ARMY RESEARCH LABORATORY

An Initial Assessment of the Fit, Retention, and Visual Display Characteristics of the Kaiser Proview™ Head-Mounted Display System

David B. Durbin

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Abstract

Head-mounted displays (HMDs) are a potentially viable technology for presentation of the "out-the-window" (OTW) scene for Army aviation simulators. As part of an effort to evaluate their suitability for Army aviation, a preliminary assessment of three Kaiser ProView™ HMDs was conducted during a simulation exercise at the U.S. Army Aviation Test Bed, Fort Rucker, Alabama. The assessment evaluated the fit, retention, and visual display characteristics of the HMDs. The method used to assess the HMDs included aviator responses to a usability survey, statistical correlation of survey responses with head measurements obtained from each aviator, observation of aviator performance during their missions, and post-mission interviews. Most of the fit, retention, and visual display characteristics of the HMDs were judged to be acceptable by the Army aviators. Suitability of the HMDs would be improved by an increase in field of view and the use of lightweight electrical cables to minimize restriction of head movement and potential for pressure-induced hot spots.

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EXECUTIVE SUMMARY

Head-mounted displays (HMDs) have potential benefits for use as the "out-the-window" (OTW) display for Army aviation flight simulators because of their small size and weight, transportability, and comparatively low costs. However, the human factors characteristics associated with the usability of HMDs as OTW displays have yet to be fully identified and evaluated. A preliminary assessment of three Kaiser ProView™ HMDs was conducted on 8 and 9 October 1998, at the U.S. Army Aviation Test Bed, Fort Rucker, Alabama. The assessment was requested by the Directorate of Training, Doctrine, and Simulation, U.S. Army Aviation Center, Fort Rucker, Alabama, and evaluated the fit, retention, and visual display characteristics of the HMDs during a mission simulation exercise. The assessment was based on aviator responses to a usability survey, statistical correlation of survey responses with head measurements obtained from each aviator, observation of aviator performance during their missions, and post-mission interviews. This report contains a description of the assessment and its findings. Most of the fit, retention, and visual display characteristics of the HMDs were rated as positive by the aviators. The usability of the HMDs would be enhanced by an increased field of view and the use of lightweight electrical cables to minimize restriction of head movement and potential for hot spots.

AN INITIAL ASSESSMENT OF THE FIT, RETENTION, AND VISUAL DISPLAY CHARACTERISTICS OF THE KAISER PROVIEW™ HEAD-MOUNTED DISPLAY SYSTEM

INTRODUCTION

Purpose

Army aviation is becoming increasingly reliant on simulation to maintain training proficiency for aircrews. Several research efforts are evaluating the training effectiveness of various simulation display technologies, including head-mounted displays (HMDs). HMDs have potential benefits for use as the "out-the-window" (OTW) display for flight simulators because of their small size and weight, transportability, and comparatively low costs. However, the human factors characteristics associated with the usability of HMDs as OTW displays have yet to be fully identified and evaluated. The purpose of this assessment was to conduct an initial evaluation of the fit, retention, and visual characteristics of three Kaiser ProView™ HMDs during a simulation exercise in the Aviation Test Bed, Fort Rucker, Alabama. This assessment was requested by the Directorate of Training, Doctrine, and Simulation and provides useful insights about the usability of HMDs as the OTW display for Army aviation flight simulators.

System Description

The three HMDs were models with 40°, 50°, or 60° fields of view (FOVs) (diagonal), dual liquid crystal displays on which the OTW scene was projected, an adjustable headband made of semi-rigid plastic, and a lightweight, inertial head tracker mounted on top of the headband (see Figure 1). The resolution of the liquid crystal displays was 640 by 480 pixels. Electrical connections were bundled into a single cable that attached to the lower back of the headband. The HMDs provided user adjustments for display brightness, interpupillary distance, eye relief, and vertical display alignment. The approximate weight of the HMDs was 1.3 pounds for the ProView™ 40 and 50 and 1.7 pounds for the ProView™ 60. During the simulation exercise, the HMDs were interfaced with a MetaVR™ image generator that provided an OTW visual scene (terrain and man-made objects) portrayed to the aviators on the liquid crystal displays.

