Technical Paper 378

THE IMPORTANCE OF PROVIDING STEREOSCOPIC VISION IN TRAINING FOR NAP-OF-THE-EARTH FLIGHT

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LEVEL II

ENGAGEMENT SIMULATION TECHNICAL AREA

U. S. Army
Research Institute for the Behavioral and Social Sciences

July 1979

U. S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency under the Jurisdiction of the Deputy Chief of Staff for Personnel

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NOTICES

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: (9) Technical Paper [redacted]	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): (6) THE IMPORTANCE OF PROVIDING STEREOSCOPIC VISION IN TRAINING FOR NAP-OF-THE-EARTH FLIGHT.	5. TYPE OF REPORT & PERIOD COVERED: --
	6. PERFORMING ORG. REPORT NUMBER: --
7. AUTHOR(s): (10) Donald E. Erwin	8. CONTRACT OR GRANT NUMBER(s): --
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Research Institute for the Behavioral and Social Sciences, 5001 Eisenhower Avenue, Alexandria, VA 22333	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: (16) 2Q161101A91B
11. CONTROLLING OFFICE NAME AND ADDRESS: Deputy Chief of Staff for Personnel, Washington, DC 20310	12. REPORT DATE: (11) Jul[redacted]79
	13. NUMBER OF PAGES: 16
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): -- (12) 26p.	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: --

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(14) ARI-TP-378

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

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18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Stereopsis
Nap of the earth (NOE)
Helicopter simulators

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

Nap-of-the-earth (NOE) flight in Army tactical helicopter operations necessitates high speed visual-motor coordinations in order to avoid obstacles in the flight path while making maximal use of the terrain for cover and concealment from enemy air defense weapon systems. The development of simulators for training pilots in NOE flight involves the design of visual display systems which provide all the important optical information available in actual flight. At the present time, however, there is insufficient information on
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Unclassified

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the role of stereopsis in NOE flight to determine whether fully binocular displays must be designed into training simulators.

This paper describes results from two preliminary studies which examined the importance of binocular disparity for the perception of three-dimensional layout of the terrain in NOE flight. In the first experiment, it was determined that stereoscopic movies taken from the cockpit of a helicopter in NOE flight produce more compelling impressions of three-dimensionality than a non-disparate bioptic display. The results of the second experiment show that simple reaction times for detection of three-dimensionality in static binocular displays were substantially longer than for detection of fusibility of otherwise identical bioptic displays. Additionally, it was found that detection of fusibility required much more time than detection of a light flash.

Strategies for further research bearing on a design recommendation are presented and discussed.

Technical Paper 378

THE IMPORTANCE OF PROVIDING STEREOSCOPIC VISION IN TRAINING FOR NAP-OF-THE-EARTH FLIGHT

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Department of the Army

July 1979

Army Project Number
2Q161101A91B

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FOREWORD

This research was performed under the in-house laboratory independent research (ILIR) program in FY 1978 of the Army Research Institute for the Behavioral ~~and Social Sciences~~. Dr. Aaron Hyman's contribution was integral to this work; he provided much of the technical expertise needed to conceive and construct a working hypothesis in the problem area and to indicate the direction that further research would have to follow. The results have also been discussed in a symposium entitled "Display Modes and Dimensions" at the national Human Factors Society meeting in 1978.

JOSEPH ZEIDNER
Technical Director

THE IMPORTANCE OF PROVIDING STEREOSCOPIC VISION IN TRAINING FOR NAP-OF-THE-EARTH FLIGHT

BRIEF

Requirement:

Nap-of-the-earth (NOE) helicopter flight requires high speed visual-motor coordination in order to avoid obstacles in the flight path while making maximum use of terrain for cover and concealment from enemy air defense weapon systems. The development of simulators for training pilots in NOE flight has generated the question of whether or not stereoptic visual displays would be more cost and training effective than the bioptic displays usually employed in aircraft simulators. The purpose of the present study was to address this question and identify the research required to determine if stereoptic displays should be developed for helicopter simulators.

Procedure:

Stereoscopic movie films were taken of passing terrain through the cockpit of an OH-58 flying NOE at speeds of 20, 40, and 60 knots. Observers compared stereoscopic presentations of the films to bioptic presentations and found the depth perceived in the stereoscopic film much more compelling. This study demonstrated that it is possible to perceive stereoptic three-dimensionality with the stimulus environment available through the windscreen of a helicopter flying NOE. Observers were then asked to make motor reaction times when they perceived three-dimensionality in stereoscopic slides of wooded terrain. These reaction times were compared to motor reaction times to binocular fusion and a simple flash of light to determine if the perception of stereoscopic three-dimensionality has a measurable "rise time." A "rise time" of approximately 400 msec was measured. Catch trials were used to insure that observers waited until three-dimensionality or fusion was perceived before responding. This result suggests that a discrete interval is required after "seeing" something to perceive stereoptic three-dimensionality, and, this interval may or may not be available to observers depending on the rate at which they scan the visual stimulus environment.

