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AVIATOR'S NIGHT VISION IMAGING SYSTEM HUD: AN ANALYSIS OF ITS APPLICATION TO NAVAL HELICOPTERS

16 October 1995

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SUMMARY

Combat Search and Rescue (CSAR) helicopter pilots routinely utilize Night Vision Goggles to enhance visual capabilities during night operations. The Aviator's Night Vision Imaging System (ANVIS) HUD, recently tested on the HH-60H Seahawk, provides the capability to display critical flight parameters to the pilots via goggle-mounted display units, thus minimizing head-down time in the cockpit. As more and more Naval helicopter missions diversify to include CSAR and CSAR support, devices which effectively enhance night mission performance should be made available to the mission pilots. This report describes the developmental testing results of the ANVIS HUD system and critically analyzes its advantages and limitations for use in Naval helicopters. In addition, ANVIS HUD symbology is examined from a human factors perspective with recommendations for symbology design and placement.

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INTRODUCTION

BACKGROUND

1. Since the early 1970's, NASA and corporate industry have been investigating the use of helmet mounted displays and HUD's in rotary wing aircraft. The Aviator's Night Vision Imaging System (ANVIS) HUD is a system wherein symbology is projected from an optical device which fits over one monocular lens of a pair of ANVIS-6 Night Vision Goggles (NVG's) to provide the pilot with real time critical flight parameters in a head-up fashion. Unlike HUD devices in fixed wing aircraft, the ANVIS HUD makes available the ability to look off axis while viewing the displayed symbology.

2. The AVS-7 ANVIS HUD, manufactured by Elbit, Ltd of Israel, was recently installed in an HH-60H helicopter at Patuxent River, Maryland, in October 1993, and was evaluated for use in the Combat Search and Rescue (CSAR) and Special Warfare Support (SWS) missions. Other military platforms utilizing or currently evaluating the system include: the Israeli AH-1 and CH-53; the USA UH-60, CH-47, and UH-1; and the USMC UH-1N, CH-53E, and CH-46E. This report describes the AVS-7 system, summarizes the engineering test results, and examines the use of ANVIS HUD's in Naval helicopters.

HH-60H DESCRIPTION

3. The HH-60H Seahawk, manufactured by Sikorsky Aircraft, is an extensively modified derivative of the SH-60F CV inner zone helicopter. Some of the major modifications to the SH-60F airframe include: removal of avionics and cabin mission equipment to provide room for cargo and personnel; installation of the Hover IR Suppression System and an NVG compatible cockpit; reconfiguration for Aircraft Survivability Equipment; incorporation of a port gunner's window in the cabin; and installation of a SATCOM radio system. The HH-60H aircraft avionics center around the AN/ASN-150 Tactical Data System, which is tied to a dual redundant MIL-STD-1553B data bus. The aircraft has a partially configured "glass cockpit" in that each pilot has a flat plate CRT display beneath the attitude indicators, which make available several possible displays, controllable by push keys. Additionally, system functions such as radio selection and tuning, navaid selection, navigation initialization, and fuel monitoring are accomplished via cockpit display units located on the center console.

HH-60H MISSION DESCRIPTION

4. The primary missions of the HH-60H are CSAR and SWS. In execution of these missions, the aircraft and crew must be capable of both unopposed and opposed low altitude insertion and extraction of Special Warfare Personnel and retrieval of downed aircrew. The mission requires operation in both the overwater and overland environment and is performed primarily at night using NVG's. Crews are subsequently trained to be proficient in low level terrain navigation, downed aircrew search techniques, formation flight, confined area landings, suppressive fire techniques, small deck shipboard landings, and precision night hovering both overwater and

overland. All of these flight regimes require significant head-out-of-cockpit time, and proficiency in the use of NVG's is considered essential to safe accomplishment of the mission.

AVS-7 DESCRIPTION

5. The AVS-7 ANVIS HUD is a sensory gathering system which takes analog and digital aircraft sensor information into a Signal Data Converter (SDC), converts it into symbology, and transmits the information into an optical combiner. The combiner, as part of a Display Unit (DU), is attached to either the left or right objective lens of a pair of ANVIS-6 NVG's, depending upon pilot preference. In this manner, the symbology is overlaid on the image provided by the NVG's and provides the pilot with a see-through central data display. The symbols in the display can vary in brightness from 0 to 0.51 fL, adjustable in 32 step increments. Four normal and four declutter display modes are available and independently programmable by each pilot. The display modes are defined by making selections from a master symbology menu.

