Advanced Helmet Mounted Display (AHMD)

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ABSTRACT

Due to significantly increased U.S. military involvement in deterrent, observer, security, peacekeeping and combat roles around the world, the military expects significant future growth in the demand for deployable virtual reality trainers with networked simulation capability of the battle space visualization process.

The use of HMD technology in simulated virtual environments has been initiated by the demand for more effective training tools. The AHMD overlays computer-generated data (symbology, synthetic imagery, enhanced imagery) augmented with actual and simulated visible environment. The AHMD can be used to support deployable reconfigurable training solutions as well as traditional simulation requirements, UAV augmented reality, air traffic control and Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) applications. This paper will describe the design improvements implemented for production of the AHMD System.

Keywords: Advanced Helmet Mounted Display, augmented reality, wide field-of-view, stereoscopic, simulation and training, deployable, reconfigurable

1. INTRODUCTION

It has been said that Helmet-Mounted Displays (HMD) are the biggest advance in force-multiplying technology to have hit combat aviation since fire-control radars were deployed in the 1950s. Merging HMDs into the already highly 'fused' data environment of a modern combat aircraft has proved challenging, but the end result is giving pilots equipped with the capability a critical edge. HMDs are poised to create a similar revolution in the Simulation & Training arena.

As a result of the rapid advancement in networking capability, both local area and satellite-based wide area, personal computer (PC) and displays technology, networked deployable trainers scattered around the world allow U.S. and coalition military personnel to train collectively, in a synthetic, but realistic environment. Realism has been greatly enhanced by use of very accurate terrains created from aerial and satellite photographs. Joint forces aircraft, ship and tank simulators based in different parts of the world today can participate in the same virtual battle as the result of this networked simulation capability. Visual display capability has long been a critical element in successfully training military aviators. For dual seat aircraft such as the F/A-18 E/F, F-15E, and many rotary wing platforms, the Link AHMD can be used to provide independent non-interfering visual displays to both crewmembers. Currently available real-image display systems occupy a relatively large volume and require facilities that make them impractical for use as deployable trainers. Existing HMDs have deficiencies such as excessive weight, unfavorable center-of-mass, poor image quality and ergonomics, which have hindered their widespread user acceptance. The Link AHMD has been introduced at a time when the need for innovative visual display solutions is at a premium.

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In previous papers[1, 2] we had described the innovative design concepts, development, manufacture and performance of the resulting prototype Advanced Helmet Mounted Display (AHMD) system. Subsequently we had evaluated the AHMD to validate the system performance and its ergonomic design features and to highlight areas that required improvement.

This paper will present the improvements made for production. The AHMD with its superior visual performance will enhance pilots' situational awareness, which greatly improves piloting and navigation tasks, enabling training in a synthetic, yet realistic environment.

1.1 Link's HMD Legacy

Visual display capability has long been a critical element in successfully training military aviators. Link's heritage in HMD systems goes back more than 50 years. The early development was driven by military requirements for a display system that could be mounted on the helmet, providing information to either a fixed or rotary wing pilot.

