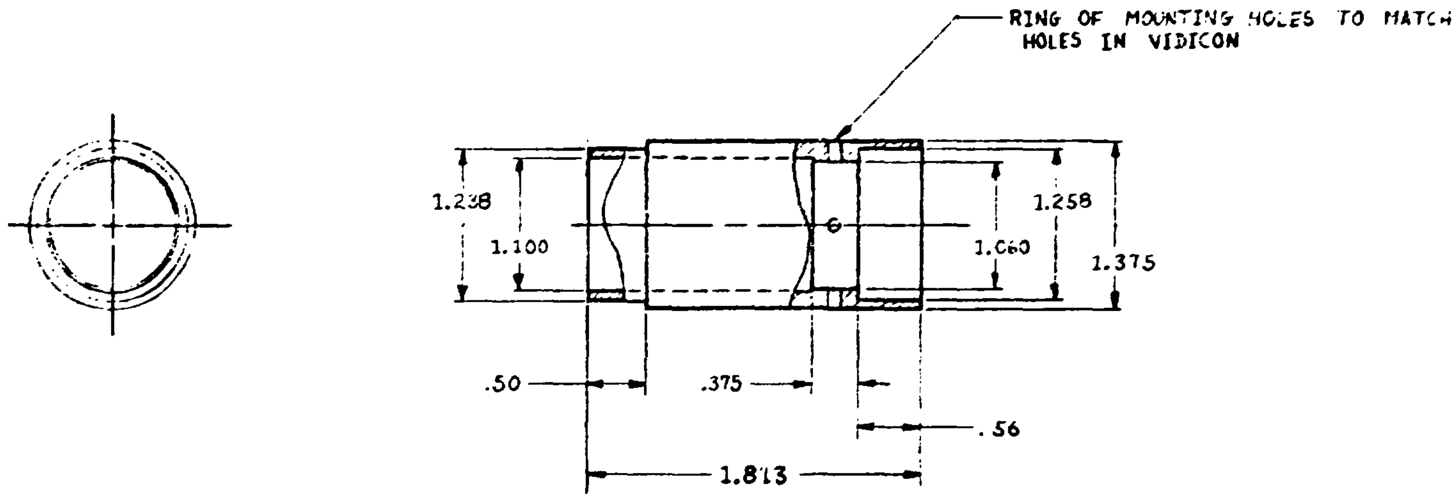


*ABOVE DRAWING IS FOR LEFT SIDE. DESIGN IS SYMMETRICAL ABOUT HELMET CL

NOTE: ALL HARDWARE 6-32 NYLON SOCKET HEAD SCREWS PER MIL-M-20693 UNLESS OTHERWISE NOTED


120° X .313 SLOT ALLOWS ±.10 FOCUSSING TRAVEL
RING OF RADIAL HOLES TO SECURE CRT TO ASSEMBLY
8.25 REF
2.00
FOCUSSING KNOB, TWIST CLOCKWISE TO LOCK
6-32 X .75 THREADED NYLON ROD
PART 20
PART 21
PART 22
FERRANTI TYPE Q2D2 CRT
ALL BODY JOINTS CEMENTED
FIBER OPTICS BUNDLE POTTED & CEMENTED TO CRT & E
RETAINING RING CEMENTED IN PLACE
LENS CELL SPACER
LENS CELL AN RC7 FIT (.0015-.0027 CLEARANCE) TO PART 23
PART 23*
NOTE: * RIGHT AND LEFT ASSEMBLIES ARE IDENTICAL. MAKE FINAL IMAGE ROTATION ORIENTATION BEFORE CEMENTING PART 23 TO PART 20
OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA
CRT HOUSING ASSEMBLY
CRT HOUSING
FULL
0601-15


OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA
CRT HOUSING
FULL
MATERIAL: SAUNDERS S-410 BLACK DELRIN AS PER LP-392 (FED.)
MAKE 2



