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Performance Effects of Mounting a Helmet-Mounted Display on the ANVIS Mount of the HGU-56P Helmet (Reprint)

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The U.S. Army, under the auspices of the Air Warrior Product Office, is developing a modular helmet-mounted display (HMD) for four aircraft series within its helicopter fleet. A design consideration is mounting the HMDs to the HGU-56P Aviator's Night Vision Imaging System (ANVIS) mount. This particular mount is being considered, presumably due to its inherent cost savings, as the mount is already part of the helmet. Mounting the HMD in this position may have consequences for the daylight performance of these HMDs, as well as increasing the forward weight of the HMD. The latter would have consequences for helmet weight and center-of-mass biodynamic issues. Calculations were made of the increased luminance needed as a consequence of mounting the HMD in front of an HGU-56P tinted visor as opposed to mounting it behind the visor. By mounting in front of the helmet's visor, the HMD's light output will be filtered as light coming from the outside world. Special consideration then would have to be given to the HMD's light source selection process, as not to select a source that would differentially reduce luminance by a mounted visor (e.g., laser protection visor) compared to the ambient light in the aviator's field-of-view.

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ABSTRACT

The U.S. Army, under the auspices of the Air Warrior Product Office, is developing a modular helmet-mounted display (HMD) for four aircraft series within its helicopter fleet. A design consideration is mounting the HMDs to the HGU-56P Aviator's Night Vision Imaging System (ANVIS) mount. This particular mount is being considered, presumably due to its inherent cost savings, as the mount is already part of the helmet. Mounting the HMD in this position may have consequences for the daylight performance of these HMDs, as well as increasing the forward weight of the HMD. The latter would have consequences for helmet weight and center-of-mass biodynamic issues. Calculations were made of the increased luminance needed as a consequence of mounting the HMD in front of an HGU-56P tinted visor as opposed to mounting it behind the visor. By mounting in front of the helmet's visor, the HMD's light output will be filtered as light coming from the outside world. Special consideration then would have to be given to the HMD's light source selection process, as not to select a source that would differentially reduce luminance by a mounted visor (e.g., laser protection visors) compared to the ambient light in the aviator's field-of-view.

Keywords: Air Warrior, helmet-mounted display, ANVIS, HMD, HUD, model, simulation, symbology, natural backgrounds, helmet weight, center-of-mass

1. INTRODUCTION

The Army, under the auspices of the Air Warrior Product Office, is developing a modular HMD for several aircraft including the CH-47D, CH-47F, MH-47D, OH-58D, US-60A, UH-60L, UH-60M, HH-60M, MH-60L and the Armed Reconnaissance Helicopter (ARH). The HMD, termed the Modular Integrated Helmet Display System (MIHDS), is being developed to provide day/night capability in any kind of weather or operational environment. Reportedly, the MIHDS will have a day and night capability, and, in addition to displaying symbology, will present situational maps, etc., and will interface with all aircraft sensors. One of the design considerations is to mount the HMD to the HGU-56P ANVIS mount (Figure 1). The ANVIS mount is located in the front center of the helmet, and any device mounted to it will lie outside of the helmet's visor assembly, i.e., an HMD mounted to the ANVIS mount will be located in front of the helmet's visor. Thus, just like ambient light, the light output from the HMD will be filtered by any visor that is used. Compare this with the Integrated Helmet and Display Sighting System (IHADSS) mount in the AH-64 Apache aircraft (Figure 2). The IHADSS is mounted inside the visor, on the right side of the helmet. By mounting the IHADSS behind the tinted visor, Apache aviators are capable of flying daylight missions with HMD symbology.[1, 2]

Mounting the HMD combiner lens outside of the visor's position will have performance issues (e.g., center of mass, image contrast, etc.) that need to be understood, and engineering solutions must be sought to overcome these performance losses. To analyze imaging performance of an HMD based upon its mounting position relative to a visor, we make use of an HMD simulation model that was previously developed[3, 4]. In this evaluation, the modeled HMD was generally based on the Microvision, Inc., Redmond, Washington, Spectrum SD2500 HMD. The SD2500 is a monocular, full-color, scanning laser HMD.[5]

Figure 1. Front view of the HGU-56P helmet showing the ANVIS mount and the tinted visor.

Figure 2. Artist rendering of IHADSS shown with a tinted visor on the outside.

