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ADVANTAGES OF USING A PROJECTED HEAD-UP DISPLAY IN A FLIGHT SIMULATOR

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When viewing a real planar image through an aircraft head-up display (HUD) focused for "infinity," diplopia and other related problems render the HUD useless as a training device. Future flight simulator visual displays are being developed with real planar image projections; therefore, this problem must be resolved. Past research into decollimating aircraft HUDs for real planar visual displays presented several solutions, but major side effects limited the tasks that could be trained with a decollimated HUD. Recent advances in projector and graphics technology have made projecting a real planar HUD an attractive solution. Projected HUD technology at Armstrong Laboratory, Aircrew Training Research Division, Williams AFB, Arizona is described. The advantages of using a projected HUD were investigated and are discussed. Advantages of using projected HUDs in simulators with a real planar visual display are numerous. Projected HUDs are lower cost, produce an accurate HUD field of view, are easily maintained, and are flexible. Projected HUDs are undoubtedly a technology for tomorrow.

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PREFACE

This investigation contributes to the development of cost-effective flight simulation visual display technology. For a pilot to perform air-to-air, air-to-ground, and terrain-following fighter aircraft maneuvers in a flight simulator, it is mandatory that information presented via the head-up display (HUD) be seen singly and clearly against the computer generated out-of-the-cockpit visual scene. Specifically, effective combat mission training depends upon proper integration of HUD symbology and the simulator visual display. This investigation addresses this critical requirement for development of a cost effective, high fidelity visual display system.

I wish to thank Dr. Harry Warner of the University of Dayton Research Institute, Mr. Gale Reining of General Electric Government Services, and Mr. Todd Baruch of Armstrong Laboratory for their assistance in preparing this report. I would also like to acknowledge the General Electric engineering support team for their expertise in developing the HUD projection system described herein.

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ADVANTAGES OF USING A PROJECTED HEAD-UP DISPLAY IN A FLIGHT SIMULATOR

SUMMARY

To develop wider, brighter, and less expensive flight simulator visual displays, engineers have developed domes and rear-projection systems for flight simulators that present real planar images. When collimated aircraft Head-Up Displays (HUDs) are used with planar displays, pilots experience severe doubling of HUD symbology and other related problems. To make these visual displays useful with HUD equipped aircraft simulations, this problem must be addressed and solved. Several simulations have used external decollimating lenses on aircraft HUDs, but major side effects (such as 12% shrinkage of the HUD field of view (FOV)) make certain tasks impossible. At Armstrong Laboratory, Aircrew Training Research Division (AL/HRA), Williams AFB, Arizona, General Electric has developed a projected HUD that will function with dome displays, rear-projection displays, and "infinity" optics. The projected HUD has two major components: a HUD symbology generation system and a projector. An alignment procedure is used to ensure mapping between the visual system and the HUD symbology. Using a projected HUD in a flight simulator can offer many advantages. Projected HUDs can be mapped to ensure accurate HUD FOV and placement. As long as HUD symbology is accurate, the ability to correctly map a projected HUD with the visual improves the capability of the simulator to perform tasks with similar fidelity as the aircraft. A projected HUD is approximately one-fifth the cost of using aircraft components. Projected HUD systems use commercially available, nonproprietary, low-cost parts making maintenance and spares inventory an affordable and straightforward task. Considering the problems and costs associated with using aircraft HUDs in a flight simulator, projected HUDs are undoubtedly a technology for tomorrow.

INTRODUCTION

To "blend in" the pilot's view of the world on actual real-life missions, head-up displays (HUDs) were designed with "infinity" optics. That is, HUDs were so designed that their images would appear to originate at "infinity." Light from HUD symbology appears to come from a great distance away and is collimated; i.e., the light rays are practically parallel. Thus, when pilots fixate on a target through the HUD in the real world, all the information they need is presented by the HUD without the pilots having to shift their gaze and change their visual accommodation (deGroot & Peppler, 1986).

