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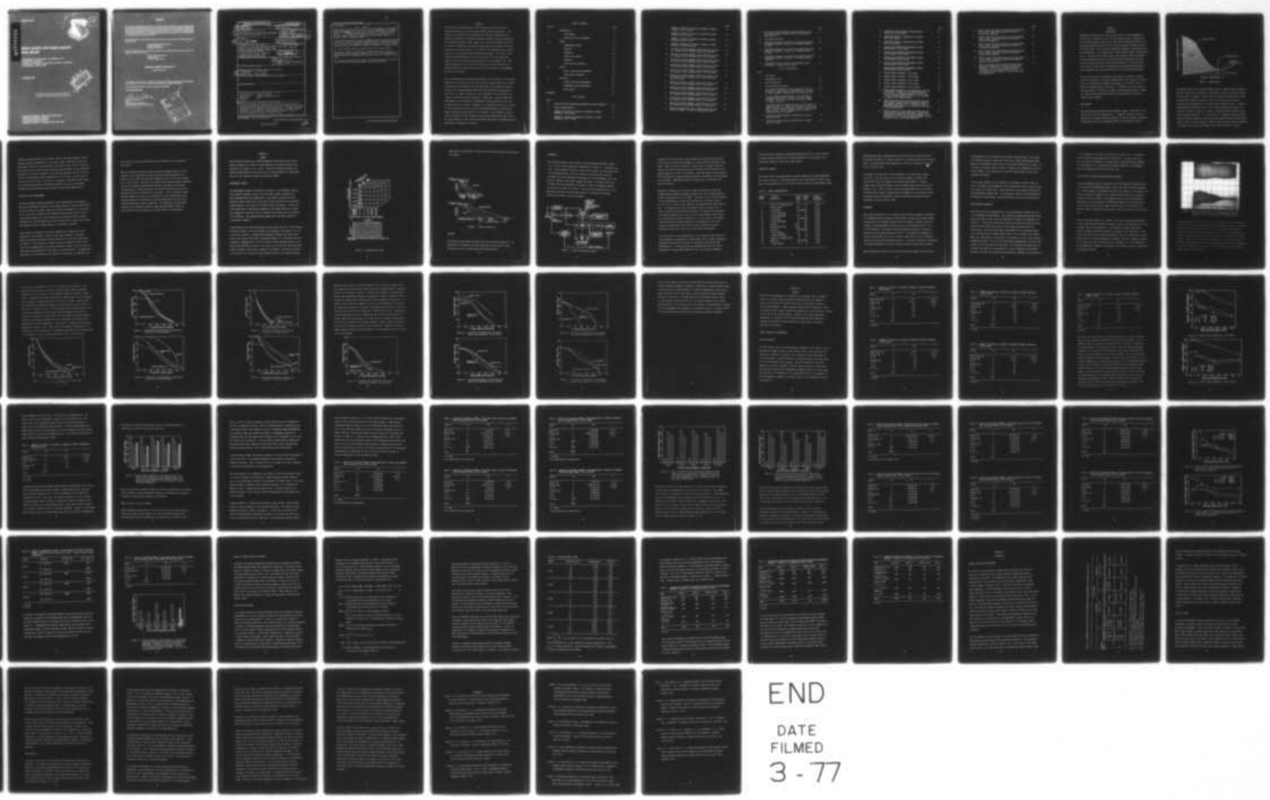

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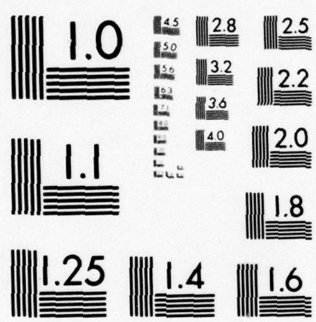

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VISUAL SEARCH AND IMAGE QUALITY: FINAL REPORT

DEPARTMENT OF INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
BLACKSBURG, VIRGINIA 24061

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AEROSPACE MEDICAL DIVISION
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AMRL-TR-76-89

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

FOR THE COMMANDER

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

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of an air-to-ground television target acquisition experiment which investigated the effects of mission profile, video system line rate and bandwidth, and video noise level. The target acquisition performance data are related to these variables and to a measure of display image quality, the Modulation Transfer Function Area (MTFA), which is measured microphotometrically at the display surface.

The target acquisition performance results are largely as expected. For a over

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20. Abstract

camera field of view of 18.8° x 14.2°, the mean ground ranges of correctly acquired targets are 28,661, 24,376, and 12,171 ft, respectively, for mission profiles of 23° depression angle, 500 ft/s velocity; 23°, 3000 ft/s; and 45°, 500 ft/s. As depression angle decreased, there was a large decrease in acquisition range; as velocity increased, there was a smaller decrease in acquisition range. Altitude was 10,000 ft.

Corresponding percentages of targets correctly acquired for these three missions were 75, 55, and 97%. As velocity increased, there was a significant decrease in the number of targets acquired; as depression angle of the airborne camera increased, there was a significant increase in the number of targets acquired.

The target acquisition data are consistent with other related studies.

Image quality measures were moderately correlated with target acquisition performance; linear correlations ranged from 0.22 to 0.70. Correlations were generally higher for two-dimensional MTFA values than for one-dimensional measures.

Also discussed are problems and concepts related to photometric noise measurement, eye movements during visual search, and display photometry.

PREFACE

This study was initiated by the Visual Display Systems Branch, Human Engineering Division, of the Aerospace Medical Research Laboratory. The research was conducted by the Department of Industrial Engineering and Operations Research, of Virginia Polytechnic Institute and State University of Blacksburg, Virginia 24061, under Air Force Contract F33615-71-C-1739. Dr. Harry L. Snyder was the principal investigator for Virginia Polytechnic Institute and State University. Mr. James L. Porterfield was the technical monitor for the Aerospace Medical Research Laboratory. This report covers research performed between June 1971 and October 1975, with particular emphasis upon work performed between October 1974 and October 1975. Other reports issued under this contract contain more detailed information regarding individual studies and results, and are indicated in the REFERENCE section of this report.

Several persons have contributed substantially to the conduct of the research reported in this document as well as to previous studies under this contract. Although major contributions have been indicated by authorship in previous reports, the following persosn and their contributions are acknowledged at this time: Dr. Robin L. Keesee, for his assistance in the formulation and conduct of this and previous studies; Mr. Edwin Evers, for his timely and knowledgable care and design of considerable complex equipment, both video and photometric; Mr. William S. Beamon, for his general assistance in conduct of this and previous studies, and for his equipment design and maintenance support during the early stages of this contract; to Ms. Deborah G. Bonnet, for her assistance in data collection and analysis during this study; and to Ms. Kathy Taszarek for her overall secretarial assistance, including manuscript preparation, throughout the contract.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

Considerable progress has been made in recent years in the determination of valid metrics of image quality for line-scan display systems. Concepts such as the displayed signal-to-noise ratio, SNR_D (Rosell and Willsoń, 1973), noise equivalent bandwidth, N_e (Schade, 1953), and the modulation transfer function area, MTFA (Snyder, 1973) have been proposed and evaluated, either analytically or experimentally. In a previous report (Snyder, Keesee, Beamon, and Aschenbach, 1974), it was shown that the MTFA concept best predicted operator performance in tasks employing both static and dynamic display interpretation, but that there was also good prediction using the SNR_D concept. It was also pointed out that the N_e concept did not appropriately treat displays having various noise components other than white noise over the entire displayed passband.

This report describes an experimental study which was designed to evaluate further the MTFA metric for dynamic image displays, and to assess the requirement for two-dimensional photometric measurement of the MTFA for cases in which the displayed image is anisotropic. In addition, this report serves as the final report of this research contract, and therefore attempts to combine the results from the present experiment and several previous studies in a single, final discussion.

MTFA CONCEPT

The MTFA has been described in detail elsewhere (Snyder, 1973; Snyder, *et al.*, 1974) and will only be summarized here. In general, the MTFA is the area bounded by the system's sine-wave response curve and the observer's threshold detectability curve for a sinusoidal grating, as illustrated in figure 1.

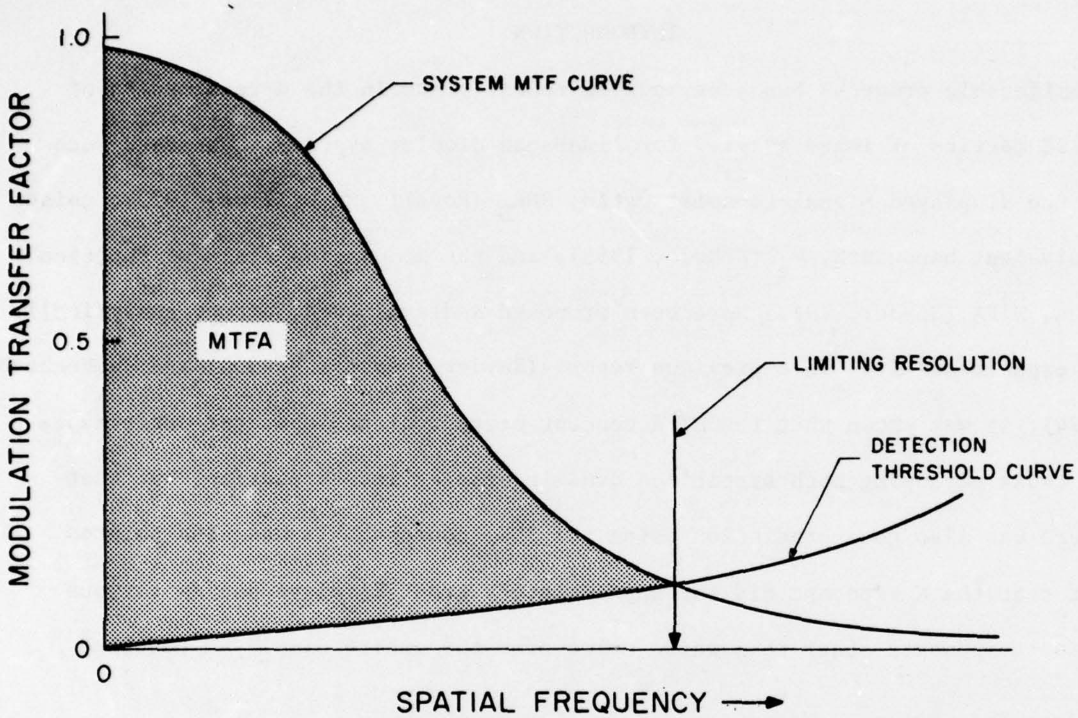

Figure 1. MTFA Concept.

Any imaging system will typically display objects of higher spatial frequency (smaller size) with less contrast, or modulation, than it will display objects of lower spatial frequency. This rolloff in transferred modulation is termed the modulation transfer function, or MTF, of the system if the input is sinusoidal and the assumptions of linear system analysis are met. In figure 1, the threshold detectability curve is the contrast modulation required, as a function of spatial frequency, to detect a standard sinusoidal grating under normal viewing conditions. It can be shown (*e.g.*, Campbell and Robson, 1968; Lowry and DePalma, 1961) that this human visual system threshold detectability curve is lower in the mid spatial frequency range, with the contrast threshold increasing below 2 cycles per degree (c/deg) and above about 10 c/deg.

Previous research under this contract (Snyder, *et al.*, 1974) has been shown that there is a consistently high correlation between the MTFA and the performance of human observers in obtaining information from a line-scan display. This research also determined the influence of noise amplitude and noise passband on the threshold detectability curve for a tribar target, rather than for a sinusoidal grating. In general, as the noise amplitude increased, the threshold modulation increased. Also, as more noise power was placed in the lower spatial frequencies (*i.e.*, below about 2 MHz), the noise threshold increased rapidly, demonstrating the greater interference of the lower frequency noise spectrum as compared to higher frequency noise.

A linear relationship proved to be an excellent fit for the noise threshold, and was of the form:

$$N = a\,SF + b\,M + c, \qquad (1)$$

in which N = noise amplitude at threshold.

SF = tribar target spatial frequency,

M = target modulation, and

a, b, c, = linear regression least-squares best-fit constants.

This linear regression was found to produce a linear correlation of at least .90 for 11 combinations of noise passband and video system line rate/video passband. Table 1 gives these correlations and equations.

The above threshold detectability regression data are based upon tribar (square-wave) target thresholds, and therefore do not strictly meet the requirements of linear systems analysis. Subsequently, Keesee (1976) extended this work by determining the threshold modulation for sinusoidal gratings for a variety of noise passbands and video line rates. His data generally show much lower

Table 1. MULTIPLE LINEAR REGRESSION EQUATIONS FOR NOISE THRESHOLDS

$\Delta F/N_V$	ΔF_N	R	N = a	(SF) + b	(M) + c
32 MHz/1225 lines	0.0 - 20.0 MHz	.92	-.22	117.79	17.39
	0.0 - 5.0 MHz	.94	-.16	63.61	11.41
	3.6 - 5.0 MHz	.93	-.16	112.89	10.04
	3.6 - 10.0 MHz	.93	-.24	171.73	15.73
16 MHz/945 lines	0.0 - 5.0 MHz	.95	-.24	68.44	14.65
	0.0 - 10.0 MHz	.90	-.27	92.47	16.64
	3.6 - 5.0 MHz	.94	-.21	118.95	11.85
	3.6 - 10.0 MHz	.91	-.29	185.01	14.99
8 MHz/525 lines	0.0 - 5.0 MHz	.91	-.28	95.01	20.44
	1.9 - 5.0 MHz	.91	-.42	162.75	22.07
	3.6 - 5.0 MHz	.91	-.58	168.75	31.30

$\Delta F/N_V$ = video bandwidth/noise passband

R = multiple correlation

N = noise threshold, in millivolts

SF = spatial frequency, in cycles per inch at display

M = tribar target modulation

threshold modulations but of the same form as those given by Snyder, *et al.* (1974). Keesee's curves are employed in subsequent portions of this report to assure that the linear model requirements are met, while his detailed results are presented in a separate report (Keesee, 1976). Perhaps of greatest importance is the fact that the Keesee data indicate that the display variables which predict threshold modulation are different for sinusoidal gratings oriented parallel to the raster lines of line-scan displays, than for gratings oriented perpendicular to the raster lines. Specifically, when the grating has its bars oriented parallel to the raster lines, there is a distinct interference of the raster spatial frequency with perception of the sinusoidal gratings as the spatial frequency of the grating approaches that of the raster. However, for gratings oriented perpendicular to the raster, no such raster or line-rate effect is noted. The reader is referred to the Keesee (1976) report for a detailed discussion of differences between his data and conjectures offered by previous theorists in the area of video system image quality.

OBJECTIVE OF THIS EXPERIMENT

The previous dynamic imagery experiment used microphotometric techniques to obtain the square-wave response of the display system (to tribar targets) when the major axis of the tribar targets was oriented perpendicular to the raster lines. Thus, with reference to the conventional horizontal raster lines of a television display, the tribar targets were oriented vertically, and the scanning slit of the microphotometer was oriented with its major axis vertical and scanned across the tribar targets in a horizontal direction.

As the spatial frequency of the tribar targets was increased, the output modulation of the tribars, relative to the input modulation, decreased, thereby producing the typical system response curve of the form illustrated in figure 1. This photometric response curve was obtained for each of the three video passband/line rate systems indicated in table 1, but only with the scanning slit perpendicular to the raster, as described above. Although scans were made with the photometer slit parallel to the raster, no threshold data were available to use with such MTF curves, and therefore no use was made of these scans.

With the completion of Keesee's (1976) sinusoidal threshold curves, it is now possible to treat separately the vertical and horizontal dimensions of the display, and not merely the horizontal component as was the case in the Snyder, *et al.* (1974) report. Therefore, this present study obtained observer performance data for five different display quality systems, and compared the obtained performance data in target acquisition with the MTFA values measured for both horizontal and vertical dimensions of the display. The five different display systems included three which were essentially isotropic (approximately equal limiting resolution in horizontal and vertical dimensions) and two that were decidedly *anisotropic (unequal resolution)*. The advantage of an anisotropic display has been suggested previously (Humes and Bauerschmidt, 1968), but their data have not been related to any unitary metric of image quality.

