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THE AN/AVS-7 HEAD UP DISPLAY AND THE NAVY COMBAT SEARCH AND RESCUE/SPECIAL WARFARE SUPPORT HELICOPTER

A Thesis

Presented for

the Master of Science

Degree

The University of Tennessee, Knoxville

Kevin M. Kenney

May 1994

DISCLAIMER

The information presented in this thesis is the sole opinion of the author and in no way reflects the views of the Naval Air Warfare Center Aircraft Division, Naval Air Systems Command, or the United States Navy.

ABSTRACT

Military helicopters continue to expand into mission areas requiring the use of Night Vision Goggles (NVGs). Incorporating Head Up Display (HUD) symbology within the pilot's field of view is becoming a necessity to ensure safety of flight during NVG missions. Current HH-60H projected operational environments require reduced head-down time in order to successfully complete assigned tasks. To this end, NVG compatible helmet mounted displays (NVG HUDs) are being developed and tested by the various armed services.

The HH-60H Seahawk is the U.S. Navy's combat search and rescue (CSAR) and special warfare support helicopter. Crews flying it operate using NVGs a large part of the time. Because of this, the Rotary Wing Aircraft Test Directorate (RWATD) of the Naval Air Warfare Center Aircraft Division (NAWCAD) was tasked to begin developmental testing of the AN/AVS-7 NVG HUD system.

120 hours of ground testing were conducted, with 60 hours of flight testing following to determine whether the ANVIS HUD

would meet operational requirements and enhance aircrew mission performance.

Testing concluded that the AN/AVS-7 NVG HUD system significantly increased aircrew safety and mission effectiveness in HH-60H tactical employment. Future testing was recommended to ensure shipboard compatibility, to assess future software upgrades and improved symbology modes.

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LIST OF ABBREVIATIONS

AFCS........................Automatic Flight Control Systems

AGL.................................Above Ground Level

ANVIS..................Aviator's Night Vision Imaging system

ATEF..................Aircraft Test and Evaluation Facility

CAL...............................Confined Area Landing

CRT...................................Cathode Ray Tube

CSAR.............................Combat Search and Rescue

DDU................................Display Driver Unit

E^3.................Electromagnetic Environmental Effects

ECP...........................Engineering Change Proposal

EFP..............................Elevated Fixed Platform

FOV.....................................Field Of View

FPM...................................Foot Per Minute

HMD..............................Helmet Mounted Display

HUD...................................Head Up Display

IMC....................Instrument Meteorological Conditions

KIAS...........................Knots Indicated Air Speed

LLF...................................Low Level Flight

LLL...................................Low Light Level

MCAS..............................Marine Corps Air Station

NAS...................................Naval Air Station

NAWCAD.............Naval Air Warfare Center Aircraft Division

NOE...............................Nap Of the Earth Flight

NVD...................................Night Vision Device

NVG...................................Night Vision Goggle

SAR.....................................Search And Rescue

SWS...............................Special Warfare Support

TERF..............................Terrain Following Flight

TEMP.........................Test and Evaluation Master Plan

TOR..........................Tentative Operational Requirement

VSI...............................Vertical Speed Indicator

GLOSSARY OF TERMS

Confined area landing (CAL): Any landing to an unprepared surface which is surrounded by obstacles such as trees or power lines. CALs vary in size from large parking lots down to just slightly larger than the aircraft attempting the landing. Thus what may be a small CAL zone for an H-53 Super Stallion would be considered large for an H-1 Huey.

Doppler display: A display used to allow hovering in environments with little to no outside cuing. By flying the aircraft using this display, pilots are able to maintain a specific position over the water or land at night, usually a position referenced to a survivor desiring rescue.

Eye relief: The distance between the front of the eye and the objective lens of the NVGs. Significant because the full goggle field of view is only possible when the eye relief is set to the correct value or closer. Older style goggles use an eye relief of 18 mm, which is very small. Newer style goggles use 25 mm eye relief which is easier to achieve.

Jitter: A term used to describe behavior of flight displays characterized by rapid, apparently random oscillations of an indicator.

Low level flight: Flight at altitudes below 500 feet above ground level (AGL).

Low light level: Any NVG flight conducted under ambient light conditions less than .0022 lux. Significant because extensive training is required prior to qualification for low light level flying.

Nap of the earth flight (NOE): Flights flown extremely close to the ground to provide some protection from enemy forces. Generally flown at altitudes of 100 feet AGL and below and at slow airspeeds to allow for obstacle avoidance. Groundspeed in knots will usually equal the number of feet above ground the aircraft is flying.

Ratcheting: A term used to describe behavior of flight displays characterized by an indicator freezing momentarily then "jumping" rapidly to display a new value rather than smoothly scrolling at a uniform rate.

Terrain following flight: Flight which uses natural topographic features such as ridge lines or hills to provide cover from enemy forces. Generally flown at altitudes of 250 to 100 feet AGL.

Time constant: A term used to categorize the length of time it takes for a first order system to stabilize. After three time constants, a first order system will be almost completely stable. As used in this paper it refers to a combination of factors such as damping, data sampling, screen frame rate, and transport delay, all of which may cause an electronic display to behave in a manner unlike actual aircraft displays. (see jitter and ratcheting).

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

The U.S. Navy has expanded the roles and capabilities of its helicopter forces greatly in recent years. One of the driving factors in this expansion has been the introduction of Night Vision Goggles (NVGs) to both the Navy and Marine Corps aviation communities. The U.S. Army was the first service to fully introduce NVGs into flying service (1)[1]. Other armed forces around the world soon followed. The Royal Navy introduced NVGs into action in 1982, where they proved very effective in the Falkland Islands conflict (2). More recently, the U.S. Navy has begun its introduction of NVGs into service wide use, but is presently behind the Army in implementation.

The author has been an NVG pilot since 1990, and has extensive experience both operationally and as a developmental

[1]Numbers in brackets indicate number used in bibliography.

test pilot flying NVGs under conditions varying from full moonlight to Low Light Level (LLL, defined as lighting less than .0022 lux). The author's most recent experience has been as an NVG instructor pilot and during the test and evaluation of the ANVIS-7 NVG Helmet Mounted Display system, called the NVG HUD, from August 1993 to January 1994.

1.2 OPERATIONAL REQUIREMENTS

Two mission areas for the HH-60H were the primary reasons for the development of the ANVIS-7 NVG HUD system. Both Combat Search and Rescue (CSAR) and Special Warfare Support (SWS) require considerable time spent flying close to the ground at night. The three flight regimes most often used during these missions are Low level Flight (LLF), Terrain Following Flight (TERF) and Nap Of the Earth flight (NOE) (3). All require extensive crew coordination and concentration, as well as high levels of situational awareness to succeed. In response to these mission requirements fleet units generated a Tentative Operational Requirement (TOR) requesting an NVG HUD system be developed. This TOR was used as a basis for a Test and

Evaluation Master Plan (TEMP), upon which RWATD's test plan was based (4,5).

1.3 SUMMARY

This thesis details the developmental testing of the ANVIS-7 NVG HUD system in the U.S. Navy HH-60H aircraft. A brief discussion of NVGs provides some information on how ANVIS-6 series NVGs operates and what benefits they provide as well as some operational drawbacks of their use. The ANVIS-7 NVG HUD system is described, providing operating details. Next the ground testing accomplished prior to actual flight test is discussed, including cockpit testing and laboratory testing at the Aircraft Test and Evaluation Facility (ATEF). Then actual flight tests on the HH-60H detailing the flight configurations and mission areas tested is described. Finally, based on these tests, the author's conclusions and recommendations are presented.

CHAPTER II

ANVIS-6 NIGHT VISION GOGGLES

2.1 NVG SYSTEMS OPERATION

Figure 1 illustrates the basic principles of operation for NVGs[2]. Ambient light such as moonlight, artificial light sources or star light is reflected off of objects and into the objective lens of the NVG. This entering light is passed via an image intensification tube onto the photocathode. The photocathode is sensitive to light from the visible spectrum to the near infrared (625 to 950 nanometers for ANVIS-6 series NVGs). Figure 2 illustrates the ANVIS-6 response sensitivities to various wavelengths of light. Each photon which strikes the photocathode causes a release of electrons from it. The electrons then pass through a charged microchannel plate which is slightly angled. The angled plate causes each electron to

[2] All figures are located in the Appendix.

rebound many times as it passes through, releasing more electrons with each collision. This eventually cascades the entering electrons causing a gain of up to 25,000:1. The electrons next strike a phosphor screen, producing green monochromatic images in much the same way that a black and white television does. The image then passes through an eyepiece lens which focuses the picture for viewing by the human eye (3).

2.2 ANVIS-6 SYSTEM SPECIFICATIONS

ANVIS-6 NVGs are a third generation electro-optical viewing system designed to amplify existing light allowing flight crews to fly in conditions of reduced illumination without using supplementary lighting. They are designed to provide a gain of 25000:1, a nominal field of view (FOV) of 40 degrees, and a resolution of 20/40. The ANVIS-6 system is shown in figures 3 and 4. The system weighs approximately 16 ounces and power to operate it is supplied from a battery pack containing two AA batteries which mounts on the rear of the helmet. The battery pack can be configured to use either two 3.0 volt lithium batteries or, more commonly, four 1.5 volt AA

Alkaline batteries. While mercury batteries can be used, they rarely are due to the difficulty in disposing of them when spent. Average operating life varies with type of batteries and ambient conditions, but the author's experience indicates that an average life of approximately 16 hours is not uncommon. The ANVIS-6 system is designed to provide adequate pilot vision down to clear starlight, although they work best when ambient lighting is above Low Light Level conditions below .0022 lux (3). Table 1 presents specific ANVIS-6 system characteristics.

2.3 ANVIS-6 OPERATIONAL CONSTRAINTS

While the ANVIS-6 system is extremely useful and does increase mission flexibility for Navy aircrews, there are some significant system limitations which should be mentioned. The goggles work well in light levels above .0022 lux, but as light levels go below this value image quality rapidly degrades. Because of this, NVG crews are trained to three varying levels of proficiency called level I, II and III.

Table 1. ANVIS-6 Operating Characteristics

Gain	25,000:1
Field of View	40 Degrees[1]
Resolution	20/40
Magnification	1:1
Weight	16 Ounces
Focus Range	10 inches to ∞
Diopter Adjustment	+2 to -6 diopters
Inter-Pupillary Adjustment	51-72 mm[2]
Brightness	1.0 mLux
Photocathode	Gallium Arsenide
Average Battery life at 70° F	16 Hours for AA Alkaline/14.5 for Lithium

[1] 40 degree field of view with eyepiece 18 mm from wearer's eye.

[2] Not independently adjustable for each eye.

Source: *Helicopter NVG Manual*, Revision 1, Marine Aviation Weapons and Tactics Squadron One, Yuma, Arizona, September, 1990.