2. METHODS

Figure 3 depicts the tri-color laser spectra used for modeling the HMD. The four-nanometer bandwidth lasers peak at 474 (blue), 532 (green) and 658 (red) nanometers (nm). Using these emission spectra, we modeled a see-through transmission of the HMD's optics with a highly selective, triple-notch spectrum that is typical of rugate filter coatings. The see-through transmission spectra can be seen in Figure 4. We used a flat-transmission spectrum of 90%, interrupted by notches centered at the peaks of the emission spectra. The notches had a bandwidth of 8 nm. At the center of the notches, the transmission was set to 20%.

All of the simulations used an HMD luminance of 1000 foot-Lamberts (fL) (each laser contributing equally) with a contrast ratio of 33. This contrast ratio was derived from a recent evaluation of the Microvision, Inc., Virtual Cockpit Optimization Program (VCOP) HMD.[6]

For calculating simple see-through grayshades, contrast ratios, and Michaelson contrast, we simulated skylight using a color temperature of 25,000^{o}K by using the Commission Internationale de l'Eclairage (CIE) S0, S1 and S2 variables. Separate S0, S1, and S2 values must be calculated for each wavelength. The color temperature chosen provides a predominantly blue sky with limited contribution from the red portion of the spectrum.

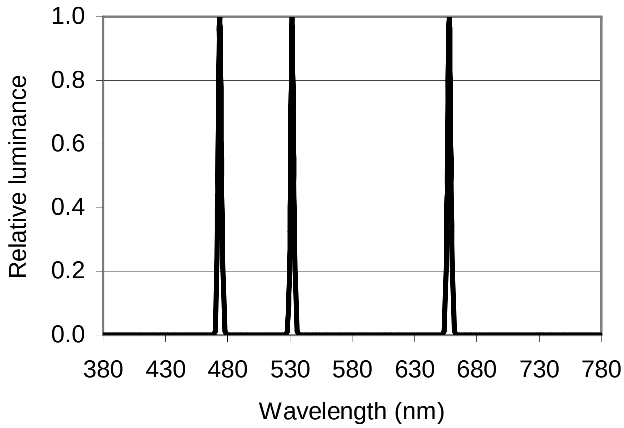

Figure 3. Modeled HMD emission spectra.

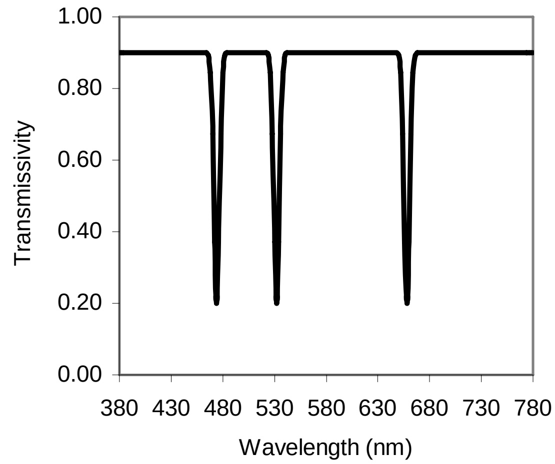

Figure 4. HMD see-through transmission spectra.

We used the windscreen transmission data from a UH-60 Black Hawk aircraft, as well as other airframes. For modeling visors, we used a no-visor condition and the Gentex Corporation, Carbondale, PA, Class II tinted, laser (2-notch) and laser (3-notch) visors. As some of these spectra are sensitive data, only the modeling results using these visors are presented and not their actual spectra.

3. RESULTS

Contrast as a function of HMD placement

The average background luminance L_B is represented by

$$L_B = L_{DB} + L_{AE}$$

where L_{DB} is display background luminance at the eye, and L_{AE} is the ambient luminance at the eye. L_B is used in the following formulas for contrast ratio (CR), grayshades (GS), and Michaelson contrast (C_M),

$$CR = (L_{DF} + L_B)\ )L_B$$

$$GS = 1 + (\log(CR)/\log(2^{0.5}))$$

$$C_M = L_{DF}\ )\ (L_{DF} + L_B),$$

where L_{DF} is display foreground and is set to 1000 fL in all calculations.

To cover a wide range of daylight luminance values, simulations were performed at various skylight luminance values from 500 to 10,000 fL for every combination of visor and HMD position. Figures 5 and 6, as well as Table 1, show the results of these simulations for Michaelson contrast. Figure 5 shows contrast for the HMD mounted <u>outside</u> the visors. Note that the “no visor” and “tinted visor” contrast values are nearly identical when the HMD is positioned outside the visor. This is because the tinted visor attenuates the background and the HMD emission spectrum by approximately the same amount. For these calculations, the emission spectrum was white and therefore all lasers were equally represented. As expected, the Gentex Corporation Laser (2-notch) visor and, especially, the 3-notch visor attenuate the contrast substantially. At 2,000 fL luminance and above, contrast is reduced to below 50% for all conditions. Of course, using more traditional image sources, such as cathode ray tubes or flat panel displays, with more broadband emission spectra, would significantly alter the results with the laser visors.