6. The SDC is the central controller of the ANVIS HUD system and senses avionics information by sampling transducer voltage levels and monitoring information on the MIL-STD-1553B data bus. It then provides low voltage video and power outputs to the DU's, with a refresh rate of 50 Hz designed to minimize display flicker.

7. Each of the two DU's is comprised of an optical unit and a power supply and cable, which attach to the overhead above each pilot's shoulder. The optical unit consists of a 1/2 in. CRT housed with a miniature beam splitting lens which collimates the symbols from the CRT onto a 512 X 512 pixel array, which is projected onto the NVG objective lens via the combiner (mirror). The array occupies a square measuring 8.3 mm per side and is designed to produce a square image field subtending 24 deg per side (34 deg diagonal FOV).

8. Other components of the system include: the Converter Control Unit (CCU), which mounts in the cockpit and provides pilot control functions; the mode select/dimming switch, which is mounted on each collective control; and associated mounting trays and wiring. The SDC, CCU, and DU's are designed to be quickly removed for interoperability with other HH-60H aircraft. The prototype system for the HH-60H required approximately 3 weeks to install. The total system weight was approximately 25 lb with a weight of 450 g for the helmet mounted hardware.

RESULTS AND EVALUATION

SYMBOLOGY SET DESIGN CONSIDERATIONS

9. As was shown by Fischer, Price, and Haines, the mere presence of symbology in a flight display drags attention away from the environment (reference 1). "Cognitive capture" is one term used to describe this phenomenon which results in pilot fixation, especially on symbology which requires interpretation. On the other hand, certain symbology has been proven to significantly improve performance during specific mission tasks, such as visual tracking or maintaining a specific altitude or glide slope. This improved performance, however, usually occurs at the expense of reduced environmental cues, and it thus becomes evident, that in every specific mission scenario, a tradeoff between increased task performance and loss of environmental cuing must be considered. The HH-60H master symbology set is shown in figure 1.

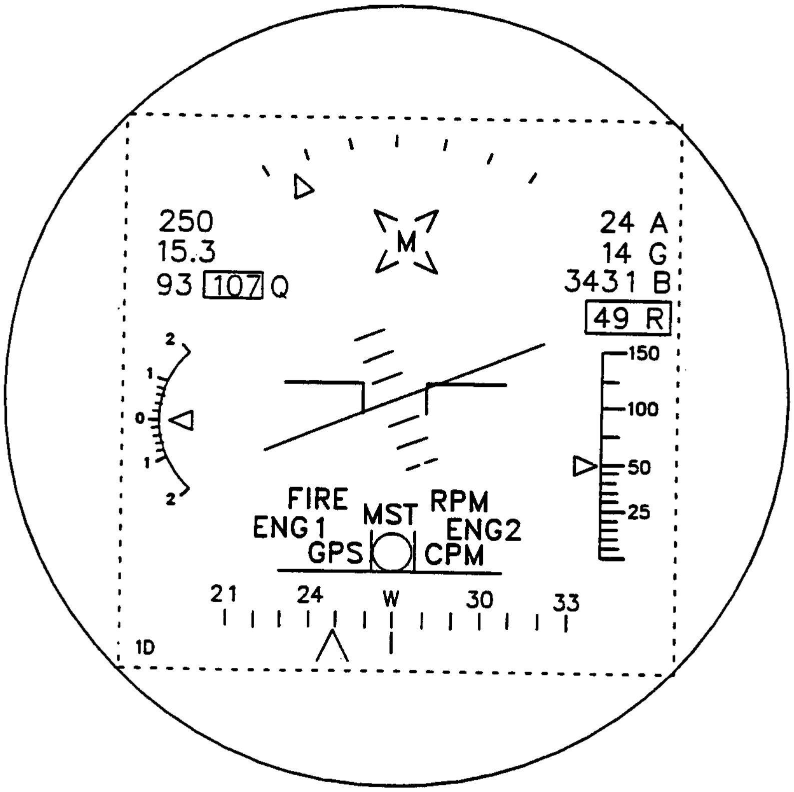

Figure 1
HH-60H MASTER MODE SYMBOLOGY

10. In the design and subsequent evaluation of the HH-60H symbology set, the following characteristics were considered imperative for enhanced mission performance:

a. Each symbol in the display must provide value. The area available in an already limited 34 deg diagonal FOV permits the display of only that information required to accomplish specific mission tasks. For this reason, information such as engine speed, oil temperatures and pressures, rotor speed, and fuel quantity, which are all necessary periodic scan indications, but are not necessarily normal scan items for mission maneuvers, were not included.