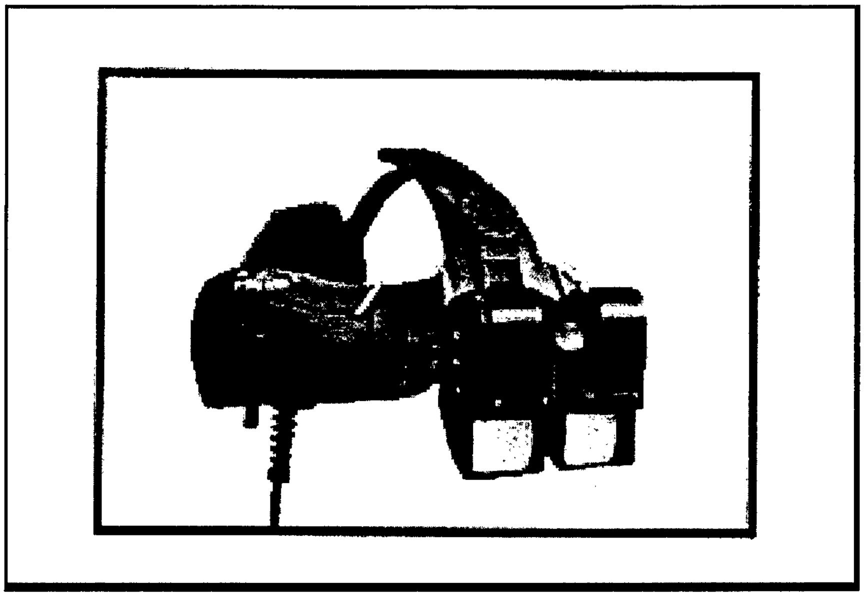

Figure 1. Kaiser ProView™ 40 HMD.

METHOD

Subjects

Subjects were eight males who were current or former Army aviators. They represented a group of highly experienced aviators with an average of 4,300 hours of flight time in Army aircraft. Five of the aviators also had significant experience using HMDs in a simulation environment. Their relevant demographic characteristics are listed in Table 1.

Table 1

Demographic Characteristics of Aviators
(N = 8 males)

Summary of demographic characteristics	Age (years)	Total flight hours	Total hours aviators have used an HMD to date[a]	Corrective lens worn during assessment
Mean	44.3	4300	203.9[b]	Yes—37%[c]
Range	37 to 52	1800 to 6000	1.2 to 1200	No—63%

[a]See Appendix F for total HMD hours for each aviator
[b]Median total hours = 26.0
[c]Three aviators wore eyeglasses

Procedure

The assessment was conducted using the HMDs in a fully reconfigurable experimental device (FRED) simulator located in the Aviation Test Bed, Fort Rucker, Alabama. The FRED simulators are used primarily for collective task training by the U.S. Army Aviation Center. They contain generic helicopter flight controls, provide the OTW scene on five 60-inch monitors, and can be configured to functionally represent the AH-64, OH-58C or D, and UH-60 helicopters. The FRED simulator used for the HMD simulation exercise was configured to represent an AH-64. The 60-inch monitors were turned off for the exercise because the HMD provided the OTW scene.

Before entering the simulators to begin their mission, the aviators were briefed about the purpose of the assessment, and their heads were measured (see Table 2) by personnel from the Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL). In addition, Kaiser personnel provided each aviator with a "hands-on" demonstration of the method for adjusting the HMD to fit his head and the method for adjusting the position of the displays. The aviators then entered the simulator, were asked to don the HMDs, perform necessary adjustments to accommodate their head sizes, and begin their mission.

During the assessment, one aviator flew the simulator in the pilot's seat while the other aviator sat in the copilot-gunner's (CP/G) seat and attempted to acquire and engage targets. A contractor sat in a third seat close to the pilot's seat to help with HMD adjustments and to troubleshoot technical problems that arose during the simulation. The aviator sitting in the CP/G seat wore the ProView™ 60, while the aviator sitting in the pilot seat wore the ProView™ 40 or 50. At the mid-point of the mission, the aviators switched seats in order to wear the other HMD models during the mission.

