Technical Report 441

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HELICOPTER ELECTRO-OPTICAL SYSTEM DISPLAY REQUIREMENTS: I.

The Effects of CRT Display Size, System Gamma Function, and Terrain Type on Pilots' Required Display Luminance

Aaron Hyman, Richard M. Johnson, and Paul A. Gade

MANPOWER AND EDUCATIONAL SYSTEMS TECHNICAL AREA

U. S. Army
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March 1980

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Twenty-four Army helicopter pilots viewed videotaped segments of low-level and nap-of-the-earth (NOE) helicopter flights as presented on television monitors designed to simulate an airborne low-light-level television cockpit display system. While viewing these displays in an environment having no additional ambient illumination, these pilots were asked to set cockpit monitor luminance at the lowest level that they judged would permit successful flight control over the terrain being overflown. Each pilot adjusted

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20. luminance levels for eight different display conditions formed by the factorial combination of display size, type of terrain, and object-luminance to display-luminance transfer function (system gamma function). Results show that pilots used lower luminance settings when viewing the larger of the two display sizes presented. They also used significantly lower luminance settings when viewing wooded terrain, with the system gamma function modified to provide "enhanced" contrast in the luminance range of interest, as against an unmodified system gamma function. The pilots' subjective impressions agreed with their measured settings. This report discusses the impact of these results on the specification of display requirements for a low-light-level television system for aiding night NOE flight.

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Helicopter Display Requirements

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FOREWORD

Under daylight nap-of-the-earth (NOE) flight conditions, little time is available for the correct detection of obstacles and targets. The helicopter pilot's detection and reaction time is greatly reduced when NOE flight must be performed at night. Previous ARI research on NOE has addressed various factors involved in obstacle detection, recognition, and avoidance, such as pilot response time as a function of aircraft velocity, obstacle shape, and distance; and accuracy of judgments based on the perception of absolute distances. This report is the first of three reports on experiments designed to determine the behavioral requirements for a helicopter electro-optical display system for use in night NOE flight. The experiment described here is specifically concerned with determining the effects on display requirements of display size, system gamma function (a contrast/brightness function), and type of terrain overflown.

This experiment resulted from an in-house, technology-based research effort begun under the direction of Dr. Aaron Hyman. It is responsive to the requirements of Army Project 2Q162722A765. The results of this experiment are also responsive to Human Resources Need 77-311 from the Deputy Chief of Staff for Plans and Operations.

JOSEPH ZEIDNER
Technical Director

HELICOPTER ELECTRO-OPTICAL SYSTEM DISPLAY REQUIREMENTS: I. THE EFFECTS OF CRT DISPLAY SIZE, SYSTEM GAMMA FUNCTION, AND TERRAIN TYPE ON PILOTS' REQUIRED DISPLAY LUMINANCE

BRIEF

Requirement:

To reduce the hazards of flying in high-threat environments, the Army has emphasized low-level flying and night operations. In nap-of-the-earth (NOE) flight, the aviator stays as close to the ground as vegetation and other obstacles will permit. This is a stressful task, and the problems associated with using this tactic during daylight hours are intensified at night. For nighttime NOE operations to be successful, usable visual aids need to be developed, and the specification of their related display parameters is a necessary first step.

Procedure:

Twenty-four Army rotary wing pilots viewed videotaped segments of low-level and NOE helicopter flights, presented on television monitors designed to simulate a low-light-level television display system for helicopters. They were asked to set the display luminance at the lowest level that they judged would permit successful flight over the terrain. Each subject adjusted the luminance level for eight different display conditions derived from the combination of two different display sizes (13- or 26-cm CRTs viewed at 69 cm), two types of terrain (wooded or semi-arid with sparse vegetation), and two different system gamma functions (normal contrast or enhancement of contrast in darker portion of display luminance range). Participants were also asked for their subjective impressions of the various display conditions.

Findings:

Pilots were able to use significantly lower luminance settings with the 26-cm display than they were with the 13-cm display. They also used significantly lower settings when viewing videotapes of wooded terrain presented on displays with enhanced contrast in the darker areas (i.e., system gamma modification). The pilots' subjective impressions and indicated preferences agreed with their measured settings. Pilots preferred a 26-cm over a 13-cm display.

Utilization of Findings:

Pilots are able to use larger displays at lower luminance levels. The fact that the utility of modifying the system gamma functions was terrain-specific opens up the possibility of developing optimal object-luminance to display-luminance transfer functions for different types of terrain. However, before specific recommendations for display luminance requirements can be made, dark-adaptation losses with larger but dimmer displays need to be determined so that an objective evaluation of the utility of low-luminance displays can be established.