MATERIAL: SAUNDERS S-410 BLACK DELRIN AS PER LP-392 (FED.)
MAKE 2

OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA

DESCRIPTION
CRT HOUSING
PART 21

TITLE
VCASS

SCALE FULL

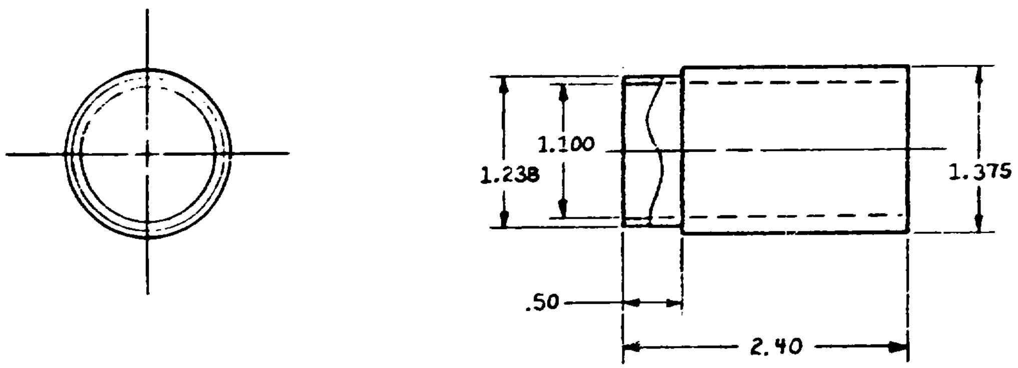
DRAWN BY DV

DWG NO. 0501 - 15

REV. | DESCRIPTION

FINAL ASSEMBLY | NEXT ASSEMBLY

TOLERANCES ±.01 ±.03



MATERIAL: SAUNDERS S-410 BLACK DELRIN AS PER LP-392 (FED.)
MAKE 2

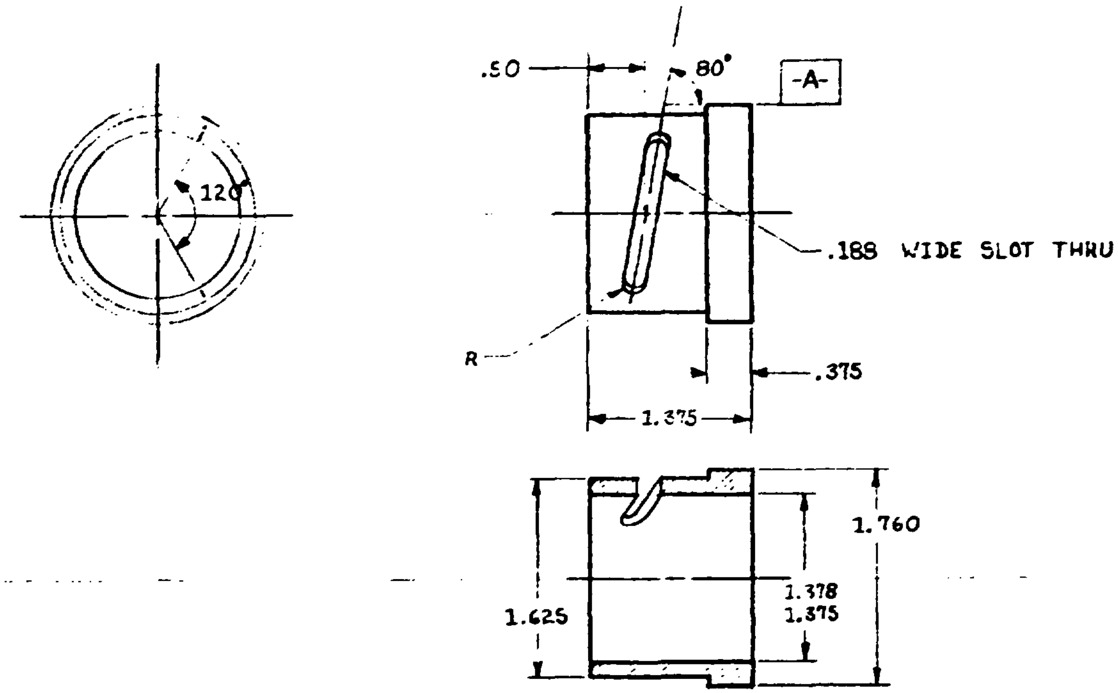
OPTICAL SCIENCES CEN[illegible]
UNIVERSITY OF ARIZONA

TOLERANCES (EXCEPT AS NOTED)
DECIMAL INCHES: ±.01, ±.03
MILLIMETERS: ±
ANGULAR: ±

DESCRIPTION: CRT HOUSING PART 22
TITLE: VCASS
SCALE: FULL
DRAWING NUMBER: 0591-16

REV.	DESCRIPTION	DATE	BY

FINAL ASSEMBLY | NEXT ASSEMBLY



MATERIAL: SAUNDERS 5-410 BLACK DELRIN AS PER LP-392 (FED)
MAKE 2

REV.	DESCRIPTION	DATE	BY
FINAL ASSEMBLY		NEXT ASSEMBLY	

TOLERANCES (EXCEPT AS NOTED)
DECIMAL INCHES
2 PLACES ± .01
3 PLACES ± .03
MILLIMETER ±
ANGULAR ± 30'

OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA

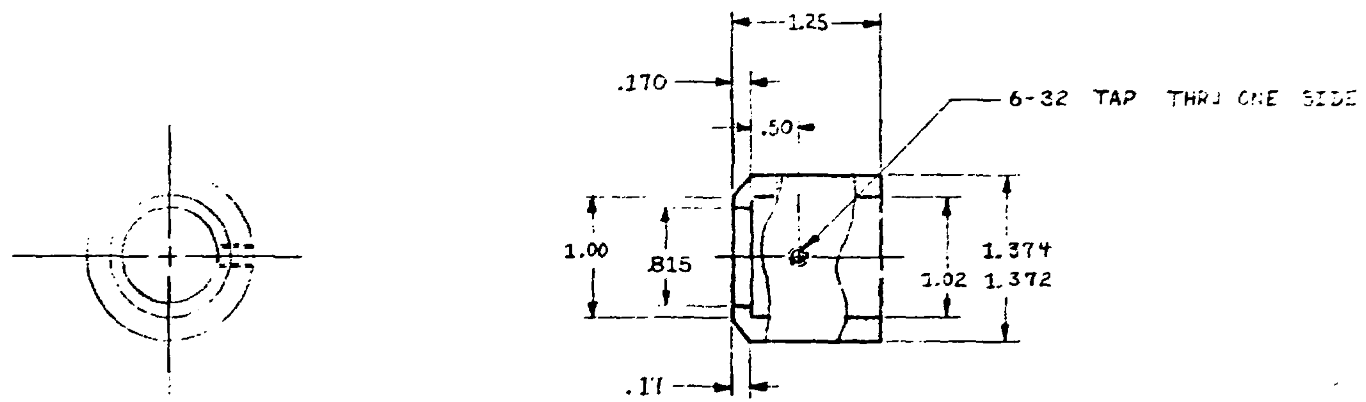
DESCRIPTION
CRT HOUSING
PART 23

TITLE
VCASS

SCALE
FULL

DESIGNED BY DV | DATE 0501?? | APPROVED BY | DATE
DRAWN BY DV | DATE 0501?? | MATERIALS APPROVED BY | DATE
CHECKED BY | DATE