Level one is basic NVG flight familiarity and consists primarily of learning to properly operate the goggles and fly the aircraft in normal landing pattern and hover maneuvers. A pilot is usually given a checkride and considered level I qualified after approximately 10 hours of NVG flight time. Level II is qualification for mission areas. This includes TERF or NOE, Confined Area Landings (CALs), and troop insertion and extraction, all done while on goggles. Pilots are usually given a level II checkride and considered level II qualified between 25 to 50 hours of NVG flight time. Level III is the qualification for NVG flights in LLL conditions from .0022 lux down to starlight conditions. This qualification is usually conferred after a checkride once a pilot has over 50 hours of NVG time, some part of which is spent with an instructor during LLL periods. In addition to the time required for qualification, additional flight time is required to maintain currency, usually 10 hours per month. This is a considerable training load on operational units. One way to ease this load would be to have goggles which would able to deal with lower light levels without loss of image quality.

The ANVIS-6 system is extremely sensitive to point light sources of incompatible wavelengths. These lights cause an effect called blooming, which is when the image area around the light source is washed out and no detail can be discerned. NVGs are especially sensitive to blooming from light sources in the red part of the spectrum. Many aircraft warning and caution lights are in the red part of the spectrum, which produces challenges in making aircraft cockpits NVG compatible. Using current state of the art image processing capabilities, it should prove possible to produce goggles that are not as vulnerable to point source blooming as the current ANVIS-6 system (6).

Current goggle design provides for a maximum field of view (FOV) of 40° when the eyepiece is 18 mm or less from the wearer's eye. In practice it is often impossible to achieve the required eyepiece to eye separation due to factors such as eyeglasses or helmet fit (7). Increasing the distance at which maximum FOV can be achieved would rectify this problem.

Lastly, current ANVIS-6 design allows for interpupillary adjustment of the goggles, but only from a fixed central point for both tubes. For most people, the distance that the eyes are located from the centerline of the face varies for the right and left eye. Because current goggle designs do not allow for this, many pilots cannot adjust the goggles to get the maximum FOV from both tubes simultaneously. One tube can be adjusted for full FOV while the other is "clipped" allowing the pilot only a partial FOV which loses the image around some portion of the edge. A design allowing for independent interpupillary adjustment would alleviate this problem.

CHAPTER III

ANVIS-7 NVG HELMET MOUNTED DISPLAY

3.1 ANVIS-7 SYSTEMS OPERATION AND SPECIFICATIONS

The ANVIS-7 HMD system is an electro-optical system designed to project flight and aircraft instruments, as well as threat/mission symbology into the objective lens of one of the two imaging tubes of current generation NVGs. Table 2 presents specific ANVIS-7 system characteristics. A symbol generator called the Signal Data Converter (SDC), using bit plane memory compiles information from various aircraft instruments and systems, most of which is passed along on the HH-60H's two MIL standard 1553B data busses. This information is processed and then displayed on a pixel array which projects the data into the tube. The pixel array is 512 x 512 pixels, and occupies a square measuring 8.3 mm per side.

This is designed to give a display measuring 34° diagonally when viewed by the pilot. Actual specifications allow the display to measure 32°-35° and still be within tolerance (4,5). Pilots may independently select among the various preprogrammed modes as well as adjust brightness levels. These selections and adjustments may be done using the converter control panel or using a four position control switch located next to each pilot's thumb on both collectives. ANVIS-7 system components are shown in figures 5 and 6, figure 7 presents an ANVIS-7 block diagram and figure 8 presents the Signal Data Converter functional diagram.

3.2 ANVIS-7 SYSTEM SYMBOLOGY

The ANVIS-7 NVG HUD is designed to allow the pilot and copilot to independently select from four normal symbology modes and four declutter modes that have been pre-programmed as subsets of the HH-60H Master symbology. HH-60H master symbology is presented in figure 9 and accompanying

Table 2. ANVIS-7 Operating Characteristics

Interoperability	Between HH-60H/UH-1N/CH-46E with no modification necessary
Symbology Illuminance	0 to 5.1 ±10% Foot Lamberts
Linear Distortion	Maximum of ± .05% effect on scene path
Transmissivity	Minimum 90% of that with objective lens alone
Reliability	MTBF of 400 Hours minimum
System Weight	Total weight less than 25 pounds
Helmet Mounted Hardware Weight	Less than 450 Grams
Power requirements	28 VDC nominal (150 Watts maximum) / Shall operate normally down to 22.5 VDC

Source: *Prime Item Function Specification for Night Vision Goggles/Heads-Up Display*, AEL Defense Corporation, December, 1992.

descriptive table. Because each of the symbol elements is programmable in each mode, some considerable thought and testing went into producing the final four primary and declutter modes prior to flight test. The author and other members of the NVG HUD test team attempted to utilize a rational philosophy of symbol inclusion/exclusion. The test team's design philosophy was that the Head Up Display symbology design must be based on the mission needs of the pilot and aircraft (8,9,10), it must be fully compatible with the cockpit environment, and it must be safe for both pilots to use during standard mission scenarios. Because of this, each display mode was designed with a specific mission area in mind (11,12,13). While testing started with four standardized modes, the display modes tested evolved over time to match specific pilot preferences. One pilot might prefer to have the Vertical Speed Indicator (VSI) present in all modes, while another might find it distracting. During testing, one of the great strengths of the system appeared to be that it could be programmed to accommodate both pilots prior to flight.

CHAPTER IV

ANVIS-7 GROUND TESTS

4.1 SUMMARY OF GROUND TESTS

Before flight testing of the ANVIS-7 system could begin, approximately 120 hours of ground testing took place. Ground testing was broken up into five phases: Design, electrical, NVD compatibility, E^3, and human factors (4,5). All ground testing was accomplished at the Systems Engineering Test Directorate (SETD) located at NAS Patuxent River.

4.2 DESIGN OF SYMBOLOGY AND MODES

The design phase was conducted over a period of approximately three weeks at the Aircrew System Evaluation Facility (ASEF). The ASEF uses a device called "Predator" which is a multiconfigurable rapid prototyping computer display system. Using this system, various symbol elements could be designed, placed, moved, and evaluated in minutes, giving test team members rapid feedback of individual as well as total symbol set design. Much of the test and evaluation at this point was done utilizing techniques outlined in NASA Technical Memorandum 103947, *Test Techniques For Evaluating Flight Displays* (14), with the above stated design goals of meeting mission/pilot needs and enhancing specific mission areas. At this point the four available modes and four associated declutter modes were developed. Pilots requested that the fourth mode be a doppler hover mode (15). This mode would be similar to existing doppler hover displays presented to the pilot and copilot on the aircraft's Horizontal Situation Video Displays, two small multipurpose CRT (Cathode Ray Tube) displays located on the instrument panel in the cockpit. This mode was not available for inclusion in the current revision of software, but may be available in future revisions. Because of this, the fourth mode was used to evaluate suggested changes to the three primary modes on an as needed basis. Figures 10 through 13 show the initial design primary and declutter modes tested as well as the requested doppler hover design.

4.3 ELECTRICAL INSPECTION

The next phase of testing essentially involved verification of system installation and electrical inspections to ensure compliance with ANVIS-7 system specifications (16,17). Four minor wiring discrepancies were noted during this phase and corrected. A more serious discrepancy was discovered in that the ANVIS-7 control panel lighting was not compatible with existing aircraft power sources. This problem persisted during the first several weeks of flight testing, but was corrected prior to the finish of the flight test phase through a redesign of the panel backlighting. The redesigned panel was installed and flight tested with no further discrepancies noted.

4.4 NVD COMPATIBILITY TESTING

The ANVIS-7 system was tested for compatibility with existing ANVIS-6 NVGs as well as advanced design NVG replacements (called "Super sixes" and "Enhanced sixes") at the Crew System Integration Laboratory (CSIL). During this testing period it was learned that the ANVIS-7 lens did not properly fit the objective lens of existing ANVIS-6 NVGs. The system was designed to fit over the objective lens when a neutral density gray laser filter is installed. While this is standard design for U.S. Army NVGs, this is not included in standard Navy/Marine Corps goggle systems (18). Several filter adapters were obtained from the Army to assist in the completion of testing. The ANVIS-7 symbol projections were tested to ensure compliance with NVG specifications for brightness, chromaticity, gain/degain, contrast, and possible goggle imaging tube burn-in. It was noted that at the highest brightness the ANVIS-7 system tended to degain, or wash out, the visual scene in the goggle tube it was installed on. Total gain reduction was between 25 - 30% at full HUD brightness (19). This was not considered to be a major detractor for two reasons. Normal usage does not require the HUD to be set to full intensity. It is normally set to some value significantly less than full bright and the intensity is easily changed using either the system control box or the brightness toggles on both pilot collective sticks. Also, in later flight testing it was seen that in areas of high ambient light, such as dense urban areas, the ability to make the HUD very bright prevented symbol washout to some degree. During this phase of testing no significant problems were noted with NVD compatibility (19).

4.4 ELECTROMAGNETIC ENVIRONMENTAL EFFECTS TESTING

E^3 Testing was completed to ensure there were no areas of electromagnetic intrusion. DC bonding resistance measurements as well as inter/intra-system Electromagnetic Compatibility (EMC) were completed with no discrepancies noted. The system appears to be well shielded and will be acceptable for use in the shipboard environment, an environment that includes high levels of electromagnetic radiation and traditionally causes problems for systems designers (5).

4.5 ANVIS-7 HUMAN FACTORS TESTING

Human factors testing was done at the Aircrew Systems Aircraft Lighting Laboratory (ASALL) and the Aircraft Test and Evaluation Facility (ATEF). The system was tested as fully installed in the HH-60H helicopter during simulated day and night conditions. This phase of testing included placement of controls and displays; emergency egress conditions; effects on external target acquisition; weight induced fatigue; and display accessibility. In addition system software design was evaluated for ease of use, consistency, and transient power effects due to unstable aircraft power sources.

4.5.1 CONTROL PANEL PLACEMENT

The ANVIS-7 converter control panel was designed to need minimal cockpit space. It measures 4" deep x 5.7 " wide x 3" high. Original designs placed the system control panel in the aft right corner of the lower console, well behind the shoulders of both pilot and copilot. Because programming the system required approximately ten minutes, test team members requested that the control panel be moved to a more accessible location. The optimum location was found to be on the right side of the lower console, eight inches up from the rear. The position of the control panel can be seen in figure 14.

4.5.2 EMERGENCY EGRESS TESTING

The ANVIS-7 display unit attaches to the aircraft over the inboard shoulder of each pilot and is designed to have a nominal release force of 7.5 pounds (straight pull) in the event of emergency egress. Simulated ground egress testing found that although the potential exists for the extra cord (approximately 36" extra) to cause entanglement this possibility is slight. Breakaway forces were felt to be acceptable and ground egress was not hindered by the system.

4.5.3 TARGET ACQUISITION TESTING

Previous testing suggested that the combination of symbology and NVG imagery might adversely affect pilot target acquisition time (20). Navy ground testing confirmed that although the amount of information does tend to initially slow target acquisition times, the effect is transient. Ground testing done prior to and after actual flights with the ANVIS-7 system indicated that with between 6-10 hours of ANVIS-HUD experience pilots were able to acquire targets with no real increase in time required (19).