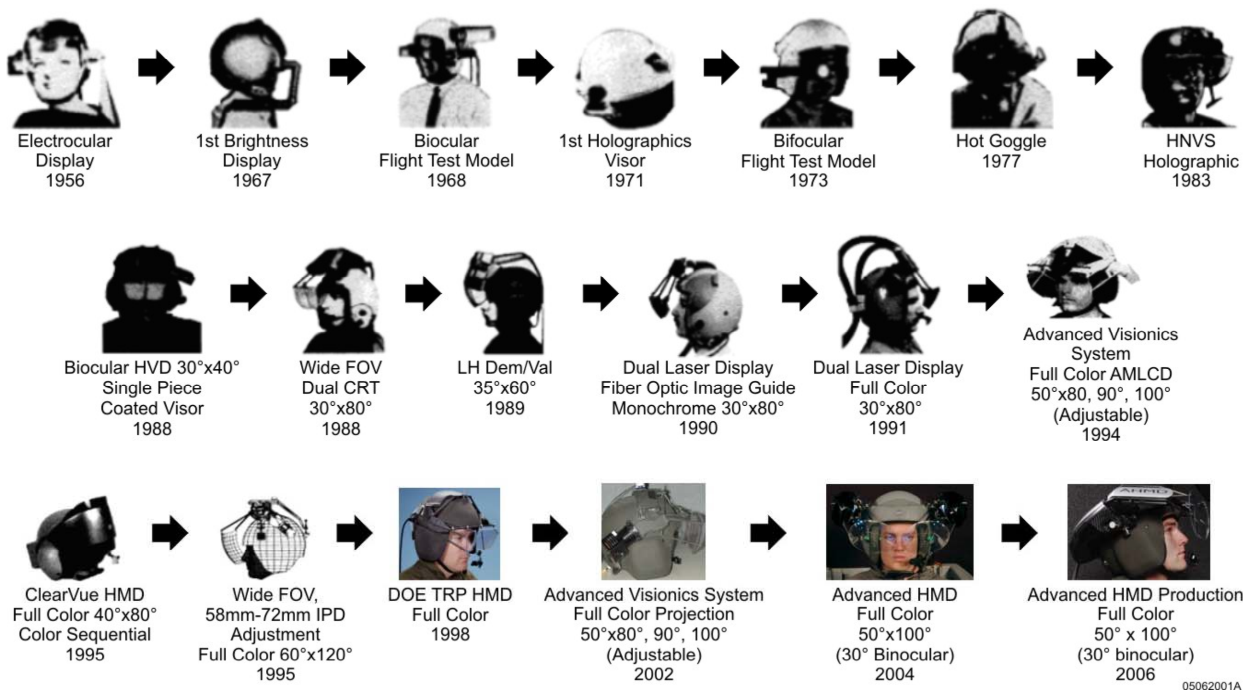


Figure 1: Link's HMD Legacy

Extensive experience with HMDs has given Link an understanding of the challenges involved in the design of HMDs in order to meet the training mission's and the user's requirements for flight and simulator use. Link produced test HMDs for actual flight use as early as the late 1960s and early 1980s, in addition to ground based simulation and training in the early 1990s. Human factors and systems engineering lessons learned over time have been used to arrive at Link's innovative AHMD Production design.

1.2 AHMD Description

The AHMD displays highly realistic out the window visual scenes to support student training. These scenes are generated via modeled realistic terrain databases stored in the Image Generator (IG) combined with simulated on-ground and in-flight inputs from the student pilot interfacing with cockpit controls. The AHMD provides the same visual cues to the pilot as would be received in actual flight. An integrated head tracker system, employing proprietary predictive tracking techniques, provides head motion compensation for the overall visual scene. The head tracker determines the pilot's instantaneous head position and attitude that is passed to the IG to define, in real-time, the instantaneous pilot viewport (direction of gaze) into the database world. The IG uses the corresponding eye point position data to provide a dynamic vignette mask that simulates the effect of the eye shifting relative to the aircraft when the pilot moves his head. The anchored virtual mask, representing the particular aircraft, is placed over the data occulting the information that would not be seen in the aircraft while simultaneously enabling clear view of the physical inner cockpit. The configuration of the AHMD system is shown in the functional block diagram in Figure 2.

