SIMULATION OF THE PILOT'S VISUAL WORLD

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I. INTRODUCTION

The studies being reported here today were conducted by the Martin Marietta Corporation's Orlando Division under a current contract to the Naval Training Device Center.

Historically, in the field of military visual simulation, a general rule has been to attempt 1:1 replication whenever possible. In cases where the effect of specific parameters on simulation were know, trade-offs of less than 1:1 were made to reduce cost. However, when little or no information of this type was available, every effort was made to produce 1:1 simulation since the effects of anything less than 1:1 could not be readily predicted in terms of simulation adequacy. There is still another case where, even when 1:1 seems desirable without regard to cost, it may not be possible within the state-of-the-art to produce it.

Our studies fall in this last category. A T.V. system is being used to represent the pilot's view of the outside world through a windscreen. In this case, many of the parameters of vision cannot be met by state-of-the-art television systems. Therefore, we are attempting to determine the specific television simulation parameters required to display targets relative to the same fidelity as actually perceived by a pilot under given tactical conditions of air-to-surface target acquisition. Since our primary goal is to delineate an approach to the problem, rather than to define specific T.V. system requirements, we chose to use the available and representative high resolution T.V. system attached to the Martin Marietta Guidance Development Center. Later, as we understand the role of each variable, we can then relate the data from our T.V. system to other T.V. systems including those of the future. The stress in our tests is to determine the psychophysical equivalence of performance rather than the role of specific electro-optical T.V. parameters.

This work is currently in progress and only preliminary data is being reported at this time. However, the final report covering this work will be available 17 February 1969.

II. OBJECTIVES

BASIC OBJECTIVES

- To obtain data on pilot's basic visual capability to acquire targets.
- To establish the basis for determining the optimum T.V. simulation parameters to provide the same capability.

In more definitive form, the objectives of this study are:

1. To determine the basic capability of the human eye to recognize targets relative to the following simulated conditions: target size, contrast, reflectance, background, and flight parameters (i.e., speed and altitude).

This capability will be measured in terms of visual angle subtended by the target at the acquisition slant range.

2. To determine the basic human visual resolution capability in terms of visual angle when directly viewing bar charts of the same contrast and reflectance as the simulated targets.

3. To determine the resolution capability of the eye and T.V. display combination with the T.V. camera viewing bar charts of the same contrast and reflectance as the simulated target. The T.V. system will be adjusted to have essentially linear gray scale transfer characteristics.

4. To determine the relationship between target image size and contrast on the T.V. display to replicate basic unaided human vision capability. It is expected that these data will indicate the trade-offs available between contrast and target image size on the T.V. display to produce psychophysical performance equivalent to that of the eye against simulated targets.

5. To develop the necessary control techniques for running these types of tests in the Guidance Development Center simulator. This involves:

- Generation of targeting and stimulation materials and establishment of photometric techniques to achieve contrast values as low as 5 percent to accuracies of ± 2 percent. This applies both to direct view simulated targets and to T.V. displayed target images.
- Determination of T.V. system set-up and controls so that manipulated parameters can be accurately repeated day-to-day and also so that a high degree of short term stability can be achieved.

Figure 85 is a photo of the special gray scale chart which was used to calibrate the brightness of the lighting in the GDC and to establish the contrast transfer characteristics of the T.V. system. The terrain model can be seen in the background.

Figure 86 is a photograph of the GDC terrain model.

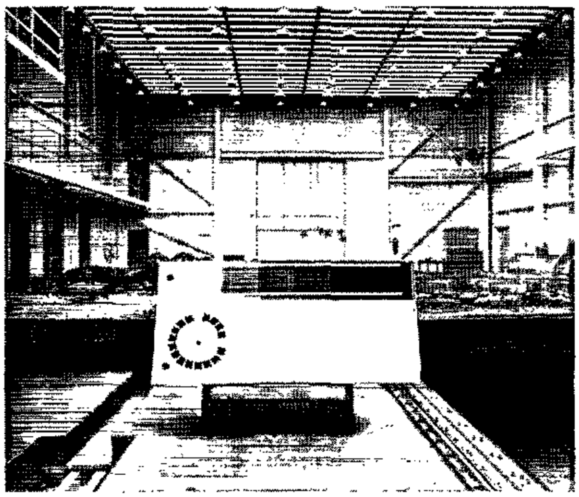

Figure 85. Special Gray Scale Chart in the GDC Lab

Figure 86. Nighttime View of GDC Terrain Model

III. STUDY RATIONALE AND CONSTRAINTS

° In order to devote our main efforts to obtaining foundation-type data, bounds have been placed on this initial experimental study by establishing the following ground rules:

