The F-35 Gen III HMDS shows Joint Strike Fighter pilots symbology and sensor imagery overlaid on the helmet visor. (US Air Force)

HEADS UP, EYES OUT, ALL AROUND

A Comanche-style helmet-mounted display is operational on the F-35 Joint Strike Fighter, but comparable wide-field-of-view technology still needs to be tailored to rotorcraft and their missions.

By Frank Colucci

The pilot-vehicle interface of Future Vertical Lift (FVL) is conjecture, but whether FVL starts with armed reconnaissance or long-range assault rotorcraft, next-generation helmet mounted displays (HMDs) will likely keep heads up and eyes out of the cockpit. The biocular (two-eye) Gen III Helmet Mounted Display System (HMDS) operational in the F-35 jet has its roots in the canceled Comanche scout/attack helicopter. It overlays monochrome flight and targeting symbology on a 40-by-30-degree field of view, stitches all-round imagery together from a distributed aperture system, and steers sensors and missile seekers with pilot head movements. The US Army has no current requirement for a biocular display on the Apache attack helicopter, but Boeing Mesa engineers looked at the F-35 helmet in studies for a new AH-64 cockpit. Boeing director of attack helicopter modernization Paul Meyers summarized, "We're really trying to get an understanding of situational awareness. How can [pilots] best absorb information and get more out of it."

Head-tracking fighter pilot helmet displays today overlay computer-generated flight and targeting symbols alone on a clear visor or on the same visor integrated with imagery from a helmet camera or aircraft sensors. The F-35 helmet, for example, has an electron-bombarded active pixel sensor on the centerline to send night imagery directly to the visor and taps infrared sensors built into the aircraft. BAE Systems is testing a rotary-wing version of its Striker II fighter helmet with two night-vision cameras, one mounted on either side of the helmet next to the eyes, rather than the "cyclops-style" camera in the fighter helmet. Nigel Kidd, BAE Systems director of helmet-mounted displays, noted, "The rotary-wing market has been driven by degraded visual environments (DVE) and improved situational awareness for pilots. To make a system work well in a DVE, it needs to integrate multiple sensors and symbologies, high visual acuity, and a wide field of view, all within a binocular high-resolution display. Head tracking is also important to accurately stabilize symbols and video."

The F-35 Gen III HMDS is made by Rockwell Collins ESA Vision Systems, LLC (RCEVS), a joint venture of Elbit Systems of America and Rockwell Collins. It has a hybrid optical/inertial/magnetic head tracker for pointing accuracy. The HMDS eliminates a fixed head-up display (HUD) in the F-35 and taps distributed sensors for the pilot to see all around, even "through" aircraft structures. The BAE Systems Striker II helmet with opto-inertial head tracker adds picture-in-picture windows, notionally to pipe live video from an unmanned air vehicle into a corner of the flight display. BAE is also testing false-color fusion video in a helicopter version to flag real-world dangers.

Today's jet fighter helmets could display imagery from helicopter sensors. Monocular displays present imagery or symbology to one eye. Biocular displays show both eyes the same image from one or more sensors. Binocular displays (note the slight difference in spelling) give each eye perspective or stereo views from two displaced sensors. The monocular, magnetically-tracked Joint Helmet Mounted Cueing System (JHMCS) projects information within a 20-degree day field of view on the helmet visor to aim sensors and weapons where the pilot looks. It is compatible with night vision goggles. The second-generation JHMCS II introduces an optical-inertial tracker.

Senior researcher Joseph McIntyre at the US Army Aeromedical Laboratory (USAARL) at Fort Rucker, Alabama, nevertheless cautioned that a fighter pilot HMD is primarily a weapons delivery system while helicopter pilot displays commonly support pilotage. "There's quite a different purpose between the Army [helicopter] and Air Force fixed-wing guys." McIntyre also pointed out that helicopter and fixed-wing HMDs differ in crash protection and ejection safety requirements. "They've got different threats, whether wind blast, crash pulse, impact. Rotary-wing helmets [criteria] are more stringent than fixed-wing helmets."

