Comparison of Display System Options for Helicopter Aircrew Tactical Training Systems

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ABSTRACT

The paper presents considerations for determining the appropriate type of visual display system to support helicopter aircrew training with an emphasis on tactical military training. Main discussion points include: identification of tasks dependent upon out-the-window cues; display related performance necessary to support tactical training maneuvers; types of displays that are considered for helicopter training systems; and further considerations including deployment, reconfiguration, acquisition and support costs.

The discussion of display related features is limited to those essential to support modern military tactical training tasks. Some of these tasks include nap-of-the-earth flight; confined area landings; formation flight; external load operations; shipboard operations; target detection and recognition; weapons operation; air-to-air refueling; fast rope operations; emergency/autorotation landings; and stimulation of night vision goggles (NVGs). There are many additional tasks, but this paper will limit discussion to these.

The discussion of the types of display systems used for helicopter aircrew training includes characteristics, performance, features, and benefits of several display types including dome displays, rear-projection mosaic displays, cross-cockpit collimated displays, and Helmet Mounted Displays (HMDs). Examples of state of the art helicopter displays are included for each display type.

The paper presents a high level summary of a training task analysis comparing the ability of each display type to support the previously discussed training requirements. A comparison matrix follows the discussion.

The paper presents a discussion of the acceptance of HMDs in helicopter aircrew training systems. These systems include the US Army's BICEP and AVCATT systems. Factors affecting pilot acceptance including eyeglass compatibility, pupil size, ease of fit, and helmet weight are discussed. A comparison between leading HMD systems is presented.

Other factors in determining the appropriate display system for the training application are also discussed. These factors include forward deployment of the training system, support for reconfigurable cockpits, and the effect on total cost of the training system.

ABOUT THE AUTHORS

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INTRODUCTION

Tactical helicopter simulators require specific visual display characteristics to support their training objectives. These characteristics can be very demanding and may not be satisfied by even the most state of the art and highest cost display system. A number of different display system types are in use in helicopter simulation today. Each type can provide certain advantages and disadvantages for tactical training. The most appropriate display should be determined through an analysis of the training task objectives, with considerations for helicopter configuration, deploy-ability, and impact to total trainer cost.

This paper will provide a list of display dependent characteristics for support of mission task objectives, current performance characteristics and limitations of the various types of displays in use for tactical helicopter training, and a high level summary of training task analysis comparing the training task objectives with each of the displays.

TRAINING TASKS REQUIRING VISUAL DISPLAY SUPPORT

US Army Aircrew training programs are governed by specific guidelines in FM 25-101, *Battled Focused Training, the Commander's Guide to the Aircrew Training Program* (TC 1-210-1), and the Aircrew Training Manuals (ATMs) appropriate for the respective aircraft. The ATMs provide comprehensive lists of tasks to be performed in each respective aircraft. Not all tasks, such as training in use of instruments, require a visual display to support training in a flight simulator. Training for other tasks may be unavailable in the simulator due to lack of visual cues required to perform the task. Primary mission tasks, requiring visual display support to perform training in a flight simulator, are described below.

Nap-of-the Earth Flight

The pilot must maintain appropriate altitude and airspeed for the selected terrain, weather, and visibility. The pilot must focus on the terrain outside the aircraft, note significant terrain features, anticipate wires, negotiate properly, and must minimize the time that the aircraft becomes unmasked. The copilot must also monitor the terrain, especially when the pilot's attention is focused inside the aircraft, assist in detection of obstacles, and be capable of taking over the controls and flying the aircraft

To support this training task, the visual display must provide a wide field of view, in proper perspective to both the pilot and copilot. High resolution is required in order to provide clear texture pattern and object detail on the terrain. High resolution, contrast, and dynamic range are required in order to discern wire obstacles from the background scene.

Confined Area Landings

Confined area landings require accurate height above ground cues, obscuration due to rotor wash, battlefield smoke, weather, and obstacles requiring avoidance. In addition friendly and/or hostile dismounted troops may be in the area, and the pilot must be able to distinguish between the two and react appropriately. A combination of looking low toward the ground during descent, and looking high through the windshield during climb out demand a large vertical field-of-view.

