A Moveable View

Head-up displays are paving the way for head-worn displays designed to provide information and flight guidance.

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Head-worn displays will enable pilots to keep flight information in sight while looking outside the aircraft.

As head-up displays (HUDs) gradually become standard equipment in commercial jets worldwide, researchers are looking toward what many believe will be one of the next developments in flight deck technology: head-worn displays (HWDs).

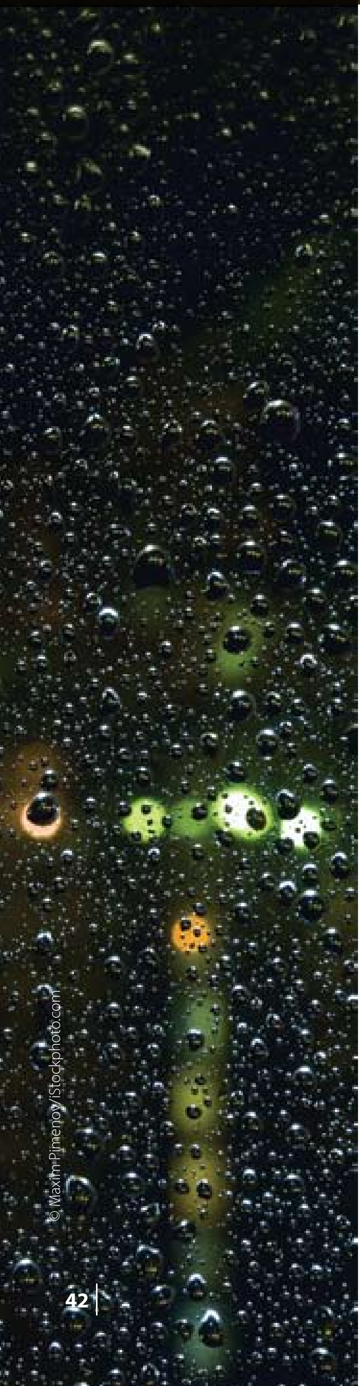
HWDs — in use since the 1980s in the military, where they are known as helmet-mounted displays (HMDs) — are like HUDs in that they not only duplicate the information on instrument displays but also play the role of flight guidance systems by providing additional flight cues and indicators.

But HWDs have unique advantages. The most significant is that they give pilots an almost unlimited see-through field of vision, enabling them to look anywhere without losing sight of the head-up flight information that HWDs provide. This look-around capability opens the way for increased use of enhanced vision systems (EVS) and synthetic vision systems (SVS) — advanced vision systems that provide pilots with greater situational awareness during low visibility takeoff and landing conditions.[1]

In HWDs, the reflective surface of the HUD design is moved from the transparent glass or plastic plate mounted inside the windshield to a "beam-splitter" located in front of a pilot's eyes — or often in front of one eye. To accomplish this, the beam-splitter — an optical device that reflects imagery while also enabling see-through vision — is attached to some form of headgear. In military HMDs, the flight information and imagery are projected onto either a visor or a beam-splitter located in front of the eyes, with both monocular and binocular applications.

An HWD has four basic components:

Helmet-mounted displays — military precursors of head-worn displays — have been used for years by pilots in the armed forces.



- A mounting platform, which can be as simple as a headband or as sophisticated as a full flight helmet. In addition to serving as an attachment point, it must provide the stability to maintain the critical alignment between a pilot's eyes and the HWD viewing optics;

- An image source for the information imagery that is optically presented to the pilot's eyes. Advances in miniature displays have produced a wide selection of small, lightweight and low-power choices at moderate cost, while meeting the demands of high luminance and resolution;

- Relay optics, which relay to the eyes the information produced by the image source. Relay optics typically consist of multiple elements, usually lenses. The last element is the beam-splitter. Initial designs for commercial aviation are expected to be monocular with the beam-splitter in front of one eye; and,

- A head-tracker, which is optional if the HWD is used only to present information with symbols but required if EVS and SVS imagery is to be presented. With this equipment, the pilot's directional line of sight must be recalculated continuously and used to point the sensor in the EVS forward-looking infrared (FLIR) camera in the same direction or to select SVS data that correlates with the pilot's line of sight. Presentation of FLIR or synthetic imagery requires a preflight procedure called boresighting, which aligns the sensor's line of sight with the pilot's line of sight.