1. Measurement of direct viewing and displayed viewing resolution as well as target recognition threshold values will be emphasized under essentially static conditions.
2. Evaluation of the contrast and resolution degradation caused by atmospheric effects is not included in this study. A device to simulate this effect is planned. Actually, once the basic transfer data (real world to T.V.) is available, the atmospheric parameter will help the T.V. to approach 1:1 simulation since the eye performance is reduced by the atmosphere, but the T.V. simulator can work in clear air with no reduction in performance.
3. Simulated targets are limited to simple shapes viewed against relatively uniform backgrounds.
4. Daylight target illumination levels are used (approximately 200 foot candles).

° Direct eyeball capability is the reference used in evaluating T.V. simulation performance.

° Measured T.V. system performance is that achieved by the 1029 scan line closed circuit T.V. system located in Martin Marietta's GDC facility. The equipment includes a high resolution camera (COHU) using a 1 inch vidicon sensor, and a high resolution, 14 inch display (MIRATEL). It operates at standard frame rates with a standard scan format.

IV. TEST SUMMARY

The objectives previously described are being met by the following tests:

Category I - Resolution Tests-Bar Chart Targets
1. Direct vision resolution
2. TV-Limited resolution
3. Eyeball-limited resolution.

Category II - Recognition Tests - Simulated Targets
1. Direct vision recognition
2. TV recognition

Category I represents static tests which employ resolution bar charts. They provide data on the relative resolution capabilities of direct vision compared to viewing of the test TV display. Category II tests use real world forms and shapes. These tests provide data to compare target recognition achieved by direct vision and by viewing the test TV display.

V. TEST SET-UP AND PROCEDURES

A. Category I Tests

Figure 87 depicts major Category I test elements and identifies certain visual angles which are the dependent variables in the graphical data which will be discussed shortly.

In these and in planned Category II tests, experienced former military pilots are used as the test subjects. Test variables are presented to these subjects in a counterbalanced fashion. GDC Lab lighting is carefully balanced to provide essentially uniform target illumination at all viewing distances.

