To the Graduate Council:

I am submitting herewith a thesis written by Major Marcus Gerard Mannella, USMC, entitled "Qualitative Evaluation of the AN/AVS-7 ANVIS Head Up Display with Baseline UH-60A/L Symbol Set as Installed in the USMC UH-1N Helicopter." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

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QUALITATIVE EVALUATION OF THE AN/AVS-7 ANVIS HEAD UP DISPLAY WITH BASELINE UH-60A/L SYMBOL SET AS INSTALLED IN THE USMC UH-1N HELICOPTER

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Marcus Gerard Mannella

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DEDICATION

This thesis is dedicated to my best friend and partner; my wife

Crystal Michelson Mannella

who knows better than anyone the investment of time, energy and thought required for me to arrive at the conclusions presented in this paper. Thank you, always, for your unselfish support during my tour as a Marine Test Pilot.

ABSTRACT

The UH-1N Helicopter is used to conduct Terrain Flight (TERF), Nap-of-the-Earth (NOE) Flight, Formation Flight with other helicopters, and Rotary Wing Close Air Support (RWCAS) to fulfill the requirements of the USMC Assault Support "Utility" Mission. To seize the advantage of surprise, these operations are often conducted in darkness, under very low ambient light levels. The AN/AVS-7 Night Vision Goggle (NVG) Head Up Display (HUD) system, or ANVIS HUD, allows pilots to maintain visual contact outside the cockpit while simultaneously monitoring vital flight instrument and navigation information.

The Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, MD recently conducted a qualitative evaluation of the UH-60A/L Baseline Symbol Set. A total of 36 pilots participated in the inflight evaluation. Roughly two-thirds of the group had some experience as a USMC Utility Mission Pilot. Additionally, the Pilot-Evaluator group included 14 school-trained Test Pilots with operational experience in 12 different types, models, or series of aircraft.

The ANVIS HUD demonstrated mature technologies which have tremendous potential for Assault Support Helicopters. The system will greatly enhance warfighting capability at night, especially in periods of reduced visibility.

The results, documented in this paper, revealed major deficiencies in the UH-60A/L Baseline Symbology as applied to the USMC Utility Mission. Flashing symbols were visually compelling causing a degree of fixation. For most NVG flight tasks, a less cluttered, essential-information-only display was desirable.

Flightworthy symbology for Rotary Wing applications must be aircraft and mission oriented. Presentation and functionality deemed acceptable for one community of Pilots may not be suitable for other communities and/or missions.

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LIST OF ABBREVIATIONS

AGL	-	Above Ground Level
ANVIS	-	Aviator's Night Vision Imaging System
AOB	-	Angle of Bank
ASAP	-	Aircrew Systems Advisory Panel
ASEF	-	Aircrew Systems Evaluation Facility
ATEF	-	Aircraft Test and Evaluation Facility
ATTD	-	Attitude (of the aircraft)
BARALT	-	Barometric Altimeter
BHTI	-	Bell Helicopter Textron, Incorporated
BIT	-	Built-in-Test
CCU	-	Converter Control Unit
CG	-	Center of Gravity
CRT	-	Cathode Ray Tube
CSERIAC	-	Crew Systems Ergonomics Information Analysis Center
DCR	-	Display Controllability Rating
DRR	-	Display Readability Rating
DU	-	Display Unit
DVE	-	Degraded Visual Environment
EMC	-	Electro-Magnetic Compatibility
EEPROM	-	Electronically Eraseable, Programmable, Read-Only-Memory
FOT&E	-	Follow On Test and Evaluation
FOV	-	Field of View
GCA	-	Ground Controlled Approach
HDIP	-	Head Down Instrument Panel
HDU	-	Helmet Display Unit
HIGE	-	Hover in Ground Effect
HMD	-	Helmet Mounted Display
HOGE	-	Hover out of Ground Effect
HQR	-	Handling Qualities Rating

HUD	-	Head Up Display
HVPU	-	High Voltage Power Unit
Hz	-	Hertz (cycles per second)
ICS	-	Intra-cockpit Communications System
IHADSS	-	Integrated Helmet and Display Sight System
II	-	Image Intensifier
ILS	-	Instrument Landing System
IMC	-	Instrument Meteorological Conditions
IOC	-	Initial Operational Capability
ITT	-	Inter-Turbine Temperature (T5 section)
KIAS	-	Knots, Indicated Airspeed
LLL	-	Low Light Level
MAWTS	-	Marine Aviation Weapons and Tactics Squadron
MCAS	-	Marine Corps Air Station
MIPL	-	Toggle back and forth between two solutions
NAS	-	Naval Air Station
NASA	-	National Aeronautics and Space Administration
NATC	-	Naval Air Test Center
NATOPS	-	Naval Aviations Training and Operating Procedures
NAVAIR	-	Naval Air Systems Command
NAWCAD	-	Naval Air Warfare Center Aircraft Division
NOE	-	Nap of (the) Earth
Nr	-	Main Rotor RPM (%)
NVD	-	Night Vision Device
NVG(s)	-	Night Vision Goggle(s)
NVIS	-	Night Vision Imaging System
OLF	-	Out-Lying Field
PCU	-	Pilot Control Unit
PMA	-	Program Manager Air
PNAC	-	Pilot-Not-At-the-Controls
RADALT	-	Radar Altimeter

RWCAS	-	Rotary Wing Close Air Support
SDC	-	Signal Data Converter
SOAR	-	State of the Art Report
TEMP	-	Test and Evaluation Master Plan
TERF	-	Terrain Flight
USMC	-	United States Marine Corps
USN	-	Unites States Navy
USNTPS	-	United States Naval Test Pilot School
Vne	-	Velocity, Never Exceed (Red Line)
VSI	-	Vertical Speed Indicator
WTI	-	Weapons and Tactics Instructor

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

The UH-1N Helicopter is used to conduct Terrain Flight (TERF) and Terrain Flight Navigation (TERF NAV) operations, Nap-of-the-Earth (NOE) flight operations, Formation Flight with other helicopters and Rotary Wing Close Air Support (RWCAS) to fulfill the requirements of the USMC Assault Support "Utility" Mission. To seize the advantage of surprise, these operations are often conducted in darkness, under very low ambient light levels. The AN/AVS-7 Night Vision Goggle (NVG) Head Up Display (HUD) system, or ANVIS HUD, allows pilots to maintain visual contact outside the cockpit while simultaneously monitoring vital flight instrument and navigation information.

The ANVIS HUD program is a joint acquisition between the U.S. NAVY and the U.S. ARMY with the oversight from the Program Manager for Night Vision and Electro-Optics (PM-NVEO), Ft. Belvoir, VA. One major goal of the program is commonality of components between services and across all airframes. The following ARMY aircraft are scheduled to receive the AN/AVS-7: the UH-60A/L, CH-47D, OH-58C/D, AH-1F and UH-1H. In addition to the USMC UH-1N, the following NAVY/MARINE CORPS aircraft are scheduled to receive the AN/AVS-7: the KC-130R, HH-60H, CH-46E, and potentially the CH-53D/E.

Originally, all ten aircraft were programmed to receive common functionality and a common symbol set. The Baseline Symbol Set was named "UH-60A/L" because the ARMY UH-60A/L aircraft received the first pre-production units for test (1).

The Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, MD (formerly known as the Naval Air Test Center (NATC)), was tasked with conducting a qualitative flight test evaluation (2) of the UH-60A/L Baseline Symbol Set, depicted in Appendix B, Figure B-1. The results, documented in this paper, revealed major deficiencies in the symbology as applied to the USMC Utility Mission.

Upon completion of a quick response development program by the NAWCAD Aircrew Systems Evaluation Facility (ASEF) to rapidly prototype the baseline symbology and after several meetings of the UH-1N Aircrew System Advisory Panel (ASAP), the UH-1N Program Manager decided to procure a mission specific symbol set, and substantially different functionality... uniquely tailored for the UH-1N mission. Shortly thereafter, the HH-60H, CH-46E and CH-53D/E followed suit by developing mission-specific symbol sets.

1.2 PURPOSE

The purpose of this paper is two-fold. First, and most directly, the purpose is to discuss the results of a qualitative evaluation of the UH-60A/L Baseline Symbol Set for the purpose of documenting symbology characteristics and developing a knowledge base regarding operator considerations for night vision device symbology in Assault Support Aircraft applications.

A secondary purpose is to provide a short discussion describing the rationale leading to the development of the UH-1N Specific Symbol set and the associated mitigation of previously documented deficiencies.

1.3 DESCRIPTION OF TEST AIRCRAFT

The UH-1N helicopter is a utility helicopter manufactured by Bell Helicopter Textron, Inc. of Fort Worth, Texas. The helicopter is powered by two T400-CP-400 turboshaft engines rated at 900 shaft horsepower each, un-installed. It has a two-bladed teetering rotor of 48 ft diameter and a two-bladed tail rotor. The UH-1N is capable of operating from prepared or unprepared surfaces, under visual or instrument conditions, day or night. The aircraft maximum allowable gross weight is 10,500 lbs. The flight crew consists of a Pilot, Co-Pilot, Crew Chief, and a Qualified Gunner (optional). The test aircraft, Bureau Numbers (BuNo's): 158768 and 160457, were representative of fleet UH-1Ns with the exception of the equipment under test and prototype mission systems (FLIR, Doppler, GPS etc...) A more detailed description of the UH-1N NATOPS Flight Manual (3). Photographs of the test aircraft are presented in Appendix B, Figure B-2.

1.4 <u>DESCRIPTION OF TEST EQUIPMENT</u>

1.4.1 AN/AVS-6 ANVIS NIGHT VISION GOGGLES (NVGs)

AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS) NVGs were 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. ANVIS are extremely sensitive to radiation in the 600 to 900 nanometer portion of the electromagnetic spectrum (orange to near infrared). They were designed to provide a gain of 25000:1, a nominal field of view (FOV) of 40 degrees, and a visual acuity of 20/40 under optimal conditions. The viewing module consisted of two Image Intensifier (II) tubes, each of which has a combination microchannel plate and a Cathode Ray Tube (CRT) to project a virtual image depicting an amplified scene (4). Power to operate the image intensifier tubes was supplied by a plastic, dual redundant, battery pack which attached to the back of the aviator's helmet and connected to the II tubes through a special visor housing. The battery pack could be configured to use either two 3.0 volt lithium batteries or four 1.5 volt AA Alkaline batteries (5). The ANVIS are Type I, Class A NVD's. Type I meaning directly viewed NVD's (Generation III image intensifiers) and Class A meaning the employment of a 625 nm objective lens filter. Additional AN/AVS-6 NVG operating characteristics are presented as Table A-1, Appendix A. Photographs of a pair of ANVIS-6 NVGs mounted on the standard helicopter helmet (Part No. SPH-3) are presented in Appendix B, Figure B-3.

1.4.2 AN/AVS-7 HEAD UP DISPLAY (ANVIS HUD)

The AN/AVS-7 ANVIS HUD was an electro-optical system combining the NVG image with digital symbology and computer-generated graphics. It was intended to display all information required by the aircrew for flight and to eliminate the need to constantly monitor the instrument panel. The ANVIS HUD is mounted on the AN/AVS-6 NVG, thereby providing head up display within the AN/AVS-6. The HUD is lightweight and can be mounted to either tube. It maintained display quality compatible with second and third generation goggles, and caused no apparent degradation in NVG performance. The AN/AVS-7 consisted of an "A" kit and a "B" kit. The "A" kit included: Mounting Hardware and Transducers, Wiring Provisions, Connectors, a Pilot Control Unit for each pilot's Collective Control Lever. The "B" kit included a Signal Data Converter (SDC), or system processor, a Helmet Display Unit (HDU) for each pilot and a Converter Control Unit (CCU) for in-flight programming and adjustments. A photograph of the system is presented as Appendix B, Figure B-4.