DRAWING NUMBER
0?01-17



MATERIAL: SAUNDERS S-410 BLACK DELRIN AS PER LP-392 (FED.)
MAKE 2

REV.	DESCRIPTION	DATE	BY
FINAL ASSEMBLY	NEXT ASSEMBLY		

TOLERANCES (EXCEPT AS NOTED)
DECIMAL INCHES
3 PLACES ±.01
2 PLACES ±.03
MILLIMETER ±
ANGULAR ±

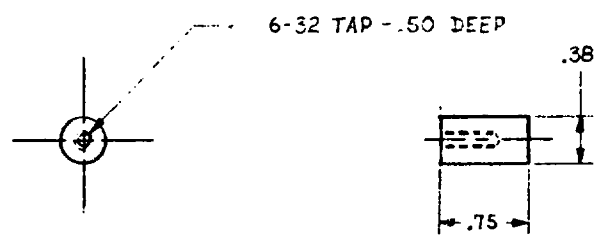
OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA

DESCRIPTION
CRT HOUSING
PART 24 - LENS CELL

TITLE
VCASS

SCALE
FULL

DESIGNED BY IV | DRAWN BY JN | CHECKED BY | APPROVED BY | MATERIALS CHECKED BY | DRAWING NUMBER 0001-18



MATERIAL: SAUNDERS S-410 BLACK DELRIN AS PER LP-392 (FED.)
MAKE 2

OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA

TOLERANCES (EXCEPT AS NOTED)
DECIMAL INCHES
2 PLACES ± .01
3 PLACES ± .03
MILLIMETER ±