SECTION II

METHOD

The procedures followed, the variable-parameter video system used, and the imagery displayed are similar to those employed in previous studies in this laboratory (cf. Snyder, *et al.*, 1974). They will be summarized below, and detailed descriptions will be given only for the measurements and techniques which were not reported or used in the earlier studies.

EXPERIMENTAL DESIGN

The experimental design is illustrated in figure 2. Ten different subjects were randomly assigned to each of the five video systems, designated by video bandwidth/line rate combinations. Each subject searched for three different targets under each of five noise levels on each of three different filmed missions, for a total of 45 target "trials" per subject. Within each video system/noise level/mission combination, the three targets per subject were assigned so that each of the 15 targets used in this study was assigned to two subjects. The simulated flight geometry for the three missions is illustrated in figure 3.

In this manner, each subject searched for each target only once on each mission. A different subset of the three targets was assigned to each subject for each of the three missions. Although some incidental learning could have taken place as the subject "flew over" nonassigned targets, it is believed that such learning is negligible due to (1) the relatively large masking effects of the noise levels presented on most of the trials, and (2) the fact that there were several examples of each type of target in the imagery, requiring the subject to be careful not to confuse a given assigned target on the display with the

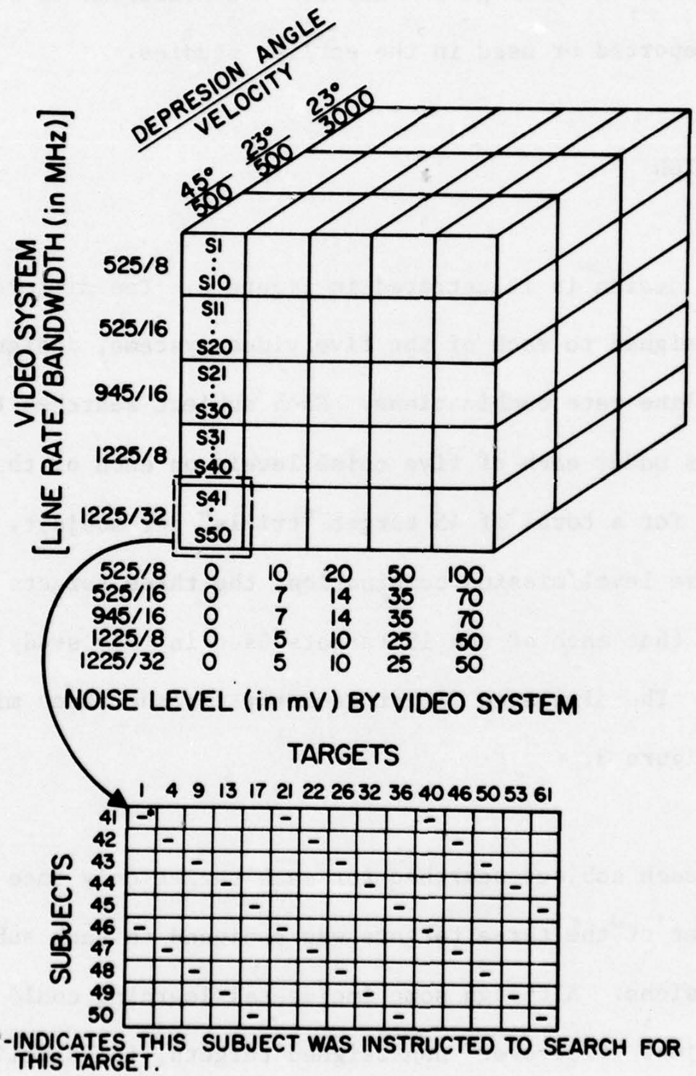

Figure 2. Experimental Design.

same target type presented at another time in another ground location during the mission.

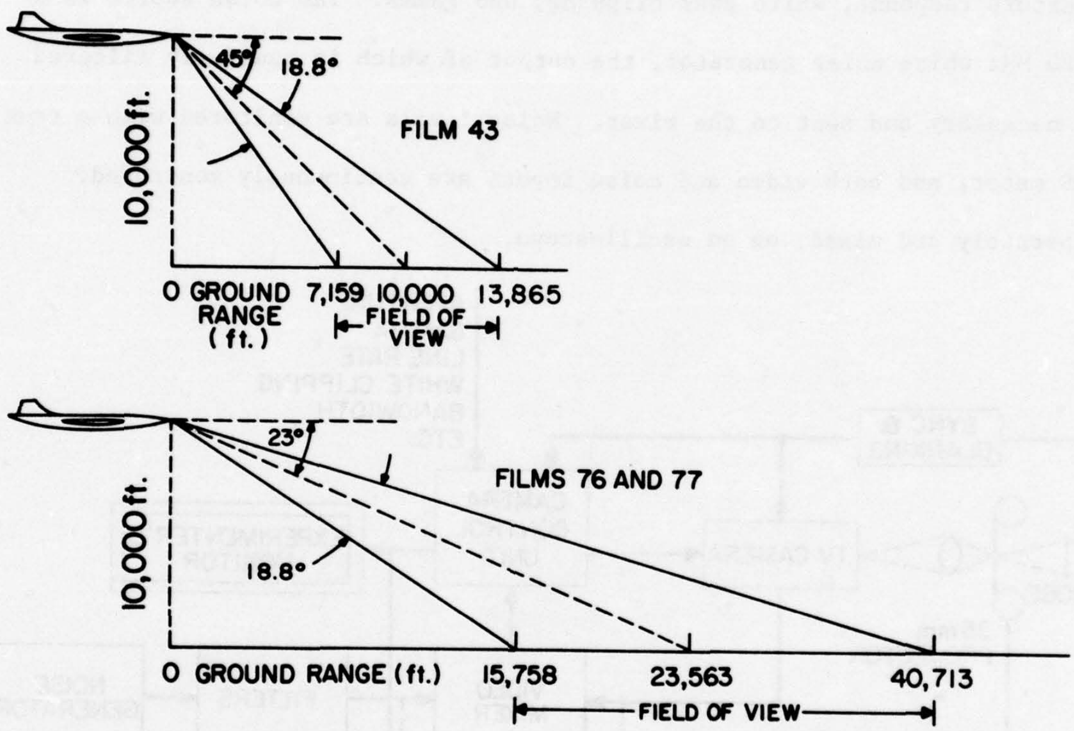

Figure 3. Mission Conditions.

SUBJECTS

The subjects were 55 paid volunteers from the University population. All subjects were screened for at least 20/22 near and far visual acuity, uncorrected, with a standard Bausch and Lomb Orthorater.

APPARATUS

The variable-parameter video system has been described previously (Snyder, *et al.*, 1974), and is summarized schematically in figure 4. A variable line rate, 17-inch diagonal TV monitor receives mixed signal and noise inputs from a wide bandwidth mixer. The video signal is calibrated and altered in accordance with the experimental requirements of video bandwidth, line rate, aperture response, white peak clipping, and gamma. The noise source is a 0-20 MHz white noise generator, the output of which is passively filtered as necessary and sent to the mixer. Noise levels are monitored with a true RMS meter, and both video and noise inputs are continuously monitored, separately and mixed, on an oscilloscope.

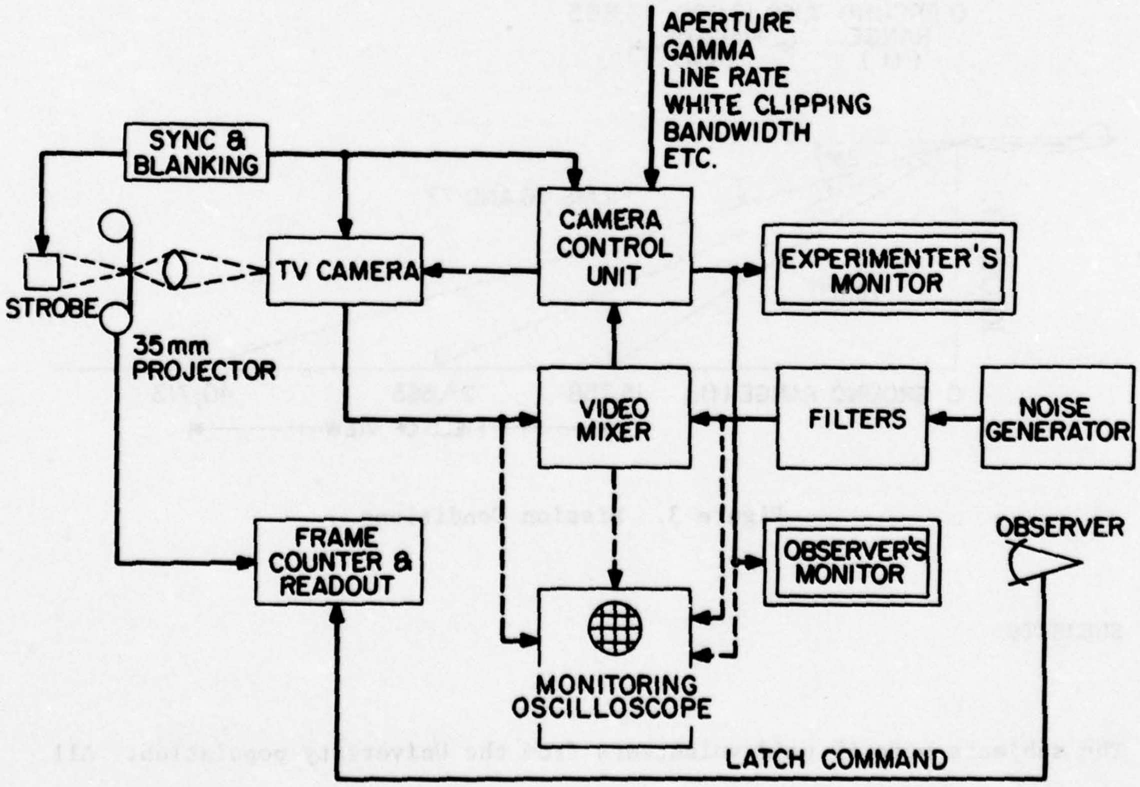

Figure 4. Video System Block Diagram.

A counter on the 35mm projector counts frames of the 35mm air-to-ground film. The film has previously been catalogued for target content by individual frame number. When the observer responds to a given target by pushing a hand-held button, the counter latches and prints out the number of the film frame in the projector gate at the time of the response. This frame number is then compared with the previously obtained catalogue information to determine the "correctness" of the response. Responses made when the target is not on the display are scored as incorrect.

Photometric measurement of the tribar targets on the monitor is made with a Gamma Scientific digital photometer equipped with a slit scanning eyepiece having a slit aperture of 25 μ by 2500 μ. By using 1X, 2.5X, or 10X objectives on the microphotometer, the slit width equivalent at the display plane is 25, 10, or 2.5 μ, while the slit length at the display plane is 2500, 1000, or 250 μ. The eyepiece has a motor drive which produces a constant rate of travel of the slit aperture across the display. The output of the photometer is typically plotted on the Y axis of an X-Y plotter while the slit position, as it traverses the display, is plotted as X. In this manner, and following calibration of both luminance and position, the modulation of the tribar target can be measured *at the display* for both horizontal and vertical orientation of the tribar, and for any video system configuration.

The tribar input for this experiment was a set of positive (black tribars on clear background) transparencies, in 35mm format, with the spatial frequencies decreasing by sixth-root-of-two steps in conformance with the 1951 USAF specifications. All tribar patterns were scanned previously with a microdensitometer to assure 100% modulation for all input spatial frequencies, so that the output modulation, determined photometrically, is a direct measure of output modulation divided by the input modulation or, equivalently, the square-wave response of the entire video system.

TARGETS AND IMAGERY

The targets used in this experiment, and their simulated real-world dimensions, are listed in table 2. The films were made from a high-fidelity, 3000:1 scale model incorporating both flat and rolling terrain (Humes and Bauerschmidt, 1968)

Table 2. TARGET CHARACTERISTICS

Target Number	Target Description	Target Length (ft)	Element Width (ft)	Target-Background Contrast
1	Convoy of 5 Missile Vans	37	15	0.189
4	11 Unit Train	85	21	0.375
9	4 POL Tanks	340 Diameter		0.603
13	6 Small Buildings	45	30	0.396
17	2 Large Buildings	129	65	0.396
21	6 POL Tanks	75 Diameter		0.603
22	3 Large Buildings	70	60	0.559
26	Airport	4,212	792	0.401
32	Construction Yard	1,000	875	0.550
36	SAM Site	340 Diameter		0.414
40	6 Ammo Bunkers	66	32	0.662
46	5 Small Buildings	48	30	0.257
50	Convoy of 5 Missile Vans	37	15	0.750
53	SAM Site	340 Diameter		0.324
61	9 Ammo Bunkers	60	32	0.414

Photography was with a gimbal-mounted 35mm motion picture camera which was positioned accurately by a hybrid computer for repeated passes over the terrain model. The 35mm camera was equipped with a 75mm lens, resulting in an 18.8^{o} by 14.2^{o} field of view.

The imagery was made with the major dimension of the 35mm frame oriented vertically. For this reason, the TV camera and subject's monitor were rotated 90^{o} so that the imagery was presented appropriately. Previous studies have used this technique, and no untoward results have been noticed (Snyder, *et al.*, 1974); in fact, it has been demonstrated that a vertically oriented raster produces slightly better performance for air-to-ground target acquisition than a horizontally oriented raster when the display system is essentially isotropic (Rusis, 1966).

PROCEDURE

Each subject was given a set of target pictures which were masked to eliminate all background scene information, and was asked to study these ordered target pictures until he was highly familiar with the targets, at which time he was brought to the experimental room and seated in an adjustable chair in front of the TV monitor. The subject's head was positioned against a headrest to maintain an eye-to-monitor distance of 40 in. The subject was permitted to hold the target book in his lap, so that he could refer to it for refamiliarization with each target during the mission. A dim lamp sufficiently illuminated the target photograph in the book without casting any glare upon the monitor.

When the subject was ready, the first film mission was begun, with the order of presentation of three films to each subject counterbalanced. The subject was told which target to search for first, and to press the hand-held switch when he was reasonably certain that he had visually identified the target. In the event the subject wished to cancel a response, and subsequently found the correct target, he was instructed to press the switch again, and the first response was ignored.

As each target passed out of the bottom of the subject's field of view, he was so informed by the experimenter via an intercom and told to search for the next target in his photo book. Rest pauses were taken between missions while the experimenter changed films. An experimental session lasted approximately 55 minutes for each subject, including briefing time and all three missions.

VIDEO SYSTEM CALIBRATION

The video system was calibrated prior to each experimental session and prior to all photometric measurements. This procedure included setting video levels within the camera control unit and adjusting the monitor for brightness and contrast. A 15-step gray scale was used for this purpose; the gray scale was placed in the projector gate, and the video signal was monitored on an oscilloscope. This gray scale signal was measured (1) at the camera output, (2) at the output of the camera control unit, (3) at the output of the video mixer (or, equivalently, at the input to the monitor), and (4) at the monitor's preamplifier output. For all five video system configurations, the same video levels for each gray scale step were used. For this particular gray scale of 15 steps, the monitor was then adjusted, using the brightness and contrast controls, such that the second gray step produced a luminance on the monitor of

1.5 foot-Lamberts, the seventh step produced a luminance of 7 foot-Lamberts, and the fourteenth step produced 35 foot-Lamberts. The input gray steps were not of equal increments, as measured with a microdensitometer; however, the luminances set at the display were linearly related to the individual gray-step transmissions on the gray scale film.