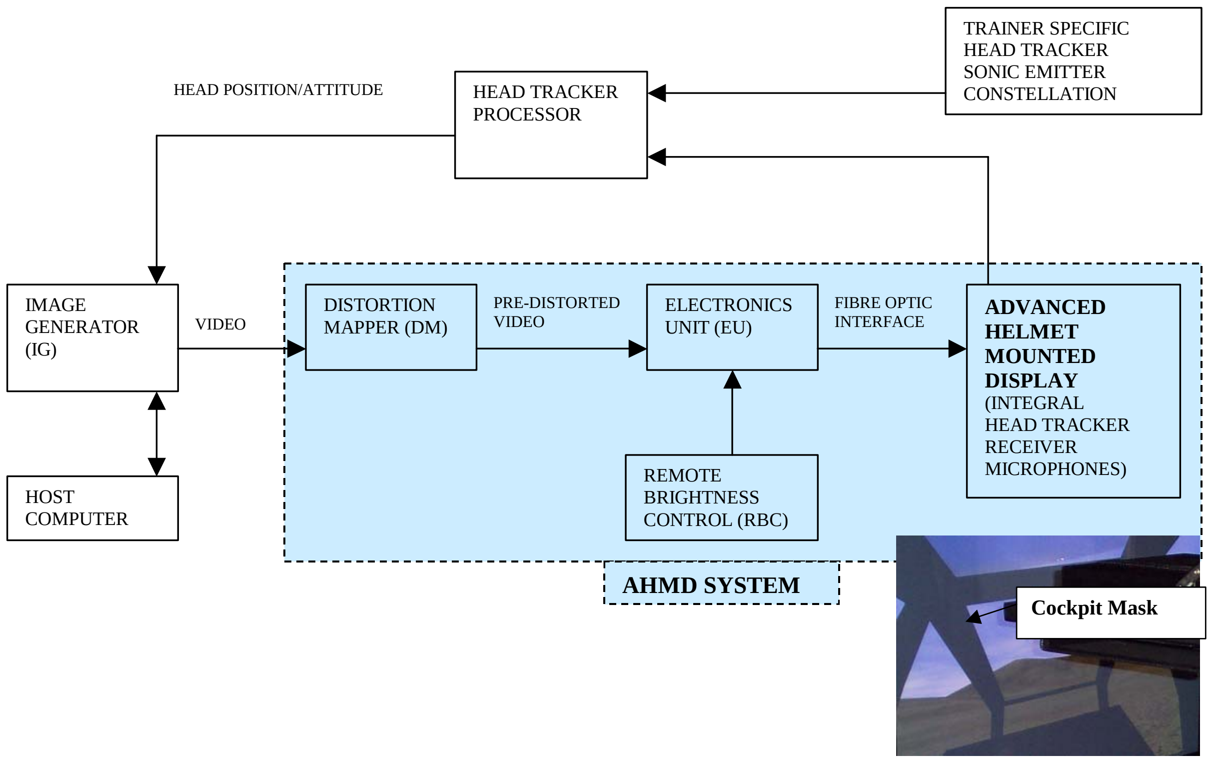


Figure 2: System Block Diagram and Cockpit Mask

By employing dedicated IG channels providing distinct laterally disparate images to the left and right eye, the partially overlapped AHMD design enhances pilot situational awareness by displaying stereoscopic imagery in the overlapped central 30 percent of the instantaneous field of view. Stereoscopic viewing conditions result in enhanced visual acuity, thereby improved visual target detection and aircraft maneuvering.

It is important that the design approach of an HMD be at the system level. The HMD fuses elements of optical, display, electronics, mechanical and, ergonomic designs to a single system. The objectives are to demonstrate reduced pilot workload, increased situational awareness, and the ability to perform critical training functions.

The key AHMD system parameters are shown in Table 1.

Parameter	Link AHMD	Comments
Safety	No glass in vicinity of face	Plastic combiners
Helmet	Pilot's personal flight helmet / Simulator helmet	User acceptance & Comfort
Platform commonality	Custom mounts for: HGU-55 & HGU-56 helmets	Rotary and Fixed Wing Helmets
Minimum HMD Occlusion/Large Eye Relief	Off-axis optical design	User Acceptance, Enhanced immersion & Eliminating "claustrophobic" sensation
Configuration	Binocular/ Partial overlap	Wide field-of-view, 30° Binocular overlap
Electric Interconnect	All digital	High immunity to radiated EMI
Tether	High-speed fiber optic data bus/very flexible and lightweight	Unrestricted head movement and supports higher bandwidth
Interchangeability/Modularity/Field Maintainability	Any HMD may be assigned to any simulator station/Extensive field repair or replace ability	Increased System Availability, Logistic support, Reduced inventory

TABLE 1: AHMD SYSTEM PARAMETERS

The AHMD Technology and Performance Parameters are listed in Table 2.

Parameter	Link AHMD	Comments
Display Technology	Ferroelectric LCOS	Fast switching for single panel solution
Illumination	LED	Solid state colour sequential
Eye relief (mm)	> 50	No interference to eyeglasses
Exit Pupil (mm)	15	Accommodate eye movement and helmet slippage due to head motion
Transmissivity (%) [see through]	> 60	Ease of viewing cockpit instruments and controls
Field of View (H x V)	100° x 50°	Sense of immersion
Resolution per Eye	1280 x 1024	Satisfies intended application
Center of Mass	Balanced	User comfort
Head Tracking	Integrated 6-DOF	Full 360 degree field-of-regard

TABLE 2: AHMD TECHNOLOGY AND PERFORMANCE PARAMETERS

2. ENHANCEMENTS FOR PRODUCTION

The user evaluations conducted with the prototype AHMD system enabled refinements to be incorporated during transition to production. These design enhancements are described below.