HELICOPTER ELECTRO-OPTICAL SYSTEM DISPLAY REQUIREMENTS: I. THE EFFECTS OF CRT DISPLAY SIZE, SYSTEM GAMMA FUNCTION, AND TERRAIN TYPE ON PILOTS' REQUIRED DISPLAY LUMINANCE

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INTRODUCTION

Technological advances in enemy visual and sensor surveillance systems threaten combat survivability of the Army helicopter. As a countermeasure, the Army has emphasized using low-level flying and night operations. More specifically, nap-of-the-earth (NOE) flight is the tactic of choice for helicopters in this high-threat environment (U.S. Army, 1976; Abbey & Carson, 1978). In NOE flight, the aviator stays as close to the earth's surface as vegetation and obstacles permit. Thus the use of natural terrain features as a mask increases the probability of avoiding detection by the enemy.

Performing NOE flight is a difficult and fatiguing task for the pilot, and the margin for pilot error is extremely small. Since NOE flight is much more difficult at night, effective night vision aids and displays are important to successful nighttime NOE flight.

This research was directed toward obtaining data to aid in specifying display parameters for a low-light-level television (LLLTV) system as a visual aid in night NOE flight. An LLLTV camera is an image-intensifying device capable of responding to low-intensity radiation in the visible and near infrared regions of the electromagnetic spectrum. The radiation is first converted to a highly amplified electrical signal and then reconverted to a raster-scan visual display on a cathode ray tube (CRT). A suitably mounted LLLTV camera on a helicopter and an accompanying display of the output on a monitor in the cockpit can provide the pilot with a real-time television picture of the terrain in front of the helicopter. But for safe and effective use of such an LLLTV display, optimal display parameters need to be specified. Before the specific parameters to be investigated in this research effort were selected, several germane factors were analyzed.

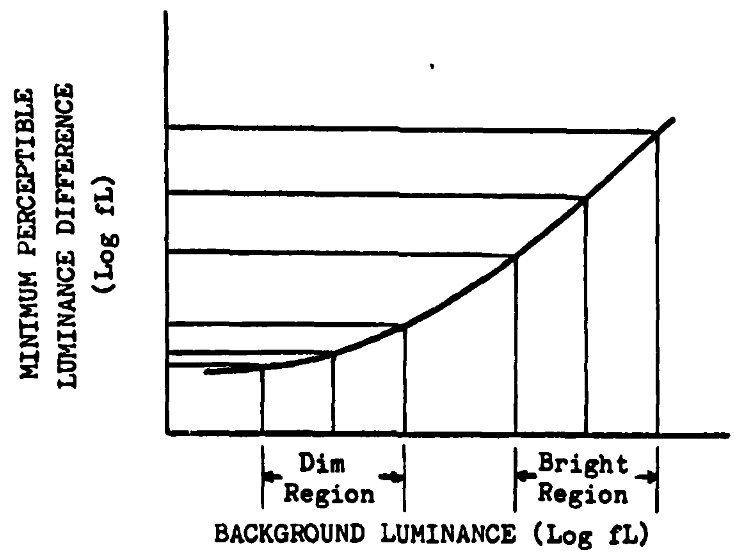
Rectangular TV displays usually have a 3-by-4 aspect ratio. Thus a CRT display that is 15.6 cm high is 20.8 cm wide; and its diagonal is 26 cm; and it is characteristically described in terms of its maximum linear dimension, namely, the diagonal: a 26-cm display. Similarly, a rectangular CRT display 7.8 cm high and 10.4 cm wide is called a 13-cm display. When the latter display is viewed from 69 cm, its height subtends approximately 388 arc minutes. If the viewer has the normal visual acuity of 20/20 Snellen (i.e, 2 arc minutes per line pair or 1 arc minute per TV line) and the display has a resolution of 400 TV lines per picture height, there is good matching of eye and display resolution.

Visual acuity, however, depends partly on display luminance level (Shlaer, 1937; Riggs, 1965; Kaufman & Christensen, 1972). For example, when the luminance of the background is about 0.2 footlambert (fL) and the target has high contrast, acuity is approximately 20/20 Snellen; when background luminance is about 0.015 fL, acuity is approximately 20/40 Snellen (i.e., 4 arc minutes per line pair). In the latter case, retaining the resolution match between display and the eye now requires a 26-cm CRT with 400 TV lines per picture height resolution.

There is an advantage in flying with a dim TV display at night, because as visual dark adaptation increases, the pilot is better able to see the external environment when looking through the windscreen. Research by Baker (1953, 1963), also described by Bartlett (1965) and by Brown and Mueller (1965), shows that dark adaptation recovers at a very rapid rate during the first 1/2 second after an adapting luminance is turned off. The question is, can one set cockpit TV displays for night flying so they are bright enough to permit acceptable form perception when flying "heads-down" (i.e., looking at the instrument panel) and yet dim enough to allow rapid acquisition of the visual world when flying "heads-up" (i.e., looking through the windscreen)?