ANGULAR ±

DESCRIPTION
CRT HOUSING
PART 25 - FOCUSSING KNOB

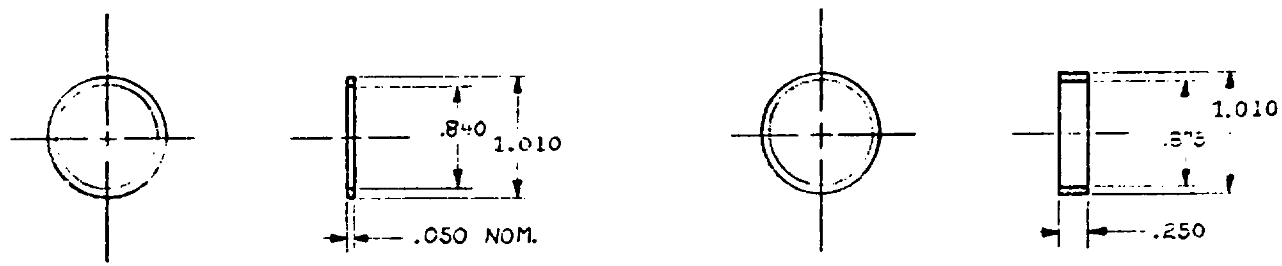
TITLE
VOASS

SCALE
FULL

DESIGNED BY DV
DRAWN BY DV
CHECKED BY

REV. | DESCRIPTION | DATE | BY

FINAL ASSEMBLY | NEXT ASSEMBLY



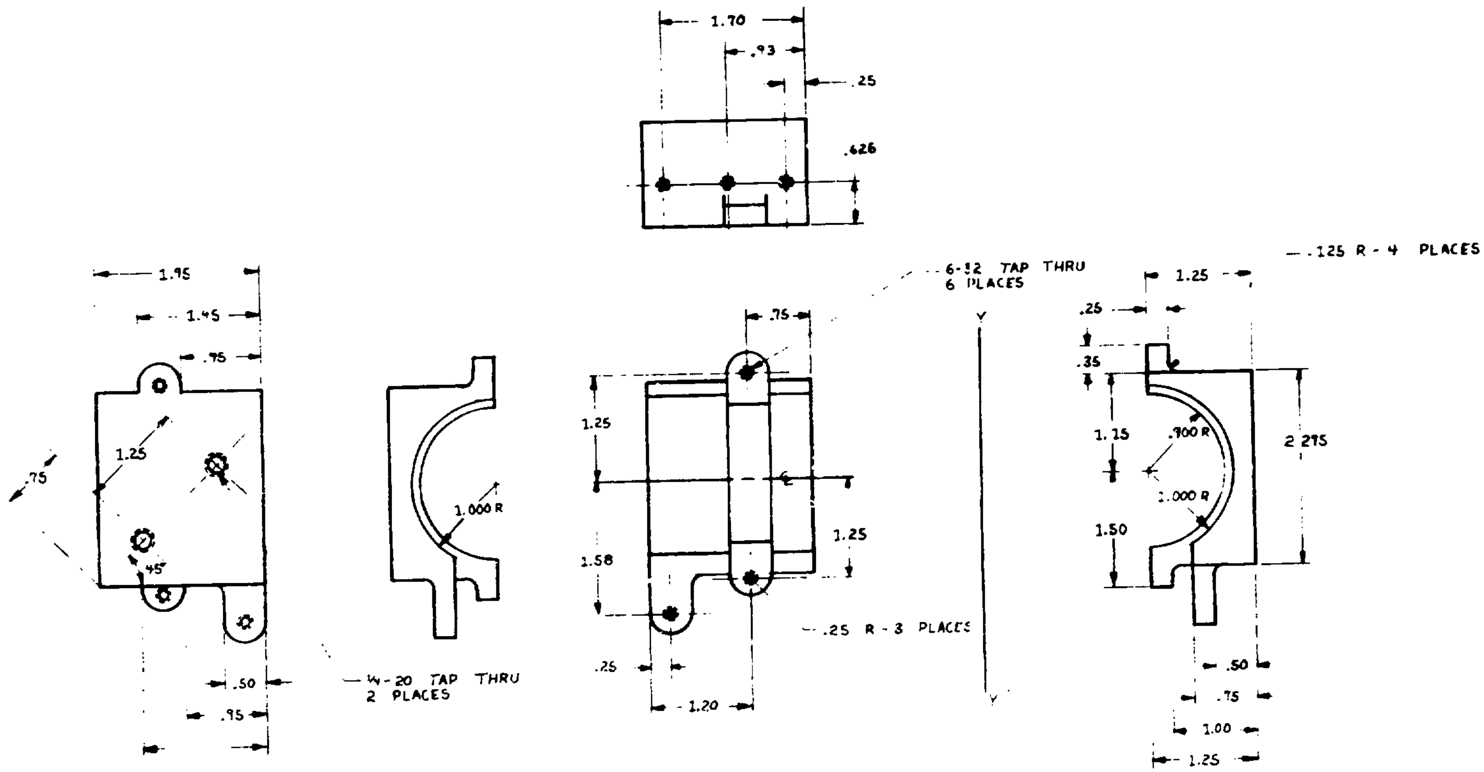
PART 26 - SPACER RING
MAKE 2

PART 27 - LENS RETAINING RING
MAKE 2

MATERIAL: SAUNDERS S-410 BLACK DELRIN AS PER LP-392 (FED.)

TOLERANCES (EXCEPT AS NOTED)	OPTICAL SCIENCES CENTER UNIVERSITY OF ARIZONA
DECIMAL INCHES 2 PLACES ± .01 3 PLACES ± .03	DESCRIPTION CPT HOUSING PART 26 & PART 27
MILLIMETER ±	TITLE VCASS — SCALE FULL
ANGULAR ±	DRAWN BY DV — [illegible]

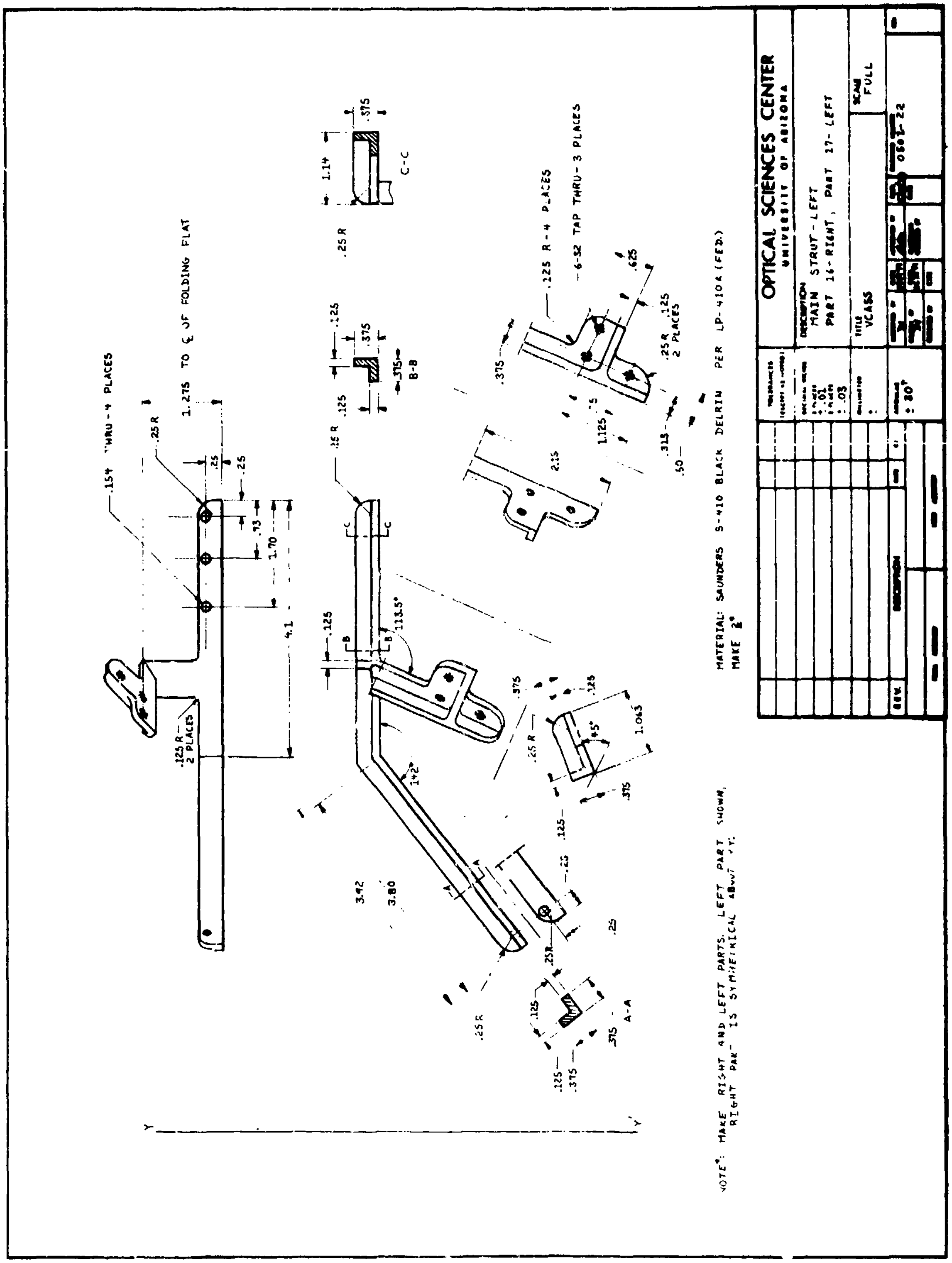
REV.	DESCRIPTION	DATE	BY
FINAL ASSEMBLY	NEXT ASSEMBLY		