Formation Flight

To properly and safely perform the tasks associated with formation flight the pilot must maneuver into the flight formation, change position in the formation, and maintain proper separation at all times. The pilot must focus primarily outside the aircraft for clearing and keeping track of other aircraft (see Figure 1). Crewmembers must provide warning of traffic and other obstacles.

Figure 1 - Formation Flying by the 160th SOAR (A)

To support this training task, the visual display must provide a wide field of view, in proper perspective to both the pilot and copilot.

External Load / Ship-Board Operations

For external load operations, the pilot must be able to identify the external load, comply with directions of the ground guide, position the aircraft over the load, hook-up and safely get the load off the ground or off the deck.

For ship-board operations, the flight crew must comply with arrival / departure and Landing Signal Enlisted (LSE) instructions, maintain clearance from obstacles, identify the intended point of landing, and comply with LSE hand signals (see Figure 2). A clear view of the landing area is essential – the pilot must be able to identify the intended point of landing, rate of closure and evaluate the touch-down for pitching and rolling of the ship in high sea-states.

Figure 2 - Conducting shipboard operations

To perform these tasks in a flight simulator, a clear view must be provided to the ground guide or LSE. The display system must provide a generous field-of-view downward and forward. Directions from simulated ground guides must be discernable at near real world distances.

Target Detection and Recognition

Detection, identification, and recognition of targets at distances typical of real world missions is critical to successful training. In tactical helicopter trainers these missions are often at relatively short distances, so the limitations in display system performance is not as critical a factor as in other simulators. Cues required include accurate depiction of the target, adequate color and texture to support recognition, and sufficient resolution to allow determination of target orientation. In addition, weapons launched against the ownship must be detected and identified.

The crew must use visual search techniques to acquire and identify targets, friendly elements in the target area, and no-fire locations while maintaining situational awareness. The display resolution must be sufficient to allow the pilot or copilot to detect targets at real world ranges and discern elements of the entity that provide friend or foe determination to support counter-fratricide training.

Weapons Operation

Employment of ownship weapons is a primary task of tactical flight simulators. The out-the-window display must provide clearly identifiable targets (as discussed above). Effects of the weapons such as flash, smoke trail, tracers, impact, and battle damage must appear as in an actual mission to the extent supported by the simulator. Critical performance also includes correlation of the weapon with other sensors, cockpit displays, and provide for pilot and copilot cues.

Aerial Refueling

One of the more difficult tasks for rotary wing pilots is air-to-air refueling. Proficiency in this task requires extensive training and practice and the skills are easily lost if not frequently refreshed. The pilot must be able to quickly and accurately place the aircraft in position behind the refueling aircraft. Once in place, the pilot must position the helicopter refueling probe into the refueling basket (see Figure 3). Delays and inaccuracy in accomplishing the task can put critical mission elements in jeopardy.

Figure 3 - Conducting Aerial Refueling Operations

This maneuver requires a generous upward and forward direction to provide visibility of the rotor tip, tanker, and basket to the pilot.

Fast Rope Operations

The pilot must maintain a stabilized hover until all ropers are clear and must perform airspace surveillance. The copilot assists in maintaining hover and may also

Table 1 - **FOV Requirements by Training Task**		
Training Task	**Key FOV Support**	**Copilot Visuals**
Nap-of-the-earth Flight	Low / Wide	Highly Important
Confined Area Landings	Low/High	Highly Important
Formation Flight	Wide	Highly Important
External Load / Ship-board Ops	Mostly Front	Low Importance
Target ID and Recognition	High Vert/ Wide Horizontal	Highly Important
Weapons Operation	Mostly Front	Low importance*
Aerial Refueling	Upward	Low Importance
Fast Rope Operation	Downward	Moderate Importance
Emergency Landings	Downward	Moderate Importance
NVG training	High Vert/ Wide Horizontal	Highly Important
* Except when copilot is firing the weapons		

be tasked to determine when the ropers and ropes are clear.

The maneuver requires extreme downward FOV for the copilot to determine when the ropers and ropes are clear.