The RCEVS joint venture supplies both fixed- and rotary-wing HMD solutions. Elbit Systems America (ESA) vice president for airborne programs Brian Sinkiewicz acknowledged, "From a design perspective, there are a lot of safety elements that are different. Some of that is what drives the cost and requirements on the F-35 side." Headlines pegged the F-35 HMDS price tag at roughly $400,000.

ESA has a biocular helmet display for helicopters in development and hopes to test the X-Sight HMD with Apache pilots in simulators and a real AH-64 next year. The company's airborne program manager, and former Marine Corps H-1 program manager, Harry Hewson observed, "Generally, rotary-wing helmets are expected to be lower cost. They also have to work in a different environment — sandy, dusty, knocked-around more … They're usually more rugged than what the fighter guys are getting."

Hewson said, "What it really comes down to is use-case. A fixed-wing helmet is used for high-off-boresight weapons aiming and generally works with a fixed HUD. The helicopter [helmet display] is bringing you all your situational awareness data, and it's slaved to line-of-sight … The lower you get to the ground, the more critical the line-of-sight accuracy is. That's why it becomes more of a systems solution than just a display." Hewson added, "For the attack requirement, the most difficult thing is line-of-sight accuracy for the weapons. The Apache generally uses the FLIR [forward-looking infrared sensor] on the nose as part of the M-TADS [Modernized Target Acquisition and Designation Sight] for targeting and night pilotage. There's a high demand to port a lot of imagery in real-time and without latency in that system."

The Army Product Manager Air Warrior in Huntsville, Alabama, integrates aviation life support and mission equipment into an ensemble that improves the combat effectiveness of Army aircrews. The office has a competition underway for a color common helmet mounted display (CHMD) to fit the new modular integrated helmet display system (MIHDS) — see "Eyes-Out in Brownout," *Vertiflite*, July/Aug 2016. Selection and contract award are expected by the end of September. USAARL tested CHMD

The Joint Helmet Mounted Cueing System (JHMCS) puts targeting symbology into fighter pilot helmets with a narrow field of view. It is meant to cue missile seekers to off-axis targets in air-to-air combat. (Rockwell Collins)

Abbreviations

3D	three dimensional
AFCS	automatic flight control system
AMLCD	active matrix liquid crystal display
ANVIS	Aviator's Night Vision Imaging System
ATD/C	Assisted Target Detection/Classification (Westinghouse on Comanche)
CDDM	Color Day Display Module (Elbit)
CHMD	Common Helmet Mounted Display
CNDM	Color Night Display Module (Elbit)
CRT	cathode ray tube
DVE	degraded visual environment
DVE-M	Degraded Visual Environment Mitigation (a US Army program)
EOSS	Electro-Optical Sensor System (Lockheed Martin on Comanche)
ESA	Elbit Systems America
FVL	Future Vertical Lift
HDTS	helmet display tracking system (Elbit on Osprey and Chinook)
HDU	helmet display unit (Elbit on Apache)
HIDSS	Helmet Integrated Display Sighting System (Rockwell Collins on Comanche)
HMD	helmet mounted display
HMDS	Helmet Mounted Display System (RECVS on F-35)
HUD	head-up display
I2	Image intensifier
IHADSS	Integrated Helmet And Display Sighting System (Honeywell on Apache)
JHMCS	Joint Helmet Mounted Cueing System (Rockwell Collins on F-15, F-16 and F/A-18)
MIHDS	Modular Integrated Helmet Display System
M-TADS	Modernized Target Acquisition and Designation Sight (Lockheed Martin on Apache)
NVPS	Night Vision Pilotage Sensor (Lockheed Martin on Comanche)
OLED	organic light-emitting diode
OTO V2	Optimized Top Owl Version 2 (Thales on H-1)
PNVS	Pilot Night Vision Sensor (Lockheed Martin on Apache)
RCEVS	Rockwell Collins Elbit Vision Systems
TAS	Target Acquisition Sensor
USAARL	US Army Aeromedical Laboratory

The BAE Striker II system used in Gripen and Typhoon fighters has a wide-field-of-view visor display with color symbology and co-picture-in-a-picture capability for situational awareness. (BAE Systems)

A medevac Black Hawk pilot adjusts night vision goggles. ANVIS HUDS such as the Elbit HDTS show flight symbology on a day or night monocle within the 40-degree field of view of NVGs. (US DOD)

prototypes for vendors. Dr. Thomas H. Harding, director of the lab's Warfighter Performance Group noted, "It's supposed to be a full-color system, but it's a low field of view — less than 30 degrees for symbology … It's for utility and lift helicopters, not for attack helicopters."