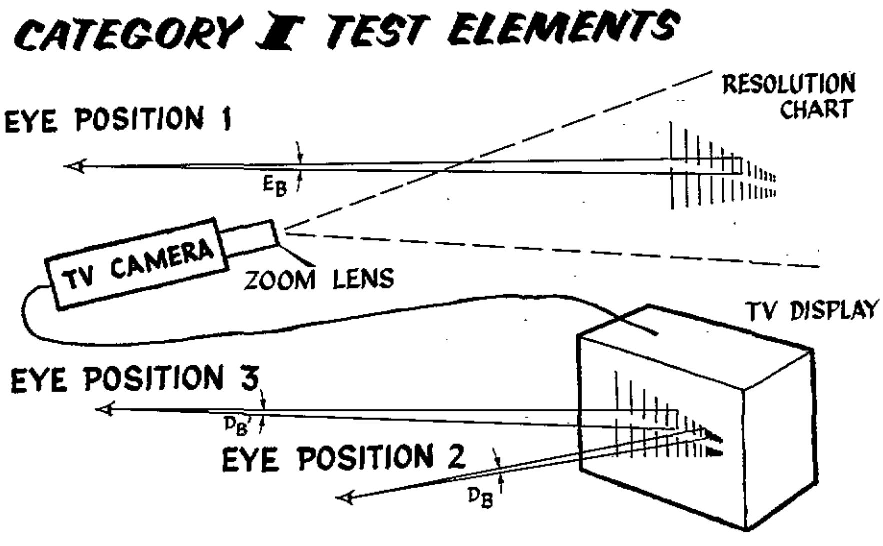

Figure 87. Category I Test Elements

The direct visual resolution test is depicted at top, corresponding to eye position 1. The test subject is in a seat which is located on the GDC transverse carriage and vertical beam assembly. The selected bar charts (three bar orientations, Horizontal, Vertical, and Diagonal and six contrasts - 5, 10, 15, 20, 25 and 35%) are sequentially mounted at the front of the terrain model, which provides accurate longitudinal positioning (viewing distance) relative to the observer. In this static test, two sets of elevation viewing angles are used (simulated 3,000 feet and 7,000 feet altitudes) together with four viewing distances (15, 20, 40 and 65 feet). As suspected, these different range and altitudes are essentially test replications. The threshold eyeball-bar chart resolution angle, E_B is computed relative to eye position 1 for horizontal, vertical, and diagonal bar types.

Eye position 2 corresponds to the close viewing distance (nominally 30 inches) used in the TV limited resolution tests. Here the TV camera uses a zoom lens to view the same series of bar charts previously described (which have white backgrounds approaching 100% reflectance) and in addition views a similar series of charts with 40% background reflectances. The test subjects observe the smallest discernible bar set and indicate when this bar set alternately becomes undiscernible and then discernible as the calibrated zoom lens is slowly adjusted over a very limited field-of-view range (method of limits test). The TV-limited horizontal, vertical, and diagonal resolutions are calculated based on the size of the smallest viewed bars relative to display raster height.

The corresponding displayed bar chart resolution angles, D_B, are computed relative to eye position 2.

The eyeball-limited T.V. resolution tests are conducted using the same procedure and setup just described except that the eye is located at an extended viewing distance represented by eye position 3. In our tests, this average distance equals 19 feet. Under these conditions, the observed T.V. resolution is limited primarily by the subject's visual acuity rather than by the actual number of T.V. resolution lines available. The corresponding displayed bar chart resolution angles, D_B' are computed relative to this eye position.

DISCUSSION OF EXTENDED DISPLAY VIEWING

This extreme viewing case was selected to permit us to assess how closely we could approach direct vision resolution performance using an idealized T.V. display. With a fixed number of measured T.V. resolution lines (and fixed video bandwidth), we have decreased the angle subtended by a displayed resolution element approximately by the ratio of viewing distances (19 feet to 2.5 feet $\cong$ 7.5 to 1). Thus relative to the eye, the displayed spatial frequency corresponding to a particular bar image spacing is increased 7.5 times. The eye then perceives an apparent high resolution image, in which the visible noise has actually decreased to a very low level. Of course, the total display viewing angle decreases with increased viewing distance. At 19 feet, the total vertical viewing angle is about 2°, which generally would not be useful for a T.V. simulation. If, for example, a 20° by 20° minimum display viewing angle were specified in which equivalent resolution were required over this much larger display area, video bandwidth would have to be increased by 100 times. This represents a 100 times increase in video noise power, and $\sqrt{100}$ = 10 times increase in video noise voltage. This would decrease the video S/N by 20 db, which represents a very significant degradation factor.

Therefore, our extended viewing case may be considered idealized from the noise standpoint if the T.V. display system we use is thought of as one small portion of the large system just postulated. Although an equivalent level of performance with wide display viewing angles is not attainable with known hardware and techniques, the idealized presentation does represent a maximum system performance limit. It was considered instructive, therefore, to evaluate the subject's visual performance under such conditions.

V-H Bar Chart. A photograph of one of the V-H resolution bar charts is shown in Figure 88. The resolution elements are arranged in sets of four bars and three spaces, and a size ratio of $1/\sqrt{2}$ is maintained between successive sets. A total of 13 bar sets of H and V orientations are provided on this chart.

It should be noted at this point that by the definition we are using, a visual resolution angle subtends a bar and a space.

As previously indicated, both 100% and 40% background reflectance charts are used in our tests, each with the six bar-to-background contrast levels. This represents the situations in which a range of low contrast targets are viewed against a high brightness background and against a lower brightness background. The significance of the reduced video S/N values expected with the lower brightness background will be evaluated.