Emergency Landing/Autorotation

The pilot must fly the aircraft in autorotation and make a safe autorotative landing. Crewmembers must visually determine a suitable landing area. High angles of bank and pitch attitude are common during autorotative flight and landing. Visual cues are derived from lateral visual cues for rates of closure and from downward cues for pitch attitude during deceleration and landing.

The autorotation maneuver requires support from a wide field of view display system in order to provide banking and pitch cues, and a large downward field of view to provide rate of closure cues during deceleration and landing, as well as to determine a suitable landing site.

Stimulation of Night Vision Goggles (NVGs)

Flight with NVGs is a very demanding task for both pilot and copilot. Out-the-window cues critical for NVG flight include height and velocity, obstacles, cultural and tactical lighting, and weapons effects. Often the NVGs include a head's-up-display which must be quickly and easily viewed against the outside environment.

NVGs are used throughout the viewing envelope of the operational helicopter; therefore necessitate a very large field-of-view display. Operation in the near infrared range at extremely low light levels require the display system to have a wide dynamic range (if it also supports day, night and dusk), in both chrominance and luminance.

DISPLAY SYSTEMS USED IN HIGH-FIDELITY HELICOPTER TRAINING

Helicopter flight simulators have employed a diverse variety of visual displays to support their training tasks. Advancements in technology, evolving requirements, and training objectives have resulted in several different display solutions for the trainers.

The displays can be categorized into four basic types:

1. Dome Display
2. Collimated Cross-Cockpit Display
3. Rear Projection Mosaic Display
4. Helmet Mounted Display

Characteristics to consider in the display's ability to support training tasks are

1. Field of View
2. Resolution
3. Brightness
4. Contrast
5. Collimation
6. Distortion

Key differences between the display types are field of view limits and scene perspective errors. Scene perspective errors encountered when a non-collimated image, calculated for one viewer's perspective (e.g. Pilot eyepoint) is viewed from another location in the cockpit (e.g., Copilot eyepoint). Field of view determines the visibility of visual cues, out the windows, and may limit the ability of the crewmembers to perform training tasks. The comparison of the display types will be limited to these general features.

Dome Displays

Dome displays have been in wide use in rotary wing military simulators. In this type of display, a large dome, typically of around 12 ft. radius is located around the cockpit. A real image is projected on the inside surface of the dome using multiple projectors. These images are blended together to provide a continuous image. The dome may also be mounted on a motion base to support the highest level of fidelity flight trainers. The key advantage of the dome display is a large continuous field of view, particularly in the downward area. Downward field of view is typically limited by the ability to project imagery over the front and sides of the cockpit.

Figure 4 – The Royal Navy's Merlin CDS Dome Display

The Royal Navy Merlin (EH-101) Cockpit Dynamics Simulator (CDS) (see Figure 4) provides a current example of the state of the art in helicopter dome display systems. The dome, mounted on a 6-degree of freedom (DOF) motion system, utilizes 8 high-resolution video projectors to project a continuous image onto the inside surface of a 24-foot diameter dome. The display provides a continuous 245 H x 90 V degree image to the pilot and copilot, who are seated in a side-by-side configuration (see Figure 5).

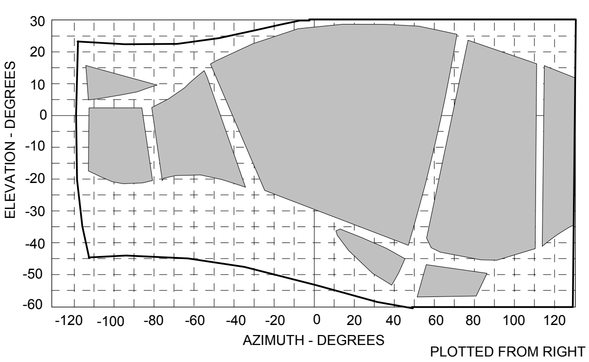

Figure 5. Field of View from Pilot Eye Point for the Merlin (EH-101) CMS Dome Display

For the US Army's AH/MH-6 "Little Bird" Combat Mission Simulator (CMS), the CMS dome will be augmented with the addition of flat screen overhead panels. The AH/MH-6 (see Figure 1) has a clear roof canopy and these additional monitors will support training maneuvers at extreme pitch angles.