2.1 Image quality;

1. Increased brightness resulting in enhanced visual acuity
2. Improved brightness and color uniformity across the field of view resulting in enhanced immersion in the virtual environment

The first has been achieved with improved light coupling between the LED and the fiber optic light guides and the second by the novel manufacturing method employed resulting in improved fiber distribution within the light guide bundles.

A solid optic fiber coupler was designed and fabricated. The coupler collects light from a Lambertian LED with a domed package. The collected light distribution is optimized to provide etendue limited performance with the fiber bundle. The coupler design was optimized using LightTools® from Optical Research Associates. Measurements of the collected light as a function of fiber diameter (Figure 3) very closely match the simulations performed in LightTools®.

The new coupler (Figure 4) was specifically designed to match the fiber numerical aperture. Its coupling efficiency is limited by the etendue of the source. Because performance is etendue limited, significantly better performance would require a higher luminance source. The new coupler's performance resulted in an approximate 50% increase in the overall brightness.

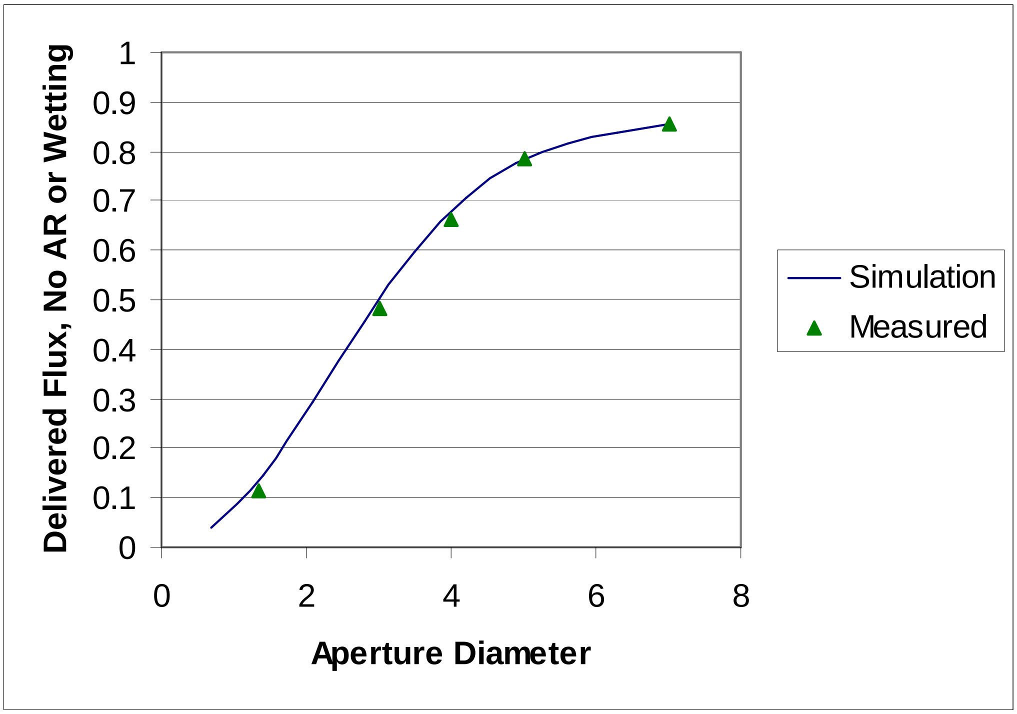


Figure 3: LightTools® Simulation versus Measured performance for the new coupler using a White LED