4.5.4 PILOT FATIGUE TESTING

The ANVIS-7 system design specification calls for the combined weight of the HUD head mounted hardware, sufficient counterweight to ensure no shift of helmet center of gravity, and one foot of attaching cable, not to exceed 450 grams (15). During both ground and flight tests, periods of use exceeding four hours caused no excessive fatigue to be noted by any test team member.

4.5.5 DISPLAY ACCESSIBILITY

During ground testing for display accessibility some pilots noted that not all of the symbol elements could be seen at the same time. The symbol spread of the HUD system allows for a 32-35° diagonal field of view when set to an eye relief (the distance between the goggle eyepiece and the surface of the eye) of 18 mm. Further fine tuning of goggle position alleviated this problem during ground tests. Tests involving a prototype 25 mm eye relief eyepiece showed a marked improvement in all pilot's ability to view the total display area.

4.5.6 SOFTWARE TESTING

Software testing found no significant discrepancies. The programming sequence was somewhat lengthy (about 10 minutes) but was not considered to be excessive as the programmed modes stay in nonvolatile memory once set and only rarely need to be reprogrammed. The programming of the various modes was logical and consistent. No transient power effects were noted during testing.

CHAPTER V

ANVIS-7 FLIGHT TESTS

5.1 SUMMARY OF FLIGHT TESTS

Approximately 60 hours of flight tests were completed during the evaluation of the ANVIS-7 NVG HUD system. Flights were broken up into six flight configurations: Daylight familiarization, Hover/pattern work, Navigation, Simulated Overland and Overwater SAR, Simulated Overland and Overwater Combat SAR (CSAR), and Simulated shipboard compatibility. Flight testing was accomplished at the Naval Air Warfare Center, Aircraft Division (NAWCAD) at NAS Patuxent River, MD.; NAWCAD at NAS Lakehurst, NJ.; Marine Corps Air Station Quantico, VA; FT A.P. Hill, VA.; and surrounding areas. Tests were flown by ten different test pilots who filled out daily flight reports detailing test findings immediately after each test flight. The author served as project officer for the testing during all phases from planning to report completion.

5.2 DAYLIGHT FAMILIARIZATION

Four flights were flown during this phase. The primary purpose was to familiarize pilots with hazards along the low level navigation routes, introduce pilots to confined area landing techniques, and allow pilots to familiarize themselves with the operational usage of parts of the ANVIS-7 system such as installation, programming, and self test modes. Because the system is designed for use with NVG's no actual daylight flying was done with the system fully operational.

5.3 SYSTEM NIGHT FAMILIARIZATION

The second flight configuration tested was basic familiarization maneuvers completed at a local outlying landing field. During the first two of the three flights flown in this phase one pilot (the safety pilot) used standard NVG's while the copilot evaluated the NVG HUD system. For the third flight in this phase and all subsequent flights both pilots used the ANVIS HUD system.

5.3.1 PATTERN WORK AND LOW WORK

Initially the evaluation pilot flew standard landing pattern and low work maneuvers such as sideward slides, pedal turns, and vertical and running takeoffs and landings. The evaluation pilot flew each maneuver with the HUD off and then with the HUD on. Using a three point scale the pilot evaluated each maneuver as being either easier with the NVG HUD, harder with the NVG HUD, or showing no appreciable difference with or without the NVG HUD. In addition the evaluation pilot looked for proprioceptive problems and evidence of target fixation with off axis HUD viewing during various maneuvers such as sideward sliding flight.

The author noted that during cross cockpit sliding maneuvers the HUD initially appeared to make the maneuver more difficult. This was believed to be caused by a combination of poor outside cuing (the cross cockpit field of view in the HH-60H is very limited) and having the HUD set too bright. This maneuver was repeated three times, each time becoming progressively easier. This learning curve was much in evidence throughout all flight test phases, with test team members rapidly gaining confidence in the system within the first six to ten hours of ANVIS-7 use (21).

During previous system testing in other platforms such as the UH-1, some displayed flight parameters such as pitch angle and angle of bank had been erroneous (22). Although some limited ground testing of HH-60H flight parameters had been accomplished by injecting synthetic signals into the ANVIS HUD system, a priority during this phase was to confirm that all displayed parameters were operating correctly. Testing during this phase identified some erroneous information. The torque reading from both engines was consistently 10 - 12% high, this also led to false indications of engine over torque. The balance ball indication operated with reverse sensing, causing pilots to input corrections which made the aircraft have more sideslip rather than less. Bearing to a selected navigation waypoint was displayed in degrees true but showed as degrees magnetic, causing a 10° error due to magnetic variation in the Patuxent River area. Other than the improper waypoint guidance, these indications were fixed through software modifications midway through the flight testing period.

More troubling were the pitch, roll, and yaw indications which showed considerable lag in display as well as rate ratcheting when dynamic maneuvers were flown. The barometric altimeter also evinced a considerable lag in display, typically taking up to 45 seconds to stabilize after a 500 foot per minute rate of climb or descent. The VSI display was unfiltered, causing a constant apparently random jitter of ± 200 to 500 feet per minute. This makes the VSI as currently implemented by the system unusable. These display problems are currently unresolved.

Several factors contribute to these dynamic problems with electronic displays. These include damping, transport delay, display frame rate, and data sampling rate. For purposes of communicating the observed problems with the software engineers, all of these problems are grouped under the heading of time constants. For instance, the test team would report that the time constant for the heading tape is poor, causing ratcheting. The software engineers would then determine which factors may be the cause, such as excessive damping, and would modify them in an effort to make the electronic display behave more like the actual aircraft display. Software modification of display time constants will be flight tested within the next three months in an effort to resolve them.

Although the displays had problems with jitter and dynamic lag, test team members felt that the system was completely safe to fly, and in fact improved pilot ability to execute most pattern and low work maneuvers. Altitude retention during low work tasks tended to be ± 2 feet with the HUD vice ± 8 feet without. Those tasks that were not enhanced by the ANVIS HUD showed no change. These maneuvers were those that typically require very little inside scan, such as landing the aircraft.

5.3.2 UNUSUAL ATTITUDE RECOVERY

The final part of this flight test configuration was unusual attitude recovery using the NVG HUD. The evaluation pilot would close his eyes while the copilot would place the aircraft in an unusual attitude such as 30° nose up, 45° right wing down and 800 fpm rate of descent. The evaluation pilot would attempt to recover the aircraft into level unaccelerated flight at 80 KIAS using only the information presented on the NVG HUD. This proved to be relatively easy, and all test pilots commented that the HUD greatly improved situational awareness over goggles alone. During this phase of testing several pilots reported that although the symbology was fully visible when the airplane was static, dynamic maneuvers which put any acceleration on the aircraft caused the display to shift, clipping parts of the symbology. This clipping does not allow the pilot full access to the information being displayed and is a serious problem.

Upon investigation of this FOV clipping problem it was speculated that the eyepiece used was out of adjustment and had too large a symbol spread, greater than the 35° maximum allowed. Unfortunately, this unit had already been returned to Elbit systems Ltd. for modifications unrelated to this problem, and the test team could not substantiate this theory. Nevertheless, this problem did not appear on other eyepiece units during subsequent flights. The problem of helmet rotation causing FOV clipping points to a definite need to ensure proper fit of flight helmets, both for safety and to allow the optimum use of the ANVIS-7 system.

5.4 NAVIGATION AND CONFINED AREA LANDINGS

The third flight configuration was primarily concerned with navigation and CALs. Six flights were flown during this phase of testing including overland, overwater, low level and terrain following flights (TERF). In addition the system was evaluated for use during instrument meteorological conditions (IMC). Confined area landings were evaluated to ensure that pilots could safely execute landings and departures to unprepared surfaces and zones without becoming distracted by the NVG HUD symbology.

Test pilots found that during low level and TERF flying the HUD allowed significantly greater situational awareness of aircraft attitude, power conditions and altitude. By allowing the pilot at the controls to concentrate his scan outside the aircraft, pilot workload was greatly reduced. All pilots commented, however, that the system did not allow them to operate significantly lower or at greater groundspeeds than before. It simply gave them a greater comfort level when operating at previously flown altitude and airspeed combinations.

Pilots evaluated the system for use in IMC conditions (ceilings less than 1000 feet and visibility less than three miles) by utilizing standard IMC simulation tools such as instrument hoods which block outside view. Although several simulated instrument approaches were successfully attempted, the inherent lags in pitch, roll, yaw and altitude coupled with the unusable VSI presentation caused the test team to recommend that the system not be used as a primary instrument flight reference. Future testing of improved display time constants should remedy this problem, and more simulated IMC testing will be done to verify the system's capability under instrument conditions.

The system was evaluated during confined area landings and departures at MCAS Quantico Va, and FT AP Hill, VA under varying light from full moon to low light level conditions. Pilots commented that the system improved performance during the approach phase as well as during the departure phase from

CAL zones, but was mostly distracting during the landing phase. A technique was developed where the pilot at the controls would fly the approach with his HUD set to a comfortable brightness level. Once established in the CAL zone the pilot would then begin to dim his HUD display using the collective thumb switch while simultaneously switching to an outside landing scan. The copilot would continue to monitor the HUD symbology in the event a waveoff should be required. This technique allowed both pilots to maintain maximum situational awareness while still allowing the pilot at controls to safely land with no distractions from too bright or intrusive HUD symbology. The NVG HUD system showed great promise for allowing much safer operations in the field and for confined area landings and departures.

5.5 UNOPPOSED/COMBAT SEARCH AND RESCUE AND SPECIAL WARFARE SUPPORT

This flight configuration evaluated system performance during simulated overland and overwater search and rescue missions using mission representative maneuvers and scenarios. Six flights were flown during this phase of testing. As most of the standard overland SAR maneuvers had already been tested individually no appreciable changes were noted during mission representative scenarios where multiple maneuvers such as quick stops and survivor retrieval were executed. This was the first flight phase where extended overwater flight was attempted at altitudes of 150 feet AGL down to 10 feet AGL.

Overwater SAR flights tested the system's ability to enhance pilot navigational awareness as well as whether the system would allow the pilot to fly a manual hover without benefit of doppler cuing or hover coupler features. Because the system displays only the next selected navigation waypoint, enhancement of pilot navigational awareness was minimal. Although the system allowed pilots to safely maintain altitude overwater without benefit of a hover coupler, even with the aircraft velocity vector displayed, pilots were unable to hover the aircraft within acceptable mission tolerances. Typically pilots would maintain a hover within a circle approximately 100 yards in diameter if no hover coupler were used. The tolerance required to allow a survivor to be hoisted out of the water is an order of magnitude less, a maximum of approximately five to ten feet. Use of a doppler display such as the proposed mode four display (similar to existing doppler hover modes used in Navy helicopters today) would result in closer hover tolerances. Pilots noted that the system made them much more comfortable during night overwater operations at low altitudes. Where most night overwater SAR flying previously involved solely an instrument scan, the NVG HUD system allowed for a partial VFR scan greatly improving reaction time in the event of an emergency. Typical time required to attain a fly out attitude (10 - 15° nose down, 135-144% torque) was decreased by more than half simply because the system allowed pilots to monitor aircraft altitude and engine power without losing sight of a visual horizon reference.