Recently, simulators with "infinity" windows were used so there would be no conflict with HUD imagery. But simulators with "infinity" windows are dim, can be expensive, and present a small field of view (FOV) when used singly (usually the straightahead scene). To develop wider, brighter, and less expensive displays, engineers have developed domes and rear-projection displays for flight simulators. However, these displays present real planar images.[1] When collimated HUDs are used with planar displays, pilots experience severe doubling of HUD symbology and other related problems (deGroot & Peppler, 1986).

Several simulations, including the F-16A limited-field-of-view (LFOV) dome simulator at AL/HRA, Williams AFB, Arizona, have used external decollimating lenses mounted on top of the exit lens of the HUD display unit to diverge the HUD symbology so that it appears to fall on the surface of the dome. That is, light from the HUD is focused so that it appears to match the distance between the pilot's eyepoint and the dome surface. The lens is inexpensive and cures the double imaging, but it has one major side effect. For a 7.3-m (24-ft) dome application, the external lens causes a 12% shrinkage of the HUD's FOV. Internal adjustments to the gain potentiometers in the HUD display unit decreased the shrinkage some, but pilots found the shrunken FOV made certain F-16A HUD tasks such as high angle-of-attack (AOA), instrument landing system (ILS) approaches difficult if not impossible. Smaller domes would produce even greater HUD FOV shrinkage. Clearly, an approach that provides real HUD symbology without shrinking the FOV would be beneficial.

THE TECHNOLOGY

At AL/HRA, General Electric has developed a projected HUD that will function with dome displays, rear-projection displays, and "infinity" optics. The projected HUD is operational in the Display for Advanced Research and Training (DART), a rear-projection, full FOV, flight simulator display system. The DART projects a real image. HUD symbology for an F-16C aircraft is rear projected onto the front window of the DART display. The symbology appears to overlay the out-the-window visual scene (Fig. 1). An alignment procedure is used to ensure mapping between the visual system and the HUD symbology. Future plans are to use the projected HUD in AL/HRA's full-field-of-view (FFOV) dome and fiber-optic helmet-mounted display (FOHMD). The projected HUD has two major components: a HUD symbology generation system and a projector.

The HUD symbology generation system is an I/O Incorporated graphics board set. AL/HRA has previously used these Versabus Modified for Eurocard (VME) bus-based graphics boards in various part-task trainers. The HUD symbology for an F-16C aircraft is programmed into the graphics system. Navigation and air-to-air weapon delivery capability is available. Avionics data driving the HUD symbology is calculated in the avionics simulation software and sent to the symbology generation system in the same 1,553 bus format used in the aircraft. The same data could drive an aircraft HUD if required. This format allows the projected HUD and an aircraft HUD to be quickly interchangeable. The HUD symbology generation system outputs a 1,023 x 1,023 line interlaced image at 30-Hz frame rate to the projector.

[1]A real image occurs when the rays of light from an object actually converge to form an image that can be seen on a screen from which rays of light appear to diverge.