DIAGONAL BAR CHART

Figure 89 is a photograph of one of the diagonal bar charts. Both diagonal orientations are shown, and again there are 13 bar sets for each orientation. Since many man-made objects of military significance have diagonal structures, a knowledge of this effect is important.

B. CATEGORY II TESTS

Major test elements included in Category II target recognition tests, together with pertinent visual angles, are shown in Figure 90.

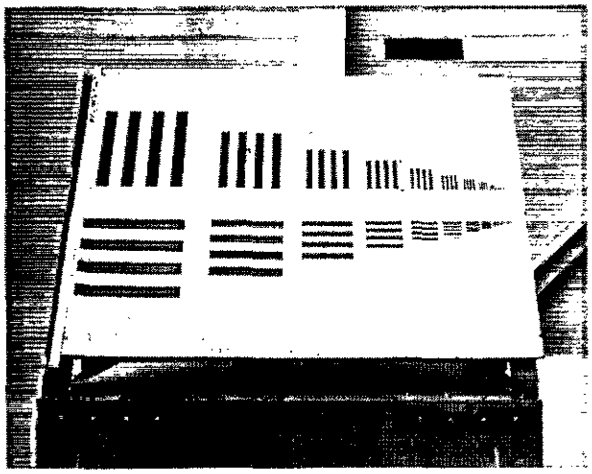

Figure 88. Vertical - Horizontal Resolution Bar Chart

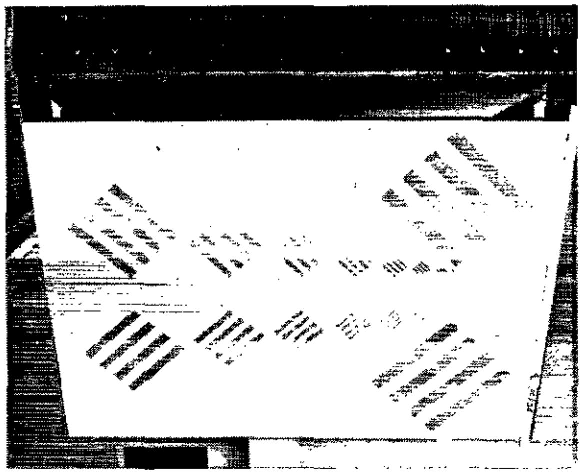

Figure 89. Diagonal Resolution Bar Chart

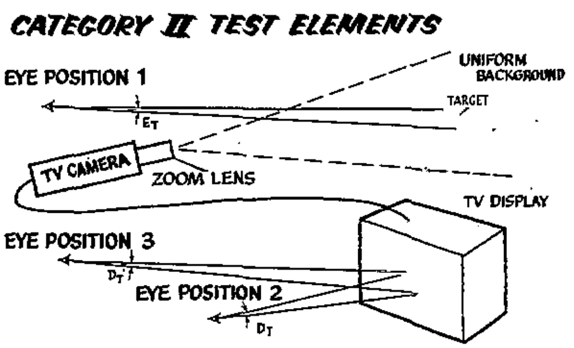

Figure 90. Category II Test Elements

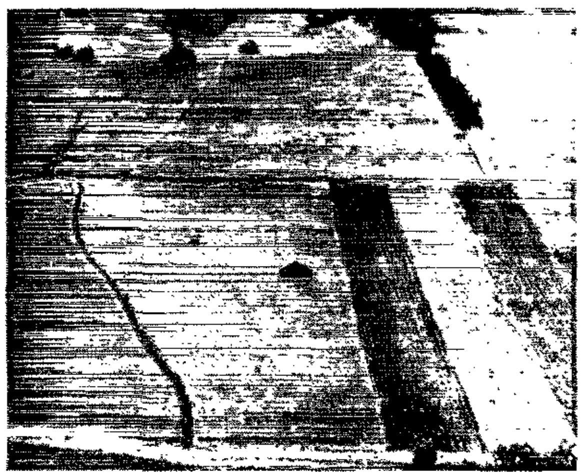

Figure 91. Typical Target on GDC Terrain Model

The direct visual target recognition test, corresponding to eye position 1 is depicted at the top. The subject is located in the GDC lab in similar fashion to that used in the Category I direct vision test. Two dimensional test targets, representing a left shed, right shed, and house, are provided. Figure 91 shows one of the targets located on the terrain model. Relative to the selected uniform background area, target contrast values range from 5% to 35%.