Findings and Conclusions:

At the rate with which pilots flying NOE must scan the visual stimulus environment, and, the various other attentional loads resulting from communications and avionics systems, stereoptic depth perception may not occur. Although it is theoretically possible, as demonstrated in the laboratory, actual flight conditions may interfere with the development of stereoptic three-dimensionality. Consequently, pilots flying NOE may perceive depth bioptically. If this is the case, stereoptic visual displays in NOE simulators would be inappropriate. To determine if stereoptic displays should be developed for flight simulators, five research questions must be addressed:

(1) At what rate do pilots scan the stimulus environment?

(2) Is stereoptic depth perception associated with significantly more proficient psychomotor performance?

(3) Are there attentional requirements in NOE flight that can significantly lengthen the rise time for the perception of stereoptic three-dimensionality?

(4) Can bioptic depth information be used as effectively?

(5) Is a stereoptic display more cost-effective than extra time in the aircraft?

Utilization of Findings:

Before proceeding with technological feasibility studies of stereoscopic visual displays for helicopter simulators, the research questions outlined in this report should be addressed to determine if helicopter pilots see stereoptic as opposed to bioptic depth. This report sharpens the focus and makes more explicit the research requirement on "stereo displays" outlined in the Five Year Development and Management Plan for Flight Simulation published by the Army Training Device Agency in 1975.

THE IMPORTANCE OF PROVIDING STEREOSCOPIC VISION IN TRAINING FOR NAP-OF-THE-EARTH FLIGHT

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INTRODUCTION

Current U.S. Army doctrine on tactical helicopter operations states unequivocally that if the likelihood of contact with the enemy is "possible" or "expected", both scout and attack helicopters should fly "nap-of-the-earth" (NOE) whenever possible (Figure 1) (US Army Armor School, 1975). NOE flight is currently defined as flying as "close to the earth's surface as vegetation or obstacles permit, while generally following the contours of the terrain. In flight, the helicopter pilot uses a weaving route within a preplanned corridor...in order to take maximum advantage of the cover and concealment afforded by terrain, vegetation, and man-made features. The restrictive nature of this type of flight demands almost instantaneous reaction from the flight personnel involved " (US Army Training Device Agency, 1975).

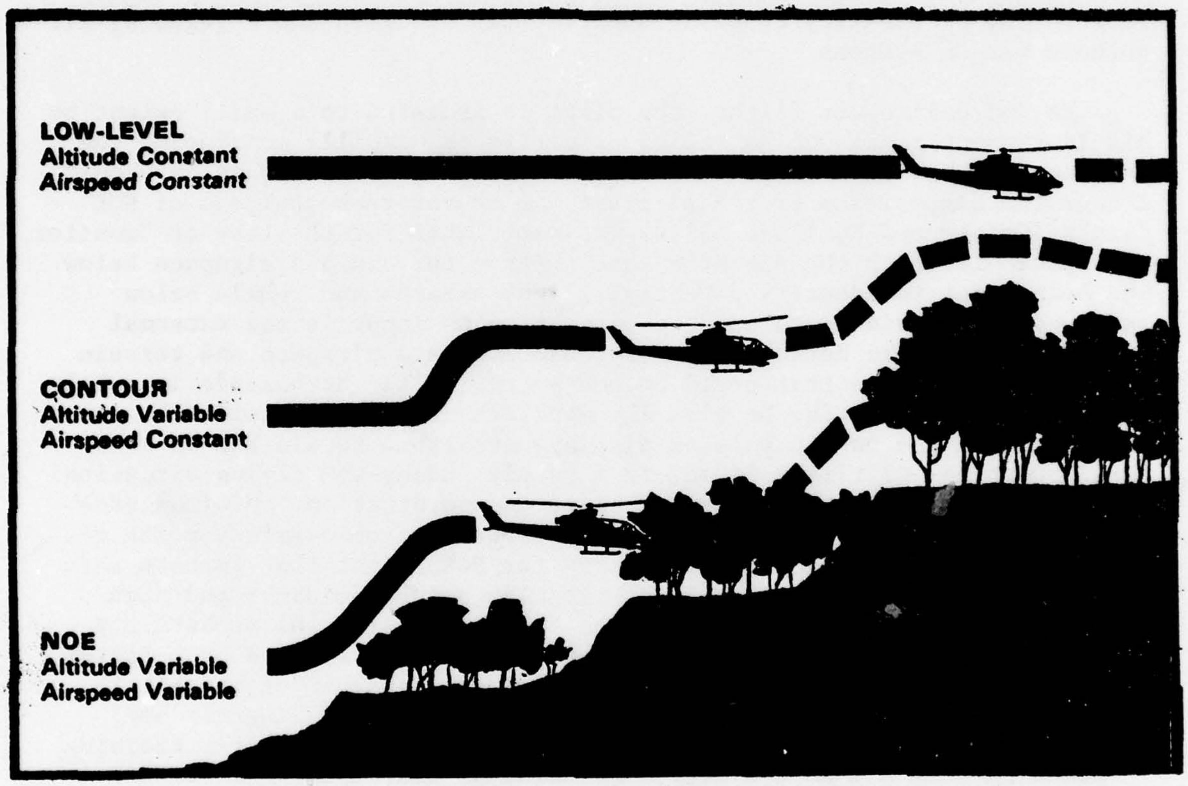

Figure 1. Nap-of-the-Earth Helicopter Flight

NOE flight is demanding both psychologically and physically. The threat during NOE flight is, in a sense, two-fold. The pilot is forced to pay constant attention to oncoming and passing terrain and execute motor responses quickly enough to avoid obstacles and make maximal use of changes in the terrain to hide his aircraft. The pilot must also attend to the amount of time he stays unmasked at any given location: 15-20 seconds is just about enough time for acquisition and engagement by most anti-aircraft guns and short range missile systems. The pilot must respond to two threats: terrain and the enemy. That threat of most immediate concern to the pilot in the tactical environment requiring NOE flight is, of course, the terrain. If he can successfully cope with the perceptual and motoric demands of NOE flight, then he has significantly reduced the probability of being unexpectedly acquired and engaged by air defense weapon systems.