Determination of Video System Square-Wave Response

Following equipment set-up as described, each video system configuration was calibrated by the following procedure. First, the vidicon input was replaced by a vidicon simulator to determine the electrical response of the system. The input to the vidicon simulator was a swept sinusoidal wave form, varying in frequency from DC to 50 MHz. The response of the TV chain was measured by displaying, on an oscilloscope, the amplitude response to the swept input at (1) the camera output, (2) the camera control output, (3) the monitor pre-amplifier input (following the video mixer), and (4) the monitor's CRT cathode input.

This oscilloscope display (*e.g.*, figure 5) was used to make final adjustments to those video system parameters necessary to define and differentiate the five "systems" used in this experiment. Such parameters include cable delay, aperture response, white peak clipping, and overall video signal gain. Every effort was made to obtain a smooth bandwidth rolloff, at 6 dB/octave, for each system, and to avoid any unevenness or ringing in the video frequency response. For the most part, this objective was met, although it is of less importance if the photometric response of the system at the display is used to characterize the system's response.

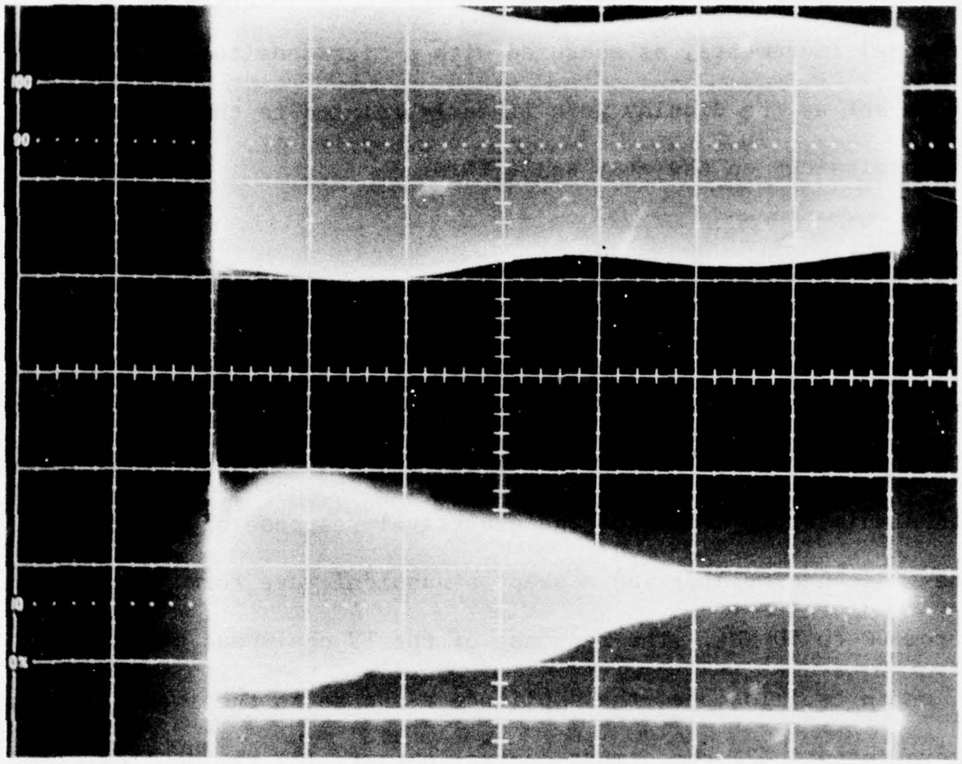

Figure 5. Oscilloscope Photograph of Video Bandpass for 0-16 MHz Conditions. Bottom Trace is Video Bandwidth; Top Trace is Input Passband. Horizontal Scale is 4 MHz/Division.

Following adjustment of the system by the sweep generator and vidicon simulator, as described above, the system calibration was made photometrically. The vidicon simulator was removed from the camera, the tribar transparency was placed in the projector gate, and the transparency was moved so that the particular tribar target to be scanned was in the approximate center of the display, with the bars carefully oriented either parallel or perpendicular to the raster. The system response to this tribar pattern was then measured electrically and photometrically for tribars perpendicular to the raster, and only photometrically for tribars oriented parallel to the raster.

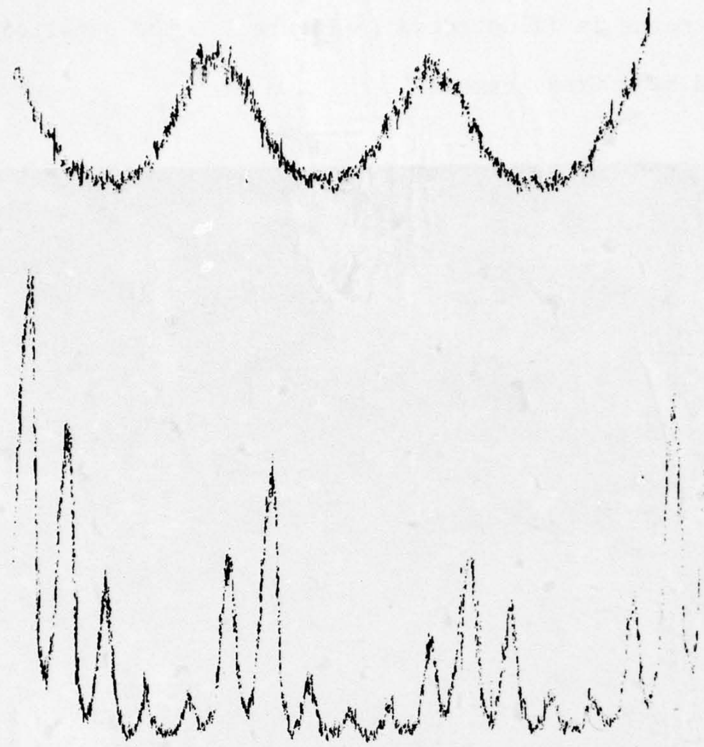

Figure 6. X-Y Plot of Tribar Scans from CRT. Top is with Slit Perpendicular to Raster; Bottom is with Slit Parallel to Raster. Target is 3-5 of USAF 1951 Tribar; System is 32 MHz, 1225 Lines.

For the perpendicular orientation, photometric scans were made from the monitor CRT in a totally darkened room with the display's implosion shield in place, as it was when the human performance data were subsequently collected. Figure 6 shows a typical photometric scan from the face of the monitor's CRT as recorded on the X-Y plotter. In addition, single raster line triggering was used on a wide-bandwidth oscilloscope to display a single scan line through the middle of the tribar pattern. Four simultaneous samples of this single scan line were displayed on the oscilloscope: (1) the camera output, (2) the camera control unit output, (3) the monitor's preamplifier output, and (4) the monitor's CRT cathode input. An example of the oscilloscope image of these tribar patterns is illustrated in figure 7. The oscilloscope image was photographed by a Grass camera.

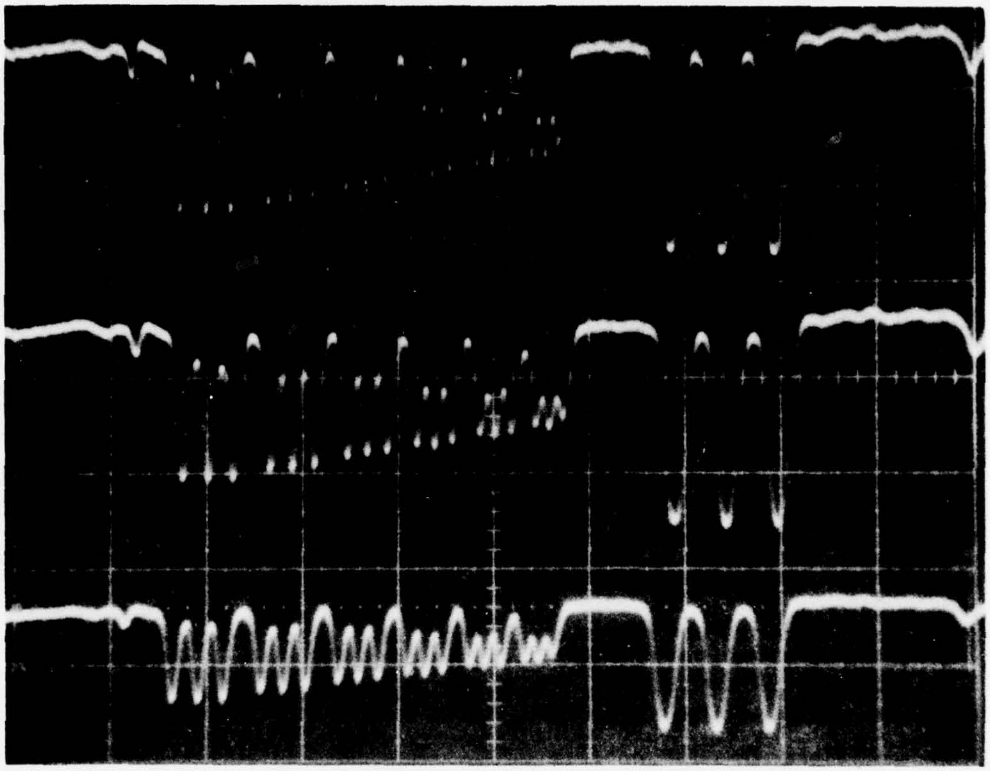

Figure 7. Oscilloscope Photo of Tribar Scan for 1951 USAF Targets 3-1 through 3-6 and 2-1. System is 16 MHz and 525 Lines. Top Trace is Monitor Input, 200 mV/div; Middle is CRT Cathode Input, 5 V/div; Bottom is Camera Output, 50 mV/div. Horizontal scale is 1 μsec/div.

These X-Y plots and photographs of the oscilloscope displays were then measured for signal modulation at each tribar spatial frequency and for each system. The photometric scans are measured in absolute values (foot-Lamberts), and therefore have a meaningful zero value; that is, they are *not* normalized to unity modulation at zero spatial frequency. However, the electrical video signal is AC coupled throughout the system, so that the calculated modulation is necessarily normalized to unity at the lowest spatial frequency. The measured system responses of the five systems for the tribar orientation perpendicular to the raster are illustrated in figures 8 through 12 respectively. Examination of figures 8 through 12 indicates that the video response of each system is largely as expected. That is, the camera, camera control unit, and monitor preamplifier outputs are similar in most cases, and the CRT output is similar to that of the electronic system response except at the low spatial frequencies, at which point the CRT response levels off at a value on the order of 70 to 80 percent. Internal reflections and non-black response at low spatial frequencies prevent the monitor DC response from approaching 100 percent modulation. This result is consistent with previous measurements (Snyder, *et al.*, 1974), and is an accurate reproduction of the modulation seen by the observer. To normalize this photometric response would be to distort the nature of the actual visual input to the observer.

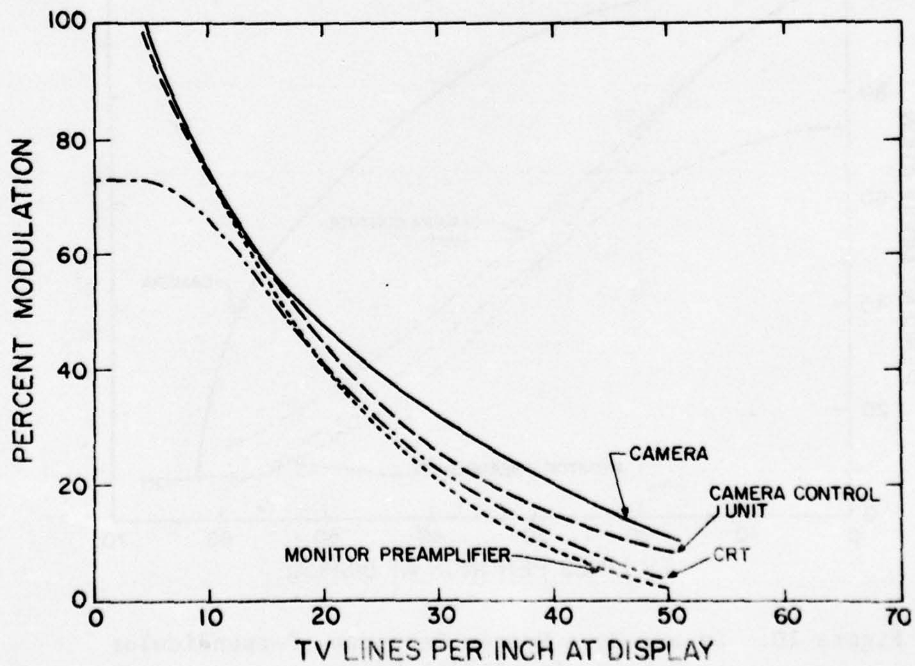

Figure 8. Square-Wave System Response, Perpendicular to Raster, for 8/525 System

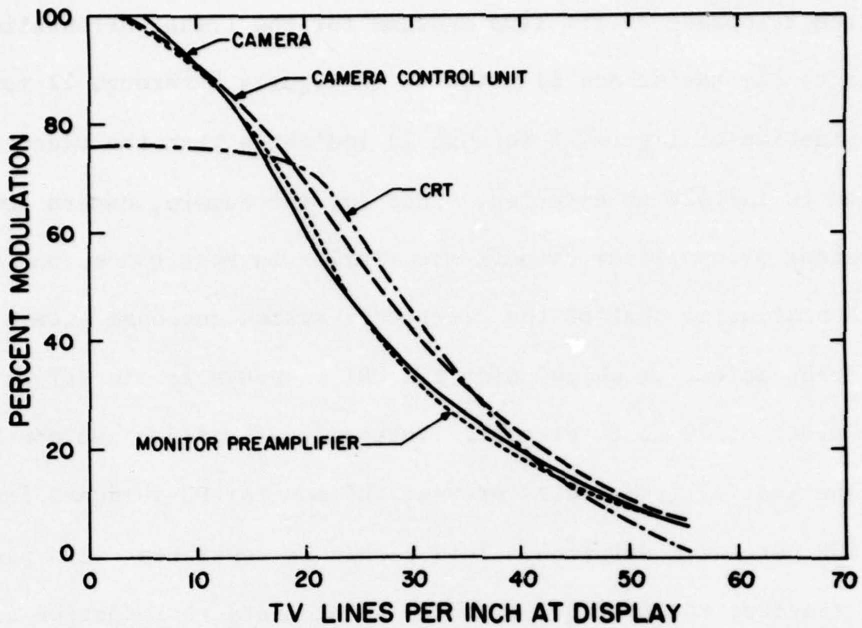

Figure 9. Square-Wave System Response, Perpendicular to Raster, for 16/525 System.

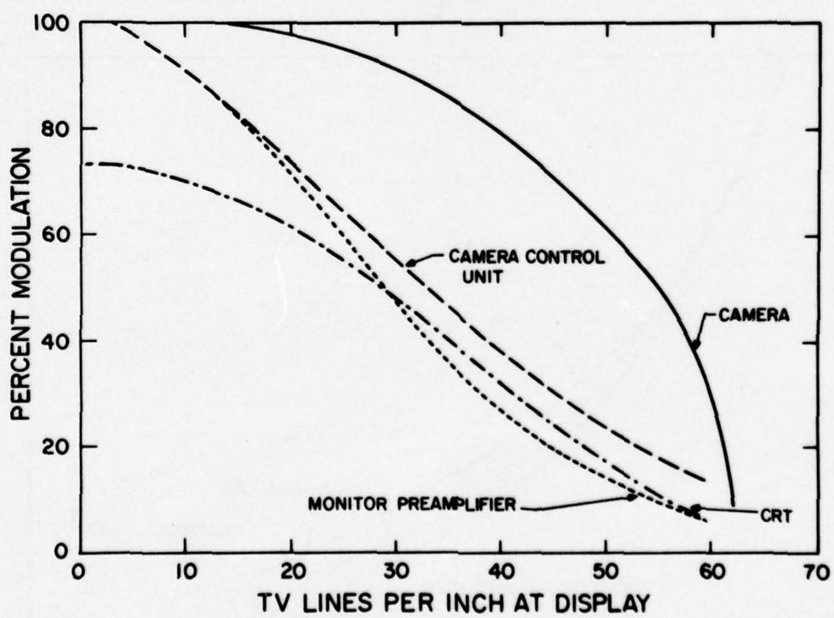

Figure 10. Square-Wave System Response, Perpendicular to Raster, for 16/945 System.