The aviators flew a mission route (see Figure 2) from a forward assembly area (FAA) to a battle position (BP), attempted to acquire and engage targets in the engagement area (EA), and then returned to the FAA. In order to maximize the aviators' exposure to different visual scenes, while they wore the HMDs, two different terrain databases were used during the mission. On the outbound leg of the mission, a hilly terrain database with moderate vegetation was used. On the inbound leg of the mission (after departure from the EA), a desert terrain database modeled after the National Training Center, Fort Irwin, California, was used. Upon completion of their mission, the aviators exited the simulator, were interviewed by ARL personnel, and completed an 11-page survey regarding their assessment of the fit, retention, and visual characteristics of the HMDs.

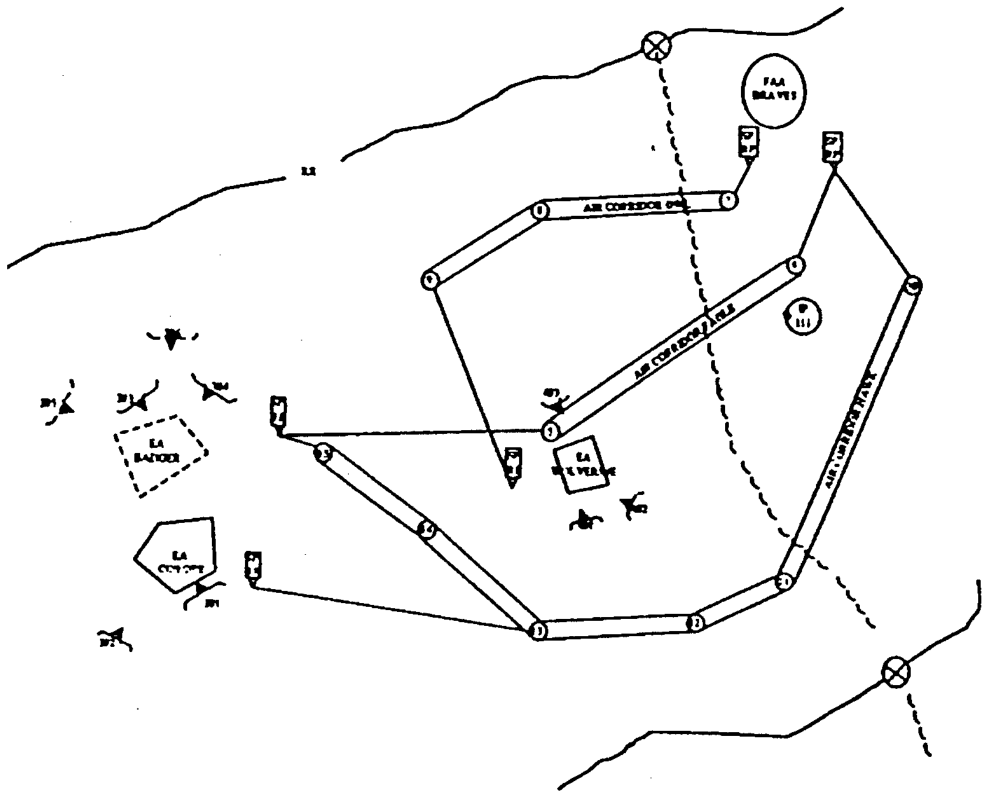

Figure 2. Mission route for HMD simulation exercise.

The aviators spent an average of 74 minutes in the simulator performing their mission while wearing the HMDs. Seven aviators wore their flight suits during the assessment, while the eighth wore civilian clothes. The ambient temperature in the simulator during the assessment varied between 66° and 69° F. Incident light levels in the simulator were measured at less than 10.0 lux (< 1.0 footcandle).