In NOE helicopter flight, the pilot is assisted to a small extent by his instrument panel but he relies primarily on visually monitoring the oncoming and passing airspace for cues indicating how and when he should change the disposition of the aircraft. A recent task analysis of NOE flight (Gainer and Sullivan, 1976) indicates that for the task of "monitor air space" in which the operator must observe terrain and airspace below the helicopter to identify potential flight hazards and remain below surrounding terrain features, the only stimulus input is the external visual display. To detect, identify, and evaluate airspace and terrain objects and features that could become potential flight hazards is solely the task of the pilot as he visually monitors the world outside the aircraft. There are no controls or displays available to aid him in this task. Daytime NOE flight, then, is a purely "heads-up" flying situation requiring a high degree of perceptual/motor coordination. Minimum proficiency in obstacle avoidance may be acceptable from a safety point of view, but high proficiency is necessary for NOE flight that is both safe <u>and</u> tactically acceptable. This distinction between minimum and high proficiency is a critical one. In the two World Wars, the probability that a pilot would be killed in a combat mission was reduced by a factor of 20 if the first five missions were survived. And, 4% of the pilots have produced 40% of the kills in every war since WW I. (Merrit and Sprey, 1972). The goal of minimally adequate performance after training is becoming more and more widely considered as unacceptable in training pilots in combat aircraft.

For NOE flight training, the US Army has begun to procure flight simulators for attack and scout helicopters. The two driving forces for research, design, and procurement of flight simulators are that they are more cost-effective, and theoretically, more training effective than actual flight training.

In existing simulators for the attack helicopter, terrain model boards with optical probes are used for presenting a visual display to the pilot/trainee. The display originates via high resolution closed circuit color television and is 48^{o} horizontal by 36^{o} vertical. The viewing position and directed lines of sight are controlled by the simulation computer to precisely track the simulated aircraft in all six natural degrees of freedom relative to the geographic location and orientation of the modeled area.

The pilot/trainee sees only one image of the area scanned by the optical probe: it is as if the pilot were monitoring the airspace and terrain with only one eye, as shown in Figure 2. The trainee, when flying