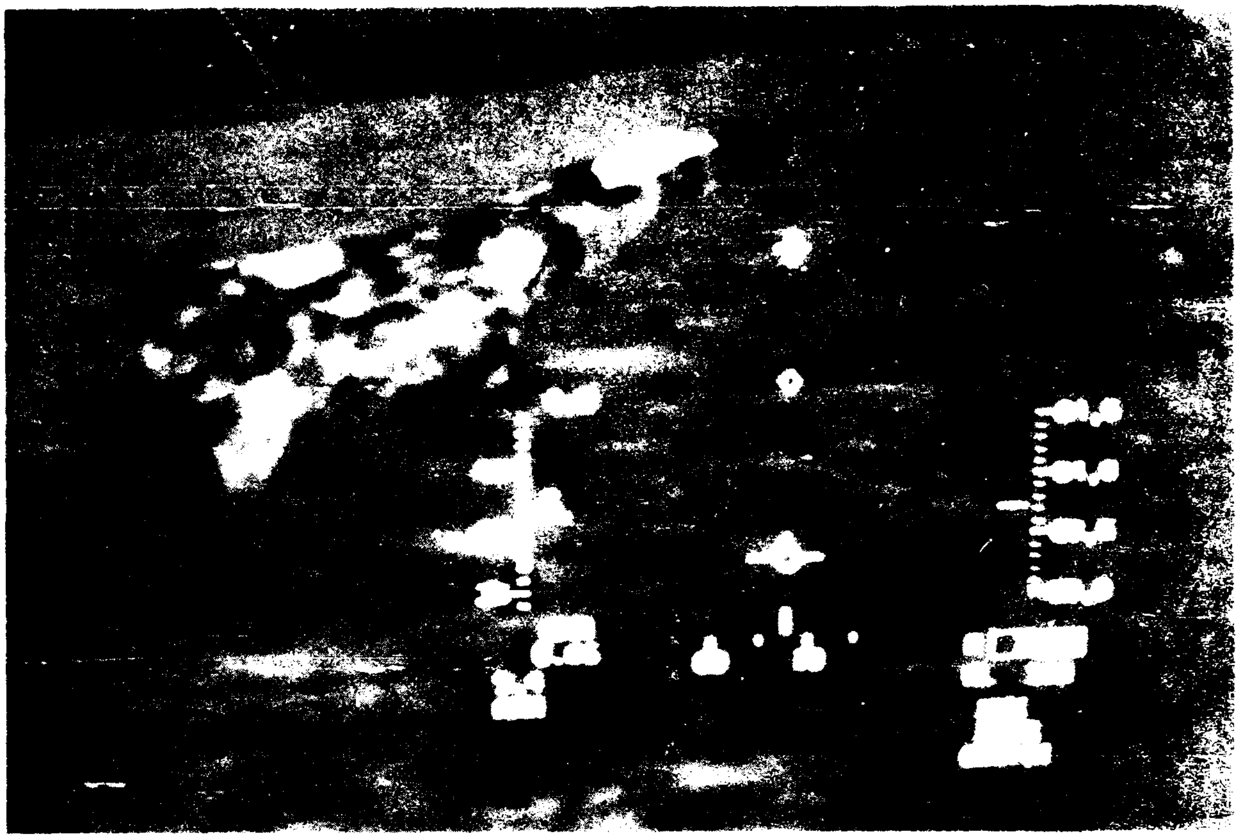

Figure 1
HUD Symbology in the DART

Pilot inputs to the avionics simulation software are made through an inte[illegible] control panel (ICP) similar to the panel located on the aircraft HUD. The [illegible] is located in the simulator cockpit at the exact location as the one [illegible] F-16C aircraft. The ICP was fabricated locally. The panel looks, a[illegible] feels like the aircraft ICP.

When General Electric engineers began designing the projection sys[illegible] the HUD, they had to determine the FOV and image resolution requ[illegible] for the projector. AL/HRA has had both F-16A and F-16C simulations [illegible] Low Altitude Navigation Targeting Infrared for Night (LANTIRN) capab[illegible] projector was needed that could project HUD symbology over the tot[illegible] for any of these configurations. The F-16A HUD has a 21 total FO[illegible]

[illegible]

F-16C, a 25° total FOV, and the LANTIRN HUD, a 30° total FOV. Therefore, the projector had to have the capability to project an image with a total FOV of as much as 30°. Desired resolution for the HUD symbology was established at 1.5 arcminutes.[3] The projector also had to display the 1,023 x 1,023 line rate coming from the symbology generation system.

With the requirements for the projector established, General Electric chose to procure a Macro Data Incorporated 36 (Macro Data 36) projector. The Macro Data 36 is a portable, monochrome, auto-lock computer projector designed to project a high contrast image from a personal computer/terminal to a curved high gain, flat, or rear screen. The projector displays monochrome (green image) from most standard video outputs. The auto-lock circuitry searches for horizontal and vertical sync signals in the 13 kHz to 36+ kHz frequency range horizontal and 45 Hz to 85+ Hz vertical. Brightness output is 300 Lumens.

The Macro Data 36 has easy-to-locate controls for tilt and leveling, brightness, contrast, keystone effect, horizontal size, vertical size, center focus, top/bottom alignment, and electronic focus.

