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EARTH ORBITAL TELEOPERATOR
VISUAL SYSTEM EVALUATION PROGRAM

TEST REPORT NO. 5

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EARTH ORBITAL TELEOPERATOR VISUAL SYSTEM EVALUATION PROGRAM

TEST REPORT NUMBER 5

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FOREWORD

This 1976 year end visual laboratory report is one of a set of three volumes that describe the teleoperator design studies performed by Essex Corporation under NASA contract NAS8-31848. The three volumes describe the tests conducted in the mobility, manipulator and visual laboratories at Marshall Space Flight Center (MSFC) and the concomitant results. This effort was directed by Mr. Edward G. Guerin (COR).

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1.0 EXECUTIVE SUMMARY

NASA's Marshall Space Flight Center (MSFC) is currently involved in the development of technology to support teleoperator flight experiments. Development and evaluation is being performed in three technology areas:

- Visual Systems
- Manipulator Systems
- Vehicle Mobility Systems.

The current report describes three experiments which were carried out to examine operator performance using a stereoptic television system and color discrimination performance using color television. In addition, a computer program is described which predicts depth resolution performance and field of view for a stereoptic television system.

1.1 STEREOPTIC RANGING TEST

Remote vehicle docking and remote manipulation require that the operator be able to acquire depth or range information from the visual system. For a monoptic television system, the available cues are limited primarily to apparent target size and apparent brightness. A ranging scheme for monoptic TV was described in an earlier report (Ref. 3). This method used a movable cursor controlled by the operator. Matching the cursor width to the image of a known dimension of a target permits estimation of range.

In the stereoptic mode, a pair of cursors is used. One cursor line appears in each of the two rasters. The operator adjusts the cursors until he sees a single line which appears at the same range as that of the target.

In the ranging test performed, operators used the stereo system to estimate the range to a target object. The actual range was varied and per cent range estimation error was found to increase as the square of range which would be expected. The target ranges employed ran from 152.4 cm (60 in.) to 518.2 cm (204 in.). Per cent error was found to vary from 5 to 30 per cent.

Comparison of the results of the stereo ranging test with data from the monoptic system showed that the stereo system achieved smaller error of range estimation provided that the target is close to the point of convergence of the camera pair lines of sight. For target ranges much greater than the convergence range, the monoptic ranging system will yield smaller per cent error.

In comparing the two systems, it should also be kept in mind that the monoptic system requires that the true size of the target object be known. Furthermore, measurement error will increase if the monoptic camera line of sight is not close to normal to the target dimension being used. The stereoptic system does not require that the target dimension be known and allows the target to be viewed at any point on the screen since range errors away from the stereo center line were not sufficient to be considered significant.

1.2 COLOR DISCRIMINATION TEST

The question has often been asked whether use of color TV can facilitate operator performance in remote control tasks. This question is too gross to be answered empirically. To refine it, it can be noted that use of color TV should permit the operator to make additional discriminations (color in addition to brightness). Facilitation of performance would then occur if the additional discriminations were essential to performance. A test was carried out to determine the number of separate colors which can be identified with negligible error using color TV.

The test was carried out using 15 Munsell color chips which had previously been determined to be maximally discriminable (Ref. 1). These 15 chips were presented in all possible pairings and were presented to subjects via a Sony color television system. The subject responded "same" or "different" to each pair. The test confirmed the discriminability of the set of chips selected. The vast majority of errors noted were false alarms where the subject responded "different" to a chip paired with itself. Confusion errors were noted for only chip pairs. One of these chips was removed leaving a set of 14 Munsell chips which can be discriminated via color TV with negligible error.

Problems noted in color discrimination testing included a phase shift of the 3.58 MHz subcarrier and apparent color differences resulting from small variations in lighting across the scene.

An attempt was made to determine if absolute identification of colors could be done using a set of chips which were viewed directly and compared with the color TV presentation. This would permit color coding. This attempt was largely unsuccessful. Changes in apparent hue were introduced by the video system which caused unacceptable error levels for absolute identification. Color coding of targets presented via color TV would, therefore, appear to be feasible only if the comparison color chips are presented along with the target via TV.

1.3 COMPARISON OF SOLID STATE AND VIDICON CAMERA SYSTEMS

Stereoptic video tests previously reported (Ref. 1) have utilized a pair of Vidicon cameras with zoom lenses. The objective of this test was to evaluate effects of use of General Electric solid state cameras as a stereo pair. The task performed by the subject was to control a target motion generator so as to place a movable target in the same fore-aft position as a fixed target. Trials were conducted using two different camera pairs - the solid state cameras and a pair of COHU Vidicon cameras.

The results of the camera comparison test did not show a general effect of camera type in terms of response time. The effect of camera type was found to depend on fixed target range. The expected response time for a system using solid state cameras in place of Vidicons will increase with increasing operating range.

Analysis of absolute adjustment errors data showed no effect of camera type.

1.4 STEREOPTIC TV PARAMETER PROGRAM

A computer program was developed to calculate detectable range difference and thus width of the stereoptic field of view based on disparity thresholds and limits determined in earlier experiments (Ref. 1). The inputs to the program include:

- Monitor to eye viewing distance
- Monitor dimension
- Video system constant
- Visual angle at operator's eye for vertical target detection based on empirical studies
- Visual angle at operator's eye for horizontal target detection based on empirical studies
- Average interocular distance
- Retinal disparity at operator's eye for range increment detection based on empirical studies
- Maximum value of linear disparity which will permit stereopsis based on empirical studies
- Stereo camera baseline

- Single camera field-of-view
- Camera convergence angle.

The program calculates and outputs the following data:

- Horizontal resolution factor
- Vertical resolution factor
- Stereo exaggeration ratio
- Resolvable horizontal increment
- Resolvable vertical increment
- Range at which maximums value of retinal disparity occurs
- Range resolution factor
- Detectable range increment
- Width of stereo field of view.

The program can be used to determine the coverage and range increment sensitivity for a proposed set of stereo system parameters.

2.0 INTRODUCTION

2.1 BACKGROUND

NASA's Marshall Space Flight Center is currently involved in the development of technology to support two teleoperator flight experiments - the Space Teleoperator Demonstration Unit (STDU) and the Space Teleoperator Evaluation Vehicle (STEV). As currently conceived, the STDU will be mounted in the Shuttle payload bay where it will perform a variety of simulated payload servicing tasks to evaluate the manipulator and visual systems. The STEV will be a fully mobile teleoperator system complete with propulsion and attitude control systems.

The initial tests of teleoperator technology will be performed using the STDU on an early Shuttle flight. Since the STDU will operate in the paylaod bay, a vehicle mobility system will not be required. The other system components including the manipulator arm, end effector, visual system, data links, controls, displays and control laws will be required, however. Both STDU and STEV will utilize a visual system that permits a Shuttle based operator to perform basic tasks related to satellite servicing.

Several major technology questions must be answered before the STDU and STEV can be developed. The MSFC teleoperator development effort is aimed at the three primary technology areas - the visual system, the manipulator system, and the maneuvering/mobility system. For the visual system, a central problem is the definition of requirements and criteria for the man-machine interface. The testing philosophy currently being employed is to use simulation and laboratory testing to evaluate various operator/visual system concepts and develop an operator/system data base. These data will then be used to specify man-machine interface requirements for the STDU and STEV visual systems.

Essex Corporation is currently under contract to NASA/MSFC to perform laboratory tests of visual system/operator performance, to evaluate man-machine interface concepts, and to derive man-machine interface requirements. Essex personnel have defined visual system tasks typical of those to be encountered by the STDU and STEV and have developed several laboratory and simulation test plans based on these tasks. These test plans have been implemented and carried out in the MSFC Visual System Evaluation Laboratory during 1976 resulting in quantitative performance data suitable to support trade-off studies of visual system concepts and choice of system parameters. Essex has also carried out analytical studies in the area of visual system component geometry.

2.2 SCOPE

This 1976 year-end report describes three laboratory investigations of visual system parameters and one analytical study to evaluate stereoptic television component geometries for optimum viewing. The three visual system tests described in the following sections include:

- Stereo Ranging Test S-1: To evaluate the accuracy of operator range estimation using a Fresnell stereo television system with a three dimensional cursor.
- Stereoptic Test S-2: To evaluate an operator's ability to align three dimensional targets using vidicon tube and solid state television cameras as part of a Fresnell stereoptic system.
- Color Discrimination - Phase 2 Test: To determine an operator's ability to discriminate between paried color samples viewed with a color television system.

Also reported is an analytical investigation to develop a computer program that can be used to predict the width of stereo field of view and range resolution as functions of range and empirical data on stereoptic disparity thresholds.

3.0 LABORATORY DESCRIPTION

3.1 GENERAL FACILITY DESCRIPTION

The Teleoperator Visual System Evaluation Laboratory at Marshall Space Flight Center's Electronics and Control Laboratory permits operator visual performance data to be collected over a wide range of mission oriented visual system tasks. The laboratory provides for the study of tasks which involve the manipulation of any of the following parameters:

Transmission

- black and white
- one gun color

Camera/Monitor Configurations

- 1 camera, 1 monitor
- 2 cameras, 2 monitors
- 2 cameras, 1 display

Depth of View

- monoptic
- stereoptic

Monitor Sizes

- 19.7 cm (7.75 in.) diagonal
- 30.5 cm (12 in.) diagonal

Field of View of Camera

- 8 degrees to 35 degrees horizontal

Frame Rate of Display

- 15 frames/sec
- 30 frames/sec

Signal Format

- analog
- digital, 4 bit

Signal Bandwidth

- 4.5 MHz
- 1.0 MHz Narrow Band

Signal to Noise Ratio

- 32 db
- 21 db
- 15 db

Viewing Aids

- electronically generated reticles and cursors
- overlayed reticles

Target Motion

- fore-aft, variable translation rates
- rotation, variable rates

Variable Target Parameters

- size
- Shape
- brightness
- 2 or 3 dimensional

Variable Target/Background Contrasts

Variable Target/Camera Geometries

Variable Scene Lighting

Each of the several parameters can be combined with one another to permit the study of system component interactions.

The equipment necessary to generate and control the various video transmissions is housed in the experimenter's station of the Visual System Evaluation Laboratory. The general equipment which was utilized includes:

- Cohu Model 2000 CCTV Cameras for Black & White Transmission
- Sony Model DXC-5000B Camera for Color Transmission
- Colortran Model 104-311 Studio Lights
- Kleig Brothers Studio Lights
- Computer Lab A/D and D/A Converter for Digital Transmission
- General Radio Corporation Random Noise Generator for Varying S/N Ratios

- Narrow Band Pass Filters for 1.0 MHz Transmission
- Tektronix Wave Form Monitor for System Calibration
- Tektronix Vectorscope for Color System Calibration

The specific equipment and laboratory configurations used in each of the experiments are described in Sections 4.0, 5.0 and 6.0 of this report.

The system allows a maximum of two video inputs from any two sources. For example, two black and white cameras or two color cameras are available which would be necessary for the Fresnell stereoptic TV system. System inputs are selected and switched via two RCA T5-28, one output audio follow switchers. A complete description of this signal injection/modification system is contained in Reference 1.

3.2 VISUAL SYSTEM LABORATORY UTILIZED IN STEREO RANGING TESTING

The arrangement of the visual systems laboratory can be changed to accommodate particular testing situations. The configuration used in the stereo ranging testing is represented in Figure 3-1.

The laboratory in this configuration allowed the experimenter to accurately place a target globe at any one of 21 premeasured locations. These locations were determined by placing 1.27 cm (.5 in.) black tape along the floor as shown in Figure 3-1. The center target line was placed along the center line of the stereo camera pair with lines on either side at 8° angles to the center line.

Since the target globe used in this experiment was internally lit, no studio lights were used. The experimenter operated the test from a control panel located in the experimnetal area but out of sight of the camera pair. The subject was isolated in a shrouded subject station where he viewed the scene on the Fresnell stereo system.

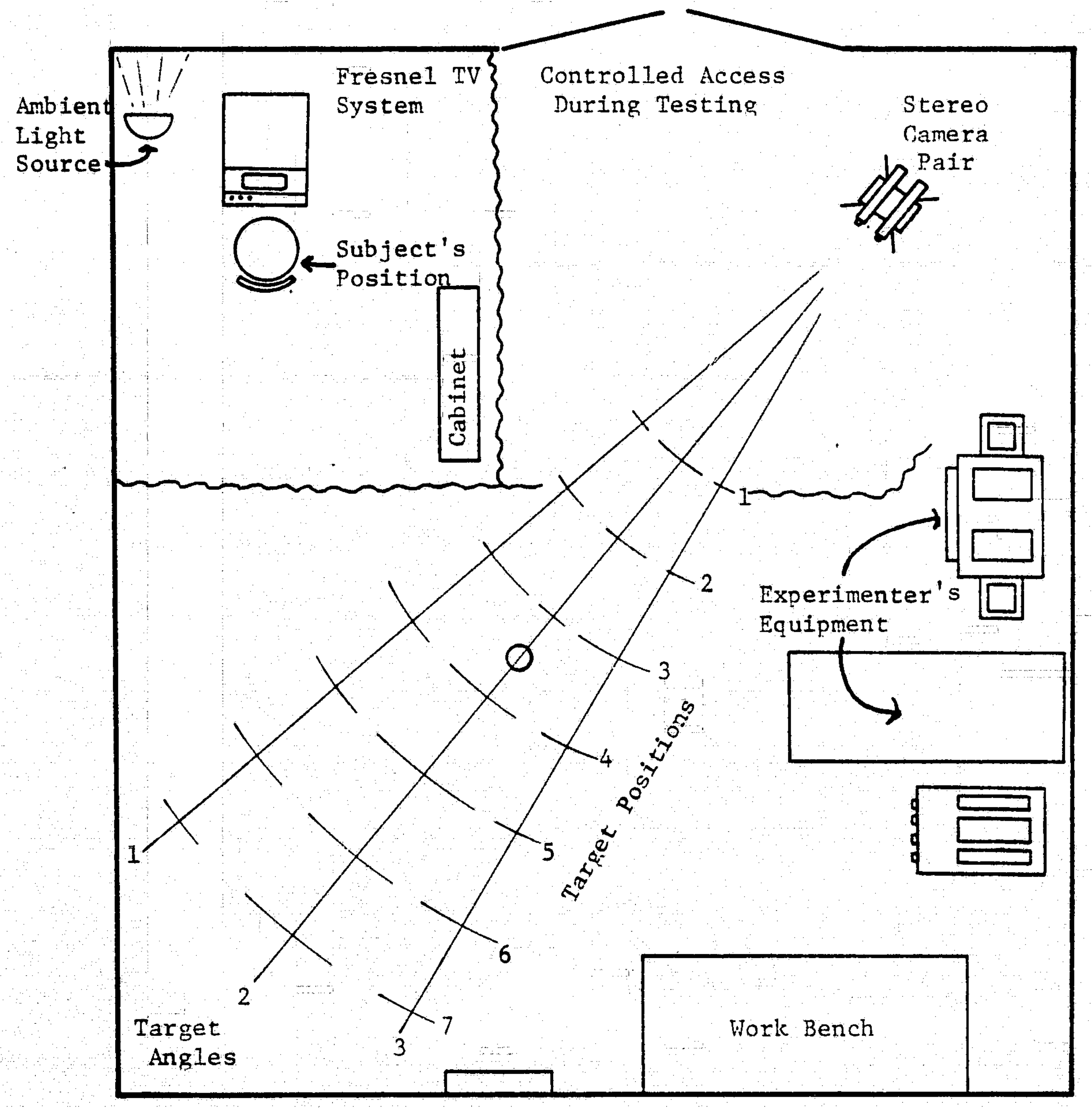


Figure 3-1: Visual System Laboratory Configuration for Stereo Ranging Testing

3.3 VISUAL SYSTEM LABORATORY UTILIZED IN COLOR DISCRIMINATION TESTING

Figure 3-2 shows the color discrimination panel and color wheels which were used in this testing. This board was placed on a tripod and lit by two banks of lights as shown in Figure 3-3. The light sources were placed so that the illumination produced no unwanted reflections from the color chips.

The timing and video selections were controlled by the experimenter who sat at the console behind the task board. The subject viewed an enlarged view of the colors through the two openings in the task board.

Again the subject was segregated from the experimental area by a heavy black fabric shroud.

3.4 VISUAL SYSTEM LABORATORY UTILIZED IN CAMERA COMPARISON TESTING

The major task equipment used in the comparison tests was the target motion generator (TMG) which has been used in prior Essex testing. The TMG was placed as shown in Figure 3-4 so that the translational motion of the movable target was directly along the camera line of sight. The studio lights were placed to prevent unwanted shadows and reflections.

The subject was seated in front of the Fresnell system behind heavy black curtains. In addition, the experimental area was not viewed by subjects prior to testing. This was accomplished by drawing heavy black curtains in front of the experimental area when subjects were entering or leaving the test area.

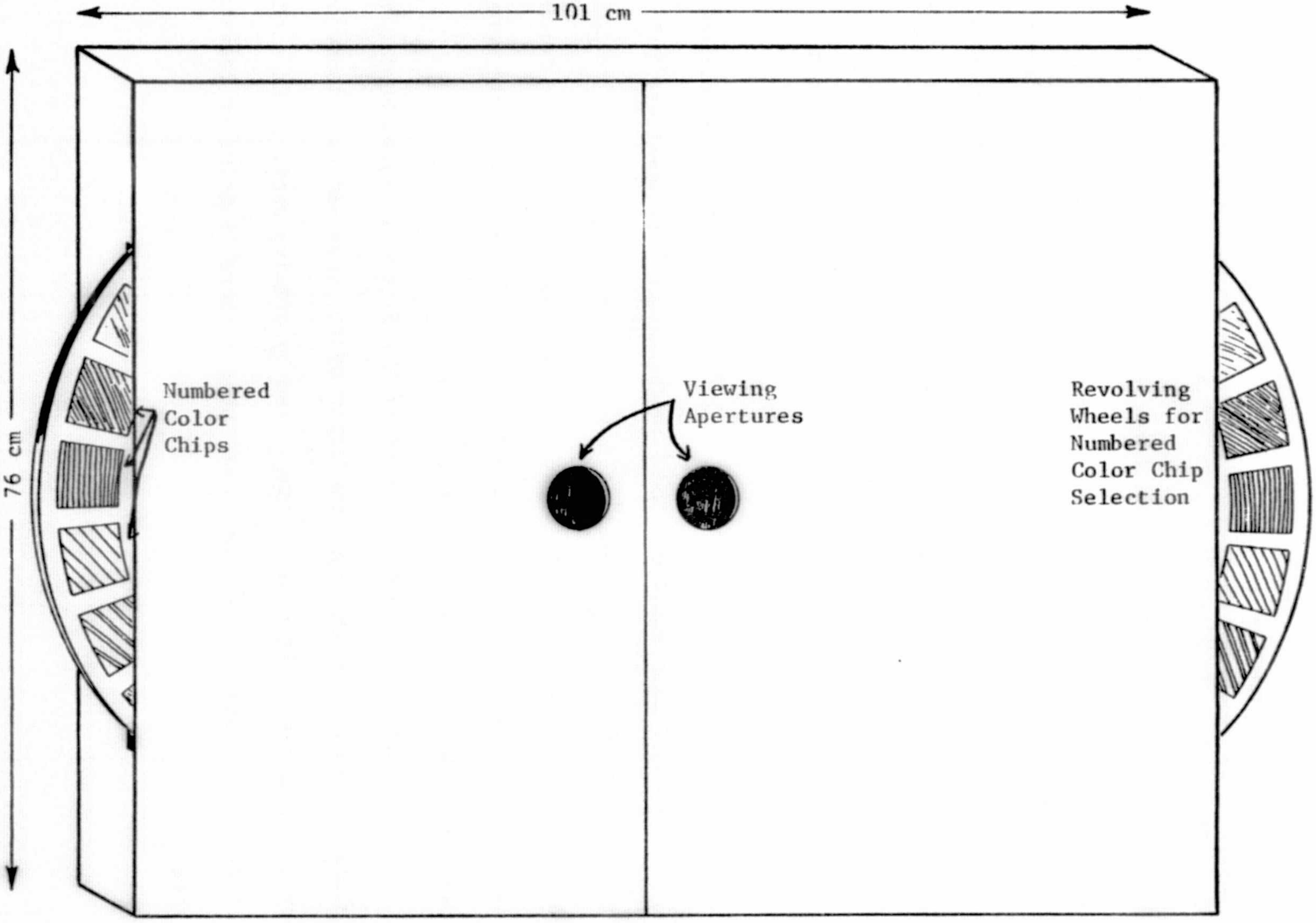


Figure 3-2: Apparatus for Displaying Color Samples for Subject Viewing Via Television

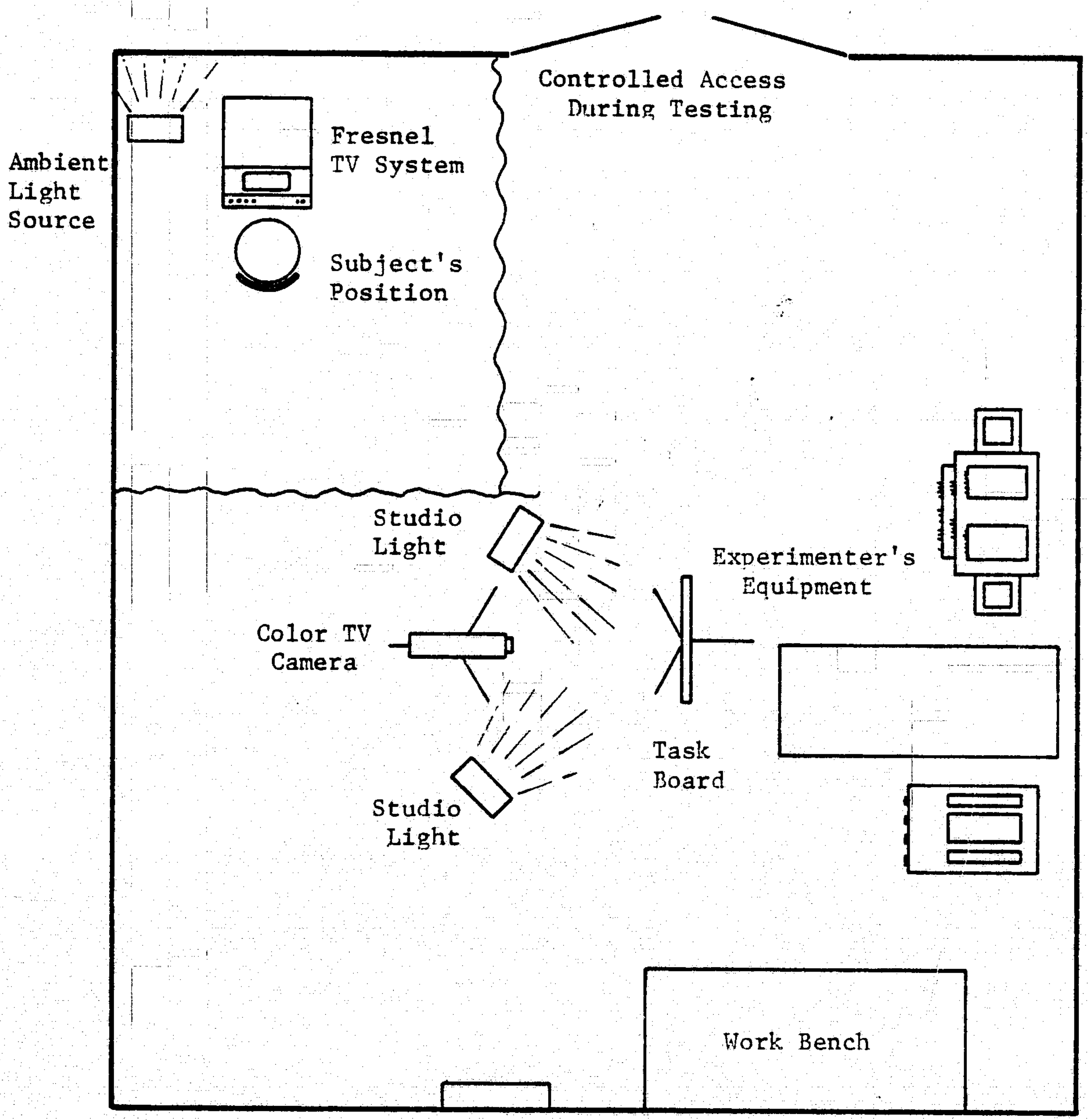


Figure 3-3: Visual System Laboratory Configuration During Color Discrimination Testing

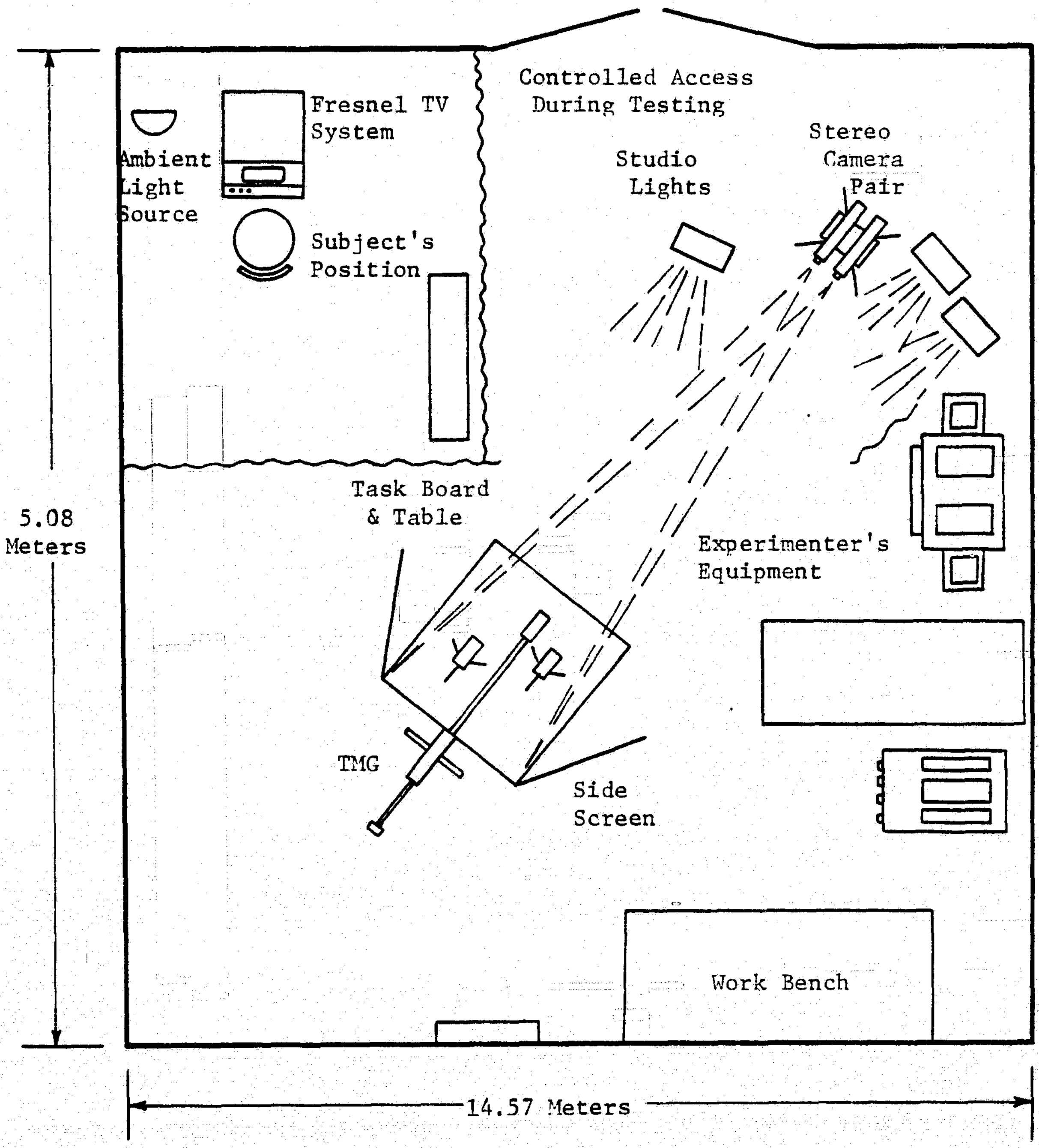


Figure 3-4: Visual System Laboratory Configuration During Camera Comparison Range Testing

4.0 STEREO RANGING - TEST S-1

4.1 OBJECTIVE

Prior testing by Essex Corporation of range estimation in the Visual Systems Laboratory involved monoptic television systems using both fixed and movable ranging cursors superimposed over the television scene. The cursors were used to measure known object sizes within the scene from which range estimates could be obtained.