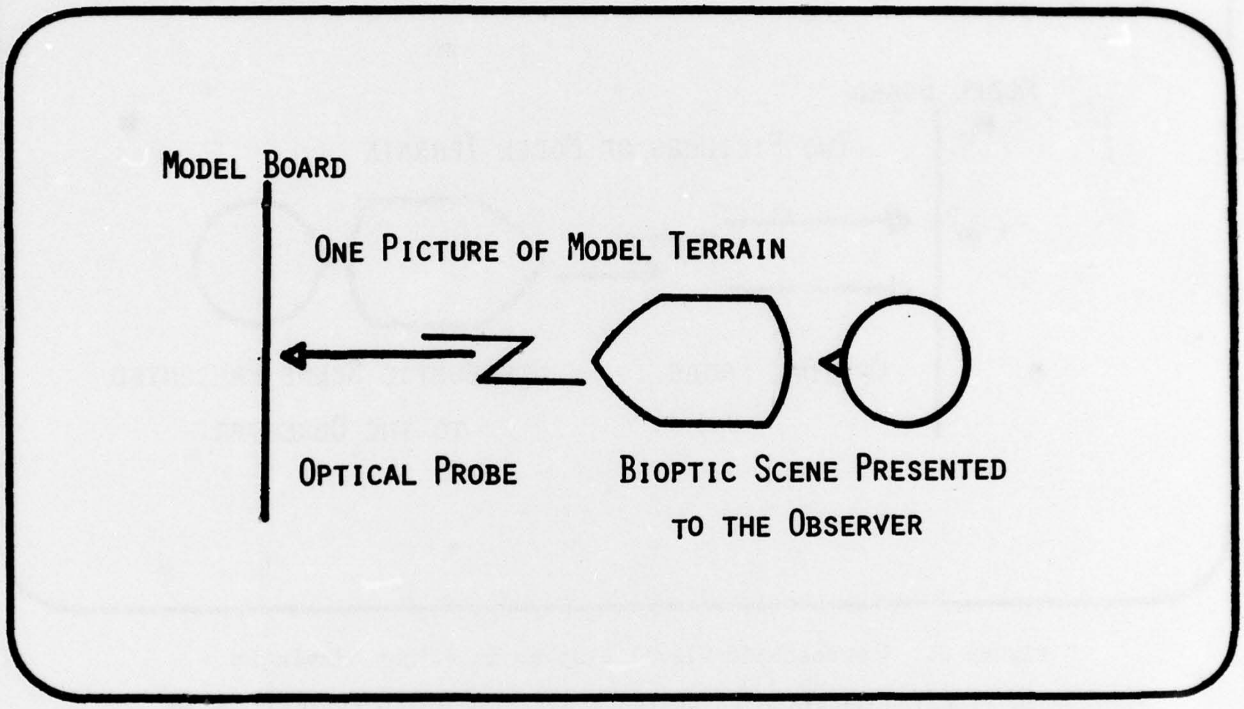

Figure 2. Bioptic Visual Display in Flight Simulation

the simulator, has bioptic, as opposed to stereoptic, vision. The U.S. Army is not sure precisely what impact this sort of visual environment has on the training effectiveness of the simulator. If one of the reasons for building flight simulators is to train highly proficient pilots, and the visual display in the simulator does not allow the pilot/trainee to develop and practice certain critical perceptual/motor skills that may be dependent upon stereoscopic perception, then there is a design deficiency in the simulator.

An attempt is being made to determine if stereoptic vision significantly contributes to the helicopter pilot's ability to "...evaluate airspace and terrain objects and features that could become potential flight hazards and/or unmask the aircraft " (Gainer and Sullivan, 1976). If stereoscopic vision can be shown to be critical in facilitating maximally safe and tactically proficient NOE flight skills, then the importance of a stereoscopic display for NOE flight simulators will have been demonstrated (Figure 3). The next requirement will be to determine what sort of displays are technologically feasible for use in the simulator.

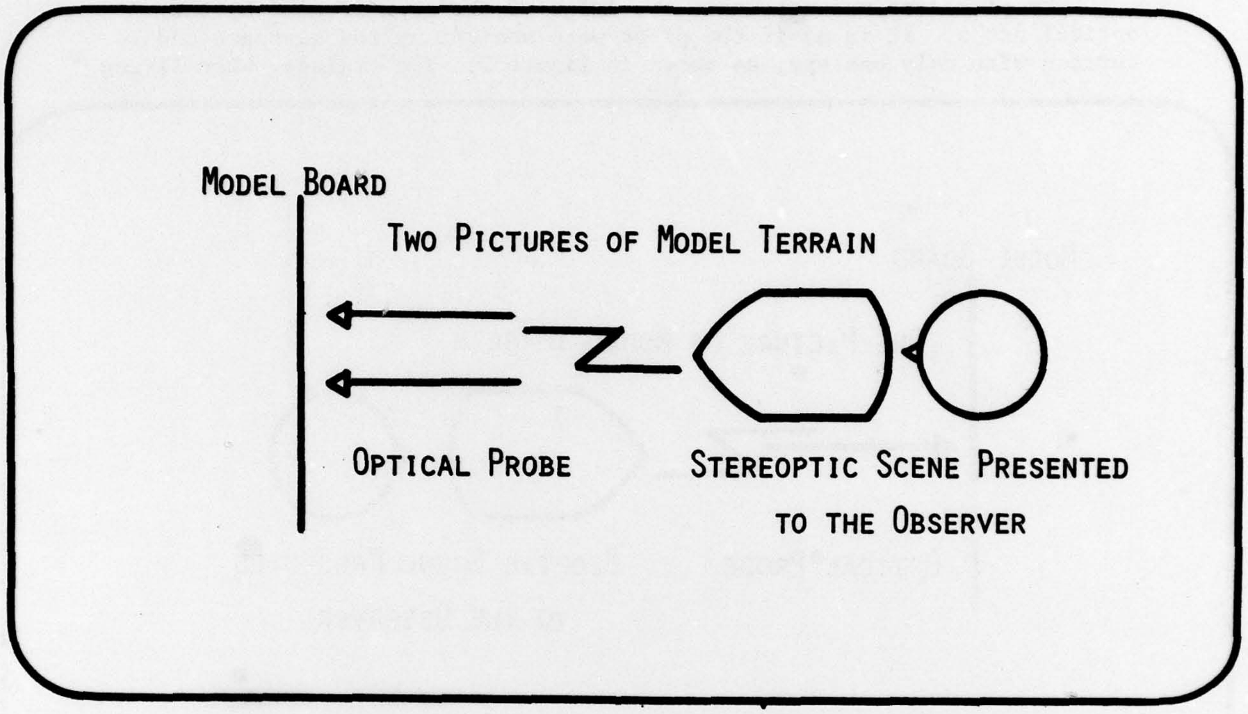

Figure 3. Stereoscopic Visual Display in Flight Simulation

This research question is stated explicitly in an exploratory research and development program outlined for Army flight simulators by the Army Training Device Agency entitled, "Nap-of-the-Earth Technology Study" which is appended to the Five Year Development and Management Plan for Flight Simulation (Army Training Device Agency, 1975). The following statement presents the research requirement:

> The perception of distance and depth is vital in the judgement of terrain contours during NOE flight. Conventional two-dimensional display systems do not permit the human operator to make full use of a highly refined sense of depth. With depth added to the display, the operator will be able to perform more efficiently by taking advantage of depth perception capabilities.