Three flights were flown during flight configuration five, the combat SAR and SWS evaluation. Simulated swimmer and seal team deployments and extractions were evaluated both overland and overwater. Pilots noted that the ability to precisely control altitude (an extremely important factor in deploying personnel from a helicopter) provided an increased margin of safety compared to operations using NVGs alone. In addition the ability to have missile and enemy emitter bearings displayed on the HUD allowed for more timely evasive maneuvering to break lock with the threat systems.

5.6 SHIPBOARD COMPATIBILITY

This final flight configuration phase consisted of simulated shipboard landings at the elevated fixed platform (EFP) located at NAS Lakehurst NJ. The system was evaluated during all phases of approach/departure to the simulated ship deck and landing spot. Once again pilots noted that the system was extremely valuable during the approach and departure phases of shipboard operations, but was of only marginal value once over the deck where the flight cuing is primarily outside the aircraft. Test pilots strongly praised the ability to monitor aircraft attitude, power settings and rate of climb while looking off axis to clear the ship superstructure on a night departure. As this phase of shipboard operations is one of the most demanding and dangerous, this new ability provides a very meaningful improvement in flight safety. The author recommends testing the ANVIS-7 system during actual shipboard operations at the earliest possible opportunity.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

As the U.S. Navy expands it's capabilities in the CSAR and SWS mission areas helicopter crews will use NVGs more and more. The use of HUD symbology projected into aircrew NVGs reduces pilot workload during many mission phases by allowing less time spent head down in the cockpit. In addition situational awareness is enhanced due to the rapid acquisition of HUD displayed information such as warnings, cautions, and aircraft performance data.

Mission areas that were enhanced by using the NVG HUD included basic familiarization, low level navigation, terrain following flight, overland and overwater combat SAR, special warfare support maneuvers, and shipboard operations. Due to dynamic lag problems with displays, the system is not currently recommended for use as a primary scan instrument during instrument meteorological conditions. During flight test, techniques were developed that allowed the HUD to be used when it was needed and ignored when it was deemed not necessary or distracting. Various modes were available and were selected based upon the particular mission phase being flown, thus allowing pilots to customize the displays to suit individual needs or flight techniques. The great flexibility of this system provides for important advantages of safety and situational awareness during helicopter CSAR and SWS missions.

6.2 RECOMMENDATIONS

Based on extensive evaluations, both on the ground and in flight, the author believes that the ANVIS-7 HUD system is a necessity for Navy helicopter crews flying on NVGs. Because of the numerous and significant improvements in mission safety the author would recommend that not just the HH-60H CSAR/SWS helicopter be fitted with the system, but that all NVG capable helicopters be retrofitted with the system.

Further testing should be done to perfect the use of HUD technology in helicopters. While the ANVIS-7 system is useful in it's present form many enhancements should be made. The author recommends modifying ANVIS-7 display time constants in the HH-60H to eliminate rate ratcheting in pitch, roll and yaw, as well as jitter of the VSI and lag of the barometric altimeter display. Further flight testing should then be accomplished to determine if the system is capable of extended IMC flight as a primary aircraft scan instrument. In addition, further testing under actual shipboard conditions should be done to confirm shipboard compatibility.

Other recommended improvements include: making the system self contained thus eliminating the need for the cumbersome and annoying power cord going from helmet to aircraft; stabilizing the display so that the horizon line does not tilt as the pilot's head tilts; improved modes including a doppler hover mode to be used when outside cuing is inadequate (similar to existing doppler hover modes used in Navy helicopters today); and inclusion of navigation aid information such as glideslope and lineup information to allow use with instrument landing systems.

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APPENDIX

FIGURES

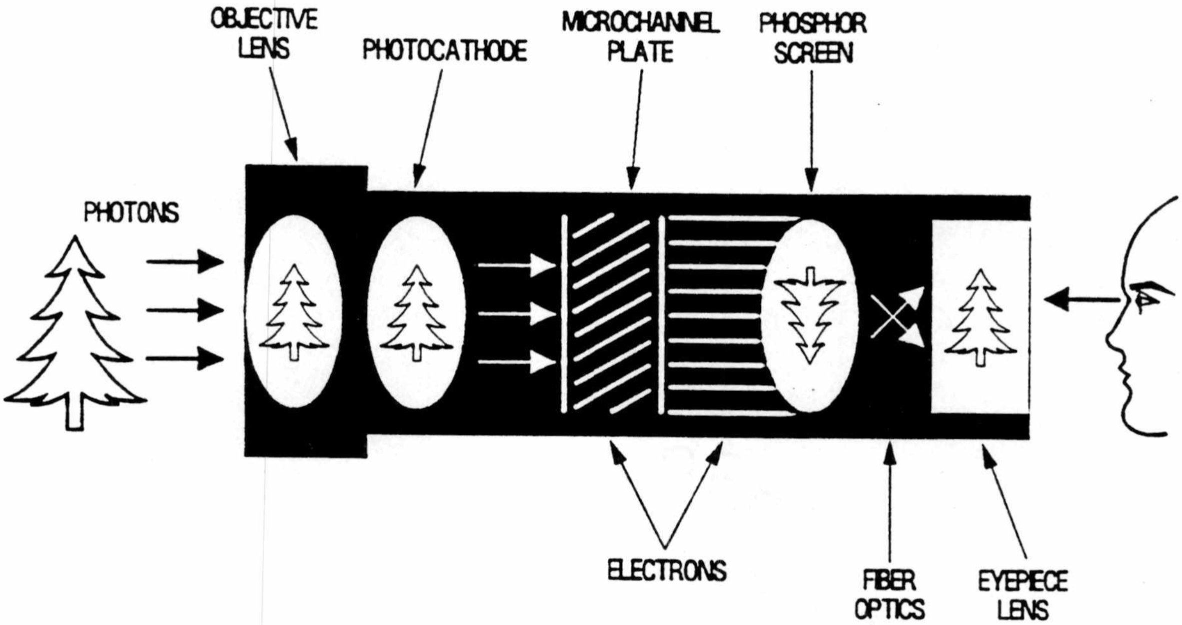


Figure 1. NVG Operating Principles
Source: *Helicopter NVG Manual*, Revision 1, Marine Aviation Weapons and Tactics Squadron One, Yuma, Arizona, September, 1990.

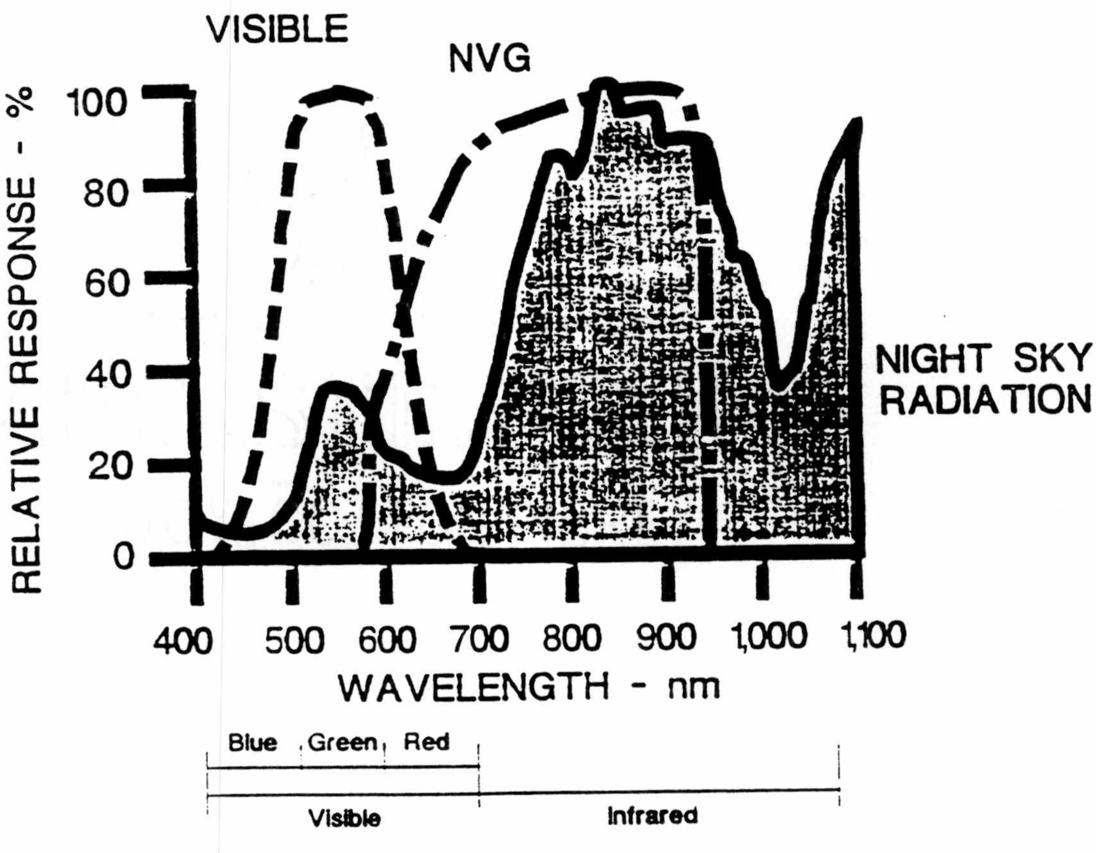


Figure 2. ANVIS-6 Spectrum Sensitivities
Source: *Helicopter NVG Manual*, Revision 1, Marine Aviation Weapons and Tactics Squadron One, Yuma, Arizona, September, 1990.