The subject is briefed as to target position on the terrain model. At the start of the run, the subtended target size will be below the subject's visual recognition threshold. The terrain model then is translated at a longitudinal simulated velocity of 350 knots towards the subject. The subject indicates the moment of target recognition on a strip-chart recorder by depressing an event mark button. This recorder provides a continuous record of target slant range. Referring again to Figure 90, the threshold eyeball-target recognition vertical and horizontal angles, E_T, are computed with respect to the slant range at recognition.

Eye positions 2 and 3 depict the close and extended T.V. display viewing conditions. As in Category I tests, the T.V. camera uses a zoom lens to view the target and its uniform background. The same target contrast range is provided as before, relative to 100% and 40% background reflectance levels.

The subject is briefed relative to location of the target on the display. At the start of the run, the calibrated zoom lens is adjusted to provide a target image which is too small for the subject to recognize. The T.V. camera field of view then is slowly zoomed in to continuously increase the image size to the point where the subject signals recognition. The vertical and horizontal displayed target recognition angles, D_T and D_T' are calculated based on the target image sizes relative to the display viewing distances at eye position 2 and position 3.

VI. DISCUSSION OF DATA

Actual test results obtained to date are discussed below. Also presented are sample plots, representative of expected future test results.

Direct Vision Resolution -

Figure 92 shows the effect of low contrast bars on direct visual resolution. At the 5% point, resolution is reduced nearly to 1/2 of that at the 35% point. The value of E_B at each contrast level is the average of all corresponding data samples.

Displayed Resolution - Extended Viewing -

Figure 93 depicts the effect of viewing low contrast bar images on a T.V. display from an extended distance of 19 feet. Again, D_B' values are averages of all data samples.

Direct Vision and Displayed Resolutions -

Figure 94 shows the difference between direct eyeball resolution E_B (lower curve) and displayed resolution-extended viewing, D_B' (upper curve). From this, we can start to see the trends and effects of the T.V. presentation even at near idealized conditions.

T.V. Limiting Resolution -

Sample plots are presented in Figure 95 to show the expected shapes and relative locations of the curves of T.V. limiting resolution vs. bar chart contrast for two chart background reflectance values. Performance at 100% contrast also is included as a reference point.

With operating conditions properly specified (i.e., target background brightness, camera optics f/no.), this resolution vs. contrast characteristic provides a very useful and effective means of defining system performance, since optical and electronic modulation transfer function measurements are not included in this study. Sets of curves corresponding to vertical, horizontal, and diagonal resolutions will be obtained.

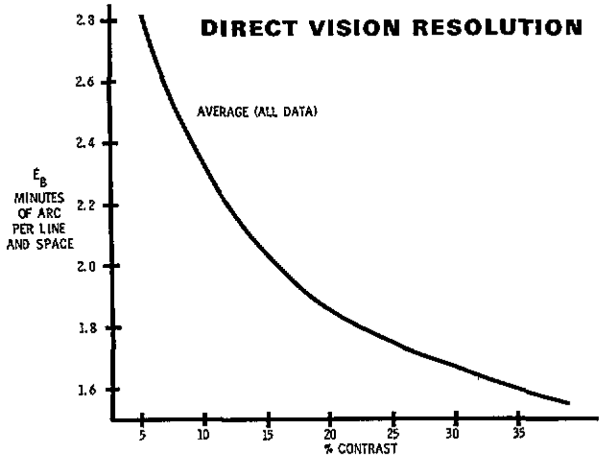

Figure 92. Eyeball Angular Resolution vs Bar Chart Contrast

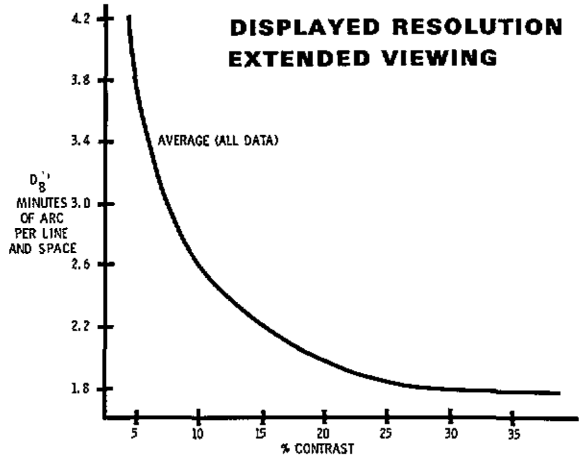

Figure 93. TV Displayed Angular Resolution (Extended Viewing Distance) vs Bar Chart Contrast