Recently conducted research indicates that the use of stereo television displays permit more efficient low-altitude, terrain-following flight. Whether stereo displays would permit improved operator performance during NOE flight is a question, as yet, not fully answered. Also not certain is whether flight training simulators could be adapted for stereo display if such were found to provide an advantage in NOE flight. The NOE technology study would be directed toward obtaining data applicable to answering both of these questions.

The research reported in this paper bears on the first of these two areas.

RESEARCH RESULTS

The basic objective of the research program is to determine if a recommendation should be made that stereoscopic displays be developed for helicopter simulators in which the pilots can train for NOE flight. There are a number of questions that have to be answered before this objective can be met and the research program described here has begun to look at the most basic of these questions: Does the helicopter pilot use stereoscopic vision in analyzing and responding to the visual environment during NOE flight?

Project I

The initial work on this question involved the development and evaluation of a dynamic stereoscopic display system. An Arriflex two-perforation pull-down 35mm cine camera with a stereoscopic lens system was used to collect approximately 1000 ft. of through-the-cockpit stereo film of an OH-58 Scout helicopter flying NOE at speeds of 20, 40, and 60 knots. The film was collected at the NOE flight training area of the 3d Armored Cavalry Regiment at Fort Bliss, Texas. Each frame of the film contains two 60° diameter circular images that approximate the pair of scenes available to the pilot as he flies NOE and looks through the windscreen. When the images are projected to the appropriate eyes using the technique of crossed polarizing filters, observers perceive three-dimensionality as the aircraft moves along the terrain, 3 or 4 feet above the ground, at speeds of 20, 40, or 60 knots. This display is presented schematically in Figure 4.

Observers report that the impression of three-dimensionality is much more compelling with a stereoscopic presentation than with a bioptic display, in which the observer looks at only one of the two 60° diameter images with both eyes.

The purpose of this exercise was to try to determine quickly and inexpensively if a pilot flying NOE perceives depth, and if he does, is stereoscopic depth more compelling than bioptic depth in a dynamic real-world display. After a number of observers had viewed the displays, it was possible to conclude that they are able to perceive compelling three-dimensionality when one has a stereoscopic view of the world while moving along NOE terrain at 20, 40, or 60 knots.

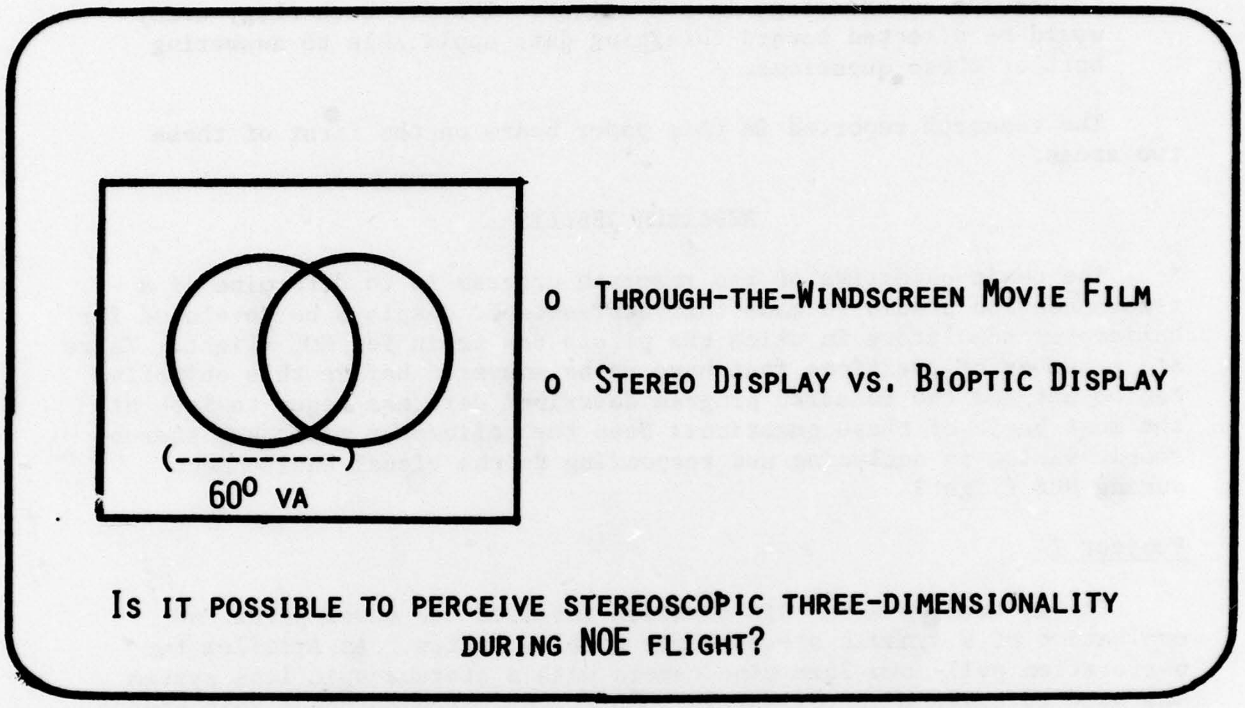

Figure 4. Project I

It was also possible to demonstrate that standard 35mm color negative cine film could be used to provide dynamic stereoscopic views of the visual environment, that airborne filming with stereo cine equipment can provide dynamic stimulus material for experimental studies of depth perception during NOE flight, and that the prototype lens system used both as a taking and projection lens and mated with a shoulder-mounted camera was a low-cost, feasible alternative for collecting stereo cine film compared to synchronized, shock-mounted cine or videotape camera systems.