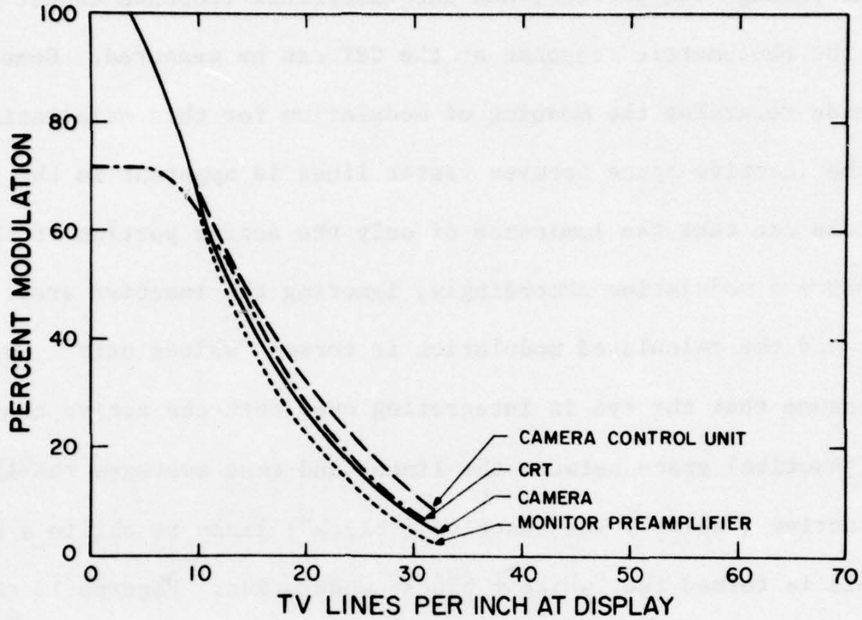

Figure 11. Square-Wave Response, Perpendicular to Raster, for 8/1225 System.

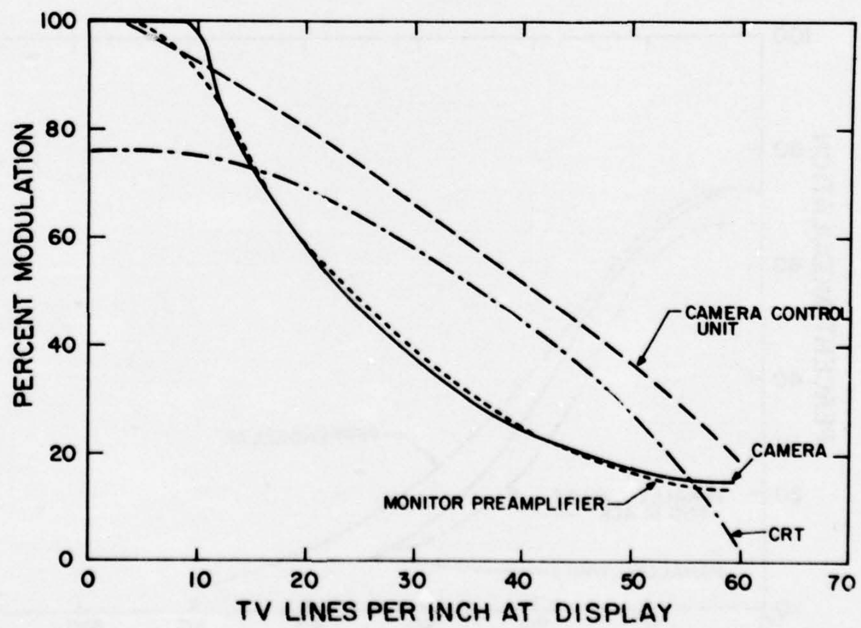

Figure 12. Square-Wave Response, Perpendicular to Raster, for 32/1225 System.

When the tribar pattern is oriented parallel to the raster, no single raster line scans through the pattern, and the electrical response cannot be measured; however, the photometric response at the CRT can be measured. Some decision must be made regarding the meaning of modulation for this orientation, however, in that the inactive space between raster lines is apparent in the plots. For example, one can take the luminance of only the active portion of the raster, and calculate a modulation accordingly, ignoring the inactive area. This has been done and the calculated modulation is termed "whites only". Alternatively, one can assume that the eye is integrating over both the active raster line and the (inactive) space between the lines, and thus averages the luminance of both the active ("white") and inactive ("black") lines to obtain a modulation value; this is termed the "white + black" modulation. Figures 13 through 17 compare these two parallel system responses to the perpendicular system response for the five systems.

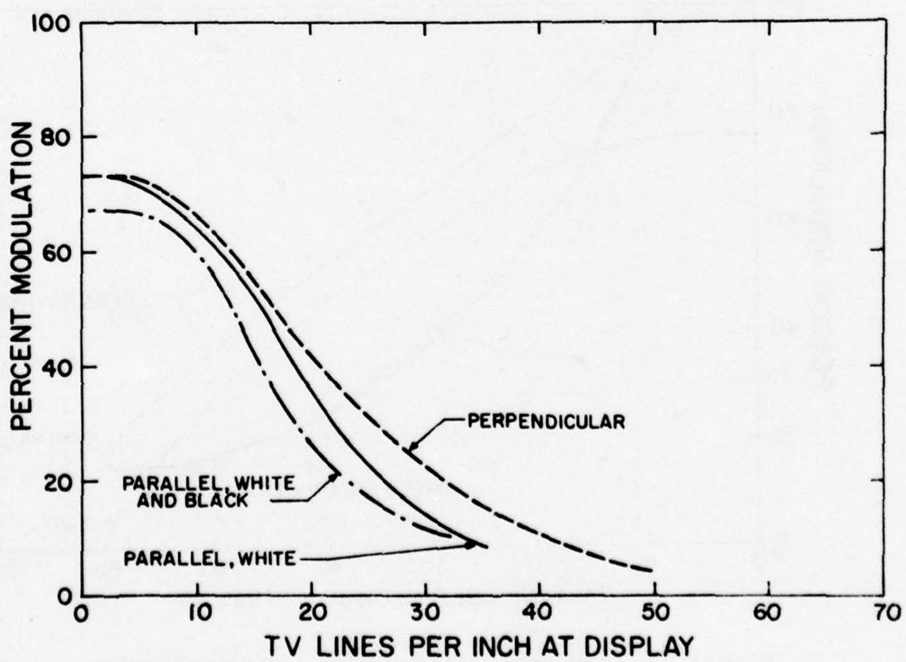

Figure 13. Parallel and Perpendicular Photometric Square-Wave Responses, 8/525 System.

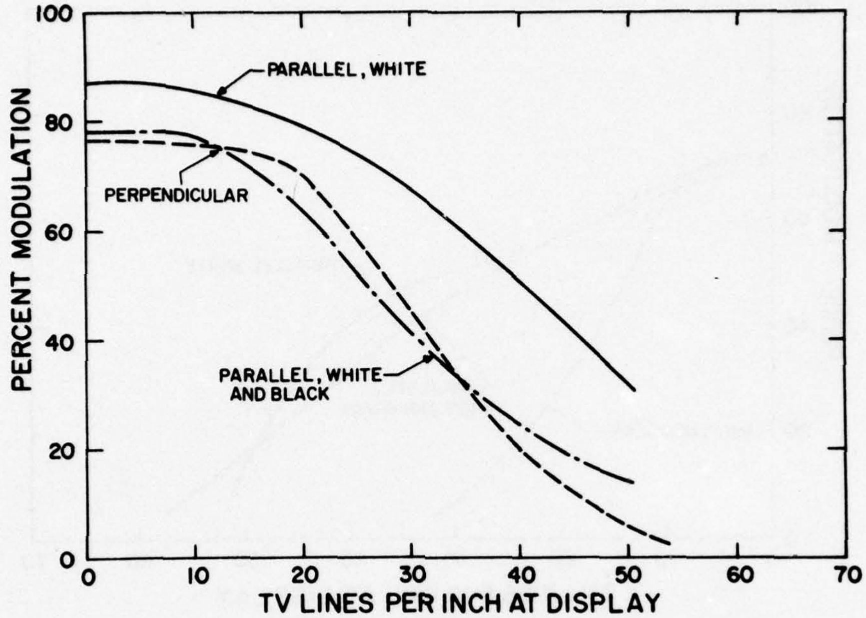

Figure 14. Parallel and Perpendicular Photometric Square-Wave Responses, 16/525 System.

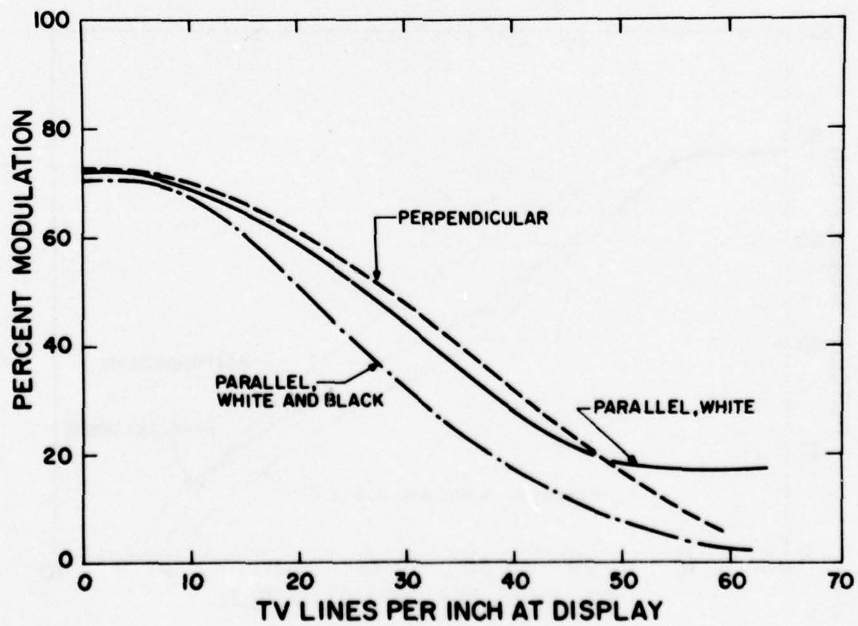

Figure 15. Parallel and Perpendicular Photometric Square-Wave Responses, 16/945 System.

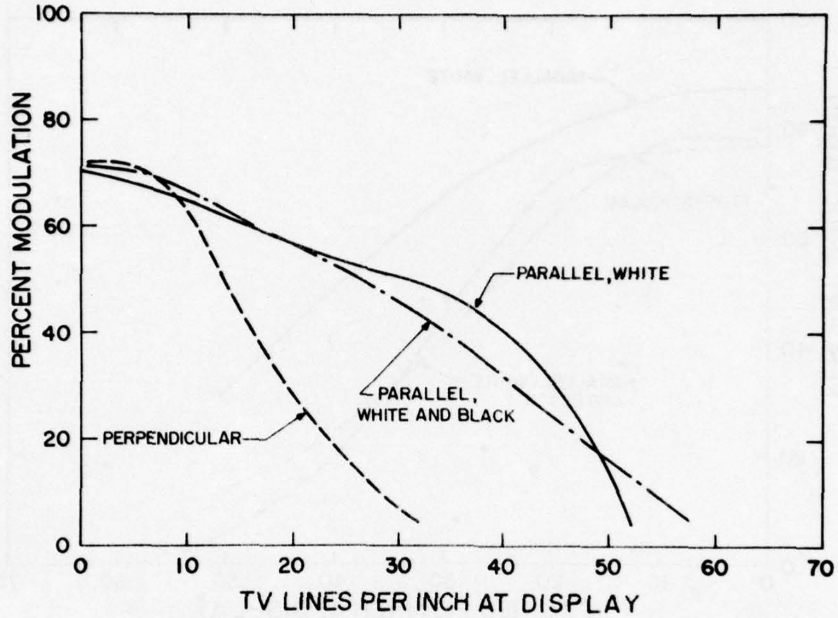

Figure 16. Parallel and Perpendicular Photometric Square-Wave Responses, 8/1225 System.

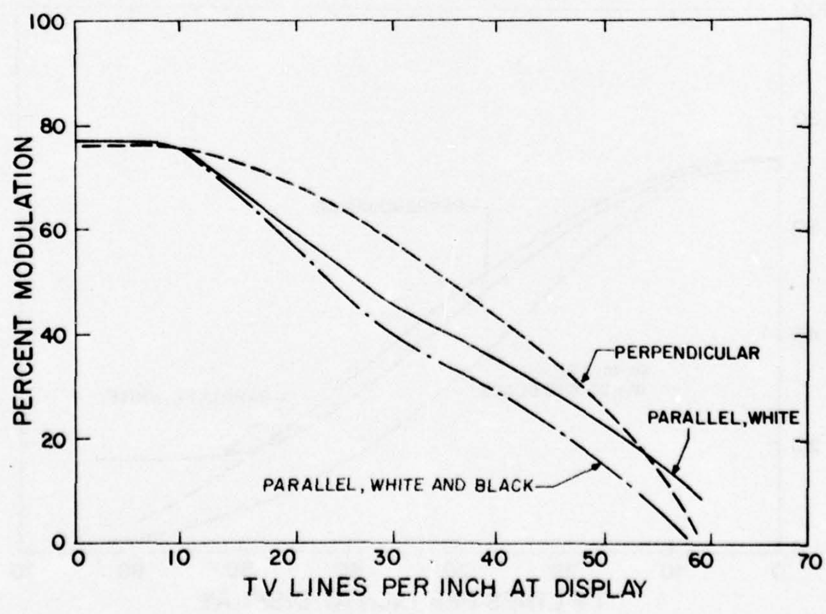

Figure 17. Parallel and Perpendicular Photometric Square-Wave Responses, 32/1225 System.

For all five systems, the effects of line rate and video bandwidth upon the system response are largely as expected. Reduction in system bandwidth causes a faster rolloff in system response for tribars perpendicular to the raster, while reduction in line rate causes a faster reduction in system response parallel to the raster. Although there are some slightly unusual results in these system calibration data (*e.g.*, the camera response of the 16/945 system compared to the camera control unit response for perpendicular targets), the final photometric data appear to be reasonably accurate, at least as much as can be obtained with present state-of-the-art photometric equipment.

SECTION III

RESULTS

Results of the experiment are divided into two separate sets of analyses. First, the observer target acquisition performance data are analyzed to parcel out the effects of system, noise level, and mission on target acquisition performance. Target acquisition performance is measured in both (1) percent correct target acquisition responses and (2) ground range to target at the time of the correct response. Secondly, the target acquisition performance is related to the one- and two-dimensional MTFA measures to evaluate the effects of these indicators of image quality upon target acquisition performance.

TARGET ACQUISITION PERFORMANCE

Correct Responses

For each subject and for each experimental combination, the number of correct responses was summed across the three target trials. These sums were then subjected to analyses of variance, with a separate analysis performed for each video system. Separate analyses are necessary because the noise levels for the five systems are not equated. These five analyses of variance, summarized in tables 3 through 7, indicate that the effects of noise level (N) and mission type (M) are statistically significant for all five systems, but that the N x M interaction is not significant ($p > .05$). The numbers of correct responses, expressed as percent correct, are illustrated in figures 18 through 22.