Another variable to be considered when using a dim display is the object-luminance to display-luminance transfer function, usually called system gamma function (where gamma is the slope of the curve describing the object to display luminance functional relation when the coordinates are in log units). The advantage in having a nonlinear gamma function with dim displays arises from the fact that the minimum perceptible luminance difference (i.e., contrast discrimination) is a nonlinear function of background luminance (Mueller, 1951; Brown & Mueller, 1965; Kaufman & Christensen, 1972). For a given ratio of luminances, contrast discrimination is poorer for the lower portion of the associated log-luminance range when the display is dim, whereas contrast discrimination is almost linear for a comparable log-luminance range in a bright display. In Figure 1, the upper drawing shows the perceptual nonlinearity in contrast discrimination for dim display luminance levels as compared to bright display luminance levels. The lower drawing in Figure 1 shows how this can be compensated for, by modifying the system gamma function. Curve A shows an object-luminance to display-luminance transfer function useful with a bright TV-generated display. Curve B shows an object-luminance to display-luminance transfer function useful with a dim TV-generated display. It is designed to counteract the nonlinearity in contrast perception at dim luminance levels, as demonstrated by the curve in the upper panel. "Gamma" is the term used to designate the slope of the object-luminance to display-luminance transfer function, for displays originating from TV cameras, when coordinates are plotted in log units.

Thus, for a given range of input signals, to obtain a relatively uniform perceptual discrimination of contrast such as can be achieved with a bright display and the transfer function defined by curve A, the transfer function defined by curve B is needed for a dim display. To evaluate this, two representative system gamma functions have been selected for comparison in this research. These are shown in Figure 2. Curve N in Figure 2 describes the system gamma function identified in this report as "normal." Curve M describes the system gamma function identified in this report as "modified." Photometric measurements were made of the display face from input obtained using an EIA Logarithmic Reflectance Chart. Three different levels of display highlight luminance were used. Obtained logarithmic values were then averaged, and the sets of data were shifted vertically to represent the case where highlight luminance is 0.2 fL.



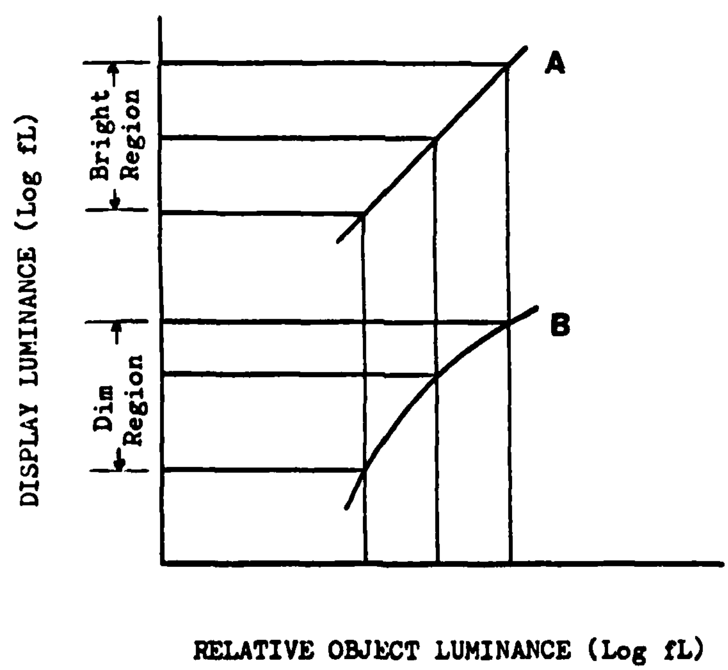


Figure 1. Functional relations illustrating advantage in modifying the system gamma function when luminance level of television display is decreased.

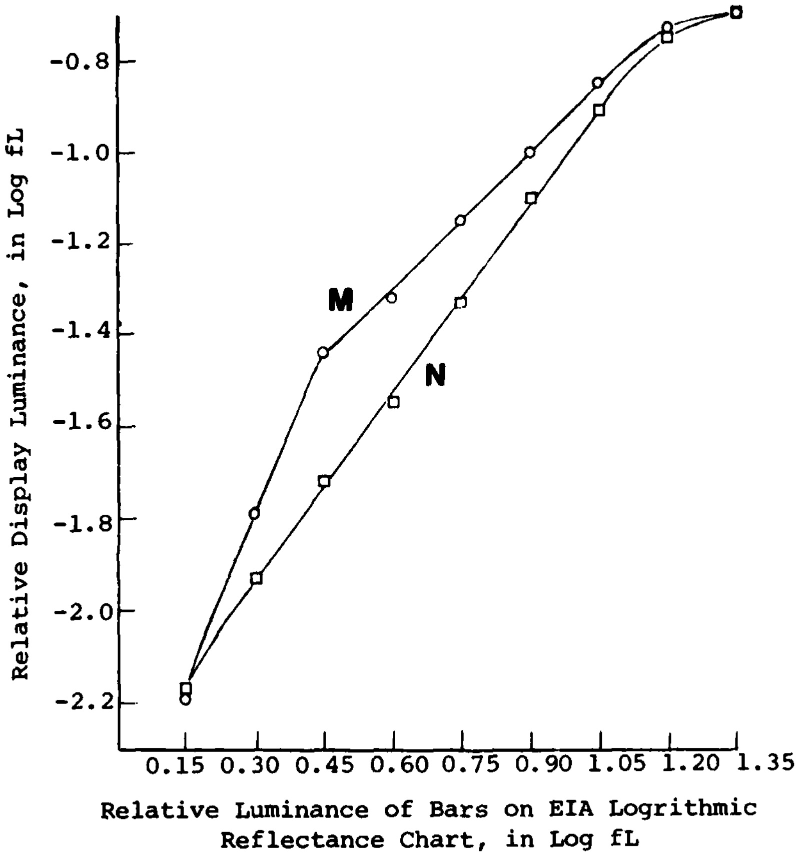


Figure 2. System gamma functions used in present research.

