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Introduction to HMDs

Uses of Helmet Mounted Displays (HMDs) in Aircraft and Associated Testing to Insure Sustainable Performance

An electronically generated image overlaid onto a pilot's real-world view makes information immediately available. If a head tracker is operating, symbols can be positioned to match the visual position of corresponding objects. This display capability, provided by a Helmet Mounted Display (HMD), can serve a pilot in a number of ways. Each operating mode has its own tolerance for errors and defects in the HMD unit. Defects, which are inconsequential in one mode of use, could be catastrophic in another. Understanding the HMD performance which can be sustained in field use allows the selection of safe and effective combat uses. Over optimism on the part of the HMD vendor can lead to frustrating and dangerous attempts to use the unit in demanding modes prematurely. Given today's steady advances in technology, these more difficult roles will be achieved, but often not on the original schedule.

HMD uses can be categorized as:

- Off Axis Missile Targeting
- Other Targeting
- Pilot Cuing and Data Fusion
- Night Vision
- Aircraft Systems Data Display
- Navigation and Landing Aids

Off Axis Targeting of air-to-air missiles is so important an application that it guarantees that HMDs will be used in all future combat aircraft. Many combat aircraft worldwide are already equipped for this purpose. A modest performance HMD with head tracker can be used by a pilot to direct the attention of a missile's radar toward a target far off the aircraft axis. Once lock is confirmed, the missile is fired and makes an immediate turn to pursue the target. Given the several degree search window of the missile radar, the HMD serves basically as a target designator. Turning the nose of a supersonic aircraft 60 degrees can take 11 seconds. The aircraft equipped for off axis targeting can fire without this delay. This important mode does not require high performance from an HMD, but since it requires an HMD, it is inevitable that other applications will be considered.

At the other extreme is the targeting for classical aircraft cannon. An HMD could in theory serve just like the traditional panel mounted Head Up Display (HUD) for this purpose. But the traditional HUD is one hundred times more accurate than an HMD just good enough for missile targeting. HMDs will probably never be used in this mode. Alternatives - including those that incorporate cameras into the cannon module - can be much more accurate and even offer automatic target tracking.

Pilot Cuing is important enough to be integrated into the program name of the first U.S. deployable HMD -- the Joint Helmet Mounted Cuing System (JHMCS). Pilot Cuing is essentially the reverse of the missile-targeting mode. In that mode, the pilot directs the attention of the electronic systems toward a selected target. In the reverse, the Pilot Cuing Mode, the aircraft systems direct the pilot's attention toward an electronically identified target. A low-grade system would equal the old "Ten O'clock High!" callout and get the pilot looking roughly in the right direction. A precision cuing system could allow the pilot to see and identify targets far beyond normal visual range. The term "Virtual Beyond Visual Range" has been coined for this mode, where visual rules of engagement would be satisfied at two to four times the normal distance. A pilot with such a system would have many seconds advantage over another pilot with a poorer system.

Other electronic information can be integrated into the pilots view to give him "X-ray Vision". Radar can penetrate camouflage, allowing the pilot to see hidden guns and tanks. Satellite and AWACS data can be used to image threats hidden behind a hill so the pilot knows exactly what he will face as he clears the crest. IR data can mark men and vehicles screened in foliage. But images that poorly match the real-world view can cause confusion with a form of double vision, and do more harm than good.

Night vision can be another form of data fusion. It is difficult to use Night Vision Goggles (NVGs) while wearing an HMD. An option is to use starlight TV cameras and feed the images into the HMD. Image processing promises better performance that standard NVGs, and RADAR, FLIR and other data can be added. Yet nighttime scenes often have brighter, directly visible components, and a poorly adjusted system can again produce double images. The resolution of standards NVGs is also higher than that normally available with HMDs.

Critical aircraft systems data can also be displayed on an HMD. This can keep the pilot informed of airspeed and altitude, for example, without looking down at the instrument panel. This mode is sensitive to the sharpness of the HMD symbology - in the presence of vibration and buffeting - since fuzzy numbers are useless. Vibration induced blurring (which results from optical parallax) has been observed to destroy the utility of such data in actual HMD flight tests. Displaying larger numbers may work, but over optimism about HMD performance can result in a design that is useless and dangerous. A related problem is the danger of pilot attention fixation. A pilot studying the displayed symbology - particularly if is appears optically close up - can loose situational awareness. A Navy pilot, flying with a poorly collimated HMD, reported a near midair collision due to this. Anyone riding in a car in traffic can experience this effect by focusing on the details of a spot or bug on the windshield - awareness of the traffic situation ahead is quickly lost.

Navigation and landing aids are widespread uses of panel mounted Head Up Displays, both in commercial and military aircraft. Transferring this to an HMD requires a moderately accurate unit, but symbols can be designed which tolerate blurring and other errors.

Some of these modes require a high-resolution image, others do not. Some require high brightness, others a dim image with little stray light. Some do not need head tracking, others require both a reliable head tracker and a geometrically accurate image so that symbology will match the visual position of the corresponding target.