Data Collection

The methodology used by ARL (HRED) personnel to collect human factors data included obtaining head measurements from each aviator, administering a usability survey, observing aviator performance during their missions, and interviewing the aviators after they completed their flight. The survey was developed in accordance with published guidelines for proper format and content (Babbitt & Nystrom, 1989; Georgia Institute of Technology, 1994). A brief pre-test was conducted to refine the survey and to establish its content and face validity. Survey results were augmented and clarified with observations recorded during missions and with information obtained during aviator interviews. Because the fit, retention, and visual display characteristics were essentially identical (except for FOV) for the ProView™ 40, 50, and 60 HMDs, the aviators completed one survey that addressed all three HMDs. The aviators reported that differences in the FOV between the HMDs were not noticeable and did not affect the HMDs' performance. Observations of aviator performance during their missions and a hands-on evaluation of the HMDs by ARL personnel supported the aviators' judgments that the differences in FOV were not noticeable. In the few instances when aviators noted minor differences among the three HMDs, they reported the differences on the survey.

Anthropometry

Head measurements (see Table 2) were obtained from each aviator for four anthropometric dimensions including head length, breadth, and circumference, and interpupillary breadth. The measurements were obtained in accordance with published procedures (Gordon et al., 1989) and were used to determine how well the HMDs accommodated the range of the aviators' head sizes. This was accomplished by constructing a correlation matrix (see Appendix A) matching the aviators' head measurements with their survey responses in order to determine any statistically significant relationships. For example, correlation coefficients were computed to determine whether aviators with larger head sizes reported significantly more (or fewer) problems with HMD stability than did aviators with smaller head sizes. The upper percentile ranks for male soldiers were well represented for head breadth, length, and circumference. The lower percentile rank for female and male soldiers was represented for interpupillary breadth. Three aviators wore eyeglasses. This allowed an assessment of how well the eye relief adjustment on the HMDs accommodated eyeglasses and whether there were any optical distortions because eyeglasses were worn.

Table 2

Head Measurements of Aviators

Summary of aviator head measurement data	Head breadth (cm)	Head length (cm)	Head circumference (in.)	Interpupillary breadth (cm)
Mean	15.6	20.0	22.9	6.2
SD[a]	0.5	0.6	0.5	0.3
Rangeψ (percentile)	14th to 97th	15th to 92nd	30th to 98th	1st to 65th[b]

[a]SD = standard deviation
[b]1st percentile male is equivalent to 3rd percentile female
ψRange for Army male soldiers

Data Analysis

Survey data were entered into the Statistical Program for the Social Sciences (SPSS®) for reduction and analysis. Descriptive statistical data including percentages, averages (means), standard deviations, and medians were generated. The data were further analyzed using a chi-square goodness-of-fit test to determine any statistically significant response trends to survey items. These trends indicate that the responses provided by the aviators to a particular survey item were not random but were attributable to a systematic factor such as a strong like or dislike for a particular characteristic of the HMDs (e.g., display resolution). These trends increase the level of confidence that the aviators' responses are accurately measuring a usability characteristic of the HMDs. Because of the small number of aviators who were surveyed, an exact chi-square probability value was computed for each survey item. Additionally, a correlation matrix that matched aviator head measurement data with their survey responses was developed. This helped determine how well the fit and retention characteristics of the HMDs accommodated the aviators' range of head sizes.

Limitations of Assessment

Schedule and funding constraints precluded a comprehensive assessment of the Kaiser ProView™ HMDs. The entire simulation exercise lasted only 2 days. The amount of time available for aviator selection and training, flight time with the HMDs in the simulator, and data collection was very limited. Technical problems with the aviation test bed (AVTB) image generator resulted in noticeable image lag on the HMD visual scene and caused occasional system crashes. The aviators were annoyed by the technical problems, but they reported that it did not significantly alter their judgments about the fit, retention, and visual characteristics of the HMDs. They felt that the human factors characteristics pertaining to the fit, retention, and visual display were very apparent and were not obscured by image lag, occasional system crashes, or other technical problems.

RESULTS

Fit and Retention

Overall, the aviators reported that the fit and retention characteristics of the ProView™ 40, 50, and 60 HMDs were good (see Appendix B). In general, the HMDs

- were quick and easy to adjust,

- maintained adequate stability on the aviators' heads, even during quick head turns in the horizontal and vertical axes,

- did not cause uncomfortable head temperatures,

- had adequate eye relief adjustment to accommodate eyeglasses worn by aviators,

- seldom required adjustment of interpupillary distance during the mission for most of the aviators,

- had a comfortable center of gravity, and

- induced no upper body discomfort.