Table 3. SUMMARY OF ANALYSIS OF VARIANCE OF NUMBER OF CORRECT RESPONSES, 8/525 SYSTEM

Source	df	MS	F
Noise Level (N)	4	5.55	13.21*
Mission (M)	2	19.44	25.15*
N x M	8	.31	1.06
Subjects (S)	9	1.06	
S x N	36	.42	
S x M	18	.77	
S x N x M	72	.30	
Total	149		

* $p<.001$

Table 4. SUMMARY OF ANALYSIS OF VARIANCE OF NUMBER OF CORRECT RESPONSES, 16/525 SYSTEM

Source	df	MS	F
Noise Level (N)	4	3.51	6.91*
Mission (M)	2	21.14	50.23*
N x M	8	.65	1.87
Subjects (S)	9	.80	
S x N	36	.51	
S x M	18	.42	
S x N x M	72	.35	
Total	149		

* $p<.001$

Table 5. SUMMARY OF ANALYSIS OF VARIANCE OF NUMBER OF CORRECT RESPONSES, 16/945 SYSTEM

Source	df	MS	F
Noise Level (N)	4	1.69	5.92*
Mission (M)	2	20.91	46.77*
N x M	8	.62	1.94
Subjects (S)	9	.53	
S x N	36	.29	
S x M	18	.45	
S x N x M	72	.32	
Total	149		

* *p*<.001

Table 6. SUMMARY OF ANALYSIS OF VARIANCE OF NUMBER OF CORRECT RESPONSES, 8/1225 SYSTEM

Source	df	MS	F
Noise Level (N)	4	6.37	18.74*
Mission (M)	2	24.18	47.79*
N x M	8	.19	.34
Subjects (S)	9	.78	
S x N	36	.34	
S x M	18	.51	
S x N x M	72	.56	
Total	149		

* *p*<.001

Table 7. SUMMARY OF ANALYSIS OF VARIANCE OF NUMBER OF CORRECT RESPONSES, 32/1225 SYSTEM

Source	df	MS	F
Noise Level (N)	4	4.16	9.67*
Mission (M)	2	20.64	42.13*
N x M	8	.35	.23
Subjects (S)	9	1.80	
S x N	36	.43	
S x M	18	.49	
S x N x M	72	1.49	
Total	149		

* $p<.001$

The percent correct responses are consistently greatest for the 45° depression angle, 500 ft/s condition, regardless of the video system employed. As the depression angle is decreased or, equivalently, as the observer's ground view is elevated toward a greater distance from the nadir, performance decreases. Similarly, as the aircraft velocity increases from 500 ft/s to 3000 ft/s, the percent correct decreases for four of the five systems. Only the 8/525 system produced (slightly) better performance at 3000 ft/s than at 500 ft/s. For this system, a Newman-Keuls test (Kirk, 1968) showed that the 45° depression angle led to more correct responses ($p<.01$) than did either of the 23° depression angle missions, with the two 23° missions essentially equivalent ($p>.05$) in mean number of correct responses over all five noise levels. For each of the other four video systems, the 45° depression angle was superior to each of the 23° depression angle missions ($p<.01$). Further, the 23°, 500 ft/s mission was superior to the 23°, 3000 ft/s mission for each of these four systems ($p<.05$ for the 16/525 system, $p<.01$ for the other three systems).

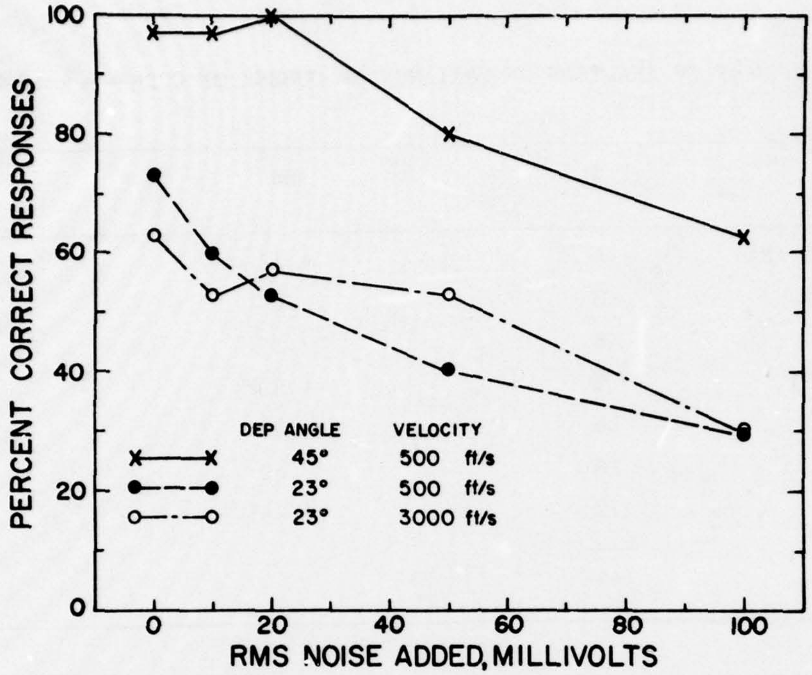

Figure 18. Percent Correct Responses, 8/525 System.

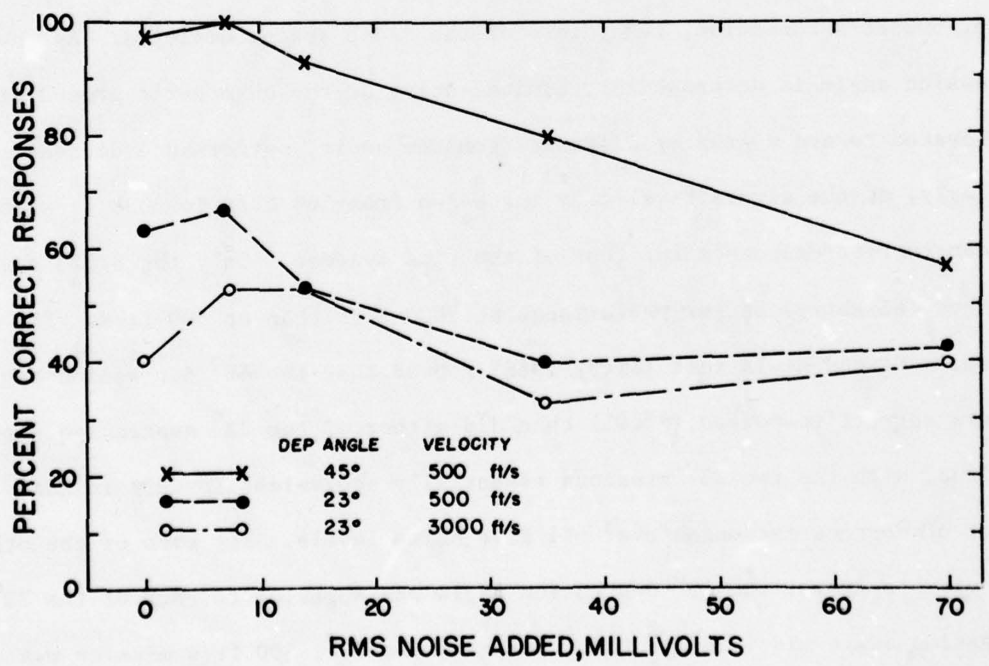

Figure 19. Percent Correct Responses, 16/525 System.

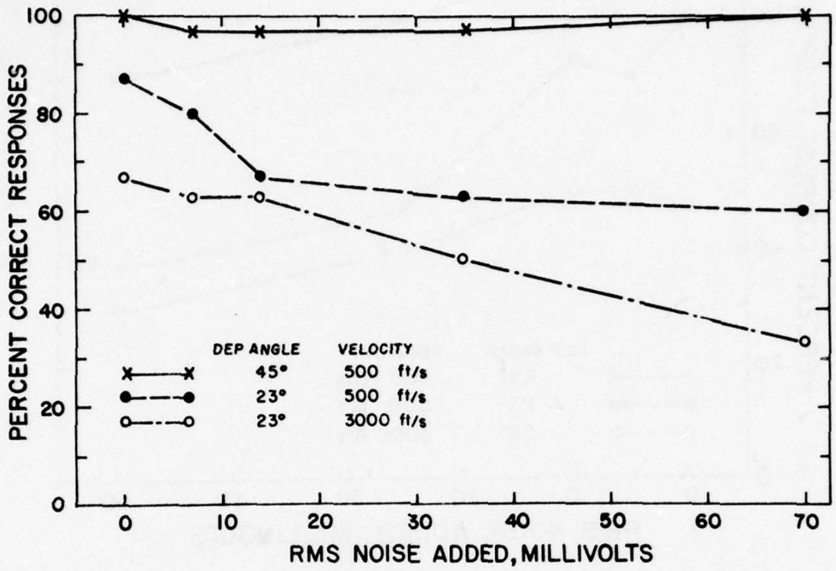

Figure 20. Percent Correct Responses, 16/945 System.

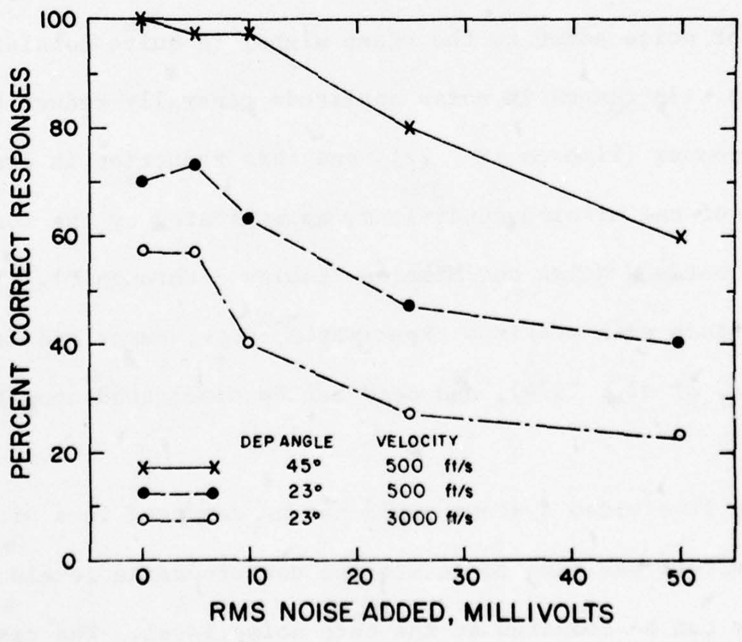

Figure 21. Percent Correct Responses, 8/1225 System.

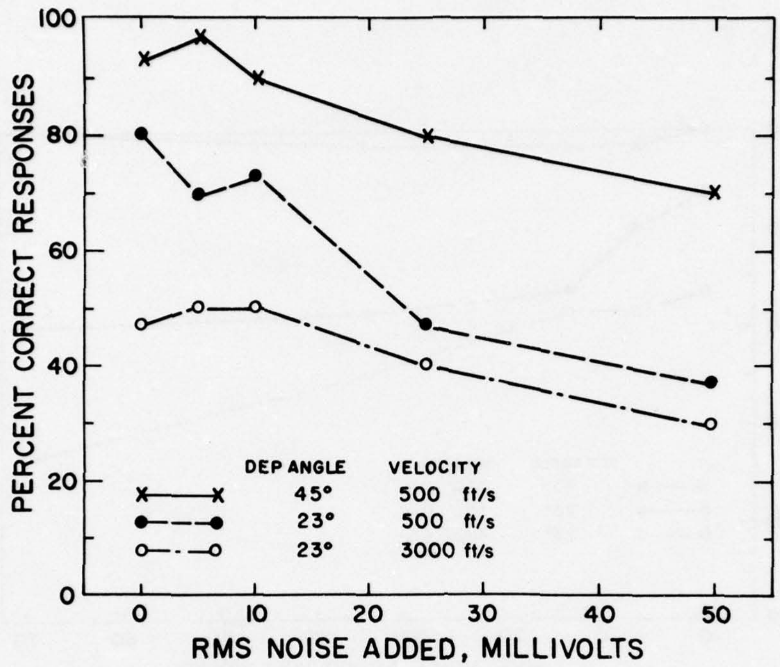

Figure 22. Percent Correct Responses, 32/1225 System.

The effect of noise added to the video signal is quite consistent across all five systems. Increases in noise amplitude generally reduce the percent correct responses (figures 18 - 22), and this reduction is essentially independent of the mission conditions, as indicated by the nonsignificant interaction between Noise and Mission (tables 3 through 7). This result is in consonance with previous experiments (*e.g.*, Humes and Bauerschmidt, 1968; Snyder, *et al.*, 1974), and need not be elaborated upon for that reason.

Although the five video systems could not be compared in a single analysis because no effort was made to equate the nonzero noise levels used for each system, they can be compared at the zero noise level. The results of this analysis of variance are presented in table 8, which indicates that Mission type (M) and Video System (V) have a significant effect upon the number of correct responses, but that the M x V interaction is nonsignificant. The effects of M and V are indicated in figure 23, which shows that, at zero noise level, the 45° depression angle, 500 ft/s condition is superior to either of the 23° depression angle conditions. Using the Newman-Keuls test (Kirk, 1968), each of the mean numbers of correct responses by mission differs significantly from the other two means ($p<.01$). This result also agrees with that of Humes and Bauerschmidt (1968).

Table 8. SUMMARY OF ANALYSIS OF VARIANCE OF NUMBER OF CORRECT RESPONSES AT ZERO NOISE LEVEL

Source	df	MS	F
Mission (M)	2	20.51	51.53**
Video System (V)	4	1.13	2.71*
M x V	8	.40	1.00
Subjects (S/V)	45	.42	
M x S/V	90	.40	
Total	149		

* $p<.05$
** $p<.001$

Comparisons across the five video systems using the Newman-Keuls test indicate that the performance with 16/525 system is significantly poorer than that with the 16/945 system ($p<.05$). No other comparisons were statistically significant ($p>.05$). This result also agrees generally with that of Humes and Bauerschmidt (1968), who found a significant difference between 729 and 1029 line systems in an oblique viewing mode. They tested neither a higher line rate nor a lower line rate in the same experiment. However, other studies have indicated that, all things being equal and in the absence of photometric verification of image quality measures, there is a diminishing benefit to increasing line rate much beyond about 1000 lines.

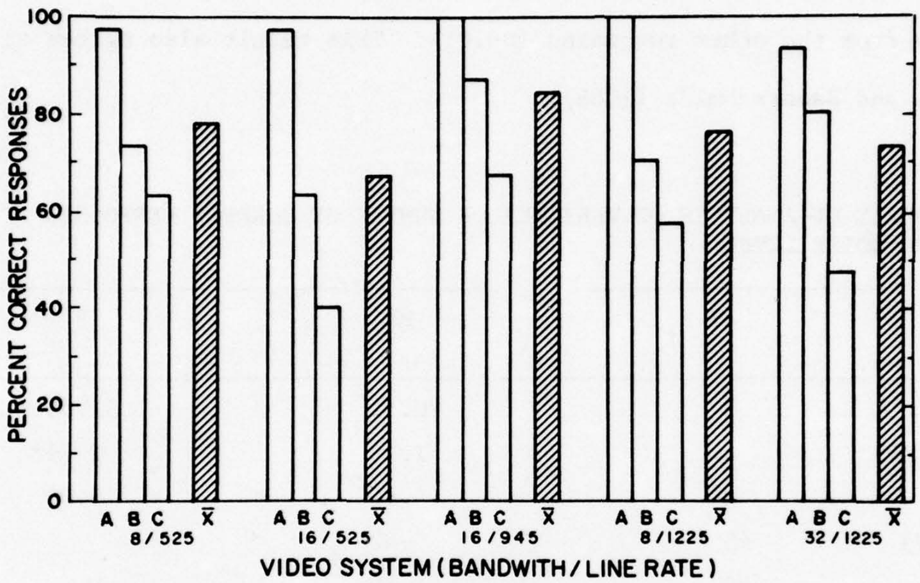

Figure 23. Percent Correct Responses at Zero Noise Level for the Five Systems. Mission A is 45° Depression Angle, 500 ft/s; B is 23° Depression Angle, 500 ft/s; and C is 23° Depression Angle, 3000 ft/s. $\bar{X}$ is the Mean, by System, of All Three Missions.