For rear-screen projection the scan can be reversed on the projector. Inside the projector there are two yoke scan jacks. One jack is for standard scan, the other for reverse scan. The desired scan pattern is selected by placing the yoke wires into the appropriate jack.

To install the HUD projector in the DART the Macro Data 36 projector was connected to the symbology generator and then placed behind the front screen (Fig. 2). Placing the projector in this location required that reverse scan be selected. The projector is placed approximately 1.2 m (4 ft) from the screen and below the mirror reflecting the out-the-cockpit visual scene. There is no conflict between the out-the-cockpit scene and the projected HUD.

It should be noted here that as long as a cockpit and its associated simulation has a HUD symbology generator compatible with the Macro Data 36 projector, the same projection setup in the DART could be used for that cockpit as well. This setup could be useful if quick change out of cockpits/simulators and visual displays is a priority.

To ensure correct mapping of the HUD symbology with the visual display an alignment procedure is required. First of all, a boresight alignment T must be modelled in the visual database (Fig. 3). This T is commanded on in the scene by setting a discrete variable at the simulator control station. An identical alignment T is modelled in the HUD symbology generation system and is commanded on in a similar manner as the visual alignment T. To begin

[3]An arcminute is a measurement of a visual angle, which is subtended at the eye by the viewed object. For visual angles less than 10° an arcminute equals (57.3) x (60) x L divided by D where L is the size of the object measured perpendicular to the line of sight, and D is the distance from the eye to the object; 57.3 and 60 are constants for angles less than 600 minutes.

alignment, both alignment Ts should be commanded on. Assuming the visual projectors are properly aligned, the HUD projector is then adjusted until the HUD alignment T exactly overlays the visual alignment T. Once this alignment is complete the HUD symbology should be mapped with the visual scene and everything should line up. The "pipper should overlay the target." This alignment procedure can be modified depending upon the application and capabilities of the simulators involved.