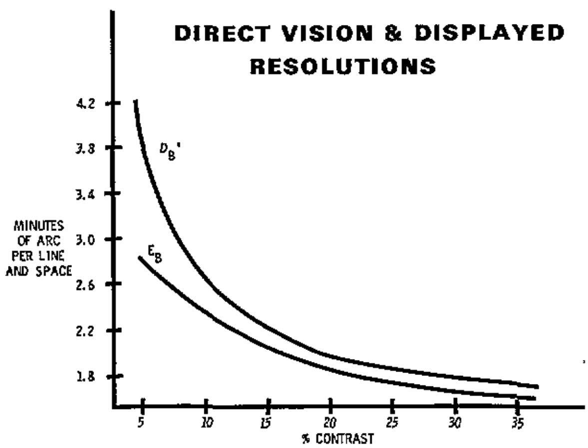

Figure 94. Comparison of Eyeball and Displayed (Extended Viewing) Angular Resolution vs Bar Chart Contrast

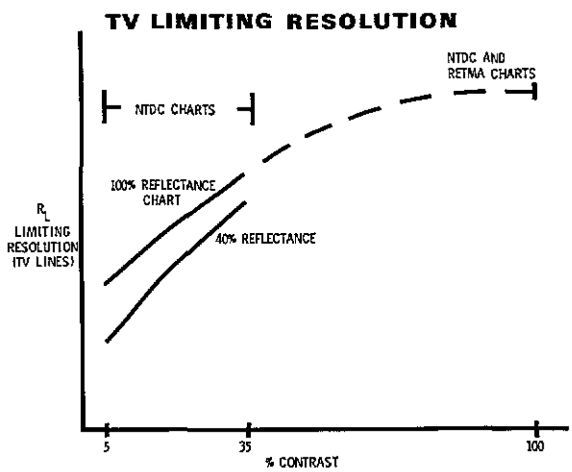

Figure 95. TV Limiting Resolution vs Bar Chart Contrast (Sample Curves)

Displayed Resolution - Close Viewing -

Sample plots shown in Figure 96 are representative of expected displayed resolution vs. bar chart contrast curves which will be obtained. The values of D_B are calculated from the T.V. limiting resolution test data, where the displayed resolution angle subtends the minimum size bar and space discernible at the close display viewing distance.

Direct Vision Recognition -

The sample plot in Figure 97 depicts representative curves of direct vision target recognition angles vs. target contrast. E_T (horizontal) and E_T (vertical) are the angles subtended by the horizontal and vertical dimensions of the target at the recognition range.

Displayed Recognition -

The sample curves in Figure 98 depict displayed target recognition angles vs. target contrast. D_T (horizontal) and D_T (vertical) are the angles subtended at the eye position by the corresponding smallest recognized target image dimensions.

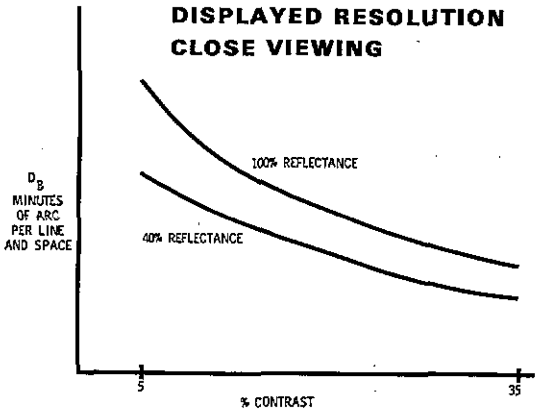

Figure 96. TV Displayed Angular Resolution (Close Viewing Distance) vs Bar Chart Contrast (Sample Curves)