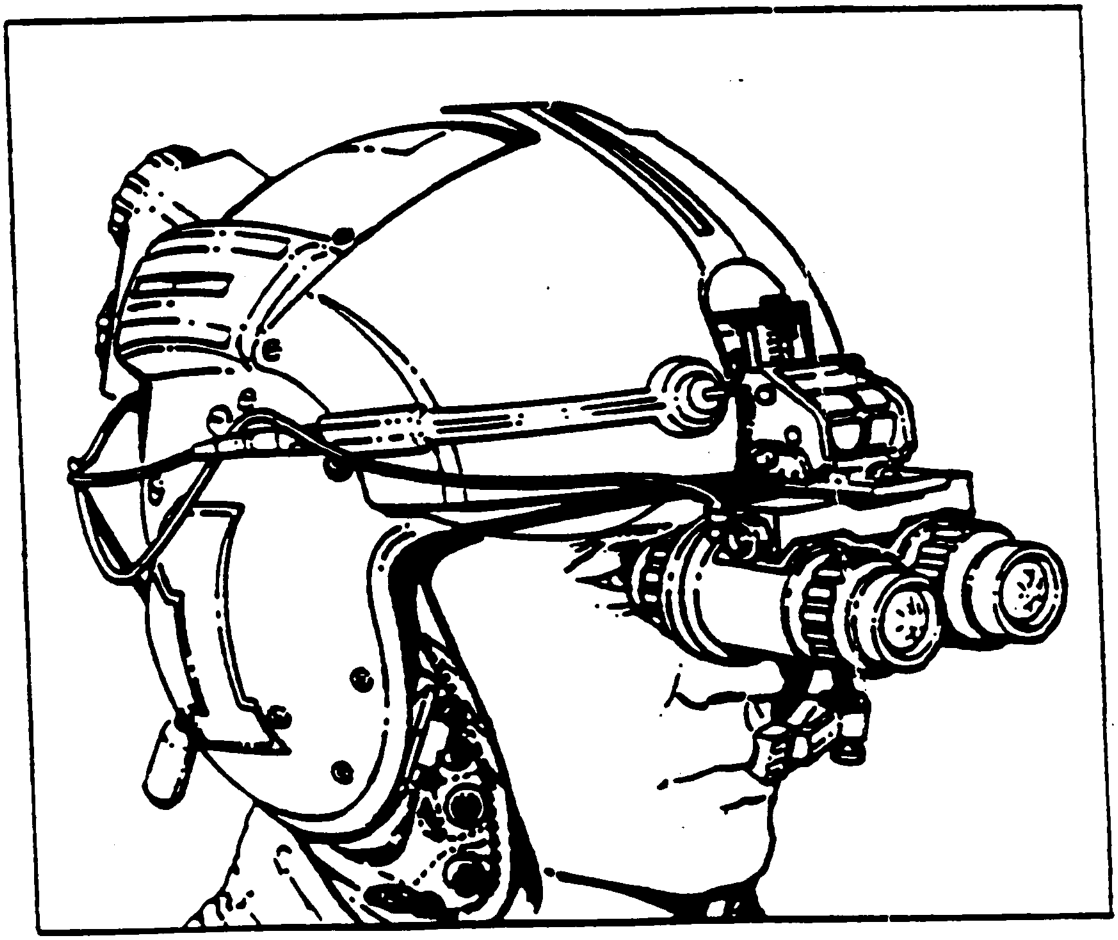


Figure 3. ANVIS-6 System

Source: Kenney, K. *NVG HUD Developmental Testing*, Draft Report to The Naval Helicopter Association Symposium, March 1994

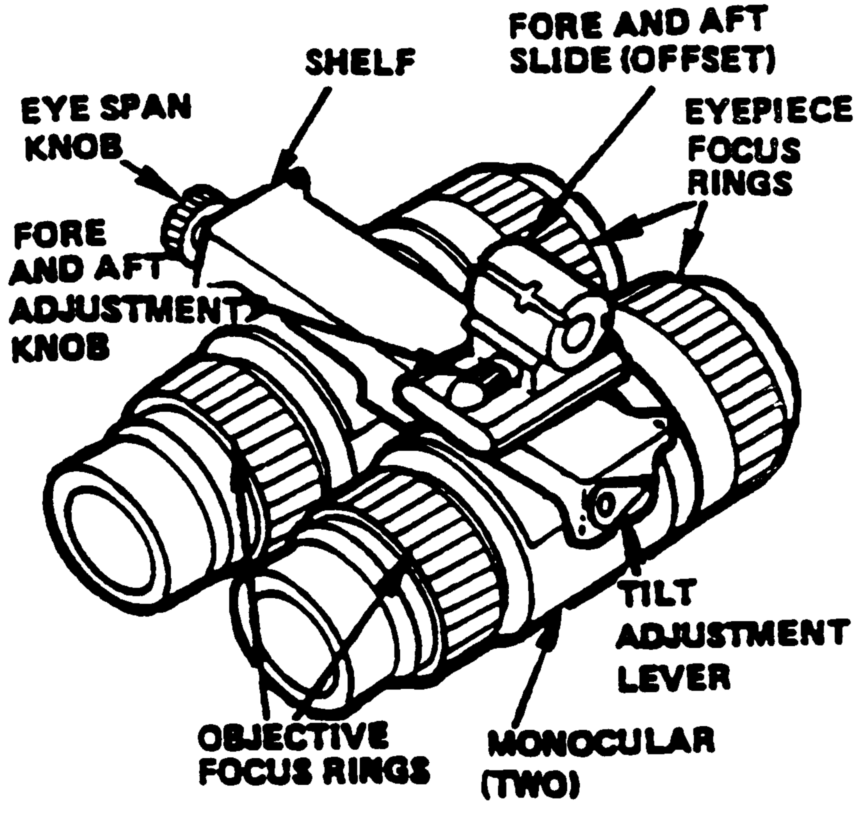


Figure 4. ANVIS-6 Parts Breakdown
Source: *Helicopter NVG Manual*, Revision 1, Marine Aviation Weapons and Tactics Squadron One, Yuma, Arizona, September, 1990.

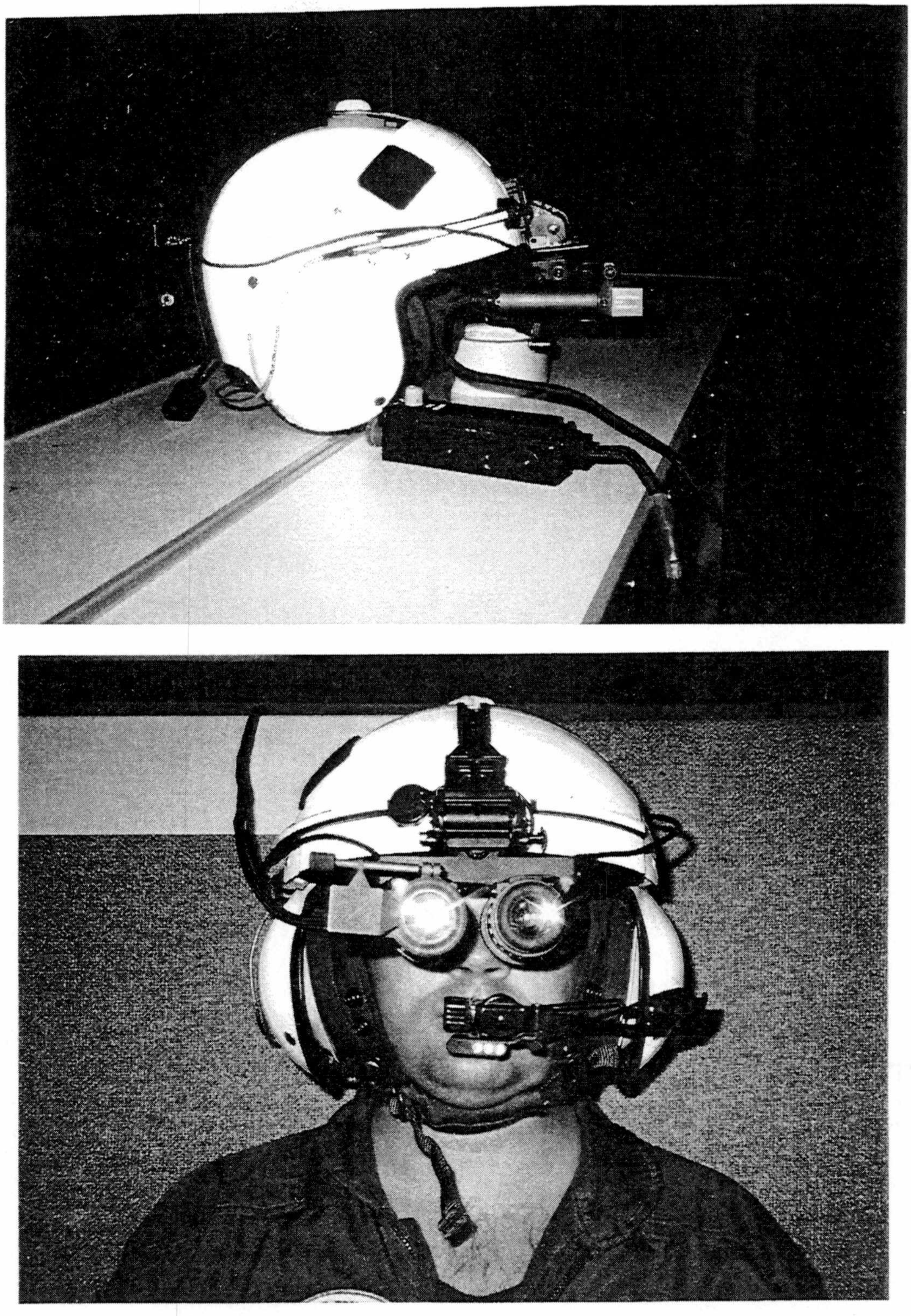


Figure 5. ANVIS-7 Display Driver Unit (DDU) As installed on ANVIS-6 NVGs

Source: *Kenney, K. NVG HUD Developmental Testing*, Draft Report to The Naval Helicopter Association Symposium, March 1994

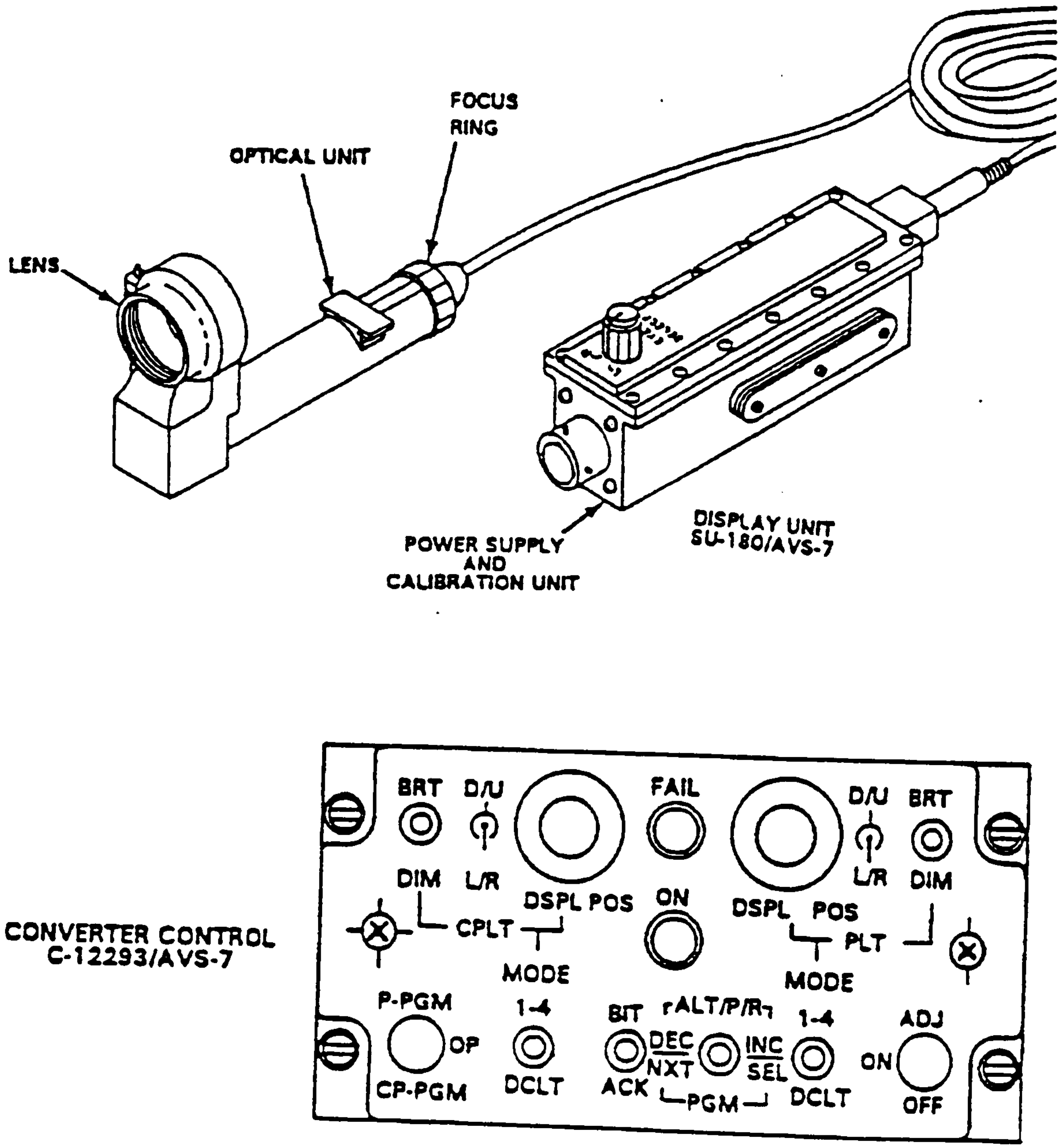


Figure 6. ANVIS-7 Display Driver Unit (DDU) And Converter Control Unit (CCU)

Source: *NATOPS Flight Manual Navy Model HH-60H Aircraft*, Naval Air Systems Command, Washington, D.C., January, 1991.