Project II

The stereoscopic cine film demonstrated that pilots flying NOE at 20, 40, or 60 knots at least have the cues available for the development of stereopsis: observers are able to perceive three-dimensionality when viewing the film. But the question remains, are pilots forced by NOE flight conditions to monitor the visual environment at a rate or with various attentional requirements that might prevent the development of the perception of three-dimensionality, and utilization of stereoscopic cues for depth perception takes an appreciable amount of time, the rate at which the pilot flying NOE has to scan the visual world may militate against the development and use of obstacle avoidance information available by three-dimensional, stereoscopic perception.

The research discussed in this section was designed to determine if three-dimensional stereoscopic perception takes a significant amount of time and what is the approximate time relative to that required for binocular fusion. Data from two experienced observers is discussed for static displays of real-world scenes.

Methodology. Observers were seated at a response console in front of a rear projection screen and were instructed to rest their forearms on the table and use their thumbs to activate left and right microswitches, as shown in Figure 5.

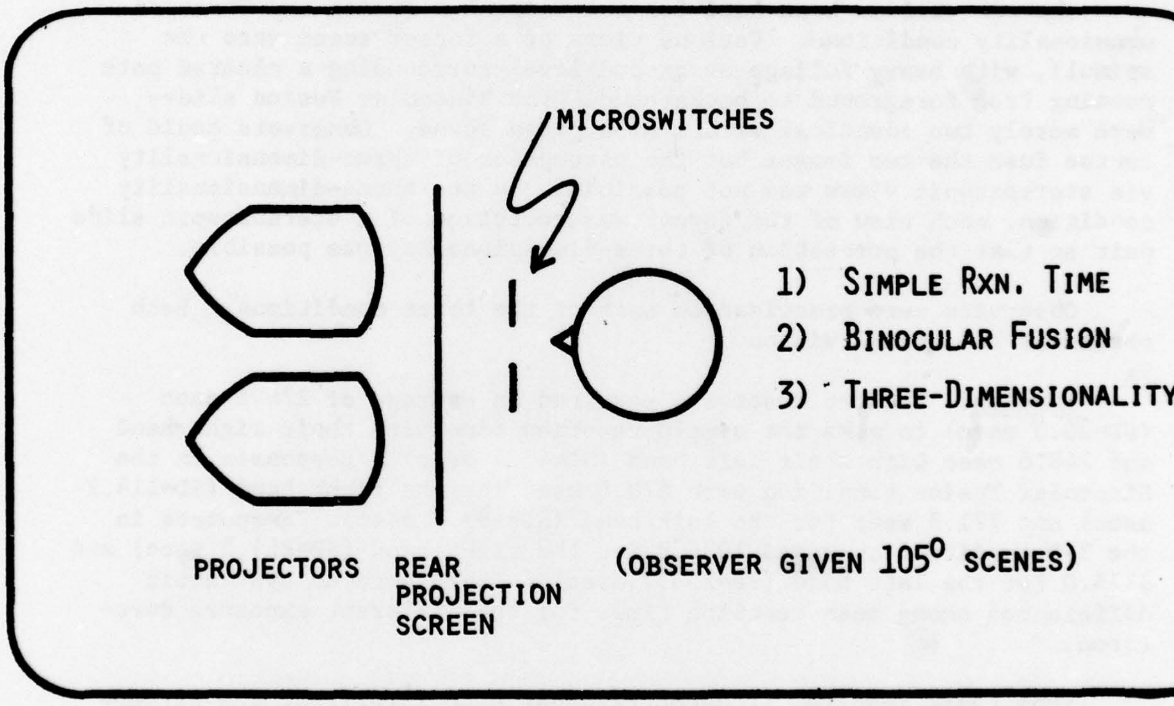

Figure 5. Project II

Observers were instructed that there were three conditions: (1) Simple Reaction Time. In this condition, observers merely had to release the microswitch when a white light appeared on the screen. For one set of trials, observers responded with their left hands, and in a second set, with their right hands. There were four different exposure durations: 5, 4, 3, and 2 seconds with ten trials per hand per exposure duration. (2) Binocular Fusion: In this condition, observers were instructed to release the microswitch as soon as they saw one image on the screen. Two sets of 12 trials were used, one set per hand. Two out of the 12 trials were "catch" trials; i.e., binocular fusion was not possible. Observers were told that if it was not possible to fuse the two images, they should not respond. Again, four exposure durations (5, 4, 3, and 2 seconds) were used. (3) Three-dimensionality: In this condition, observers were told to release the microswitch when they saw "3-D". Again, 12 trials for left and right hands were given, with two catch trials per set, for four exposure durations (5, 4, 3, and 2 seconds). In the catch trials, the observer was able to fuse the two scenes but the slides were not stereoscopic views. Observers were instructed not to respond if they did not see "3-D".