1.4.2.1 <u>Helmet Display Unit</u> (HDU)

The AN/AVS-7 HDU consisted of the High Voltage Power Unit (HVPU) module connected to a Display Unit (DU) module via a 150 mm cord. The HVPU was designed to provide for quick release while simultaneously eliminating the potential for an electrical arc in the event of a rapid egress from the aircraft. The assembly was designed to require a release force of 7.5 pounds in the event of emergency egress. The HVPU also had an eye selection feature for left or right eye HUD viewing. The DU imaging device is clamped to a AN/AVS-6 II tube. The wearer was provided with a 512 x 512 pixel array display with an area of 8.3 mm x 8.3 mm and Field of View (FOV) of up to 34 degrees diagonally. The projected HUD display could be adjusted +/- 1 mm, horizontally and vertically, for operator flexibility. A photograph of the HDU components is presented as Appendix B, Figure B-5.

1.4.2.2 Signal Data Converter (SDC)

The SDC was a symbol generator designed to use bit plane memory to compile information from various aircraft instruments and systems. This information was processed and sent to the DU for display. The symbol set generated in the SDC can be upgraded in software through the Electronically Erasable, Programmable, Read-Only-Memory (EEPROM). This allowed for individual tailoring to different missions or aircraft while maintaing commonality. The common SDC will be transformed to a mission specific processor at the unit level. The SDC was installed in the nose electronics bay (between fuselage stations 0 and 15) on the right side of the lower shelf, next to the battery.

1.4.2.3 Pilot Control Unit (PCU)

The Pilot Control Unit (PCU) consisted of a five position, four axis, non-latching switch, located on the Pilot and Co-Pilot Collective Lever control grips, which allowed the Pilot to increase/decrease symbology brightness and change modes. A photograph of a PCU is presented as Appendix B, Figure B-6.

1.4.2.4 Converter Control Unit (CCU)

The Converter Control Unit (CCU) was installed on the forward left hand side of the lower instrument console in the UH-1N. The CCU provided for in-flight control of functionality including:

1. Adjustment of Display Centering - Left, Right, Up & Down.
2. Adjustment of Symbology Modes - Modes 1 through 4 (Normal).
3. Toggling between Normal and Declutter Modes.
4. Symbol Set Programming.
5. Brightness Control - (Intensity Levels from Zero).
6. Built-In-Test (BIT) Actuation.

The CCU incorporated a programmable feature, which the average aircrew successfully manipulated in 10 minutes or less, allowing selection of four different modes of symbology. A photograph of the CCU is presented as Appendix B, Figure B-6.

1.4.3 DESCRIPTION OF THE UH-60A/L BASELINE SYMBOL SET

Prototype symbology was developed in May 1991 by a joint services working group as common symbology for all potential AVS-7 users. The Baseline Symbol Set was dubbed "UH-60A/L" because the ARMY UH-60A/L aircraft received the first pre-production units for test. The following paragraphs describe key symbols included in the UH-60A/L Baseline Symbol Set which is depicted in Figure 1.

Engine Torque values were presented numerically and were located at the eight o'clock position of the symbol set. When the "Yellow Arc" Intermediate (30 minute) Torque value (88%) was exceeded, a box appeared around the number as shown in Figure 1. When the "Red Line" Maximum Allowable Torque value (100%) was exceeded the box flashed at a rate of 2 Hz. The fixed Aircraft Attitude Reference Symbol consisted of a "Plus Sign" reticle centered on a conventional Pitch Ladder and Virtual Horizon Line combination which, in turn, provided the moving reference. The Angle-of-Bank Scale was presented in the lower half of the display, below the horizon and depicted +/- 30 degrees of Roll.

Angles of Bank greater than 30 degrees caused the Roll Pointer Symbol, which consisted of a small line segment similar in size to the Roll Angle graduations, to park at the 30 degree graduation and flash (also at 2 Hz).

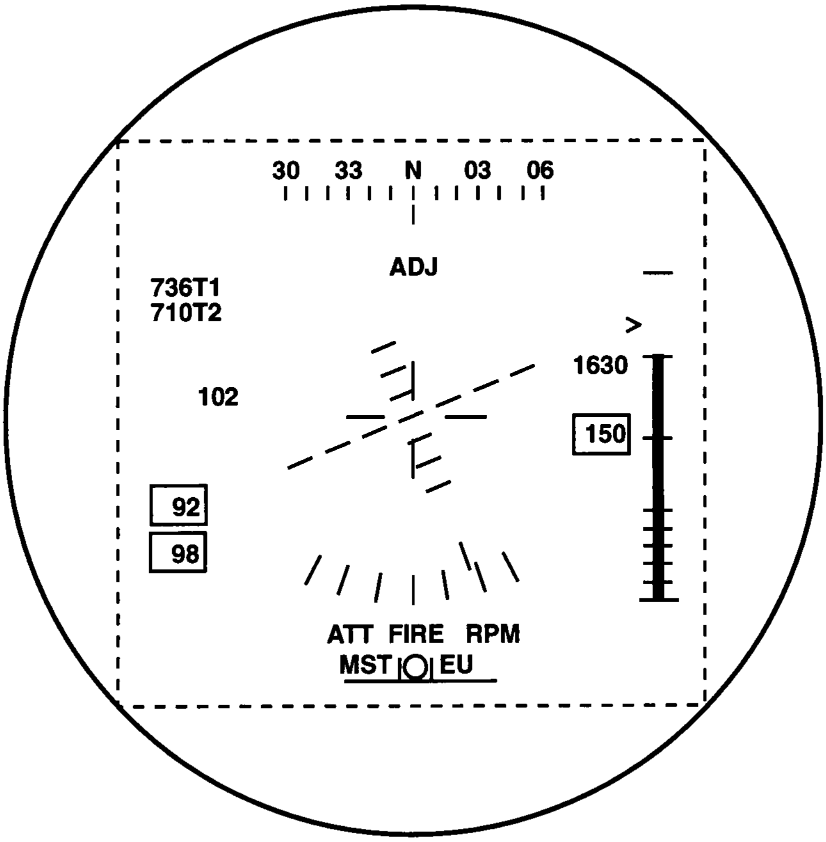

Figure 1

UH-60A/L BASELINE SYMBOL SET

The Radar Altimeter (RADALT) Symbol consisted of a thermometer type scale set inside a logarithmic scale from 0-200 ft AGL with fine 10 ft graduations for altitudes between 0-50 ft. The RADALT scale was located at the three o'clock position. The Low Altitude Symbol was depicted by a flashing box, similar to that prompted by overtorque conditions, wrapped around the RADALT Numerical value. The Vertical Speed Indicator (VSI), which depicted rate of climb or descent, was presented as a horizontal "V-Shaped" carrot along side the same scale used for the RADALT. Level flight, or a rate of climb/descent equal to zero, was indicated by a carrot position equivalent to 100 ft AGL on the RADALT scale, with +/- 2000 Feet-per-Minute (FPM) states being represented by a carrot position equivalent to the 200/0 ft AGL graduations, respectively. Illumination of the aircraft's Master Caution segment light, indicating illumination of one or more of the twenty-nine Caution-Warning Panel segments, was presented by the appearance of an "MST" message next to the trim ball. Inter-Turbine Temperatures (ITT) were displayed in alphanumeric format at the ten o'clock position of the display.

A more detailed description of the UH-60A/L Baseline Symbol Set is presented as Appendix B, Figure B-1.

1.5 HUD vs. HMD DISCUSSION

When describing a monocular overlay of symbology on a head worn NVD, the term Head Up Display or HUD is truly a misnomer. The ANVIS HUD is not a HUD in the conventional sense. Typical HUD applications consist of a combiners lens, rigidly attached and referenced to the airframe, which provides critical aircraft performance or targeting information, as is the case with the Kaiser Electronics display in the rear Pilot station of the BHTI AH-1W "SuperCobra" Helicopter, shown in Figure 2.

One might argue that because the ANVIS HUD is mounted on the ANVIS goggles, which are in turn mounted on the Pilot's helmet, that the AVS-7 would be more aptly described as a Helmet Mounted Display (HMD). While this description appears more accurate than HUD, HMDs are generally renowned for incorporating head tracking; and Pilot or world-stabilized frames of reference. To date there have been only a few HMD development efforts fielded. Although HMDs are generally thought of as being binocular, fielded monocular systems like the Integrated Helmet and Display Sight System (IHADSS) used in the AH-64 Apache helicopter, for example, could easily be considered HMDs. The author believes the AN/AVS-7 falls into another category altogether for two reasons.

First, unlike the combiner lens, the ANVIS HUD is not fixed to the airframe. Although the imagery behind the symbology is sensor driven, the sensor, or NVD, is attached to the Pilot's helmet. For this reason, the device is not limited to a particular head orientation for viewing.

Photo: *Gary Hammett, NAWCAD Patuxent River, MD*

Figure 2

KAISER ELECTRONICS HUD IN THE AH-1W "COBRA" HELICOPTER

The Pilot can view both the sensor imagery and symbology presentation while looking left, right, up or down... even while looking inside the cockpit! This type of flexibility is not typical of conventional HUD applications. As further discussion will show, such flexibility may come with a hazardous downside.

Secondly, unlike the HMD, the Helmet Display Unit (HDU) associated with the ANVIS HUD is not head-tracked. It is merely a monocular symbology *overlay* for the helmet-mounted ANVIS. Conformality, or the marriage of the virtual horizon to the actual horizon, becomes a key issue. In Rotary Wing applications, frame of reference has monumental implications as shown in Figure 3.

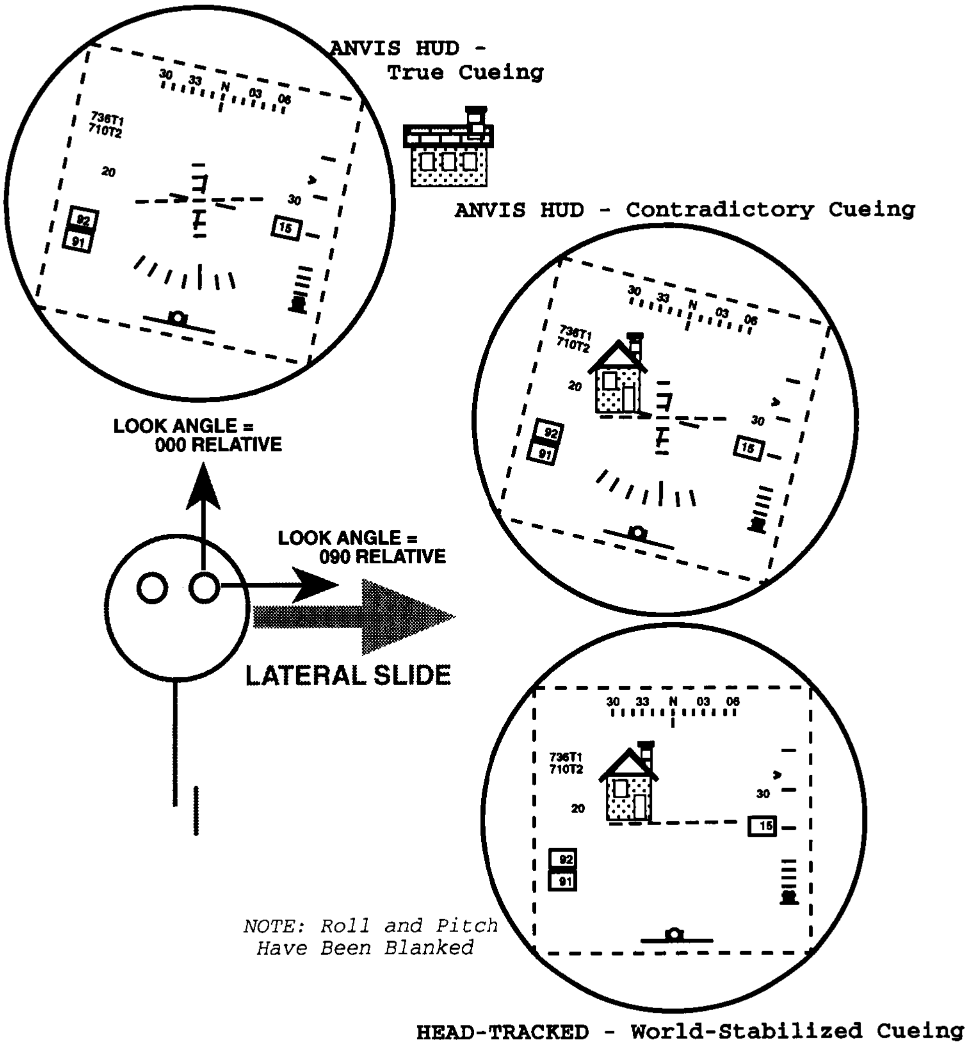

Figure 3

LATERAL SLIDE WITH DIFFERENT LOOK ANGLES

A world-stabilized reference system either blanks or transforms the symbology to account for look angles which differ significantly from aircraft motion. In the AN/AVS-7 application, the symbology is aircraft referenced, the display is head worn but <u>not</u> head tracked... leading to contradictory cueing. The ANVIS HUD is conformal if, and only if, the Pilot cooperates by orienting his head so that the two horizon depictions coincide! Whenever the Pilot tilts his head, e.g. towards the inside of a turn, the fidelity of the attitude symbology will be degraded. For this reason, use of such a device as a primary flight reference in degraded visual conditions may not be successful. Conformality issues are not limited to turning flight. In the case of the lateral slide from a hover, for example, with the Pilot looking 90 degrees away from aircraft heading (along the axis of translation), Roll cues appear as if oriented along the Pitch axis and vice versa as shown in Figure 3.