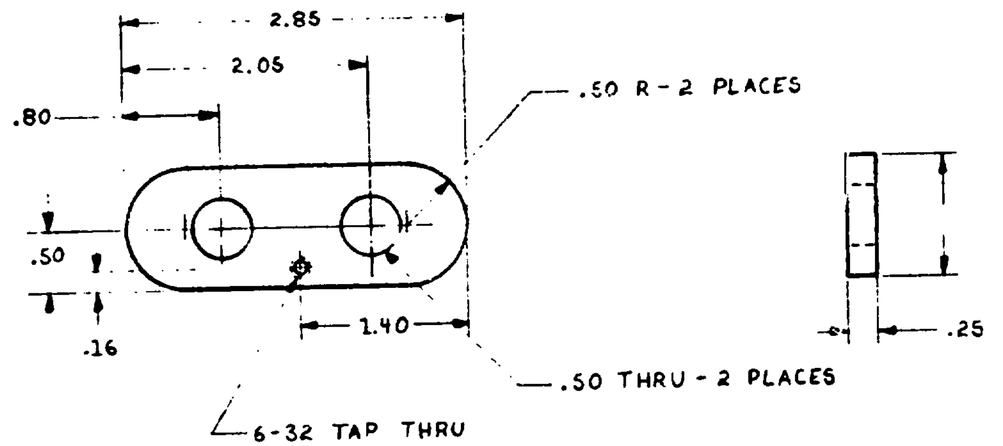


NOTE: MAKE RIGHT AND LEFT PARTS. LEFT PART SHOWN, RIGHT PART IS SYMMETRICAL ABOUT Y-Y

MATERIALS: SAUNDERS S-910 BLACK DELRIN PER LP-410A (FED)
MAKE 2

REV.	DESCRIPTION	TOLERANCES (EXCEPT AS NOTED)	OPTICAL SCIENCES CENTER, UNIVERSITY OF ARIZONA
		DECIMAL INCHES: 2 PLACES ±.01, 3 PLACES ±.03	DESCRIPTION: CRT ASSEMBLY CLAMP BASE-LEFT, PART 14 - RIGHT, PART 15 - LEFT
		ANGULAR ±30'	TITLE: VCASS — SCALE: FULL
			0501-21


OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA
DESCRIPTION MAIN STRUT - LEFT
PART 16 - RIGHT, PART 17 - LEFT
TITLE VCASS
SCALE FULL
MATERIAL: SAUNDERS S-410 BLACK DELRIN PER LP-410A (FED.)
MAKE 2
NOTE: MAKE RIGHT AND LEFT PARTS. LEFT PART SHOWN, RIGHT PART IS SYMMETRICAL ABOUT Y-Y.
.154 THRU - 4 PLACES
1.275 TO ℄ OF FOLDING FLAT
.125 R - 4 PLACES
6-32 TAP THRU - 3 PLACES
.125 R 2 PLACES
.25 R 2 PLACES
113.5°
142°
45°
C-C
B-B
A-A



MATERIAL: SAUNDERS S-202 #105 BLACK NYLON PER LP-410A (FED.)
MAKE 2

OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA

TOLERANCES (EXCEPT AS NOTED)
DECIMAL INCHES
2 PLACES ± .01
3 PLACES ± .03
MILLIMETER ±
ANGULAR ± 30'