The purpose of the present testing, as discussed in Section 2.0, was to evaluate the accuracy of range estimation using a three dimensional cursor and the Fresnell stereo television viewing system.

Using this system, range was estimated not by the size of the object but by its perceived distance from the subject. In the previous testing using movable cursors, motion of the cursors was restricted to a plane lying on the viewing screen. The objective of this test was to evaluate the difficulty and accuracy of obtaining range estimates using a cursor and viewing system with an additional degree of freedom, depth.

4.2 APPARATUS

The experiment was performed in the Visual Systems Laboratory, Marshall Space Flight Center. The general laboratory description is contained in Section 3.0, and the specific laboratory setup for this experiment is contained in Section 3.3.

The operator's station contained the Fresnell stereoptic display. This display was mounted in a console containing the two 23 cm (9 in.) diagonally measured, Conrac Type SNA9A monitors and the associated optical train composed of mirrors and lenses as described in Section 3.0. The Fresnell display screen actually observed by the subject was a 23 cm (9 in.) diagonally measured unit. A hand-held, thumb operated, momentary contact pushbutton was provided for the subject to signal task completion. Depression of this button also served to generate signals to terminate task timing equipment and to terminate the subject's video signal in preparation for the presentation of the next trial.

Three potentiometers were mounted in a row on the front of the subject's display immediately beneath the Fresnell display. These controlled the movements of the stereo cursor. One moved the cursor left and right (Y axis), another up and down (Z axis), and the third controlled the apparent fore/aft movement (X axis) of the cursor.

The stereoptic cursor consisted of a movable, white, .20 cm by .50 cm rectangle oriented vertically on the face of the screen. The cursor was electronically created and presented to the left and right TV screens with a variable delay, controlled by the subject's potentiometer, which served to delay the presentation of the cursor relative to the left and right screens. The amount of delay was measured by a Hewlett Packard,type 5245L digital counter using a type 5262A pulse width measurement module. With zero delay, that is, with both cursors presented at the same spot on both left and right monitor screens, the cursors were presented to the subject with no linear disparity thus producing the effect, when viewed on the Fresnell screen, of lying at the same distance as the Fresnell screen. Increasing the delay caused the left and right cursors to move apart on the two TV screens, the left cursor moving left and the right cursor moving right thus producing, when viewed stereoptically on the Fresnell screen, the effect of movement away from the viewer into the scene. Further details of the measurements and method of obtaining range using this system are discussed in Section 4.5.

Ambient lighting at the subject's station was provided by one 50 watt incandescent bulb mounted in a lamp to the left and behind the Fresnell display. Light intensity from this source was 1.94 lumens/sq.meter measured by a Tektronix model J-16 digital photometer at the position of the subject's head when viewing the Fresnell stereo system.

The experimenter's station contained a pair of repeat monitors showing the video inputs to the Fresnell system. Video control equipment included remote focus, zoom and iris controls for both cameras; a Tektronix type Rm-529 NTSC television waveform monitor which could be switched to monitor either of the two video images and the switching, signal injection/modification equipment described in Section 3.0 of Reference 1. The only signal modification performed in this experiment was the use of the 1.0 MHz bandwidth limitation option during one half of the experimental trials.

The target consisted of a 15.2 cm (6 in.) diameter, white, translucent globe lit from within by a 7.5 watt incandescent bulb. Without any other illumination, this globe radiated 1.94 lumens/sq. meter. During testing with the overhead lights on, it measured 5.49 lumens/sq. meter as measured by a type J-16 Tektronix digital photometer at a distance of 23 cm (9 in.). This globe was mounted on a tripod which was draped with non-reflective black cloth such that when the camera contrast was set for experimental purposes, only the globe appeared in the scene. In order to provide further contrast to the globe and to provide the subject more ease in locating the center of the globe, one-half inch wide, black, non-reflective tape was placed vertically and at 30 degrees from vertical across the face of the target globe as shown in Figure 4-1. The height of the tripod was adjusted so that the center of the globe was at the same height as the camera lens center point.

The video system consisted of a pair of COHU model 2000 television cameras fitted with COHU model 2305, 20 to 80 mm zoom lenses mounted on a base plate which allowed independent movement of the rear of the camera body about a vertical fulcrum point located immediately beneath the front of the vidicon tube face as shown in Figure 4-2. The distance between these two fulcrum points (camera baseline) was 12.1 cm (4.75 in.). All ranges and convergence point distances were measured from a point equidistant from each fulcrum point along the 12.1 cm (4.75 in.) baseline of the stereo camera pair as shown in Figure 4-2. Convergence distance was set at 152.4 cm (60 in.) by orienting the camera lines of sight so as to superimpose, on the Fresnell display, an object placed at this distance. Iris, zoom and focus functions were controlled from the experimenter's console. For this experiment, the zoom lenses were set to provide a 3:1 object size/display size ratio with the object being viewed at the 152.4 cm (60 in.) convergence point.

4.3 EXPERIMENTAL DESIGN

The independent variables manipulated during the testing were:

- Background Condition - Low complexity (Unlighted, black background)
  High complexity (Lighted background)
- Target Distance - Seven target distances: 152.4 cm (60 in.), 213.4 cm (84 in.), 274.3 cm (108 in.), 335.5 cm (132 in.), 396.2 cm (156 in.), 457.2 cm (180 in.), 518.2 cm (204 in.).
- Target Angle - Three target angles: at 0 degrees to camera pair centerline and off set 8 degrees to the left and right of this centerline.

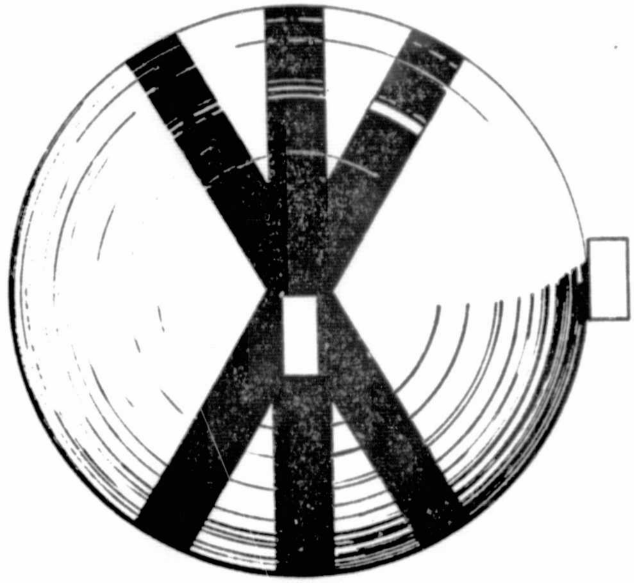


Figure 4-1: Diagram of Target Globe Showing Center and Right Side Cursor Alignment Approaches

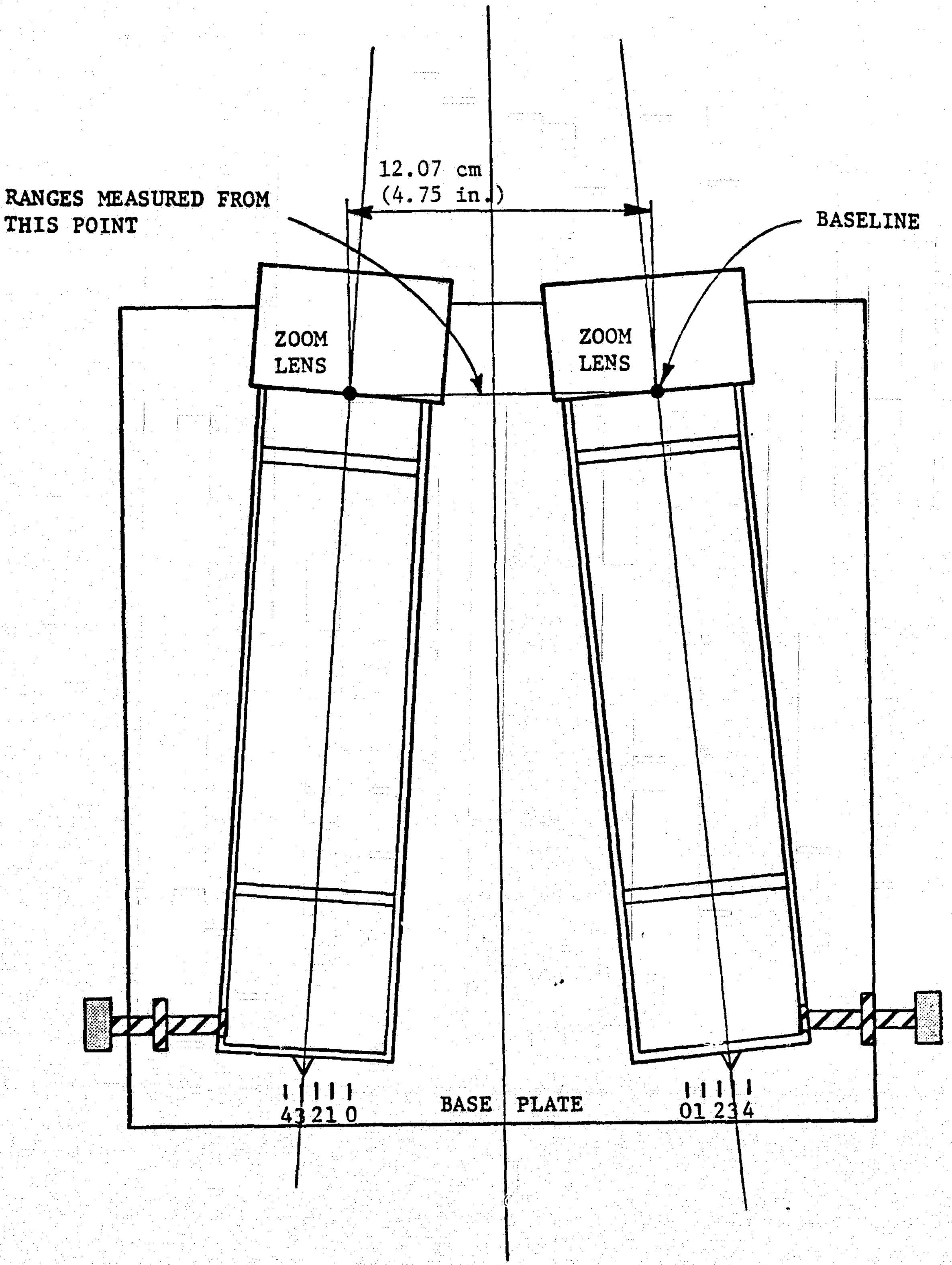


Figure 4-2: Overhead View of Stereo System and Base Plate

All experimental trial conditions were randomized with no replications for a total of 168 trials per subject, 840 trials total. The trials were blocked for presentation to the subjects to compensate for learning effects.

Dependent measures were:

- Response Time - The time from presentation of the scene until the subject had completed the ranging task.
- Accuracy of Cursor Alignment - The counter reading showing the number of microseconds delay between the left and right monitor cursors.

4.4 SUBJECTS

Initially five subjects were selected for testing, all of whom were given a standard Orthorator examination at the Marshall Space Flight Medical Center. However, it was discovered that not all subjects could achieve stereopsis of the stereo cursor and scene for this series. In order to obtain sufficient test subjects, attempts were made by a total of nine persons to perform the testing. Of these, four persons could not, after attempting the trials, consistently view the cursor with depth perception.

Of these four potential subjects who could not use the Fresnell stereo system, two were unable to achieve image fusion at very low levels of linear disparity. During the instruction phase, when they were initially shown a scene for practice using the system, they stated that they could see only two separate images. Then, with coaching from the experimenter, they attempted to converge the target globe image at the fourth target position. When they were unable to do this, the experimenter moved the globe forward to the convergence point where the subjects were experiencing no linear disparity. At this point both subjects saw a single image. While the subjects observed this image, the experimenter moved the target slowly away from the stereo camera pair in an attempt to gradually increase the disparity. In both cases the two subjects were unable to maintain fusion of the images. Both stated that at no time while observing the scene were they ever able to achieve stereopsis except at the convergence point distance. The other two subjects were both able to fuse, according to their statements, the target globe at target distance four, but when actual testing was commenced, they were unable to maintain image fusion consistently at that distance and almost never at the greater distance.

Normally in viewing objects at distances less than 3 to 6 meters away using unaided binocular vision, compulsory convergence and automatic accommodation occur simultaneously. That is, when looking at an object less than 6 meters away, the eyes are pointing inward at some angle so that both eyes point or converge on the object. Simultaneously, the lens curvature is changed to bring the object into sharpest focus. In other artificially created stereo imaging devices such as the stereoscope or the child's View-Master, the images are presented to the subject at maximum disparity, i.e., the interocular distance. The devices are equipped with lenses which change the focusing requirements such that the eye is caused to focus at infinity. Therefore, there is no conflict between the convergence and accommodation requirements. The same was true of the 3-D movies of the 1950's and 1960's. Although there were disparate images being presented to the viewer, the screen was usually located at distances greater than the 6 meters so that again the accommodation point was at or near infinity. In the Fresnell system, the screen is viewed from approximately 48.3 cm (19 in.) away from the the viewer, and, in order to maintain the scene in focus, the viewer must always focus both eyes at a distance of 48.26 cm (19 in.). However, when disparate images are presented, the viewer is required to converge his eyes at a point which would normally require focusing of the eye at much greater distances. This creates a conflict which, in order to be resolved, may require eye muscle skills which are not strongly developed in the majority of the general population and which are not predicted by the present visual acuity tests administered to the subjects. It is believed that this skill can be learned since one of the experimenters in this testing was originally unable to use the Fresnell system but has, with practice, become proficient in fusing disparate images.

This inability to converge disparate images is not unique to this experiment, and since the purpose of the experiment was to evaluate the ranging ability of the system, subjects who could not perform were eliminated from the testing until five were obtained who appeared to be able to perform the test task consistently.

4.5 PROCEDURE

All equipment was energized at least 30 minutes before each test session to ensure stabilization prior to calibration. Before each test session, all equipment settings, video signal levels and light levels as outlined in Section 4.2 were checked to ensure consistency throughout the testing sessions.

The subject was seated at the Fresnell console and a set of standard instructions, Appendix A, was read to him. These instructions explained the system and the experimental procedure and gave subjective instructions on the best way to use the system. As part of the instructions, he was shown a copy of a line drawing of the target globe with the two required cursor position alignments (Figure 4-1). In addition, he was shown a scene of the target object and cursor and allowed to practice alignment several times until it was felt that he clearly understood the operation of the stereo cursor. As soon as the subject indicated that he understood the operation of the system and the experimental requirements, his scene was terminated and the first experimental conditions were set up. The subject was then told whether to align the cursor to the right or at the center of the target globe, given a verbal "ready" by the experimenter and presented with the scene via the Fresnell. Presentation of the scene automatically started timing equipment. The subject then aligned the stereo cursor with the target, either to the right of the globe or at the center as instructed. When this had been accomplished, the subject terminated the scene using the hand held switch which also stopped the automatic timing equipment. The experimenter recorded the response time and the subject called out the counter reading from his console. The counter reading was used to determine the amount of alignment error.

The experimenter then selected another set of test parameters and repeated the process described above until the test sequence block was completed. To ensure absolute certainty that fatigue did not become a factor, no test session was longer than 45 minutes since subjects had used the system for periods up to one hour without reports of tiredness.

4.6 RESULTS

The dependent measuresobtained from this testing were response time and the sweep delay in micro-seconds between the left and right cursors. In order to obtain range errors, these delay values had to first be converted to range estimations.

Since linear disparity, D, can be calculated from the formula:

$D = BK/C - BK/R$, where B is the stereo camera baseline distance; K is a constant determined by the image size ratio; C, the convergence distance and

R, the actual viewing range, then the apparent range of the cursor, R, can be calculated providing the linear disparity between the two cursors is known. (Derivation and explanation of these and subsequent equations are contained in Ref. 2).

To determine linear disparity between the two cursors, they were set to a measured physical distance of 2.54 cm (1 in.) by displaying both on the same TV screen. At this value of linear disparity the sweep delay counter reading was 5.77 micro seconds. This yields a direct linear conversion of micro seconds delay into linear disparity of 2.27 micro sec/cm (5.77 micro sec/in.). These calculated values of disparity are listed in Table 4-1 along with average observed delay readings obtained by averaging the range settings of experienced visual laboratory personnel for each of the seven target ranges employed. From these data it can be seen that the calculated disparities do not deviate significantly from those empirically determined using experienced operators. The deviations osberved are most likely due to slight non-linearity of the television sweep signal of the two television monitors employed.

Since the delay can be found by the formula:

$X = 2.27$ micro sec/cm x D where X is the delay in micro seconds and D is the linear disparity in centimeters, then:

$$D = X/2.27 \text{ micro sec./cm}$$

and, substituting this value for D in the formula for linear disparity:

$$X/2.27 \text{ micro sec./cm} = BK/C - BK/R.$$

In the present laboratory setup, B is equal to 12.07 cm (4.75 in.), K is 50.8 and the convergence distance, C, is equal to 152.4 cm (60 in.) therefore:

$$BK = 241.3 \text{ and } BK/C = 1.583$$

Table 4-1: Image Size and Error Percentages for Stereo and Monoptic Ranging Aids

STEREO DATA			MONOPTIC DATA		
Target Range	Image Size (cm)	Movable Cursor % Error	Image Size (cm)	Fixed Cursor % Error	Movable Cursor % Error
60	5.08	4.9	.75	24.9	6.5
84	3.62	7.9	1.25	14.2	3.4
108	2.82	8.0	2.00	4.4	3.3
132	2.31	12.3	3.50	5.3	1.8
156	1.95	18.1	5.00	3.1	1.3
180	1.69	26.4	6.50	4.6	1.2
204	1.49	27.6	8.00	2.4	1.4
			9.50	2.3	1.2
			11.00	1.3	1.1

and, solving for R in the equation D = BK/C - BK/R and substituting into this formula the values of BK and BK/R yields:

R (estimated) = 241.3 x 2.27/(9.1339 - X) (X less than 9.1339)

where R is the range estimate and X is the counter reading in micro seconds. Using this formula, a computer program was written to convert all reported micro second delay readings into range estimations. Using these estimates, a second computer program was written which converted these range estimates into per cent error values using the following formula:

Per Cent Error = (Range Estimate - Actual Range)/Actual Range.

The results of a six way analysis of variance of these per cent error values is shown in Table 4-2. The error as a function of target range was significant ($\alpha<.01$) and is plotted in Figure 4-3. The only other factor found to be significant ($\alpha<.05$) by this analysis was the error percentage as a result of interaction between target range and the viewing angle relative to the centerline of the stereo camera pair. These interactions are shown in Figure 4-4.

In order to effectively compare the error percentages found in this testing with those found in range estimation testing using monoptic ranging aides, actual ranges could not be used. In the B-3 test series reported in Reference 3, using monoptic reticles and a movable cursor to estimate range, the range estimation had been dependent on target image size and the range error derived from error in the subject's estimation of the image size. Since the presented image size, I, is equal to KT/R, where K is a systems constant dependent on the image to physical size ratio; T, the actual size of the object being viewed; and, R, the range to the target, then the viewed image size of the globe used in this testing can be derived at each target range. These conversions were completed for each target range and are listed, along with the image

Table 4-2: Analysis of Variance, Per Cent Range Error

SOURCE	DF	SS	MS	F RATIO
MEAN	1	15.18656	15.18656	130.039
BACKGROUND (B)	1	.04344	.04344	.609
DISTANCE (D)	6	4.84157	.80692	4.909 **
CURSOR POSITION (C)	1	.11480	.11480	2.528
ANGLE (A)	2	.51416	.25708	7.483
BANDWIDTH (W)	1	.56735	.56735	9.463
SUBJECTS (S)	3	.35036	.11678	
BD	6	.51526	.08588	1.901
BC	1	.00541	.00541	.223
DC	6	.30945	.05157	.882
BA	2	.27229	.13615	1.124 *
DA	12	1.07062	.08922	1.891
CA	2	.30005	.15003	1.395
BW	1	.16999	.16999	4.349
DW	6	.43416	.07236	2.753
CW	1	.03639	.03639	.707
AW	2	.26229	.13115	3.907
BS	3	.19869	.06623	
DS	18	2.95887	.16438	
CS	3	.13623	.04541	
AS	6	.20764	.03460	
WS	3	.17987	.05595	
BDC	6	.10818	.01802	.453
BDA	12	.63318	.05277	1.567
BCA	2	.14843	.07422	1.863
DCA	12	.48836	.04069	1.011
BDW	6	.10070	.01784	.516
BCW	1	.01584	.01584	9.075
DCW	6	.09296	.01549	.381
BAW	2	.14007	.07004	.956
DAW	12	1.17615	.09801	1.858
CAW	2	.06210	.03105	2.161
BDS	18	.81317	.04518	
BCS	3	.72914	.02431	
DCS	18	1.05280	.05849	
BAS	6	.72669	.12111	
DAS	36	1.69880	.04719	
CAS	6	.64530	.10755	
BWS	3	.11721	.03907	
DWS	18	.47312	.02628	
CWS	3	.15450	.05148	
AWS	6	.20142	.03357	
BDCA	12	.77539	.06462	1.999
BDCW	6	.15413	.02569	.676
BDAW	12	.92832	.07736	1.574

Table 4-2: Analysis of Variance, Per Cent Range Error (Continued)

SOURCE	DF	SS	MS	F RATIO
BCAW	2	.02248	.01124	.133
DCAW	12	.83328	.06944	1.189
BDCS	18	.71710	.03984	
BDAS	36	1.21191	.03366	
BCAS	6	.23900	.03983	
DCAS	36	1.45000	.04027	
BDWS	18	.58542	.03252	
BCWS	3	.00523	.00175	
DCWS	18	.73285	.04071	
BAWS	6	.43878	.07313	
DAWS	36	1.89948	.05276	
CAWS	6	.08619	.01437	
BDCAW	12	.53278	.04439	1.1646
BDCAS	36	1.16370	.03233	
BDCWS	18	.68360	.03800	
BDAWS	36	1.76917	.04914	
BCAWS	6	.50843	.08473	
DCAWS	36	2.10218	.05840	
BDCAWS	36	1.37238	.03812	