As with standard HUDs, HWDs can present virtually any type of informational format: numerical data, such as altitude and airspeed values; pictorial or color symbols; maps; and video information.[2] The first three formats currently are more common, but the video format is expected to become popular because of the increasing availability of EVS and SVS imagery.

Advantages of HWDs

HWDs offer all of the advantages of HUDs, including — most importantly — increased situational awareness. By centralizing critical flight information within a pilot's line of sight, operational safety is enhanced. Transitioning from heads-down instrument flight to visual flight can be problematic. As with all HUDs, however, HWDs offer pilots the advantage of monitoring critical aircraft status data without having to repeatedly look down to scan flight instrument displays.

Another proven benefit of HUDs, and also of HWDs, is that, with the ability to keep their eyes fixed to the outside world, pilots are more likely to detect important changes within the field-of-view[3] — an advantage important in identifying runway incursions.

Potential Problems

Most of the disadvantages of HWDs are well known because they are common to all HUDs. First is the phenomenon of "attention capture" — or tunneling — which is the unwanted tendency for pilots to pay too much attention to the HUD and not enough attention to events in their field of vision outside the airplane.[4,5]

Attention capture with HUDs mounted just inside a windshield has been blamed for undetected runway incursions — one of the types of events that HUDs are intended to prevent. Numerous studies have attempted to understand attention capture and how it can be mitigated. Most disturbing is a developing consensus that HUDs limit a pilot's ability to simultaneously process information derived from HUDs and from the real world.[6]

Most HUD symbols are not "conformal" — that is, they are not overlaid in a one-to-one relationship to match shapes and features in the real world. Therefore, the HUD symbols are perceived as different from the scene outside an aircraft's windows. This causes pilots to deliberately shift their attention to view either the symbols or the outside scene. The transition to conformal symbology may mitigate the attention capture problem.[7] This conformity must be required for video imagery presented in HWDs.

A second disadvantage is the possibility that HUD symbols or other imagery could obscure critical objects in the outside scene.[8] This problem can be reduced by keeping the number of symbols presented to a minimum and within the recommended size. Reducing the clutter caused by too many symbols also can decrease the potential for attention capture.

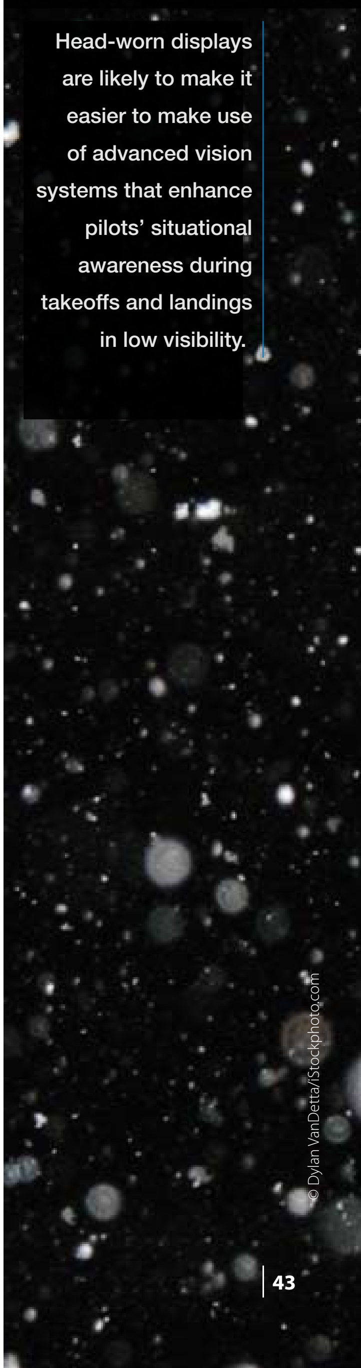
In addition to these general HUD-related disadvantages, other concerns are unique to HWDs — and unique to the concept of mounting the display to the head. The first of these is user acceptability, which is important when any new technology is introduced; without user acceptance, the technology will not be used. The primary factors affecting acceptance are the head-supported weight, center-of-mass offset, required modification in head movement and display lag.