DESCRIPTION
SLIDE PLATE
PART 18

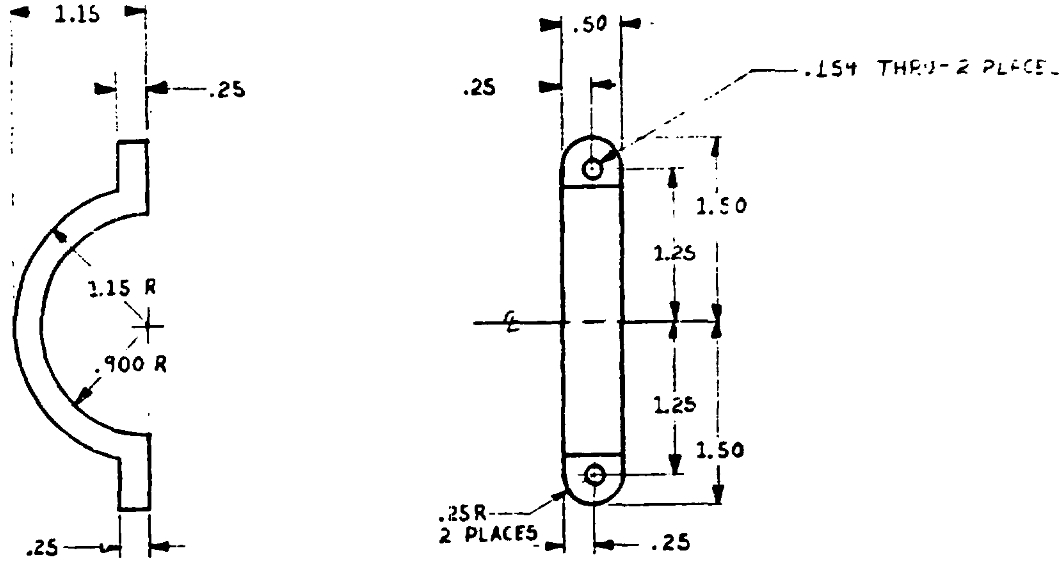
TITLE
VCASS

SCALE [illegible]

DESIGNED BY DV
DRAWN BY DV
CHECKED BY
APPROVED BY
DRAWING NUMBER OSC1-23

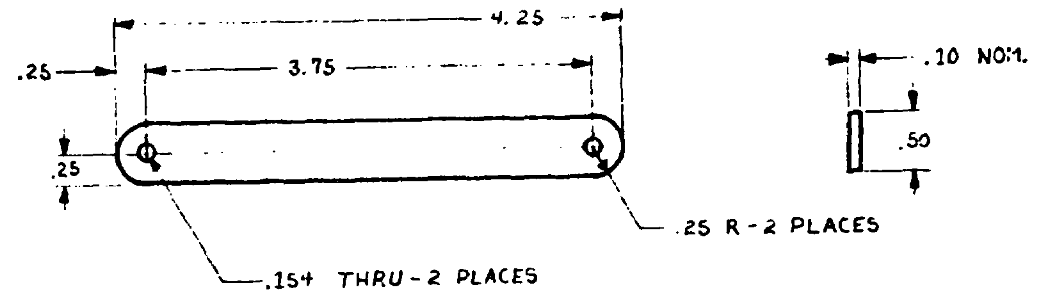
REV.	DESCRIPTION	DATE	BY

FINAL ASSEMBLY | NEXT ASSEMBLY



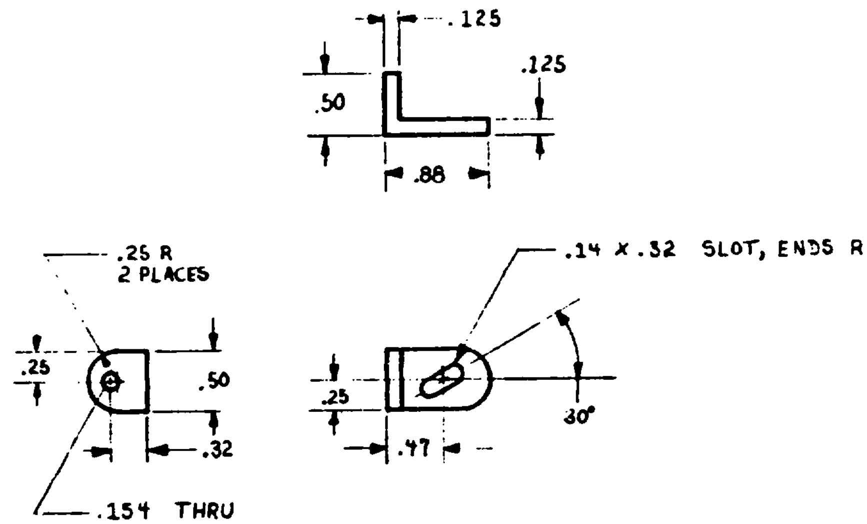
MATERIAL: SAUNDERS 5-410 BLACK DELRIN PER LP-410A (FED.)
MAKE 2

REV.	DESCRIPTION	DATE	BY	TOLERANCES (EXCEPT AS NOTED)	OPTICAL SCIENCES CENTER, UNIVERSITY OF ARIZONA
				DECIMAL INCHES: 2 PLACES ±.01, 3 PLACES ±.03	DESCRIPTION: CRT UPPER CLAMP, PART 19
				MILLIMETER ±	TITLE: VCASS; SCALE: FULL
				ANGULAR ±30'	DESIGNED BY DV; DATE 5/10/71; DRAWN BY DV; DATE 05/11/71; CHECKED BY; DRAWING NUMBER 0521-24
FINAL ASSEMBLY		NEXT ASSEMBLY			



MATERIAL: CLEAR ACRYLIC
MAKE 2

				TOLERANCES (EXCEPT AS NOTED)	OPTICAL SCIENCES CENTER UNIVERSITY OF ARIZONA
				DECIMAL INCHES 2 PLACES ±.01 3 PLACES ±.03	DESCRIPTION VERTICAL STRUT PART 28
				MILLIMETER ±	TITLE VCASS — SCALE FULL
REV.	DESCRIPTION	DATE	BY	ANGULAR ± 30°	DESIGNED BY DV — DRAWN BY DV — CHECKED BY
FINAL ASSEMBLY		NEXT ASSEMBLY			