Based on the findings of other investigators (e.g., Baker, 1953, 1963; Mueller, 1951; Shlaer, 1937), it was estimated that a TV display having a highlight luminance of about 0.05 fL might provide a pilot with an acceptable presentation with which to perform night NOE flights and also have an acceptably low impact on dark adaptation. The data in the literature are reported in trolands; in converting them to footlamberts, it was assumed that the observer would have a pupil diameter of 5 mm and that retinal integration time would be 0.1 second.

A special simulation facility was developed, and three display parameters were selected for initial investigation. The first parameter was CRT display size. Because of limited panel space in the helicopter cockpit, the smallest CRT that can be safely used by a pilot must be selected. Therefore CRT displays with an aspect ratio of 3:4 and diagonals of 13 cm and 26 cm were compared. With reference to real-world visual angles and rate of closure on obstacles, these CRT displays, when viewed at about 69 cm, represented about a 6x and 3x minification respectively.

The second parameter investigated was display luminance. Because the pilot or copilot may periodically have to look through the windscreen, the CRT display must be dim enough to optimize dark adaptation and bright enough to permit adequate form perception when viewing the cockpit display.

The electro-optical system gamma function (i.e., the transfer function of input luminance to CRT display luminance) was the third parameter studied. The gamma function can be readily manipulated electronically in a TV system; such manipulation, through local contrast variation, can enhance the visibility of selected features (e.g., trees and green foliage).

The specific objective in studying the effects of the above parameters is to provide data for developing some critical display requirements for a helicopter-mounted LLLTV system.

METHOD

Research Facility

A flexible NOE visual flight simulation facility was developed at the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) to provide various modes of presentation of stimulus materials to the participant pilots. The three configurations used in the present series of research efforts are described below.

Configuration I. A 16-mm filmchain projector (Bell and Howell model 652),[1] together with an optical projection system, was used to present the participant with both a full-color windscreen display, which simulated real-world visual angles, and a panel CRT display of the same scene but minified and in monochrome. The windscreen display, which could be presented at various luminance levels, was projected on a rear-projection screen and viewed through a

[1]Commercial names are used in this report for purposes of clarity only and do not represent endorsement by the Department of the Army.

Fresnel lens that placed the image at optical infinity for the observer. A television camera (GBC model CTC 6000), mounted in line with the 16-mm projector, was used to generate a simulated LLLTV display to the participants. The use of a beam splitter suitably placed in the optical train provided the participant simultaneously with the simulated windscreen display and the correlated LLLTV display. The size, luminance level, and system gamma function of the simulated LLLTV display could be adjusted by the experimenter. A schematic view of this system is shown in Figure 3.

In Figure 3, panel A is a plan view of the arrangement in which the simulated TV camera is fixed with respect to the aircraft. For this configuration, the TV camera must have its vertical sweep reversed. Panel B is a plan view of the arrangement in which the simulated TV camera can be moved in azimuth and elevation with respect to the aircraft coordinate axes. Because of the relatively low screen luminance and the need for using a small lens aperture to obtain depth of field, a silicon-intensified TV camera (SIT) (GBC model NVC 100) was used here. Panel C shows a side view of the participant's work station, which is the same for either of the above arrangements. In panel A, focal length of the projection lens is 25 mm, faces of the beamsplitter are 50 mm by 50 mm, and the relay lens system used for converging the rays to form an image on the TV camera tube comprises an Erfle eyepiece of 37 mm focal length plus a Barlow lens of minus 44 mm focal length. The Fresnel lens shown in panel C is 38 cm in diameter and has 49 grooves per cm and a focal length of 32 cm. It images the projection screen (i.e., windscreen display) at optical infinity. Also shown is the two-mirror arrangement for presenting a virtual image of the cockpit monitor at 69 cm from the observer.