Due to the relatively constant proportion of errors of commission and no-response trials across the various experimental conditions, analyses were not conducted on either of these potential measures of performance.

Range of Target at Time of Response

Several measures have been used in the literature to relate system variables to either slant range or ground range. One of the statistical problems which has caused this variety of measures is the existence of "no-response" trials;

that is, trials or target encounters in which either an error *of omission or* an error of commission is made. Errors of omission result in missing data in a statistical sense, while ranges of errors of commission cannot meaningfully be included as range data because the subject is responding typically to something other than the target and the range to that "nontarget" is not a useful value in such an analysis. For this reason, several ways to handle such missing data have been suggested and used with some success, although they produce different results. Two of these measures will be used here.

The first measure simply substitutes the mean of all other correct responses in a given data cell for any missing responses, and corrects the degrees of freedom accordingly. Thus, the mean value of all ranges for correct responses in that cell is unaffected by such missing data.

The second measure is to substitute zero range (or some other arbitrary value) for errors of omission and commission, thereby reducing the mean range for that cell by some amount related to the likelihood of making errors. Thus, this measure becomes a combined score, including the effect of the likelihood of making a correct response with the range effect. Previous studies (*e.g.*, Bonnet and Snyder, 1976; Gilmour, 1964) have demonstrated the meaningful use of this measure.

Separate analyses of variance were performed on each system, using the mean range of correct responses for all missing range data. The results of these analyses are given in tables 9 through 13. In each case, the Mission (M) effect was statistically significant ($p<.001$), but the Noise (N) effect and the N x M interaction were not significant. The significant Mission effects are illustrated in figure 24. It is clear from this figure that the Mission effect is very consistent across all five video systems. A much smaller acquisition range is obtained for the 45^{o} depression angle, while there is very little difference between the two 23^{o} conditions, although there is a slight reduction in acquisition range as ground velocity is increased from 500 ft/s to 3000 ft/s. Evaluation by the Newman-Keuls test (Kirk, 1968) demonstrates that the difference between the 45^{o} depression angle mission and either of the two 23^{o} depression angle missions is significant ($p<.01$) for all five video systems, and that the difference between the two 23^{o} depression angle missions is significant ($p<.01$) for all but the 8/525 system, for which the difference is not significant ($p>.05$).

Table 9. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO MEAN FOR INCORRECT AND NO RESPONSE TRIALS, 8/525 SYSTEM

Source	df	MS	F
Noise (N)	4	19,480,081	1.12
Mission (M)	2	3,337,229,971	203.77*
N x M	8	18,656,270	0.78
Subjects (S)	9	46,766,958	
N x S	36	17,448,864	
M x S	17**	16,377,295	
N x M x S	55**	23,791,660	
Total	131**		

* $p<.001$

** df subtracted for missing data

Table 10. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO MEAN FOR INCORRECT AND NO RESPONSE TRIALS, 16/525 SYSTEM

Source	df	MS	F
Noise (N)	4	6,537,103	0.23
Mission (M)	2	3,543,736,721	318.81*
N x M	8	18,316,633	0.64
Subjects (S)	9	14,329,617	
N x S	36	29,047,995	
M x S	18	11,115,536	
N x M x S	64**	28,605,253	
Total	141		

* *p*<.001

** df subtracted for missing data

Table 11. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO MEAN FOR INCORRECT AND NO RESPONSE TRIALS, 16/945 SYSTEM

Source	df	MS	F
Noise (N)	4	11,304,222	0.66
Mission (M)	2	3,521,923,817	202.68*
N x M	8	5,569,150	0.30
Subjects (S)	9	39,110,815	
N x S	36	17,141,373	
M x S	18	17,376,651	
N x M x S	69**	18,751,569	
Total	146**		

* *p*<.001

** df subtracted for missing data

Table 12. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO MEAN FOR INCORRECT AND NO RESPONSE TRIALS, 8/1225 SYSTEM

Source	df	MS	F
Noise (N)	4	11,750,028	0.95
Mission (M)	2	2,882,663,841	196.24*
N x M	8	5,618,398	0.23
Subjects (S)	9	9,709,691	
N x S	35**	12,415,508	
M x S	18	14,689,129	
N x M x S	58**	24,712,940	
Total	134**		

* $p<.001$

** df subtracted for missing data

Table 13. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO MEAN FOR INCORRECT AND NO RESPONSE TRIALS, 32/1225 SYSTEM

Source	df	MS	F
Noise (N)	4	14,785,497	1.44
Mission (M)	2	3,893,277,760	252.26*
N x M	8	15,492,816	0.69
Subjects (S)	9	24,686,158	
N x S	36	10,300,425	
M x S	18	15,433,866	
N x M x S	59**	22,332,701	
Total	136**		

* $p<.001$

** df subtracted for missing data

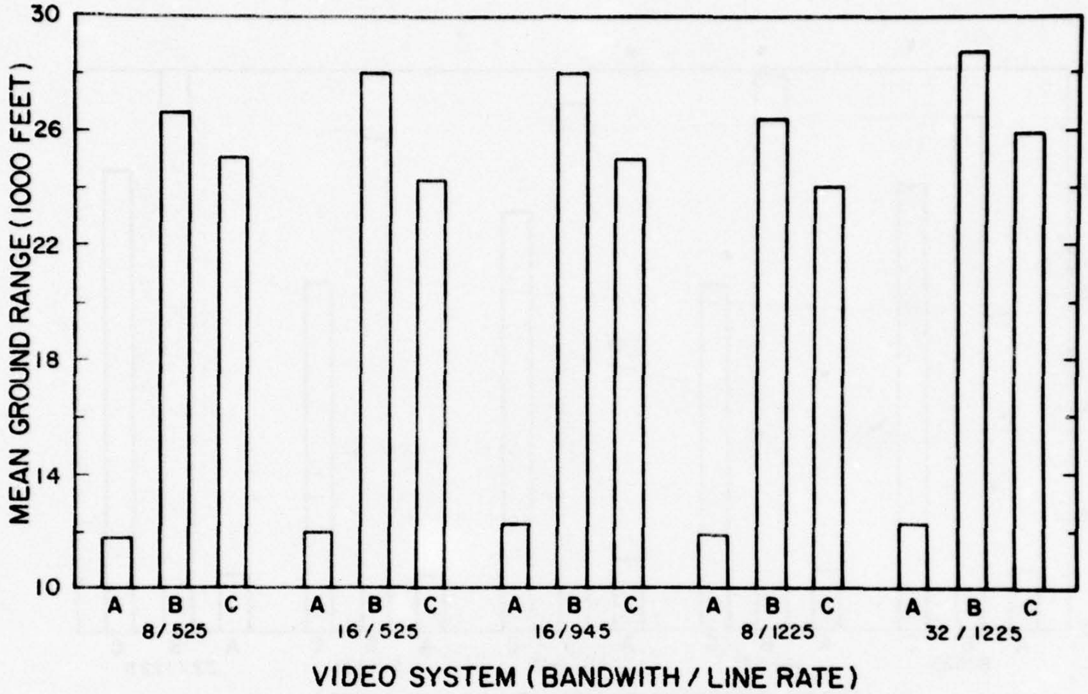

Figure 24. Effect of Mission Type on Acquisition Range for Each Video System. Missing Data are Replaced by Means of all Correct Responses in Cell. Mission A is the 45° Depression Angle Mission; B is 23° and 500 ft/s; and C is 23° and 3000 ft/s.

Comparisons of all five video systems at only the zero noise level, inserting the mean range for missing data, are illustrated in figure 25. The summary of the analysis of variance of these data is given in table 14. The differences among the Video Systems are not significant, but the Mission effect is. A Newman-Keuls test (Kirk, 1968) indicates that, averaging across all five video systems, the 45° depression angle mission produces shorter ground ranges than either of the 23° depression angle missions ($p<.01$), and that the 23° depression angle, 500 ft/s mission produces longer acquisition ranges than does the 23° depression angle, 3000 ft/s mission ($p<.01$).

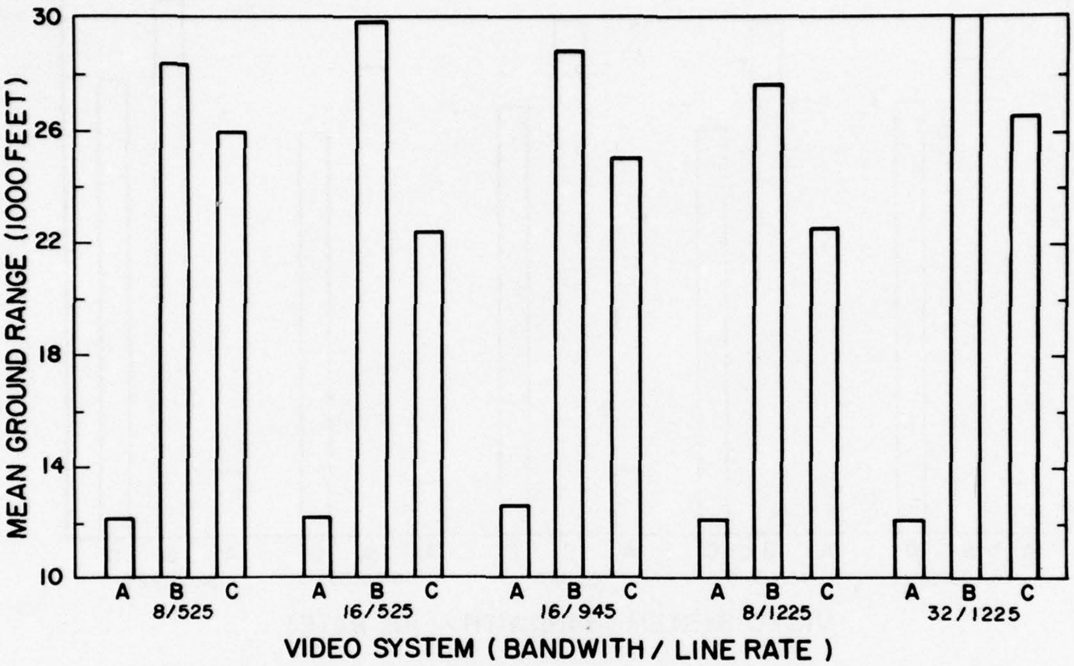

Figure 25. Effect of Mission Type on Acquisition Range for Each Video System at Zero Noise Level Only. Missing Data are Replaced by Means of All Correct Responses in Cell. Mission A is the 45° Depression angle Mission; B is 23° and 500 ft/s; and C is 23° and 3000 ft/s.

These results also agree reasonably well with the Humes and Bauerschmidt (1968) data, who obtained mean acquisition ranges of 10,800 feet for the 45° depression angle, 500 ft/s mission; 24,300 feet for the 23° depression angle, 500 ft/s mission; and 25,300 feet for the 23° depression angle, 3000 ft/s mission. Our corresponding mean ranges are 12,171, 28,661, and 24,376 feet, respectively.

When a ground range of zero is inserted for errors of either omission or commission, the results are somewhat different. Tables 15 - 19 summarize the analyses of variance, one analysis for each video system, while the mean ranges are illustrated in figures 26 through 30. For the 8/525 system, the Noise effect is significant ($p<.001$) while the Mission effect barely misses statistical

Table 14. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO MEAN FOR INCORRECT AND NO RESPONSE TRIALS, FIVE SYSTEMS AT ZERO NOISE LEVEL

Source	df	MS	F
Mission (M)	2	3,464,548,546	68.92*
Video System (V)	4	18,714,734	1.09
M x V	8	78,986,863	1.57
Subjects (S/V)	45	17,223,759	
M x S/V	86**	50,267,697	
Total	145**		

* *p*<.001

** df subtracted for missing data

Table 15. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO ZERO FOR INCORRECT AND NO RESPONSE TRIALS, 8/525 SYSTEM

Source	df	MS	F
Noise (N)	4	282,066,424	7.39*
Mission (M)	2	140,494,405	2.91
N x M	8	33,839,015	1.09
Subjects (S)	9	83,138,094	
N x S	36	38,185,936	
M x S	18	48,230,084	
N x M x S	72	31,062,860	
Total	149		

* *p*<.001

Table 16. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO ZERO FOR INCORRECT AND NO RESPONSE TRIALS, 16/525 SYSTEM

Source	df	MS	F
Noise (N)	4	196,814,815	6.38*
Mission (M)	2	317,389,834	16.49*
N x M	8	21,943,851	0.76
Subjects (S)	9	73,300,703	
N x S	36	30,847,302	
M x S	18	19,247,728	
N x M x S	72	29,055,973	
Total	149		

* $p<.001$

Table 17. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO ZERO FOR INCORRECT AND NO RESPONSE TRIALS, 16/945 SYSTEM

Source	df	MS	F
Noise (N)	4	118,941,481	4.55*
Mission (M)	2	1,120,228,934	24.81**
N x M	8	27,122,918	1.02
Subjects (S)	9	82,901,120	
N x S	36	26,142,270	
M x S	18	45,142,704	
N x M x S	72	26,550,178	
Total	149		

* $p<.01$

** $p<.001$

Table 18. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO ZERO FOR INCORRECT AND NO RESPONSE TRIALS, 8/1225 SYSTEM

Source	df	MS	F
Noise (N)	4	228,500,234	8.06*
Mission (M)	2	691,148,338	24.95*
N x M	8	26,137,061	0.54
Subjects (S)	9	49,468,932	
N x S	36	28,340,008	
M x S	18	27,701,154	
N x M x S	72	48,173,795	
Total	149		

* $p<.001$

Table 19. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO ZERO FOR INCORRECT AND NO RESPONSE TRIALS, 32/1225 SYSTEM

Source	df	MS	F
Noise (N)	4	292,015,569	14.50*
Mission (M)	2	710,455,622	13.93*
N x M	8	59,868,247	1.69
Subjects (S)	9	100,728,243	
N x S	36	20,142,567	
M x S	18	50,997,336	
N x M x S	72	35,439,552	
Total	149		

* $p<.001$

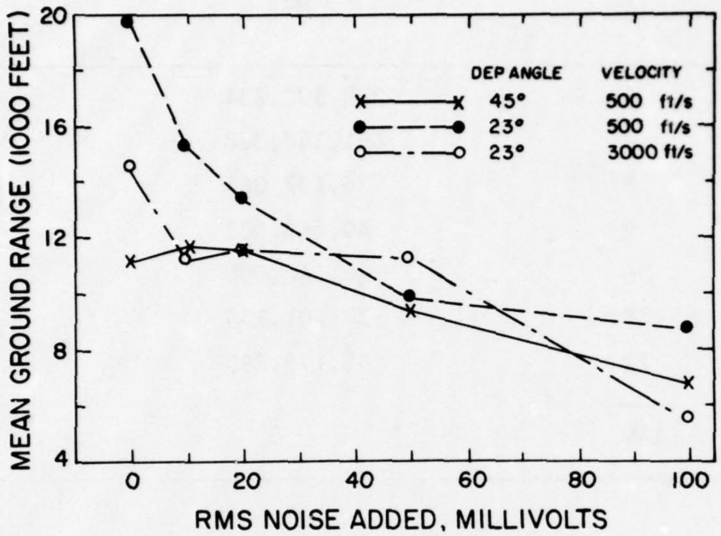

Figure 26. Effect of Noise and Mission Type on Acquisition Range, 8/525 System. Zero Range Inserted for Errors of Omission and Commission.