MATERIAL: SAUNDERS S-410 # 507 BLACK DELRIN PER LP-392A (FED.)
MAKE 2

OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA

DESCRIPTION
VERTICAL TILT ADJUSTING BRACKET
PART 29

TITLE
VCASS

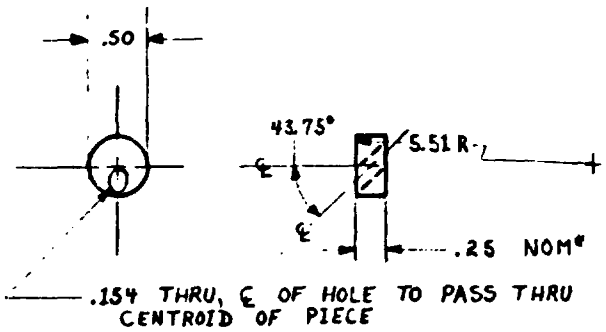
TOLERANCES (EXCEPT AS NOTED)
± .01
± .03
ANGULAR ± 30'

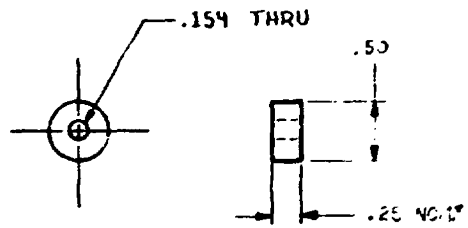
REV. | DESCRIPTION

FINAL ASSEMBLY | NEXT ASSEMBLY

DESIGNED BY DJ
DRAWN BY DJ
CHECKED BY

0001-26





* PIECE THICKNESS ADJUSTED AFTER INITIAL ASSEMBLY

FACEPLATE SPACER
MAKE 8
PART 30

SPACER
MAKE 10
PART 31

MATERIAL: SAUNDERS S-201 #105 BLACK NYLON PER LP-410A (FED.)

REV.	DESCRIPTION	DATE	BY

FINAL ASSEMBLY	NEXT ASSEMBLY

TOLERANCES (EXCEPT AS NOTED)
DECIMAL INCHES
2 PLACES ±.01
3 PLACES ±.03
MILLIMETER ±
ANGULAR ±30'

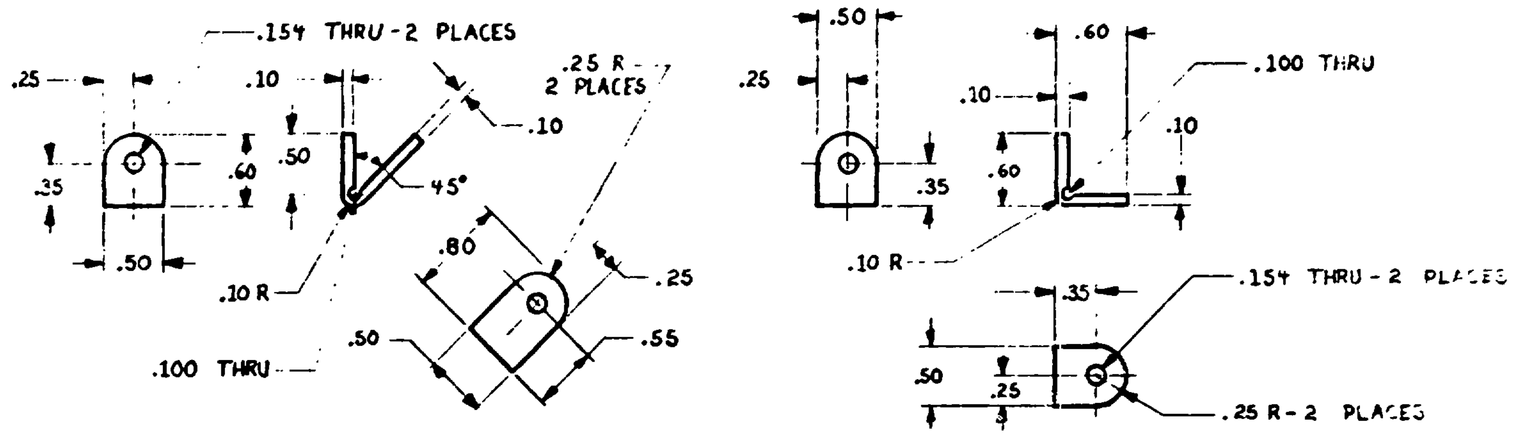
OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA

DESCRIPTION: FACEPLATE & STANDARD SPACERS
PARTS 30 & 31

TITLE: VCASS

SCALE: FULL

DESIGNED BY [illegible] DATE [illegible]
DRAWN BY [illegible] DATE [illegible]
CHECKED BY
APPROVED BY [illegible] DATE [illegible]
MATERIALS CHECKED BY
DRAWING NUMBER 0501-27



BEAMSPLITTER HINGE - PART 82
MAKE 4

FACEPLATE CENTER HINGE - PART 32
MAKE 2

MATERIAL: SAUNDERS S-201 #105 BLACK NYLON PER LP-410A (FED.)