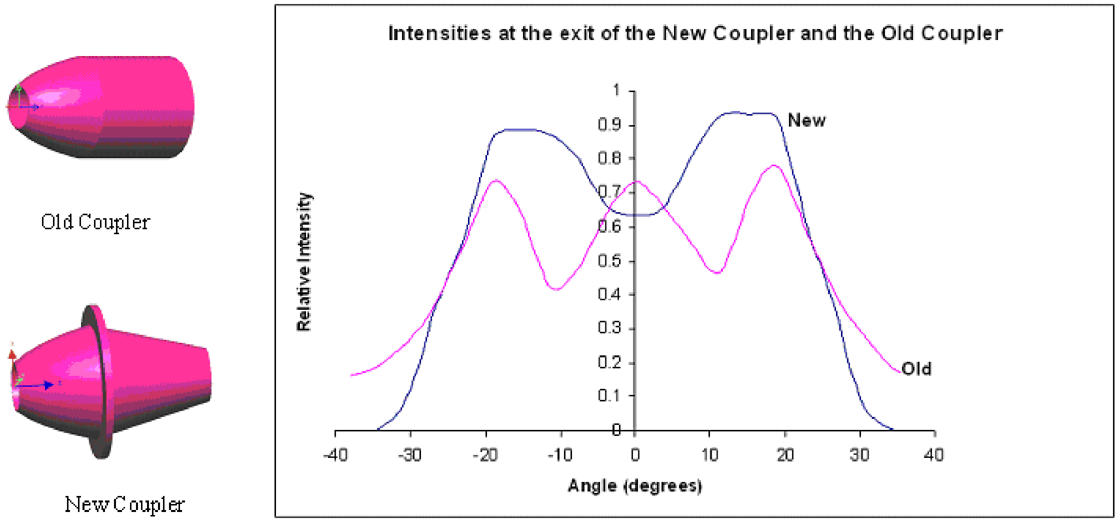


Figure 4: Relative intensity distribution for Old and New couplers

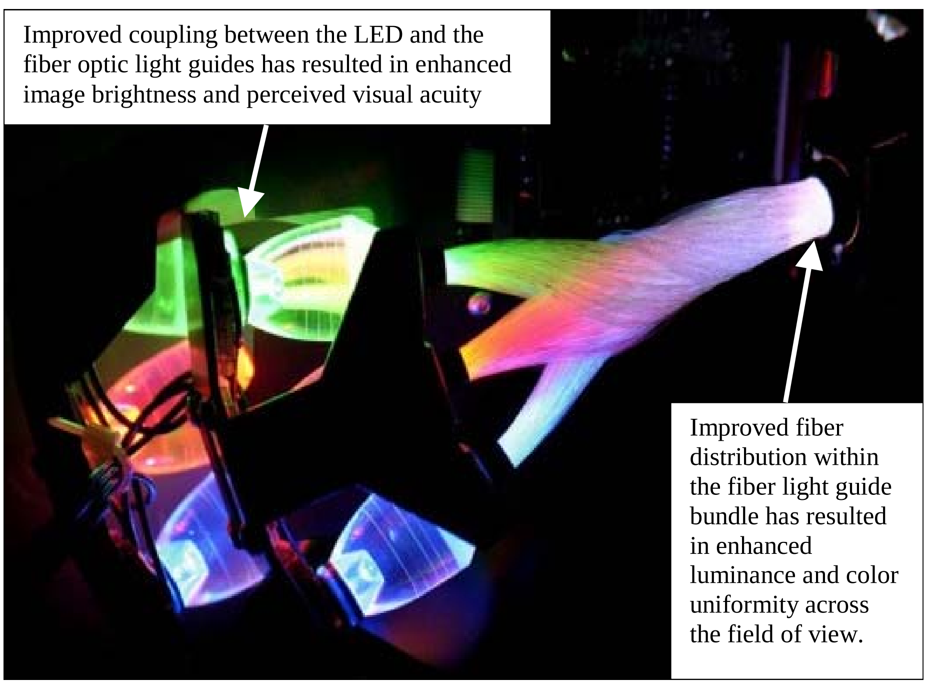


Figure 5: Illuminator Enhancements

2.2 User Adjustments;

User adjustments refer to the ocular adjustment for positioning the HMD exit pupil at the viewer's eye pupil. This critical user interface feature ensures optimum image quality (unvignetted instantaneous field of view) for the maximum user population anthropometric range. The prototype AHMD mechanical adjustments provided discrete increments of a few millimeters per step movement for IPD, up/down and fore/aft adjustments respectively. The user simply grasped the oculars and moved them by pushing towards the head or pulling away from the head in all three axes either by independent axial or even cross-axial movements for rapid alignment (see Figure 6). However, with usage the smooth adjustment could not be maintained due to binding at the extremes of travel and due to change in friction characteristics resulting from material wear. The initial force to move the ocular would result in the ocular traversing to the end stop so it became more difficult to achieve incremental step movement.