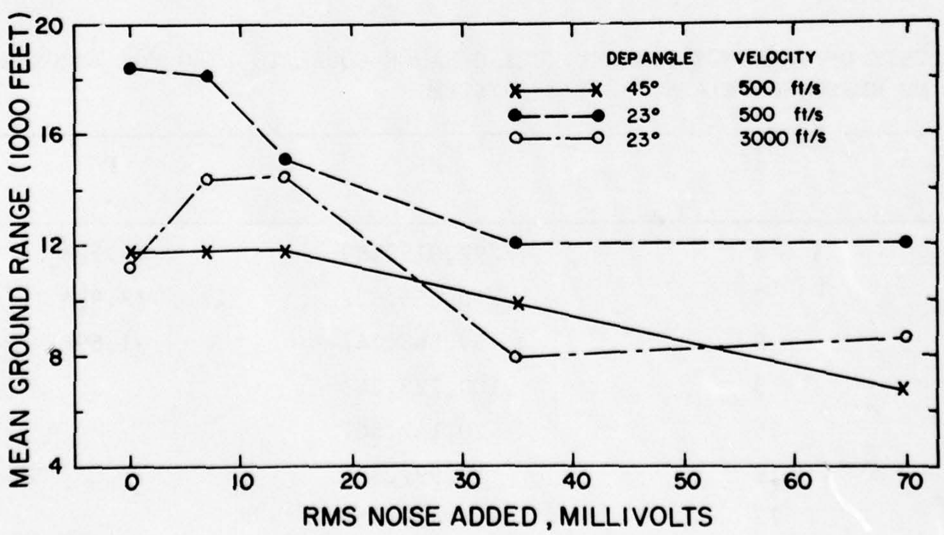

Figure 27. Effect of Noise and Mission Type on Acquisition Range, 16/525 System. Zero Range Inserted for Errors of Omission and Commission.

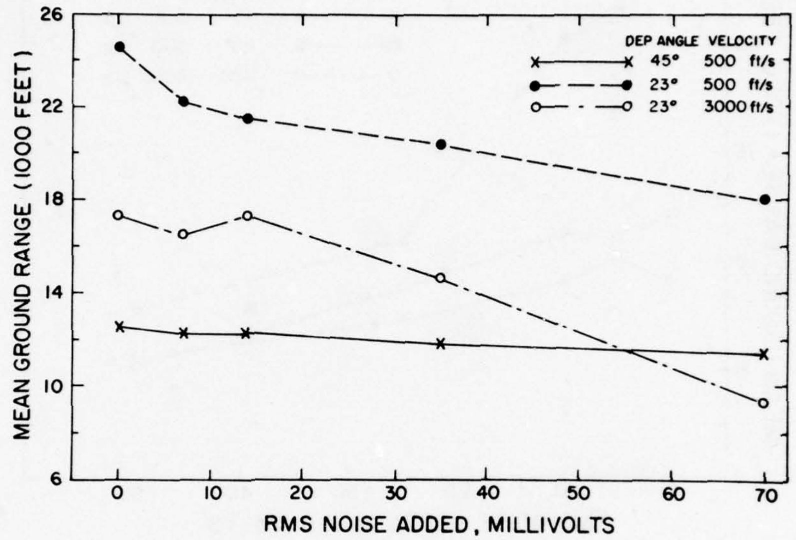

Figure 28. Effect of Noise and Mission Type on Acquisition Range, 16/945 System. Zero Range Inserted for Errors of Omission and Commission.

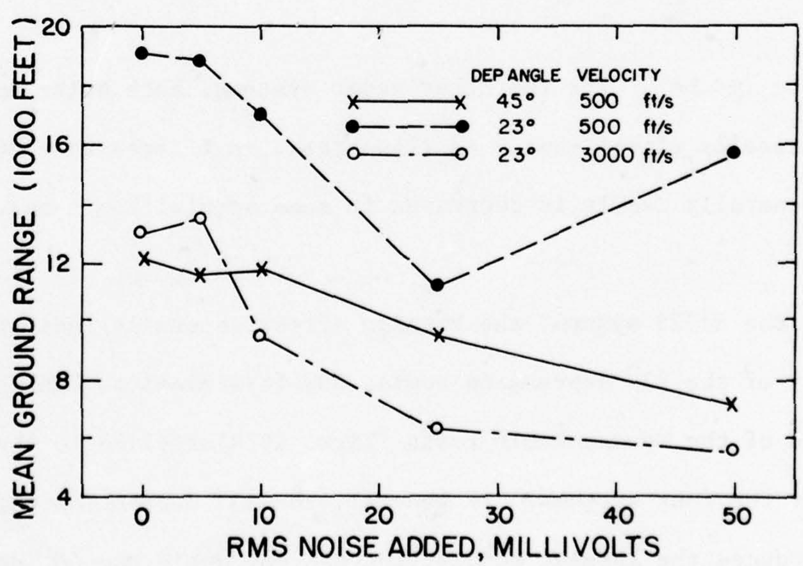

Figure 29. Effect of Noise and Mission Type on Acquisition Range, 8/1225 System. Zero Range Inserted for Errors of Omission and Commission.

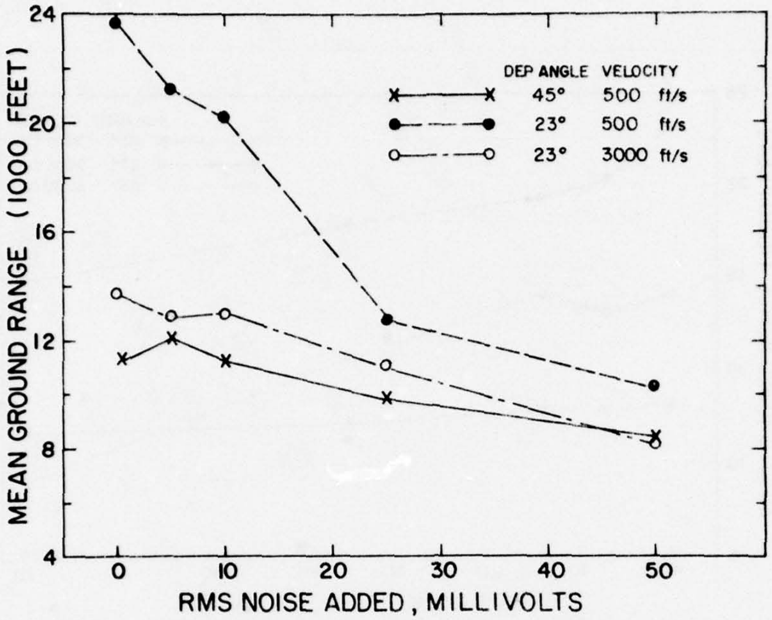

Figure 30. Effect of Noise and Mission Type on Acquisition Range, 32/1225 System. Zero Range Inserted for Errors of Omission and Commission.

significance ($p<.08$). For the other video systems, both Noise and Mission are statistically significant. As illustrated in figures 26 - 30, increases in Noise generally result in decreases in mean acquisition range.

Except for the 8/525 system, the Mission effect generally indicates the superiority of the 23^{o} depression angle, 500 ft/s mission. Table 20 summarizes the results of the Newman-Keuls tests (Kirk, 1968) applied to the Mission effects for the four systems. In general, the 23^{o} depression angle, 500 ft/s mission produces the largest acquisition ranges, while the 45^{o} depression angle, 500 ft/s mission resulted in the shortest acquisition ranges for all but the 8/1225 system. Using this measure of performance, one can see the reduced range resulting from either a decrease in depression angle or an increase in velocity.

Table 20. RESULTS OF NEWMAN-KEULS TESTS: MISSION EFFECTS ON MEAN ACQUISITION RANGES. MISSING DATA ARE REPLACED BY ZEROS. TABLED VALUES ARE MEAN DIFFERENCES.

System	Mission	23°, 500 ft/s	23°, 3000 ft/s
16/525	45°, 500 ft/s	4762*	960
	23°, 500 ft/s		3802*
16/945	45°, 500 ft/s	9262*	2934**
	23°, 500 ft/s		6328*
8/1225	45°, 500 ft/s	5986*	828
	23°, 500 ft/s		6814*
32/1225	45°, 500 ft/s	7048*	1208
	23°, 500 ft/s		5840*

* $p<.01$

** $p<.05$

An analysis of variance across video systems, using only the zero noise level conditions, indicated that the Mission (M) effect was significant, but that the Video System (V) and M x V interaction were not, as shown in table 21 and figure 31. A Newman-Keuls test (Kirk, 1968) leads to the conclusion that acquisition ranges for the 23° depression angle, 500 ft/s mission are significantly greater than for either of the other two missions ($p<.01$), but that the other two missions did not differ significantly ($p>.05$).

Table 21. ANALYSIS OF VARIANCE SUMMARY, USING RANGE EQUAL TO ZERO FOR INCORRECT AND NO RESPONSE TRIALS, FIVE SYSTEMS AT ZERO NOISE LEVEL

Source	df	MS	F
Mission (M)	2	1,193,585,325	34.06*
Video System (V)	4	81,077,468	2.36
M x V	8	25,293,922	0.72
Subjects (S/V)	45	34,329,555	
M x S/V	90	35,039,649	
Total	149		

* $p<.001$

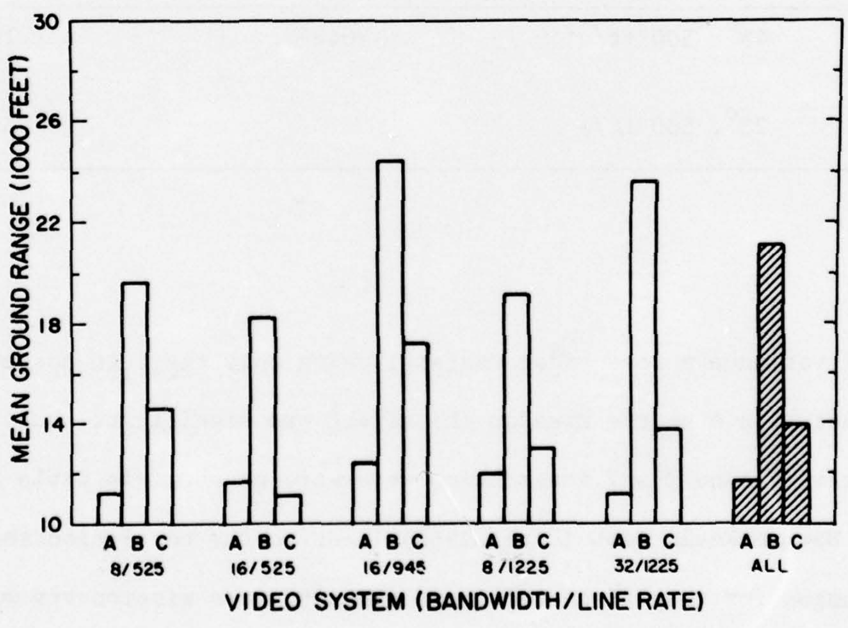

Figure 31. Effect of Mission on Mean Acquisition Ground Range. Zero Range Substituted for Errors of Omission and Commission. Mission A is 45° Depression Angle, 500 ft/s; B is 23° Depression Angle, 500 ft/s; C is 23° Depression Angle, 3000 ft/s. Data are for Zero Noise Level Only.

Summary of Target Acquisition Results

In general, the target acquisition performance data are reasonably consistent. The steep depression angle (45^{o}) enhances the probability of locating a target because it permits the target to be seen at a greater size on the display before the target passes from the field of view. The penalty paid for this greater probability of acquisition is a reduced acquisition range. Further, for the more shallow depression angle (23^{o}), the increase in velocity from 500 ft/s to 3000 ft/s results in shorter acquisition ranges, at least in part due to a constant reaction time on the part of the subject, during which the "aircraft" moves closer to the target at the higher velocity. These results are consistent with previous studies (*e.g.*, Humes and Bauerschmidt, 1968; Rusis and Calhoun, 1965).

IMAGE QUALITY MEASURES

As indicated previously, the system response curve and the observer's threshold detectability curve can be combined to produce the integral Modulation Transfer Function Area, or MTFA (figure 1). While it is theoretically possible to obtain this quantity empirically, as a practical matter it is virtually impossible to produce or purchase nondistorted sinusoidal gratings in 35mm transparency form of the size needed to obtain a *photometric* video system transfer function. It is possible, however, to obtain 35mm transparencies of square-wave gratings or tribar targets; accordingly, tribar targets were used in this experiment to measure the system (square-wave) response. Although the observer threshold data to be reported here are obtained with a sinusoidal grating (Keesee, 1976), the combination of the system square-wave response and the observer sine-wave response curves are considered meaningful, at least to a reasonable order of approximation, for development and evaluation of the concepts involved. It is not felt that the use of a system sine-wave response, in lieu of the system square-wave response, were one available, would change the results appreciably. The Keesee (1976) empirically obtained threshold curves and best-fitting equations were used to generate both the parallel and perpendicular observer threshold functions for the MTFA calculations. These equations are:

$$m_V(\nu) = (6.21 + .000124\ \text{CUMNP} + 698\ \text{DEPALM} + .000489\ \text{NPSFT}) \times 10^{-3}, \text{ and} \quad (2)$$

$$m_H(\nu) = (-5.73 + .000159\ \text{CUMNP} + 705\ \text{ORSF} + .107\ (\text{SF}-9)^2) \times 10^{-3}, \quad (3)$$

in which

$m_V(\nu)$ = threshold modulation of a grating having a spatial frequency of ν cycles/degree and oriented perpendicular to the raster,

$m_H(\nu)$ = threshold modulation of a grating having a spatial frequency of ν cycles/degree and oriented parallel to the raster,

CUMNP = $\frac{n}{\nu_T} \int_0^{\nu_T} N(\nu)\, d\nu$, where n is noise amplitude in rms mV, $N(\nu)$ is noise power as a function of spatial frequency for a noise amplitude of 1 mV rms, and ν_T is grating spatial frequency in cycles/degree,

DEPALM = value of the modulation detectability threshold determined by DePalma and Lowry (1962) for ν_T,

NPSFT = $n \int_{\nu_T - 3}^{\nu_T + 1} (\nu-(\nu_T-3))\, N(\nu)\, d\nu$, and

ORSF = $\frac{1}{\nu_R}$, where ν_R is the raster spatial frequency, in cycles/degree, and

SF = spatial frequency in cycles/degree measured with reference to the position of the subject's eyes = ν_T.

Thresholds predicted by these equations have correlations of .77 and .74, respectively, with the experimentally determined thresholds. These coefficients measure the correlation of the models with the experimental data which included replications both within and between subjects. As Keesee (1976) points out, the correlations may be conservative estimates of the models with the population means, in that no attempt was made to predict either specific subject bias or replication effects within subjects.

These models were then used to generate threshold curves for each Video System and Noise amplitude combination in the present experiment. Cross-plotting the threshold curves with the system response curves (figures 13 - 17), and performing the appropriate integration yielded the MTFA values given in table 22. It was assumed that the eye effectively integrates the active raster lines and the darker spaces between the active lines; thus, the "white-and-black" system response curves were used for the parallel MTFA calculations.

These calculated MTFA values were then correlated with observer target acquisition performance. Because the depression angle of the taking film camera imposes geometric constraints upon the acquisition ground range, it is not possible to correlate the MTFA values with ground ranges across Missions. Further, the image quality of the display is constant across missions, as measured by the MTFA, and one would not therefore expect to predict Mission differences by this static MTFA measure.

Therefore, correlations between target acquisition performance and MTFA measures were only made within Missions, or for the five Video System by five Noise level (= 25) combinations for each Mission. The resulting correlations

Table 22. CALCULATED MTFA* VALUES

System	Noise Level (mV)	Perpendicular	Parallel
8/525	0	6.80	4.53
	10	6.73	4.48
	20	6.64	4.42
	50	6.35	4.20
	100	5.67	3.68
16/525	0	9.08	8.30
	7	9.06	8.28
	14	9.01	8.26
	35	8.75	8.17
	70	8.01	7.93
16/945	0	9.44	7.73
	7	9.42	7.72
	14	9.34	7.69
	35	8.92	7.45
	70	7.66	6.79
8/1225	0	4.78	7.98
	5	4.77	7.96
	10	4.76	7.91
	25	4.67	7.57
	50	4.38	6.54
32/1225	0	10.89	8.87
	5	10.87	8.84
	10	10.83	8.80
	25	10.58	8.57
	50	9.93	7.90

$$*\text{MTFA} = \int_{\nu = o}^{\nu = \nu_c} (m_s - m_o)\, d_\nu,$$ where ν is in cycles/degree at observer's eye, m_s is system modulation at ν, m_o is observer's threshold modulation at ν, and ν_c is ν at which m_s equals m_o. For these experimental conditions, cycles/degree x 2.865 = TV lines/inch at the display.

are indicated in tables 23 - 25. In these tables, both the perpendicular and parallel MTFA values are correlated independently with all three measures of target acquisition performance -- mean acquisition range using means for missing data; mean acquisition range using zero for missing data; and number of correct responses. Then, the two one-dimensional MTFAs are combined to produce four different two-dimensional MTFAs, as defined in the tables -- a simple arithmetic mean, a quadratic mean, a harmonic mean, and a geometric mean.