Other secondary factors may be equally important in operation. The cushions and straps that hold an HMD in place on a pilot's head have some elasticity. With aggressive maneuvering, an HMD may pulled up or pushed down with 30 pounds of force. The pilot's eye will not remain in a fixed position relative to the Helmet Mounted Display optics. A small optical exit pupil may cause the image to blank-out during such maneuvers. Parallax may make symbols blur and become unreadable with vibration and buffeting. Parallax can also cause unpredictable changes in the apparent position of symbols so that they no longer match the visual location of the corresponding target objects. Worse yet, parallax - combined with maneuvering loads - may shift the relative position of the right and left eye images in a binocular system. Double vision and disorientation can result.

As noted earlier - once a production HMD has been well characterized - all these effects can be easily simulated and safe and effective combat uses selected and implemented. Yet this selection must reflect the HMD performance that can be sustained in the field, using the planned support strategy. The operational degradation of HMDs is extremely difficult to model and predict and even visor replacement causes changes. The temporary use of an optical preflight tester is a very wise option, as it would build a history of HMD performance and calibration stability at the same time that qualification flight-testing was being done. This would be early enough so that the operational use of preflight testers, or more restricted combat roles for the HMD, could be wisely considered.

Testing and Maintenance:

Traditionally, customers have inspected the product they received, at least on a sample basis. A theory exists that partnerships can be formed with vendors that eliminate the need for even this audit inspection - although this theory has never been applied to the money side of the transaction, and audits are still required. This idea is particularly attractive when the testing is difficult and the test equipment development expensive and risky. This situation does not exist with HMDs since proven COTS test systems cost only as much as one to three HMD units, and test costs are less than shipping costs.

Helmet Mounted Displays are complex, sophisticated and somewhat fragile. Certainly they cannot be given the rough handling tolerated by ordinary protective helmets. The prototype HMDs available for early flight and qualification tests are often particularly fragile. The consequences of running critical tests with degraded units can be large. It is thus particularly important to have an HMD optical test system available to monitor the stability and similarity of HMDs used in such efforts. This is not a theoretical consideration as degradation of evaluation HMDs has occurred more than once. Once the ruggedness of the HMDs has been verified in actual use, a rented HMD Optical Test System could be returned.

As mentioned earlier, some HMD uses are so tolerant of errors that quick cockpit checks are all the operational testing needed. These minimal tests are described below. Other uses are much more sensitive to degradation and hidden damage. If these additional modes are considered to be frills added to help sell the product, and no great loss if unusable, then they don't need to be tested. If, on the other hand, these modes are mission critical, the costs of inadequate field-testing can be very large. At a minimum, each HMD suspected of degradation or hidden damage would have to be replaced by a spare unit until the originals could be shipped to the factory, inspected or repaired, and returned.

Binocular and Pseudo-Binocular HMDs:

Human vision is enhanced by its binocular nature. The visual field is larger with two eyes, visual acuity is noticeably improved and depth perception gives important three-dimensional clues. Some of these advantages can be achieved with state of the art binocular HMDs. However, it is difficult to maintain the correlation between the right and left eye images that is necessary for visual image fusion instead of double vision. The thin visor used as an optical combiner in jet fighter HMDs is a key optical element. The smallest flexing of this thin plastic can be shown to create asymmetrical distortions that destroy image fusion. Fatigue reduces the ability of a user to tolerate such errors. Thus a unit that looked OK to a fresh pilot could create double vision after a long mission. A quick automated preflight optical calibration trim will be necessary to make this mode usable.

Pseudo-binocular HMDs are an alternative. They are actually binocular, but not stereoscopic in that virtually every symbol is generated for only one eye. If the cost is acceptable, they offer advantages. First, the two image fields can be displaced outwards, to create a larger total display field. Second, pilots could selectively view central symbology with their dominant eye. And finally, the double system provides redundancy. Critical modes would be usable with one failed display unit, and would also be usable if irritation caused the pilot to have temporary difficulty with one eye.

It is easy to imagine situations in which an HMD manufacturer, particularly one who had a profitable business inspecting and recalibrating the HMD units, would be less then co-operative with a customer who wished to independently test the displays. Since calibration factors are often buried in proprietary software, it would be easy to block such efforts. A customer unwilling to be held hostage for years of expensive maintenance could require such co-operation up front. However much of the utility of preflight testing is retained even without such co-operation.

Preflight testing is an operational, not a design test. Its purpose is to identify degradation in an HMD that would be dangerous or undermine its effectiveness. About 90% of the performance changes caused by aging, distortions or damage could be quantified by comparison with the test data when the unit was initially put into use. A sixty second preflight test, performed by the pilot slipping his HMD into a test fixture, could track the operational history of each HMD and document accumulating errors or abrupt changes caused by damage. With adequate information from the manufacturer, a two-minute procedure could recalibrate the HMD, including the optical properties of the currently installed visor, and verify the resultant improvement. Both support options would eliminate the problem of suspected damage, and unnecessary spares.

With a monocular, or pseudo-binocular, HMD intended for only the most basic uses, a field tester is no more necessary than a flashlight battery tester. Using a panel mounted collimator, or even the nose of the aircraft, the pilot can quickly calibrate the head tracker with a simple targeting symbol. If this step works, the HMD works. If large symbols are used for critical aircraft systems data and landing aids, so that blurring is tolerable, then these modes take no additional testing. A "ready room tester" does avoid the disruption of a pilot powering up an aircraft, only to find that his HMD is inoperative. However more demanding uses of the HMD promise large combat benefits. Adding suitable optical tests to the preflight check can be no more burdensome for the pilot than actually using the tester now built into flashlight batteries.