In Figure 6, the same calculations are performed with the HMD mounted inside the visor. As expected, contrast is increased substantially for all visor conditions. Of course the no-visor condition is the same curve as seen in Figure 5. By way of comparison, the no-visor condition represents the highest contrast observed in Figure 5 and the lowest contrast observed in Figure 6. With the neutral density offered by the Gentex Corporation tinted visor, 50% contrast is achieved out to 10,000 fL.

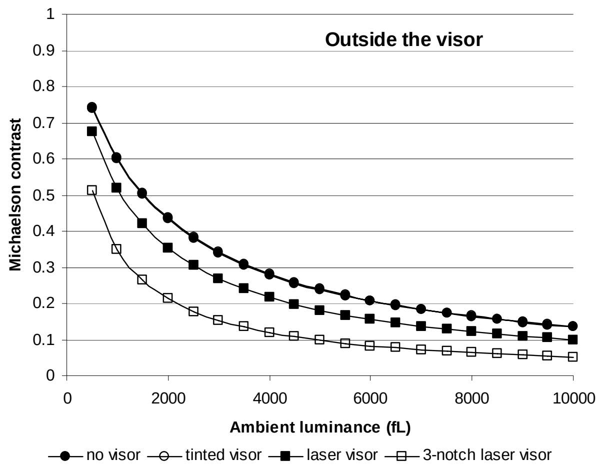

Figure 5. Michaelson contrast as a function of ambient luminance for the HMD mounted outside the visors.

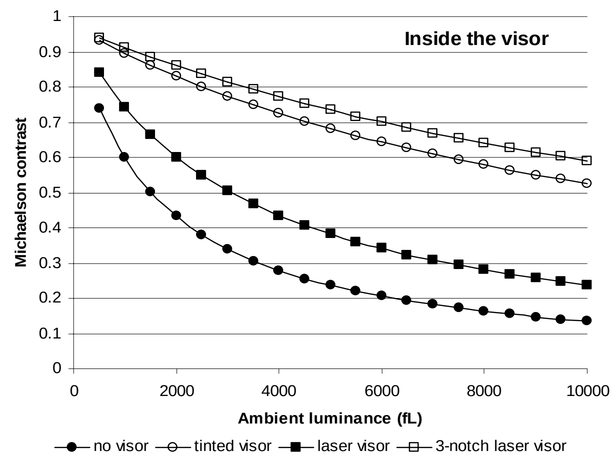

Figure 6. Michaelson contrast as a function of ambient luminance for the HMD mounted inside the visors.

Table 1.
Three measures of contrast as a function of ambient luminance (average outside-the-cockpit luminance) and whether or not the HMD was mounted behind the tinted visor.

Behind the Tinted Visor	Mean Ambient Luminance (fL)	Grayshades	Contrast Ratio	Michaelson Contrast
No	500	4.89	3.86	74.61%
No	1000	3.63	2.49	59.87%
No	2000	2.64	1.76	43.29%
No	4000	1.94	1.39	27.86%
No	6,000	1.66	1.26	20.54%
No	8,000	1.51	1.19	16.26%
No	10,000	1.42	1.16	13.46%
Yes	500	8.69	14.37	93.04%
Yes	1000	7.46	9.38	89.34%
Yes	2000	6.07	6.07	82.76%
Yes	4000	4.69	3.59	72.14%
Yes	6,000	3.92	2.77	63.93%
Yes	8,000	3.46	2.35	57.40%
Yes	10,000	3.13	2.09	52.08%

Symbology luminance requirements as a function of HMD placement

In a see-through HMD, the daylight luminance requirements for symbology, pilotage, and situational awareness are not easily determined. To garner an educated guess, we make use of a previous study.[5] In this simulation study, a fixed symbology image was overlaid over each of ten background images. The white symbology was fixed at 1,000 fL, and the background images were varied over a peak luminance range of 500 to 10,000 fL. Eight of the background images were of natural scenes; the ninth background was a uniform field; and the tenth was an image composed of moderate to high spatial frequency noise (i.e., artificial clutter). In all, twenty "contrast correct" overlaid images were evaluated by observers for each of the ten backgrounds. Observers judged the quality of the symbology on a scale of 1 to 7, with 7 being "High contrast" and 1 being "Difficult to detect the presence of symbology." An average score of 4.0 was deemed the least amount of symbology contrast to be of operational use.