The main disadvantage of the dome is that the image is not collimated. This means that the image can only be presented in proper perspective from a single location in the cockpit. If the image is computed for the pilot's perspective, then it will appear distorted from the copilot's perspective. For a side-by-side seating configuration in a 12-foot radius dome, with a separation of 48 inches between pilot and copilot, line of sight errors can be as high as 17 degrees and magnification errors can be as great as 30%. The smaller the separation and the larger the dome diameter, the lower the distortion. This geometric distortion varies throughout the field-of-view, with the largest errors when both pilots in a side-by-side configuration are looking forward, dropping to low levels as the area of interest approaches ±90° horizontal. Conversely, in a tandem configuration the error is at its highest at ±90° horizontal.

Geometric distortion issues can be avoided in either configuration when a separate dome is used for each crewmember.

Continuous Mirror Displays

Continuous Mirror displays are also in use on military helicopter flight simulation displays. Unlike domes, these displays provide a collimated image so that the image is in truer perspective for both the pilot and copilot simultaneously. This is limited to a side-be-side configuration, due to the size and shape of the viewing volume. For a tandem configuration (as in an attack gunship) two separate displays would be required. For this reason discussion here will be limited to a side-by-side configuration.

Limitations due to geometry of the mirror and screen have traditionally limited the vertical FOV coverage of these displays (see Figure 6).

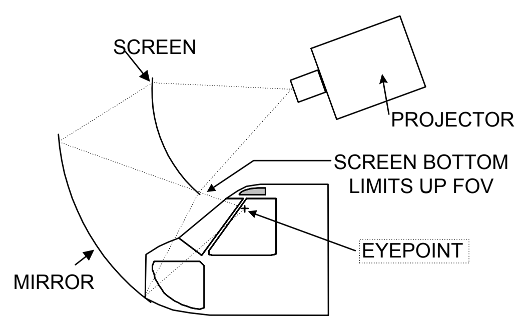

Figure 6 - Continuous Mirror Display

Recent advances in layout have made it possible to provide up to a 60 degree vertical FOV, such as on the display for the Australian Army S-70A-9 Black Hawk Full Flight and Mission Simulator (FF&MS) (see Figure 7).

Figure 7 – The Australian Army's Black Hawk Continuous Mirror Display

The Black Hawk display provides a continuous 220 H x 60 V degree image across the forward and side windows and is augmented by additional real image projected displays in the chin window areas. The FOV coverage extends downward to –45 degrees through the side window areas (see Figure 8).

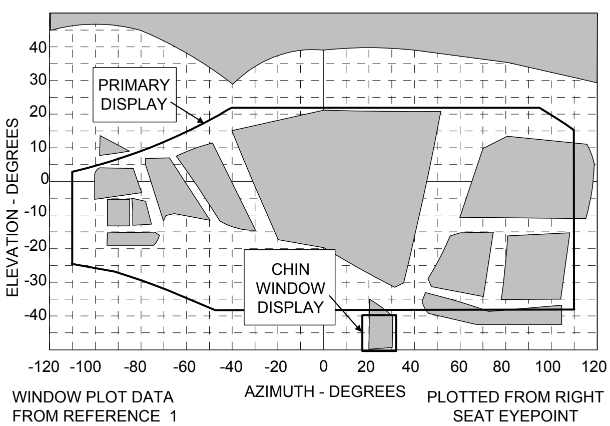

Figure 8. Field of View from Pilot Eye Point for the Australian Black Hawk FF&MS Display

Rear Projection Mosaic Displays

The rear projection mosaic display (see Figure 9), originally pioneered by the Air Force Human Research Lab (AFHRL) provides another category of displays that can be useful for flight simulator displays.