Configuration II. The windscreen stimulus materials in this configuration were presented by means of a CONRAC RQA 17 television monitor instead of a rear-projection screen. The resultant monochrome windscreen display was collimated and provided the observer with a 36-by-48-degree field of view (FOV) presented at real-world angular subtense. The observer looked at this display through goggles mounted on a light-tight viewing hood. Display luminance was varied by one of two methods. With the first method, only the experimenter controlled the luminance of the display, and the luminance level was discretely varied by inserting neutral density filters into the goggles. With the second method, the goggles were fitted with a fixed and a rotating polaroid filter that permitted the subject to continuously vary the luminance level; the setting could also be remotely monitored by the experimenter. Stimulus material could be generated from an on-line TV camera or from videotape recordings played back on a SONY videotape recorder (model VO 1800). Directly below the viewing hood was another CRT monitor simulating a cockpit panel display viewed at 69 cm and presenting the same material as that generated for the windscreen display. The size of the panel display could be varied by the experimenter, and its luminance level was controlled by the participant, who set the angular position of the rotating member of a pair of polaroid filters mounted in front of the simulated panel area. The panel display luminance level was continuously adjustable and was remotely monitored by the experimenter. The participant's work station environment was an enclosed, dark-walled, sound-attenuating chamber.

Configuration III. The participant's environment was the same as that used in Configuration II. The source for the stimulus material, however, was a 1.22 m by 1.83 m, three-dimensional, full-color terrain model designed to

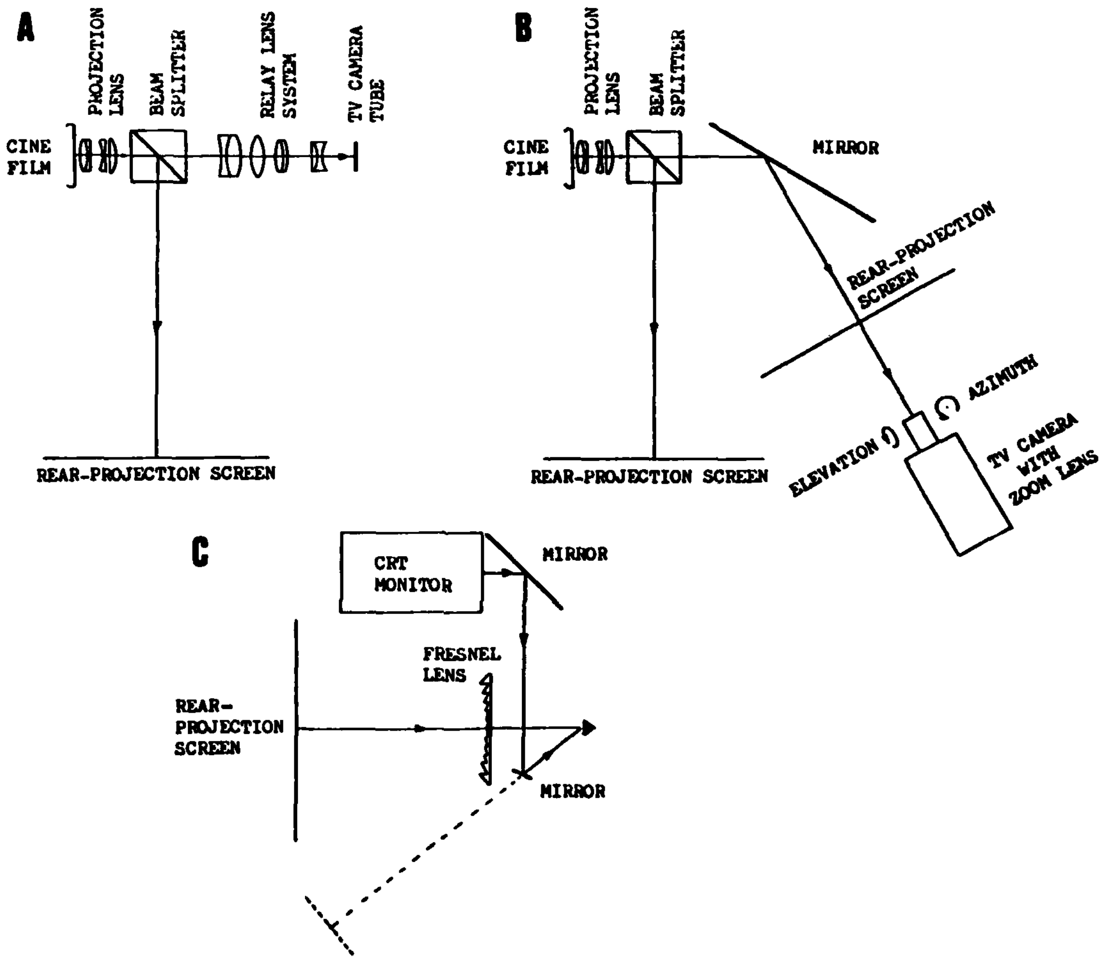


Figure 3. Schematic presentation of optical layout utilizing filmchain projector for simulating a full-color windscreen display and correlated LLLTV cockpit monitor.

simulate partially wooded terrain at a 1:300 scale. It was used in conjunction with an optical probe mounted on a TV camera (GBC model NVC 100) that had a SIT camera tube to provide the video output. The probe (see Figure 4), with its symmetrical optical system and telecentric aperture stop, was designed to have unit magnification, a 60-degree circular instantaneous FOV, good color correction, and very little distortion. A scanning mirror, rotatable on two orthogonal axes and located at the entrance pupil of the probe, was used to set the pitch and the heading of the simulated aircraft. Roll angle and any needed derotation was obtained by rotating a Pechan prism about the optic axis. (Rotational servo controls had not then been incorporated in the probe, so that for a given simulated flight, the pitch, heading, and roll settings remained fixed.)