OPTICAL SCIENCES CENTER
UNIVERSITY OF ARIZONA

DESCRIPTION: FACEPLATE & BEAMSPLITTER HINGES PARTS 32 & 33

TITLE: VCASS

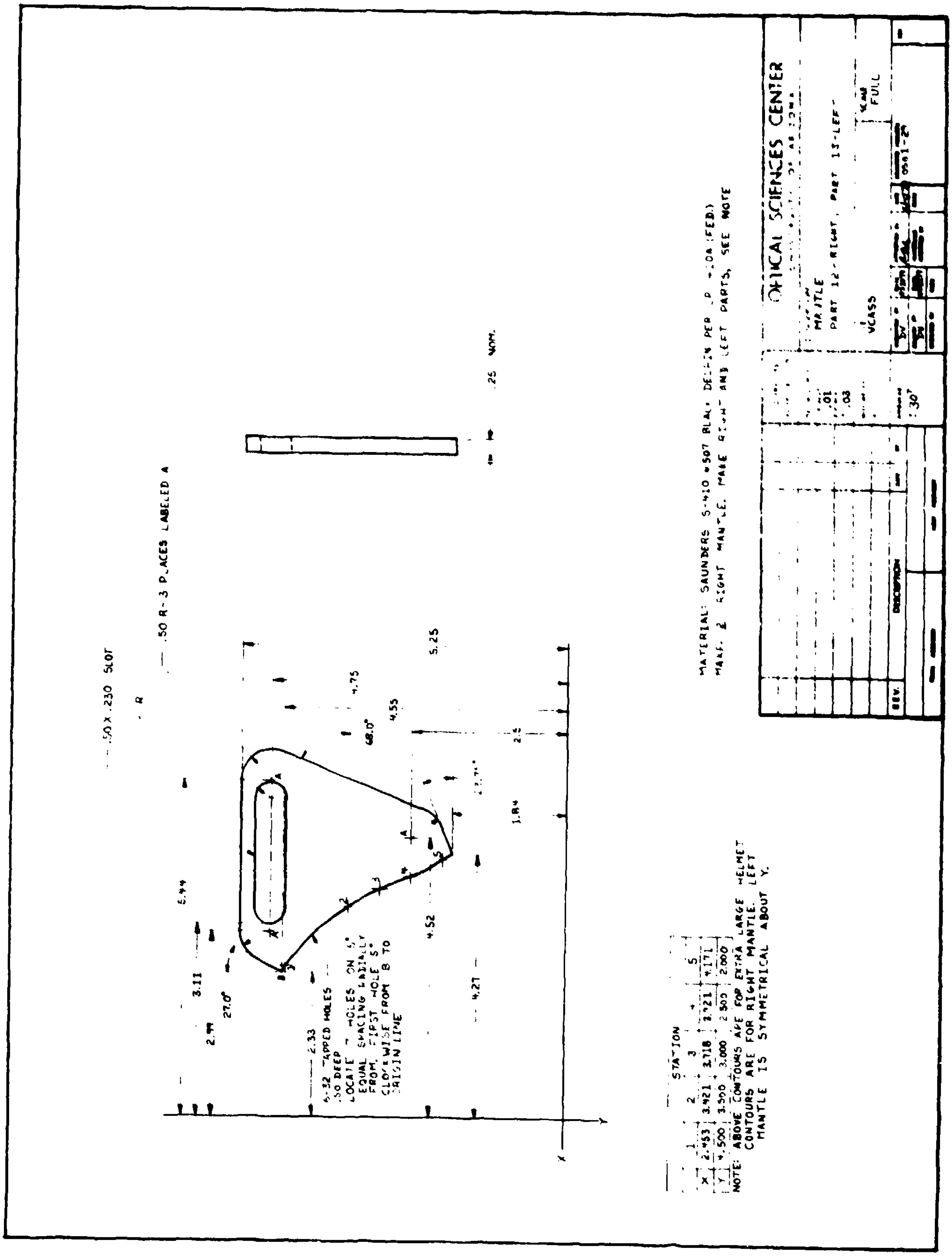
SCALE: FULL

TOLERANCES (EXCEPT AS NOTED): DECIMAL INCHES 2 PLACES ±.01, 3 PLACES ±.03; MILLIMETER ±; ANGULAR ±30'

DESIGNED BY DV; DRAWN BY DV; DATE 050179

REV.	DESCRIPTION	DATE	BY

FINAL ASSEMBLY | NEXT ASSEMBLY


OPTICAL SCIENCES CENTER
MANTLE
PART 12-RIGHT, PART 13-LEFT
FULL
MATERIAL: SAUNDERS S-410 #507 BLACK DELRIN
MAKE 2 RIGHT MANTLE, MAKE RIGHT AND LEFT PARTS, SEE NOTE
.50 X .230 SLOT
.50 R-3 PLACES LABELED A
.25 NOM.
4-32 TAPPED HOLES .30 DEEP
LOCATE 7 HOLES ON 5° EQUAL SPACING RADIALLY FROM FIRST HOLE 5° CLOCKWISE FROM B TO ORIGIN LINE
STATION
NOTE: ABOVE CONTOURS ARE FOR EXTRA LARGE HELMET
CONTOURS ARE FOR RIGHT MANTLE. LEFT MANTLE IS SYMMETRICAL ABOUT Y.
DESCRIPTION
REV.

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VISION AND TASK PERFORMANCE

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