Figure 9 - Rear Projection Mosaic Display

This rear projection mosaic display consists of an array of rear projection panels, juxta-positioned around the pilot's head location. Proximity to the panels can be offset through head-tracking of the computed viewpoint. The display is capable of projecting a very high resolution to the viewer, using inexpensive projector technology. Due to the small size of the arrangement, the display is only suited for a single viewpoint. Multiple viewers would require separate flight trainers with separate displays. The display, however, remains very economical in cost, even when considering the multiple display requirements. The display can also be fitted into a small volume to support deployable training and installations in facilities with limited space.

For an aircraft with a tandem seating arrangement, such as the AH-64 Longbow, the pilot and copilot can be located in separate flight trainers without detracting from training.

The display is capable of providing very large fields of view, but with the trade-offs of increased physical size and image generator channels. This paper will consider a display of moderate size, where two crew stations can be fit into a transportable trailer arrangement.

Helmet Mounted Displays

Hemet Mounted Displays (HMDs) (see Figure 10) are currently in use in two US Army training programs. The HMDs consist of see-through optics, with either CRT or LCD image sources, to provide a collimated stereoscopic image to the viewer. Head tracking is used to match the visual scene to the viewing direction. Separate HMDs are used to provide imagery to multiple crewmembers in the cockpit. The image is computed in proper perspective for all crewmembers wearing the HMDs.

Figure 10 - BICEP Helmet Mounted Display

The HMDs can provide an unrestricted and unlimited field of regard to the crewmembers (Field of regard is the total field of view that can be seen with head movement). A 3-D model of the cockpit matches out-the-window FOV to that of the actual flight cockpit. Resolution can also be very high. The HMDs require very little space beyond the natural shell of the cockpit.

Stereoscopic 3-D view is also provided, since independent visual channels are provided for the right and left eyepoints. This can greatly enhance depth perception, particularly in low-level, low-speed, maneuvers, when the aircraft is flown close to buildings, trees, and other objects.

Simulating the NVG image through the HMD can provide effective training. The visual scene is computed to simulate the response and field-of-view characteristics of the operational NVG device.

Despite their advantages, there are some key issues that have limited the acceptance of HMDs for helicopter tactical training. These factors will be discussed further in the following sections.

COMPARISON OF TRAINING TASK SUPPORT FROM EACH AVAILABLE DISPLAY TYPE

Many of the training tasks can be performed with the support provided by all of the display types. For instance, a landing guide assists tasks such as shipboard and external load operations. The guide is viewed through the forward window areas where all of the displays can provide coverage.

Some of the tasks require that the copilot observe the visual scene, to monitor direction to targets, obstructions, and terrain, and to be capable of taking over flight control at any time. These tasks are best suited to displays that present the visual scene in proper perspective to both crewmembers simultaneously, such as continuous mirror or helmet-mounted displays.

Some of the tasks are better performed with very large fields of view, or visibility down low, such as low level flight, fast rope operations, and emergency landings.

Support for each training task by each of the display type is discussed in the following sections.

Support for Nap-of-the-Earth Flight Training

Low-level flight is best supported by a display that can provide a large downward field of view. Since the copilot is also responsible for observing the terrain, identifying obstacles, and must be capable of taking over flight control at any time, the display should also provide a visual scene in proper perspective to the copilot.

The dome display with large downward field of view capability can do an excellent job in supporting the visual requirements for the pilot. However, the visual scene for the copilot will appear distorted, providing limited ability to discern direction and distances to targets, obstacles, and terrain. Flying the aircraft would also be difficult. To partially offset this, the visual scene can be computed from the location midway between the pilot and copilot eyepoints. This improves the situation for the copilot but at the expense of the pilot.

The continuous mirror display provides accurate scenes in proper perspective for the pilot and copilot simultaneously, but has limitations to downward field of view out the side windows. Also, in general geometric distortion is lower in a collimated display as an object is farther away, and lower in a dome (or other real image display) as an object is closer.

The flat panel mosaic display provides accurate scenes in proper perspective for the pilot and copilot simultaneously, if independent visual channels are computed for each crew station. The need for realistic crewmember interaction limits this task to cockpits with tandem seating.

The helmet-mounted display provides the field of view desired for low-level flight, and provides the pilot and copilot with true perspectives simultaneously.