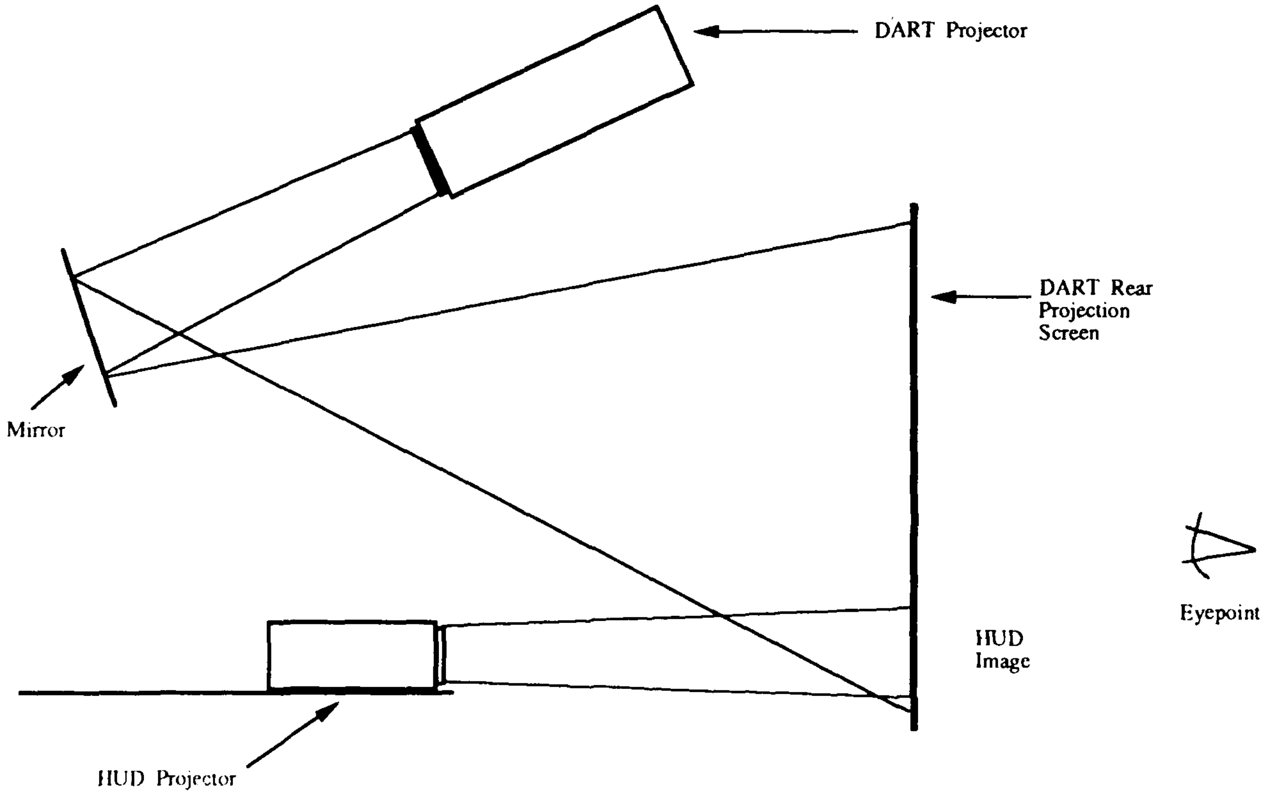

Figure 2
Schematic of Projected HUD in the DART

AL/HRA plans to install a HUD projection system in the FFOV dome. For this installation the same equipment will be used but the approach will be different (Fig. 4). The simulator will have a similar HUD symbology generator as the F-16 in the DART. Another Macro Data 36 or similar projector will be used. Because the projected HUD is on the surface of a 7.3-m (24-ft) diameter dome, standard scan will be set in the projector. Due to the nature of the visual projection system in the FFOV dome, the HUD projector will be mounted such that a reflecting mirror will direct the image onto the surface of the dome.

Because the distance from the dome to the reflecting mirror is greater than the distance between the projector and the rear-projection screen of the DART, the exit lens of the projector may have to be modified to obtain correct mapping and focus.