Again, selective blanking of particular symbols elements might be the most effective way to mitigate such a situation in an application which incorporates head-tracked world-stabilized cueing.

With these considerations in mind it may be best to think of the ANVIS HUD as providing flightworthy symbology for a night vision device rather than as a stand alone HUD or HMD.

CHAPTER II

SCOPE AND METHODS OF TEST

2.1 SCOPE OF TESTS

The evaluation was conducted from 15 August 1993 to 26 January 1994 and included a one week period of ground testing in the NAWCAD Aviation Test and Evaluation Facility (ATEF), and extensive flight testing in the NAS Patuxent River, Yuma Proving Ground and MCAS Camp Pendleton[1] operating areas. The system was evaluated during fleet representative flight maneuvers covering most of the Utility Mission spectrum. Test and test conditions (6) are listed in Tables 2 and 3, Appendix B. Approximately 28 dedicated sorties and a total of 74.8 hours of flight testing were completed. In addition, qualitative impressions of the ANVIS HUD were recorded during use in conjunction with non-dedicated HUD test sorties (an actual overwater night search and AN/AAQ-22 FLIR vehicle detection, recognition and identification testing). The aircraft was flown at a nominal 9,250 lb start gross weight and a midrange 138 inch start Center of Gravity (CG). Meteorological conditions, including transmissivity, varied extensively. Ambient illumination conditions ranged from 100% Moon phases with clear skies to Low Light Level (LLL) Starlight-Only conditions (<.0022 Lux) with both clear skies and overcast skies.

2.2 PILOT-EVALUATOR DEMOGRAPHICS

2.2.1 GENERAL

A total of 36 Pilots participated in the evaluation. The evaluator base included one USMC Colonel (O-6)[2], two USN Captains (O-6), five Lieutenant Colonels (O-5), five Majors (O-4), nineteen USMC Captains (O-3) and four USN Lieutenants (O-3). Roughly two-thirds (23/36) of the

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1 Patuxent River, MD / Yuma, AZ / Camp Pendleton, CA

2 Officer Rank levels - accepted by all U.S. Dept of Defense agencies.

group had completed at least one tour of duty as a USMC Utility Mission Pilot. In fact the majority of those had been only "Huey" Pilots with the mean flight time in model across the UH-1N group being 1745 hours. Additionally, the Pilot-Evaluator group included 14 United States Naval Test Pilot School (USNTPS) graduates with operational experience in the following 12 types of aircraft: the UH-1N, HH-1N, AH-1T, AH-1W, SH-2F, SH-3D, HH-46D, CH-46E, CH-53E, MH-53E, SH-60F and KC-130 making for a diverse mix of experiences and training. The following paragraphs are intended to draw a demographic picture of the evaluator base. Values are as reported by individual Pilot-Evaluators after their sortie.

2.2.2 TOTAL FLIGHT TIME DISTRIBUTION

Total flight time ranged from 780 hours to 5700 hours with a fairly linear distribution as shown in Figure 4:

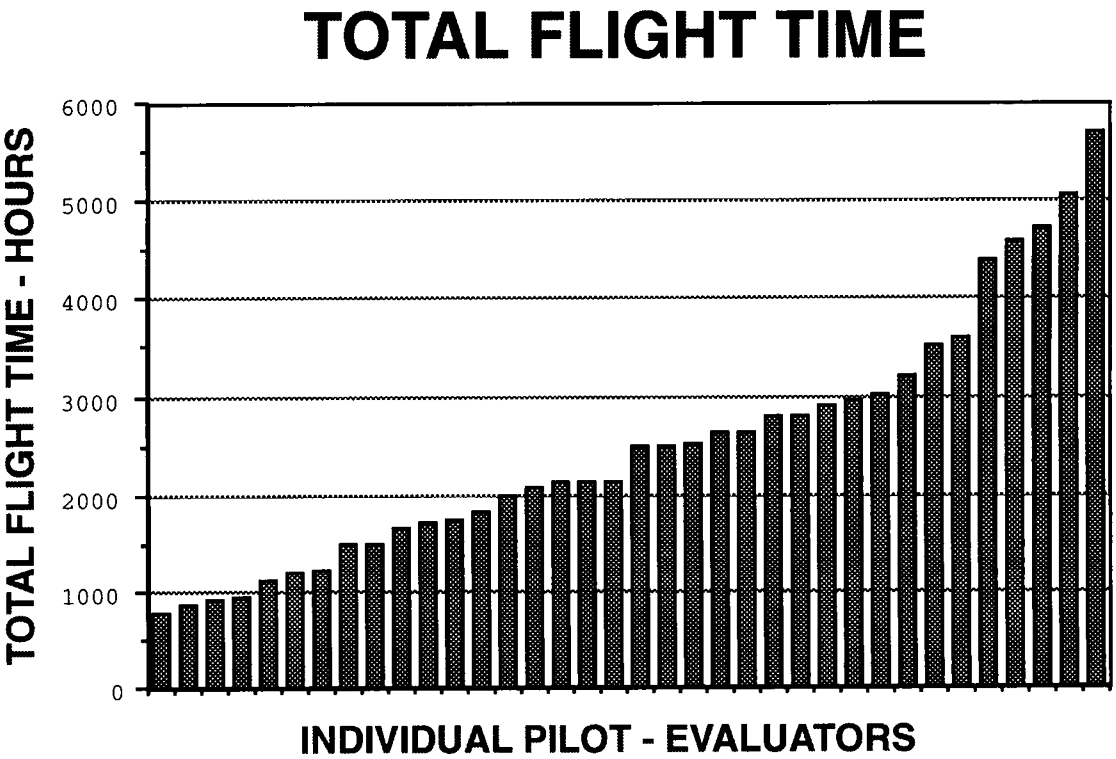

Figure 4

TOTAL FLIGHT TIME DISTRIBUTION

The mean flight experience across the Pilot-Evaluator base was 2845 total hours, with an average 1640 hours in one primary aircraft.

2.2.3 TOTAL FLIGHT TIME BY RANK

Total flight time by rank, presented as the mean per military rank grouping, is shown in Figure 5:

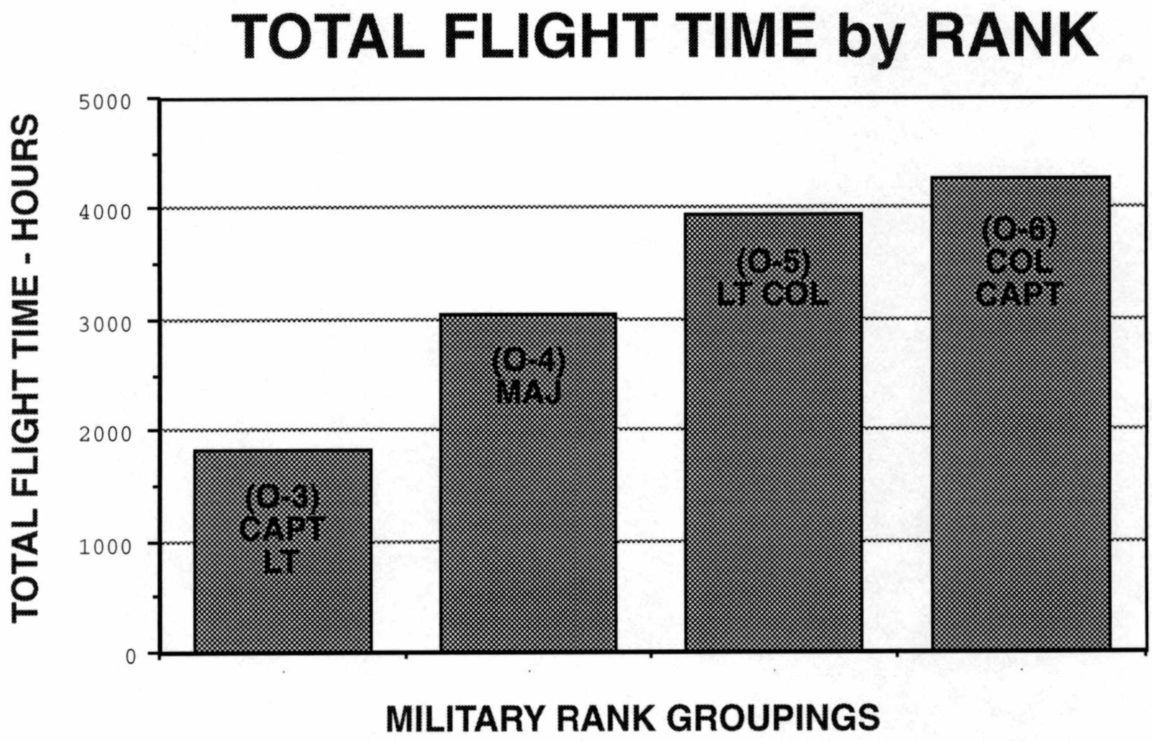

Figure 5

TOTAL FLIGHT TIME BY RANK

As one might expect, as a general rule, the more senior the Pilot-Evaluator was, the more total flight time reported. The average flight experience for the four ranks was as follows: Captain (USMC)/Lieutenant (USN) - 1850 total hours, Major - 3096 total hours, LtCol - 3940 total hours and Colonel (USMC)/Captain (USN) - 4629 total hours. The distribution was consistent with that of a typical USMC/USN aviation unit in that annual flight time for officers tapers off after the rank of O-5.