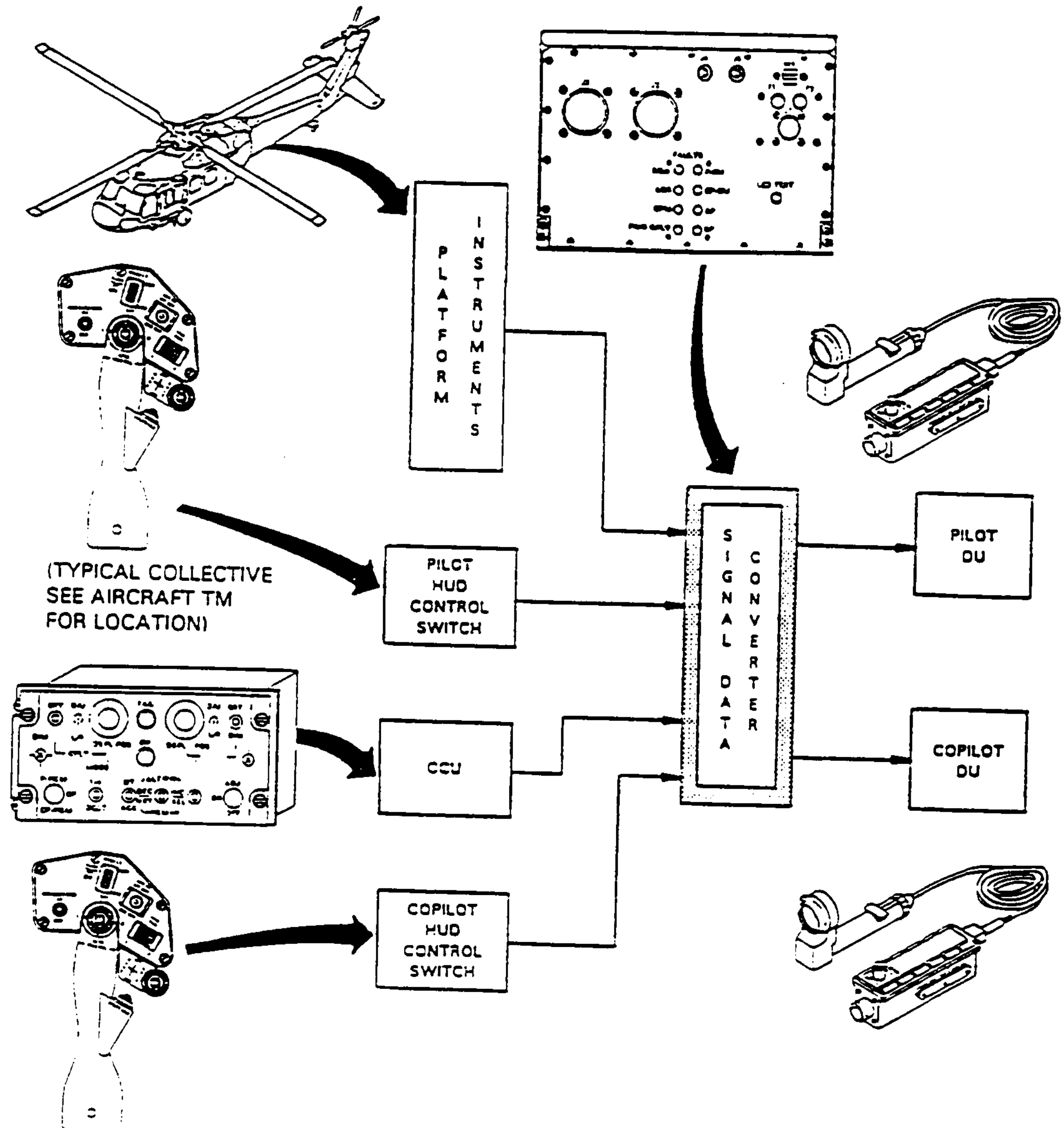


Figure 7. ANVIS-7 System Block Diagram
Source: *NATOPS Flight Manual Navy Model HH-60H Aircraft*, Naval Air Systems Command, Washington, D.C., January, 1991.

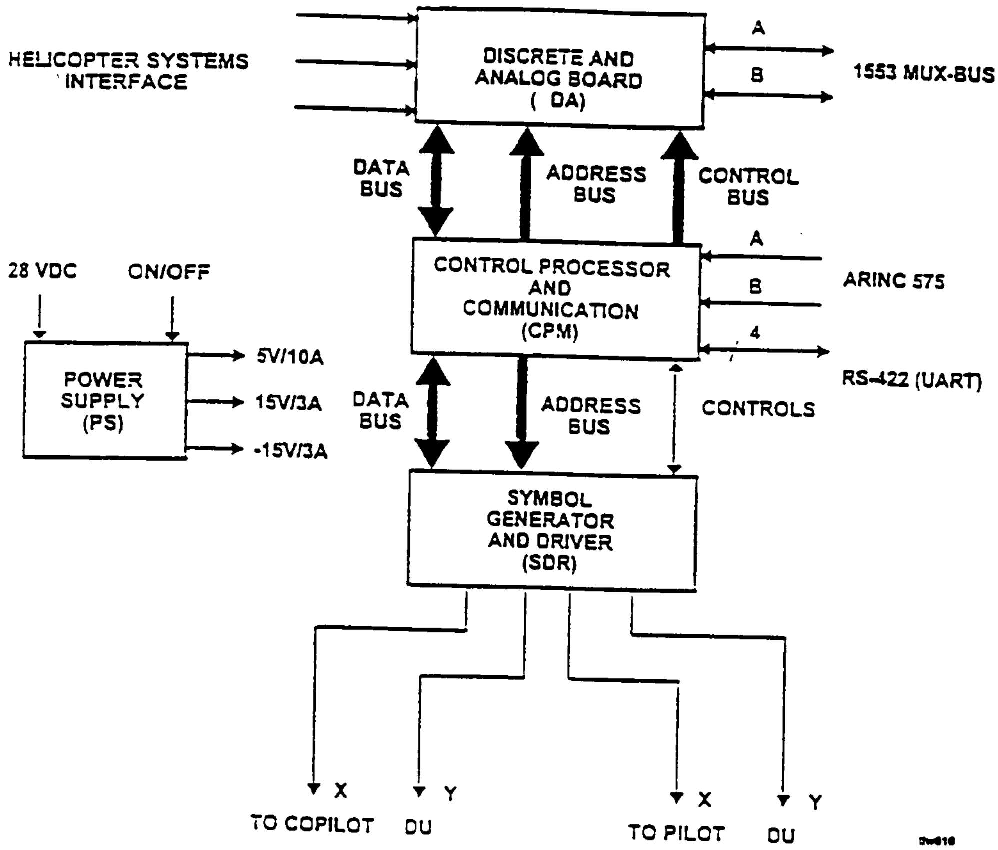


Figure 8. ANVIS-7 Signal Data Converter (SDC) Functional Diagram

Source: *NATOPS Flight Manual Navy Model HH-60H Aircraft*, Naval Air Systems Command, Washington, D.C., January, 1991.

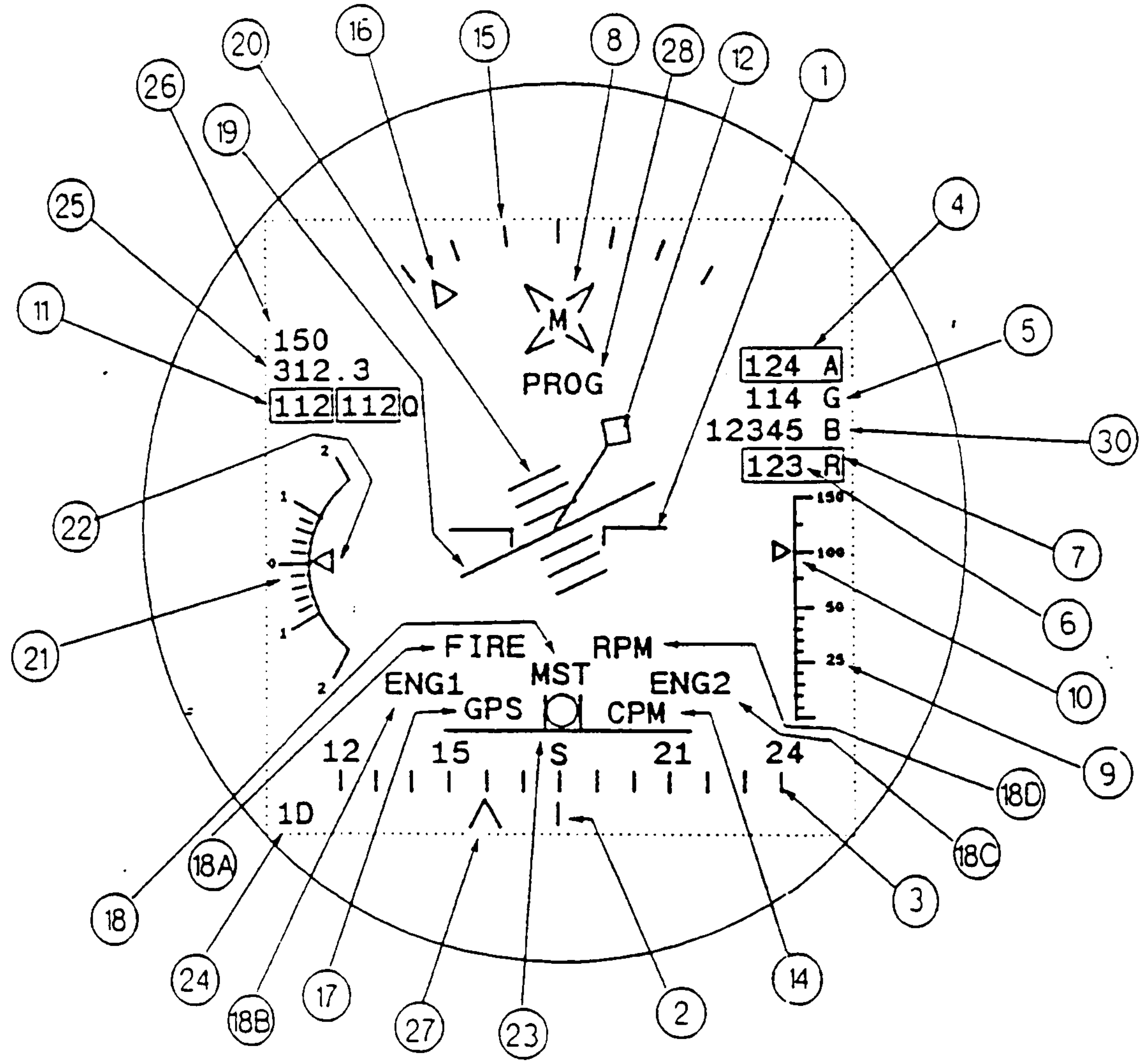


Figure 9. HH-60H ANVIS-7 Master Mode Symbology
Source: *Prime Item Function Specification for Night Vision Goggles/Heads-Up Display*, AEL Defense Corporation, December, 1992.