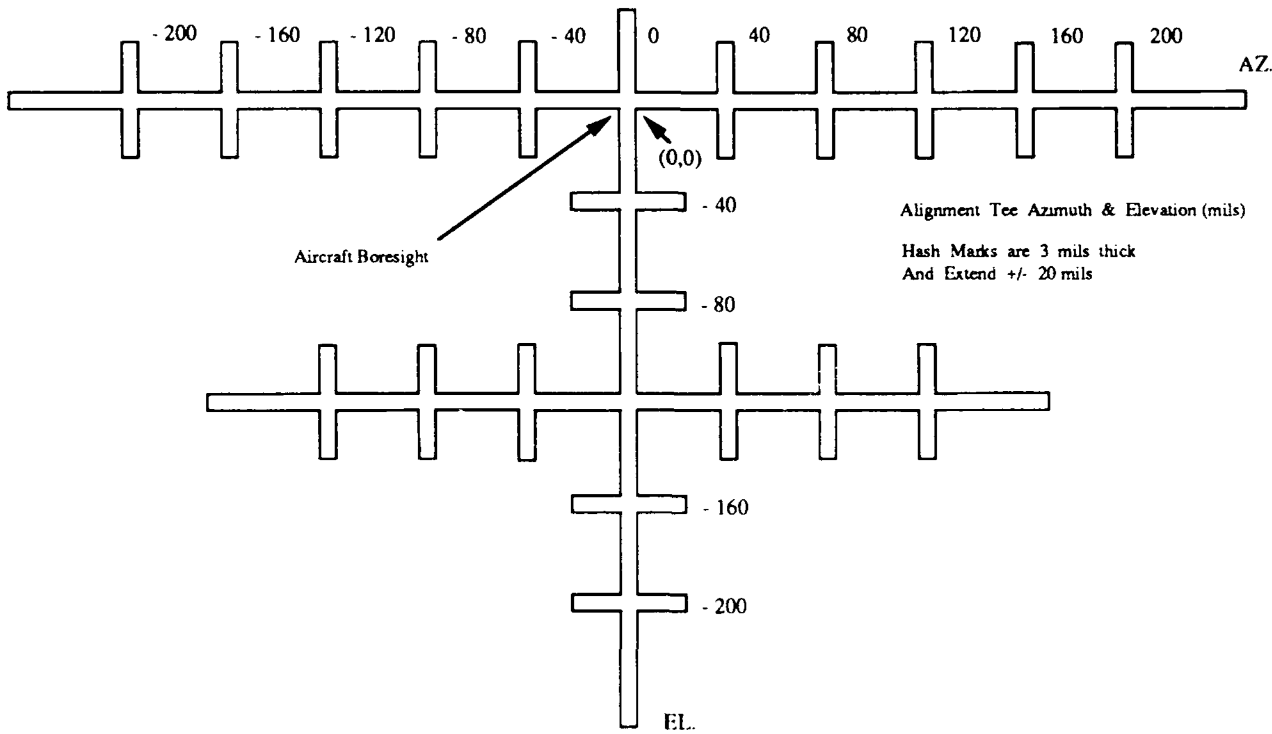

Figure 3
HUD and Visual Alignment T

The alignment process for the FFOV dome application will be similar to the one used for the DART. Depending on which cockpit/simulator is in the dome, some modifications to the alignment procedures may have to be made.

ADVANTAGES

Using a projected HUD in a flight simulator can offer many advantages over an aircraft HUD. Even though HUD symbology displayed on a cathode-ray tube (CRT) may have possible application with FOHMD "infinity" optics visual display systems, this report only addresses the advantages of using a projected HUD in simulators with visuals that project real planar images.

One significant advantage of using a projected HUD is its ability to produce an accurate HUD FOV. Aircraft HUDs decollimated for use with a real planar image experience a shrinkage in total FOV. This shrinkage has been determined to be 12% for a 7.3-m (24-ft) dome. Smaller domes would cause even greater shrinkage. This shrinkage can make tasks such as high AOA ILS approaches and high drag bomb deliveries unachievable (deGroot & Peppler, 1986).