b. The information presented must be both timely and accurate. For this reason, only those flight parameters which could be sensed and displayed in real-time with a high degree of accuracy were considered for use in the symbology set. As shall be discussed later, digitized analog signals such as pitch and roll indications did not satisfactorily meet these criteria.

c. Symbols must be readable and not masked by other symbology. Results of the testing found that assigning a symbol to its own separate position in the display does not necessarily guarantee these characteristics. For example, stacked numerical digits often make it difficult to read each individual number.

d. Symbology, while not necessarily mimicking normal aircraft displays, should not be significantly different either. The mental conversion required in such circumstances is equivalent to time which could be better spent interpreting other bits of information.

e. The location of the symbology must be such that a minimal eye scan is required to locate necessary and related information during mission tasks. This characteristic was considered desirable in the initial planning stages and became glaringly evident during flight tests. High workload tasks which require monitoring of several flight parameters simultaneously quickly resulted in eye fatigue if the parameters were located at opposing corners of the display. Such findings have been frequently documented in oculomotor studies of the Apache Pilot's Night Vision System symbology.

LABORATORY TEST RESULTS

GENERAL

11. Approximately 85 hr of laboratory evaluation were conducted at the Lighting Lab and the Crew Systems Integration Lab at Patuxent River. The system optics, i.e., the 3-element combiner and the DU, were tested for transmissivity loss, magnification, and linear distortion. The results of the transmissivity tests are presented in figure 2 and are valid for both the upper and lower elements of the combiner and for the center element, which supports the reflective mirror used to direct symbology into the NVG objective lens. In all cases, transmissivity was greater than 92% of that available with the objective lens alone. Linear distortion and magnification effects were negligible (<1%).

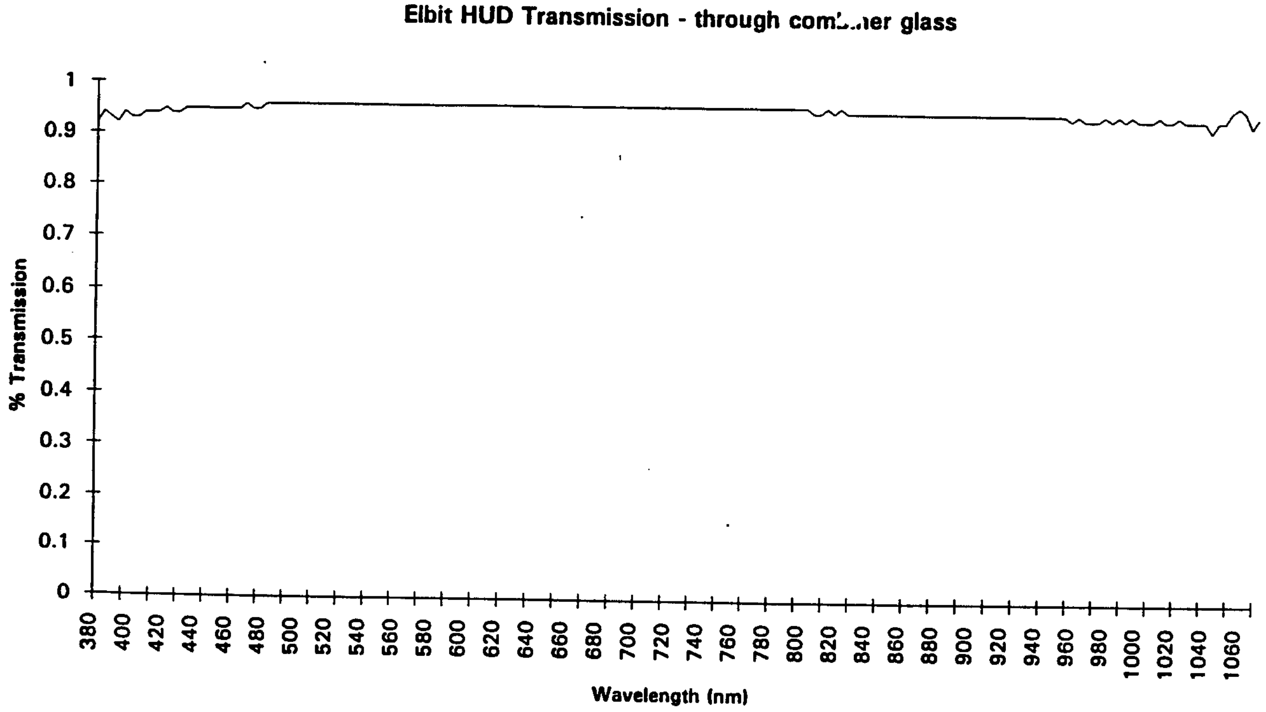

Figure 2
HUD TRANSMISSIVITY

GAIN AND RESOLUTION

12. Gain and resolution, considered to be the most important performance parameters of the optical system, were evaluated at luminance levels from 1.0E-6 fL (well below complete overcast) to 2.0E-3 fL (above clear night full moon levels). The HUD brightness level was set at 50% (.25 fL) for the resolution tests and was not energized during gain tests due to lack of a meaningful procedure. It was noted, however, that although operationally unlikely, increasing the HUD to full brightness (.51 fL) produced a veiling glare on the display which would have adversely affected the gain under most ambient conditions.