Table 2 - **Key Characteristics for Helicopter Compatible Display Systems**				
Feature	Dome Display	Continuous Mirror Display	Rear Projection Mosaic Display	Helmet Mounted Display
Field of View	245°H x 90°V	220°H x 60°V	180°H x 60°V	Unlimited*
Downward FOV Limit	60°	40°	30°	Unlimited
In perspective for all crewmembers	No	Yes	Yes	Yes
Crewmembers share same cockpit	Yes	Yes	No	Yes
Pilot Acceptability	High for single pilot application	High	High	Low
Motion Compatible	Yes	Yes	Yes	Yes
Relative Cost	High	High	Moderate	Moderate
Relative Size	Large	Large	Moderate	Small
Channels for a 2-man display	8	7 (With chin windows)	10 (5 per crew station)	4 (2 per HMD)
* Unlimited field of view with head movement. Instantaneous field of view 100°H x 50°V				

Confined Area Landings

A dome display can provide a very large field-of-view, critical to confined area landings. Downward field-of-view during descent, and upward field-of-view during ascent is supported. The geometric distortion can result in negative cues for the non-computed eyepoint, but may not be disruptive when the copilot has in-cockpit tasks, or when the distance between pilots is small.

A collimated display provides for good crew coordination with minimal geometric distortion errors, but limited vertical field-of-view. In some configurations these can be complimented with single window wide-angle-displays (WAC windows) at chin and/or side locations.

A flat panel mosaic display can provide all necessary out-the-window cues for confined area landings, but does not support crew coordination well in a side-by-side configuration, where the two members require separation.

HMDs can provide all cues necessary for confined area landings.

Formation Flight

Formation flight requires field of view through the pilot's forward and side windows to support the view to other aircraft when flying in formation and changing position. The copilot needs to view the visual scene to monitor the other aircraft in the formation.

All of the displays provide the necessary FOV to both the pilot and copilot to support this training task. Line of sight and magnification errors from the copilot location may degrade the ability of the copilot to accurately monitor the positions of other aircraft.

External Load / Ship-board Operations

These tasks require sufficient field of view to follow directions from a simulated ground guide located in the forward direction. All of the displays can provide the necessary queues to support these training tasks.

Target Identification and Recognition

A dome display with sufficient resolution in both surfaces and lightpoints can support this task up to distances typically encountered by tactical helicopter training. Available calligraphic lightpoints increase the performance over raster only configurations.

A collimated cross-cockpit display can also support this task with similar caveats as a dome.

A real image display can be supplemented by a target projector; therefore supporting detection and identification of targets at greater ranges.

HMD support of this task is somewhat limited by reduced resolution, and some potential transport delay during maneuvers requiring quick large head movements, as is often the case when engaging targets.

Weapons Operation

Each of the display types can support weapons operation. A dome can have some limitations if the pilot in the non-computed eyepoint is employing the

Table 3 – **Training Task Compatibility with Display Systems**				
Training Tasks	Dome Display	Continuous Mirror Display	Rear Projection Mosaic Display	Helmet Mounted Display
Nap-of-the-Earth	Full	Partial	Full	Full
Confined Area Landings	Partial	Partial	Full	Full
Formation Flight	Full	Full	Full	Full
External Load / Ship-board Ops	Full	Full	Full	Full
Target Detection and Recognition	Full	Partial	Full	Partial
Weapons Operation	Partial	Partial	Full	Full
Aerial Refueling	Partial	Full	Full	Full
Fast Rope Ops	Partial	Partial	Partial	Full
Emergency Landing	Full	Partial	Partial	Full
NVG Operation	Full	Full	Unknown	Partial

weapon due to the geometric distortion. The collimated display and HMD eliminate this problem.

Air-to-air refueling

This is a very demanding task for any display system. Dome displays provide the upward field-of-view required, but encounter significant geometric distortion as an object approaches the distance of the dome surface.

Collimated images also have distortion problems, as the image is collimated at typically 30 feet or more, resulting in distortion at closer distances.

A flat screen mosaic display will provide excellent resolution and depth cuing.

With the HMD's stereoscopic 3-D depth perception, the closeness of the receptacle tube extending from the ownship can be realistically simulated.