** P<.01
* P<.05

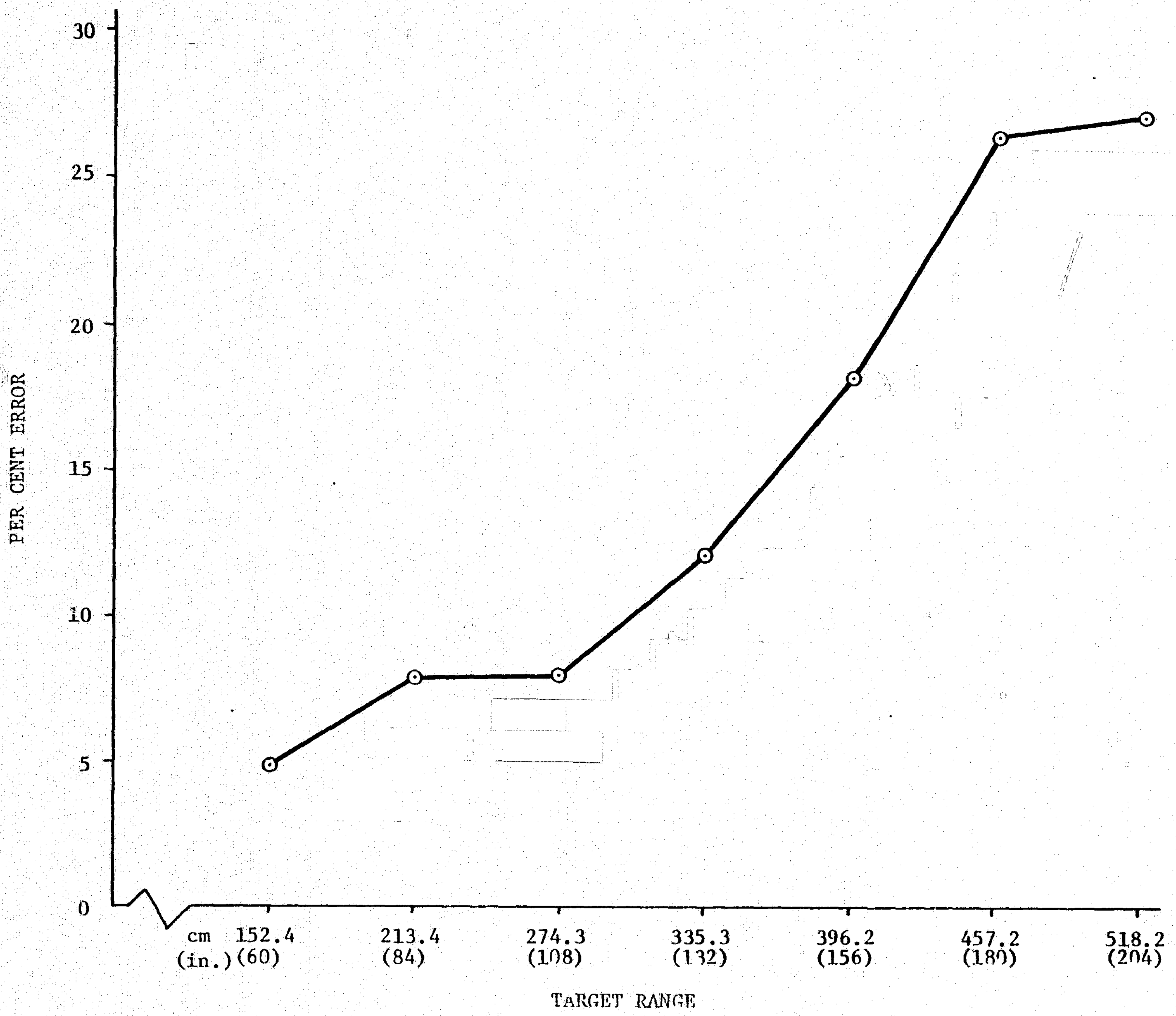


Figure 4-2. Per Cent Range Estimation Errors as a Function of Target Range

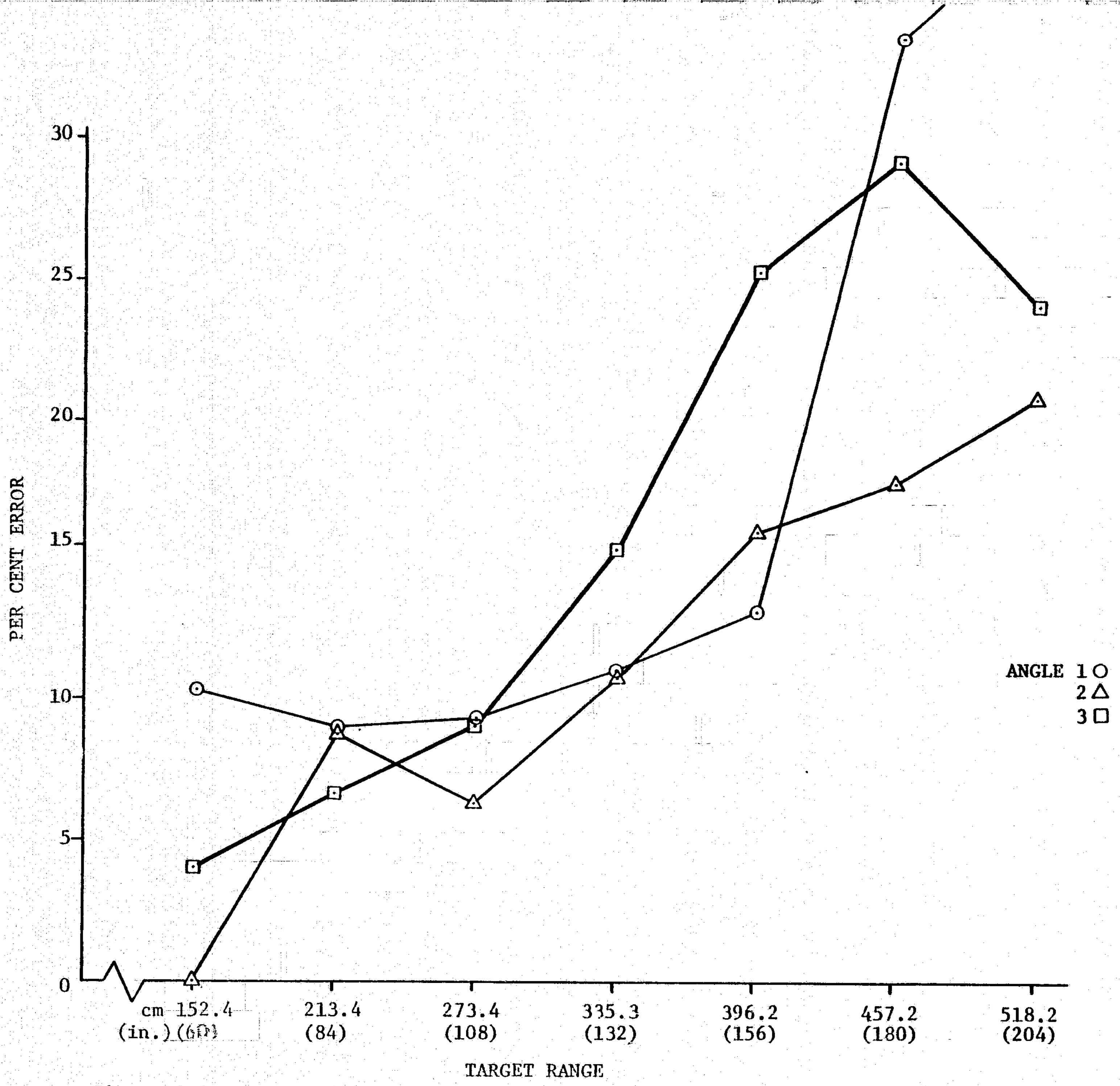


Figure 4-4: Per Cent Range Estimation Error by Target Range and Viewing Angle

sizes from the B-3 test series, in Table 4.2.

Since, for the present stereo camera setup, K is equal to 50.8 and the globe diameter (T) is 15.24 cm (6 in.), then KT is equal to 304.8 cm which, when divided by each target range, yields the image size of the globe as presented on the Fresnell display. The percentage range errors for movable cursor, fixed reticle and stereo cursor range estimations are plotted as a function of image size in Figure 4-5.

As can be seen from Figure 4-5, the ranging ability of the stereo cursor system results in a higher overall error percentage than either of the two monoptic systems previously evaluated. It should be noted, however, that range estimation using monoptic aides requires that the size of some object at the ranging distance be known while the stereo cursor system can be utilized to estimate range to any object in the viewing field.

The response time data were also subjected to analysis of variance, the results of which are shown in Table 4-3. Three of the independent variables sufficiently influenced the results to be significant ($\alpha<.05$). These were target range, viewing angle and bandwidth limitation. Three and four way interactions involving viewing angle and bandwidth limitation were also significant ($\alpha<.05$). However, these are continuations of the original single influences and are not discussed separately.

Response time as a function of target range is shown in Figure 4-6 which shows a much greater time requirement at the two nearest target ranges, then a slow, near linear increase to the greatest target range. Since this task required alignment of the cursor with specific target areas, this could have been the result of the subject having to spend more time in moving the cursor in the X - Y plane since the target image size increases as the inverse of the

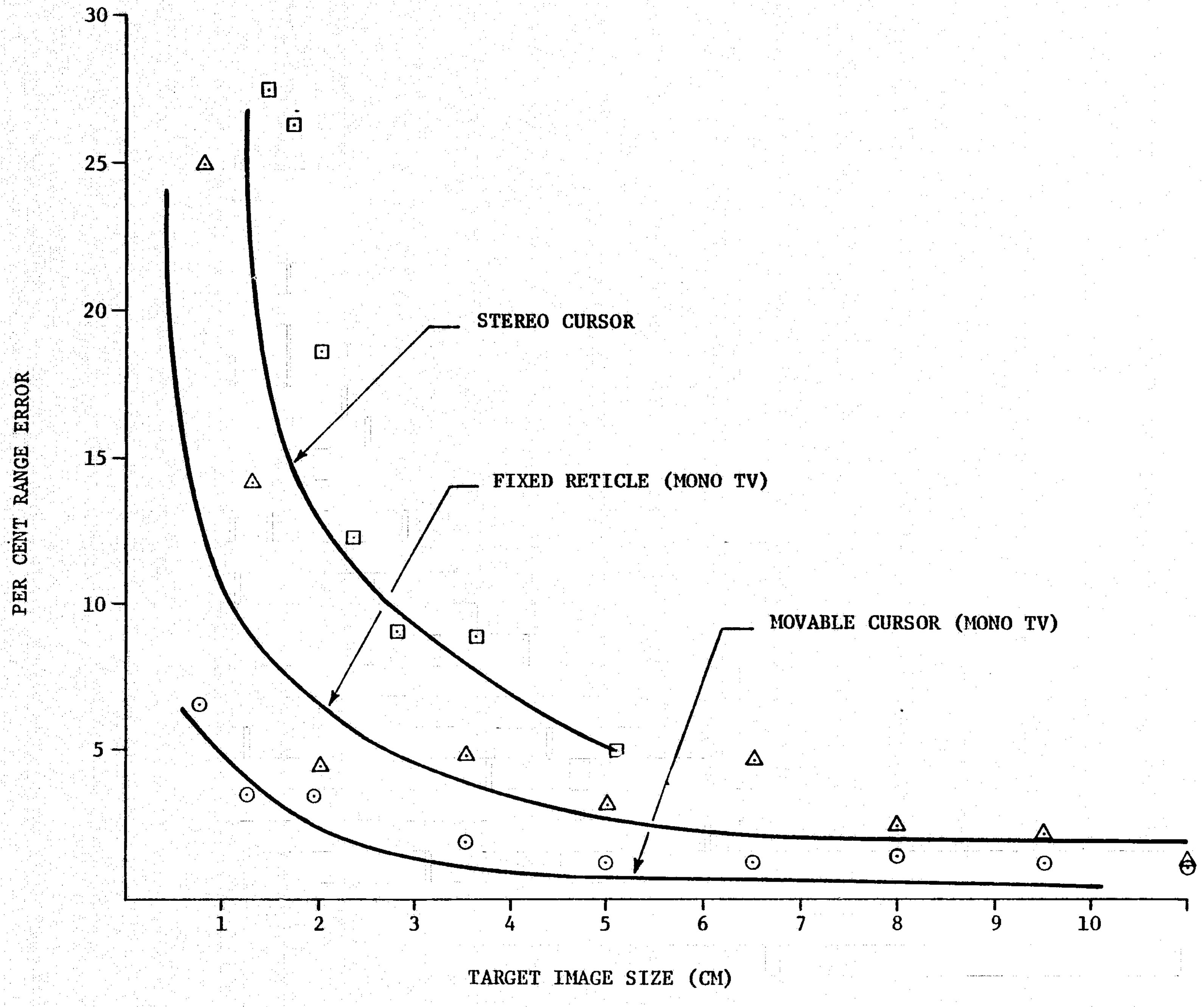


Figure 4-5: Per Cent Range Error as a Function of Image Size for Fixed Reticle, Monoptic and Stereo Cursor Ranging Aids

Table 4-3: Analysis of Variance, Response Time

SOURCE	DF	SS	MS	F RATIO
MEAN	1	214184.6	214184.6	29.310
BACKGROUND (B)	1	40.17203	40.17203	3.872
DISTANCE (D)	6	2912.010	485.3450	2.750 *
CURSOR POSITION (C)	1	6.785908	6.785908	.048
ANGLE (A)	2	822.5337	411.2669	8.000 *
BANDWIDTH (W)	1	73.98859	73.98859	10.341 *
SUBJECTS (S)	4	29230.08	7307.520	
BD	6	194.2897	32.38101	1.332
BC	1	9.621132	9.621132	.845
DC	6	528.0337	88.00812	1.700
BA	2	38.35172	19.17586	.415
DA	12	494.5950	41.21500	1.468
CA	2	2.088755	1.044377	.027
BW	1	39.56265	39.56265	.499
DW	6	249.2116	41.53531	1.062
CW	1	39.47672	39.47672	2.670
AW	2	52.05484	26.02742	1.481
BS	4	41.50015	10.37504	
DS	24	4235.270	176.4694	
CS	4	571.9087	142.9772	
AS	2	411.4075	51.42594	
WS	4	28.61824	7.154560	
BDC	6	140.8053	23.46785	.318
BDA	12	524.8775	43.74039	1.433
BCA	2	40.09000	20.04500	.359
DCA	12	725.3462	60.44547	1.831
BDW	6	227.9069	37.98453	1.362
BCW	1	24.10555	24.10555	2.030
DCW	6	227.1022	37.84976	.859
BAW	2	104.0472	52.02359	4.640 *
DAW	12	1163.567	96.96515	2.240 *
CAW	2	372.6731	186.3366	5.575 *
BDS	24	583.3775	24.30769	
BCS	4	45.55875	11.38969	
DCS	24	1245.755	51.90640	
BAS	8	370.0012	46.25015	
DAS	48	1347.505	28.07234	
CAS	8	305.5637	38.19547	
BWS	4	316.9544	79.23859	
DWS	24	938.2837	39.09390	
CWS	4	59.14859	14.78715	
AWS	8	140.6334	17.57918	
BDCA	12	754.6275	62.88492	1.910
BDCW	6	266.7356	44.45523	.916
BDAW	12	419.8762	34.99039	.590
BCAW	2	82.66047	41.33023	.448

Table 4-3: Analysis of Variance, Response Time (Continued)

SOURCE	DF	SS	MS	F RATIO
DCAW	12	728.5337	60.71109	2.270 *
BDCS	24	1771.005	73.78937	
BDAS	48	1465.442	30.53035	
BCAS	8	446.9075	55.86344	
DCAS	48	1584.817	33.01773	
BDWS	24	669.1587	27.88191	
BCWS	4	47.49234	11.87309	
DCWS	24	1057.942	44.08023	
BAWS	8	89.69953	11.21244	
DAWS	48	2077.885	43.28922	
CAWS	8	267.3919	33.42398	
BDCAW	12	346.2669	28.85555	.5905
BDCAS	48	1580.442	32.92594	
BDCWS	24	1164.942	48.53922	
BDAWS	48	2848.010	59.33414	
BCAWS	8	737.5025	92.18781	
DCAWS	48	1283.567	26.74129	
BDCAWS	48	2345.635	48.86734	

** P<.01
* P<.05

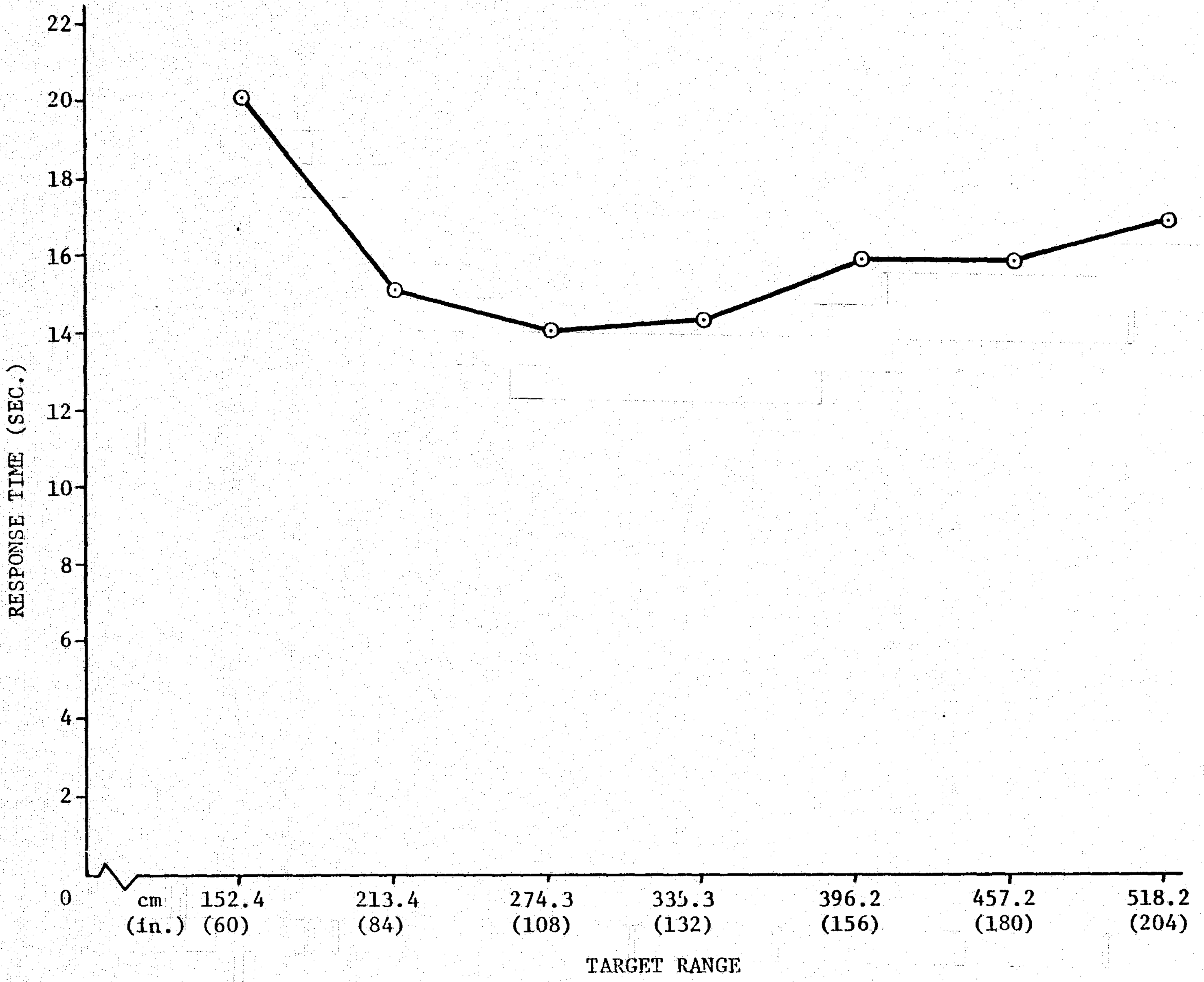


Figure 4-6: Response Time as a Function of Target Range

target range. If this were the case, one would expect the response time to decrease as a linear inverse of the target range which it does not; therefore, another explanation although more complex is considered plausible.

In the stereo system, although the disparity increases as a function of range, the change in linear disparity over a given change in range decreases with increasing range. This results in much stronger stereo cues at those points immediately at and slightly beyond the convergence distance. For this reason, the subject would use more time in performing the more critical alignment possible due to the presence of the more obvious stereo cues available to him at the near target positions. This would account for the decrease in task time up to target position three. At this point the change in disparity factor becomes negligible; however, the difficulty of achieving stereopsis would then become a factor (Reference 1). Due to this difficulty of achieving stereopsis, response time would increase at an almost linear rate.

The response time as a function of target angle is shown in Figure 4-7. Since each presentation of the target to either side of the display requires additional manipulation of the Y coordinate axis control, this additional time requirement could have been predicted. If one considers the time required to traverse the entire width of the screen to be equal to some arbitrary unit, S, then since one-third of the trials require placement of the cursor at the left side of the screen, one-third to the right and one-third to the left of center, then for all center target alignments an approximate equation of required movement could be written:

$$.5\ S + .5\ S + 0\ S = 1.0\ S$$

and

$1.0\ S + .5\ S + 0\ S = 1.5\ S$ for target alignments to either side of

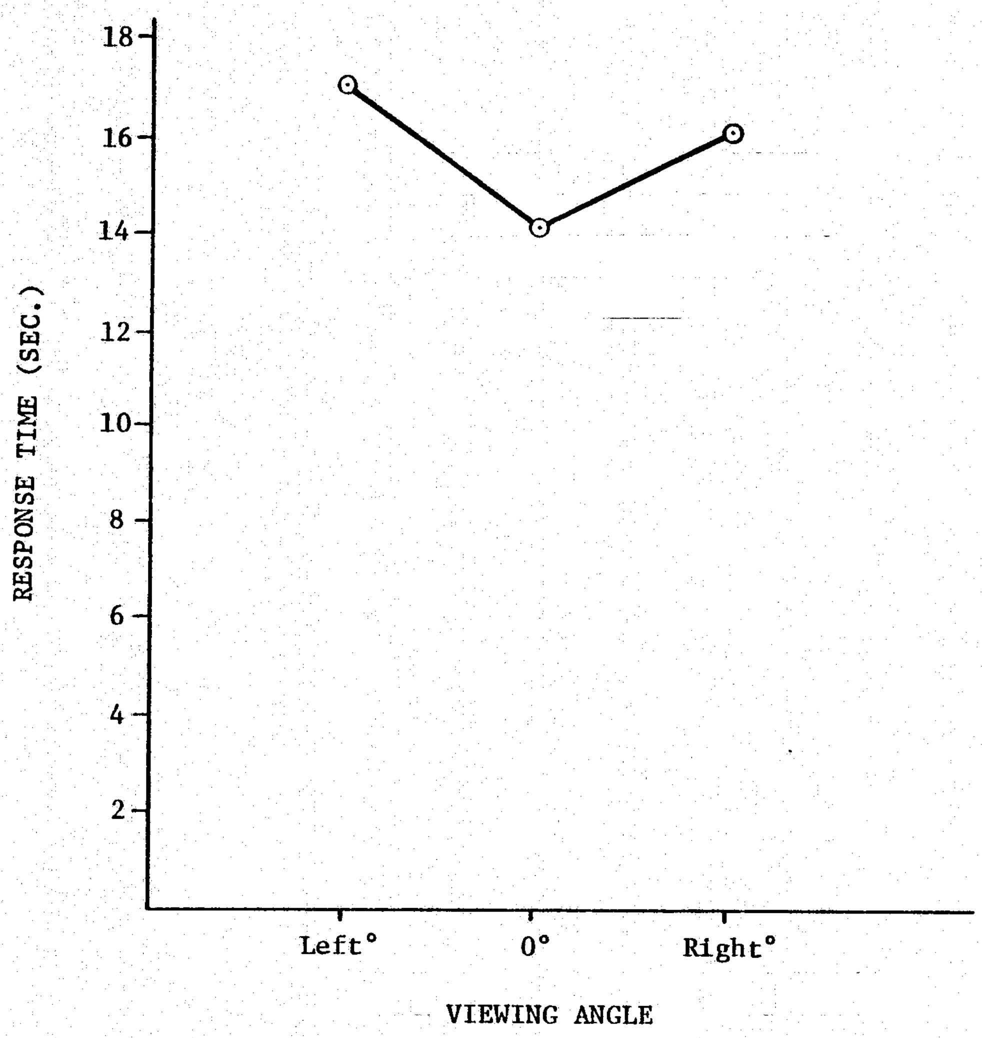


Figure 4-7: Response Time as a Function of Viewing Angle

the center, therefore it would be expected that task time would increase for targets to either side of the center.

Bandwidth limitation on the stereo viewing system produces a slightly less sharp edge definition on the target making it more difficult to precisely align the stereo cursor thus resulting in more time being required to perform the task. This did not, however, significantly affect the accuracy of the range estimate. The response time differences are shown in Figure 4-8.

The most significant result of this testing was the overall time requirement for the task performance compared to the task time requirements for range estimation using monoptic ranging aides. In the testing using fixed reticles, the overall average response time was 4.06 seconds; with movable monoptic cursor, 5.62 seconds; and with the present stereo system the overall mean was 15.97 seconds, over three times the time required for the monoptic modes. Using a fixed reticle, the subject was required to simply observe the target overlaid with the concentric reticles and estimate the image size by counting the reticles. In the monoptic range estimation using a movable cursor, the subject again observed the scene and moved a single axis cursor to the right side of the image. The present testing required manipulation of a cursor in both X and Y planes and along a Z axis while maintaining fusion of disparate images. Half of the trials required ranging to the center of the target and one half to the right side. In addition, the targets were presented at three different positions on the screen. Considering the additional complexity of the stereo cursor testing, this time increase does not appear to be unreasonable.

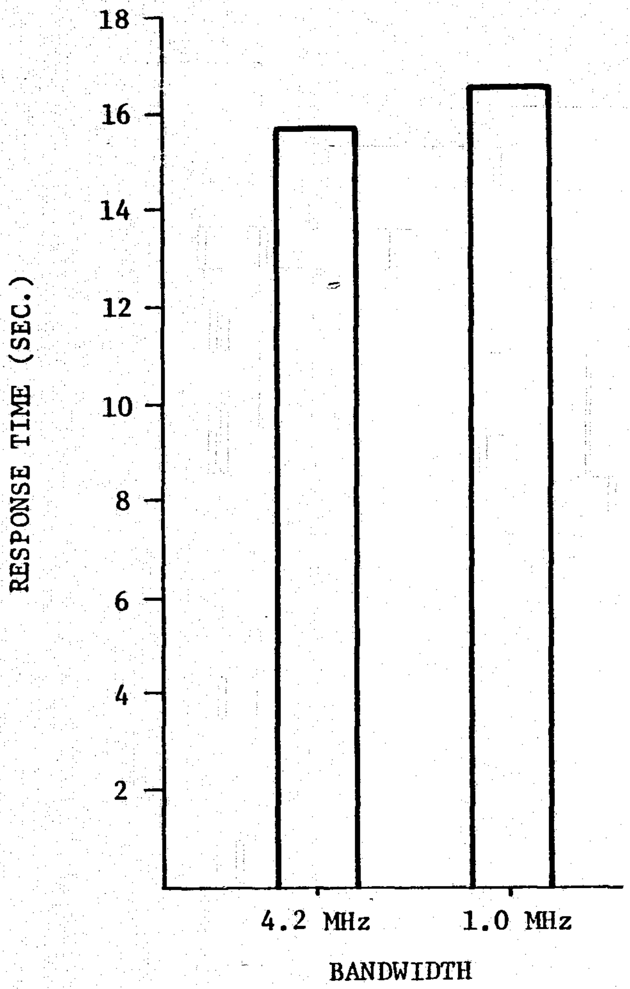


Figure 4-8: Response Time Under Conditions of Bandwidth Limitation

4.7 RECOMMENDATIONS

By observing Figure 4-4, it can be seen that the angle of viewing had a strong effect on the ranging ability ($\alpha < .05$). However, if one uses only the data from angle 2, target centered in the field of view, the ranging ability of the stereo system near to and at the convergence point appears to be nearly equal to that shown by the monoptic aids. At the convergence point, the error is equal to less than one per cent (1%), which is less than either of the monoptic systems. This could result from the fact that the Fresnell system provides the strongest changes in stereo cues (linear disparity) for a given change in range near to and at the convergence point.

