

Evaluation of the Use of a Head Worn Display (HWD) for Flight Support in the Commercial Flight Deck

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ABSTRACT

This study compared the performance of pilots flying a series of approach and landings under each of three conditions: using standard 737-NG flight deck displays only, using those displays with an optical head up display (HUD), and using those displays with a head worn display (HWD) depicting the same symbology as the HUD.

Display condition had no effect on pilots' normal landing flight profiles or successful avoidance of a runway incursion. However, pilots reported decreased situation awareness and increased perceived workload when using the HWD as compared to the other two conditions. Pilot comments suggested that the poorer ratings for HWD were attributed to physical characteristics of the hardware and noticeable head-tracking latency.

The results indicate that while the HWD technology still needs more refinement, the near-to-eye display concept is a viable alternative to a HUD.

INTRODUCTION

Head worn displays (HWDs), also known as head or helmet mounted displays (HMDs), have been implemented in flight helmets in military aircraft for decades. Recently there has been increasing interest by NASA and several avionics companies in investigating the use of HWDs in commercial flight decks, especially for future applications such as the integration of synthetic or enhanced vision and conformal imagery^[1].

While some research for the particular application of HWD as a direct replacement for the HUD has been performed for military fixed-wing and rotorcraft aircraft^[2], it has not yet been done in the specific domain of commercial transport aviation, or if it has, the literature is not readily available. Similarly, while industry standards and FAA certification requirements do exist for HUDs, standards and requirements do not yet exist for commercial aviation use of HWDs, leaving researchers without clear guidance as to the optimal, or even minimal, design requirements for such a system.

There are compelling reasons for the aviation industry to continue pursuing HWDs as a future flight deck technology, including two primary advantages of a HWD over a HUD in the flight deck context^[3]. First, the HUD has a very limited field of view, while the HWD allows for an expanded field of regard and the potential to display a significantly larger amount of information in the off-axis or peripheral areas. Physical real estate on the flight deck dashboard is at a premium, but virtual screens expand the possibilities for information display. Second, the HWD allows for conformal imagery to be displayed throughout that entire expanded field of regard without being restricted by the physical confines of the flight deck or of a fixed combiner screen. The pilot could literally see through the flight deck to identify traffic, taxi in fog, or observe potential weather or terrain hazards.

Quite a lot of research exists on HUD usage in aircraft (see Crawford & Neal, 2006^[4], for a recent review). There is a much smaller body of literature on HWD usage, and what is available covers a wide range of domains (e.g. gaming, military ground operations) and implementations (virtual reality vs. augmented reality); very few look at HWDs in a commercial flight deck context. A number of studies address the general perceptual and psychophysical issues of HWDs, such as management of depth perception^[5], binocular rivalry^[6], and latency in head-tracking^[7,8]. These lay the foundation for determining what the minimum acceptable standards will be for developing future HWDs; however, the next step is to determine whether any of these issues would prevent a HWD from supporting pilot performance at least as effectively as a HUD.

In order to determine whether a HWD is as effective as a HUD, this study evaluates a commonly found benefit as well as a potential risk associated with HUD usage. Pilots who use HUDs show improved flight path tracking performance over conditions with no HUD in all phases of flight except cruise^[3,9]. This is attributed to the presentation of the information in an integrated fashion (e.g. the flight director symbol) and in a more naturalistic alignment with the out-the-window view. To the extent that HWDs present integrated information in a naturalistic configuration, as HUDs do, it is expected that HWDs that are used as HUD replacements will provide equivalent benefits to flight path tracking performance to HUDs, and similarly improve tracking performance for takeoff, approach, and landing compared to conditions with no HUD/HWD support.

A potential risk reported in simulator studies is that the use of HUDs was found to impair the detection of *unexpected* events, specifically during approach and landing (e.g. runway incursions)^[4,9,10]. If the HWD symbology is as perceptually engaging as HUD symbology, it is expected that this will result in similar rates of detection of unexpected events during approach and landing with HWD as is found with HUDs. It should be noted that, because the focus of the current study is in comparing the HWD directly to the HUD in terms of the effectiveness of information presentation, no hypothesis is made here concerning the performance of either the HUD or the HWD to a baseline condition with respect to unexpected event detection.

In sum, to date I have not been able to find research that evaluates the basic premise that a head-worn display can be used at least as effectively as a head-up display for those commercial flight deck tasks that involve head-up display usage. Thus, the goal of the current study is to evaluate whether it is feasible to replace the standard head-up display (HUD) optics with a head-worn display (HWD) intended for use in a commercial flight deck.

METHODS

PARTICIPANTS. Fourteen pilots (all male, ages 30-57) with current training on a Boeing 737-NG, who had HUD and/or HWD experience, were recruited for this study. Total flight hours averaged 7357 (range of 600 to 19000), and flight hours on the 737 averaged 854 (range of 20 to 5500). All of the pilots had experience flying with a HUD for an average of 1584 hours (range of 3 to 3200), and 6 of the 14 pilots reported some flight hours with a helmet-mounted visual display device, averaging 55 hours (range of 20 to 500).

APPARATUS. Baseline 737 flight deck displays were presented on several 24" monitors representing the simulator's dashboard, to provide sufficient instrumentation for approach and landing tasks. Video projection provided the out-the-window view on a large screen mounted 9 feet in front of the simulator. A Precision Flight Controls yoke and column system was used for flight control (pilots were to hand-fly the approach and landing).

During the HUD conditions, the HUD combiner was positioned about 12 inches in front of the participant, centered within the eye-box of each participant. A second projector displayed Rockwell Collins' HGS-4000 symbology on a screen mounted overhead, which was reflected in the half-silvered glass of the HUD. On the non-HUD conditions, the HUD combiner was positioned out of the line of sight.

During the HWD conditions, participants wore the NVIS NVisor ST, which displayed the same HGS-4000 symbology in a biocular format (no stereopsis) with 1280x1024 resolution. Although the NVisor allows for full color display, the HGS-400 symbology was depicted in the same monochrome green as that presented on the HUD. Head-tracking was achieved through LaserBird optical sensors mounted behind and above the participant, with an update rate of 200 Hz. The effect of the head-tracking was to make the ILS symbology appear fixed in front of the pilot exactly as if they were looking through the HUD, regardless of head movement, creating a "virtual HUD". Figure 1 depicts a participant wearing the HWD and seated in the flight simulator.

Although all trials used the HGS-4000 Primary mode as the default, pilots were allowed to request the IMC mode if they preferred.

SCENARIOS. This study contained three display conditions: the baseline condition which consisted only of the standard head-down flight deck instruments, the HUD condition which included use of the optical HUD, and the HWD condition which included use of the NVisor