The same slides were used for the Binocular Fusion and Three-dimensionality conditions. Various views of a forest scene were the stimuli, with heavy foliage at ground level surrounding a cleared path running from foreground to background. The Binocular Fusion slides were merely two identical slides of a given scene. Observers could of course fuse the two images but the perception of three-dimensionality via stereoscopic views was not possible. In the three-dimensionality condition, each view of the forest was comprised of a stereoscopic slide pair so that the perception of three-dimensionality was possible.

Observers were practiced on each of the three conditions. Both observers had normal vision.

Results. The two observers required an average of 276.1 msec (SD=30.3 msec) to make the simple reaction time with their right hand and 248.6 msec with their left hand (SD=41.4 msec). Responses in the Binocular Fusion condition were 670.6 msec for the right hand (SD=114.2 msec) and 771.3 msec for the left hand (SD=189.3 msec). Responses in the 3-D condition averaged 1036.8 for the right hand (SD=264.3 msec) and 1114.0 for the left hand (SD=256.7 msec). There were no systematic differences among mean reaction times for the different exposure durations.

From these results, it seems reasonable to infer that the perception of three-dimensionality based on stereoscopic cues in real-world scenes takes some finite amount of time past the occurrence of binocular fusion. A motor reaction to the stereoscopic perception of three-dimensionality in a static display appeared to take at least one second in the two observers studied. If this reaction in and of itself requires about 200-250 msec to execute, it is not wholly unreasonable to suspect that the perception and reaction to three-dimensionality takes 600-800 msec.

These results have important implications for the question of whether or not pilots flying NOE have sufficient time to perceive a stereoscopic, three-dimensional world while they are flying, or, if their impression of and reactions to depth depend on the bioptic characteristics of the visual world. We can be relatively sure that in fixed wing aircraft, which operate at much higher speeds, pilots do not have ample time to resolve and utilize stereoscopic cues for depth. In a helicopter flying NOE, however, when obstacle avoidance occurs at speeds of 20-60 knots, and, tolerances are much closer due to the tactical requirement to stay as close to the terrain as possible, pilots may indeed have the time and the requirement to utilize stereoscopic information for depth.

Further research in several areas is required. First, at what rate does the pilot flying NOE scan the visual environment? Is it at a rate that prevents the development of stereoscopic perception and utilization of that information? Second, is stereoscopic perception associated with significantly more proficient psychomotor performance of the kind critical for obstacle avoidance? Third, are there attentional requirements in tactical NOE flying that interfere with the utilization of stereoscopic information? Fourth, are there strategies for more effective bioptic depth information utilization that can be trained in the flight simulator which represent a more cost and training effective alternative than providing a stereoscopic display? Fifth, do pilots learn to use stereoscopic depth information as efficiently as possible within several hours of actual NOE flight so that provision of this capacity in a simulator could more cost effectively be replaced by several extra hours of actual flight training time?

These questions are discussed in more detail below.

STRATEGIES FOR FURTHER RESEARCH

Research completed to date has demonstrated that observers can see three-dimensionality during NOE flight and that stereoscopic displays are noticeably more compelling than bioptic displays, and that the stereoscopic perception of depth in static real-world displays requires a finite amount of time beyond the latency for binocular fusion. Strategies for further research basically revolve around determining if pilots flying NOE use stereoscopic depth information which makes them more proficient on obstacle avoidance, and, if stereoscopic information during training in a flight simulator is more cost- and training- effective than using an aircraft or a part-task training device.

Strategy A

To determine if NOE flight allows the pilot to scan the visual environment at a rate allowing the temporal development of stereoscopic depth perception and utilization of stereoscopic information, two studies need to be done. First, pilots' eye movements and fixation rates when flying NOE have to be determined. The most feasible research strategy would be to record pilot eye movements in the attack helicopter flight simulator scheduled for operational testing at the U.S. Army Aviation School at Fort Rucker, Alabama. Intrusive measurements, such as electromyographic recordings, during actual NOE flight are too much of a hazard for the pilot in terms of distractions and interference with usual headgear and cockpit configuration.

The information on fixation rate and duration could be correlated with specific types of terrain if NOE courses are clearly marked on the model board in the simulator. This information would in turn have to be matched to the results of a study in which pilots are required to make absolute and relative distance judgements for static real-world stereoscopic displays of different exposure durations. Earlier research has indicated that stereoscopic depth perception requires a discrete amount of time after binocular fusion. Presumably, judgements of relative and absolute distance to targets in a stereoscopic display should be very poor for exposure durations less than this time. Operating speeds and/or terrain types that require pilot eye movements and scan rates that yield fixations shorter in duration than that required for stereoscopic perception would most probably be attended by bioptic as opposed to stereoptic depth perception.

A parametric study to determine when distance estimation stabilizes relative to exposure duration would indicate the minimum duration required for the successful utilization of stereoscopic information. It is difficult to predict the shape of the curve relating distance judgements to exposure duration, but if stereoscopic information does represent a significant factor in this ability, there would be a discrete point at which performance markedly improves and stabilizes. If this minimum exposure duration is very much greater than the amount of fixation time observed in most pilots' visual processing of the NOE environment, then the inference can be made that helicopter pilots flying NOE probably do not "see", much less use, stereoscopic depth information. This finding would provide compelling evidence that a stereoscopic display in a flight simulator is <u>not</u> a critical requirement.