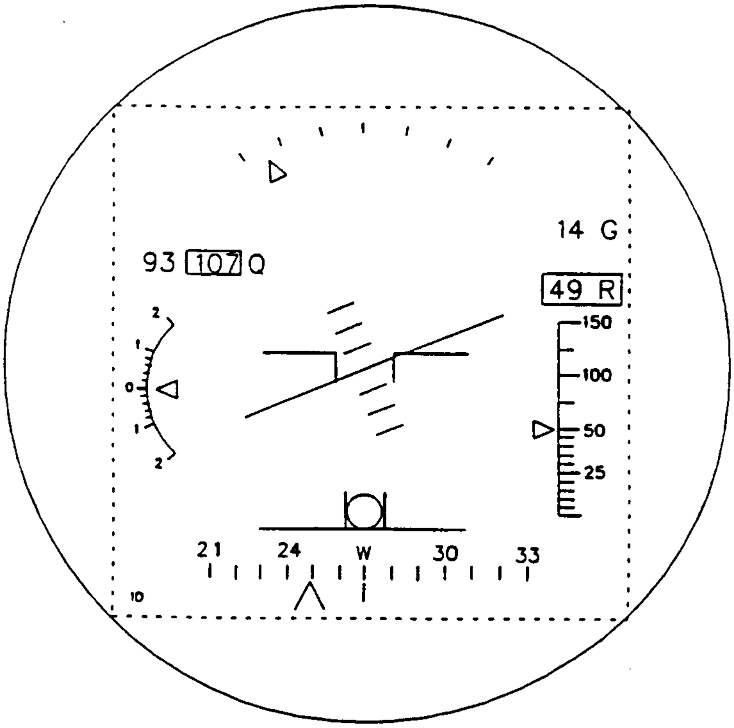
APPENDIX, Table 1. HH-60H Master Mode Symbology Description

No.	Symbol	Range
1	Aircraft Reference	Fixed
2	Aircraft Heading Fixed Reference	Fixed Relative to Compass
3	Compass Scale	0 - 359°
4	Digital Airspeed	38 - 200 KIAS
5	Digital Groundspeed	-40 - 220 Kts
6	Digital Radar Altimeter	0 - 999 Feet
7	Low Altitude Warning (Boxed RADALT)	Upon Occurrence
8	Quadrant Threat Warning	Upon Occurrence
9	Radar Altimeter Analog Scale	0 - 150 Feet
10	Radar Altimeter Analog Pointer	0 - 150 Feet
11	Left/Right Engine Torque	0 - 150 %
12	Velocity Vector	0 - 15 Kts
13	Deleted	N/A
14	HUD Fail Warning	Upon Occurrence
15	Bank Angle Scale	± 30°
16	Bank Angle Pointer	± 45°
17	NAV System Fail Warning	Upon Occurrence
18	Master Warning	Upon Occurrence
19	Horizon Line	Concurrent With Pitch Scale
20	Pitch Angle Scale	± 45°
21	Vertical Speed Scale	± 2000 FPM
22	Vertical Speed Pointer	± 2000 FPM
23	Trim Ball	2 Diameters Left or Right
24	Display Mode Numbers	1 - 4 & D if in Declutter Mode

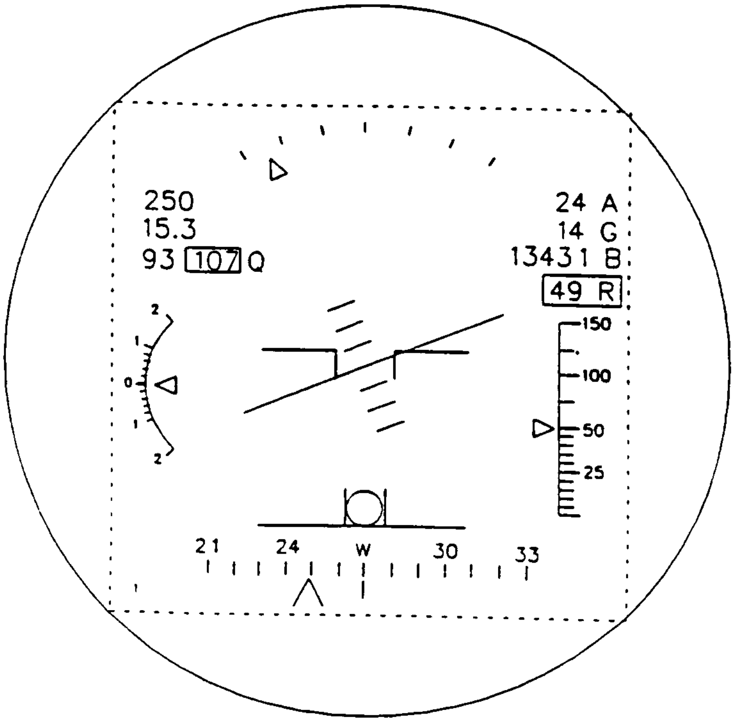
APPENDIX, TABLE 1 Continued

No.	Symbol	Range
25	Digital Range to Waypoint	0 - 999.9 NM
26	Digital Heading to Waypoint	0 - 359°
27	Analog Heading to Waypoint	± 65° of Compass Heading
28	Program Mode	During Programming
29	Adjust Mode	During Adjustments
30	Digital Barometric Altimeter	-1000 to +20,000 FT MSL
31	Flash Rate	2 Hz

Source: *Prime Item Function Specification for Night Vision Goggles/Heads-Up Display*, AEL Defense Corporation, December, 1992.



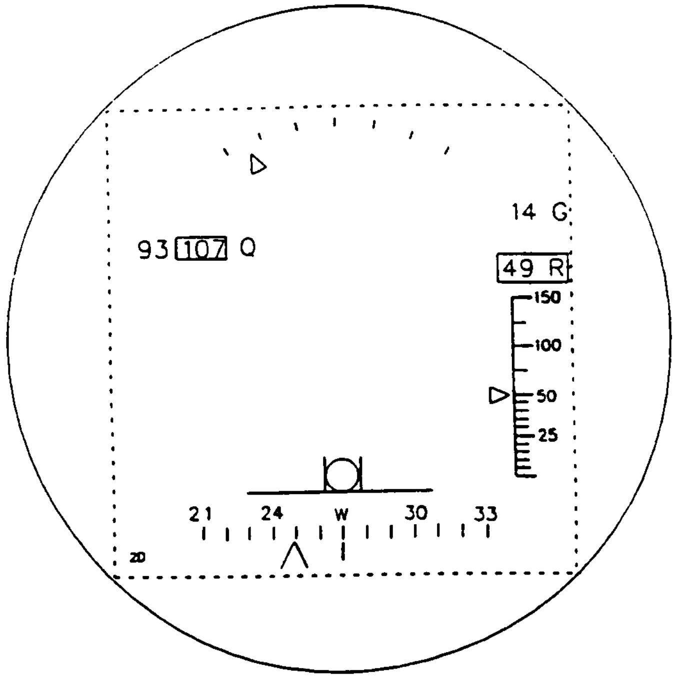
Mode 1D - Secondary (decluttered) Mode 1 Display



Primary Mode 1 Display

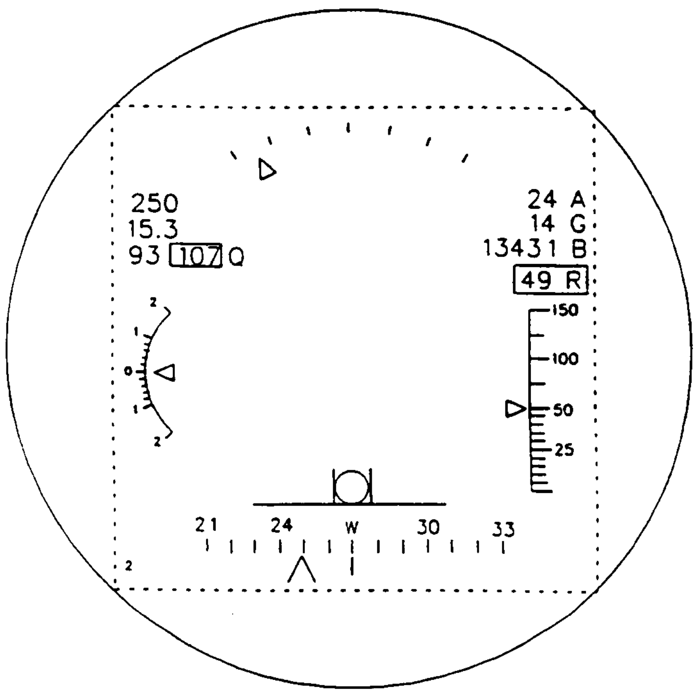
Figure 10. HH-60H ANVIS-7 Mode 1 Primary/Declutter Displays

Source: Kenney, K., and Peters, G.: *HH-60H Mission Mode Displays For The ANVIS-HUD System,* Rotary Wing Aircraft Test Directorate Memorandum, Naval Air Warfare Center Aircraft Division, Patuxent River, MD., August, 1993.