Due to this fact and the difficulty of using the system when significant [greater than 1.5 cm (.6 in.)] linear disparity is experienced, it is believed that viewing using this system should be limited to areas at or slightly beyond the convergence distance. If this requirement were to be met, the stereo camera pair would have to be fitted with remote convergence mechanisms which would allow the operator to change the convergence distance when viewing at different ranges. This would result in lower levels of conflict between convergence and accommodation requirements since with variable convergence, the disparities occurring would be within the range of almost any operator's capability to fuse them. In addition, ranging would be performed at the points of greatest change in disparity for a given change in range which would provide the cues necessary for accurate ranging.

If remote convergence capabilities are included in a future system, it is believed that more accurate ranging could be performed by using the camera convergence angles to determine the range to an object. This could be accomplished by temporarily rotating the Fresnell screen 90 degrees so that both stereo camera views were presented to the operator as two separate disparite images. Thus, by simply superimposing one object over the other using the convergence capability, similar to a split image rangefinder, the range to that object could be obtained.

This method would again result in freedom from having to range only to known object sizes, as is necessary with monoptic aids and could result in greater accuracy than that of the systems tested.

5.0 COLOR DISCRIMINATION - PHASE 2 TEST

5.1 OBJECTIVE

The objective of this experiment was to determine the human operator's ability to discriminate between paired color samples presented via a color television system.

5.2 APPARATUS AND PROCEDURE

In previous visual system experiments, it was determined that from a sample of 80 Munsell color chips, 15 were maximally discriminable (Reference 1) and might be useful in color coding visual information to a human operator. These 15 color samples were arbitrarily numbered with the number corresponding to the following Munsell notations:

Chip Number	Munsell Notation
1	2.5 R 4/14
2	3.75 R 4/14
3	8.75 R MAX
4	6.25 YR MAX
5	8.75 YR MAX
6	2.5 Y 8/16
7	2.5 GY 7/12
8	7.5 GY 6/12
9	7.5 G 5/10
10	7.5 G 4/10
11	7.5 BG 4/8
12	3.75 PB 4/12
13	10 P 5/12
14	10 P 4/12
15	5 RP 3/10

Two sets of 6.35 cm (2.5 in.) by 7.6 cm (3 in.) Munsell color chips of the fifteen colors were obtained by cutting the standard 7.6 cm by 12.7 cm (3 in. by 5 in.) Munsell color chip in half. Each set was then mounted on a

55.8 cm (22 in.) diameter wheel, and both wheels were mounted in a frame to allow rotation of the wheels. The face of the frame provided masking of all of the color chips, except a particular one chosen for display. An aperture with a diameter of 5.08 cm (2 in.) was provided for both wheels with the two apertures separated by 5.08 cm (2 in.) as shown in Figure 3-2. The color chip display frame was illuminated to a level of 969 lumens/sq. meter by two Colortran 104-311 studio lights. The two lights were directed at the display frame so no reflectance was obtained from the color chips. The task scene was viewed by a Sony DXC-5000B color television camera. Other apparatus included a Tektronix 1420 NTSC vectorscope and NTSC color bar generator to assure appropriate phase relationships to the subject's monitor. A Tektronix model RM 129 waveform monitor was used to monitor correct brightness and contrast of the video signal. Cabling, power equipment, a Sony CG-101 synch generator and associated components were located inside the test area. At the subject's station, the ambient light level was set at 2.15 lumens/sq. meter measured at the TV monitor face.

The task scene was displayed at the subject's station using a Sony Trinitron DVM-1200. 30.5 cm (12 in. diagonal) color TV monitor. The subject viewed the scene while seated at a display console with the subject's eye to monitor distance approximately 71 cm (28 in.) and the viewing attitude declined 15° form the horizontal.

The subject was read a set of standard instructions prior to testing (Appendix B) and asked if he understood the task to be performed. Following the instructions, the experimenter left the subject's station and proceeded to set up the first experimental trial.

At the beginning of a test trial, the subject's monitor was blank. The experimenter selected a color pair from a randomized list of all experimental combinations. The pair was then presented to the subject who made a determination as to whether or not the chips were the same color. Each color was paired with itself as well as other selected colors. As soon as the subject made his determination, he depressed a handheld switch which terminated his display and stopped the timing equipment at the experimenter's station. He then reported his determination which was recorded by the experimenter with the response time. The experimenter set up the next color pair and repeated the sequence until all 270 test trials had been completed. The confusion matrix from which the trials were derived is given in Table 5-1.

5.3 EXPERIMENTAL DESIGN

The relative probabilities of confusing different colors among a total of 80 samples have been reported in Reference 1. By preparing an 80 x 80 element confusion matrix using these 80 color identifiers as the X and Y coordinates, it was possible to determine those color samples which yielded the least probability of confusion with others. This confusion matrix is shown for color chips 1 through 20 of the original set in Table 5-1. By looking across the top row for chip number 1, it can be seen that the probability of it being perceived as "identical" by a subject when paired with itself is equal to 1; with color chip number 6 the probability drops to .122 and as the color chips change in hue as one travels to the right across the row, it drops to .020 at color chip 16 and to zero at chip 17.

The 15 chips under consideration in this experiment were obtained by selecting those colors which had the least amount of vertical overlap in the

COLOR CHIP NUMBERS

COLOR CHIP NUMBERS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	061	143	306	388	122	143	143	143	122	143	041	020	020						
2		1	184	306	245	367	429	429	429	367	429	122	061	061						
3			1	306	245	367	429	429	429	429	122	061	061							
4				1	531	612	714	714	714	612	714	204	102	102						
5					1	490	571	571	571	490	571	163	082	082						
6						1	857	857	857	755	857	347	245	245	143	143	143	143	122	102
7							1	1	1	857	1	286	143	143						
8								1	1	857	1	143	143							
9									1	857	1	286	143	143						
10										1	857	1	286	143	143					
11											1	286	143	143						
12												1	653	653	714	714	714	714	612	510
13													1	714	857	857	857	857	735	612
14														1	857	857	857	857	735	612
15															1	1	1	1	857	714
16																1	1	1	857	714
17																	1	1	857	724
18																		1	857	714
19																			1	653
20																				1

Table 5-1: Confusion Matrix Showing Probability of Confusing Sample Chips 1 through 20 of the Original 80 Chip Sample

probability listing; that is, their probabilities of being confused were closest to being zero. To provide additional color samples, those five colors immediately to the right of each of the 15 chosen were also included in the sample set. This resulted in 6 x 15, or 90 color pairs. Each pair was presented to the subject three times for a total of 270 trials for each of five subjects. All trials were presented in random order.

The subjects were all males ranging in age from 19 to 46 years in age. Each was screened for normal vision using the standard orthorator visual tests.

Dependent measures during the tests included:

- Response accuracy
- Response time.

The control variables were set as follows:

- Camera to task board distance - 121.92 cm (4 ft)
- Illumination at task site - 969 lumens/sq. meter
- Transmission conditions - analog signal, 4.5 MHz
  >32 db S/N ratio
- Contrast and brightness at subject's monitor -
  Signal set at Max 80 NTSC units Max video background level and ≥15 units color chip. The subject's monitor was initially set, measured and maintained throughout all trials at these input conditions.
- Color phase (hue) to subject's monitor - initially set using color bar pattern.
  Checked before and after each test session.
  White purity calibration procedure completed prior to each test session.
- Light level at subject's monitor - 2.15 lumens/sq. meter
- Subject to monitor distance and attitude - 71.1 cm (28 in.) at 15° decline from horizontal.
- Field of View - set to accommodate the two chips such that chips are presented with a 1.5:1 ratio.

The Visual System Evaluation Laboratory has controlled access during testing to eliminate interruptions, and the subject is isolated in a comfortable station to minimize confounding environmental effects.

5.4 RESULTS

After administering the complete test sequence of 155 color combinations to four subjects, errors had occurred in only eight color combinations. Seven of these error types were the result of perceiving the same color pair as being different. In only one combination involving pairing color chips 1 and 2 were different colors mistaken for the same color. These combination error percentages are shown in Table 5-2; all other possible combinations were correctly discriminated.

It was suspected that the apparent color difference between chips could be due to a phase shift in the 3.58 MHz sub-carrier since the colors were being presented side by side along the horizontal plane of the monitor. Therefore, a second test sequence was run with the chips vertically oriented, one over the other. The combinations tested were those which had been previously mis-identified in the first test. The error percentages from this test are shown in Table 5-3. All other possible combinations were correctly identified. The results from the vertically oriented chips are similar to those when the chips were oriented horizontally. During this retest portion, one subject stated that he was identifying the chips as different due primarily to a difference in brightness and not in hue. A check of the video waveform showed that there was a decreasing difference in brightness level from top to bottom of the video signal of approximately three NTSC units between the two chips. This was compensated for by adjusting the light levels such that there was no measurable differences between chips, with the result that no errors were made with the vertical orientation except in the case of chips 1 and 2, and 2 and 2.

An attempt was made to determine if the chips presented via color television viewing could be absolutely identified when presented one at a time.

Table 5-2: Per Cent Incorrect Responses for Paired Color Samples, Horizontally Oriented

CHIP COMBINATION NUMBERS		PER CENT INCORRECT RESPONSE
1	2	41
2	2	22
4	4	50
6	6	64
7	7	30
8	8	33
9	9	38

Table 5-3: Per Cent Incorrect Responses for Paired Color Samples, Vertically Oriented

CHIP COMBINATION NUMBERS		PER CENT ERROR
1	2	83
2	2	40
4	4	44
6	6	33
7	7	43
8	8	71
9	9	50

This was accomplished by having the subject observe the comparison chip by direct viewing as the test chip was being presented on the TV monitor. This could not be successfully accomplished since the color of the chip as seen on color television was significantly changed in hue from what was perceived in direct viewing. Attempts to compensate for this change, that is, to equalize the color for one part of the spectrum, resulted in further color shift in other portions of the spectrum.

The same color comparison test using the color pairs which had been previously mis-identified was performed in the MSFC Communication Center television studios. The camera used was an RCA TA-44 studio camera which utilized three plubicon tubes to generate the green, red and blue colors signals. This camera was directly connected via a console switcher to a Tektronix TM-462B color television monitor. The scene was evenly lit and the trial sequence was presented to three subjects. Under these conditions all subjects could easily identify the chips as the same or different with the exception of chips 1 and 2 which continued to be identified as alike in approximately 50 per cent of the trials administered.

From these tests, it appears that there are three major effects on the ability of the subject to discriminate colors using color television systems. These are:

1. Phase shift of the 3.58 MHz subcarrier as the horizontal sweep traverses the monitor screen.
2. Small signal level differences between colors due to unequal sensing response of the camera or due to unequal scene lighting.
3. The fact that the colors are not faithfully reproduced by the television system in the same tones as are seen with direct viewing.

All three of the above factors are dependent on the quality of the video equipment and lighting. From this testing, however, it appears that when using an inexpensive system such as the Sony camera and monitor utilized for this test, there are 14 colors which can be identified without error provided they appear at near equal illumination. These 14 are the original set minus color chip 2, 3.75 R 4/14. The color shift due to subcarrier instability with these colors does not appear to be sufficiently large enough to cause confusion of these 14 colors. It is, however, sufficiently large enough to cause the colors to appear dissimilar, in fact, when the same colors are compared.

If absolute identification of a certain color is necessary, it cannot be accomplished via color comparison samples which are directly viewed or previously learned. It would be possible, however, if the sample could be placed in the same physical area as the color to be identified such that they both were subjected to the same illumination and hue changes caused by the characteristics of the video viewing system.

6.0 STEREOPTIC TEST S-2

A Comparison Between Solid State and Vidicon Systems

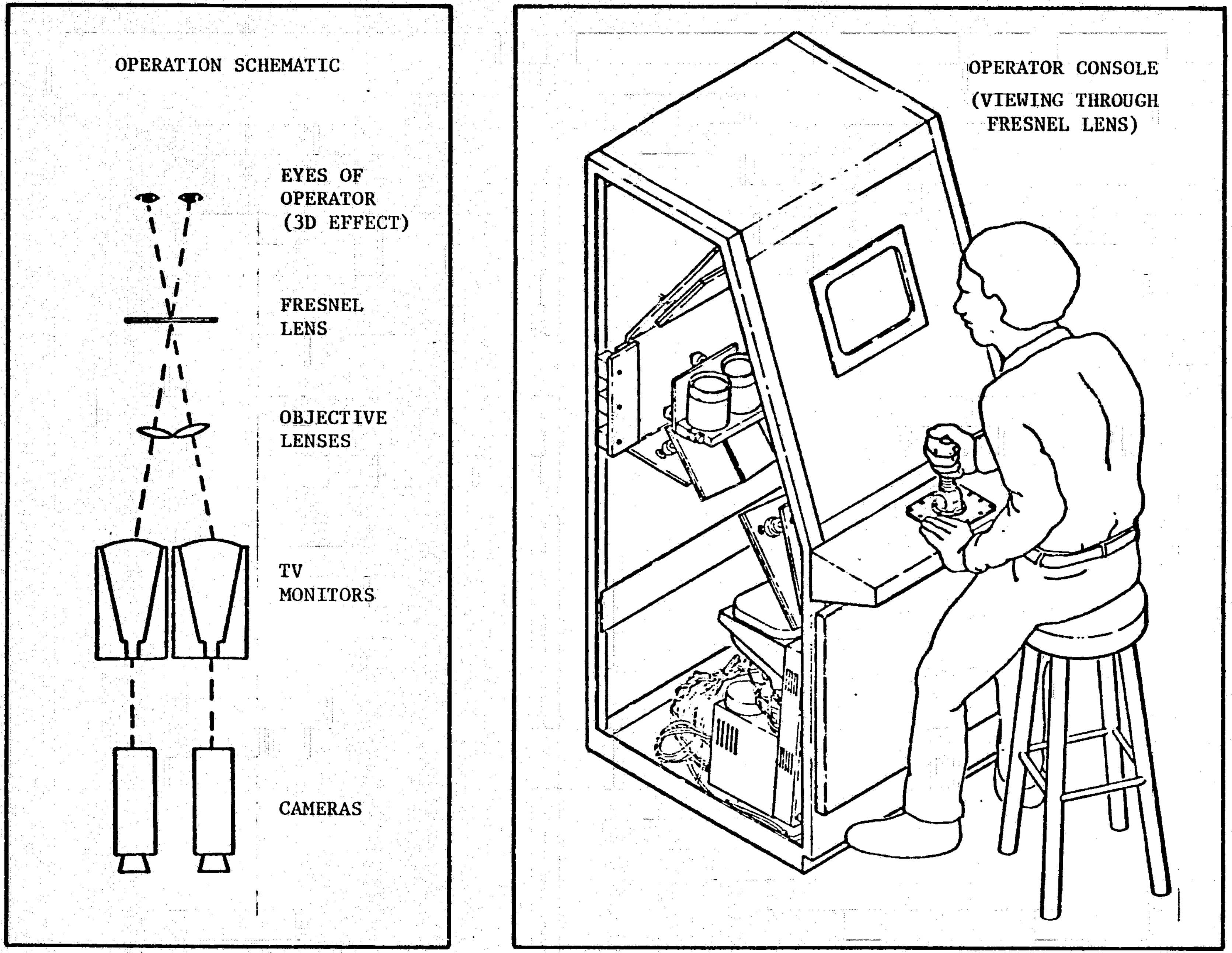
6.1 OBJECTIVE

The overall objective of this experiment was to evaluate human operator performance in the alignment of three dimensional targets using televised visual feedback.

6.2 PROCEDURE AND APPARATUS

This experiment was conducted in the Marshall Space Flight Center's Visual System Evaluation Laboratory by Essex researchers. The Fresnell stereoptic viewing system, shown in Figure 6-1 and described in detail in References 1 and 2, was utilized for operator visual feedback of the task site. As sensors, the Fresnell system provides for two television cameras mounted as an integrated pair with a center to center lens baseline of 12.1 cm (4.75 in.). This experiment was conducted using two types of camera pairs. One camera pair consisted of General Electric solid state television cameras (prototype) with 22 mm fixed lenses. The other camera pair was of two COHU vidicon cameras (Model 2000) which were fitted with 20 mm to 80 mm zoom lenses. Each camera pair was separately integrated with the Fresnell stereoptic viewing system for purposes of this experiment which allowed comparison of performance between camera systems.

Two white cylindrical targets (7.6 cm diameter and 10.2 cm length) with an albedo of .7 were used in this experiment. One target was mounted on a target motion generator (Figure 6.2) which permitted target movement fore and aft along the viewing axis of the camera pair. The fore and aft motion was controlled from the subject's viewing station for purposes of target alignment


OPERATION SCHEMATIC

OPERATOR CONSOLE (VIEWING THROUGH FRESNEL LENS)

Figure 6-1: STEREO TV SYSTEMS -- LABORATORY MODEL

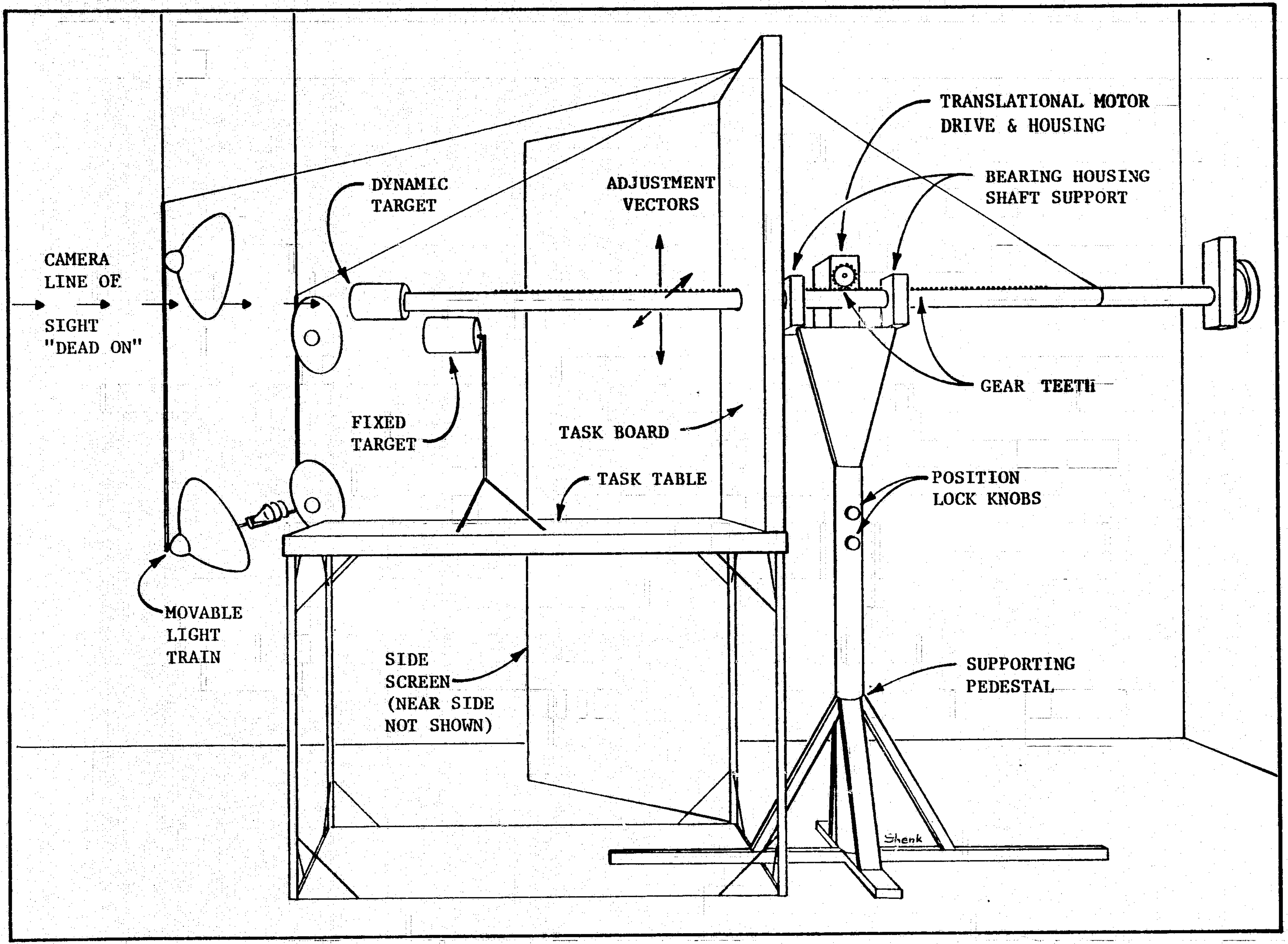


Figure 6-2: TMG APPARATUS

and from the experimenter's station for purposes of resetting the start position for each trial. The direction of target movement was controlled by an Electro-Craft Motomatic Speed Control (Model E-550-M) motor control unit. While this unit provides for varying rates of motion, for the purposes of this experiment the rate was fixed at 11 cm per second for all trials. The maximum travel train was limited to 71 cm. The second cylinder was mounted on a tripod which permitted target alignment in the horizontal plane.

Task site lighting was provided by two Colortran studio lights (Model 104-311), which were located on either side of the stereo camera pair. Trial timing and video presentation for the subject was done utilizing a two channel switching and signal injection/modification system which provided discrete ON/OFF functions and trial timing and described in detail in Reference 3.

All laboratory equipment was activated at least 30 minutes prior to any testing for the purpose of allowing the systems to stabilize before calibrating the equipment. In calibrating the system output, both camera apertures for each stereo pair were adjusted to provide the 50 units NTSC video when viewing the .7 reflectance target at a distance of 223.52 cm from the camera pair. This target sensitivity level was set and maintained throughout each experimental run.

In order to provide the same displayed image size of the target at the monitor, a 7.6 cm square target was placed 152.4 cm from the face of the stereo pair which yielded a 2.5 cm square target displayed on the monitor for the fixed lens camera pair. The zoom lens on the COHU camera pair was then manipulated to yield the same size displayed target under the same conditions.

Following equipment stabilization and calibration, the subject was seated at his station (Figure 6-3) in front of the Fresnell display and was read a set of standard instructions (Appendix C). The subject was then positioned 48 cm

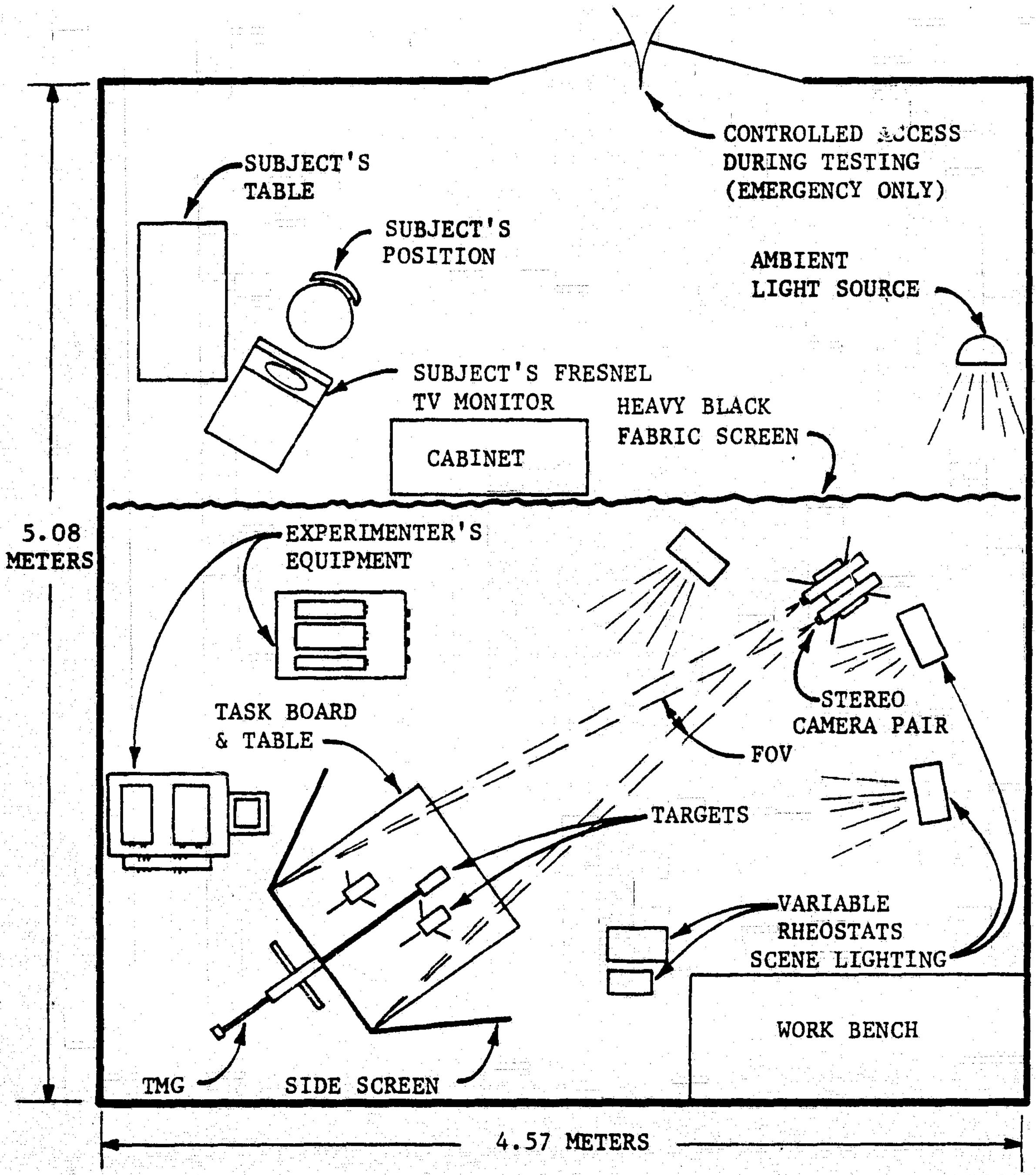


Figure 6-3:Laboratory Layout with Subject's Station

in front of the monitor face and viewed the monitor at a 15° angle declined from the horizontal. At this distance and angle, subjects were capable of viewing the display and of perceiving depth (stereopsis) at the Fresnell display.