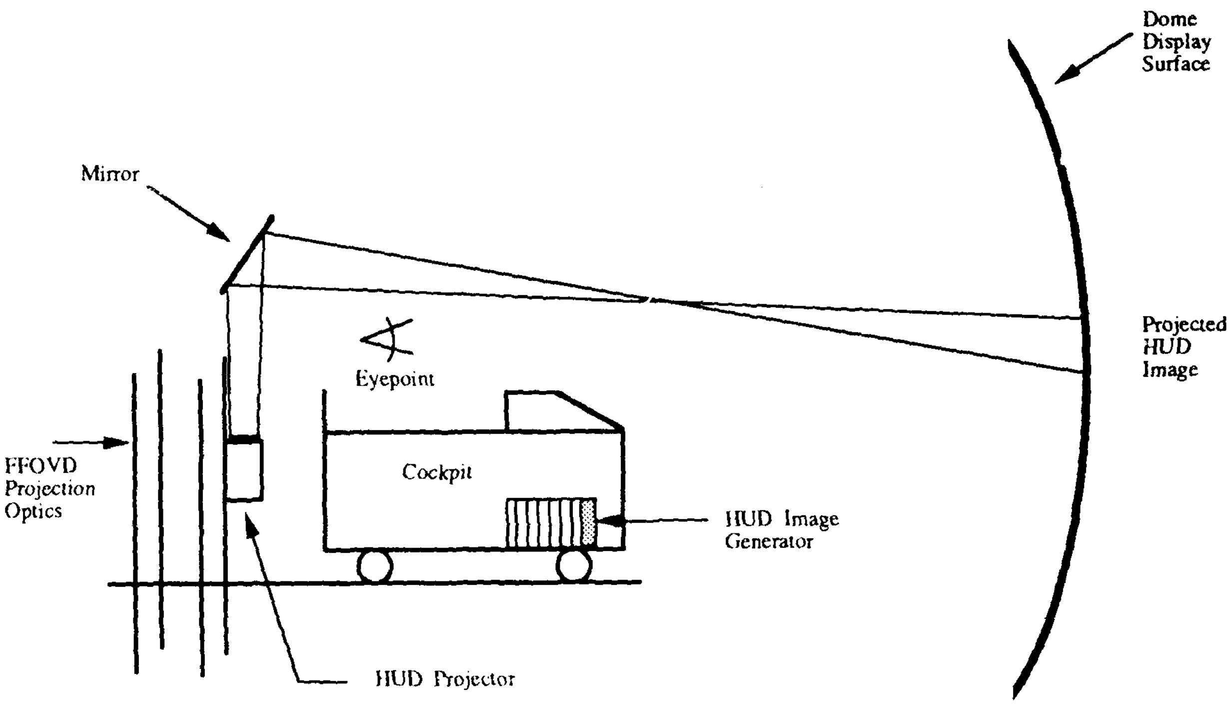

Figure 4
Schematic of Projected HUD in the FFOV Dome

Projected HUDs can be mapped to ensure accurate HUD FOV and placement. As long as HUD symbology is accurate (this can be verified through testing), the ability to correctly map a projected HUD with the visual improves the capability of the simulator to perform training tasks with similar fidelity as the aircraft.

When developing training devices, cost is always a major factor. When one evaluates the cost of procuring an aircraft HUD vs. a projected HUD, cost is clearly in favor of the projected HUD system (Table 1). A projected HUD is approximately one-fifth the cost of using aircraft components.

Table 1. Cost Comparison Aircraft HUD vs. Projected HUD

		Cost
Aircraft HUD		
F-16 HUD Pilot Display Unit (PDU)		$150,000
F-16 HUD Electronic Unit (EU)		$ 75,000
External Decollimating Lens		$ 5,000
	TOTAL	$230,000
Projected HUD		
HUD Symbology Generation System		
I/O Inc. Graphics Set		$ 12,000
HUD Symbology Graphics Software		$ 30,000
HUD Integrated Control Panel w/Cabling		$ 4,000
Micro Data HUD Projector		$ 3,000
	TOTAL	$ 49,000

Projected HUD systems are flexible. If designed properly, they are visual display and cockpit independent. That is, a projected HUD system can be used in a rear-projection visual display or, with adjustments, it can be used in a dome visual display. A projected HUD system can be used with various fidelity trainers, from part-task trainers to weapon system trainers and anything in between. A properly designed projected HUD system can satisfy the HUD requirements for various simulations (F-16, F-15, F-18, etc.).

Projected HUDs are useful for instructors who prefer looking over the shoulder of the trainee. Aircraft HUDs are focused to an eyepoint, making observance of the HUD impossible. With a projected HUD, the symbology overlays the visual scene so that both the trainee and instructor can see it.

Repairing aircraft HUDs can be difficult and time-consuming. Spares for aircraft HUDs are usually impossible to obtain. Therefore, when repairs are required, the simulator can be without a HUD for weeks. Projected HUD systems use commercially available, nonproprietary low cost parts making maintenance, spares inventory, and if necessary, replacement an affordable and straightforward task.

CONCLUSIONS

The advantages to using a projected HUD are obvious. With the push for higher fidelity, lower cost training devices in full swing, the projected HUD should help bolster that effort and should become a valuable tool in future developments. With the probability that future visual displays will be real planar projection systems, projected HUDs may find their place in production simulators as well.

It is probably too early to conclude that there are no disadvantages involved with projected HUDs. There may be some, such as the ability of the pilot to move his head out of the eyepoint and still see the projected HUD. There may be others. Hopefully, future use will uncover any disadvantages that may exist, but, the advantages gained by using a projected HUD cannot be overlooked.

Projected HUDs are lower cost; they produce an accurate HUD FOV; they are easily maintained; and they are flexible. If designed properly, they are visual display and cockpit independent. Considering the problems and costs associated with using aircraft HUDs in a flight simulator, projected HUDS are undoubtedly a technology for tomorrow.

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