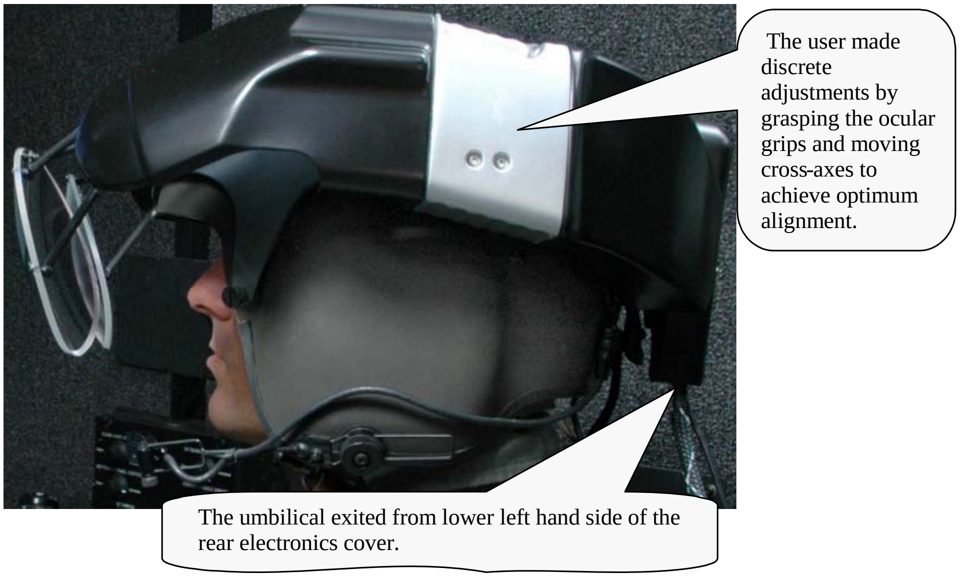


Figure 6: Prototype AHMD

However, with usage the smooth adjustment could not be maintained due to binding at the extremes of travel and due to change in friction characteristics resulting from material wear. The initial force to move the ocular would result in the ocular traversing to the end stop so it became more difficult to achieve incremental step movement.

The enhancement made for production (see Figure 8) was to move to independent axial movement. This provides continuous travel in contrast to the previous discrete travel.

2.3 Unrestricted Head Movement

The prototype AHMD evaluation conducted with quite a varying population sample highlighted up-look head movement restriction for heavyset users. Even though the umbilical is very flexible, having a bend radius of approximately an inch, the fact that it exited lower down at the back, see Figure 6, caused problems for some users. For production the exit point was moved up and centrally located, see Figure 7, allowing unrestricted head movement for all users.