At the start of each experimental trial, the subject's display was blank. This enabled the experimenter to arrange the specified task conditions according to the test schedule. The experimenter positioned both cylindrical targets at predetermined positions at the task site. These were:

(Distance from Sensor Face)

Fixed Target	Movable Target
198.12 cm	203.20 cm
223.52 cm	228.60 cm
248.92 cm	254.00 cm

At the three ranges employed in the present experiment, there were different linear disparities between the images being presented to the subject for stereo cues. These can be calculated by a formula discussed in Essex reports (Reference 1). To determine linear disparity, D:

$$D = BK/C - BK/R$$

where B is the camera baseline distance; C, the convergence distance; and R, the range to the object being viewed. K is a constant determined by the camera field of view, K = RI/T where R is the range to the object viewed; T, the object size and I, the image size of the object as presented on the Fresnell screen. In this case, the value of K was limited by the fixed lenses of the solid state cameras and was equal to 20. Therefore, with a baseline of 12.1 cm and convergence point of 152.4 cm, the disparity at the three target positions were as follows:

Target position 1 - .9271 cm disparity
Target position 2 - 1.2776 cm disparity
Target position 3 - 1.5596 cm disparity

With both targets in their appropriate positions, the experimenter initiated the trial at his console which simultaneously initiated the subject's display and an automatic timing device as well as transferred control of the target motion generator (TMG) to the subject. The subject was required to move the TMG target fore or aft to bring the front faces of the cylinders into alignment. When the subject had determined alignment, he pushed a response key which terminated his TV image and the timer. The experimenter recorded the trial time and the alignment error value. The next target distance and starting position was then set up by the experimenter and the procedure was repeated until all test sequence blocks were completed.

6.3 EXPERIMENTAL DESIGN

The independent variables manipulated during this testing were:

Fixed target distances:	198.12 cm from camera baseline 223.52 cm from camera baseline 248.92 cm from camera baseline
Starting positions of TMG cylinder:	203.2 cm from camera baseline 228.6 cm from camera baseline 254.0 cm from camera baseline
Camera types:	COHU Model 2000 (600 horizontal lines) GE solid state (188 horizontal lines)

The following variables were controlled during the experiment:

Video signal:	Measured and maintained such that at target position 2 (223.52), the target produced a video signal of 50 NTSC units as measured on a Tektronix type RM 529 waveform monitor
Target lighting:	Sufficient to provide the video signal as described above

Camera field of view: 20 degrees (K = 20)

Camera convergence: 152.4 cm during all testing.

6.4 TEST SUBJECTS

The five male subjects participating in this experiment ranged in age from 20 to 48 years. Each subject was screened for visual anomalies through the Standard Orthorator examination, and each was found to have normal visual acquity and depth perception. Subjects' experience and background were generally of a technical and engineering nature. All subjects had participated in prior visual system experiments in the laboratory and had familiarity with the standard laboratory equipment.

Each of the five subjects performed the test under 18 different combinations of target distances, camera types and initial comparison target starting distances. Each combination was repeated twice for a total of 36 trials per subject, and 180 trials in total. The camera type conditions were run in counterbalanced blocks to control for any possible learning effects. The remaining levels of variables studied were randomized within these blocks.

6.5 RESULTS

The dependent measures recorded during this experiment were target alignment error and response time. The target alignment error was defined as the linear error measured across the face of both targets, the movable target measured either in front of (+ error), equal to (0 error) or behind (- error) the fixed reference target. Response time was the recorded interval from the time the task site was televised to the subject to the time the subject controlled the TMG to perceived alignment and terminated the display.

Given the facts that the field of view, convergence angle and signal levels, as well as subject selection, were all closely controlled in this experiment, any significant differences in operator performance, in terms of accuracy or response times, whould be attributable to the differences in the camera resolution of the two systems investigated. As pointed out, the COHU system was capable of resolving 600 horizontal lines, while the GE system could resolve 188 lines. These resolution figures represent the capabilities of the COHU and GE cameras used in the testing, not the resolution presented to the subject on the Fresnell screen. However, both presentations were decremented equally by the system.

The alignment error data collected in this experiment were initially subjected to an intermediate computer program which calculated the signed error and the absolute value of that error for each trial. Each replication of a trial was averaged to give a single Mean Response Time, Mean Signed Error and Mean Absolute Error. These values were then subjected to an analysis of variance. In determining differences in target positioning performance as a function of camera type. the statistical comparisons of interest are the main effects of camera type (C) and any interactions involving camera type.

The analysis of variance of response time shown in Table 6-1 did not result in a significant main effect of camera type so that no general difference in response time due to camera type is evident. Two interactions with camera type were found to reach the .05 level of significance. The interaction of camera type and fixed target range is illustrated Figure 6-4. The interaction takes the form of an increase in response time with fixed target range for the GE cameras but a decrease in time using the COHU cameras. These data suggest a minor decrement in performance as a result of using the reduced resolution GE cameras. The effect, however, depends on range and use of the GE cameras in an operational stereoptic system will therefore have to be

Table 6-1: Analysis of Variance of Response Time

SOURCE	SUM OF SQUARES	dF	MEAN SQUARE	F
MEAN	23545.08	1	23545.08	515.31
CAMERA (C)	1.04	1	1.04	0.01
POSITION (P)	6.57	2	3.29	0.51
TARGET (T)	139.03	2	69.52	2.94
SUBJECTS (S)	182.76	4	45.69	
CP	67.98	2	33.99	6.01*
CT	98.37	2	49.19	4.48*
PT	406.72	4	101.68	8.36**
CS	797.25	4	199.31	
PS	52.74	8	6.59	
TS	188.88	8	23.61	
CPT	22.81	4	5.70	0.51
CPS	45.26	8	5.66	
CTS	87.82	8	10.98	
PTS	194.55	16	12.16	
CPTS	178.44	16	11.15	

* = .05 Level
** = .01 Level

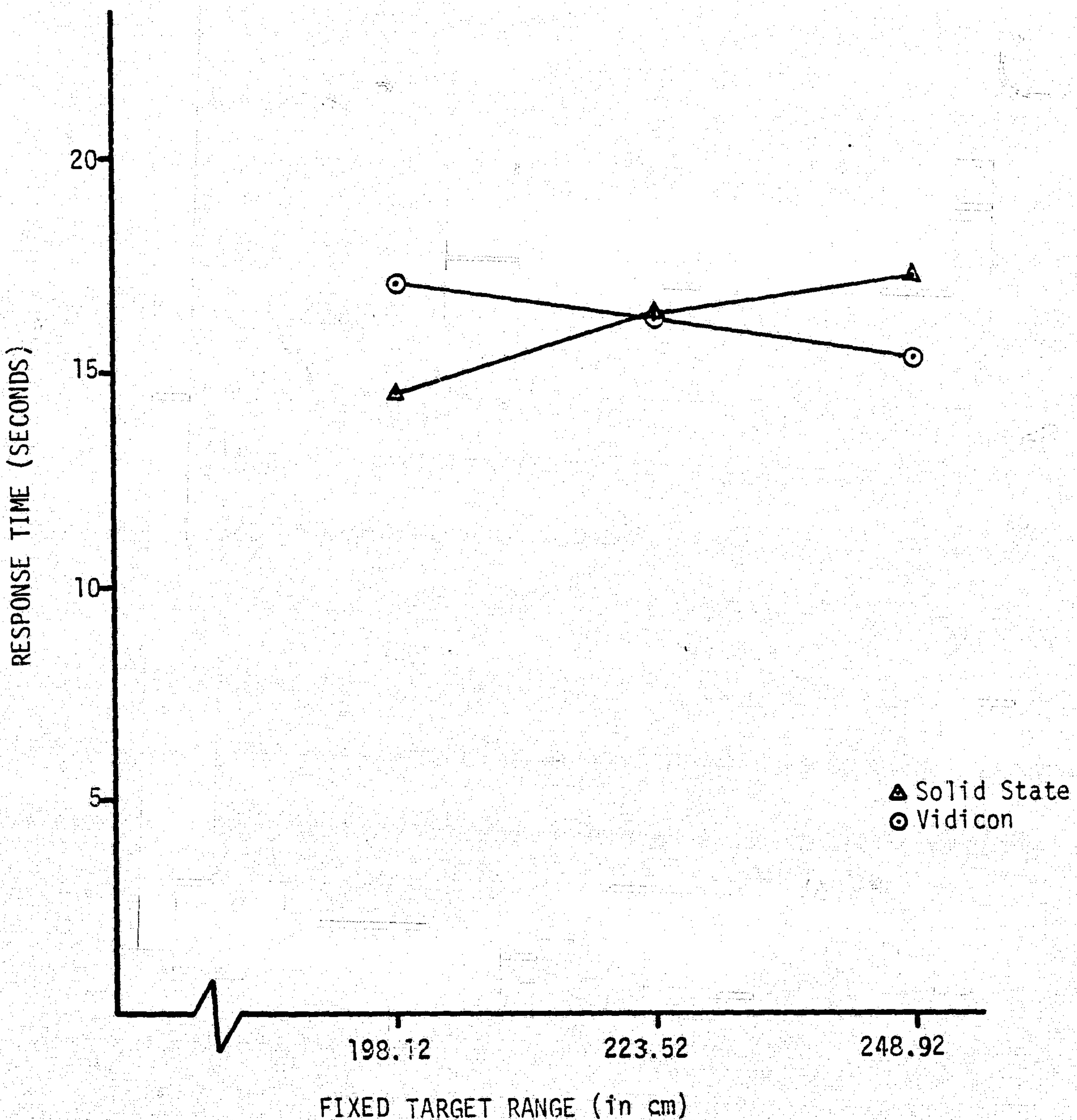


Figure 6-4: Response Time as a Function of Fixed Target Range

evaluated in light of the ranges to be encountered by the system.

For Response Time, a second interaction effect between camera type and target starting position was found to be significant at the .05 level and is illustrated in Figure 6-5. The effect is similar to that of camera type and variable target range. The GE cameras result in increased response time with increased range when compared to the COHU cameras. The same conclusion applies that operating range should be considered in evaluatine the GE cameras for use in a stereoptic system.

A further significant source of variance was the interaction of variable target starting position and fixed target range. This effect is of little interest here since it results from the means employed to vary the fixed target position and does not involve camera type.

The analysis of variance source table for signed error is presented as Table 6-2. The effect of fixed target range ($\alpha<.05$) was the only significant effect isolated. The effect is shown in Figure 6-5 where it may be seen that positive mean error values were obtained for both camera types indicating that the controlled target was generally positioned at a greater range than that of the fixed target. Figure 6-6 shows that this positive bias effect is reduced in magnitude as range increases. This effect, while statistically significant, is not of primary importance since it does not involve differences between camera systems.

The analysis of variance of absolute error is shown in Table 6-3. Mean absolute error is the most crucial dependent variable in the current context since it measures the degree of dispersion of target settings around the fixed target position. As shown in Table 6-3, none of the sources of variance were found to exert a statistically reliable effect on absolute error.

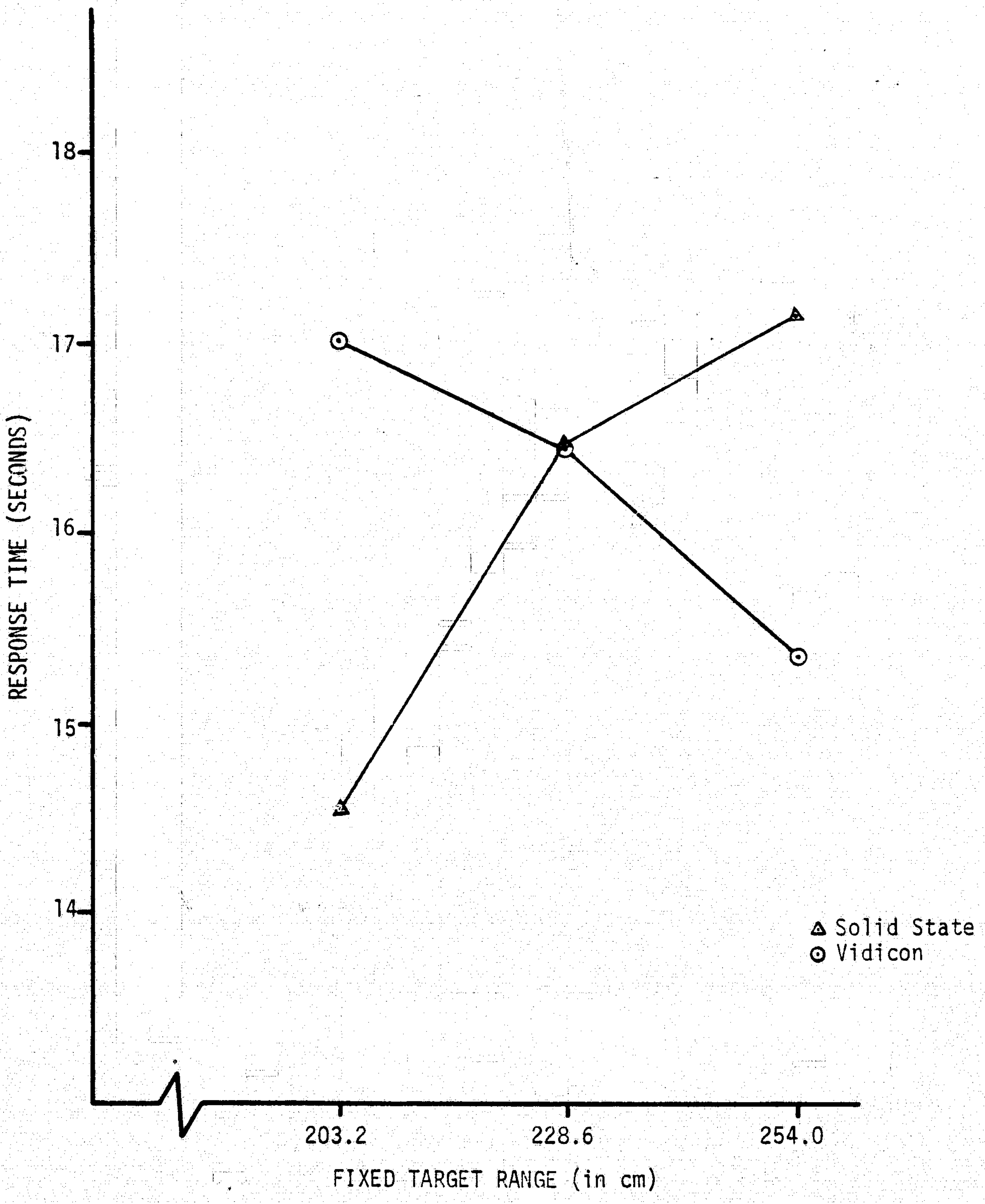


Figure 6-5: Response Time as a Function of Variable Target Starting Position and Camera Type

Table 6-2: Analysis of Variance of Signed Error

SOURCE	SUM OF SQUARES	dF	MEAN SQUARE	F
MEAN	92.84	1	92.84	11.79
CAMERA	0.09	1	0.09	0.01
POSITION	17.12	2	8.56	1.17
TARGET	65.21	2	32.60	8.90**
SUBJECTS	31.50	4	7.89	
CP	8.43	2	4.21	1.99
CT	8.60	2	4.30	1.16
PT	3.66	4	0.91	0.27
CS	75.80	4	18.95	
PS	58.72	8	7.34	
TS	29.30	8	3.66	
CPT	28.29	4	7.07	1.95
CPS	16.93	8	2.12	
CTS	29.70	8	3.71	
PTS	53.70	16	3.36	
CPTS	58.11	16	3.63	

* = .05 Level
** = .01 Level

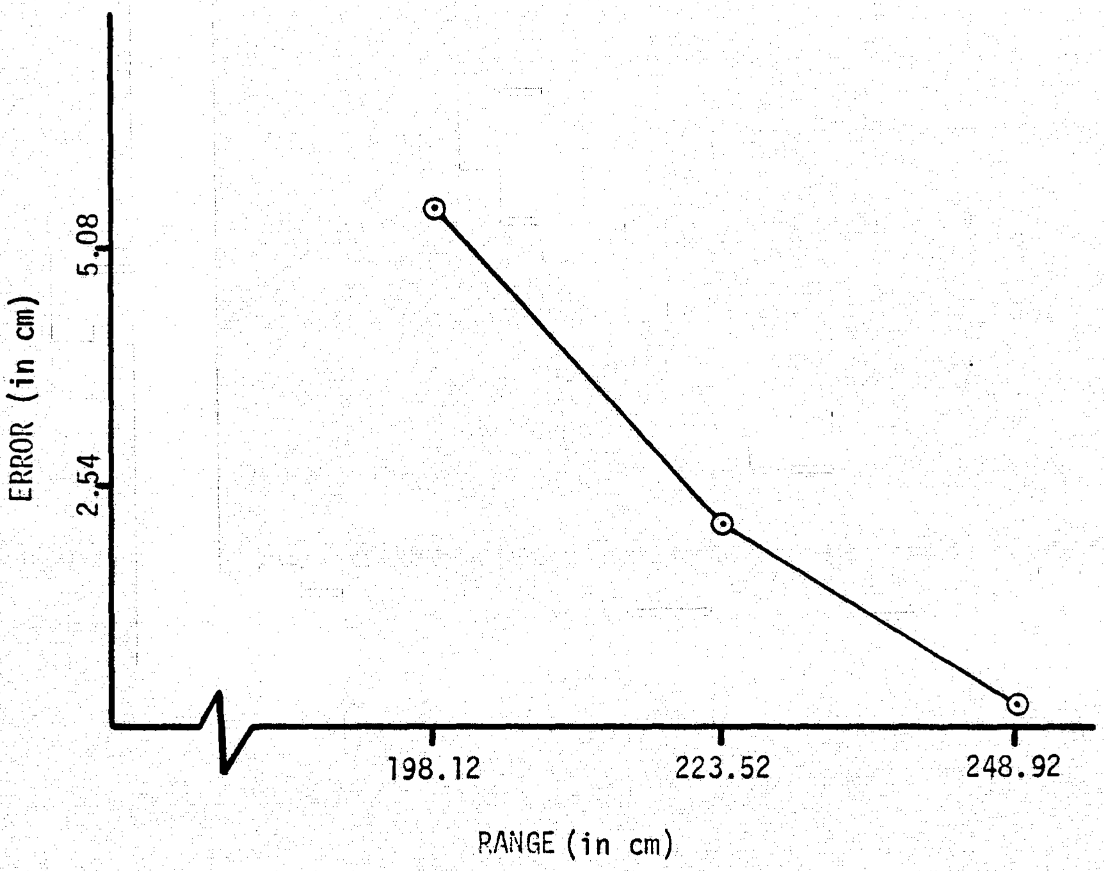


Figure 6-6: Mean Signed Error as a Function of Fixed Target Range

Table 6-3: Analysis of Variance of Absolute Error

SOURCE	SUM OF SQUARES	dF	MEAN SQUARE	F
MEAN	239.22	1	239.22	15.62
CAMERA	1.34	1	1.34	0.25
POSITION	2.11	2	1.05	0.82
TARGET	14.21	2	7.10	3,52
SUBJECTS	61.26	4	15.31	
CP	13.65	2	6.83	1.20
CT	2.32	2	1.16	0.20
PT	9.88	4	2.47	0.58
CS	21.27	4	5.32	
PS	10.27	8	1.28	
TS	16.14	8	2.02	
CPT	4.21	4	1.05	0.73
CPS	45.53	8	5.69	
CTS	45.39	8	5.67	
PTS	68.10	16	4.26	
CPTS	23.12	16	1.44	

* = .05 Level
** = .01 Level

6.6 CONCLUSIONS

There is no indication of a significant decrement in operator performance in aligning two targets which can be solely attributed to differences in camera types. It would appear from the data that performance is more significantly effected by interactions of target positions with camera types.

If the distance to the target from the two types of cameras is the principal reason for increasing or decreasing response time, then for target ranges below 225 cm, it can be seen that response time using the solid state system is significantly lower than for the vidicon system. One possible explanation for the direction of this effect is that the two camera systems are not linearly sensitive to reflected light. This would suggest, using $1/D^2$, that the solid state system is less sensitive to reflected light as distances increase. This now parallel sensitivity is put forth as a possible explanation in view of the results which show equivalent response times at the 225 cm distance, which was the approximate system calibration distance. A hardware performance analysis of both systems for several distances would be required to resolve this particular question.

With the present data, it appears that the solid state system is preferable for short distance alignment tasks, or close in tasks where depth judgment is necessary, such as manipulation of spacecraft components. For alignment of targets at distances greater than 230 cm, human operator performance seems to be enhanced with the vidicon system. The effects noted suggest that prior task knowledge is necessary for the appropriate selection of a specific type of camera system.

7.0 STEREOPTIC TV PARAMETER PROGRAM

7.1 PROGRAM OBJECTIVES

Empirical tests of stereoptic TV system performance have been presented in several Essex reports (Ref. 1). These studies have examined, as independent variables, several parameters of stereo systems including the following:

- Target-to-camera range
- Camera baseline
- Convergence angle
- System gain
- Field of view (mono and stereo)
- Bandwidth

Because a large number of variables will influence stereoptic depth resolution, empirical tests of all variable levels in combination becomes impractical. Furthermore, it should not be necessary to carry out extensive studies since analytical work to generalize available empirical data should suffice.

The intent of the program to be described is to use empirical data on stereoptic disparity thresholds to predict the width of the stereo field of view and the system range resolution as functions of range. For a particular task or stereo system application, the two primary performance factors are the stereo field of view width which will be dictated by the visual envelope necessary and the required resolution at the working range which results from the positioning accuracy necessary.

The program logic assumes that a certain threshold value of retinal disparity due to image characteristics is necessary for range increment detection. The program accepts the parameters of a stereo system and calculates range resolution data using retinal disparity threshold data obtained from empirical tests. The resolution accuracy and stereo field of view width as functions of range are then calculated.

7.2 PROGRAM INPUTS

The inputs which must be made for a run include:

- Monitor to eye viewing distance (in.)
- Monitor dimension (in.)
- Video system constant - K (in.)
- Visual angle at operator's eye for vertical target detection based on empirical studies (rad.)
- Average interocular distance (in.)
- Retinal disparity at operator's eye for range increment detection based on empirical studies (rad.)
- Maximum permissible value of linear disparity based on empirical studies (in.)
- Stereo camera baseline (in.)
- Single camera field-of-view (deg.)
- Camera convergence angle (deg.)

7.3 PROGRAM OUTPUTS

The program accepts the inputs listed in Section 7.2 and substitutes these in suitable equations developed based on stereo TV system geometry. Output values from these equations include:

- Horizontal resolution factor (dimensionless)
- Vertical resolution factor (dimensionless)
- Stereo exaggeration ratio (dimensionless)
- Resolvable horizontal increment (in.)
- Range at which maximum permissible value of linear disparity occurs
- Range resolution factor (dimensionless)
- Detectable range increment (in.)
- Width of stereo field of view (in.)

7.4 PROGRAM CALCULATIONS

The program is set up to read any of several optional input data sets. The output data are then calculated based on integer inputs which control the program.

7.4.1 Input Variables

The program always reads two integer and six real variables called I1, I2, X1, X2, X3, X4, X5 and X6. These input data are coded in an 2I2, 6F.8.4 format so that the fields on an input card are as follows:

Col.	Input Variable	Format
1-2	I1	I2
3-4	I2	I2
5-12	X1	F8.4
13-20	X2	F8.4
21-28	X3	F8.4
29-36	X4	F8.4
37-44	X5	F8.4
45-52	X6	F8.4

The variable I1 controls the meaning of X1 as follows:

If I1 = 1 X1 is assumed to equal K (in.)

If I2 > 1 X1 is assumed to equal Ω (deg.)

Thus, the program can be run by specifying either K or Ω with I1 set to the proper value.

The variable I2 controls the meaning of X4 as follows:

If I2 = 1 X4 is assumed to equal β (deg.)

If I2 = 2 X4 is assumed to equal R_c (in.)

If I2 = 0 R_c is not specified X4 is blank and the program will calculate R_c so that the maximum linear disparity value (d_m) is obtained at maximum range (R_m).

The variable X2 is read as the horizontal monitor dimension (M - in.). The variable X3 is read as the stereo baseline (B - in.). The variable X5 is read as the maximum range at which stereo viewing is required (R_m - in.). The variable X6 is read as the FORTRAN variable RCHANG which instructs the program to calculate system performance measures every RCHANG inches from the convergence range (R_c) to the maximum range (R_m).

7.4.2 Program Calculations

The system variables dealt with are listed in Table 7-1. The equations for calculation of output variables have been presented in earlier reports (Ref. 2). The geometry of the stereoptic field of view is shown in Figure 7-1.

7.4.2.1 Single Camera Field of View and System Constant

These variables are obtained from input and the relationship:

$$K = \frac{M}{2\mathrm{TAN}\ (\Omega/2)} \qquad \text{7-1}$$

If X1 is read as Ω, K is calculated from equation 7-1.