13. System gain was measured using a test set which consisted of an integrating sphere, a low light level 10 W lamp source, silicon detectors, and a photodiode probe detector. The results are shown in figure 3 and show an average loss in gain of 10% across the ambient operating range with brightness gain better with the HUD above 4.0E-04 fL. System resolution was evaluated by producing collimated images of target test reticles and measuring subsequent Night Vision Device (NVD) resolution for various luminance levels. The results are presented in figure 4 and also show an approximate average decrease of 10% across the ambient operating range, with the data becoming approximately constant above 4.0E-04 fL. As expected, and shown, the gain decreased and the resolution increased as luminance levels were increased, with the gain being approximately constant below 4.0E-04 fL. Attaching the HUD and energizing it (for resolution tests only) slightly decreased the performance of the optics in both regards. As shown, the decrease in gain was primarily at low luminance levels and the decrease in resolution was primarily at high luminance levels, with the decrease in both being small. It should be noted, at this point, that a decrease in gain without an accompanying decrease in resolution is operationally insignificant, especially for the small decreases seen

during the tests. The decrease in resolution could, however, be significant when using NVG's with very marginal optical performance. In this case, the HUD should be placed on the monocular with the best optical characteristics or at the least, the monocular with the sharpest focus.

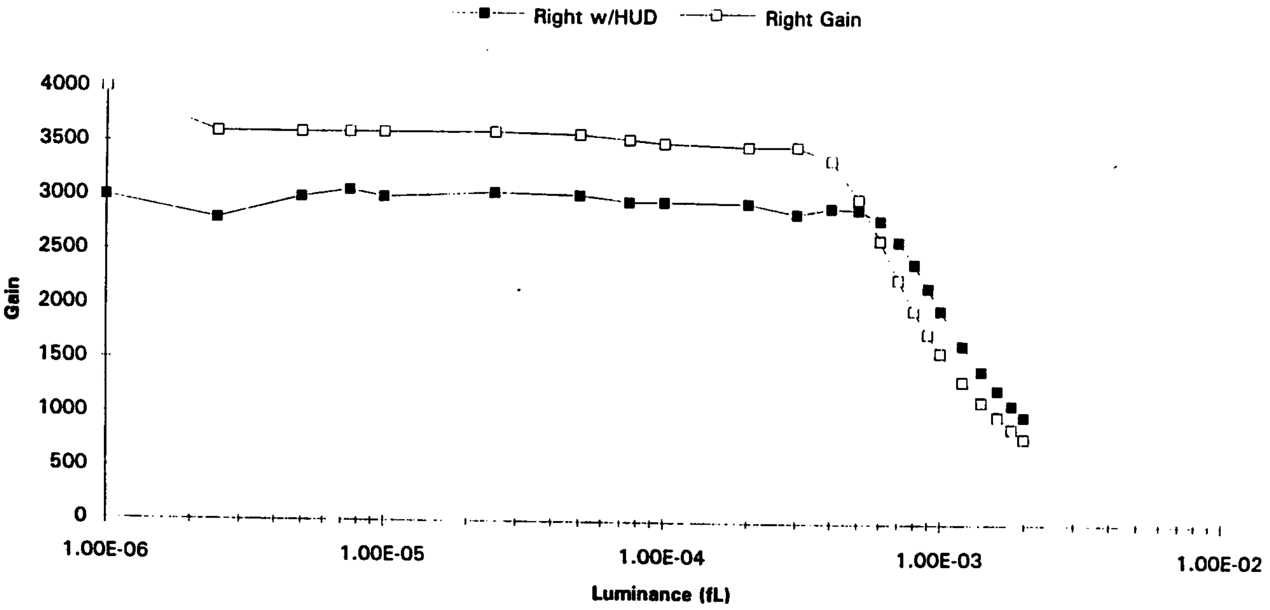

Figure 3