Fast Rope Operations

The maneuver requires extreme downward FOV for the copilot to determine when the ropers and ropes are clear. Dome displays and HMDs are best suited to provide this extreme downward field of view.

Emergency Landings

The maneuver requires support from a wide field of view display system in order to provide banking and pitch cues, and a large downward field of view to provide rate of closure cues during deceleration and landing, as well as to determine a suitable landing site. Dome displays and HMDs are best suited to provide this large field of view.

Night Vision Goggles

A dome can provide an excellent stimulation of NVGs, provided it is configured with high-resolution projectors with adequate bandwidth in color and brightness. Calligraphics enhance some blooming and overload conditions. NVGs can create more demanding performance in blending regions between adjacent channels.

Collimated cross-cockpit displays have been used successfully in many attack helicopter simulator applications.

Flat screen displays in a mosaic configuration and dome displays can present focusing problems due to changes in image distance across the field of view. This may require modification to operational goggles. However, training with unmodified NVGs is currently being done in several systems with no significant negative effects.

The flat panel displays, such as liquid crystal or gap plasma, may also lack the dynamic range and dark field performance necessary to support NVG operation without filtering.

HMDs preclude the stimulation of NVGs due to both occupying the same space. Use of HMDs require simulation of the NVGs within the HMD image. Although this can be effective in providing a properly simulated image, the physical characteristics of the device are not present. Although not previously discussed, implementation of fully simulated NVGs is an alternative to all of the display types. This requires a head tracker, dedicated sensor image channels, and results in a generation of imagery more representative of the real world.

ACCEPTANCE OF HMDS FOR MILITARY HELICOPTER TACTICAL TRAINING

The HMDs provide an unrestricted and unlimited field of regard (total FOV) to the crewmembers. They can drastically reduce the physical dimensions of the training device and can reduce the overall cost of the training system. Despite these advantages there are some key issues, unique to the HMD, which have limited the acceptance of the devices for helicopter tactical training.

Characteristics that have affected the acceptance of the HMD for flight training are as follows:

- Head weight, comfort, and ease of wear
- Pupil size, tolerance, and ease of fit
- Eyeglass compatibility
- See-Through
- Latency and swimming of the image
- Distortion, resolution, and image artifacts
- Head tracking technology

Head weight, comfort, and ease of wear:

Since the user must wear the device, it must be comfortable to wear and not add significant weight beyond that of a normal flight helmet. Another critical element is locating the center of gravity as close to the center of the head as possible. Training missions may last several hours and the added weight may cause neck fatigue and soreness. Head weight is currently between 5.5 and 6.5 lbs

Pupil size, tolerance, and ease of fit:

The HMD optics are pupil forming and must be fit to the users eyes in order to view the visual scene. Mechanical adjustments must be provided and must include, as a minimum, inter-pupil distance and vertical position. Any slippage of the helmet fit can result in a loss of image. Larger pupils require less precision in locating the optics to the eyes. Pupil size is currently around 15 mm.

Eyeglass compatibility:

Eyeglass compatibility is essential for performing tasks inside the cockpit, such as reading instruments and maps. Crewmembers who normally wear eyeglasses need to wear them during training. To be compatible with eyeglasses, there must be a minimum space between the optics and pupil location (eye relief) of no less than 30 mm. Current generation HMDs provide an eye relief of 30 – 35 mm and are eyeglass compatible.

See-through:

Training in the flight simulator requires visibility of the cockpit interior, other crewmembers, and oneself. Simulations of these features are beyond the capability of current visual system technology. Fully emersive devices are therefore unacceptable. See-through can be provided by designing an optical combiner with beamsplitter mirror elements into the HMD. Use of the beamsplitter degrades brightness but allows a clear view through the device. See-through is the measure of transparency through the HMD optics. Performance varies by HMD design.