<u>Strategy B</u>

In addition to determining if pilots do perceive their visual environments stereoscopically, it is necessary to determine if more proficient psychomotor performance associated with obstacle avoidance results from utilization of stereoscopic depth perception. A study using the stereoscopic cine display system described earlier would seem to be the simplest and least costly approach to this problem. Films taken through the windscreen of an aircraft flying at and then over various obstacles could be used as stimulus materials. Pilots used as subjects would be required to make hand and/or foot responses similar to those required to maneuver an OH or AH type helicopter away from the obstacle. The same system lag characteristics as a helicopter would be built into the response mechanisms so that the pilots would face basically the same psychomotor task as in flight. By making films in an aircraft flown by a highly proficient pilot instructed to fly safely but with tolerances that are tactically acceptable, stimulus materials that represent criterion performance will be available. By requiring the pilot to avoid obstacles in the film, and then blocking out the display after the obstacle avoidance response, the problem of the subject seeing when criterion performance (i.e., the "optimum" obstacle avoidance performance shown in the film) occurs is avoided. Dependent variables such as the number of trials to criterion, or, msec difference from criterion could be recorded for the independent variables of NOE speed, type of obstacle, and stereoptic versus bioptic display. If there are no differences between stereoptic and bioptic displays, then evidence against the inclusion of stereoscopic displays in training simulators is presented. That is, if pilots succeed in using depth information from bioptic displays as efficiently and effectively as stereoptic displays, then there is really no benefit derived from including stereoscopic displays in training simulators, or developing a part-task simulator.

Strategy C

If evidence is obtained that pilots flying NOE can in fact use stereoscopic information for obstacle avoidance, and when doing so, can avoid obstacles more efficiently and effectively, then a determination has to be made if there might be conditions in tactical NOE flight that interfere with the utilization of stereoscopic depth information. For example, does the requirement to monitor communications or divide attention between flying the aircraft and using weapon systems command sufficient attentional or information processing capacity to interfere with processing of stereoscopic information?

This question could easily be resolved using the procedures described for Strategy B but including additional attentional and/or memorial tasks, such as monitoring and responding to a tape recording of communications, or having to remember and respond to specific obstacles as targets or key locations. Under conditions of tactical NOE flight, processing of stereoscopic information for depth may be superseded by less "time-consuming" or "simpler" cues for depth. If so, the importance of a stereoscopic display in a flight simulator designed to train safe and tactically acceptable NOE flight skills may be questionable.

Strategy D

It may be possible to train NOE pilots to use bioptic information more efficiently in their visual environment. This would be especially important if Strategy C indicates that there are NOE flight conditions that interfere with the utilization of stereoscopic information. Training strategies for efficient bioptic depth perception may do more to facilitate obstacle avoidance performance than a stereoscopic display that is really not representative of the visual environment available to the pilot during tactical NOE flight. For example, repeated runs at obstacles on the model board with performance feedback given per run may give the pilot a more accurate picture of precisely what his bi-optic depth estimation abilities are for different speeds. A carefully designed training program with the objective of giving the pilot an accurate awareness of his capacity and limitations for depth perception may be far more important than a stereoscopic display in the training simulator. The visual display in the flight simulator must match the pilot's real-world visual environment. It is certainly conceivable, vis-a-vis Research Strategies A-D, that pilots flying in NOE do not actually have stereoscopic depth information available to them for either cognitive or visual reasons or both.

Strategy E

Criterion obstacle avoidance capability dependent on stereoscopic depth perception may occur after a very short time in the aircraft, in which case building a stereoscopic display system may not be the most cost-effective training alternative. If Research Strategies A, B, and C demonstrate that stereoscopic depth perception is a critical component of high proficiency obstacle avoidance in NOE flight, then it would be necessary to determine whether or not a stereoscopic display in the simulator is more cost-effective than several hours of flight time. A study comparing time and cost required for achievement of criterion performance in actual flight and in a part-task training device simulating the stereoscopic display in the training simulator would have to be done. In that the development of stereoscopic display capability for a helicopter simulator would represent a significant research and development effort, this comparison would have to be made.

CONCLUSIONS AND IMPLICATIONS

It would be premature to begin to develop a display capability for presenting stereoptic information in an helicopter flight simulator without research to first determine if stereoptic depth information is important for proficient obstacle avoidance, and, if pilots have the "time" and/or attentional capacity to develop stereoscopic three-dimensionality. Preliminary research on this problem has provided some research tools and methodologies, and has served to define various problem areas and considerations.

Too often in the simulation of work environments, the operational environment is physically replicated without consideration of what the psychological reality of that environment is for the operator. That is, in an operational situation, the pilots' attentional, visual, and motor capabilities may be continuously directed at only a very small subset of the total possible stimulus environment. For training simulation, replication of these stimuli and the behavioral contingencies that attend them is the design requirement--not the replication of the total stimulus environment. In the case of the helicopter flight simulator, it is necessary to determine precisely what would be psychologically real for the pilot/trainee in the operational environment and include that in the flight simulator if and only if it significantly contributes to performance <u>and</u> is more cost-effective than flight training. The engineer and human factors psychologist must often resist the temptation to build what they consider to be a high fidelity physical replication of the operational environment without adequate consideration of the psychological reality, the psychological fidelity, of the training simulation.

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