However, the aviators reported that the electrical cable that attached to the lower back of the HMDs partially restricted their head movement. Also, three aviators reported experiencing occasional hot spots on the back of their heads while wearing the ProView™ 60. These three aviators had larger head lengths and circumferences than the other aviators did. The correlation (see Appendix A) between their larger head lengths and circumferences and the reported frequency of hot spots was statistically significant [p ($r \geq .818$) $< .02$, head length], [p ($r \geq .799$) $< .02$, head circumference]. A likely explanation is that the weight of the electrical cable that attached to the lower back of the ProView™ 60 headband resulted in localized pressure on the back of the head of the aviators who had larger head lengths and circumferences.

Visual Display Characteristics

In general, the aviators reported that the resolution, brightness, and color of the images on the HMD liquid crystal displays were good (see Appendix C). Image flicker was infrequent and six of the eight aviators reported that the HMDs' visual scene provided good situational awareness of their immediate environment (e.g., terrain features). The three aviators who wore eyeglasses reported that they experienced no optical distortions when viewing the visual display. However, several aviators reported that the dynamic visual cues needed for flying the simulator at low altitude were less than adequate. These included depth of the visual field, rate of closure, altitude and attitude cues. The aviators reported that the limited FOV provided by the HMDs was a primary factor in contributing to their lack of adequate visual cues. The aviators also reported that the limited FOV was a significant factor in their rating the simulator as more difficult to fly than their actual aircraft. Most aviators did not experience motion sickness symptoms while wearing the HMDs. However, two aviators reported experiencing moderate symptoms of eye fatigue and nausea during their mission, and one aviator reported experiencing moderate symptoms of dizziness and nausea (see Appendix D). None of the aviators were forced to discontinue the mission because of their physiological discomfort. However, since the average mission duration was only 74 minutes, further evaluation would be required to determine if wearing the HMDs for longer periods of time would induce more severe or disabling motion sickness symptoms.

CONCLUSIONS

The Kaiser ProView™ 40, 50, and 60 HMDs show promise for use as the OTW display for Army aviation flight simulators. The overall fit and retention characteristics of the HMDs were rated as positive by the aviators. Most of the visual display characteristics of the HMDs were also rated as positive. Additionally, ARL personnel observed that the aviators appeared to be visually "immersed" in the simulation environment throughout their mission. Note, however, that at low altitude, the visual scene displayed by the HMDs did not provide adequate visual cues for judging depth of field, rate of closure, and changes in altitude and attitude. The lack of adequate cueing appeared to be caused primarily by the limited FOV of the HMDs. Kaiser is currently developing an HMD with a 100° FOV (ProView™ 100) to help address this issue.

RECOMMENDATIONS

The limitations of the simulation exercise did not allow an in-depth evaluation of the human factors characteristics of the Kaiser ProView™ HMDs. However, the survey responses provided by the Army aviators serve as useful insights about the usability of HMDs as the OTW display for Army aviation flight simulators. The survey responses also identify potential design limitations that should be the focus of a comprehensive evaluation. It is recommended that additional evaluations be conducted to accomplish the following:

1. Quantify the impact that the human factors characteristics of HMDs have on training effectiveness;

2. Assess the use of HMDs in different operational environments (e.g., high ambient illumination); and

3. Assess the physiological and performance effects of wearing an HMD for extended periods of time (e.g., 2 to 4 hours).

To be effective, the evaluation must employ a large sample size of aviators with a wide range of experience and must assess representative 5th percentile female through 95th percentile male anthropometric dimensions. The evaluation also should investigate (a) different types of electrical cables and methods of routing the cables to minimize restriction of head movement and potential for induced hot spots, and (b) HMDs with larger FOVs (as they become commercially available).