The study revealed that the complexity (defined by the standard deviation) of the background image was of paramount importance in determining the luminance requirements for symbology. Surprisingly, the luminance of the background image was of less importance. On average, the following equation summarizes the results:

$$L_{sym} \geq [0.1+(1.42*SD_B)] * L_B$$

where L_{sym} is the luminance of the symbology and SD_B is the standard deviation of the ambient background. For a uniform background, the minimum symbology luminance is only 10% of the background luminance. When the standard deviation of the background is 70%, the minimum symbology luminance increases to 110% of the background luminance (an eleven-fold increase). However, when considering minimum luminance requirements for symbology, it is best to consider the worst case, not the average, of the eight natural background images. The worst case condition was a standard deviation scalar of 2.95. Likewise, the highest standard deviation for the eight natural scene images was 74.9%. Using these two numbers, a minimum luminance for symbology of $2.3*L_B$ is obtained.

For purposes of this exercise, 5,000 fL would be considered a high out-the-cockpit ambient luminance. Using the $2.3*L_B$ formula for determining the HMD emissions requirements yields the data in Table 2.

Table 2.
Luminance requirements (fL) for symbology as a function of HMD position and visor combination.

	No Visor[1]	Tinted Visor[2]	Laser Visor[3]	3-Notch Visor[4]
HMD mounted to ANVIS outside the visor	7,358	7,233	10,326	21,147
HMD mounted inside the visor	7,358	1,006	3644	763

In Table 2, the luminance differences are quite significant. With the tinted visor in place, there is a 1,006 fL requirement with the HMD mounted inside the visor and an unrealistically large 7,233 fL requirement with the HMD mounted outside the tinted visor. The extremely large luminance requirements with the HMD mounted outside the laser visors reflect the adverse filtering of the HMD emission spectra by the laser protective visors. It is clear from these data that a laser protection visor could not be used with an HMD whose emission spectra were monochromatic, unless the HMD was mounted inside the visor. Under operational conditions, the laser visor would likely be used in conjunction with the tinted visor, and this would further reduce the luminance requirement for the behind the visor condition.

Characterizing the luminance requirements for situational maps and other more complex imagery is a much more difficult task than for symbology. A symbology set is characterized by a quasi-stationary arrangement of symbols and indicators. For example, engine torque generally would be located at the same location all of the time, e.g., it would not change randomly from the left side of the display to right side. There is general positional certainty for most all elements of the symbology set. This cannot be said for situational type displays. These displays, by their very nature, change from day to day and even from minute to minute. This perceptional uncertainty translates to increased requirements for image contrast. That is, greater image quality is required for situational type displays than for symbology. Limited unpublished data in this area confirms this increased luminance requirement for situational type displays.[5]

Helmet torque as a function of HMD placement

Mounting the HMD outside the visor housing will inevitably increase the distance from the HMD combiner lens to the eye. To maintain a constant field-of-view, the size of the combiner lens would have to increase with increasing distance from the eye. If, for example, we consider two physical eye relief distances of 25 and 50 millimeters (mm), the geometry and resulting torque issues become apparent. Figure 7 shows a diagram of three combiner lens (A, B, and C). Combiner lens A, mounted 25 mm from the eye, has a display field-of-view of 40° and is set inside the visor. The same size combiner lens (B) mounted outside the visor (an additional 25 mm out) can only achieve a field-of-view of 20°. Maintaining the 40° field-of-view at 50 mm requires a combiner lens (C) that has twice the diameter or four times the area as the lens mounted inside the visor. Thus, maintaining a given field-of-view results in an increase in the combiner lens and at least a four times increase in the mass (Figure 8). Note: The distance measures given here are an example only and do not reflect the actual distances required for mounting the combiner lens inside or outside the visor for specific helmet/visor assemblies. Figure 8 is not drawn to scale with respect to distance d.

If we consider the line of sight from the center of the eye through the combiner lens as a lever arm, then we can express the additional torque of moving the combiner lens from <u>inside</u> the visor to <u>outside</u> the visor as the ratio,

$$\mu_0 = [m_{B,C} \cong (2r+d)])/[m_A \cong (r+d)]$$

where $m_{B,C}$ is the mass of combiner lens B or C and m_A is the mass of combiner lens A. The symbol d is the distance from the eye to the center of mass of the helmet, and r is 25 mm in the example above. Using 100 mm as a representative distance from the eye to the center of mass of the helmet, then for the same field-of-view, lens C would have approximately 4.8 times greater torque than lens A. (If combiner B was acceptable, even with the field-of-view reduction, the torque ratio would be approximately 1.25.)