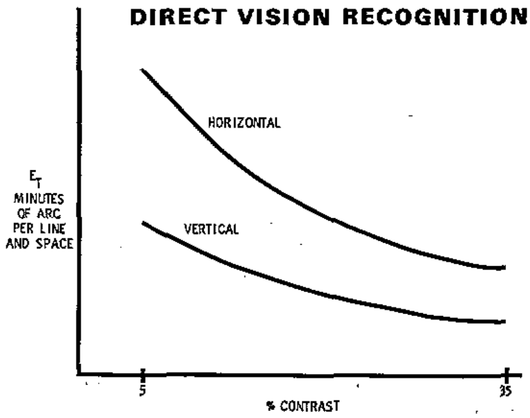

Figure 97. Eyeball Target Recognition Angle vs Bar Chart Contrast (Sample Curve)

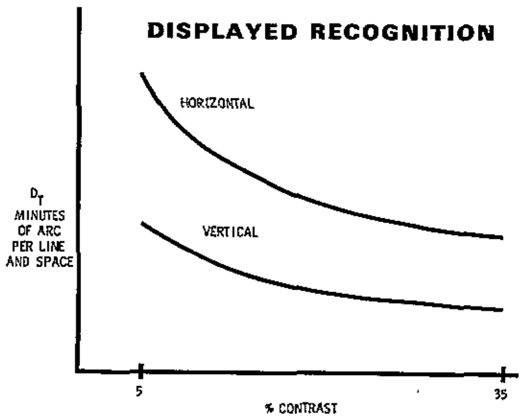

Figure 98. TV Displayed Recognition Angle vs Bar Chart Contrast (Sample Curve)

Measurements are planned for both close and extended viewing distances and for 100% and 40% target background reflectances.

VII. DESIGN IMPLICATIONS

First, let us briefly review the types of tests we are currently conducting and the types of data we are collecting.

Two main categories of tests are included; these are bar chart resolution measurements and target recognition measurements. In both cases, the unaided eyeball is used as the reference against which the performance of our test T.V. system is evaluated.

As one example of the use of the test data in the resolution bar tests, the ratio of:

$$\frac{\text{Displayed resolution angle}}{\text{Eyeball resolution angle}}, \frac{(D_B)}{(E_B)} = M_B$$

is a number which represents the display image magnification required to produce the smallest discernible bar chart image at the selected display viewing distance.

Corresponding ratios are available from the target recognition test series. Here,

$$\frac{\text{Displayed target recognition angle}}{\text{Eyeball target recognition angle}}, \frac{(D_T)}{(E_T)} = M_T$$

is a number which represents the display image magnification required to produce the smallest recognizable target image at the selected viewing distance.

The ratio of these two display magnifications provides a direct measure of the validity of using bar chart measurements to assess T.V. system target recognition performance. If at a given contrast level, this ratio is approximately unity, then it can be stated that the resolution bar measurement is a valid criterion for determining target recognition capability (the display magnifications for the two cases are equal). Data will be obtained over the selected range of contrast levels to evaluate this relationship, since either or both display magnifications may be found to vary as a function of contrast.

A second example of the application of this test data is in the area of T.V. system resolution vs. contrast. For a particular application, it may be determined that displayed image magnification must be minimized, i.e., the system must reproduce images approaching the directly viewed image in terms of subtended angle. The T.V. limiting resolution vs. contrast curve provides a means of determining what increase in resolution would result from increasing the contrast of the target image presented to the simulation camera, and thus what corresponding reduction in displayed image size could be achieved while retaining recognizable image detail. A second effect comes into play here also. If a higher contrast target image is displayed, its detectability is enhanced; therefore, tests must be conducted to verify that a valid simulation has been achieved.

A third possible application of the test data involves the "brute force" method of achieving an apparent increase in displayed resolution by extending the viewing distance. This, of course, is accomplished only at the expense of reduced total display viewing angle. Therefore, the optimum T.V. simulation trade-off may involve some extension of viewing distance, some increase in display contrast, and some increase in apparent image size compared to the real world target being simulated.