Mode 2D - Secondary (decluttered) Mode 2 Display

"Open Center"

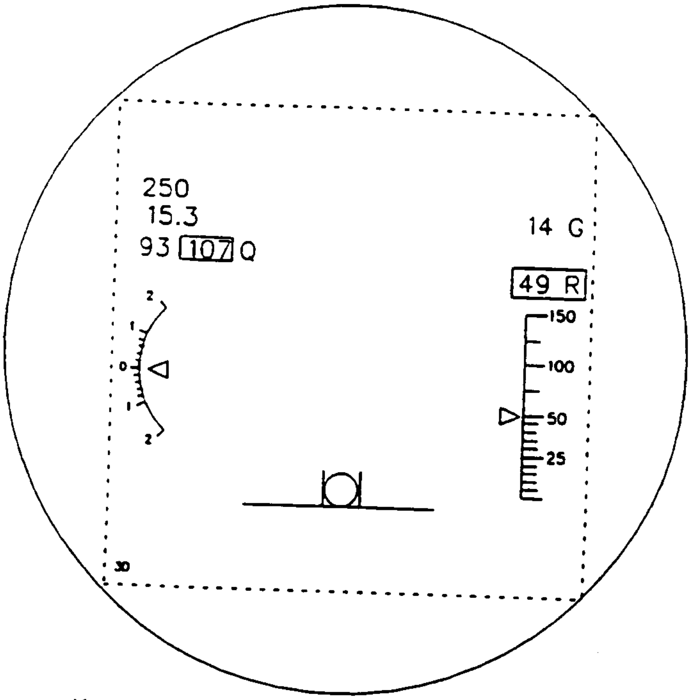


Primary Mode 2 Display

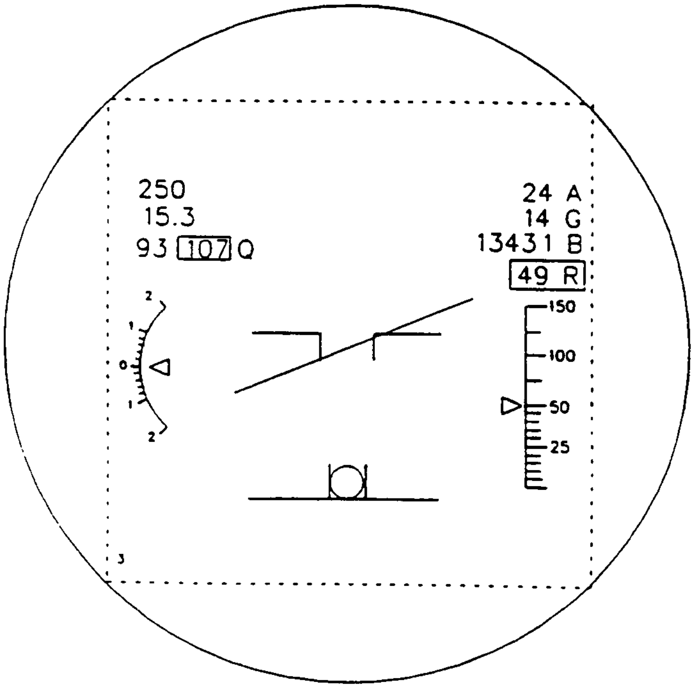
"Open Center"

Figure 11. HH-60H ANVIS-7 Mode 2 Primary/Declutter Displays

Source: Kenney, K., and Peters, G.: *HH-60H Mission Mode Displays For The ANVIS-HUD System,* Rotary Wing Aircraft Test Directorate Memorandum, Naval Air Warfare Center Aircraft Division, Patuxent River, MD., August, 1993.



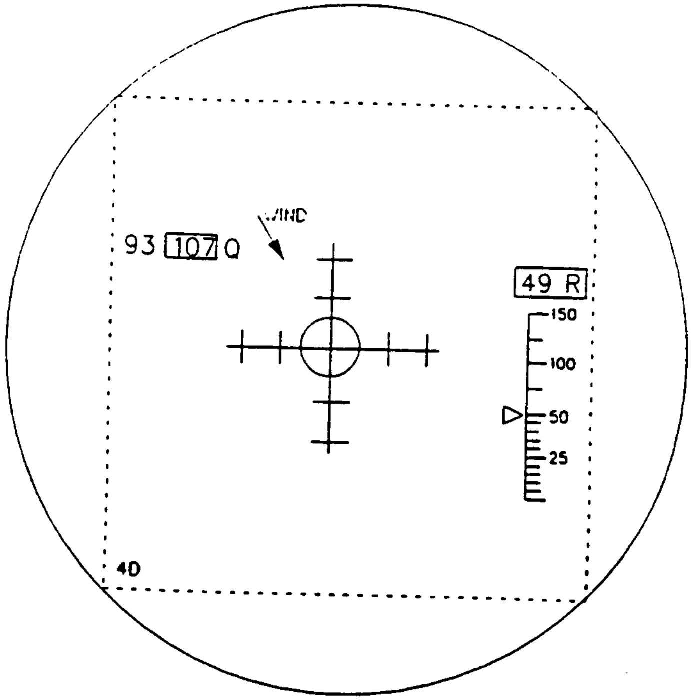
Mode 3D – Secondary (decluttered) Mode 3 Display
"Open Top & Bottom"



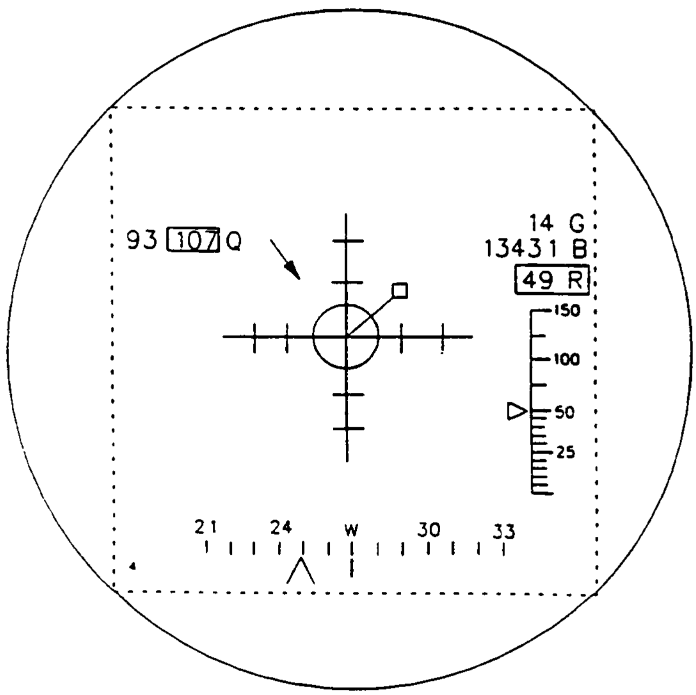
Primary Mode 3 Display
"Open Top & Bottom"

Figure 12. HH-60H ANVIS-7 Mode 3 Primary/Declutter Displays

Source: Kenney, K., and Peters, G.: *HH-60H Mission Mode Displays For The ANVIS-HUD System,* Rotary Wing Aircraft Test Directorate Memorandum, Naval Air Warfare Center Aircraft Division, Patuxent River, MD., August, 1993.



Mode 4D - Decluttered Mode 4 (Hover) Display



Primary Mode 4 (Hover) Display

Figure 13. HH-60H ANVIS-7 Requested doppler Mode Primary/Declutter Displays

Source: Kenney, K., and Peters, G.: *HH-60H Mission Mode Displays For The ANVIS-HUD System*, Rotary Wing Aircraft Test Directorate Memorandum, Naval Air Warfare Center Aircraft Division, Patuxent River, MD., August, 1993.

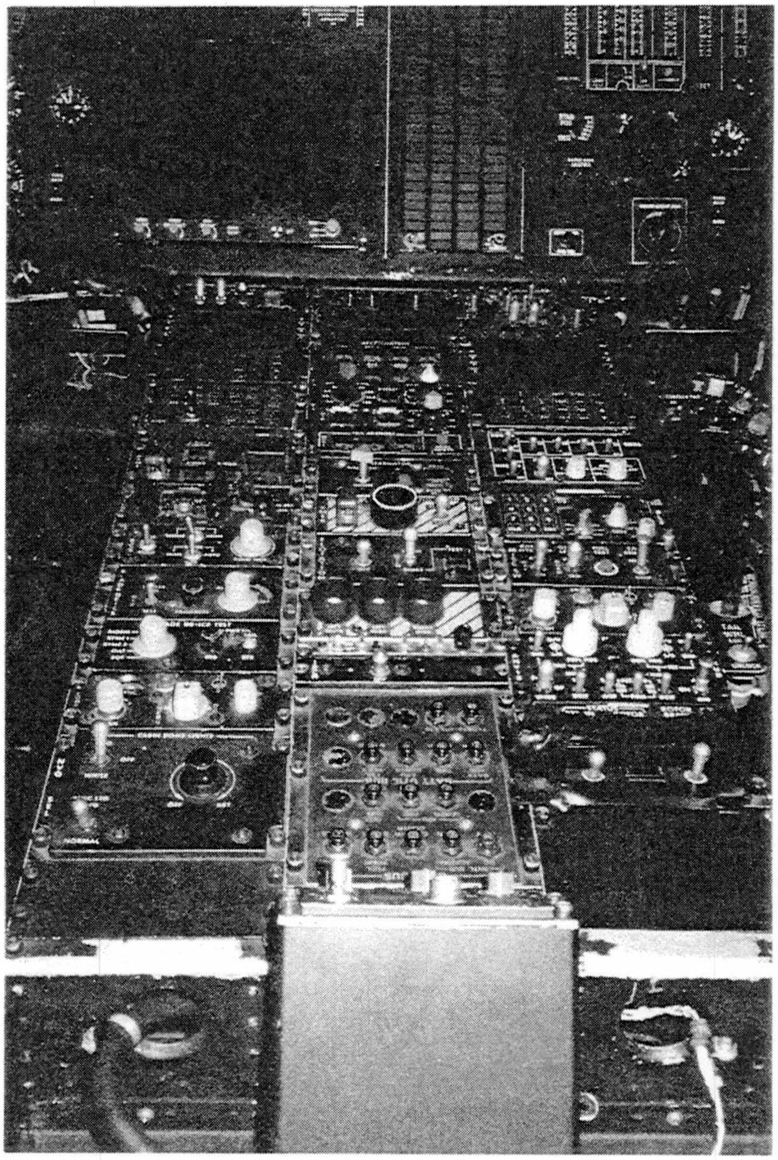


Figure 14, ANVIS-7 Control Panel Location
Source: *Kenney, K. NVG HUD Developmental Testing*, Draft Report to The Naval Helicopter Association Symposium, March 1994

VITA

Kevin M. Kenney was born in Philadelphia, Pennsylvania on August 25, 1963. He graduated from the University of Southern California in May of 1985 with a Bachelor of Science degree in Public Affairs, Cum Laude. Upon graduation he was commissioned an Ensign in the United States Navy and reported to flight school. He received his wings in July of 1986 and reported for Duty flying SH-3H helicopters with Helantisubron Sixteen and Helantisubron Two until March of 1991, during this period he transitioned to the Navy's newest helicopters, the SH-60F and HH-60H. He next attended the United States Naval test Pilot School where he flew over 25 different aircraft including sailplanes, gyrocopters, the MI-17 and MI-24, the F-16 and the KC-135. Upon graduation in July of 1992 he reported for duty in his current billet as a Developmental Test Pilot at the Rotary Wing Aircraft Test Directorate attached to the Naval Air Test Center, Patuxent River, Maryland. While serving in this billet he functioned as an NVG instructor pilot and project pilot involved with several NVG related projects including acting as the Project Officer for the NVG Helmet Mounted Display project upon which this thesis is partially based.