Many pilots are not accustomed to wearing more than a headset on their heads. Current headsets are generally lightweight, typically 12 to 18 oz (340 to 510 g).[9] HWDs will increase head-supported weight by at least 16 oz (454 g).

Because the HWD's display source and optics must be placed in front of the eye, the HWD's added weight will be above and forward of the human head's natural center of mass — a factor that, as a flight progresses, may result in muscle fatigue.

For HWDs to present FLIR and synthetic imagery that represent what a pilot is seeing, the HWD must incorporate head-tracking. The need for head-tracking increases the cost and the complexity of HWDs.

The head-tracking process of determining the pilot's head position, relaying this position



Head-worn displays are likely to make it easier to make use of advanced vision systems that enhance pilots' situational awareness during takeoffs and landings in low visibility.

to the sensor, the sensor's movement to the correct line of sight, the sensor's acquisition of the scene, and transmitting and presenting the final imagery on the HWD takes time.[10] This time is called system latency. Latency times are typically hundreds of milliseconds. The largest contributor is the "slew rate" of the sensor, or the time for the sensor to move to the new head position. Studies have shown that total system-latency times approaching one-third of a second or longer (300 or more milliseconds) are unacceptable from a performance standpoint.

These latency times have been blamed for motion sickness. The onset and severity of motion sickness symptoms are difficult to predict, and such occurrences in commercial aviation would be unacceptable. Studies by the U.S. National Aeronautics and Space Administration (NASA) have documented the need for improvement in image alignment, accuracy and bore-sighting of HMDs to help mitigate this problem.[11]

Taxiing Tests

Under NASA's Aviation Safety Program (AvSAFE), various HUD types and data formats are being evaluated for improvement of commercial aircraft taxi operations.[12] In a recent study, experienced commercial flight crews evaluated two HWD concepts and a baseline head-down display for acceptance and usability. In the study, pilots compared the three configurations while performing a series of taxi scenarios at O'Hare International Airport in Chicago. All of the taxiing tasks involved exiting the runway and taxiing to the airport terminal area.

Participating pilots described the HWDs as easy to use. They found no difference in workload between head-down designs and HWD designs. However, motion sickness was reported by 25 percent of the participating crews. Symptoms typically arose during the first HWD trial and worsened over time.

The Future

HWDs will be required if pilots are to take full advantage of EVS and SVS advanced vision systems. However, HWDs are not problem-free and will face pilot acceptance issues. Their implementation ultimately may be determined by whether they make flight tasks easier and safer by reducing workload and improving safety.

The debut of HWDs into commercial jet aviation will be easier than the introductions of many previous technologies. The military has been using HMDs for almost three decades and already has resolved most of the technical, ergonomic and human factors issues associated with their design, manufacture and use. ●

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Notes

1. An enhanced vision system (EVS) is a sensor system that extends the visual range of pilots — for example, in darkness, fog, smoke or haze. The U.S. Federal Aviation Administration (FAA) uses the term enhanced flight vision system (EFVS) to describe a sensor system used in combination with a head-up display to enable an aircraft to be landed in situations involving low visibility. A synthetic vision system (SVS) uses databases containing terrain, obstacle-clearance and runway information to provide pilots with a computerized three-dimensional view of the area surrounding their airplane.

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Further Reading From FSF Publications

Donoghue, J.A. "A Clear View at Farnborough." *AviationSafety World* Volume 1 (September 2006).

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