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APPENDIX A

CORRELATION OF HEAD MEASUREMENTS WITH AVIATOR SURVEY RESPONSES REGARDING FIT AND RETENTION OF HMDS

CORRELATION OF HEAD MEASUREMENTS WITH AVIATOR SURVEY RESPONSES REGARDING FIT AND RETENTION OF HMDS

	Head measurements			
Survey items regarding HMD fit and retention	Head breadth	Head length	Head circumference	Interpupillary distance
Ease of HMD adjustment before mission	.000	-.114	.114	.283
Time to adjust HMD	-.113	-.399	-.627	-.170
Center of gravity	.118	.438	.390	.387
Fore & aft stability of HMD	.311	.292	.536	.145
Side-to-side stability of HMD	.311	.292	.536	.145
Range of head movement	-.332	.417	.334	-.415
Hot spots	.243	.818*	.799*	-.007
Temperature	.567	.399	.456	.340
FOV adjustment	.113	.127	.317	.201
Neck comfort	.340	-.114	.171	.227
Shoulder comfort	.340	-.114	.171	.227
Upper back comfort	.340	-.114	.171	.227
Lower back comfort	.340	-.114	.171	.227
Arms comfort	.340	-.114	.171	.227

*Significant at α .05

APPENDIX B

AVIATOR SURVEY RESPONSES REGARDING FIT AND RETENTION OF HMDS

AVIATOR SURVEY RESPONSES REGARDING FIT AND RETENTION OF HMDS

Ease of HMD adjustment before mission*	Very difficult ——— 0%	Difficult ——— 0%	Borderline ——— 0%	Easy ——— 37%	Very easy ——— 63%
Time to adjust HMD*	< 2 min. ——— 63%	2 to 5 min. ——— 37%	6 to 9 min. ——— 0%	0 to 15 min. ——— 0%	> 15 min. ——— 0%
Center of gravity*	Very uncomfortable ——— 0%	Uncomfortable ——— 0%	Borderline ——— 12%	Comfortable ——— 63%	Very comfortable ——— 25%
Fore & aft stability*	Very unstable ——— 0%	Unstable ——— 0%	Borderline ——— 12%	Stable ——— 63%	Very stable ——— 25%
Side-to-side stability*	Very unstable ——— 0%	Unstable ——— 0%	Borderline ——— 12%	Stable ——— 63%	Very stable ——— 25%
Range of head movement*	Very restrictive ——— 0%	Somewhat restrictive ——— 88%	Not restrictive ——— 12%	———	———
Hot spots	Always ——— 0%	Most of time ——— 0%	Sometimes ——— 38%	Rarely ——— 12%	Very rarely ——— 50%
Temperature*	Very uncomfortable ——— 0%	Uncomfortable ——— 0%	Borderline ——— 0%	Comfortable ——— 37%	Very comfortable ——— 63%

*Significant at α .05, indicating a non-random response trend

Interpupillary distance adjustment during mission	Frequently ——— 12%	Sometimes ——— 12%	Rarely ——— 38%	Never ——— 38%	———
Upper body comfort	Very uncomfortable	Uncomfortable	Borderline	Comfortable	Very comfortable
Neck comfort*	0%	0%	0%	63%	37%
Shoulders comfort*	0%	0%	0%	63%	37%
Upper back comfort*	0%	0%	0%	63%	37%
Lower back comfort*	0%	0%	0%	63%	37%
Arms comfort*	0%	0%	0%	63%	37%

*Significant at α .05, indicating a non-random response trend

APPENDIX C

AVIATOR SURVEY RESPONSES REGARDING VISUAL CHARACTERISTICS OF HMDS

AVIATOR SURVEY RESPONSES REGARDING VISUAL CHARACTERISTICS OF HMDS

Sharpness of images displayed on HMD*	Very faded 0%	Faded 0%	Borderline 25%	Sharp 75%	Very sharp 0%
Brightness of visual scene displayed on HMD*	Very inadequate 0%	Inadequate 0%	Borderline 0%	Adequate 88%	Very adequate 12%
How often aviators experienced image lag on HMD	Always 0%	Most of time 25%	Sometimes 25%	Rarely 37%	Never 12%
Color of displayed images on HMD*	Very inadequate 0%	Inadequate 0%	Borderline 0%	Adequate 88%	Very adequate 12%
How often aviators noticed flickering of visual scene	Always 0%	Most of time 0%	Sometimes 25%	Rarely 50%	Never 25%
Adequacy of visual scene on HMD for providing situational awareness*	Very inadequate 0%	Inadequate 25%	Borderline 0%	Adequate 75%	Very adequate 0%
Ease of "flying" simulator using HMD visual scene versus flying actual aircraft	Much more difficult 38%	More difficult 50%	Same level of difficulty 12%	Easier 0%	Much Easier 0%