2.2.4 NVG FLIGHT TIME DISTRIBUTION

NVG flight time ranged from zero (for one evaluator) to 350 hours with a fairly linear distribution as shown in Figure 6:

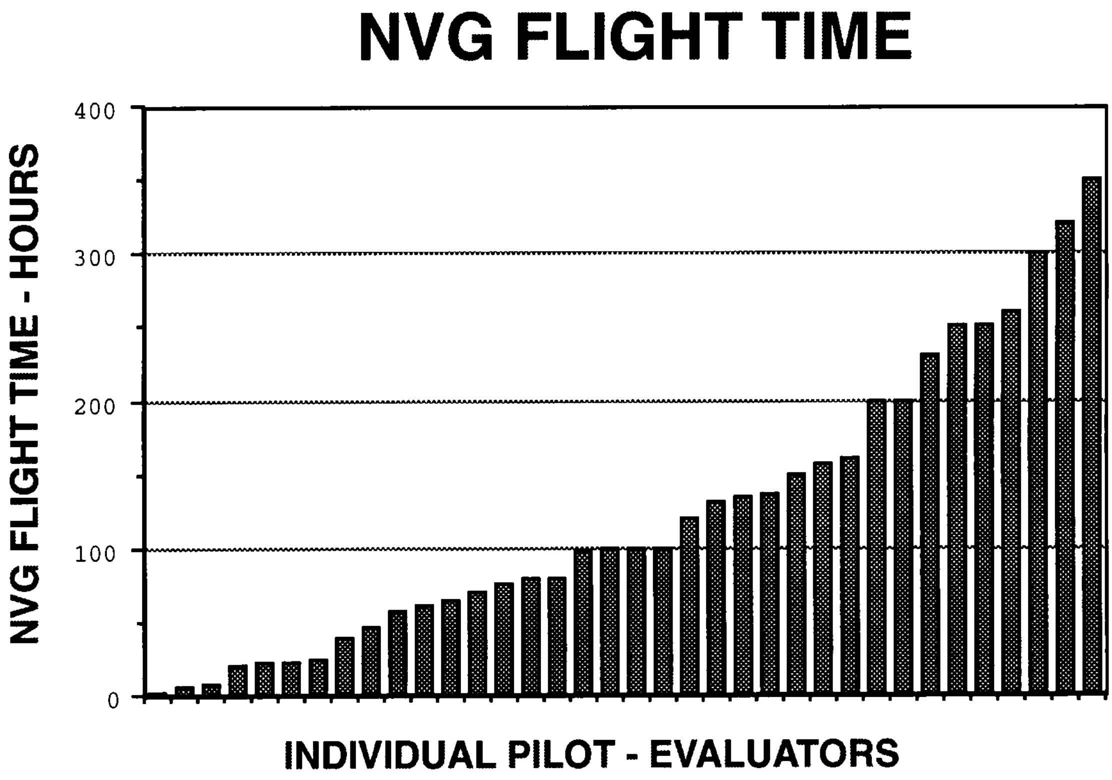

Figure 6

NVG FLIGHT TIME DISTRIBUTION

The mean NVG flight time was 123 hours. One of the USNTPS graduates was introduced to both the ANVIS-6 NVG and ANVIS HUD on the same sortie without reporting any difficulties. HUD brightness was increased from zero, introducing the symbology, after about an hour of pure NVG familiarization flight maneuvers. The Pilot-Evaluator adapted quickly and there was nothing remarkable about introduction of either system. The author estimates that a typical USMC Utility Pilot will have between 100-200 hours of NVGs at the completion of his first tour.

2.2.5 NVG FLIGHT TIME BY RANK

Total flight time by rank, presented as the mean for a military rank grouping, is shown in Figure 7:

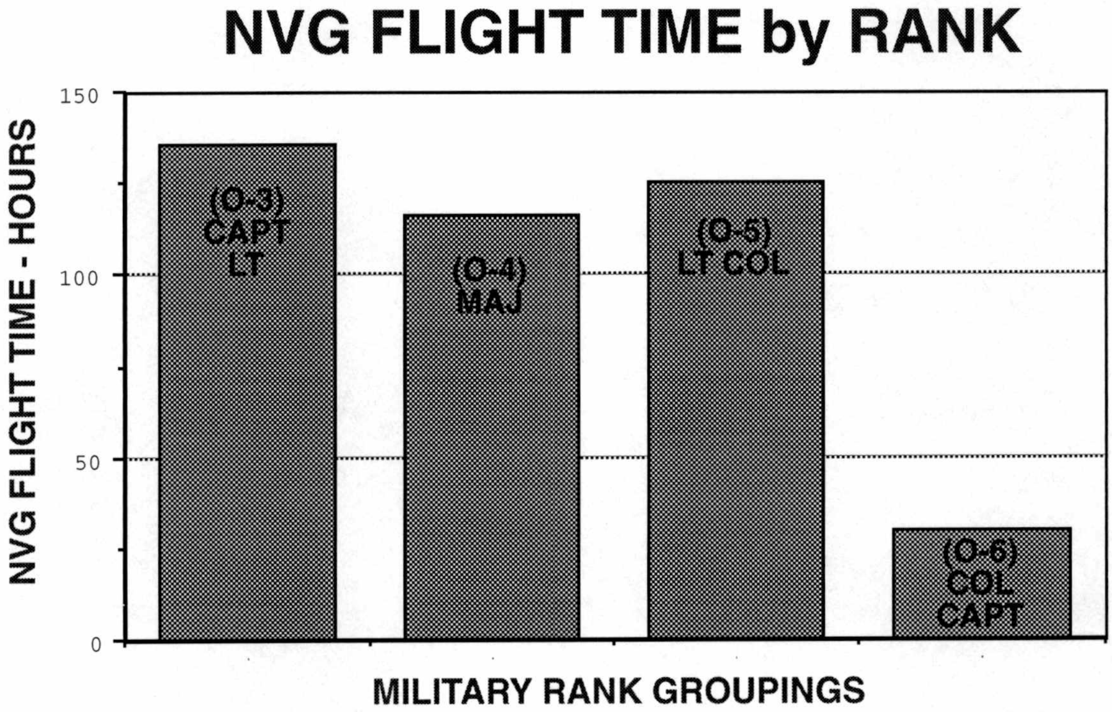

Figure 7

NVG FLIGHT TIME BY RANK

It is interesting to note that mean NVG experience was fairly constant for the lower ranks and dropped off dramatically between the O-5 and O-6 rank groupings. This apparent anomaly may be explained by reviewing the history of Night Vision Devices in the Navy/Marine Corps. The AN/PVS-5 NVG Initial Operational Capability (IOC), which marked the introduction of NVDs in the Marine Corps occurred in 1974. The AN/AVS-6 "ANVIS" IOC occurred in 1988 in the Marine Corps and around 1990 for the Navy. At the point of these hardware deliveries, the careers of each of the O-6 Pilot-Evaluators had evolved to a point which may have significantly limited opportunities for night flying and systems training.

2.2.6 AGE DISTRIBUTION

Pilot-Evaluator age ranged from 27 to 45 years with a fairly linear distribution as shown in Figure 8:

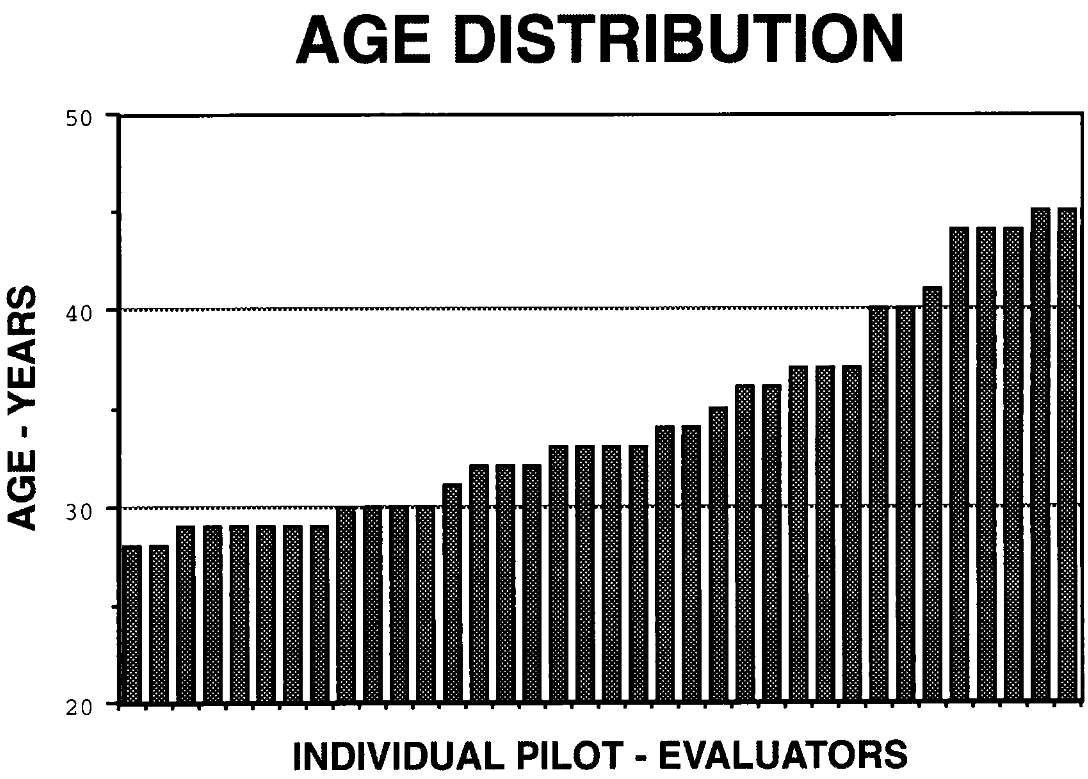

Figure 8

AGE DISTRIBUTION

The mean age of the Pilot-Evaluators was 34.5 years. The author found this interesting because Larry and Elworth (7,8) determined that refocussing onto the environment takes a long time, especially beyond age 35. Because the ANVIS HUD is not collimated, to appear as if symbols were actually "written" on the far objects in the scene, some misaccomodation[3] did occur.

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3 Misaccomodation - having to shift one's state of focus between far and near objects.

2.3 <u>METHODS OF TEST</u>

2.3.1 GENERAL

In addition to symbology effectiveness, several technical characteristics of the ANVIS HUD were documented. Lighting tests included measurement of the radiance and chromaticity of the CCU bezel lighting using a Photo Research Model PR-713AM Spectroradiometer in the cockpit, with the aircraft in a lighting controlled hangar (ATEF). System gain and resolution data was collected using a Hoffman ANV-120 System Gain and an ANV-140 System Resolution bench test set. Gain and resolution data were collected through AN/AVS-6 goggles with and without the ANVIS HUD HDU mounted on the NVD's. The compatibility of the AN/AVS-7 ANVIS HUD with the AN/AVS-6 goggles in various ambient illuminations was qualitatively evaluated by either the Pilot, Co-Pilot, or both. The ANVIS HUD was evaluated during ground turns prior to flight testing to verify that the HUD symbology corresponds to the applicable instrument. Results of the ground testing were judged against a variety of Military Standards and Specifications (9-17).

2.3.2 QUALITATIVE PILOT EVALUATION

Qualitative impressions were gathered during all flight testing, especially during the conduct of mission representative flight tasks flown in accordance with the USMC Assault Support Helicopter Tactical Manual (18). Proven USN flight test methods were implemented (19). Flight tasks, detailed in Tables A-2 and A-3, were first conducted with the non-flying Pilot <u>not</u> using the ANVIS HUD and acting as a safety observer (19). Factors that were evaluated included: symbol clarity, ease of interpretation of displayed information, head movement and stability, and FOV. Operator workload and performance evaluation were the focus of all flight tests. Interviews and engineer assessments were conducted to identify possible high workload areas. Video was recorded on all flights via a camera fixed to look through an ANVIS HUD system.

2.3.3 DAILY FLIGHT REPORT SUMMARIES

A Daily Flight Report Summary (form PRNC-NATC-3760/5) was completed following each flight evolution. Daily Reports or "Dailies", which represent a widely accepted post flight analysis tool used in flight test engineering, are designed to record major impressions immediately upon completion of the sortie. As an example, a copy of one of the "Dailies" recorded in this test is presented as Figures B-8 and B-9, Appendix B. The table and questions one through eight provided standard flight documentation (Pilot background, environmental conditions, aircraft configuration, instrumentation etc...). As a method to achieve target data and as a basis for comparison, an eighteen point survey was incorporated into the modified Daily Report format beginning with question nine. The questions contained in the survey were designed to focus the Pilot-Evaluator's concentration on specific accomodation phenomena (Was the symbology bright enough?, Did fixation occur? etc...). Although many of the "Dailies" were filled out by hand, about 45% were generated, by the Pilot-Evaluator, with an electronic form contained on a laptop computer. Eventually, all 36 "Dailies" were documented electronically and a tabulation of answer-data was created.