7.4.2.2 Convergence Angle and Convergence Range

These variables are obtained from the relationship:

$$R_c = \frac{B}{2\mathrm{TAN}\ (\beta/2)} \qquad \text{7-2}$$

If X4 is read as R_c, then β is calculated from equation 7-2. If X2 is equal to zero, X4 is undefined. In this case, R_c is calculated so that maximum linear disparity is obtained at maximum range. The relationship used is:

$$d_m = \frac{BK}{R_c} - \frac{BK}{R_m} \qquad \text{7-3}$$

7.4.2.3 Output Variables Which Are Independent of Range

Following calculation of input values, horizontal and vertical resolution factors are calculated from:

$$r_y = \frac{L\lambda y}{K} \qquad \text{7-4}$$

Table 7-1: Stereoptic System Variables

FORTRAN		SYMBOL	DEFINITION
LDISP	(REAL)	d	LINEAR DISPARITY ON MONITOR (IN)
K	(REAL)	K	VIDEO CONSTANT $K = \frac{M}{2\ \mathrm{TAN}(\Omega/2)}$ (IN)
L, VDIST	(REAL)	L	VIEWING DIST (IN)
M	(REAL)	M	MONITOR DIMENSION (IN) (HORIZONTAL)
LAMDAY	(REAL)	λ_y	HORIZONTAL VISUAL ANGLE FOR DETECTION (RAD)
LAMDAZ	(REAL)	λ_z	VERTICAL VISUAL ANGLE FOR DETECTION (RAD)
A	(REAL)	a	INTEROCULAR DIST (IN)
THETAT	(REAL)	Θ_T	THRESHOLD RETINAL DISPARITY (RAD)
DM	(REAL)	d_M	MAX VALUE OF LINEAR DISPARITY (IN)
B	(REAL)	B	STEREO BASELINE (IN)
RM	(REAL)	R_M	MAX RANGE (IN)
RCHANG	(REAL)	RCHANG	RANGE INCREMENT FOR DO LOOP (IN)
OMEGAR	(REAL)	Ω	SINGLE CAMERA ROV. (HORIZONTAL) (RAD)
OMEGAD	(REAL)	Ω	SINGLE CAMERA FOV. (HORIZONTAL) (DEG)
BETAD	(REAL)	β	CAMERA CONVERGENCE ANGLE (DEG)
BETAR	(REAL)	β	CAMERA CONVERGENCE ANGLE (RAD)
Y RES	(REAL)	r_y	Y RESOLUTION FACTOR (DIMENSIONLESS)
Z RES	(REAL)	r_z	Z RESOLUTION FACTOR (DIMENSIONLESS)
ETHETA	(REAL)	E	EXAGGERATION RATIO (DIMENSIONLESS)
DELY	(REAL)	ΔY	RESOLVABLE Y INCREMENT (IN)
DELZ	(REAL)	ΔZ	RESOLVABLE Z INCREMENT (IN)
CONLIM	(REAL)	C	RANGE AT WHICH LIMITING DISPARITY OCCURS (IN)
RRES	(REAL)	r_R	RANGE RESOLUTION FACTOR (DIMENSIONLESS)
DELR	(REAL)	ΔR	DETECTABLE RANGE INCREMENT (IN)
ANG 1	(REAL)	α	* ANGLE FROM INNER FOV LIMIT TO BASELINE (RAD)
ANG 2	(REAL)	α^1_2	* ANGLE FROM OUTER FOV LIMIT TO LOS NORMAL TO BASELINE (RAD)
ANG 3	(REAL)	α_3	* ANGLE FROM INNER FOV LIMIT TO LOS NORMAL TO BASELINE (RAD)
F	(REAL)	F	* TAN OF α_3 (DIMENSIONLESS)
RZERO	(REAL)	R_0	* RANGE TO CROSSING POINT OF INNER FOV LIMITS (IN)
G	(REAL)	G	* TAN OF α_3 (DIMENSIONLESS)
WR1	(REAL)	WR_1	* SHORT RANGE STEREO FOV WIDTH (IN)
WR2	(REAL)	WR_2	* LONG RANGE STEREO FOV WIDTH (IN)
WR	(REAL)	WR	* SMALLER OF WR_1 AND WR_2 (IN)

* See Figure 7-1

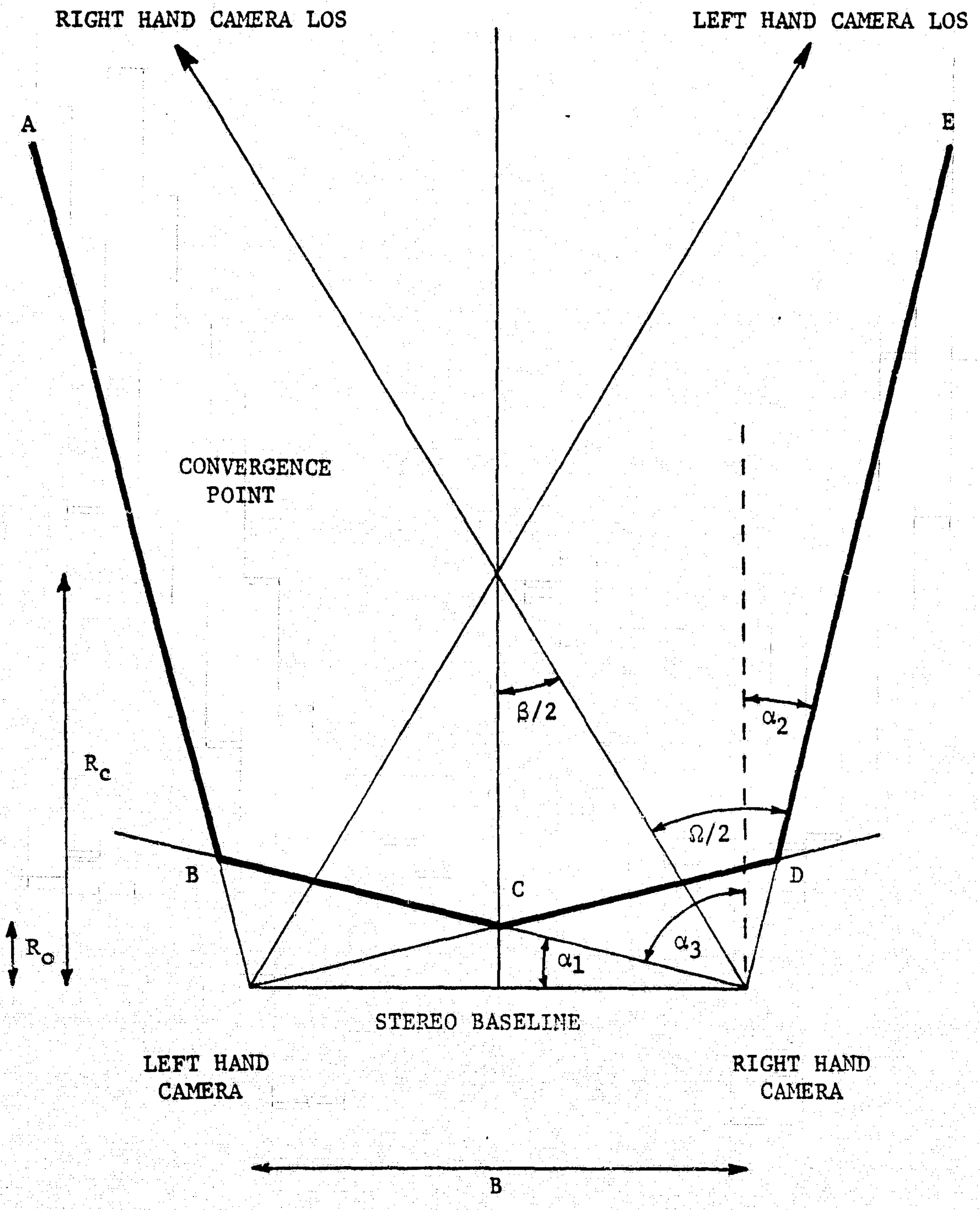


Figure 7-1: STEREO SYSTEM GEOMETRY

and:

$$r_z = \frac{L\lambda z}{K} \qquad 7\text{-}5$$

The stereo exaggeration ratio (E_θ) is calculated from:

$$E_\theta = \frac{BK}{La} \qquad 7\text{-}6$$

If I2 is set to a value other than zero, the maximum useable stereo range will not generally equal the range at which maximum disparity is obtained. In these cases, the latter parameter (c) is calculated from:

$$dm = \frac{BK}{Rc} - \frac{BK}{c} \qquad 7\text{-}7$$

The above input and calculated variables are independent of range. The program lists these values including:

- Viewing distance (in.)
- Interocular distance (in.)
- Horizontal resolution threshold (rad.)
- Vertical resolution threshold (rad.)
- Retinal disparity threshold (rad.)
- Maximum linear disparity (in.)
- System constant (in.)
- Maximum stereo range (in.)
- Monitor dimension (in.)
- Convergence angle (deg.)
- Convergence range (in.)
- Stereo camera baseline (in.)
- Single camera field of view (deg.)
- Exaggeration ratio (dimensionless)
- Horizontal resolution factor (dimensionless)
- Vertical resolution factor (dimensionless)
- Range at which maximum linear disparity is obtained (in.)

7.4.2.4 Output Variables Which Are Functions of Range

The remaining variables of interest are all functions of camera to target range. The initial calculation of these values is performed at the convergence range. Range is then incremented by RCHANG inches and the calculations performed again. When current range exceeds R_m, the iteration stops.

The resolvable horizontal increment is calculated from:

$$\Delta y = r_y R \tag*{7-8}$$

The revolvable vertical increment is calculated from:

$$\Delta z = r_z R \tag*{7-9}$$

The range resolution factor is calculated from:

$$r_R = \frac{\theta'_T R}{aE_\theta} \tag*{7-10}$$

The resolvable range increment is calculated from:

$$\Delta R = r_R R \tag*{7-11}$$

Linear disparity is calculated from:

$$d = \frac{BK}{R_c} - \frac{BK}{R} \tag*{7-12}$$

The remaining variables are associated with the width of the stereo field of view. The general configuration of a two camera stereoptic system is shown in Figure 7-1. The stereoptic field is bounded by the heavy lines in Figure 7-1. The field of view width can be determined by means of the three angles α_1, α_2, and α_3 where:

$$\alpha_2 + \alpha_3 = \Omega \tag*{7-13}$$

$$\alpha_1 + \alpha_3 = 90 \tag{7-14}$$

$$\alpha_3 = \frac{\beta}{2} + \frac{\Omega}{2} \tag{7-15}$$

Therefore:

$$\alpha_1 = 90 - \frac{\beta}{2} - \frac{\Omega}{2} \tag{7-16}$$

$$\alpha_2 = \frac{\Omega}{2} - \frac{\beta}{2} \tag{7-17}$$

$$\alpha_3 = \frac{\beta}{2} + \frac{\Omega}{2} \tag{7-18}$$

R_0 is the shortest range at which stereo coverage is obtained. R_0 is calculated from:

$$R_0 = \frac{B}{2} \text{TAN}\alpha_1 \tag{7-19}$$

The stereo field of view width is a discontinuous function of range. For short ranges, the field width is the distance between lines CB and CD. This variable is called W_{R1} where:

$$W_{R1} = 2(R-R_0)\ \text{TAN}\alpha_3 \tag{7-20}$$

Beyond a certain range, the field width is the distance between the lines BA and DE. This variable is called W_{R2} where:

$$W_{R2} = B + 2R\ \text{TAN}\alpha_2 \tag{7-21}$$

W_{R1} and W_{R2} can be calculated for any value of range and the field width (W_R) is the smaller of the two. The program calculates W_{R1} and W_{R2} at each range step and obtains W_R by means of the following logic

$$W_R = \begin{cases} 0 \text{ if } R \leq R_0 \\ W_{R1} \text{ if } R > R_0 \text{ and } W_{R1} \leq W_{R2} \\ W_{R2} \text{ if } R > R_0 \text{ and } W_{R1} \geq W_{R2} \end{cases}$$

At each value of range, the following variables are printed:

- Range (in.)
- Detectable horizontal separation (in.)
- Detectable vertical separation (in.)
- Range resolution factor (dimensionless)
- Detectable range separation (in.)
- Linear disparity (in.)
- Width of stereo field of view (in.)

7.5 PROGRAM OPERATION

A single run is made by including 6 cards which define the following fixed parameters:

- Interocular distance. This parameter is currently set at 2.5 in.

- Visual angle threshold for horizontal resolution. This value is presently set at .00175 rad. based on visual system data for a 4.5 MHz system with S/N ratio > 20 db and contrast ratio of approximately .75. If it is desirable to run the program for systems having other parameter values, the appropriate visual angle thresholds can be determined from previous Essex visual system reports.

- Viewing distance. This parameter is presently set at 19 in. which is a typical value for stereo system tests. Viewing distance may be changed as desired by modifying the card.

- Maximum value of retinal disparity. This parameter is currently set at 1.09 in. based on a study of maximum disparity tolerable to subjects and sufficiently small to permit rapid stereopsis.

- Retinal disparity threshold. This parameter is currently set at .00076 rad. based on past studies using the stereoptic system.

- Visual angle threshold for vertical resolution. This value is presently set at .00175 rad. assuming a 525 line system and the system parameters presented in connection with horizontal resolution.

Runs made to date have used the above parameter values.

The variable parameters include:

- System constant
- Single camera field of view
- Convergence angle
- Convergence range
- Monitor dimension
- Stereo camera baseline
- Maximum range
- Range increment for calculations.

These variables are input under one of six cases shown in Table 7-2. As shown, I1 may be set to 1 or 2 depending on whether the user wishes to input K or Ω as X1. I2 may be set to 1 if the user wishes to input β as X4, may be set to ι if R_c is to be input as X4 or may be set to zero. If I2 equals zero, the input variable X4 is undefined. The program will then calculate R_e so as to obtain linear disparity d equal to d_m when R equals R_m.

Each variable parameter input card results in a run. Any number of cards may be placed behind the program deck. The program reads in input card, calculates and prints the output variables which are independent of range. Next, the do-loop for functions of range is performed starting at R_c in. and incrementing by RCHANG in. At each iteration, range is tested. If range is less than R_M, the do-loop continues. If range exceeds R_M, the do-loop is terminated and the program reads the next input card. The upper limit of the do-loop is presently set at 500. The loop may terminate before range reaches R_M if:

$$\frac{R_M - R_c}{\text{RCHANG}} \geq 500$$

Table 7-2: Program Input Cases

INPUT VARIABLE	I1	I2	X1	X2	X3	X4	X5	X6	COMMENT
COL. NO.	2	4	5-12	13-20	21-28	29-36	37-44	45-52	
FORMAT	I2	I2	F8.4	F8.4	F8.4	F8.4	F8.4	F8.4	
	1	1	K	M	B	β	R_M	RCHANG	PROGRAM READS X1 AS K AND X4 AS β
	1	2	K	M	B	R_c	R_M	RCHANG	PROGRAM READS X1 AS K AND X4 AS R_e
	1	0	K	M	B	-	R_M	RCHANG	PROGRAM READS X1 AS K AND CALCULATES R_c SO THAT $d = d_m$ AT R_M
	2	1	Ω	M	B	β	R_M	RCHANG	PROGRAM READS X1 AS Ω AND X4 AS β
	2	2	Ω	M	B	R_c	R_M	RCHANG	PROGRAM READS X1 AS Ω AND X4 AS R_c
	2	0	Ω	M	B	-	R_M	RCHANG	PROGRAM READS X1 AS Ω AND CALCULATES R_e SO THAT $d = d_m$ AT R_M

In this case, it may be necessary to increase the upper limit.

A blank card should be placed behind the last input card to terminate the run.

7.6 SAMPLE PROGRAM RUN

To illustrate the operation of the program, seven runs were made with stereo camera baseline varying from 10.2 cm to 25.4 cm (4 to 10 in.). Increasing the baseline has the effect of reducing the size of the minimum detectable range increment. In the current set of runs, the width of the stereoptic field of view decreases slightly as baseline increases. This results from the fact that the convergence range was held constant at 200 cm (78.8 in.). This causes the convergence angle to decrease as baseline increases resulting in a reduction in stereo field width as baseline increases.

The stereo system parameter values used are listed below:

● Viewing distance	48 cm
● Interocular distance	6.35 cm
● Horizontal resolution threshold	.00175 rad.
● Vertical resolution threshold	.00175 rad.
● Disparity limit	2.77 cm
● Disparity threshold	.00076 rad.
● Video constant (K)	80.0 cm
● Maximum range	304.8 cm
● Monitor width	18.3 cm
● Convergence range	200.2 cm
● Convergence angle	varying from 2.9 to 7.2 degrees
● Baseline	varying from 10.2 to 25.4 cm

• Single camera FOV	13.04 degrees
• Exaggeration ratio	varying from 6.63 to 16.8 cm
• Do-loop increment (RCHANG)	2.54 cm.

The print-outs for these runs are shown as Appendix D. The resulting data are plotted in Figures 7-2 and 7-3. Figure 7-2 shows the minimum detectable range separation as a function of camera baseline with target-to-range as the curve parameter. If the required range resolution at a particular range is known, these data could be used in selecting a camera baseline. Stereo field width is shown in Figure 7-3 as a function of camera baseline with range as the curve parameter. Notice that field width is not strongly sensitive to baseline for the fairly long convergence range used for these runs. The irregular appearance of some of the Figure 7-3 data is due to the fact that the function relating field width to system parameters contains discontinuities which depend on the cross-over points of the lines of sight which define the stereo field.

In the current example, the effect of varuing baseline was investigated. The program will be used more generally to establish parameter requirements based on the range resolution and coverage necessary for manipulation tasks.

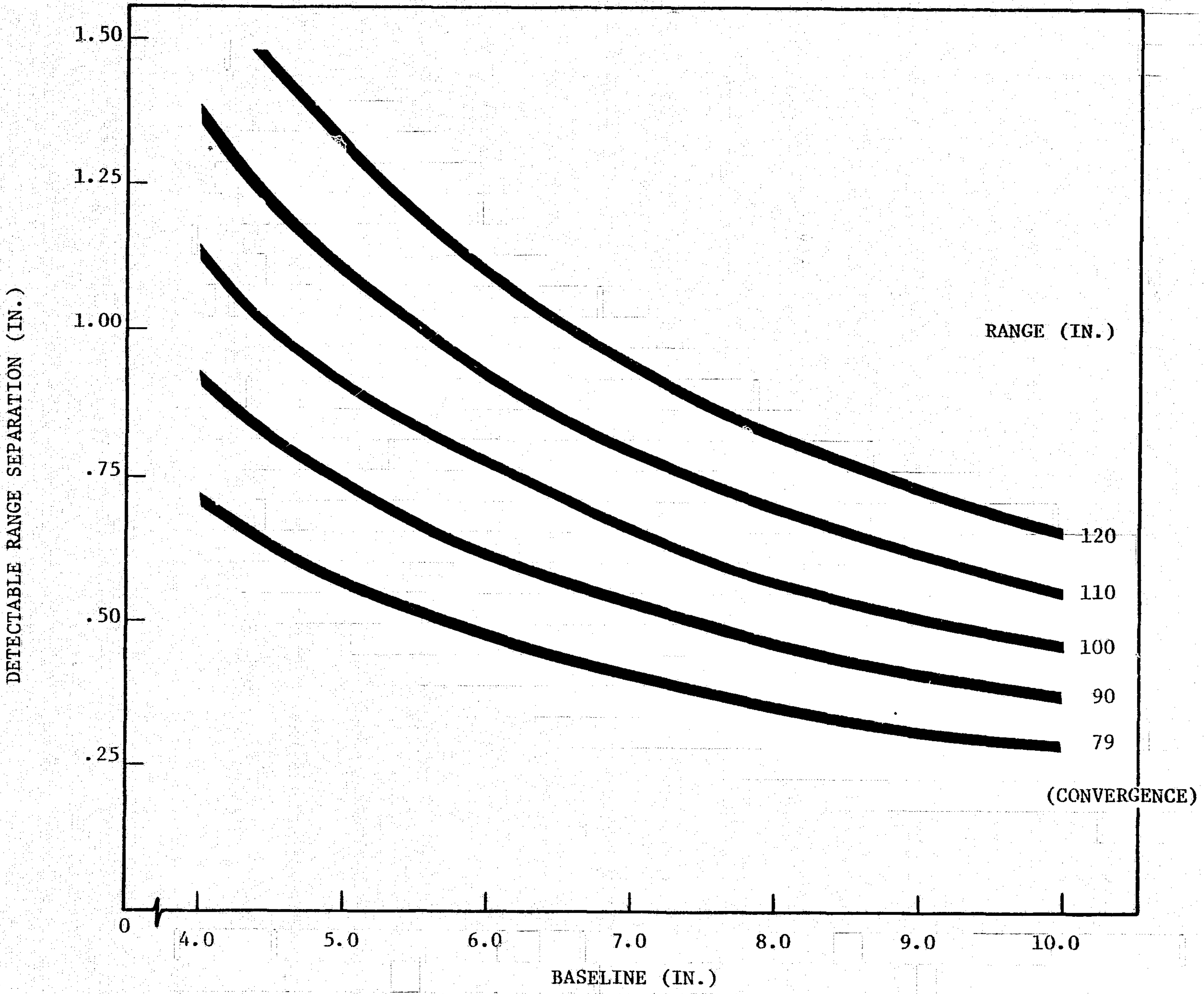


Figure 7-2: DETECTABLE RANGE INCREMENT AS A FUNCTION OF BASELINE AND RANGE

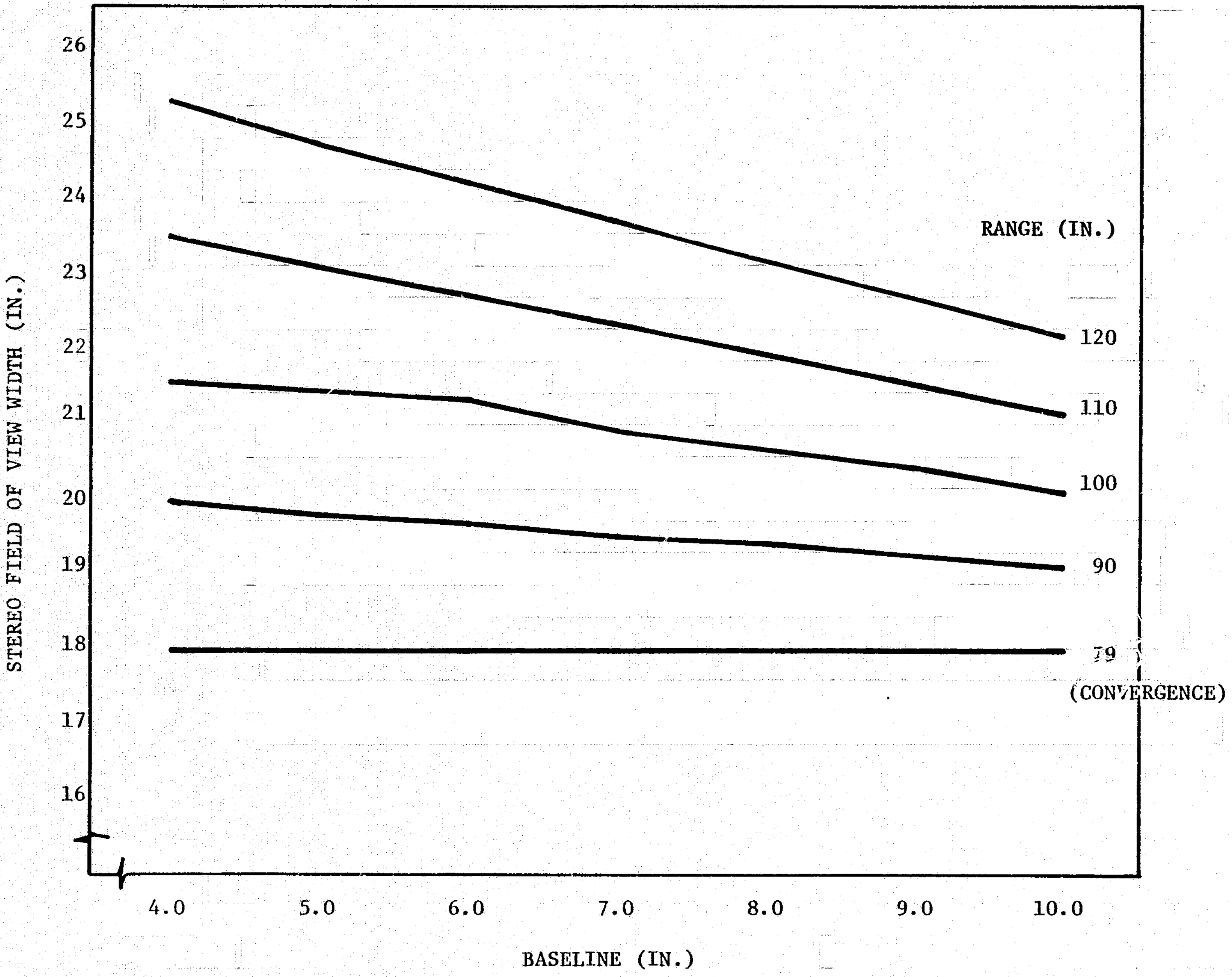


Figure 7-3: STEREO FIELD OF VIEW WIDTH AS A FUNCTION OF BASELINE AND RANGE

8.0 REFERENCES

1. Frederick, P. N., Kirkpatrick, M., Shields, N. L., Jr., and Malone, T. B., "Earth Orbital Visual System Evaluation Program," Essex Corporation, Alexandria, Virginia, under NASA Contract NAS8-30545, 1975, Report No. 4.

2. Shields, N. L., Kirkpatrick, M., Frederick, P. N., and Malone, T. B., "Earth Orbital Teleoperator Visual System Evaluation Program," Essex Corporation, Alexandria, Virginia, under NASA Contract NAS8-30545, 1975, Report No. 3.