GAIN COMPARISON WITH AND WITHOUT HUD

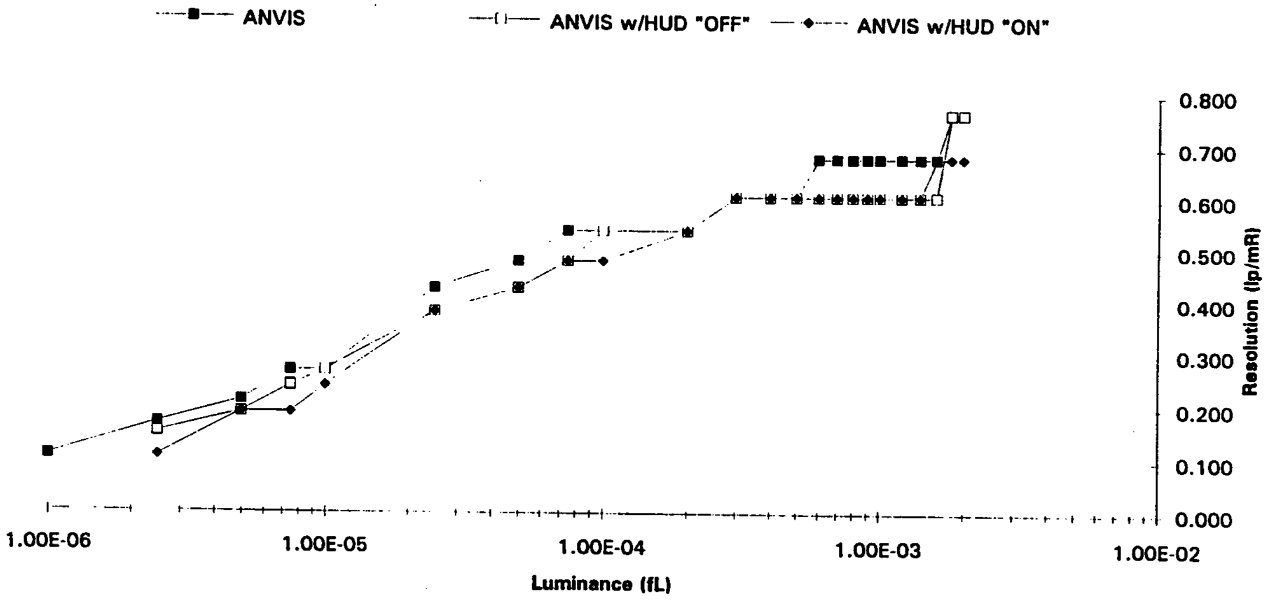

Figure 4
HUD RESOLUTION COMPARISON

FOV AND SYMBOL PLACEMENT

14. Problems with the symbology set being clipped were first identified during ground and flight tests and later confirmed in the laboratory. Approximately half of the 12 pilots who initially viewed the symbology set experienced clipping at one or more of the display corners when using the HUD with Omni II 18 mm eye relief ANVIS-6 NVG's. Laboratory tests confirmed that even at the design eye relief of 18 mm, some of the symbology was clipped, with severe clipping occurring at 20 mm or greater. The problem is illustrated in figure 5. An analogy can be made to viewing an object through a peep hole in a wall: the closer the eye to the hole, the closer the viewer approaches the maximum obtainable FOV and hence the more of the object that is visible. Like the object seen through the peep hole, the superimposed symbology image does not change in size, but can be viewed more entirely by bringing the eye closer to the lens. By comparison, the entire symbol set was visible out to 29 mm when using Omni III 25 mm eye relief NVG's. This measurement was subsequently confirmed during ground and flight tests. A portion of the user population with deep eye sockets, protruding foreheads, and those who use eyeglasses must be made aware of this characteristic of the system and of the ANVIS in general. In practice, many users will not be able to adjust the NVG eyepieces to 18 mm or less due to these facial features and/or normal helmet fit and liner configuration. The result can be a significant loss of FOV (reference 2) and subsequent HUD symbology clipping.