2.3.4 PILOT RATING SCALE

In an attempt to quantify display effectiveness and controllability issues attributed to the integration of the display, Pilot Rating Scales resembling the Cooper-Harper Handling Qualities Rating Scale (20) were adopted for use by the USNTPS graduate Pilot-Evaluators to augment their Daily Report comments. The scales were extracted from a Haworth-Newman NASA Technical Memorandum titled: Test Techniques for Evaluating Flight Displays (21). Diagrams which show the logic flow, decision matrix and criteria boundaries, for both of the scales, are presented as Appendix B, Figure B-10[4].

[4] An example deficiency statement which includes use of the scales is presented in paragraph 3.4.2

CHAPTER III

UH-60A/L BASELINE SYMBOL SET

3.1 GENERAL

Although the flight test uncovered several interesting issues regarding System Functionality (e.g. Cumbersome Warning Acknowledgement, Inadvertent Mode Changes (not labelled), Declutter Mode Capability), each worthy of discussion, the scope of this chapter is limited to issues regarding Pilot adaptation to flightworthy symbology (e.g. Fixation), the overall effectiveness of the UH-60A/L Symbol Set and more detailed observations of individual symbol elements contained therein. Likewise, several very noteworthy Operator-Machine Interface discoveries (Peripheral Vision Blockage by the the DU Cord, Egress Complications caused by the DU Cord, Insufficient Maximum Brightness Level, and Conformality Issues) have been excluded from this discussion. A comprehensive record of those findings is contained in the NAWCAD final report which is pending release. The UH-60A/L Symbol Set was evaluated under the conditions presented in Tables A-2 and A-3, Appendix A.

3.2 PILOT PREFERENCE DATA/SURVEY RESULTS

3.2.1 GENERAL

A statistical analysis of the data was accomplished to determine a confidence factor by which to view the results. Results were statistically significant in that usually two thirds or more of the group shared the same opinion on issues raised by the survey. Unprompted feedback was aligned in many cases as well. The results have been used by the author to establish operator preferences only. Specific hypothesis have been left for the reader to form on his/her own. Five of the more significant findings are presented in the following paragraphs.

3.2.2 EFFECTIVENESS OF THE ANVIS HUD

Initial acceptance of the ANVIS HUD concept was very high. Across the evaluator base, 29 of 36 "Dailies" (81%) contained positive summary comments regarding the effectiveness and potential of the ANVIS HUD. The balance of Pilot-Evaluators either did not answer or offered a neutral response to the question: "Was Symbology Effective?." There were no negative comments. A plot of individual preferences correlated to both Total and NVG Flight Times is shown in Figure 9:

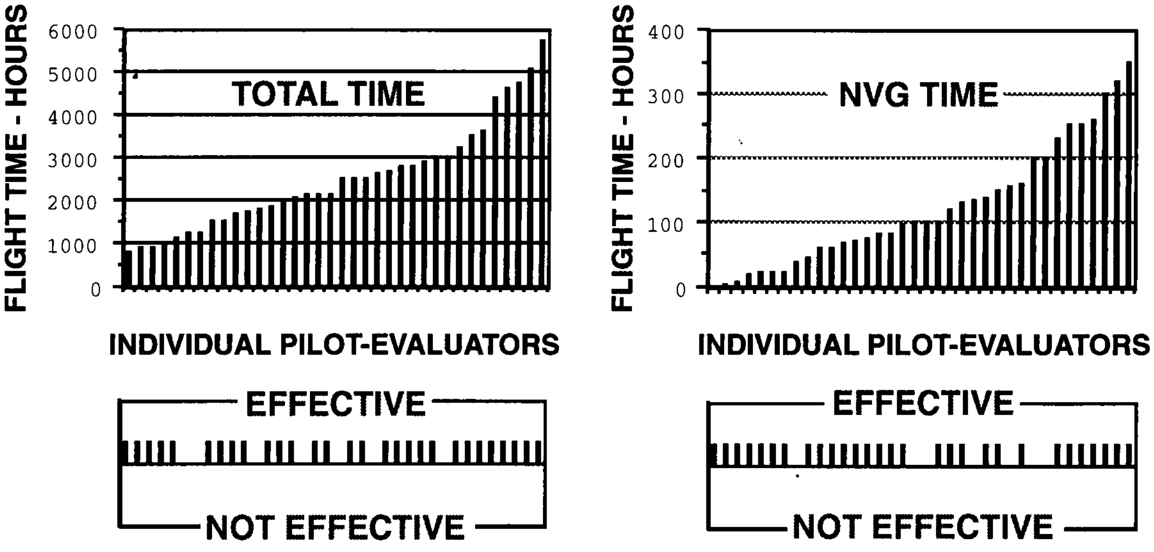

Figure 9

EFFECTIVENESS OF THE ANVIS HUD

The following excerpts help depict the excitement associated with introduction of the ANVIS HUD:

1) "Overall, very impressed!" *(Capt, UH-1N, 1225, 200)*[5]

2) "The (ANVIS) HUD should be a significant aid to NVG flying." *(Capt USN, SH-3D, 5060, 29)*

3) "...easy to use, even for a beginner." *(Lt USN, HH-46D, 1500, 1)*

4) "(The ANVIS) HUD is a Winner!" *(LtCol, UH-1N, 3500, 60)*

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5 Format = (Rank, Primary Aircraft, Total Time, NVG Flight Time)

3.2.3 EFFECTIVENESS OF THE UH-60A/L ATTITUDE SYMBOLOGY

General acceptance of the UH-60A/L Attitude Symbology was very low with negative comments recorded in 21 of 36 "Dailies" (58%). It is interesting to note that although the majority of the remaining 15 "Dailies" contained either no response or neutral comments with regards to the effectiveness of the Attitude Symbology, three contained *positive* comments to the question: "Did the Attitude Symbol provide good or bad cues?" A plot of the preferences correlated to flight experience is shown in Figure 10:

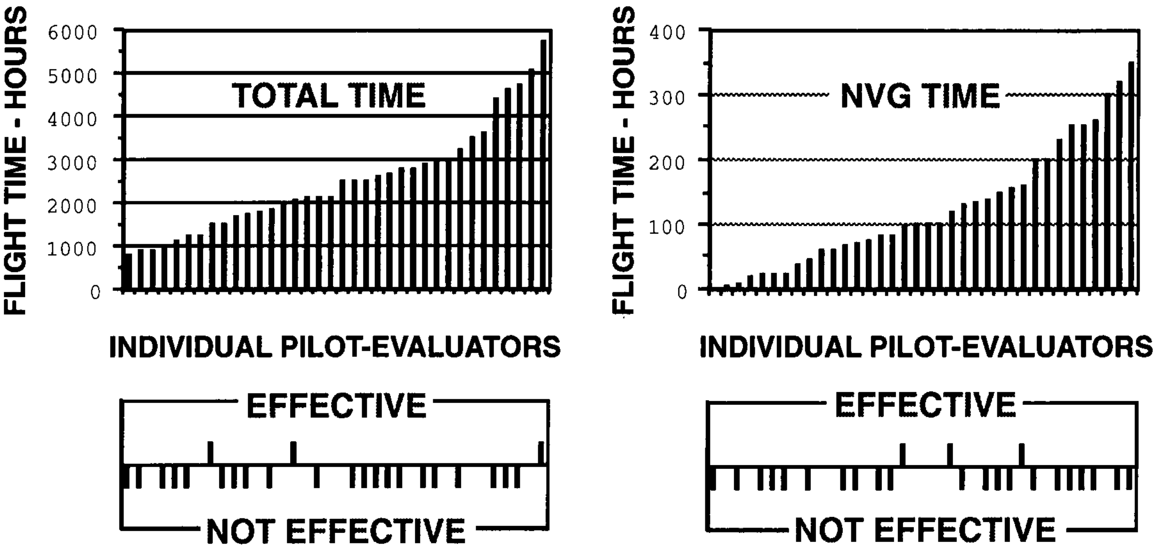


Figure 10

EFFECTIVENESS OF THE UH-60A/L ATTITUDE SYMBOLOGY

A major factor in the negative outcome of the results is attributable to the symmetrical nature of the Attitude Reference symbol, or "Plus Sign". A more detailed discussion is presented in paragraph 3.4.1 below. The following excerpts help depict the overall lack of acceptance of the UH-60A/L Attitude Symbology:

1) "The 'Plus Sign' was confusing." *(Maj, UH-1N, 2560, 80)*

2) "I did not like the attitude symbol." *(Capt, UH-1N, 1200, 200)*

3) "For most tasks, attitude cues were distracting."

(Capt USN, UH-1N, 4741, 46)

4) "Make (the) Horizon a simple line." *(Capt, UH-1N, 3200, 320)*

3.2.4 UNACCEPTABLE LEVEL OF CLUTTER

The majority of the Pilot-Evaluators made unsolicited negative comments regarding the level of clutter. A plot of individuals who considered the level of clutter to be higher than acceptable and their associated flight experience is shown in Figure 11:

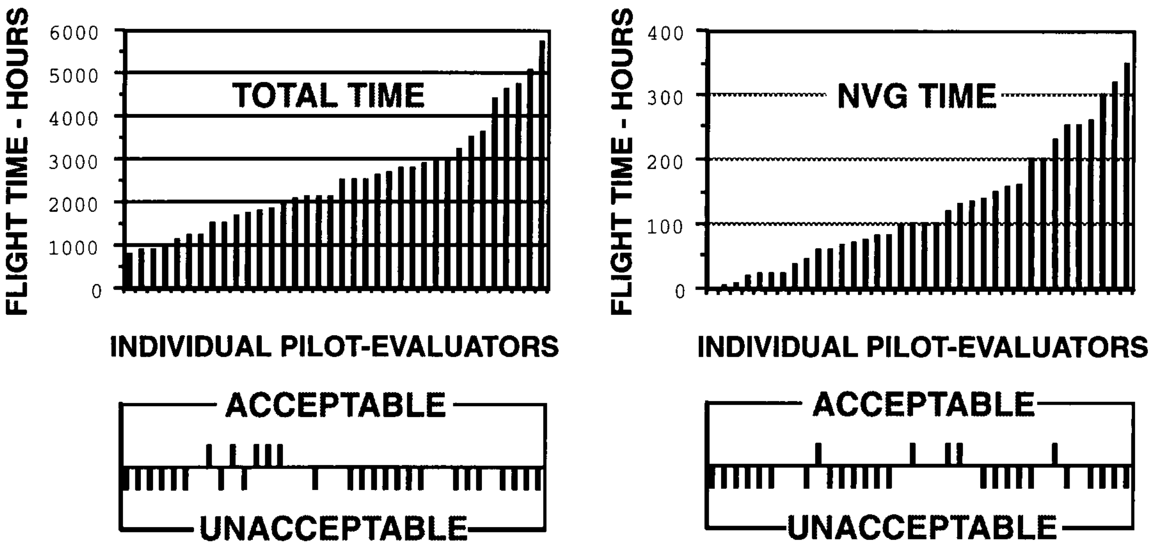


Figure 11

UNACCEPTABLE LEVEL OF CLUTTER

The following excerpts help depict the overall lack of acceptance of the level of clutter:

1) "Decluttered Mode (was) easier to use." *(Maj, UH-1N, 2800, 300)*

2) "... had an excessive amount of clutter." *(Maj, UH-1N, 2560, 80)*

3) "A less cluttered/essential-info-only display was preferred."

(Capt, UH-1N, 2800, 250)

4) "ANVIS HUD with reduced symbology worked best."