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4. Leibowitz, H. W. and Sulzer, R. L., "An Evaluation of Three-Dimensional Displays," Armed Forces - NRC Committee on Vision, 1965 under Office of Naval Research Contract No. NONR 2300(05), January, 1965.

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APPENDIX A - STANDARD INSTRUCTIONS

APPENDIX B - STANDARD INSTRUCTIONS, COLOR DISCRIMINATION TEST, PHASE 2

APPENDIX C - STANDARD INSTRUCTIONS - STEREO TEST S-2

APPENDIX D - ANALYTICAL STEREOPTIC TV SYSTEM DESIGN PROGRAM

APPENDIX A

STANDARD INSTRUCTIONS - TEST S-1

The purpose of this test is to determine how well one can estimate the range to objects using an artificially created three-dimensional cursor and a Fresnell screen 3-D system.

Prior to commencing testing, it is necessary that you become familiar with the system used for 3-D viewing. Due to the optical characteristics of this system, it is necessary that your head be held in a limited area to enable viewing the scene in three dimensions. Look at the screen. There is presently a round, white object located above the cursor in the center of the screen. Position your head so that it appears to be brightest and definitely in three dimensions. This can be tested by covering or closing one eye at a time. If your head is correctly positioned, each eye will see the target equally bright. Look at the screen from different head positions until you clearly understand the limitations and requirements for stereo viewing . (Pause.)

There is a rectangular cursor which appears to be floating in space displayed on the screen. There are 3 control knobs located on the panel in front of you beneath the screen. The one on the left (pointing) controls up and down movements of the cursor; the one on the right controls left and right movements. These will be used to orient the cursor so that it is on or immediately to the side of the target when it is presented. (Show drawing.) Try these controls. (Pause.) Any questions?

The knob in the middle controls the apparent in and out movement of the cursor. Try it. (Pause.)

Prior to each test trial the screen will be blank. I will give you a verbal "ready" and then turn on the TV presentation, showing you a target which will vary in distance from the TV camera. Using these three controls, you are to align the cursor so that it appears to you to be at the same distance from the camera as the target face when placed immediately on or to the right of the target. As soon as you have aligned the cursor with the target, you are to depress this button (Show sequence termination push button) and call out the reading on the digital counter located above the Fresnell screen. I will then set up new test parameters and repeat the test sequence.

There will be different noise and bandwidth conditions during the test sequences. However, at no time should the television screen lose horizontal or vertical hold. If you experience what you believe are abnormal TV conditions, please inform me and I will correct them.

APPENDIX B

Standard Instructions

Color Discrimination Test, Phase 2

The purpose of this test is to determine how close two colors can be to each other and the difference still be discriminated using color television.

To determine this we are going to show you several pairs of color chips on this TV screen, two at a time. At the beginning of each test trial your TV screen will be blank as it is now. I will then give you a verbal "Ready" and turn on the screen, like this. (Turn on screen showing two obviously disparite color chips.) You will then look at the colors and determine if they are the same or different. As soon as you have decided, press this switch (show seq. termination switch) and call out your determination. Just call out "same" or "different." Pressing the switch will cause your screen to go blank again and I will set up two more colors and we will do it again.

Do you understand what you are supposed to do? (Pause) Any questions? (Pause)

APPENDIX C

STANDARD INSTRUCTIONS - STEREO TEST S-2

This test is designed to evaluate the ability to align objects using the Fresnell television viewing system. Although you have used the system before, I want to go over several things which are important when using the system. (Turn on display showing single target.)

First you must position your head such that both eyes can see the object with equal brightness and definite stereo effect. You can test this by moving your head right and left noting that the images become dimmer in either eye as your head is displaced from the center line of the screen. When properly oriented, you should see the display equally bright with definite stereo effect. Try this and be sure you can achieve this effect. (Pause.) Any questions?

In this test, at the beginning, your screen will be blank. I will give you a verbal "ready" and turn on your screen. The object on the right is fixed, the object on the left can be moved towards and away from you by turning this switch. (Show three position switch on controller.) Turning it to the left brings the object nearer, right takes it away,and in the center it is stopped. Try this control. (Pause.) Any questions?

You are, when the objects are displayed, to move the one on the left so that it appears to be the same distance away from you as the one on the right. When you have done this, you will depress this button (Show sequence termination switch), your screen will go blank and I will set up a new trial condition.

At no time should you experience abnormal TV conditions such as roll over or snow. At all times your TV picture should be as good as it is right now. If you experience any abnormal conditions, inform me at once.

If there are no further questions, we will begin.

APPENDIX D - ANALYTICAL STEREOPTIC TV SYSTEM DESIGN PROGRAM

```
@FOR,IS MARK,MARK
HSA  E3 -02/16/77-18:14:46 (,0)

 MAIN PROGRAM

 STORAGE USED: CODE(1) 000657; DATA(0) 000453; BLANK COMMON(2) 000000

 EXTERNAL REFERENCES (BLOCK, NAME)

  0003    NINTR$
  0004    NRDU$
  0005    NIO2$
  0006    ATAN
  0007    SIN
  0010    COS
  0011    NWDU$
  0012    NSTOP$

 STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

  0000    000067 10F       0001    000626 112L      0001    000630 113L      0001    000635 115L      0000    000056 12F
  0000    000071 13F       0000    000076 14F       0000    000106 15F       0000    000116 16F       0000    000124 17F
  0000    000135 18F       0000    000142 19F       0000    000153 20F       0001    000653 200L      0000    000163 21F
  0000    000170 22F       0000    000200 23F       0000    000220 24F       0000    000230 25F       0000    000240 26F
  0000    000247 27F       0000    000256 28F       0000    000265 29F       0000    000273 30F       0000    000302 31F
  0000    000311 32F       0000    000321 33F       0001    000507 333G      0000    000340 34F       0000    000356 35F
  0000    000376 36F       0000    000413 37F       0000    000414 38F       0000    000210 39F       0001    000016 50L
  0001    000655 52L       0001    000106 53L       0001    000135 55L       0001    000152 56L       0001    000201 57L
  0001    000227 58L       0000 R  000007 A         0000 R  000037 AI        0000 R  000045 ANG1      0000 R  000046 ANG2
  0000 R  000047 ANG3      0000 R  000022 B         0000 R  000027 BETAD     0000 R  000030 BETAR     0000 R  000035 CONLIM
  0000 R  000044 DELR      0000 R  000041 DELY      0000 R  000042 DELZ      0000 R  000011 DM        0000 R  000034 ETHETA
  0000 R  000050 F         0000 R  000052 G         0000 I  000036 I         0000 I  000012 I1        0000 I  000013 I2
  0000 R  000002 K         0000 R  000001 L         0000 R  000004 LAMDAY    0000 R  000005 LAMDAZ    0000 R  000000 LDISP
  0000 R  000003 M         0000 R  000026 OMEGAD    0000 R  000025 OMEGAR    0000 R  000040 R         0000 R  000031 RC
  0000 R  000024 RCHANS    0000 R  000023 RM        0000 R  000043 RRES      0000 R  000051 RZERO     0000 R  000010 THETAT
  0000 R  000006 VDIST     0000 R  000055 WR        0000 R  000053 WR1       0000 R  000054 WR2       0000 R  000014 X1
  0000 R  000015 X2        0000 R  000016 X3        0000 R  000017 X4        0000 R  000020 X5        0000 R  000021 X6
  0000 R  000032 YRES      0000 R  000033 ZRES


00100      1*      C                                                                                    000000
00100      2*      C                                                                                    000000
00100      3*      C                                                                                    000000
00100      4*      C                                                                                    000000
00100      5*      C                                                                                    000000
00101      6*        12   FORMAT(1H1,15X,'***  STEREO TV CALCULATIONS  ***',//)                         000000
00103      7*         10 FORMAT(2I2,6F8.4)                                                                000001
00104      8*         13 FORMAT(1H-,6X,16HINPUT PARAMETERS)                                               000001
00105      9*         14 FORMAT(1H ,15X,16HVIEWING DISTANCE,14X,F9.5,2X,2HIN)                             000001
00106     10*         15 FORMAT(1H ,15X,20HINTEROCULAR DISTANCE,10F9.5,2X,2HIN)                           000001
00107     11*         16 FORMAT(1H ,15X,21HRESOLUTION THRESHOLDS)                                         000001
00110     12*         17 FORMAT(1H ,20X,10HHORIZONTAL,15X,F9.5,2X,3HRAD)                                  000001
```

```
00111     13*        18 FORMAT(1H ,20X,8HVERTICAL,17X,F9.5,2X,3HRAD)                        000001
00112     14*        19 FORMAT(1H ,15X,19HDISPARITY THRESHOLD,11X,F9.5,2X,3HRAD)             000001
00113     15*        20 FORMAT(1H ,15X,15HDISPARITY LIMIT,15X,F9.5,2X,2HIN)                  000001
00114     16*        21 FORMAT(1H-,6X,17HSYSTEM PARAMETERS)                                  000001
00115     17*        22 FORMAT(1H ,15X,15HSYSTEM CONSTANT,15X,F9.5,2X,2HIN)                  000001
00116     18*        23 FORMAT(1H ,15X,13HMAXIMUM RANGE,17X,F9.5,2X,2HIN)                    000001
00117     19*        39 FORMAT(1H ,15X,13HMONITOR WIDTH,17X,F9.5,2X,2HIN)                    000001
00120     20*        24 FORMAT(1H ,15X,17HCONVERGENCE ANGLE,13X,F9.5,2X,3HDEG)               000001
00121     21*        25 FORMAT(1H ,15X,17HCONVERGENCE RANGE,13X,F9.5,2X,2HIN)                000001
00122     22*        26 FORMAT(1H ,15X,8HBASELINE,22X,F9.5,2X,2HIN)                          000001
00123     23*        27 FORMAT(1H ,15X,10HCAMERA FOV,20X,F9.5,2X,3HDEG)                      000001
00124     24*        28 FORMAT(1H ,15X,18HEXAGGERATION RATIO,12X,F9.5)                       000001
00125     25*        29 FORMAT(1H ,15X,18HMINIMUM RESOLUTION)                                000001
00126     26*        30 FORMAT(1H ,20X,10HHORIZONTAL,15X,F9.5,2X,2HIN)                       000001
00127     27*        31 FORMAT(1H ,20X,8HVERTICAL,17X,F9.5,2X,2HIN)                          000001
00130     28*       32   FORMAT (1H ,15X,23HCONVERGENCE RANGE LIMIT,7X,F9.5,//)              000001
00131     29*        33  FORMAT(7X,'DETECTABLE',2X,'DETECTABLE',3X,'RANGE',4X,'DETECTABLE',  000001
00131     30*           $14X,'WIDTH OF')                                                     000001
00132     31*        34  FORMAT(7X,'HORIZONTAL',3X,'VERTICAL  RESOLUTION   RANGE',5X,'LINEA  000001
00132     32*           $R',7X,'STEREO')                                                     000001
00133     33*        35  FORMAT(1X,'RANGE SEPERATION  SEPERATION',3X,'FACTOR   SEPARATION D  000001
00133     34*           $ISPARITY',2X,'FIELD OF VIEW')                                       000001
00134     35*        36  FORMAT(3X,'IN',6X,'IN',10X,'IN',9X,'IN',9X,'IN',8X,'IN',11X,'IN')   000001
00135     36*        37 FORMAT(1H )                                                          000001
00136     37*        38 FORMAT(1H ,F5.1,2X,F8.5,3X,F8.5,3X,F8.5,3X,F8.5,3X,F8.5,5X,F9.5)     000001
00136     38*     C     VALUES OF FIXED PARAMETERS                                           000001
00137     39*           REAL LDISP,L                                                         000001
00140     40*           REAL K,M,LAMDAY,LAMDAZ                                               000001
00141     41*           LAMDAY =0.00175                                                      000001
00142     42*           VDIST=19.0                                                           000003
00143     43*           L=VDIST                                                              000005
00144     44*           A = 2.5                                                              000006
00145     45*           THETAT =0.00076                                                      000010
00146     46*           DM = 1.09                                                            000012
00147     47*           LAMDAZ = 0.00175                                                     000014
00147     48*     C     READ SYSTEM PARAMETERS                                               000014
00150     49*        50 READ(5,10)I1,I2,X1,X2,X3,X4,X5,X6                                    000016
00152     50*           M = X2                                                               000032
00153     51*           B = X3                                                               000034
00154     52*           RM= X5                                                               000036
00155     53*           RCHANG = X6                                                          000040
00156     54*           IF(I1-1)200,51,52                                                    000042
00171     55*        51 K = X1                                                               000047
00172     56*           OMEGAR = 2.0*ATAN(M/(2.0*K))                                         000051
00173     57*           OMEGAD = 57.29578*OMEGAR                                             000061
00174     58*           GO TO 53                                                             000063
00175     59*        52 OMEGAD = X1                                                          000065
00176     60*           OMEGAR = OMEGAD/57.29578                                             000066
00177     61*           K =(M*COS(OMEGAR/2.0))/(2.0*SIN(OMEGAR/2.0))                         000070
00200     62*        53 IF(I2-1)57,54,55                                                     000106
00203     63*        54 BETAD =X4                                                            000112
00204     64*           BETAR =BETAD/57.29578                                                000114
00205     65*           RC=(B*COS(BETAR/2.0))/(2.0*SIN(BETAR/2.0))                           000116
00206     66*           GO TO 56                                                             000133
00207     67*        55 RC=X4                                                                000135
00210     68*           BETAR = 2.0*ATAN(B/(2.0*RC))                                         000136
```

```
00211     69*         BETAD = 57.29578*BETAR                                    000147
00212     70*      56 YRES = LAMDAY*L/K                                         000152
00213     71*         ZRES =LAMDAZ*L/K                                          000155
00214     72*         ETHETA =(B*K)/(VDIST*A)                                   000161
00215     73*         CONLIM = (B*K*RC)/(B*K-DM*RC)                             000170
00216     74*         GO TO 58                                                  000177
00217     75*      57 RC = (B*K*RM)/(DM*RM+B*K)                                 000201
00220     76*         BETAR = 2.0 * ATAN(B/(2.0 * RC))                          000212
00221     77*         BETAD = 57.29578 * BETAR                                  000223
00222     78*         GO TO 56                                                  000225
00222     79*   C     WRITE INPUT PARAMETERS                                    000225
00223     80*      58 WRITE(6,12)                                               000227
00225     81*         WRITE(6,13)                                               000233
00227     82*         WRITE(6,14)VDIST                                          000240
00232     83*         WRITE(6,15)A                                              000246
00235     84*         WRITE(6,16)                                               000254
00237     85*         WRITE(6,17)LAMDAY                                         000261
00242     86*         WRITE(6,18)LAMDAZ                                         000267
00245     87*         WRITE(6,19)THETAT                                         000275
00250     88*         WRITE(6,20)DM                                             000303
00253     89*         WRITE(6,21)                                               000311
00255     90*         WRITE(6,22)K                                              000316
00260     91*         WRITE(6,23)RM                                             000324
00263     92*         WRITE(6,39) M                                             000332
00266     93*         WRITE(6,24)BETAD                                          000340
00271     94*         WRITE(6,25)RC                                             000346
00274     95*         WRITE(6,26)B                                              000354
00277     96*         WRITE(6,27)OMEGAD                                         000362
00302     97*         WRITE(6,28)ETHETA                                         000370
00305     98*         WRITE(6,29)                                               000376
00307     99*         WRITE(6,30)YRES                                           000403
00312    100*         WRITE(6,31)ZRES                                           000411
00315    101*         WRITE(6,32)CONLIM                                         000417
00320    102*         WRITE(6,33)                                               000446
00322    103*         WRITE(6,34)                                               000453
00324    104*         WRITE(6,35)                                               000460
00326    105*         WRITE(6,36)                                               000465
00330    106*         WRITE(6,37)                                               000472
00330    107*   C     CALCULATION OF FUNCTIONS OF RANGE                         000472
00332    108*         DO 120 I=1,500                                            000507
00335    109*         AI = I-1                                                  000507
00336    110*         R = RC + AI*RCHANG                                        000514
00337    111*         IF(R-RM)110,110,50                                        000520
00342    112*     110 DELY= R*YRES                                              000523
00343    113*         DELZ= R*ZRES                                              000526
00344    114*         RRES=(THETAT*R)/(A*ETHETA)                                000531
00345    115*         DELR= R*RRES                                              000535
00346    116*         LDISP=(B*K/RC)-(B*K/R)                                    000537
00347    117*         ANG1=1.5708-(BETAR/2.0)-OMEGAR/2.0                        000543
00350    118*         ANG2=(OMEGAR/2.0)-(BETAR/2.0)                             000545
00351    119*         ANG3=(OMEGAR/2.0)+(BETAR/2.0)                             000547
00352    120*         F = SIN(ANG3)/COS(ANG3)                                   000551
00353    121*         RZERO = (B*SIN(ANG1))/(2.0 * COS(ANG1))                   000562
00354    122*         G = SIN(ANG2)/COS(ANG2)                                   000575
00355    123*         WR1 = F*(R-RZERO)*2.0                                     000606
00356    124*         WR2 = B*(2.0 * R * G)                                     000613
```

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
00357     125*            IF(WR1=WR2)111,111,112                                      000620
00362     126*        111 WR =WR1                                                     000623
00363     127*            GO TO 113                                                   000624
00364     128*        112 WR =WR2                                                     000626
00365     129*       113  IF(R-RZERO) 114,114,115                                     000630
00370     130*       114  WR = 0.0                                                    000633
00371     131*        115 WRITE(6,30)R,DELY,DELZ,RRES,DELP,LDISP,WR                   000635
00402     132*        120 CONTINUE                                                    000653
00404     133*        200 STOP                                                        000653
00405     134*            END                                                         000656

       END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@MAP,I MAPSOU.MAPABS
MAP26R1 RL71-3 02/16/77 18:14:50 (,0)
    1.        IN MARK
    2.        LIB SYS$*MSFCS.

ADDRESS LIMITS    001000 014061      5682 IBANK WORDS DECIMAL
                  040000 045163      2676 DBANK WORDS DECIMAL
STARTING ADDRESS  013203



          SEGMENT $MAIN$          001000 014061      040000 045163

NSWTC$/FOR69             $(1)    001000 001024
NRBLK$/MSFCE3B           $(1)    001025 001117     $(0)     040000 040001
NRWND$/FOR-E3            $(1)    001120 001203     $(2)     040002 040013
NWEF$/MSFCE3A            $(1)    001204 001425     $(2)     040014 040033
NBDCV$/FOR-E3            $(1)    001426 001556     $(2)     040034 040111
NFTCH$/FOR-E2            $(1)    001557 002041     $(2)     040112 040125
NFTV$/FOR-E2             $(1)    002042 002064
NCNVT$/FOR68             $(1)    002065 002306     $(2)     040126 040222
NCLOS$/MSFCE3B           $(1)    002307 002554     $(2)     040223 040251
NWBLK$/MSFCE3B           $(1)    002555 002733     $(0)     040252 040253
NRSBL$/FOR-E3            $(1)    002734 002770
NUPDA$/FOR68             $(1)    002771 003024
N3F00$                                             $(2)     040254 042501
NOTIN$/MSFCE3A           $(1)    003025 003324     $(2)     042502 042505
NOU1$/MSFCE3B            $(1)    003325 005042     $(2)     042506 042547
NIOER$/MSFCE3B           $(1)    005043 005300     $(2)     042550 042741
NININ$/MSFCE3C           $(1)    005301 005533     $(2)     042742 042742
NINPT$/MSFCE3B           $(1)    005534 007137     $(2)     042743 042776
NFMT$/FOR-E3             $(1)    007140 010022     $(2)     042777 043053
NFCHK$/MSFCE3B           $(1)    010023 011031     $(2)     043054 043240
                         $(3)    011032 011032     $(4)     043241 043312
NTAB$/MSFCE3A                                      $(2)     043313 043402
NERCOM$/FOR-TE3          $(1)    011033 011112     $(2)     043403 043416
FORVCOM$/FOR-TE3                                   $(2)     043417 043426
FORCOM$/MSFCE3A                                    $(2)     043427 043433
NERR$/MSFCE3A            $(1)    011113 011464     $(2)     043434 043614
ERU$/MSFCE3T
NOBUF$/FOR68             $(1)    011465 011525
SINCOS$/FOR-E3           $(1)    011526 011662     $(2)     043615 043637
ATAN$/FOR69              $(1)    011663 012066     $(2)     043640 043671
NIER$/MSFCE3B            $(1)    012067 012266     $(2)     043672 044013
NIBUF$/FOR-E2            $(1)    012267 012326     $(2)     044014 044014
UDMSYS(COMMONBLOCK)                                       044015 044027
H$MONITOR/MSFCE3C        $(1)    012327 013202     $(2)     044030 044510
                                                   $(4)     UDMSYS

BLANK$COMMON(COMMONBLOCK)
MARK                     $(1)    013203 014061     $(0)     044511 045163
                                                   $(2)     BLANK$COMMON

SYS$*RLIB$. LEVEL 71-3I
END MAP
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@XQT 'HAPABS
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            *** STEREO TV CALCULATIONS ***

     INPUT PARAMETERS
              VIEWING DISTANCE                 19.00000  IN
              INTEROCULAR DISTANCE  2.50000
              RESOLUTION THRESHOLDS
                   HORIZONTAL                    .00175  RAD
                   VERTICAL                      .00175  RAD
              DISPARITY THRESHOLD                .00076  RAD
              DISPARITY LIMIT                   1.09000  IN
     SYSTEM PARAMETERS
              SYSTEM CONSTANT                  31.50000  IN
              MAXIMUM RANGE                   120.00000  IN
              MONITOR WIDTH                     7.20000  IN
              CONVERGENCE ANGLE                 2.90779  DEG
              CONVERGENCE RANGE                78.80000  IN
              BASELINE                          4.00000  IN
              CAMERA FOV                       13.03960  DEG
              EXAGGERATION RATIO                2.65263
              MINIMUM RESOLUTION
                   HORIZONTAL                    .00106  IN
                   VERTICAL                      .00106  IN
              CONVERGENCE RANGE LIMIT         247.55161

     DETECTABLE  DETECTABLE   RANGE     DETECTABLE               WIDTH OF
     HORIZONTAL   VERTICAL  RESOLUTION    RANGE      LINEAR       STEREO
RANGE SEPERATION SEPERATION  FACTOR    SEPARATION DISPARITY  FIELD OF VIEW
 IN      IN          IN        IN          IN        IN           IN

 78.8   .08318     .08318     .00903     .71162     .00000     17.97090
 79.8   .08423     .08423     .00915     .72980     .02004     18.14820
 80.8   .08529     .08529     .00926     .74820     .03958     18.32550
 81.8   .08634     .08634     .00937     .76684     .05864     18.50279
 82.8   .08740     .08740     .00949     .78570     .07725     18.68009
 83.8   .08846     .08846     .00960     .80479     .09540     18.85738
 84.8   .08951     .08951     .00972     .82412     .11314     19.03468
 85.8   .09057     .09057     .00983     .84367     .13045     19.21197
 86.8   .09162     .09162     .00995     .86345     .14737     19.38927
 87.8   .09268     .09268     .01006     .88346     .16391     19.56657
 88.8   .09373     .09373     .01018     .90370     .18007     19.74386
 89.8   .09479     .09479     .01029     .92416     .19587     19.92116
 90.8   .09584     .09584     .01041     .94486     .21132     20.09845
 91.8   .09690     .09690     .01052     .96579     .22644     20.27575
 92.8   .09796     .09796     .01064     .98694     .24123     20.45304
 93.8   .09901     .09901     .01075    1.00833     .25570     20.63034
 94.8   .10007     .10007     .01086    1.02994     .26987     20.80764
 95.8   .10112     .10112     .01098    1.05179     .28374     20.98493
 96.8   .10218     .10218     .01109    1.07386     .29733     21.16223
 97.8   .10323     .10323     .01121    1.09616     .31064     21.33952
 98.8   .10429     .10429     .01132    1.11869     .32368     21.51682
 99.8   .10534     .10534     .01144    1.14145     .33646     21.69411
100.8   .10640     .10640     .01155    1.16444     .34898     21.87141
101.8   .10746     .10746     .01167    1.18766     .36126     22.04871
102.8   .10851     .10851     .01178    1.21111     .37330     22.22600
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103.8	.10957	.10957	.01190	1.23479	.38511	22.40330
104.8	.11062	.11062	.01201	1.25869	.39669	22.58059
105.8	.11168	.11168	.01213	1.28283	.40806	22.75789
106.8	.11273	.11273	.01224	1.30719	.41921	22.93518
107.8	.11379	.11379	.01235	1.33179	.43015	23.11248
108.8	.11484	.11484	.01247	1.35661	.44090	23.28978
109.8	.11590	.11590	.01258	1.38166	.45144	23.46707
110.8	.11696	.11696	.01270	1.40694	.46160	23.64437
111.8	.11801	.11801	.01281	1.43245	.47197	23.82166
112.8	.11907	.11907	.01293	1.45819	.48196	23.99896
113.8	.12012	.12012	.01304	1.48416	.49178	24.17625
114.8	.12118	.12118	.01316	1.51036	.50142	24.35355
115.8	.12223	.12223	.01327	1.53679	.51090	24.53085
116.8	.12329	.12329	.01339	1.56344	.52022	24.70814
117.8	.12434	.12434	.01350	1.59033	.52938	24.88544
118.8	.12540	.12540	.01361	1.61745	.53838	25.06273
119.8	.12646	.12646	.01373	1.64479	.54723	25.24003

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                    ***  STEREO TV CALCULATIONS  ***

      INPUT PARAMETERS
                VIEWING DISTANCE                  19.00000  IN
                INTEROCULAR DISTANCE  2.50000
                RESOLUTION THRESHOLDS
                     HORIZONTAL                     .00175  RAD
                     VERTICAL                       .00175  RAD
                DISPARITY THRESHOLD                 .00076  RAD
                DISPARITY LIMIT                    1.09000  IN
      SYSTEM PARAMETERS
                SYSTEM CONSTANT                   31.50000  IN
                MAXIMUM RANGE                    120.00000  IN
                MONITOR WIDTH                      7.20000  IN
                CONVERGENCE ANGLE                  3.63430  DEG
                CONVERGENCE RANGE                 78.80000  IN
                BASELINE                           5.00000  IN
                CAMERA FOV                        13.03960  DEG
                EXAGGERATION RATIO                 3.31579
                MINIMUM RESOLUTION
                     HORIZONTAL                     .00106  IN
                     VERTICAL                       .00106  IN
                CONVERGENCE RANGE LIMIT          173.31862