When viewing directly through the probe, with entrance pupil set at about 0.5 mm and probe focus set for an object 26 cm from the entrance pupil, the 20/30 line of the Snellen eye chart (suitably reduced) was resolved for chart placements anywhere in the FOV. Depth of field for this 20/30 resolution was from 20 cm to infinity (i.e., for a 1:300 scale, from 60 m simulated to infinity), and at 5 cm (i.e., at 15 m simulated for a 1:300 scale) resolution was about 20/70 Snellen. When the probe was interfaced with the TV camera, the display monitor provided the observer with a 42-degree horizontal and a 31-degree vertical real-world FOV, and resolution was degraded to about 20/90 Snellen (equivalent to about 400 TV lines per picture height).

The participant controlled the probe altitude (from 0 to 61 m simulated) and forward groundspeed (from 0 to 45 knots simulated). To obtain the 3 degrees of translational freedom (continuously varied), the position of the terrain model (which could be moved in X and Y), and the position of the probe (which could be moved in Z) were controlled through an INTER DATA 90 computer and associated peripherals and electromechanical equipment. The computer was also used to record and display the participant's altitude, airspeed, flight path, and number of crashes during simulated helicopter runs over the terrain model. A schematic diagram of the probe is presented in Figure 4, and the relationship between probe and terrain model is shown in Figure 5.

Direct visual viewing of the display, with unit magnification, was obtained by removing the TV camera shown in Figures 4 and 5 and placing the observer's eye at the exit pupil of the probe (i.e., behind relay lens 3). Image focusing was accomplished through small axial movement of relay lens 2. The objective and relay lens 3 are alike, each being an Erfle eyepiece of 20 mm focal length; and relay lenses 1 and 2 are each Schneider-Kreuznach Componon lenses of 50 mm focal length. Field-of-view is 60 degrees and circular.

As shown in Figure 5, the 3 degrees of translation are controlled through servo drives. In the present series of investigations, simulated movement of the helicopter was simplified to closed loop control of translation only.

Participants

The research participants were 24 rated Army helicopter pilots who volunteered to serve in the study. All participants had normal or corrected normal vision.

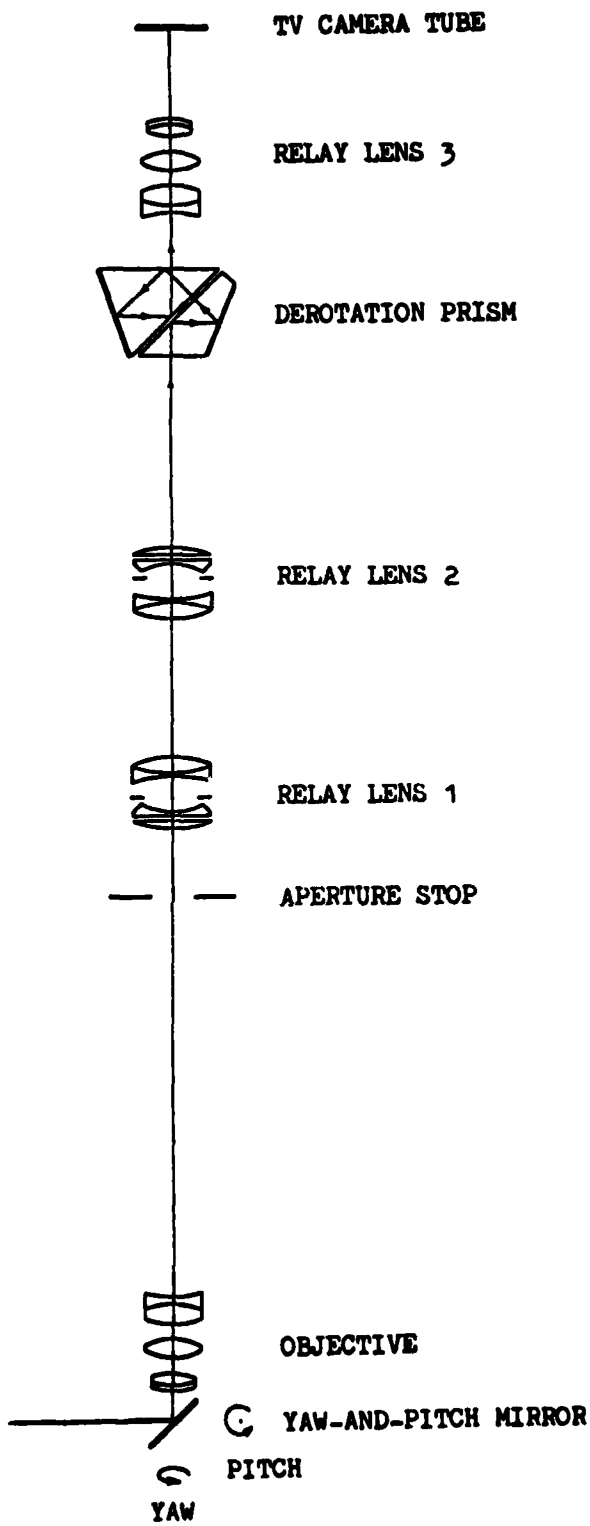


Figure 4. Schematic presentation showing arrangement of components in the optical probe.