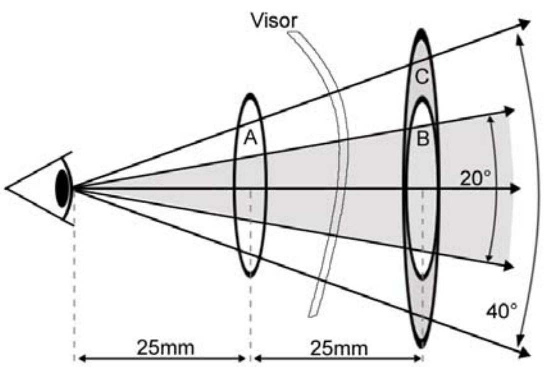

Figure 7. Diagram of positional relationship between HMD combiners (A, B, C) and field-of-view.

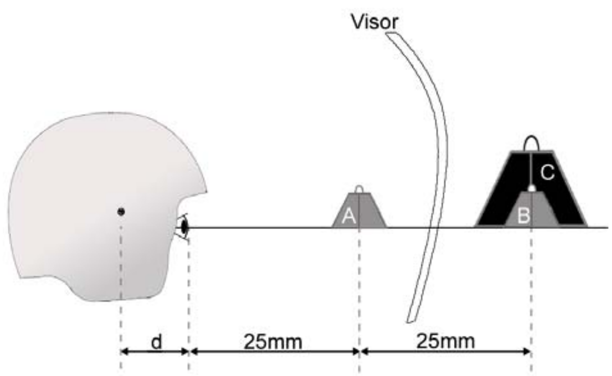

Figure 8. Diagram of lever arm dynamics for visors A, B, and C. The center of the mass of the helmet is marked with a black dot.

4. DISCUSSION AND CONCLUSIONS

In this paper, the effects of mounting an HMD to the ANVIS mount of the HGU-56P helmet versus mounting the HMD inside the visor were evaluated. Three lines of comparison were used, contrast considerations, luminance requirements, and the torque of the HMD combiner lens upon the helmet. An HMD simulation model[3,4] was used for the evaluation of contrast as a function of HMD placement and visor combination. The simulated HMD was a full-color HMD based generally upon the Microvision, Inc., Spectrum SD2500 HMD,[5] a laser scanning system utilizing red, green and blue lasers.

For evaluating contrasts, the HMD had a constant peak luminance of 1,000 fL. The contrast measurements were the contrast ratio, grayshades, and Michaelson contrast. Contrast measurements were calculated for each position/visor combination. The four visor conditions were the no visor, Gentex Corporation tinted visor, the Gentex Corporation laser (2-notch) visor, and the Gentex Corporation three-notch visor. As would be expected, contrasts were higher for the HMD mounted behind the visor for all visor conditions. Because of the emission spectra of the HMD, contrasts were dramatically reduced with the forward mounted HMD in combination with one of the laser protection visors. Alternate

HMD sources with broader emission spectra would fair better in these tests, although contrasts would still be reduced significantly when mounting the HMD forward of (outside) the visor assembly.

When calculating probable luminance requirements, calculations were based on the results from a recent study where observers rated the quality of symbology overlaid upon natural backgrounds.[4] In this study, the complexity of the background had a much greater influence upon the quality of the symbology than did the average luminance. Using a luminance requirement derived from this study, the required luminance would have to be 2.3 times greater than the ambient luminance, measured at the eye, in order for the symbology to be of sufficient contrast to be detected against the worst case background condition used in the study. Based upon an outside-the-cockpit average luminance of 5,000 fL, we evaluated the emission luminance values required for each combination of HMD position and visor condition. The results imply that if an HMD must be mounted in front of the visor housing and laser protection is required, laser scanning HMDs cannot be used.

We also presented a simple geometric consideration in terms of field-of-view versus placement of the HMD. In this example, an HMD combiner lens mounted outside the visor would have to be two times larger (in diameter) to provide the same field-of-view as a combiner lens mounted inside the visor. This realization leads to an analysis of the probable torque differential between a lens mounted inside and outside the visor. By maintaining field-of-view, a combiner lens mounted outside the visor would produce a torque approximately 4.8 times greater than an equivalent field-of-view lens mounted inside the visor (based upon our example).

All of our measures indicate that the daytime performance of an HMD mounted outside the visor would require greater maximum luminance, be of larger size, and have greater torque than an HMD mounted inside the visor.

5. DISCLAIMER

The views, opinions and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision unless designated by other documentation.

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