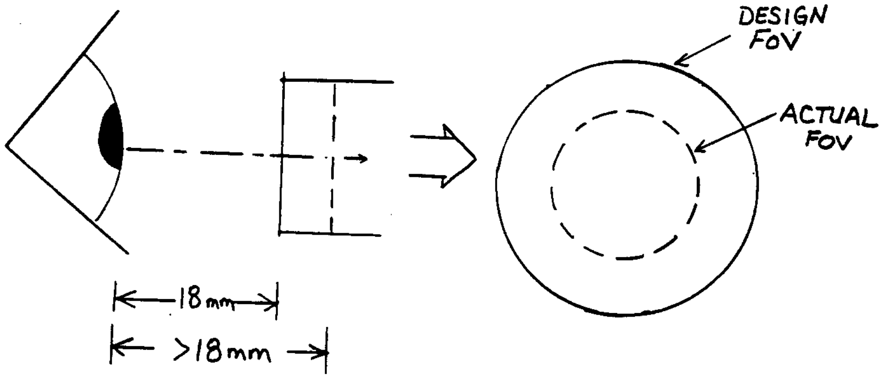

Figure 5
EYE RELIEF VERSUS FOV

15. In addition to eye relief considerations, the normal NVG FOV can be decreased when one or both of the monoculars are not centered in front of the eyes. When using standard NVG's, the monoculars are set using one adjuster for Interpupillary Distance (IPD). Because the majority of users do not have eyes which are perfectly symmetric about the face centerline, one of the monoculars will not be exactly centered in front of an eye, figure 6. The FOV for that eye will be less than the 40 deg available, and if this also happens to be the eye selected for HUD use, symbology clipping is likely to occur. NVG's incorporating monoculars that can be individually adjusted should alleviate this problem, but until these are available, effort should be made to exactly center the monocular being used with the HUD.

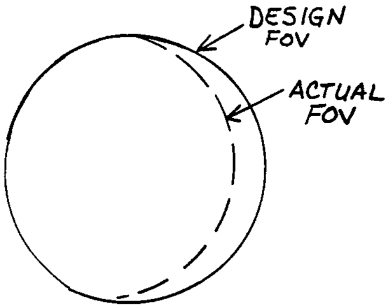

Figure 6
DISTORTION DUE TO IPD

16. For the reasons noted in the preceding paragraphs, symbol placement should be, as much as possible, away from the corners of the display. This effectively reduces the area available for placing symbology, but eliminates the clipping that will make that symbology useless for a significant number of users. With procurement of Omni III NVG's and NVG's which incorporate individually adjustable monoculars, this problem will be alleviated.

FLIGHT TESTS

GENERAL

17. The ANVIS HUD was evaluated during approximately 50 hr of in-flight tests under ambient conditions ranging from below starlight illumination levels (overcast, 0% moon) to clear night, full moon illumination levels. The ANVIS HUD and NVG's were mounted on SPH-3C helmets with standard ANVIS-6 attachments. Specific mission tasks with clearly defined tolerances were conducted with and without the HUD to include: low work (hovering turns, slides, slopes); confined area landings; terrain following (TERF) and nap-of-the-earth (NOE) flight; unusual attitude recoveries; quick stop and SEAL team insertion maneuvers; overwater SAR and CSAR operations; threat avoidance maneuvers; and simulated shipboard operations using an elevated fixed platform (EFP) patterned after an FFG-7 class ship. In addition to comparison of the tasks with and without the HUD, four different symbology modes, with associated declutter modes, were assessed for optimum use during the maneuvers. The evaluation modes were chosen as follows: Mode 1 as a "full-up" mode; Mode 2 as an "open center" mode; Mode 3 as an "open top and bottom" mode; and Mode 4 as a "minimum display" mode. In all cases, the declutter display for each mode was programmed to provide additional information such as bearing/distance to a waypoint, airspeed, barometric altitude, and attitude reference lines. In this regard, the declutter modes could more accurately be called alternate display modes.

18. In general, the use of the ANVIS HUD during all flight regimes either aided or did not significantly change the pilot's ability to perform mission tasks. To initially determine this, one pilot completed the tasks entirely using an outside scan, while a safety pilot monitored the normal in-cockpit gauges. During the course of the evaluation, several deficiencies were discovered and corrected through hardware and software modifications. The following paragraphs will concentrate on those characteristics deemed enhancing and those deficiencies which are still outstanding and warrant technical consideration.

ENHANCING CHARACTERISTICS

19. The ability to receive correct critical flight information in a head-up manner is, in itself, an enhancing characteristic of the system and significantly improves situational awareness during flight maneuvers. Because most of the displayed information was obtained from the data bus, only one indication, the torque display, was found to be in error, and this was easily corrected by using proper signal conditioning. All information necessary for accomplishment of the assigned flight maneuvers was available in the selectable master symbology menu. Threat location information was evaluated as particularly useful in HUD's for safely and quickly accomplishing threat avoidance maneuvers.

20. In addition, the ability to independently brighten/dim the displayed symbology and/or change symbology modes using the four-position switch on the collective was considered a very enhancing feature of the system. This feature is notably useful when transitioning from an in-flight regime to a landing regime where a different symbology mode is desired. The dimming feature can also be used during landing, or in flight, as ambient light levels change.