Different aircraft in different operating environments also shape helmet display integration. The original Top Owl HMD used on Tiger and Rooivalk attack helicopters and the NH90 tactical transport helicopter has a 40-degree binocular (two eyes and two sensor paths) field of view on a see-through day visor. Image intensifier (I2) cameras by the pilot's ears generate night imagery projected on the wide field-of-view visor. US Marine Corps AH-1Z attack and UH-1Y utility helicopters meanwhile use the Thales Optimized Top Owl Version 2 (OTO V2) HMD with interchangeable day and night monocles and rely on the high-quality night vision goggles.

The initial Top Owl configuration for the AH-1Z and UH-1Y fed I2 imagery from the helmet through the aircraft computer to provide a processed picture with symbology. Testers found the computer unable to keep up with rapid head movements, and display latency blurred imagery to create a safety issue. A second iteration sent imagery from the helmet side cameras direct to the visor without computer manipulation. Operational testing nevertheless revealed disturbing hyperstereopsis (exaggerated eye separation) illusions in low-level night flying, dark landing zones and night deck operations. I2 imagery projected on the visor was also prone to line-losses that degraded image quality. Optimized Top Owl V2 provided better imagery at night with NVGs. The Naval Air Systems Command has long talked about porting thermal imagery from aircraft sensors to the OTO V2 helmet, but H-1 Zulu and Yankee crews still see on-aircraft sensor imagery only via head-down displays.

Bob Foote at Rockwell Collins offered, "Helicopter pilots operate in an environment that does not easily allow for a trade of field-of-view over resolution. Both must increase together. Pilots need to be able to quickly detect and recognize wires, obstructions and items of interest at long distances." Foote added, "Currently, we are seeing more and more companies investing in higher-resolution displays in smaller sizes that could be used for HMDs in the future … Companies are also investing in electronics needed to process video and drive these displays, making future transition to high resolution more affordable."

Helmet-Mounted Display Types

- Monocular (one-eye) displays present imagery or symbology to one eye
- Biocular (two-eye) displays show both eyes the same image from one or more sensors
- Binocular (two eyes and two sensor paths) displays give each eye perspective or stereo views from two displaced sensors

Heads-Up Holy Grail

Still to be developed is a helicopter helmet able to integrate aircraft sensor imagery with symbology in a wide field-of-view, high-resolution, binocular, full-color, totally crashworthy HMD. Tom Harding at USAARL acknowledged, "That's still the Holy Grail, that plus high brightness for really good contrast in daylight conditions. Some systems that we're developing now have some high-brightness features. The older systems are fairly dim by comparison."

The Army Product Manager Apache Sensors in Huntsville is working with the Armament Research, Development and Engineering Center at Rock Island, Illinois, to modernize the Apache Integrated Helmet And Display Sighting System (IHADSS). The monocular IHADSS has a field of view 40 degrees horizontal by 30 degree vertical. It shows the AH-64 pilot and co-pilot/gunner pilotage and targeting imagery with symbology, and it aims the Apache gun.

Ongoing engineering development aims to replace the obsolete cathode ray tube (CRT) in an ESA helmet display unit (HDU) with a brighter organic light-emitting diode (OLED) flat panel display made by eMagin. OLED technology provides higher brightness, contrast and resolution than CRT displays with less power required. The thick power cable run to the Apache helmet gets notably thinner and lighter with OLEDs. The monochrome OLED HDU completed critical design and test readiness reviews successfully and should finish development in 2019. Program Manager Apache Sensors is meanwhile exploring a follow-on color OLED replacement.