Latency and swimming of the image:

Latency is more of an issue with HMD devices than with fixed displays. Since it takes a finite amount of time to render the visual scene, it is not possible to know exactly where the optics will be pointing at the time it is displayed to the viewer. This can result in visual scenes that appear to lag behind the head movement. This can cause exaggerated head movements, the appearance of swimming, and even nausea. At a minimum, the visual system must operate at a 60 Hz update rate or latency will be unacceptable for training. Delays in processing the head tracking information should be minimized.

Prediction software can reduce the appearance of swimming, especially for gradual head motions, but is not as effective for fast head direction changes that can be expected during helicopter tactical training. Reducing the total latency would be the best solution to this problem.

Distortion, resolution, and image artifacts:

Image source for the HMDs are currently AMLCD and CRT. Resolution is currently only available in XGA (1024 x 768) formats using the AMLCD's. Current AMLCD technology may exhibit motion artifacts, observed as a "smearing" effect, which degrades the resolution of dynamic scenes. CRT based devices can run at higher resolutions and do not exhibit the degraded dynamic resolution. The CRT image can also be shaped to cancel distortion in the optics, thus eliminating the need for it to be provided in the image generator. However, the CRT source tends to result in a heavier device. A comparison summary is provided in Table 4

Table 4 - **Comparison of HMD Image Sources**

AMLCD Source	CRT Source
• *Lighter Weight*	• *Higher Resolution*
• *Eliminates HV near head*	• *Distortion Correction*
• *Potential Image Artifacts*	

Table 5 - **Summary of Current Helmet Mounted Display Performance**	
Characteristic	**Performance**
Instantaneous FOV	100°H x 50°V
Field of Regard	Unlimited
Image Overlap	26° to 30°
See Through	20% to 30%
Eyeglass Compatible	Yes
Image Source	AMLCD / CRT
Resolution	Up to SXGA
Brightness	7.5 to 20 ft.-L
Pupil Size	15 mm
Weight	5.5 – 6.5 lbs

Head Tracking Technology:

The visual system must know the precise location and orientation of the HMD within the cockpit in order to accurately render a correct visual scene to the student. Various head tracking technologies are available including magnetic, inertial, acoustic, and optical. Many head trackers combine multiple technologies to form hybrid systems. Devices must be capable of operation at a minimum of 60 Hz, with minimum latency, high accuracy and stability, over the range of motion encountered in the cockpit, and with minimum weight added to the helmet.

ADDITIONAL DISPLAY SYSTEM CONSIDERATIONS

Overall impact to the training system must also be considered. Some factors have already been discussed, such as numbers of channels from the visual system, total physical size required by the training system, and motion system compatibility. Other factors include deploy-ability of the trainer, ease of supporting reconfigurable cockpits, and overall cost impact to the training system.

The small size of an HMD makes it uniquely suited to support deployable flight trainers. Several trainers can be located within a small room, on-board a ship, or in a trailer. Elimination of the need for a large facility also reduces the total cost of the training system.

Aspects of the aircraft configuration, including window visibility, interior can be simulated by the visual system and provided through the HMD. These models can be reconfigured to simulate different aircraft. This reduces the cost and complexity for a high fidelity reconfigurable cockpit.

HMDs are currently in use in the US Army's Aviation Combined Arms Tactical Trainer (AVCATT) and Battlespace Integrated Concept Emulation Program (BICEP) programs. These programs utilize HMDs in deploy-able, reconfigurable, configurations.

CONCLUSIONS

All of the display systems can be effective for training and each display provides unique advantages. The dome display can provide an extremely large field of view. The continuous mirror display can provide scenes in true perspective for multiple viewers sharing a single cockpit. The flat panel mosaic can provide both these features if separation of crewmembers into multiple trainers is acceptable. And the helmet-mounted display extends field of view, provides true perspective to multiple viewers sharing a cockpit, and requires very little space.

There is no single visual display solution that can support all of the training tasks needed for tactical helicopter flight training without some tradeoffs. The choice must be evaluated on a case-by-case basis, based upon the highest priority objectives for training, cost of the trainer, and other considerations. No single solution can meet all of the requirements.

Helmet-mounted displays are emerging as an acceptable solution for the display system. Trends toward forward deployment and reconfiguration, along with lighter weight and higher resolution devices, should lead to continued growth of HMDs in training devices.

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