SYSTEM DEFICIENCIES

21. During ANVIS HUD flight tests, the AVS-7 pitch ladder and AOB indicator were found to lag behind the aircraft's attitude indicator by as much as 2 sec. After the lag, the HUD presented correct information and precise tasks were possible; however, the initial difference in displayed information and actual aircraft attitude was very distracting during pitch-up maneuvers or quick rolls and required a momentary scan inside the cockpit. Tests were conducted with adjustable time constants which isolated the lag as a system problem and not correctable through the aircraft software. In general, adjustable aircraft software time constants were used to optimize all analog data presentations on the display, but the pitch ladder and AOB information will require system software modifications which were not feasible during developmental testing.

22. Another problem associated with the system involved the low level box around the HUD-displayed digital radar altitude reading, which continued to flash, even when the aircraft's weight-on-wheels switch was activated. In general, flashing light sources on the display will provoke an immediate response to warnings or cautions, except when constant exposure to the steadily flashing light desensitizes the pilot's signal recognition, such as in this case. This desensitizing will under some circumstances result in a delayed reaction or no reaction to the low level warning box, which is one of the most important symbols in the display. Programming the signal to adequately mirror the aircraft low level indicator will alleviate this problem and should be incorporated in the next system modification.

HUMAN FACTORS RESULTS

SYSTEM OPTIMIZATION

23. Several techniques for use of the symbology and system features were discovered during flight tests and are listed below to aid the operator in optimizing the system's capabilities.

a. During simulated SAR operations, the pilot not at the controls was able to use the ANVIS HUD to accomplish both an outside search and monitor critical flight parameters as a backup to the flying pilot.

b. For overland low work, a minimum amount of symbology should be utilized. Torque, radar altitude, groundspeed, and ball indications were considered optimal. Also, the display should be kept as dim as possible for minimize distraction away from environmental cues. When utilized with more than the minimal display or with the symbology turned up very bright, most users became fixated on impertinent information at the expense of critical scan items such as descent rate. In this regard, improper use of the symbology was considered a hindrance to the safe conduct of low altitude maneuvers.

c. When changing display modes or adjusting brightness levels, the collective mode select/dimming switch should be used to the maximum extent possible due to the limited accessibility of the CCU while flying and because it is difficult for the nonflying pilot to adjust a display that only the other pilot sees. The collective switch was used extensively during approaches to confined area landings to facilitate changing the display mode (for minimum symbology) and to progressively dim the display as the aircraft neared the ground or other obstacles.

d. Utilization of the system's horizon line and heading tape is beneficial during overwater hovering; however, reference to the aircraft's Doppler hover indication is still required for precise positioning.

e. During shipboard takeoffs at the EFP, performance was optimized by setting the nose attitude using the HUD pitch ladder and pulling in required torque as viewed on the display. In this manner, proper use of the ANVIS HUD can greatly improve situational awareness during at-sea operations.

f. The sideslip indicator (ball) provides a substitute "wings level" indicator which does not clutter the center of the display, as well as an excellent out-of-trim indicator, and should be considered for use during all flight regimes and with all display modes.

PHASE II UPGRADE

24. During the course of evaluation, several characteristics of the display were assessed as warranting improvement in the next phase upgrade of the system. Most of these characteristics have already been discussed in previous paragraphs, but are summarized below, with a suggested phase upgrade symbology set shown in figure 7.

a. Stacked numerical displays do not allow readability of individual numbers when the entire stack is displayed. For this reason, the four-stack of altitudes and airspeeds in the upper right corner should be separated, possibly as shown in figure 7.

b. A minimal eye scan is desired to reduce eye fatigue during high workload maneuvers where several parameters must be monitored. For instance, during an overwater approach to hover, the following parameters must be scanned: groundspeed, radar altitude, compass heading, vertical velocity, drift, torque, and pitch attitude. For this reason, the torque and groundspeed indications should be moved lower on the display.

c. To reduce clutter at the horizon level, with no significant loss in information, average torque should be displayed instead of both engine torques. Displaying both engine torques side by side causes the second torque indication to protrude into the left center of the display which is quite annoying. Stacking of the torque indications on the display would be different enough from the actual cockpit indications to be distracting and would probably result in delayed interpretation of the information.

d. In a survey of over 15 pilots who flew with the ANVIS HUD, it was discovered that the analog radar altitude tape was almost never scanned during mission maneuvers, either due to readability of the tape or because other indications such as the Vertical Situation Indicator and digital radar altitude proved sufficient. Because of this, it is suggested that the analog radar altitude tape be removed to allow better spacing of other symbology or redesigned for easier incorporation into the pilot's scan.

e. If at all possible, the system should be upgraded to include a two-axis Doppler velocity indication patterned after the aircraft's hover display. This would allow pilots to hover overwater in a completely head-up fashion.

f. In evaluating future upgrades of the system, trained test pilots and several line pilots should both be used to obtain a cross section of user experience levels. Symbology design should take into account user opinion but, in general, should utilize task performance as the key discriminator. Pilot opinion varies widely among individuals and has often been considered prone to preset notions and difficult to standardize (reference 3).