(Capt, UH-1N, 1750, 100)

3.2.5 USE OF FLASHING SYMBOLS.

General acceptance of flashing symbols was low. A plot of those individuals who didn't approve of the use of flashing symbols and their associated flight experience is shown in Figure 12:

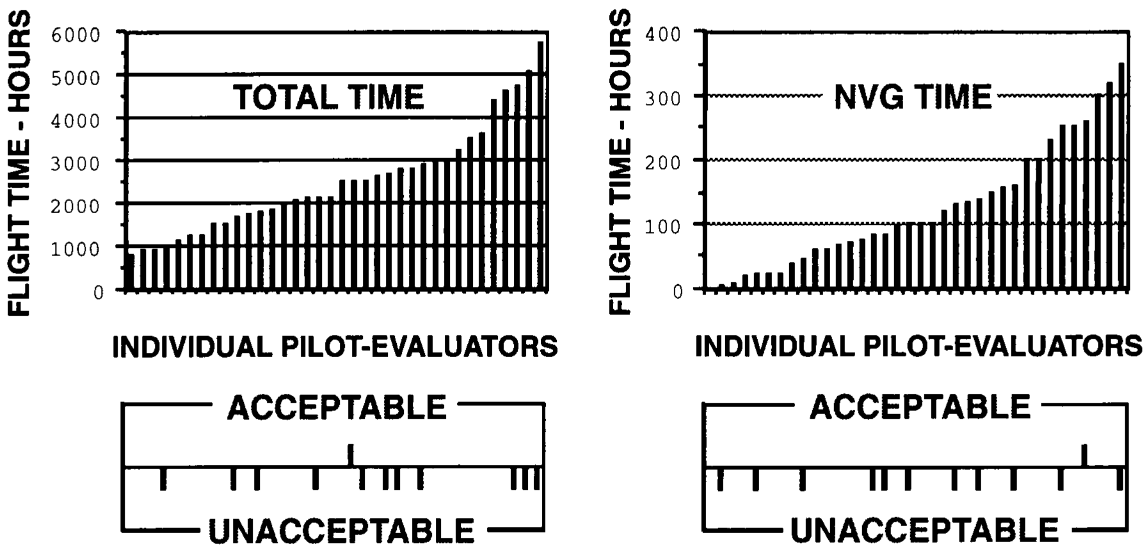


Figure 12

USE OF FLASHING SYMBOLS

Although unsolicited negative comments appeared in only 11 of 36 "Dailies" (31%), the comments were worded strongly enough to warrant further investigation. The following excerpts help depict the overall lack of acceptance of the level of clutter:

1) "The flashing box... was visually compelling and caused an aft drift in a hover." *(Capt, UH-1N, 2800, 250)*
2) "The flashing RADALT box was annoying." *(Capt USN, UH-1N, 4741, 46)*
3) "The flashing display was very distracting." *(LtCol, UH-1N, 5700, 160)*

Commentary on flashing symbology included, by far, the most entertaining, descriptive and passionate analysis received in the survey:

4) "I stared at the flashing box (RADALT) like it was a cold beer in the middle of the desert!" *(Capt, UH-1N, 980, 80)*

3.2.6 OCCURRENCE OF FIXATION.

The very colorful comment in the above paragraph points to a strong potential for fixation; which was reported by 23 of 36, or 64%, of the Pilot-Evaluators to some degree. Seven either did not respond or gave neutral answers to the question: "DID FIXATION OCCUR?" A plot of individuals reporting the occurrence of fixation correlated to flight experience is shown in Figure 13:

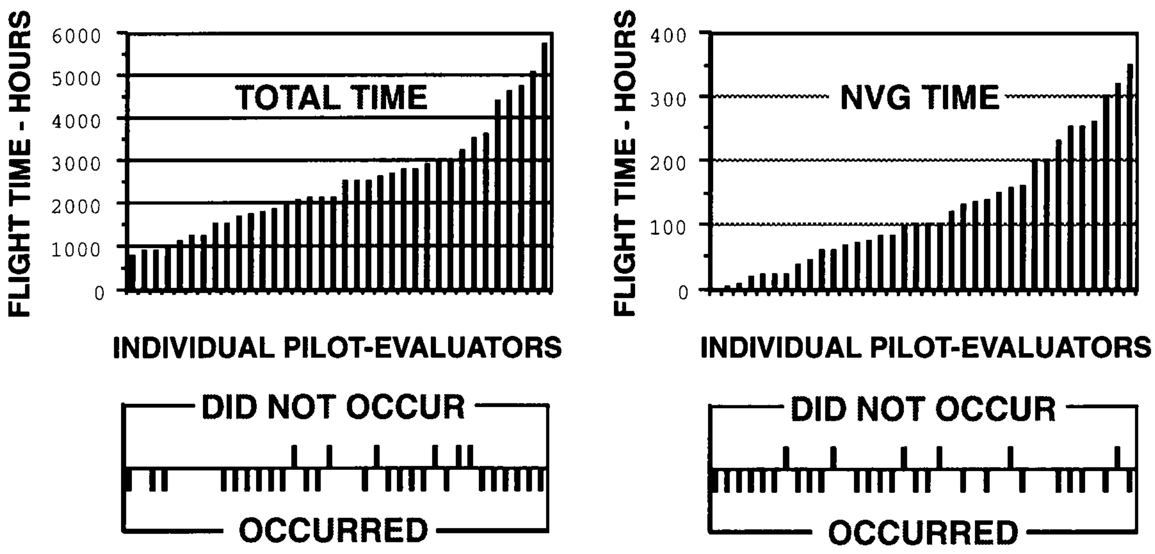


Figure 13

OCCURRENCE OF FIXATION

It is interesting to note that two of the six Pilot-Evaluators who reported not having experienced fixation at all, were the survey's only pilots who had flown a conventional-HUD-equipped aircraft, the AH-1W, as their primary aircraft. Although these data are not suuficient in quantity to establish a conclusion, it may suggest that susceptibility may decrease as experience with look-through symbology is increased.

3.3 REDUCED PILOT PREFERENCE DATA: KEY POINTS

Key Points are salient features or characteristics of the system, or it's use, which were discovered during testing. The Daily Flight Reports were reviewed to determine if trends or themes existed in the free text comments provided by the 36 Pilot-Evaluators. Significant comments were extracted, by the author, numbered in chronological order, rephrased slightly and labelled as Key Points. (Note: "Dailies" are written in bullet style. A degree of author's license has been added to the comments, creating minor differences from the original wording). A digest of Key Points and their associated Pilot-Evaluator comments is presented as Appendix C. An expanded discussion of the more noteworthy Key Points is contained in the following section.

3.4 INDIVIDUAL SYMBOL-ELEMENT OBSERVATIONS

3.4.1 CONFUSION CAUSED BY THE SYMMETRICAL NATURE OF ATTITUDE SYMBOL (KEY POINT #13 & 29).

The attitude symbol consisted of a fixed "Plus Sign" aircraft/moving reference and a Pitch Ladder/Virtual Horizon Line fixed reference. The Pitch Ladder was comprised of six small parallel graduations above the horizon, and six identical graduations below the horizon, depicting ten degree increments of Pitch Angle for a continuous total coverage of +/- 60 degrees. The Pitch Ladder was quite a bit larger and more apparent than the aircraft reference Plus Sign. The attitude symbology was designed in an aircraft stabilized frame of reference. In other words, irrespective of look angle, the Pilot viewed symbology referenced to the airframe body. Attitude symbology was as shown below in Figure 14:

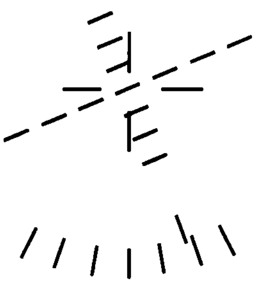


Figure 14

UH-60A/L ATTITUDE SYMBOLOGY

Because of the symmetrical nature of the plus sign, attitude cues were, at times, confusing. Roll attitude was probably the most confusing. Determining the input needed to Roll wings level during unusual attitude recoveries, over water, was slightly difficult because the symmetry caused a slight delay in decision making. Visual contact with the actual horizon immediately reduced the confusion level reinforcing the earlier Pilot-Evaluator opinions that attitude cues were not needed for NVG flight (paragraph 3.2.2). Several Pilot-Evaluators incorrectly described the Roll input needed to level the wings when presented with the depiction in Figure 14 by itself. One factor to explain this is the opposite sense of the Roll indication (from that of typical HDIP Attitude Indicators) as is discussed in paragraph 3.4.2 below. Another factor might be in the convention established for depicting symbology: aligned with the page edges. By presenting a display which has linear features, such as the RADALT thermometer, aligned in a parallel/perpendicular manner to the page edges (for aesthetic value), the horizon is depicted as having rotated dramatically (which is not physically possible). Since symbology displays such as Figure 14 rarely include a depiction of the actual horizon, the interpreter tends to equate the angled elements with a Roll angle. It is easy to see why Pilots could look at Figure 14 and think that the aircraft is rolling left when, in fact, it is rolling right as shown in Figure 15:

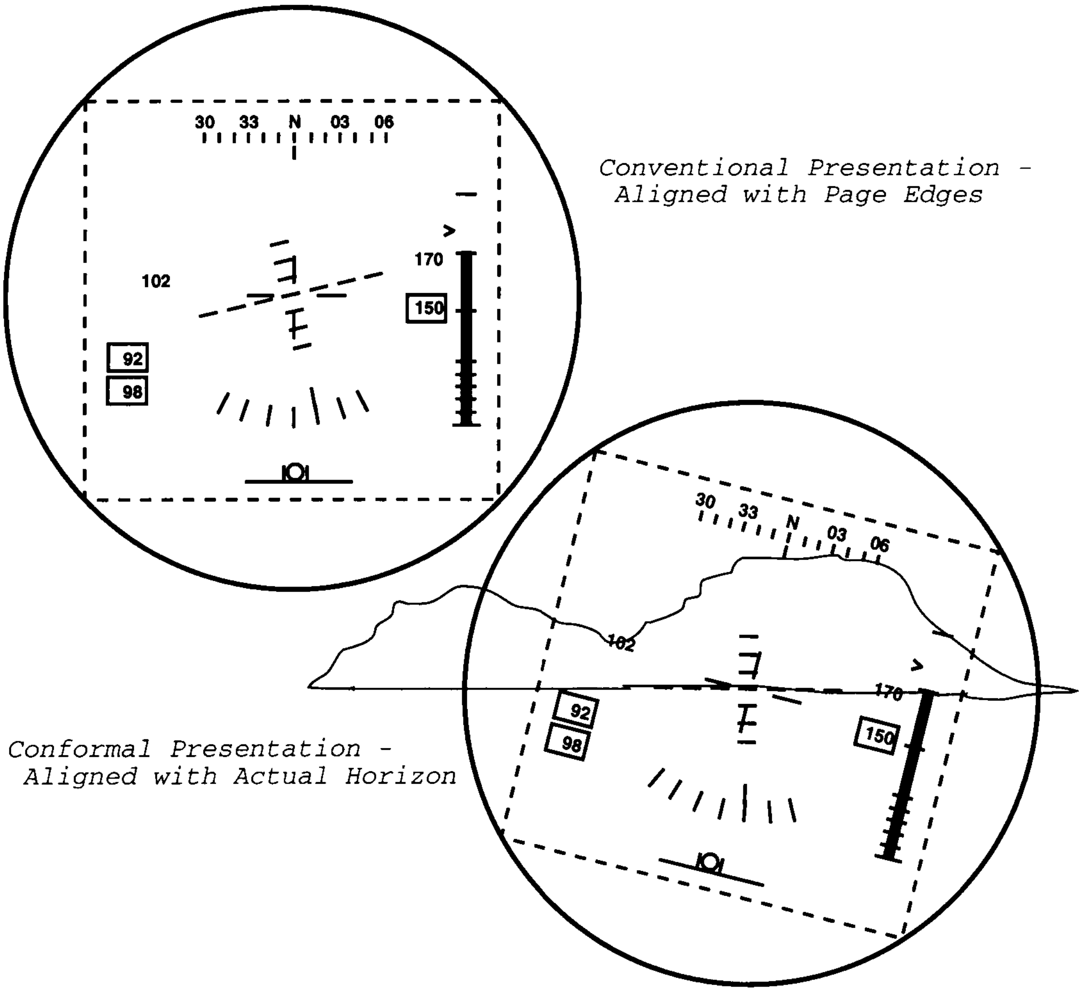


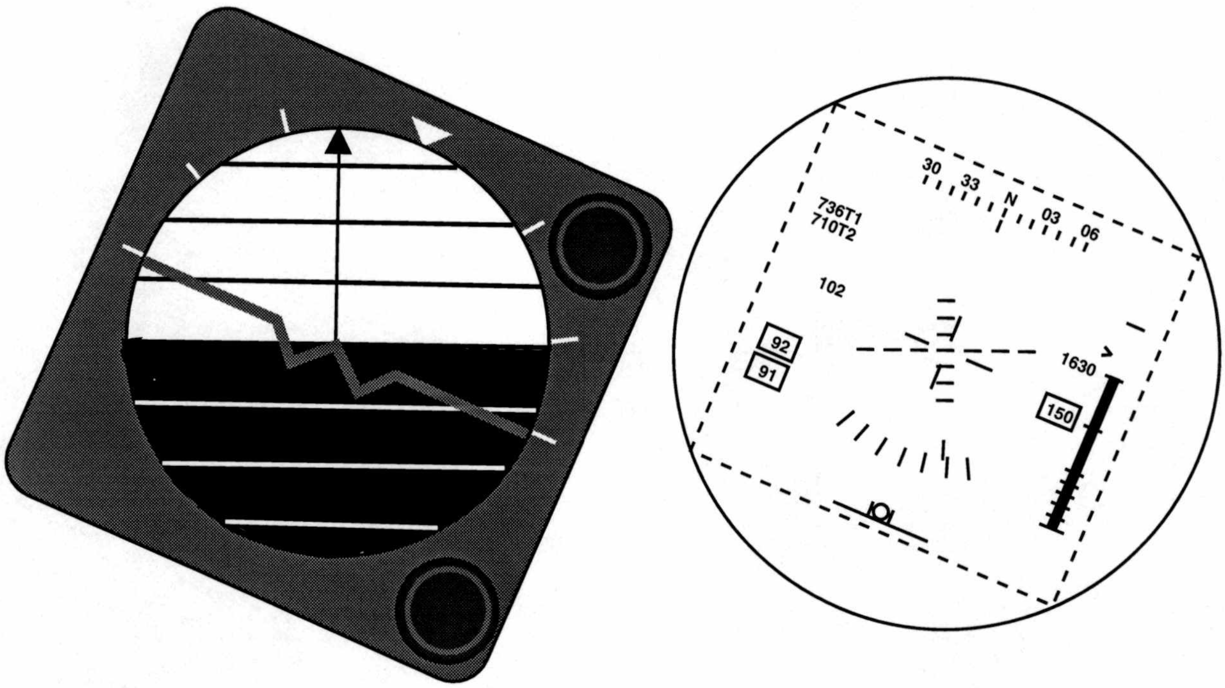
Figure 15

ATTITUDE PRESENTATION WITH AND WITHOUT ACTUAL HORIZON

Because of it's symmetrical nature, the Utility Mission Pilot will have difficulty using the UH-60A/L Attitude Symbology to correctly control the aircraft during flight in a degraded visual environment (DVE). The potential to misinterpret the symbol element is high. <u>The author believes, therefore, that the UH-60A/L Attitude Symbology should not be used as a primary flight reference</u>.

3.4.2 OPPOSITE SENSE OF THE ROLL INDICATION (KEY POINT #10).

The Roll Angle presentation consisted of a Roll Pointer and Scale in the lower hemisphere of the symbol set. The presentation had the negative or opposite sense as that of the HDIP attitude indicator. To highlight differences in presentation between the two displays, a 20 degree angle of bank right turn is depicted for both below in Figure 16:



HDIP Attititude Indicator   ANVIS HUD Roll Symbology

Figure 16

OPPOSITE SENSE OF THE ROLL INDICATION

Holding a steady bank angle (+/- 2 degrees) in a level turn was difficult requiring dedicated concentration on the Roll Pointer and two extra corrections for each mistaken input (DCR 5)[6].

Although not an immediate safety of flight concern, the inconsistency was annoying and workload intensive. An additional

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6 DCR 5 = Display Contollability Rating 5. (App B, Fig B-10, Ref 20)

discussion regarding Roll Pointer sensing is presented in paragraph 4.2.5 below.

3.4.3 DIFFICULTY IN DETERMINING RATE AND TREND INFORMATION FROM THE RADALT THERMOMETER SYMBOL.

The RADALT presentation consisted of two elements: a digital numerical value and an analog thermometer type symbol. Although the numerical value was generally useful, the analog thermometer did not provide sufficient cues for precise altitude control during low level flight over water or while executing the quick stop maneuver[7] (3). It was difficult to determine small changes in altitude or trend reversals from the thermometer itself. Although the numerical presentation provided fine detail sufficient to precisely determine altitude for steady, level flight, it was too active to be useful when the aircraft was climbing or descending, when the terrain was not level or flight under both conditions.

3.4.4 POOR TREND CUEING FROM THE TORQUE SYMBOL. (KEY POINT #5)

Because of it's numerical presentation, the torque symbol was a very poor trend cue. The following comment was extracted from an early Daily Report to form Key Point #4:

"The numerical torque value was not effective as a warning of (an) impending limit approaching. It was hard to 'find' when quick trend information was needed." *(Capt, UH-1N, 2800, 250)*

This was true, to some degree, in all numerical presentations (Airspeed, RADALT numerical), but was clearly evident in the torque

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[7] The Quick Stop maneuver is a level speed change performed at 50 ft AGL, with the goal of a rapid deceleration from 100 KIAS to zero.

presentation. Because the USMC UH-1N aircraft is often operated in extreme environmental conditions, at maximum gross weight with small power margins, the potential for overtorque situations is high. Cueing to warn of approaching limits is critical.

3.4.5 ANALOG vs. DIGITAL (KEY POINTS #4 & #18)

In addition to the issues raised in the above paragraph, digital symbology must be carefully placed to be fully effective. The following comment was extracted from the Daily Reports to form Key Point #18:

"The torque and airspeed symbols are in close proximity and are identical digital presentations which were occasionally confused with each other." *(Maj, UH-1N, 2520, 80)*

Because of visual nature of NVD flight and the need to see "through" the symbology, analog symbols are better than digital symbols for clear trend presentation. Determination of sense (e.g. climbing vs. descending) is a by-product of a clear trend presentation. Analogies of the actual scene or analog replicas of HDIP "steam" gauges which provide easily interpretable sense and trend cues in an intuitive or "nearly subconscious" manner will provide the best head up augmentation to aided night flight.

3.4.6 POTENTIAL USE OF INTENSITY DIFFERENTIALS (KEY POINT #35)

The concept of highlighting key symbols by increasing their intensity was suggested in Daily Report # 17 by a USNTPS graduate with AH-1W HUD experience. The following excerpt documents this Pilot-Evaluator's response to question 9.H.: "DID THE ATTITUDE SYMBOL ELEMENTS PROVIDE GOOD OR BAD CUES? (DESCRIBE):"

"It was OK, but the reference element (the Pitch Ladder) needs to be differentiable (by pattern/Color/Intensity etc...). Perhaps by making the Pitch Ladder intensity independently adjustable."

(Maj, AH-1W, 2628, 157)

The author concurred that the idea had merit and, subsequently, Key Point #35 was generated:

KEY POINT # 35 = A NEW APPROACH TO DECLUTTERING THE CENTER FOV, WHILE STILL PROVIDING USEFUL CUES, MIGHT BE SYMBOL INTENSITY DIFFERENTIALS.

Weintraub and Ensing, in a State of the Art (SOAR) report from the Crew System Ergonomics Information Analysis Center (CSERIAC), recommend against the use of colors for look-through symbology. The Book of HUD (7), states that, although color coding has been shown to be advantageous over shape coding in conventional (HDIP) displays, the advantage has not been demonstrated for HUDs. Apparently, the continually changing background scenery makes the differentiation of colors difficult.

The current technology appears to be easily modified to include a variable intensity feature. The Stroke Display architecture of the AN/AVS-7 lends itself more easily to the highliting of discrete symbol elements than would a Raster Scan methodology. It is difficult to predict the effectiveness of intensity differentials, however their use appears to have promise. The author believes a key to the success will lie in the ability to preserve intensity delta's between symbols, whenever the overall intensity is changed to match the scene. Intensity is generally increased above the that of non-compatible cultural lighting in urban areas, and decreased to a more comfortable level in the darker, more sparsely populated areas. Development of this application should investigate the possibility of scan degradation, due to the time required to refocus, as well as the potential for increased fixation due to the "beacon" effect of the brighter symbol(s). A further consideration is that the target differential should be as manifested at the eye (through the NVGs). Because the ANVIS-6 are light "amplifiers," a balance must be sought between the size of the differential and a degradation in NVG performance (or degaining) caused by higher display luminance.

CHAPTER IV

UH-1N SPECIFIC SYMBOL SET

4.1 DESCRIPTION OF UH-1N SPECIFIC SYMBOL SET

UH-1N Specific Symbology was developed in 1992 by Pilot's and Engineers assigned to the Naval Air Warfare Center Aircraft Division with strong input from the UH-1N Aircrew Systems Advisory Panel (ASAP). A complete description of the UH-1N Specific Symbol Set is presented as Figure B-11, Appendix B. The following paragraphs describe key symbols included in the UH-1N Specific Symbol Set; depicted in Figure 17:

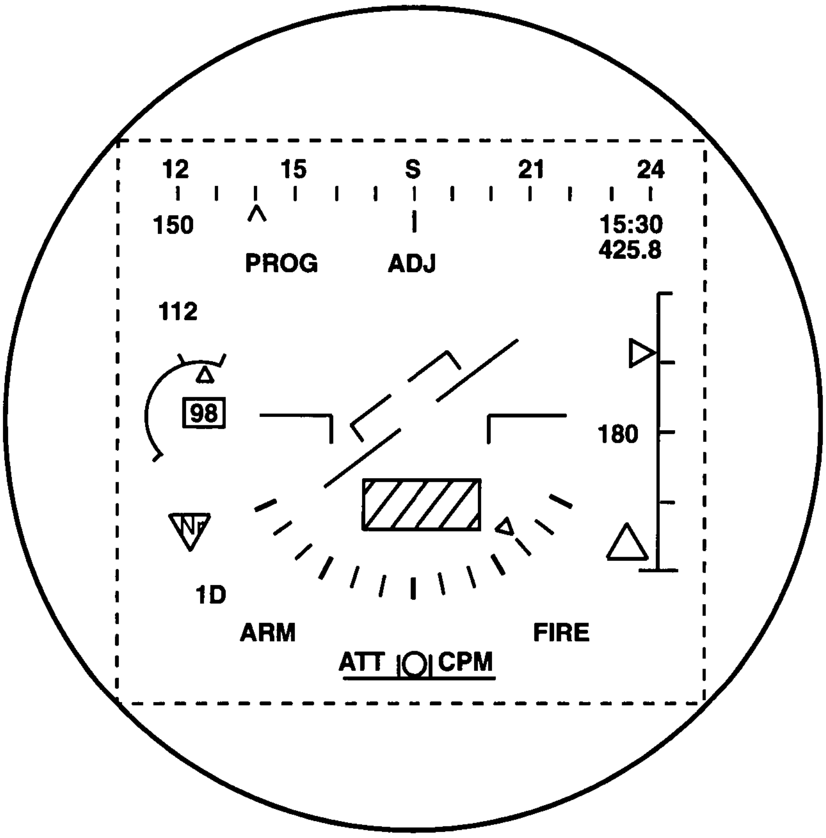

Figure 17

UH-1N SPECIFIC SYMBOL SET

Transmission Torque was presented as an analog replica of the HDIP Torque Gauge with a numerical value imbedded inside an arc and triangular pointer (nine o'clock position). When the "Yellow Arc" Intermediate (30 minute) Torque value (88%) was exceeded, a box appeared around the number. When the "Red Line" Maximum Allowable Torque value (100%) was exceeded the box flashed at a rate of 2 Hz. The fixed Aircraft Attitude Reference Symbol consisted of a set of aircraft wings centered on a truncated Pitch Ladder (20 degrees of Pitch with no "opposite sense" Ladder rungs displayed) and Virtual Horizon Line combination which provided the moving reference. The Roll Angle Scale was presented in the lower half of the display, below the horizon and spanned +/- 60 degrees of Roll. Angles of Bank (AOB) greater than 60 degrees caused the Roll Pointer Symbol, which consisted of an isosceles triangle, to park just outside the 60 degree graduation. The RADALT Symbol consisted of a simple linear scale spanning 0-200 ft AGL with four graduations at 50 ft increments and a trianglular pointer. The Low Altitude Symbol (four o'clock position) consisted of a large isosceles triangle, similar to in shape, but opposite in sense, to the Low RPM warning (eight o'clock position). This was depicted by an inverted triangle with the letters "Nr"[8] inside. Vertical Speed Indicator (VSI) cueing was removed. Illumination of the aircraft's Master Caution segment light, was depicted by the appearance of a rectangular shape analogous to the segment itself. Inter-Turbine Temperatures (ITT) and Barometric Altitude symbology was removed. Attitude Symbology was given a vastly different functionality. Cues were blanked for nominal flight conditions and presented "By-Exception-Only" in an attempt to de-clutter the center FOV. Attitude Symbology is described in paragraph 4.2.2 below.