The Optimized Top Owl V2 used by AH-1Z and UH-1Y pilots has interchangeable day and night monocles for pilotage and cueing symbology. (US DoD)

The Apache Integrated Helmet And Display Sighting System (IHADSS) uses a monocular head display unit to show imagery from the AH-64 modernized night pilotage sensor and modernized target acquisition and designation sight. (US Army)

The Apache IHADSS shows pilotage imagery from the modernized pilot night vision sensor and targeting pictures from the modernized target acquisition and designation system co-located on the aircraft nose. Dr. Harding at USAARL observed, "Depending on what sensor you have, you want to match the resolution of that. You don't want to be display-limited. Originally, the Apache was sensor-limited; now it's display limited."

The F-35 distributed aperture system provides spherical situational awareness by tapping infrared sensors on the aircraft nose, spine, cockpit sides and belly. Harding said, "For helicopters, you want those sensors close together because of parallax issues. You don't see it at altitude, but you see it when you're running close to the ground."

USAARL studies also concluded color symbology gives pilots a better grasp of aircraft warnings. Senior scientist Bill McClain said, "You can differentiate much quicker with color. The old standard is green, yellow, red; they're used to seeing that when flight parameters approach the limits. That's hard to do with just a monochrome system." The monochrome HMSD in the Marine AH-1Z and UH-1Y uses flashing cues to signal aircraft limits, but the Naval Air Systems Command plans no color symbology upgrade.

In March, the Army Operational Test Command's Aviation Test Directorate flew surrogate color helmet displays on an analog Black Hawk as part of operational tests of the Air Soldier System, which is being developed to improve Air Warrior capabilities and reduce ensemble bulk and weight. The ESA color day display module (CDDM) and color night display module (CNDM) validated the suitability and effectiveness of the MIHDS helmet and Air Soldier System flight symbology. Day and night displays showed user pilots two-dimensional symbology that moved with the field of view and provided a chance to evaluate three-dimensional symbology conformal with terrain. Conformal 3D symbology is one part of the integrated cueing environment developed under the Army's Degraded Visual Environment Mitigation (DVE-M) initiative. It gives pilots a perspective view of a landing point and flight path markers with terrain warnings to define a "pathway in the sky" for en route navigation.

Aviator's Night Vision Imaging System (ANVIS) goggles provide a 40-degree field of view. The new CHMD is meant to replace the widely-used ESA ANVIS HUD/helmet display tracking system (HDTS) in Chinooks and Black Hawks. Army Chinook and Marine Osprey pilots alike use their monochrome HDTS monocles to see airspeed, altitude, heading and hover cues head-up, day and night. At USAARL, Dr. Harding noted, "For pilotage, we recommend a fairly wide field of view. The Apache is 40 degrees. CHMD is less than 30 degrees. That's not for pilotage [imagery]; that's for symbology, flight parameters."

Third-generation AN/AVS-6 and similar AVS-9 night vision goggles have long been used with the Elbit AVS-7 ANVIS HUD to inject flight symbology into pilot's field of view. The Elbit ANVIS/HUD 24T helmet display tracking system (HDTS) introduced an interchangeable day monocle. Elbit's latest WAVES (Wide Area Viewing System) displays fit the standard night vision goggles mount. They provide an improved, wider field of view day and night on a full-color monocular image that covers the right eye.

ANVIS HUD/HDTS symbology has already evolved to keep pace with head-down displays. According to H-47 human factors and crew station lead engineer Deanna Dibernardi, at Boeing Philadelphia, "The essential primary flight symbology has largely remained the same while being augmented by features like our H-47 Digital AFCS [automatic flight control system] symbology and pointing data for integrated sensors. Hover symbology has been evolved to provide a more intuitive display to guide pilots into landing areas using velocity and acceleration cues to assist the pilots in smoother, more accurate landings." She added, "We are currently working toward integrating conformal symbology, terrain data and target tracking into these displays for increased situational awareness."

Even with better symbology, helmet display monocles have fundamental limitations. Harry Hewson at ESA explained. "There's no sensor built in, but they are completely capable of taking a sensor from the nose, or like Brightnite, our distributed aperture system. We can take all of that and bring it up in front of your eye. [However,] we're pretty much used up physiologically with the usable space of one eye and that 32-by-25 [degree] field of view. If you want to expand the field of view, you have to go to two eyes."