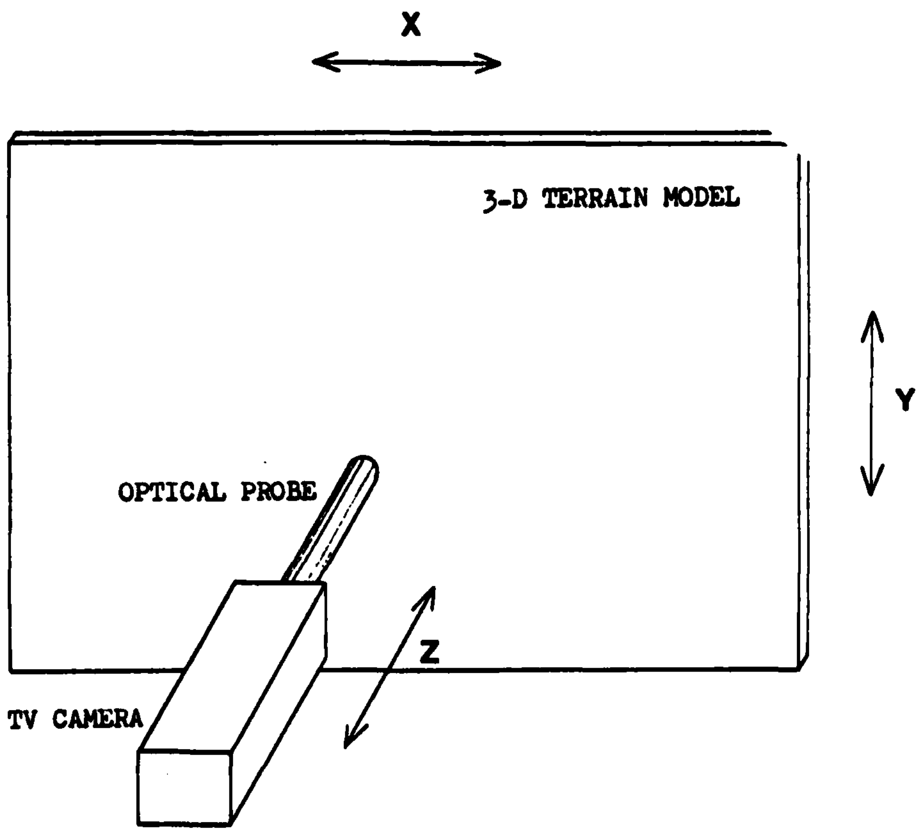


Figure 5. Schematic presentation showing the approach used for obtaining translational movement of the simulated helicopter.

Procedure

Prior to the start of data collection, all participants were shown a simulated windscreen display of NOE flight in conjunction with a correlated instrument panel CRT presentation. The Configuration I apparatus (see Figure 3, panels A and C) was used for this demonstration. The windscreen view was presented at approximately full-moon luminance levels (scene highlight luminance of 0.01 to 0.02 fL). While the participants viewed this display, the experimenter brought to their attention the angular minification present with the 13-cm CRT monitor (6x minification) and the 26-cm CRT monitor (3x minification) in comparison to the real-world visual angles as seen in the windscreen view. The experimenter also explained the potentially detrimental effect of a bright CRT display on dark adaptation.

After the familiarization demonstrations, CRT display luminance was varied, so that the participants could judge the dimmest setting they could use for the displays and still feel they could fly safely using such a system.

In the formal experiment, the Configuration II facility was used, and only the panel display was presented. The participants viewed two 10-minute segments of NOE flight, recorded on videotape. One segment was filmed at the Hunter-Liggett, Calif., military reservation, and the other segment was filmed near Fort Rucker, Ala. The tapes were viewed by each participant pilot on the 13-cm and the 26-cm CRT displays. They could attenuate the display luminance by rotating one of a pair of polaroid filters while the other remained fixed. This permitted scene highlight variation of from 0.01 fL to 0.20 fL. Participants also viewed each display with a normal system gamma function or with a modified system gamma function designed to enhance detail in the luminance range of terrain features such as trees and other green foliage. Thus, each subject made judgments in eight different conditions: 13- or 26-cm CRT display, Hunter-Liggett or Fort Rucker terrain, and normal or modified display system gamma function.