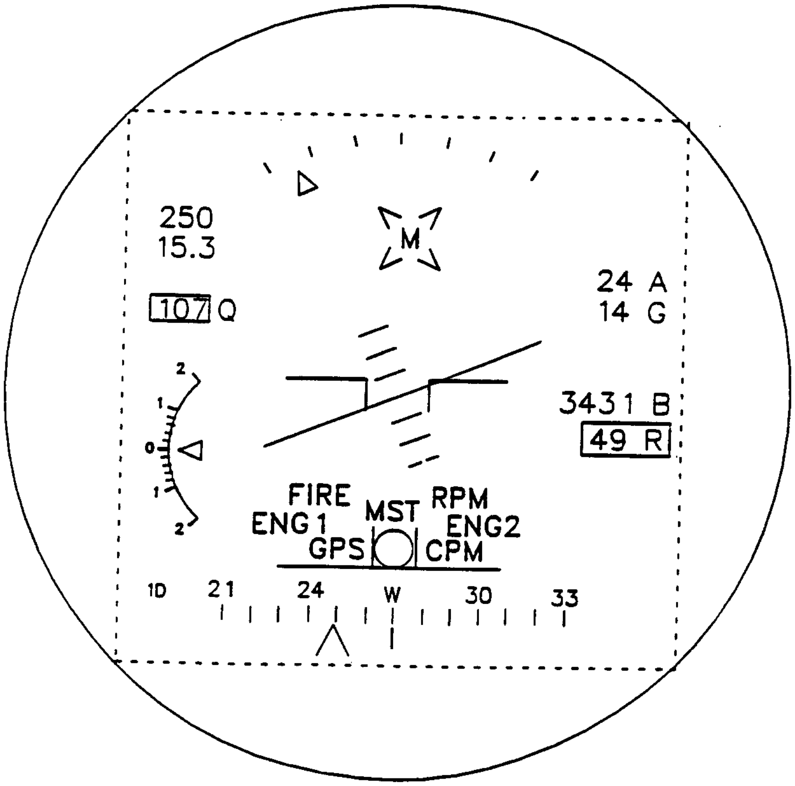

Figure 7
SUGGESTED SYMBOLOGY UPGRADE

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CONCLUSIONS

25. The ANVIS HUD is an excellent system for facilitation of the CSAR and SWS missions, in that, when used properly, it improves situational awareness in nearly all flight regimes, particularly those in the low altitude environment. It also decreases workload and improves crew coordination by allowing the pilot not at the controls to scan the horizon for downed aircrew and hostile threats or obstacles, while maintaining a backup scan of critical flight parameters.

26. The ANVIS HUD cannot, and should not be used to, facilitate decreased altitudes or increased airspeeds during low level, TERF, or NOE flight. It does not increase the pilot/ANVIS's ability to see at night and, in general, tends to slightly degrade optical performance of the NVG's. When used improperly, the ANVIS HUD may detract the user from pertinent environmental cuing. In this regard, proper utilization of display modes and dimming techniques are crucial to safe operation of the system.

27. Finally, as more and more Naval helicopter missions diversify to include CSAR and SWS, utilization of NVD's will be crucial to safe task accomplishment. Despite its limitations, the ANVIS HUD significantly enhances mission performance in this regard and, as such, should be made available to mission pilots.

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The following individuals contributed significantly to the results discussed in this report: Mr. Jim Tober, NAWCAD Patuxent River Human Factors Engineer; Mr. Chris Grable, NAWCAD Patuxent River Optics Engineer; and LCDR Kevin Kenney, USN, Engineering Test Pilot.

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NAVRWAIRTESTRON Patuxent River, MD (55RW10A-HH60H/J)	(2)
NAVTESTWINGLANT Patuxent River, MD (55TW01A)	(1)
NAVAIRWARCENACDIV Patuxent River, MD (RWSCB.4)	(3)
NAVAIRWARCENACDIV Patuxent River, MD (4.11)	(1)
NAVAIRWARCENACDIV Patuxent River, MD (7.2.4.3)	(2)