Comanche Connection

The RAH-66 Comanche was canceled in 2004, but the ambitious scout-attack helicopter provided a foundation for both the F-35 helmet mounted display system and ongoing HMD developments. Kaiser Electronics (today Rockwell Collins) prototyped its Wide-Eye HMD as an internal research and development effort and was selected for the Boeing Sikorsky LHX First Team in 1989. Risk

The Comanche Helmet Integrated Display Sighting System (HIDSS) started with the Kaiser Electronics Wide-Eye helmet display to provide a wide field, biocular field of view with overlap. (Rockwell Collins)

The Comanche HIDSS ultimately had two AMLCD monocles overlapped for a 52-by-30-degree field of view. (Rockwell Collins)

The second Comanche test aircraft flew briefly with the HIDSS in engineering and manufacturing development. (Sikorsky)

reduction work under Army contracts in 1991 sought to integrate the high-resolution helmet display with the Comanche electro-optical sensor system (EOSS), developed by Lockheed Martin.

Without the cockpit HUD and telescopic sighting unit of Army Cobras or the direct-view optics of the early Apache, the RAH-66 Comanche scout-attack helicopter relied on a Rockwell Helmet Integrated Display Sighting System (HIDSS) to provide situational awareness and aim weapons. Retired Sikorsky test pilot Rus Stiles explained, "The success of the helmet was pretty critical to our cockpit. We really didn't have any other sighting system other than the head-down display." Stiles participated in development and evaluation on successive versions of the HIDSS and flew the wide-field-of-view display on the second Comanche test aircraft. "Most of it was done in the simulator, but we did fly the helmet in the aircraft in 2002-2003."

The follow-on Comanche helmet display had a field of view 52 degrees wide by 35 degrees vertical, about 50% greater than that of the Apache IHADSS. Like the early Wide-Eye, the HIDSS had two monocle displays arranged to provide a biocular image. Comanche helmet displays afforded either pilot access to the Lockheed Martin EOSS — the Night Vision Pilotage Sensor (NVPS) with a 52-by-30-degree field of view and the target acquisition sensor (TAS) with a 30-by-30-degree field of view. The laser-designating TAS also fed objects marked by the pilots to assisted target detection/classification (ATD/C) algorithms in the Comanche core computer clusters. "We didn't really have a missile with an off-axis targeting capability," said Stiles. "You could look outside and tell the targeting system, 'I think there might be something out there.' The TAS sensor would do a search and cue the pilot on the head-down display or put it on helmet."

In engineering and manufacturing development, the Comanche helmet switched from obsolete CRT to active matrix liquid crystal display (AMLCD) flat panel technology that reduced power consumption, saved weight and improved the helmet center of gravity. Comanche engineers also planned to put I2 charge-coupled device cameras on the helmet to provide a backup to the Pilot Night Vision Sensor (PNVS) and TAS. Stiles recalled, "We were finding because the Comanche TAS targeting sensor was often being used off-line by the ATD/C, the imagery was not available to the copilot. The copilot was kind of blind as far as things outside."

The HIDSS design iterations over the course of the Comanche program culminated in a 52-by-30-degree field of view. Bob Foote at Rockwell Collins noted, "The F-35 HMD was designed initially using the Comanche optical approach as a guide, but using an off-the-visor approach instead of monocles. Monocles have mounting fixtures that the pilot can see, whereas the off-the-visor approach gives the pilots an unobstructed view of the real world." Unlike the AMLCD displays in the Comanche HIDSS, today's F-35 HMDS uses high-brightness monochrome green OLED flat panel displays for extremely high contrast images.

The HIDSS on the RAH-66 suffered from the latency that gave pilotage imagery annoying jitters. According to Stiles, "The weakest link in our approach was the helmet tracking system. The technology at that time didn't support the high bandwidth and stability needed to implement contact analog symbology." Though the magnetic head tracker in the Comanche was good at determining helmet line-of-sight, the display update rate was not fast enough for the NVPS turret. "If the pilot moved his head quickly, it took some time for it to catch up with where the pilot was looking." Stiles observed, "The F-35 had the same problem. They did something I advocated way back when they put little inertial accelerometers on the helmet that gave the system a quick cue when the pilot moved his head to compute where it's going." Rus Stiles concluded, "What we did was not wasted. When I look at what they've done, I see a lot of where we started out."