The pilots were instructed to view each display as though it were being used to perform NOE flight at night. They were asked to make the display as dim as possible without sacrificing any information necessary to conduct a safe and effective mission. Each participant made six judgments with each display condition, rotating the polaroid filter in alternate directions for successive judgments to minimize positional cues in setting the display luminance. At the end of the experiment, the participants were fully debriefed, their questions were answered, and any of their observations concerning the displays were recorded. Each participant was asked to indicate a preference for either the 13-cm or the 26-cm display and to comment on the desirability and utility of having a system gamma control.

RESULTS AND DISCUSSION

A 2 x 2 x 2 factorial ANOVA with repeated measures on all factors was used to evaluate the effects of CRT size, system gamma function modification, and type of terrain on display luminance levels used by pilots to maximize visual dark adaptation when flying with an LLLTV system. The independent variables were CRT size (13 cm vs. 26 cm), system gamma function (normal vs.

modified), and type of terrain (semi-arid as at Hunter-Liggett vs. heavily wooded as at Fort Rucker). The dependent measure was the mean of the six luminance judgments (in fL) made by each of the 24 pilots for each of the eight display conditions.

The overall mean luminance judgments made by the 24 pilots for each display condition are presented in Table 1, and some pooled means for these data are presented in Table 2. As indicated in these tables, the pilots felt that they could tolerate a 29% dimmer display when using the 26-cm as compared to the 13-cm CRT monitor (F (1,23) = 40.58, p < .01). It can also be seen that with a normal system gamma function, pilots required a brighter (i.e., higher luminance) display when flying over heavily wooded terrain than when flying over the semi-arid terrain of Hunter-Liggett (F (1,23) = 60.89, p < .01). A significant effect for system gamma function modification was also obtained (F (1,23) = 51.03, p < .01); however, this effect was mainly manifested in a terrain by contrast interaction (F (1,23) = 40.58, p < .01).

Table 1 shows that system gamma function modification had little if any effect for semi-arid terrain, but allowed for a 29% dimmer display during flights over heavily wooded terrain. No other interactions were statistically significant. Also, when a 26-cm display size was used in conjunction with a modified system gamma function, mean display highlight luminance, selected by pilots as adequate for night flying, was 0.06 fL or less. This compares favorably with the extrapolation of 0.05 fL obtained from previous research (e.g., Baker, 1953, 1963; Mueller, 1951; Shlaer, 1937).

During debriefing, 92% of the pilots felt that they would be more comfortable using the 26-cm display, 4% preferred the 13-cm display, and the remainder had no preference. All the pilots felt that the modified system gamma function would be of value when flying over heavily wooded terrain.

CONCLUSIONS

Two general conclusions can be drawn from the results of the present study. First, both the empirical and subjective data from the pilots support the use of a 26-cm CRT display when using an airborne LLLTV system. When using the 26-cm display as opposed to the 13-cm CRT display, pilots could tolerate a dimmer display, thus reducing the adverse effects of display-viewing on visual dark adaptation. In addition, the pilots felt more comfortable when using the 26-cm display. Preference was usually expressed in terms of a feeling of having a larger real-world field of view, even though the 26-cm and the 13-cm displays both presented the same real-world field of view. The "larger," subjective visual FOV provided by the 26-cm display gave pilots greater visual comfort, perhaps because the 26-cm display reduced the restriction on scanning eye movements.

Table 1

Mean Highlight Luminance Settings (in Footlamberts) for Display Size, System Gamma Function, and Terrain Type

	System gamma function			
	Normal		Modified	
Display size	Semi-arid terrain	Heavily wooded terrain	Semi-arid terrain	Heavily wooded terrain
13 cm	0.066	0.119	0.066	0.093
26 cm	0.046	0.096	0.044	0.060

Table 2

Means Pooled Across Conditions for Mean Highlight Luminance Settings Listed in Table 1

Independent variable	Mean setting (in footlamberts)
Display size	
13 cm	0.086
26 cm	0.061
System gamma function	
Normal	0.082
Modified	0.066
Terrain type	
Semi-arid	0.056
Heavily wooded	0.092

A second general conclusion is that the modified system gamma function may be useful when flying over heavily wooded terrain. The pilots thought that the fine structure of the forest canopy was more easily discriminable with this modification. Furthermore, they adjusted their displays to a lower luminance when using the modified system gamma function. They were apparently able to discern the needed detail in the heavily wooded areas, even though they were using a lower display luminance. The lack of differences with system gamma function modification when flying over semi-arid terrain is not surprising, since this terrain is comprised of high-contrast elements for either of the two gamma functions used. This finding is important because it indicates that the effect of system gamma function modification is terrain-specific and opens up the possibility of developing optimal real-world-luminance to display-luminance transfer functions for other characteristic terrain types.

A third conclusion, although tentative, is that pilots flying in moonlight can set their cockpit CRT display at a luminance level high enough to provide them with an adequate cockpit flight display and yet low enough to permit them to have relatively rapid visual acquisition when subsequently viewing directly through the windscreen (i.e., adequate visual dark adaptation for heads-up viewing).

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