*Significant at α .05, indicating a non-random response trend

Visual perception cues	Very inadequate	Inadequate	Borderline	Adequate	Very adequate
Depth	0%	12%	50%	38%	0%
Range*	0%	12%	25%	63%	0%
Rate of closure*	0%	12%	76%	12%	0%
Aircraft altitude and attitude cues (while flying at low altitude)	Very inadequate	Inadequate	Borderline	Adequate	Very adequate
Altitude cues	0%	12%	38%	50%	0%
Attitude cues	0%	12%	38%	50%	0%

*Significant at α .05, indicating a non-random response trend

APPENDIX D

SUMMARY OF AVIATOR RESPONSES REGARDING FIT, RETENTION, AND VISUAL DISPLAY CHARACTERISTICS OF HMDS

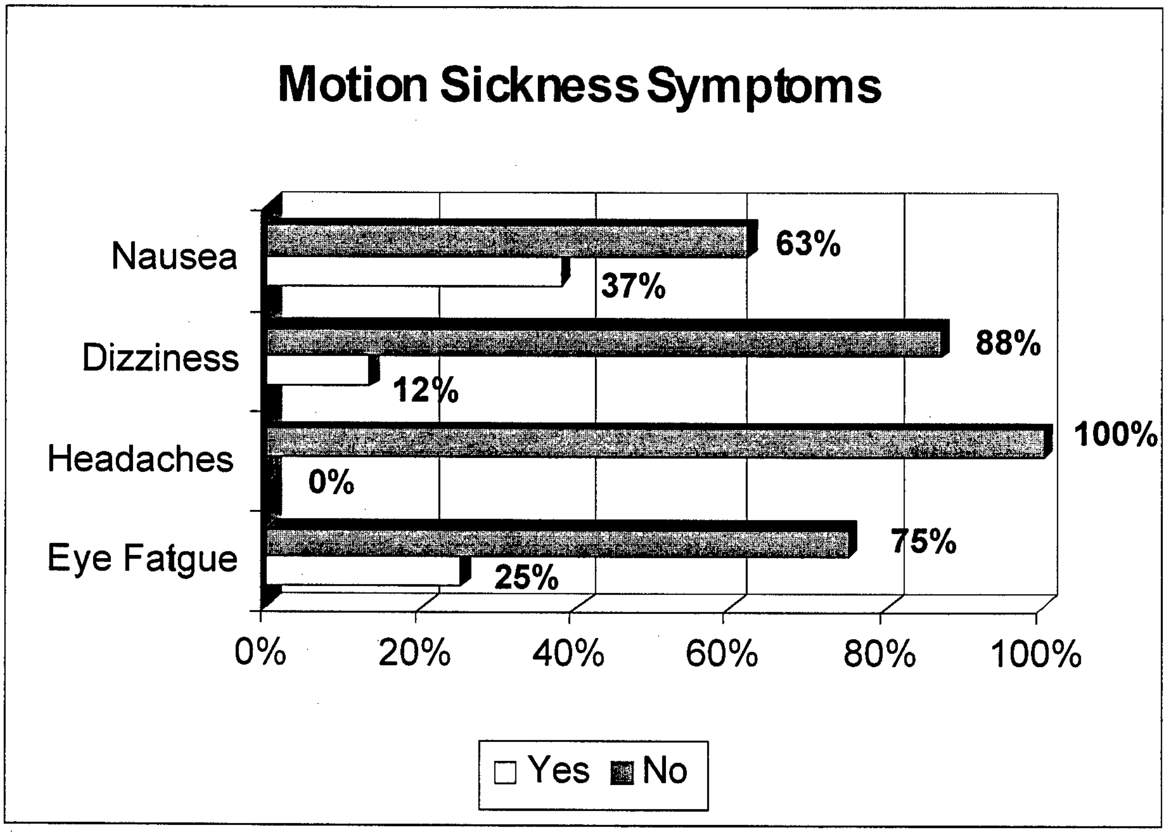
SUMMARY OF AVIATOR RESPONSES REGARDING FIT, RETENTION, AND VISUAL DISPLAY CHARACTERISTICS OF HMDS