Figure 7: Enhanced Cabling

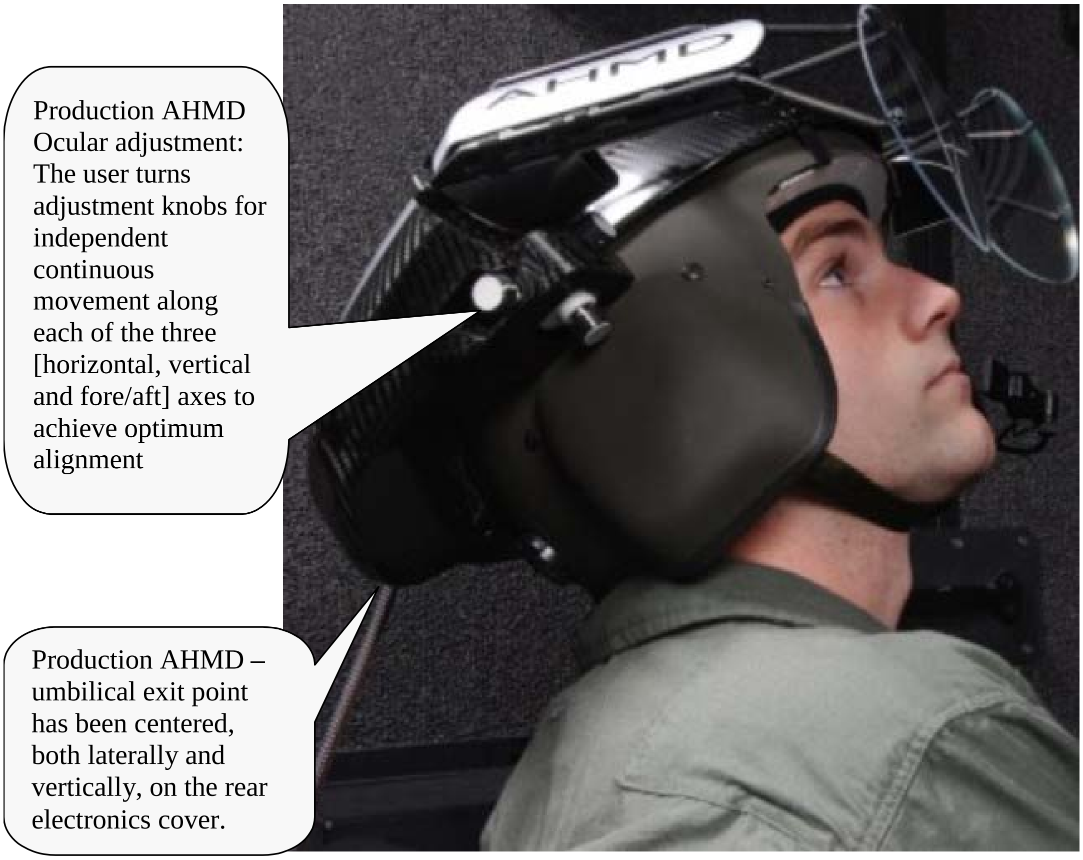
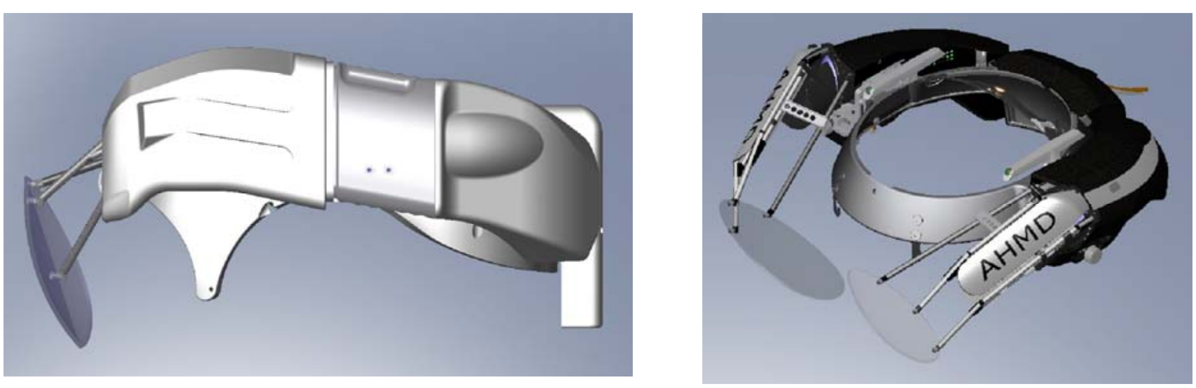


Figure 8: AHMD Improvements for Production

2.4 Aesthetics

The look of the production AHMD has been significantly streamlined (Figure 9) with the use of carbon fiber covers, which now closely wrap around the opto-electro-mechanical components mounted on the carbon fiber halo.



Prototype Production

Figure 9: Enhanced Aesthetics

3. APPLICATIONS

The AHMD provides display features enabling its use as the primary display device for all aviation trainers. High-resolution full color imagery supports target training tasks and high see-through design supports cockpit training tasks. The ergonomically designed system is user friendly, light weight with balanced center of mass to eliminate uncomfortable neck loading[3] enabling effective training sessions. Minimizing occlusion of the outside world minimizes the "claustrophobic closed in feeling", enhances immersion in the virtual world and reduces workload by eliminating unnecessary head movements in order to compensate for HMD occlusion.