      DETECTABLE  DETECTABLE   RANGE     DETECTABLE              WIDTH OF
      HORIZONTAL   VERTICAL  RESOLUTION    RANGE      LINEAR      STEREO
RANGE SEPERATION  SEPERATION   FACTOR   SEPARATION DISPARITY  FIELD OF VIEW
  IN      IN          IN         IN         IN         IN           IN

 78.8    .08318      .08318     .00722     .56930     .00000     17.96442
 79.8    .08423      .08423     .00732     .58384     .02505     18.12894
 80.8    .08529      .08529     .00741     .59856     .04947     18.29347
 81.8    .08634      .08634     .00750     .61347     .07330     18.45799
 82.8    .08740      .08740     .00759     .62856     .09656     18.62251
 83.8    .08846      .08846     .00768     .64384     .11926     18.78704
 84.8    .08951      .08951     .00777     .65929     .14142     18.95156
 85.8    .09057      .09057     .00787     .67493     .16307     19.11608
 86.8    .09162      .09162     .00796     .69076     .18421     19.28061
 87.8    .09268      .09268     .00805     .70677     .20488     19.44513
 88.8    .09373      .09373     .00814     .72296     .22508     19.60965
 89.8    .09479      .09479     .00823     .73933     .24483     19.77418
 90.8    .09584      .09584     .00832     .75589     .26415     19.93870
 91.8    .09690      .09690     .00842     .77263     .28304     20.10322
 92.8    .09796      .09796     .00851     .78956     .30153     20.26775
 93.8    .09901      .09901     .00860     .80666     .31963     20.43227
 94.8    .10007      .10007     .00869     .82395     .33734     20.59679
 95.8    .10112      .10112     .00878     .84143     .35468     20.76131
 96.8    .10218      .10218     .00887     .85909     .37166     20.92584
 97.8    .10323      .10323     .00897     .87693     .38830     21.09036
 98.8    .10429      .10429     .00906     .89495     .40460     21.25488
 99.8    .10534      .10534     .00915     .91316     .42057     21.41941
100.8    .10640      .10640     .00924     .93155     .43623     21.58393
101.8    .10746      .10746     .00933     .95013     .45158     21.74845
102.8    .10851      .10851     .00942     .96889     .46663     21.91298
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103.8    .10957    .10957    .00952     .98783    .48139    22.07750
104.8    .11062    .11062    .00961    1.00695    .49587    22.24202
105.8    .11168    .11168    .00970    1.02626    .51007    22.40655
106.8    .11273    .11273    .00979    1.04575    .52401    22.57107
107.8    .11379    .11379    .00988    1.06543    .53769    22.73559
108.8    .11484    .11484    .00998    1.08529    .55112    22.90012
109.8    .11590    .11590    .01007    1.10533    .56430    23.06464
110.8    .11696    .11696    .01016    1.12555    .57725    23.22916
111.8    .11801    .11801    .01025    1.14596    .58997    23.39368
112.8    .11907    .11907    .01034    1.16655    .60245    23.55821
113.8    .12012    .12012    .01043    1.18733    .61472    23.72273
114.8    .12118    .12118    .01053    1.20829    .62678    23.88725
115.8    .12223    .12223    .01062    1.22943    .63863    24.05178
116.8    .12329    .12329    .01071    1.25076    .65027    24.21630
117.8    .12434    .12434    .01080    1.27226    .66172    24.38082
118.8    .12540    .12540    .01089    1.29396    .67297    24.54535
119.8    .12646    .12646    .01098    1.31583    .68404    24.70987
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*** STEREO TV CALCULATIONS ***

INPUT PARAMETERS
        VIEWING DISTANCE                      19.00000  IN
        INTEROCULAR DISTANCE  2.50000
        RESOLUTION THRESHOLDS
             HORIZONTAL                          .00175  RAD
             VERTICAL                            .00175  RAD
        DISPARITY THRESHOLD                      .00076  RAD
        DISPARITY LIMIT                         1.09000  IN
SYSTEM PARAMETERS
        SYSTEM CONSTANT                        31.50000  IN
        MAXIMUM RANGE                         120.00000  IN
        MONITOR WIDTH                           7.20000  IN
        CONVERGENCE ANGLE                       4.36052  DEG
        CONVERGENCE RANGE                      78.80000  IN
        BASELINE                                6.00000  IN
        CAMERA FOV                             13.03960  DEG
        EXAGGERATION RATIO                      3.97895
        MINIMUM RESOLUTION
             HORIZONTAL                          .00106  IN
             VERTICAL                            .00106  IN
        CONVERGENCE RANGE LIMIT       144.44272


      DETECTABLE  DETECTABLE   RANGE     DETECTABLE              WIDTH OF
      HORIZONTAL   VERTICAL  RESOLUTION    RANGE      LINEAR       STEREO
RANGE SEPERATION  SEPERATION   FACTOR   SEPARATION DISPARITY  FIELD OF VIEW
  IN      IN          IN         IN         IN         IN           IN

 78.8    .08318     .08318     .00602     .47441     .00000      17.95939
 79.8    .08423     .08423     .00610     .48653     .03006      18.11116
 80.8    .08529     .08529     .00617     .49880     .05937      18.26293
 81.8    .08634     .08634     .00625     .51122     .08796      18.41470
 82.8    .08740     .08740     .00633     .52380     .11567      18.56647
 83.8    .08846     .08846     .00640     .53653     .14311      18.71824
 84.8    .08951     .08951     .00648     .54941     .16970      18.87001
 85.8    .09057     .09057     .00656     .56244     .19568      19.02178
 86.8    .09162     .09162     .00663     .57563     .22106      19.17354
 87.8    .09268     .09268     .00671     .58897     .24586      19.32531
 88.8    .09373     .09373     .00678     .60246     .27010      19.47708
 89.8    .09479     .09479     .00686     .61611     .29380      19.62885
 90.8    .09584     .09584     .00694     .62991     .31698      19.78062
 91.8    .09690     .09690     .00701     .64386     .33965      19.93239
 92.8    .09796     .09796     .00709     .65796     .36184      20.08416
 93.8    .09901     .09901     .00717     .67222     .38355      20.23593
 94.8    .10007     .10007     .00724     .68663     .40481      20.38770
 95.8    .10112     .10112     .00732     .70119     .42562      20.53947
 96.8    .10218     .10218     .00740     .71591     .44600      20.69123
 97.8    .10323     .10323     .00747     .73077     .46596      20.84300
 98.8    .10429     .10429     .00755     .74579     .48552      20.99477
 99.8    .10534     .10534     .00762     .76097     .50469      21.14654
100.8    .10640     .10640     .00770     .77629     .52348      21.29831
101.8    .10746     .10746     .00778     .79177     .54190      21.45008
102.8    .10851     .10851     .00785     .80741     .55996      21.60185
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103.8     .10957     .10957     .00793     .82319     .57767     21.75362
104.8     .11062     .11062     .00801     .83913     .59504     21.90539
105.8     .11168     .11168     .00809     .85522     .61209     22.05715
106.8     .11273     .11273     .00816     .87146     .62881     22.20892
107.8     .11379     .11379     .00824     .88786     .64523     22.36069
108.8     .11484     .11484     .00831     .90441     .66134     22.51246
109.8     .11590     .11590     .00839     .92111     .67717     22.66423
110.8     .11696     .11696     .00847     .93796     .69270     22.81600
111.8     .11801     .11801     .00854     .95497     .70796     22.96777
112.8     .11907     .11907     .00862     .97213     .72295     23.11954
113.8     .12012     .12012     .00869     .98944     .73767     23.27131
114.8     .12118     .12118     .00877    1.00691     .75214     23.42308
115.8     .12223     .12223     .00885    1.02452     .76635     23.57484
116.8     .12329     .12329     .00892    1.04230     .78033     23.72661
117.8     .12434     .12434     .00900    1.06022     .79406     23.87838
118.8     .12540     .12540     .00908    1.07830     .80757     24.03015
119.8     .12646     .12646     .00915    1.09653     .82085     24.18192
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             *** STEREO TV CALCULATIONS ***

      INPUT PARAMETERS
              VIEWING DISTANCE                 19.00000  IN
              INTEROCULAR DISTANCE  2.50000
              RESOLUTION THRESHOLDS
                   HORIZONTAL                    .00175  RAD
                   VERTICAL                      .00175  RAD
              DISPARITY THRESHOLD                .00076  RAD
              DISPARITY LIMIT                   1.09000  IN
      SYSTEM PARAMETERS
              SYSTEM CONSTANT                  31.50000  IN
              MAXIMUM RANGE                   120.00000  IN
              MONITOR WIDTH                     7.20000  IN
              CONVERGENCE ANGLE                 5.08636  DEG
              CONVERGENCE RANGE                78.80000  IN
              BASELINE                          7.00000  IN
              CAMERA FOV                       13.03960  DEG
              EXAGGERATION RATIO                4.64211
              MINIMUM RESOLUTION
                   HORIZONTAL                    .00106  IN
                   VERTICAL                      .00106  IN
              CONVERGENCE RANGE LIMIT         129.08148

      DETECTABLE  DETECTABLE   RANGE    DETECTABLE               WIDTH OF
      HORIZONTAL   VERTICAL  RESOLUTION   RANGE      LINEAR       STEREO
RANGE SEPERATION  SEPERATION   FACTOR   SEPARATION DISPARITY  FIELD OF VIEW
  IN      IN          IN         IN         IN         IN          IN

 78.8    .08318     .08318     .00516     .40664     .00000     17.95582
 79.8    .08423     .08423     .00523     .41703     .03507     18.09485
 80.8    .08529     .08529     .00529     .42754     .06926     18.23388
 81.8    .08634     .08634     .00536     .43819     .10262     18.37291
 82.8    .08740     .08740     .00542     .44897     .13518     18.51195
 83.8    .08846     .08846     .00549     .45983     .16696     18.65098
 84.8    .08951     .08951     .00555     .47092     .19799     18.79001
 85.8    .09057     .09057     .00562     .48210     .22829     18.92905
 86.8    .09162     .09162     .00568     .49340     .25790     19.06808
 87.8    .09268     .09268     .00575     .50483     .28683     19.20711
 88.8    .09373     .09373     .00582     .51640     .31512     19.34615
 89.8    .09479     .09479     .00588     .52809     .34277     19.48518
 90.8    .09584     .09584     .00595     .53992     .36981     19.62421
 91.8    .09690     .09690     .00601     .55183     .39626     19.76325
 92.8    .09796     .09796     .00608     .56397     .42215     19.90228
 93.8    .09901     .09901     .00614     .57619     .44748     20.04131
 94.8    .10007     .10007     .00621     .58854     .47227     20.18035
 95.8    .10112     .10112     .00627     .60102     .49655     20.31938
 96.8    .10218     .10218     .00634     .61363     .52033     20.45841
 97.8    .10323     .10323     .00640     .62638     .54362     20.59745
 98.8    .10429     .10429     .00647     .63925     .56644     20.73648
 99.8    .10534     .10534     .00654     .65226     .58880     20.87551
100.8    .10640     .10640     .00660     .66540     .61072     21.01455
101.8    .10746     .10746     .00667     .67866     .63221     21.15358
102.8    .10851     .10851     .00673     .69205     .65328     21.29261
```

103.8	.10957	.10957	.00680	.70559	.67395	21.43164
104.8	.11062	.11062	.00686	.71925	.69422	21.57068
105.8	.11168	.11168	.00693	.73304	.71410	21.70971
106.8	.11273	.11273	.00699	.74697	.73362	21.84874
107.8	.11379	.11379	.00706	.76102	.75277	21.98778
108.8	.11484	.11484	.00713	.77520	.77157	22.12681
109.8	.11590	.11590	.00719	.78952	.79003	22.26584
110.8	.11696	.11696	.00726	.80397	.80615	22.40488
111.8	.11801	.11801	.00732	.81854	.82595	22.54391
112.8	.11907	.11907	.00739	.83325	.84344	22.68294
113.8	.12012	.12012	.00745	.84809	.86061	22.82198
114.8	.12118	.12118	.00752	.86306	.87749	22.96101
115.8	.12223	.12223	.00758	.87816	.89438	23.10004
116.8	.12329	.12329	.00765	.89340	.91038	23.23908
117.8	.12434	.12434	.00771	.90876	.92641	23.37811
118.8	.12540	.12540	.00778	.92425	.94216	23.51714
119.8	.12646	.12646	.00785	.93988	.95766	23.65618

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***  STEREO TV CALCULATIONS  ***

INPUT PARAMETERS
        VIEWING DISTANCE                   19.00000  IN
        INTEROCULAR DISTANCE   2.50000
        RESOLUTION THRESHOLDS
             HORIZONTAL                      .00175  RAD
             VERTICAL                        .00175  RAD
        DISPARITY THRESHOLD                  .00076  RAD
        DISPARITY LIMIT                     1.09000  IN
SYSTEM PARAMETERS
        SYSTEM CONSTANT                    31.50000  IN
        MAXIMUM RANGE                     120.00000  IN
        MONITOR WIDTH                       7.20000  IN
        CONVERGENCE ANGLE                   5.81184  DEG
        CONVERGENCE RANGE                  78.80000  IN
        BASELINE                            8.00000  IN
        CAMERA FOV                         13.03960  DEG
        EXAGGERATION RATIO                  5.30526
        MINIMUM RESOLUTION
             HORIZONTAL                      .00106  IN
             VERTICAL                        .00106  IN
        CONVERGENCE RANGE LIMIT           119.54632

      DETECTABLE  DETECTABLE    RANGE    DETECTABLE             WIDTH OF
      HORIZONTAL   VERTICAL   RESOLUTION   RANGE      LINEAR     STEREO
RANGE SEPERATION  SEPERATION   FACTOR   SEPARATION DISPARITY  FIELD OF VIEW
 IN       IN          IN         IN         IN         IN           IN

 78.8   .08318      .08318     .00452     .35581     .00000      17.95368
 79.8   .08423      .08423     .00457     .36490     .04007      18.08000
 80.8   .08529      .08529     .00463     .37410     .07916      18.20632
 81.8   .08634      .08634     .00469     .38342     .11728      18.33263
 82.8   .08740      .08740     .00474     .39285     .15449      18.45895
 83.8   .08846      .08846     .00480     .40240     .19081      18.58526
 84.8   .08951      .08951     .00486     .41206     .22627      18.71158
 85.8   .09057      .09057     .00492     .42183     .26091      18.83789
 86.8   .09162      .09162     .00497     .43172     .29474      18.96421
 87.8   .09268      .09268     .00503     .44173     .32781      19.09053
 88.8   .09373      .09373     .00509     .45185     .36013      19.21684
 89.8   .09479      .09479     .00515     .46208     .39173      19.34316
 90.8   .09584      .09584     .00520     .47243     .42264      19.46947
 91.8   .09690      .09690     .00526     .48289     .45287      19.59579
 92.8   .09796      .09796     .00532     .49347     .48245      19.72211
 93.8   .09901      .09901     .00537     .50416     .51140      19.84842
 94.8   .10007      .10007     .00543     .51497     .53974      19.97474
 95.8   .10112      .10112     .00549     .52585     .56749      20.10105
 96.8   .10218      .10218     .00555     .53693     .59466      20.22737
 97.8   .10323      .10323     .00560     .54808     .62128      20.35368
 98.8   .10429      .10429     .00566     .55935     .64736      20.48000
 99.8   .10534      .10534     .00572     .57073     .67292      20.60632
100.8   .10640      .10640     .00578     .58222     .69797      20.73263
101.8   .10746      .10746     .00583     .59383     .72253      20.85895
102.8   .10851      .10851     .00589     .60555     .74661      20.98526
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103.8    .10957    .10957    .00595    .61739     .77022    21.11158
104.8    .11062    .11062    .00601    .62935     .79339    21.23789
105.8    .11168    .11168    .00606    .64141     .81612    21.36421
106.8    .11273    .11273    .00612    .65360     .83842    21.49053
107.8    .11379    .11379    .00618    .66589     .86031    21.61684
108.8    .11484    .11484    .00623    .67830     .88179    21.74316
109.8    .11590    .11590    .00629    .69083     .90289    21.86947
110.8    .11696    .11696    .00635    .70347     .92360    21.99579
111.8    .11801    .11801    .00641    .71623     .94394    22.12211
112.8    .11907    .11907    .00646    .72910     .96393    22.24842
113.8    .12012    .12012    .00652    .74208     .98356    22.37474
114.8    .12118    .12118    .00658    .75518    1.00285    22.50105
115.8    .12223    .12223    .00664    .76839    1.02180    22.62737
116.8    .12329    .12329    .00669    .78172    1.04044    22.75368
117.8    .12434    .12434    .00675    .79516    1.05875    22.88000
118.8    .12540    .12540    .00681    .80872    1.07676    23.00632
119.8    .12646    .12646    .00686    .82239    1.09446    23.13263
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*** STEREO TV CALCULATIONS ***

INPUT PARAMETERS
     VIEWING DISTANCE                    19.00000  IN
     INTEROCULAR DISTANCE  2.50000
     RESOLUTION THRESHOLDS
          HORIZONTAL                       .00175  RAD
          VERTICAL                         .00175  RAD
     DISPARITY THRESHOLD                   .00076  RAD
     DISPARITY LIMIT                      1.09000  IN
SYSTEM PARAMETERS
     SYSTEM CONSTANT                     31.50000  IN
     MAXIMUM RANGE                      120.00000  IN
     MONITOR WIDTH                        7.20000  IN
     CONVERGENCE ANGLE                    6.53683  DEG
     CONVERGENCE RANGE                   78.80000  IN
     BASELINE                             9.00000  IN
     CAMERA FOV                          13.03960  DEG
     EXAGGERATION RATIO                   5.96842
     MINIMUM RESOLUTION
          HORIZONTAL                       .00106  IN
          VERTICAL                         .00106  IN
     CONVERGENCE RANGE LIMIT            113.05109

      DETECTABLE  DETECTABLE   RANGE     DETECTABLE                WIDTH OF
      HORIZONTAL  VERTICAL   RESOLUTION    RANGE      LINEAR        STEREO
RANGE SEPERATION  SEPERATION   FACTOR    SEPARATION DISPARITY  FIELD OF VIEW
 IN       IN          IN         IN          IN         IN           IN

 78.8    .08318      .08318     .00401      .31628     .00000     17.95300
 79.8    .08423      .08423     .00406      .32435     .04508     18.06661
 80.8    .08529      .08529     .00412      .33253     .08905     18.18023
 81.8    .08634      .08634     .00417      .34082     .13195     18.29385
 82.8    .08740      .08740     .00422      .34920     .17380     18.40746
 83.8    .08846      .08846     .00427      .35759     .21466     18.52108
 84.8    .08951      .08951     .00432      .36627     .25456     18.63470
 85.8    .09057      .09057     .00437      .37496     .29352     18.74831
 86.8    .09162      .09162     .00442      .38375     .33159     18.86193
 87.8    .09268      .09268     .00447      .39265     .36879     18.97555
 88.8    .09373      .09373     .00452      .40164     .40515     19.08916
 89.8    .09479      .09479     .00457      .41074     .44070     19.20278
 90.8    .09584      .09584     .00462      .41994     .47547     19.31640
 91.8    .09690      .09690     .00468      .42924     .50948     19.43001
 92.8    .09796      .09796     .00473      .43864     .54276     19.54363
 93.8    .09901      .09901     .00478      .44815     .57533     19.65725
 94.8    .10007      .10007     .00483      .45775     .60721     19.77086
 95.8    .10112      .10112     .00488      .46746     .63843     19.88448
 96.8    .10218      .10218     .00493      .47727     .66900     19.99810
 97.8    .10323      .10323     .00498      .48718     .69894     20.11171
 98.8    .10429      .10429     .00503      .49720     .72828     20.22533
 99.8    .10534      .10534     .00508      .50731     .75703     20.33895
100.8    .10640      .10640     .00513      .51753     .78522     20.45256
101.8    .10746      .10746     .00519      .52785     .81284     20.56618
102.8    .10851      .10851     .00524      .53827     .83993     20.67980
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103.8     .10957     .10957     .00529     .54879     .86650      20.79341
104.8     .11062     .11062     .00534     .55942     .89256      20.90703
105.8     .11168     .11168     .00539     .57015     .91813      21.02065
106.8     .11273     .11273     .00544     .58097     .94322      21.13426
107.8     .11379     .11379     .00549     .59190     .96785      21.24788
108.8     .11484     .11484     .00554     .60294     .99202      21.36150
109.8     .11590     .11590     .00559     .61407    1.01575      21.47512
110.8     .11696     .11696     .00564     .62531    1.03905      21.58873
111.8     .11801     .11801     .00569     .63665    1.06194      21.70235
112.8     .11907     .11907     .00575     .64809    1.08442      21.81597
113.8     .12012     .12012     .00580     .65963    1.10650      21.92958
114.8     .12118     .12118     .00585     .67127    1.12820      22.04320
115.8     .12223     .12223     .00590     .68302    1.14953      22.15682
116.8     .12329     .12329     .00595     .69486    1.17049      22.27043
117.8     .12434     .12434     .00600     .70681    1.19109      22.38405
118.8     .12540     .12540     .00605     .71886    1.21135      22.49767
119.8     .12646     .12646     .00610     .73102    1.23127      22.61129
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              ***  STEREO TV CALCULATIONS  ***

     INPUT PARAMETERS
           VIEWING DISTANCE                  19.00000  IN
           INTEROCULAR DISTANCE  2.50000
           RESOLUTION THRESHOLDS
                HORIZONTAL                     .00175  RAD
                VERTICAL                       .00175  RAD
           DISPARITY THRESHOLD                 .00076  RAD
           DISPARITY LIMIT                    1.09000  IN
     SYSTEM PARAMETERS
           SYSTEM CONSTANT                   31.50000  IN
           MAXIMUM RANGE                    120.00000  IN
           MONITOR WIDTH                      7.20000  IN
           CONVERGENCE ANGLE                  7.26130  DEG
           CONVERGENCE RANGE                 78.80000  IN
           BASELINE                          10.00000  IN
           CAMERA FOV                        13.03960  DEG
           EXAGGERATION RATIO                 6.63158
           MINIMUM RESOLUTION
                HORIZONTAL                     .00106  IN
                VERTICAL                       .00106  IN
           CONVERGENCE RANGE LIMIT          108.34192

     DETECTABLE  DETECTABLE   RANGE     DETECTABLE               WIDTH OF
     HORIZONTAL   VERTICAL  RESOLUTION    RANGE     LINEAR        STEREO
RANGE SEPERATION SEPERATION   FACTOR   SEPARATION DISPARITY  FIELD OF VIEW
  IN      IN         IN         IN         IN         IN           IN

 78.8    .08318     .08318     .00361     .28465     .00000      17.95375
 79.8    .08423     .08423     .00366     .29192     .05009      18.05469
 80.8    .08529     .08529     .00370     .29928     .09895      18.15562
 81.8    .08634     .08634     .00375     .30673     .14661      18.25656
 82.8    .08740     .08740     .00380     .31428     .19311      18.35749
 83.8    .08846     .08846     .00384     .32192     .23851      18.45843
 84.8    .08951     .08951     .00389     .32965     .28284      18.55937
 85.8    .09057     .09057     .00393     .33747     .32613      18.66030
 86.8    .09162     .09162     .00398     .34538     .36843      18.76124
 87.8    .09268     .09268     .00402     .35338     .40976      18.86217
 88.8    .09373     .09373     .00407     .36148     .45016      18.96311
 89.8    .09479     .09479     .00412     .36967     .48967      19.06405
 90.8    .09584     .09584     .00416     .37794     .52830      19.16498
 91.8    .09690     .09690     .00421     .38632     .56609      19.26592
 92.8    .09796     .09796     .00425     .39478     .60307      19.36685
 93.8    .09901     .09901     .00430     .40333     .63925      19.46779
 94.8    .10007     .10007     .00435     .41198     .67468      19.56873
 95.8    .10112     .10112     .00439     .42071     .70936      19.66966
 96.8    .10218     .10218     .00444     .42954     .74333      19.77060
 97.8    .10323     .10323     .00448     .43846     .77660      19.87153
 98.8    .10429     .10429     .00453     .44748     .80920      19.97247
 99.8    .10534     .10534     .00457     .45658     .84115      20.07341
100.8    .10640     .10640     .00462     .46579     .87246      20.17434
101.8    .10746     .10746     .00467     .47506     .90316      20.27528
102.8    .10851     .10851     .00471     .48444     .93326      20.37621
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103.9	.10957	.10957	.00476	.49391	.96278	20.47715
104.8	.11062	.11062	.00480	.50348	.99174	20.57808
105.8	.11168	.11168	.00485	.51313	1.02015	20.67902
106.8	.11273	.11273	.00490	.52288	1.04802	20.77996
107.8	.11379	.11379	.00494	.53271	1.07538	20.88089
108.9	.11484	.11484	.00499	.54264	1.10224	20.98183
109.8	.11590	.11590	.00503	.55266	1.12861	21.08276
110.8	.11695	.11696	.00508	.56278	1.15450	21.18370
111.8	.11801	.11801	.00513	.57298	1.17993	21.28464
112.8	.11907	.11907	.00517	.58328	1.20491	21.38557
113.9	.12012	.12012	.00522	.59366	1.22945	21.48651
114.8	.12119	.12118	.00526	.60414	1.25356	21.58744
115.8	.12223	.12223	.00531	.61471	1.27725	21.68838
116.9	.12329	.12329	.00535	.62538	1.30054	21.78932
117.8	.12434	.12434	.00540	.63613	1.32344	21.89025
118.8	.12540	.12540	.00545	.64698	1.34595	21.99119
119.8	.12646	.12646	.00549	.65792	1.36808	22.09212