Fit and retention characteristics	*Visual display characteristics*
• HMD was easy to adjust before mission. Adjustment took 62 seconds, on average. • Fore, aft, and side-to-side stability of HMD during mission was generally good. • HMD did not induce uncomfortable head temperature when worn. • Weight distribution (center of gravity) of the HMD on the aviator's head was reported as comfortable. • Most aviators seldom had to adjust the interpupillary distance of the displays during their mission. • Aviators who wore eyeglasses had adequate eye relief adjustment. • Wearing the HMD caused no upper body discomfort for neck, shoulders, back, or arms. • Three of eight aviators reported occasional problems with hot spots on the back of their head while wearing the ProView™ 60. • Range of head movement was somewhat restricted by cable on back of HMD.	• Images displayed on the HMD had adequate resolution. • Brightness of the visual scene on the HMD was adequate. • Flickering of images on the HMD visual scene was minimal. • The color of the images displayed on the HMD was adequate. • The visual scene on the HMD provided most aviators with adequate situational awareness of their immediate environment. • Aviators who wore eyeglasses did not experience optical distortions of images on the display. • Most aviators did not experience motion sickness symptoms while wearing the HMDs. • Visual perception cues provided by the HMD for rate of closure and depth of visual field at low altitude were less than adequate for most aviators. • Aircraft altitude and attitude visual cues (at low altitude) were less than adequate for half of the aviators. • Image lag was often noticeable on the HMD visual scene because of problems with the AVTB image generator. • Most aviators reported that flying the simulator using the HMD was more difficult than flying an actual aircraft primarily because of limited FOV.

APPENDIX E

AVIATOR SURVEY RESPONSES REGARDING MOTION SICKNESS SYMPTOMS EXPERIENCED DURING MISSION

AVIATOR SURVEY RESPONSES REGARDING MOTION SICKNESS
SYMPTOMS EXPERIENCED DURING MISSION



APPENDIX F

TOTAL HOURS EACH AVIATOR HAD USED AN HMD BEFORE ASSESSMENT

TOTAL HOURS EACH AVIATOR HAD USED AN HMD BEFORE ASSESSMENT

Aviator No. 1	1200 hours*
Aviator No. 2	1.2 hours
Aviator No. 3	1.2 hours
Aviator No. 4	22 hours
Aviator No. 5	75 hours
Aviator No. 6	300 hours
Aviator No. 7	30 hours
Aviator No. 8	1.5 hours

*Aviator accrued hours as simulation pilot for the Army Research Institute

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Durbin, D.B. (ARL)

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13. ABSTRACT *(Maximum 200 words)*

Head-mounted displays (HMDs) are a potentially viable technology for presentation of the "out-the-window" (OTW) scene for Army aviation simulators. As part of an effort to evaluate their suitability for Army aviation, a preliminary assessment of three Kaiser ProView™ HMDs was conducted during a simulation exercise at the U.S. Army Aviation Test Bed, Fort Rucker, Alabama. The assessment evaluated the fit, retention, and visual display characteristics of the HMDs. The method used to assess the HMDs included aviator responses to a usability survey, statistical correlation of survey responses with head measurements obtained from each aviator, observation of aviator performance during their missions, and post-mission interviews. Most of the fit, retention, and visual display characteristics of the HMDs were judged to be acceptable by the Army aviators. Suitability of the HMDs would be improved by an increase in field of view and the use of lightweight electrical cables to minimize restriction of head movement and potential for pressure-induced hot spots.

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