Table 23. CORRELATIONS BETWEEN MTFA MEASURES AND TARGET ACQUISITION PERFORMANCE MEASURES. MISSION IS 45° DEPRESSION ANGLE, 500 FT/S.

MTFA	Range, $\bar{X}$	Range, 0	Number Correct	Mean r
Perpendicular ($\perp$)	.477*	.259	.185	.307
Parallel ($\parallel$)	.289	.228	.156	.224
Arithmetic Mean $(\perp + \parallel)/2$	.455*	.282	.198	.312
Quadratic Mean $[(\perp)^2 + (\parallel)^2]^{1/2}$	.467*	.290	.205	.321
Harmonic Mean $\frac{2}{(\perp)^{-1} + (\parallel)^{-1}}$	.434*	.267	.185	.295
Geometric $(\perp \cdot \parallel)^{1/2}$	.451*	.294	.211	.319
Mean r	.429*	.270	.190	.296

* $p<.05$

These linear correlations are generally best for the 23° depression angle, 500 ft/s mission (table 24), and poorest for the 45° depression angle, 500 ft/s mission (table 23). Similarly, prediction is best for the performance measure of ground range using mean scores for mission data, and poorest for the number of correct responses.

Table 24. CORRELATIONS BETWEEN MTFA MEASURES AND TARGET ACQUISITION PERFORMANCE MEASURES. MISSION IS 23° DEPRESSION ANGLE, 500 FT/S.

MTFA	Range, $\bar{X}$	Range, O	Number Correct	Mean r
Perpendicular ($\perp$)	.619**	.409*	.314	.447*
Parallel ($\parallel$)	.574**	.432*	.389	.465*
Arithmetic Mean $(\perp + \parallel)/2$	.688**	.480*	.396	.521**
Quadratic Mean $[(\perp)^2 + (\parallel)^2]^{1/2}$	.691**	.489*	.406*	.529**
Harmonic Mean $\frac{2}{(\perp)^{-1} + (\parallel)^{-1}}$	.680**	.463*	.377	.507**
Geometric $(\perp \cdot \parallel)^{1/2}$	.699**	.485*	.405*	.530**
Mean r	.658**	.460*	.381	.500**

* $p<.05$

** $p<.01$

If mean correlations are calculated across the missions by simply averaging the tabled mean r's, all four two-dimensional MTFA measures produce higher mean correlations than does either of the one-dimensional MTFAs. While these differences are not large, and of doubtful reliability, they are suggestive of the notion that both dimensions of image quality should be taken into consideration, and that a one-dimensional measure may be less predictive than a two-dimensional one. This is not surprising, in that threshold curves are different for the two dimensions of raster-scan displays (Keesee, 1976) and vertical raster orientations are generally superior to horizontal raster orientations for air-to-ground target acquisition performance (Rusis, 1965).

Table 25. CORRELATIONS BETWEEN MTFA MEASURES AND TARGET ACQUISITION PERFORMANCE MEASURES. MISSION IS 23° DEPRESSION ANGLE, 3000 FT/S.

MTFA	Range, $\bar{X}$	Range, O	Number Correct	Mean r
Perpendicular ($\perp$)	.435*	.402*	.362	.400*
Parallel ($\parallel$)	.326	.209	.234	.256
Arithmetic Mean $(\perp + \parallel)/2$	.445*	.366	.353	.388
Quadratic Mean $[(\perp)^2 + (\parallel)^2]^{1/2}$	.444*	.370	.357	.390
Harmonic Mean $\frac{2}{(\perp)^{-1} + (\parallel)^{-1}}$	.446*	.359	.343	.383
Geometric $(\perp \cdot \parallel)^{1/2}$	.462*	.375	.363	.400*
Mean r	.426*	.347	.335	.369

* $p<.05$

SECTION IV

DISCUSSION

TARGET ACQUISITION PERFORMANCE

The results of this experiment compare quite favorably with results of previous air-to-ground visual target acquisition experiments using a television-type display. For example, one can compare these data with those obtained in the previous air-to-ground search experiment of this contract (Beamon and Snyder, 1975) for the 500 ft/sec and 23^{o} depression angle condition. In that experiment, the field of view of the sensor camera was 18.8^{o} X 14.2^{o}, a condition which yielded a mean target acquisition range of 27,950 ft with a mean percent correct acquisition of 76%. In the present experiment, under the same ground speed and depression angle conditions, the mean ground range was 27,661 ft, with a mean percent correct of 75%. The data also compare reasonably with those of Humes and Bauerschmidt (1968), who obtained a mean ground range of 24,300 ft and 86% correct under nearly identical conditions. Other Humes and Bauerschmidt (1968) data are very similar to those obtained in this experiment, as also indicated in table 26, for the narrow field of view, 3000 ft/s, 23^{o} depression angle condition and for the narrow field of view, 500 ft/s, 45^{o} depression angle condition.

Thus, in general the data obtained in this experiment for target acquisition performance are quite reliable and apparently comparable to all meaningful previous experiments, except the Snyder, *et al.* (1974) data for the widest field of view. For these conditions, the ground range seems slightly larger

Table 26. COMPARISONS OF TARGET ACQUISITION PERFORMANCE ACROSS EXPERIMENTS, NO NOISE ADDED TO VIDEO

		Ground Speed					
		500 ft/s			3000 ft/s		
		Field of View			Field of View		
Depression Angle	Experiment	$18.8^{o} \times 14.2^{o}$	$27.9^{o} \times 21.1^{o}$	$52.9^{o} \times 41^{o}$	$18.8^{o} \times 14.2^{o}$	$27.9^{o} \times 21.1^{o}$	$52.9^{o} \times 41^{o}$
23°	1976 (2)	27,661/75 (5)			24,376/55		
	H&B (3)	24,300/86	21,000/83	13,800/75	25,300/68	22,000/69	14,800/57
	B&S (4)	27,950/76					
	1974 (1)			13,677/66			
	1976	12,171/97					
45°	H&B	10,800/99	10,400/95	9,600/86	11,800/78	11,400/79	10,600/66
	B&S						

(1) Data from Snyder, *et al.*, (1974), for a 945-line, 16-MHz system.

(2) Data from this experiment, averaged across all five video systems.

(3) Data from Humes and Bauerschmidt (1968), estimated as necessary from their report for a 1029-line, 15-MHz system.

(4) Data from Beamon and Snyder (1975), for a 525-line, 16-MHz system.

(5) First number is mean ground range; second is percent correct.

and the percent correct somewhat smaller than comparable data from other studies. A possible reason for this may be in the target set used in different studies.

A comparison of all target acquisition data, across missions, clearly suggests that the correlation between image quality and MTFA is best for the more difficult missions, as shown in tables 23-25. Thus, as the opportunity becomes greater for observer performance variability to increase due to mission difficulty, so does the correlation between observer performance and image quality. Stated another way, under more difficult mission conditions, the effect of image quality upon observer performance is greater. Perhaps in the evaluation of imaging systems, one should concentrate on optimization of image quality for the most difficult mission anticipated, rather than for a typical mission. Conversely, under relatively "easy" mission conditions, perhaps image quality is less critical, a fairly acceptable intuitive conclusion.

Effect of Noise

As reported in numerous previous experiments, as well as in this present experiment, increases in video noise result in deterioration of target acquisition performance. There are several reasons, of course, for this effect. First, small targets or target details are simply masked by the video noise. Keesee (1976) showed that noise power in the spatial frequency region of the target and below that of the target is most deleterious; thus, it follows that smaller targets (higher spatial frequency targets) or smaller target details are masked more effectively by noise than are larger targets or larger target details simply because there is more noise power below the smaller targets' spatial frequency (for a white noise spectrum).

This general effect also indicates why the mean acquisition range, averaged *across targets*, can *increase* as noise increases, because there is a different target subset for which acquisition ranges are obtained as noise is increased. That is, as noise is increased, those targets correctly acquired are typically larger targets because the smaller targets are not acquired at all and no mean range data can therefore be obtained. As this subset of targets changes to a higher proportion of larger targets, typically the mean acquisition range (for those targets *correctly* acquired) increases.

Secondly, visual search processes probably change as noise increases. It has been shown (Taylor and Snyder, 1976) that, as clutter increases, search time increases due to shorter visual interfixation distances. As the number of nontargets on the display increases, the distance, in angular units, between successive visual fixations on the display decreases, thereby requiring a larger number of fixations to cover a given display area. Because the mean fixation time remains approximately the same, independent of the amount of background clutter on the display, the search time is linearly proportional to the reciprocal interfixation distance. It is not unreasonable to expect that noise may have an effect similar to that of nontarget clutter.

Although it was the original intent in this contracted research to study eye movements as they are affected by video noise for a variety of display conditi such was not completed simply due to measured nonlinearities and instabilities in the eye movement apparatus. (See Taylor and Snyder, 1976, for a more complete discussion of these problems.) However, research oriented toward this objective is presently under way in this laboratory and should be completed in the very near future.

PHOTOMETRIC NOISE MEASUREMENT

In addition to the use of eye movements for determining the effect of video noise upon visual search performance, the question still remains as to the appropriate techniques for objectively measuring *displayed* video noise. It has become popular in some laboratories to measure both video signal and noise levels at the input to the raster-scan display, and to *assume* that this signal-to-noise relationship remains constant as passed by the (assumed ideal) display device. Although such an assumption is obviously questionable, it is certainly the case that it ought to be proven empirically. Accordingly, an earlier report (Snyder, *et al.*, 1974) attempted to measure the photometric noise at the display as a function of the electrical input noise. This attempt was largely unsuccessful, for reasons which were not totally understood at that time. However, since the publication of that report, close photometric analysis has indicated that the effect of amplitude modulation of the input electrical signal to the cathode-ray tube has the direct effect of primarily *spreading* the beam rather than varying its intensity. Thus, the effect of noise (or signal), random or otherwise, on a video display is to modulate the width of the active video raster line rather than to modulate its luminance. If one is therefore to measure variations in width of a single line, dynamically in real time, it is necessary to use a photometric aperture on the microphotometer which covers at least the maximum width of the single line so modulated.

This was not done in the previous experiment, which probably accounted for the nonlinear relationship between electrical input RMS noise and photometric output RMS noise. Specifically, as electrical input noise increased, the measured RMS photometric noise increased to a point at which the output photometric noise remained relatively constant (or even appeared to decrease in some cases) as electrical noise was increased further. One might assume, with some assurance, that this was caused by the CRT line width exceeding that of the microphotometer aperture projected onto the display plane.

Research using other techniques to accurately measure the photometric noise at the display surface is currently being conducted in our laboratories. These techniques include both an increase in size and variation in shape of the aperture of the microphotometer, as imaged in the display plane, with measurements similar to those reported in Snyder, *et al.*, (1974). Current measurement techniques also include high-quality, unity gamma photographic reproduction of a single video frame, followed by microdensitometric scanning of the resultant film transparency, with careful measurement of the displayed line width modulation.

IMAGE QUALITY

In general, the results of the experiment reported herein are somewhat disappointing. The correlations obtained between target acquisition performance and any of the measures of image quality are lower than those correlations obtained previously. The values of such correlations are not changed very much by combining both dimensions of the image quality measures. Certainly, the correlations are not nearly as high as those obtained previously using the same metric (Snyder, *et al.*, 1974).

Several possibilities exist for explaining these somewhat low correlation values. First, in the previous experiments (Snyder, *et al.*, 1974), only the noise level was changed, and not the system modulation transfer function. It may well be the case that observers are less sensitive to MTF changes than the MTFA measure predicts. That is, the MTFA value is affected equally by an increase in the observer's threshold or a decrease in the system MTF, assuming these changes to be of the same magnitude. It may well be the case that the contribution of a change in observer threshold (through, for example, a noise level increase) has a much greater effect upon observer performance than does an equal reduction, at any spatial frequency, in the system MTF. Further experiments are required to evaluate the effect of the shape of the MTF upon observer performance, as opposed to the overall MTFA value.

A second possible explanation for the magnitude of these correlations is that the between-subjects variability was quite large in this experiment. In the previous study, the between subject mean square value for mean acquisition range was 9,114,150 ft. For this experiment, this term varied from 9,709,691 ft to 46,766,958 ft. In all likelihood, this heterogeneity of variance may be due to the different targets assigned to each subject in this experimental design. Also, fewer targets per subject within a cell were used. This would tend to increase the variability of subject performance.

In the previous experiment, the noise-level-by-subjects mean square was nonexistant; in this experiment it varied from 10,300,425 ft to 29,047,995 ft. That is, it was of approximately the same magnitude in this study as the between-subjects variance. This general relationship of the subject-by-treatment interaction variance being approximately equivalent to the between-subject variance is quite unusual, and might easily account for the reduced sensitivity of the noise term. Even when zero range was inserted for incorrect responses, and the noise effect was found to be statistically significant, the noise-by-subject interaction mean square varied from 20,142,567 ft to 38,185,936 ft. Noise was therefore statistically significant due only to its extremely large variability when zero acquisition range was added for the more numerous incorrect responses at the very high noise levels.

Similarly, for the dependent variable of number of correct responses, this experimental design may have reduced sensitivity compared to other experimental design approaches, although the Noise term was significant for all systems.

Perhaps this extremely large between-subjects variance points out the need for observer performance measures and measures of image quality which are separate from the effects of the experimental statistical design and cognitive decision making styles. That is, we need some measure of the quality of the image, as viewed by the subject's visual system, separate from the subject's arbitrary willingness (or criterion) to make an acquisition response. Two possible measures exist for achieving this separate performance measurement: eye movement data and evoked cortical potential measurement. It is anticipated that eye movements, measured in terms of fixation durations and interfixation intervals, might be quite sensitive to several image quality variables. Similarly, we would anticipate that the amplitude and latency of several components of the classical visually evoked cortical potential might be sensitive to both noise and image quality, as suggested by previous research which shows such measures to be sensitive to the "sharpness" of the visual image. Research to test these hypotheses is currently ongoing in our laboratories.

In spite of the above noted disappointing correlation values, there seems to be a suggestion that the two-dimensional correlations of observer performance with image quality are better than are the one-dimensional correlations. This result is intuitively acceptable and is further supported by Keesee's (1976) results which showed that the raster spatial frequency has a significant contribution to the determination of the detectability threshold for targets oriented parallel to the raster, but not for targets oriented perpendicular to the raster. Thus, one would expect the contribution of parallel versus perpendicular image quality measures to have a different weighting upon observer performance for relatively small, especially periodic, target elements.

Relatedly, Albert (1975) showed that a concept similar to the MTFA for dot matrix alphanumeric displays required both display dimensions for good prediction of observer performance. As Pantle (1974) suggested, a two-dimensional Fourier spectrum may best predict image quality for relatively complex displays. Again, such analyses and experiments are currently being conducted in our laboratories. Of course, one way to eliminate the raster effect is by either smearing the raster or wobbling it to fill in the dark spaces between lines. Previous research under this contract (Beamon and Snyder, 1976) indicated that the use of spot wobble to produce a flat field (or visually nonexistent raster) improved the mean range to the target at the time of visual target acquisition. Further research on the quantification of an optimization of spot wobble for air-to-ground and alphanumeric displays is needed and is being conducted.

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