The AHMD system enables real-time visual, as well as audio, interaction in a synthetic battle space to enhance the entire military crew's proficiency.

The AHMD provides a high quality display system supporting small footprint, networked reconfigurable deployable training systems for multi-platform applications (a reconfigurable helicopter trainer providing appropriate helicopter model, cyclic, collective and rudder pilot controls is shown in Figure 11). The ability to provide a wide high-resolution instantaneous field of view and a full 360-degrees field of regard in a compact package opens up new in-theater mission readiness training potential. In addition to deployable reconfigurable training solutions, the AHMD can be used to support traditional simulation requirements, UAV augmented reality, air traffic control and Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) applications.

The enhanced situational awareness provided by the AHMD makes it applicable for unmanned vehicles control[4].

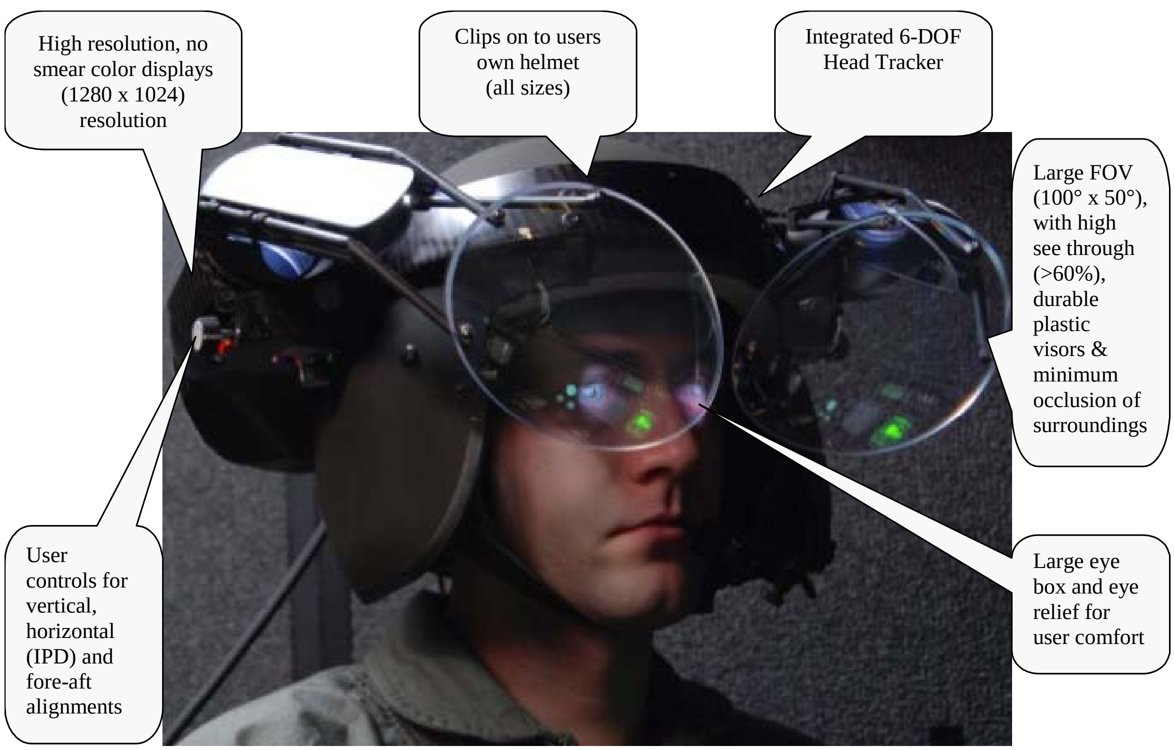


Figure 10: AHMD Design Features

Figure 11: AHMD System Reconfigurable Helicopter Trainer

4. CONCLUSIONS

This paper has briefly described the design improvements implemented for production of the AHMD System and some targeted visual simulation and training applications of this technology. With the user in mind, this minimum footprint, innovative, unobtrusive design with superior system performance, satisfies the visual display requirements for today's demanding military training.

AKNOWLEDGEMENTS

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