A more detailed description of the UH-60A/L Baseline Symbol Set is presented as Appendix B, Figure B-11.

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8 "Nr" - well recognized symbol to depict helicopter main rotor speed.

4.2 DESIGN RATIONALE

4.2.1 OVERALL DESIGN PHILOSOPHY

Based on strongly worded feedback in several "Dailies" regarding the limited effectiveness and questionable requirement for attitude cueing and the degree of clutter, a minimalist design philosophy was adopted. Although a philosophical approach was never communicated formally, the following list contains the author's recollection of design goals:

1) The prime goal of the design was to augment aided night flight (in which acceptable levels of capability and performance are already achievable with NVDs alone) by reducing Pilot workload and enhancing situational awareness.
2) Symbol elements should be mechanized to be available when needed and not occlusive when not needed.
3) The symbology should be intuitive; the use of shapes and analogies was strongly encouraged.
4) Avoid obstructing the center FOV, where the visual cues are most critical, to the maximum extent possible.

4.2.2 "BY-EXCEPTION-ONLY" ATTITUDE CUEING

Taking to heart the overwhelming number of unsolicited responses which questioned the value of an attitude cue (even a well designed attitude cue), a design goal for the UH-1N Specific Symbol Set was to present information only when required. As a result, the concept of presenting Attitude Symbology (Pitch and Roll) "By-Exception-Only" was attempted. The nominal level flight condition was determined, to be +/- 5 degrees of Pitch and +/- 5 degrees of Roll, by simulating the functionality using Silicon Graphics Workstations (4D Power Series). The hardware was located in the NAWCAD Aircrew Systems Evaluation Facility (ASEF) laboratory. A consensus was formed by "flying-off" candidate parameters in the Prototype Re-configurable Display Analysis Tool On Rollers (PREDATOR), a limited fidelity, multipurpose cockpit arrangement and flight model. The ability to rapidly evaluate subtle design changes allowed the author to substantially refine the blanking criteria prior to the first flight.

When the aircraft was in nominal level flight, the cues were blanked, thus decluttering the center FOV. When the Pitch Angle threshold of +/- 5 degrees was exceeded, the Pitch Ladder, Aircraft "Wings" and Virtual Horizon Line Symbols were presented. When the Roll Angle threshold of +/- 5 degrees was exceeded, the Roll Scale and Pointer were presented. If both thresholds were exceed simultaneously, such as in a climbing turn, Pitch and Roll Symbols were both displayed. As the condition returned to nominal, the appropriate symbol elements were again blanked.

Pitch and Roll cues have been de-coupled to the point that a pure level turn, in balanced flight, with no Pitch Angle introduced, will result in display of the Roll Symbology only. Likewise, a wings-level Pitch Angle will result in display of the Aircraft Reference and Pitch Ladder only. As the Pitch and Roll contributions to aircraft attitude return to below their nominal value, the corresponding elements are designed to be blanked accordingly.

Early flight test results have proved this concept to be not only viable, but extremely effective for the USMC Utility Mission. A high degree of visual conditioning is required, consisting of filtering and hysteresis. Filtering is required to avoid irrelevant symbol motion driven by inconsequential control inputs that result from aircraft vibration or which fall below the threshold of human perception. Hysteresis is required for dynamic cases where the flight conditions are at or near the blanking criteria to condition the symbol so that it continues to provide useful cueing and does not merely flicker on and off.

4.2.3 PRO-ATTITUDE vs. DECLUTTER CONCEPTS

Because of the unique functionality implemented for By-Exception-Only presentation of the Pitch and Roll Symbols, normal modes in the UH-1N Specific Symbol Set will be, by design, greatly uncluttered thus reducing the necessity for a dedicated Declutter Mode. In view of this, and in order to provide the operator with immediate retrieval of these critical symbols on demand, especially during periods of inadvertent flight into IMC conditions or during whiteout or brownout landings[9], the Declutter Mode has been redesigned. Actuation of the Declutter selection on the PCU (once to the right) will actually add the presentation of the Attitude Symbology for all flight attitudes (without exception).

The goal of the apparent functionality inversion was to provide an immediate fallback to attitude cueing, on demand, without restricting the potential or nullifying the benefits of the By-Exception functionality which optimizes the ANVIS HUD for the majority of NVG flight tasks flown in support of the Utility Mission.

The Pro-Attitude concept was designed, specifically, to provide immediate, head up attitude cues for waveoff from a dusty landing zone. In as much, the Pro-Attitude and By-Exception concepts are mutually supporting.

4.2.4 USE OF SHAPES

Shapes were used in place of four alpha-numerical symbol elements from the UH-60A/L Baseline Symbol Set: Torque Pointer, Low RPM Warning, Master Caution, and the Low Altitude Warning. The goal was to increase the intuitive cueing on the periphery of the display. A comparison of those symbols and their associated RADALTS, between the two symbol sets, is depicted in Figure 18:

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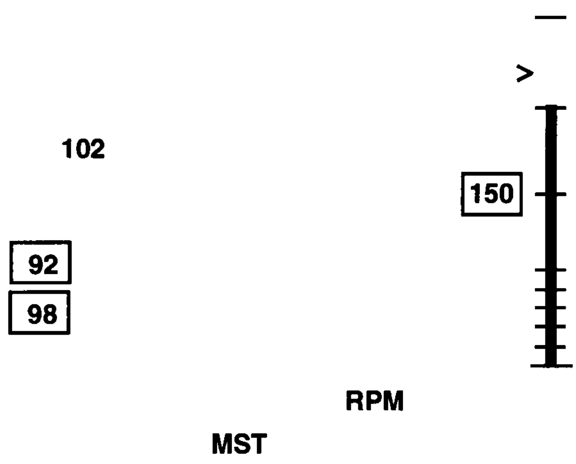
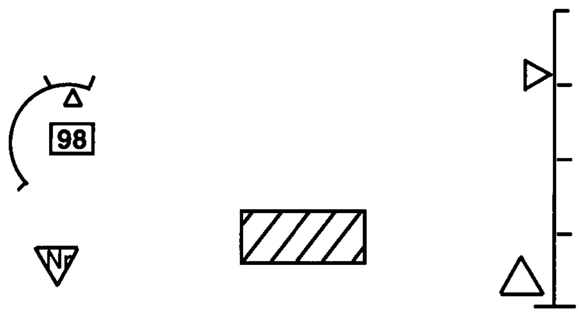
[9] Whiteout or brownout landings occur over loosely packed organic snow or sand and result in a loss of visual contact with the ground.



UH-60A/L Baseline Symbol Set



UH-1N Specific Symbol Set

Figure 18

USE OF SHAPES

The reader might note that the Master caution Symbol could hardly be considered "on the periphery". An exception was made in this case, because of the importance of recognizing the illumination of the Master Caution segment, to move it halfway towards the center of the display... where the Pilot couldn't miss it. The "tick" marks on the Torque Pointer arc, depicting the Yellow Arc and Red Line, represent the exact clock position orientation as on the HDIP Torque Gauge. The Low RPM Warning shape was designed to entice the Pilot into lowering the Collective Lever (which generally represents the proper immediate action initiated in a low RPM condition). The Low Altitude shape was designed to entice the Pilot into raising the collective to keep clear of obstacles. The RADALT scale was designed to be a simple bracket-indication of height above the ground and climb or descent trend cues. It was decided by the ASAP that, because of the dynamic nature of the Utility Mission tasks, it was much more important to know that gross values and trend information than precise values. In other words, it would be better for the Pilot to quickly determine that the aircraft was just above the 50 ft AGL mark and not descending than to have to dedicate his attention towards determining that the altitude was exactly 54 ft.

4.2.5. ROLL POINTER SENSING - ASAP DEBATE

It would seem that the optimum Symbol Set for the UH-1N would preserve Roll Pointer sensing (with that of the HDIP) to alleviate the deficiencies noted in paragraph 3.4.2. The reader will note that in Figure 17, however, the sensing is opposite that of the HDIP attitude indicator. This issue formed the basis for a lengthy debate during one ASAP design review, at which time, several candidate arrangements were presented. There were, and still are, several Pilots who hold the opinion that a pointer placed above the horizon is more intuitive as well as being more consistent. In the end however, by a narrow margin, the lower hemisphere was chosen for the location of the Roll Pointer and Scale. This choice was made less for the benefits of Roll Symbology and more for a simple lack of space. To place the Roll Scale above the horizon, one has to relocate the magnetic heading to it's spot on the bottom. In doing so, the lower half of the FOV, which is the area where the Pilot's focus will be when looking "through" the symbology at obstacles and terrain features, would be greatly occluded by this large, dynamic, constantly displayed symbol.

In the final analysis, a less than optimal Roll cue was chosen in lieu of a constantly occluded lower field of view.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 GENERAL CONCLUSIONS

The AN/AVS-7 ANVIS HUD demonstrated mature technologies which have tremendous potential for Assault Support Helicopters. The system will greatly enhance warfighting capability at night, especially in periods of reduced visibility.

Flightworthy symbology for Rotary Wing applications must be aircraft and mission oriented. Presentation and functionality deemed acceptable for one community of Pilots (performing a particular mission), may not be suitable for other communities and/or missions.

5.1.2 UH-60A/L BASELINE SYMBOL SET CONCLUSIONS

5.1.2.1 Poor Suitability to the USMC UH-1N "Utility" Mission.

The UH-60A/L Baseline Symbol Set was poorly suited to the USMC UH-1N "Utility" Mission.

5.1.2.2 Limited Effectiveness of Flashing Symbol Elements.

Flashing symbols were visually compelling causing a degree of fixation and should be avoided except to warn of extreme conditions.

5.1.2.3 Desirability of a De-Cluttered Field-Of-View.

For most NVG flight tasks, a less cluttered, essential-information-only display was desirable, especially in the center of the Field-of-View.

5.2 RECOMMENDATIONS

5.2.1 GENERAL RECOMMENDATIONS

A concerted effort should be made by Department of Defense Research, Development and Acquisition organizations to continue the development and improvement of flightworthy symbology for all Rotorcraft (Military and Civilian) with the goal of promoting and enhancing Safety of Flight especially during LLL nighttime conditions or flight in a Degraded Visual Environment (DVE).

5.2.2 AN/AVS-7 ANVIS HUD RECOMMENDATIONS

5.2.2.1 Procure the UH-1N Specific Symbol Set

The UH-1N Program Manager should procure the UH-1N Specific Symbol Set for use in support of the USMC "Utility" Mission.

5.2.2.2 Develop the By-Exception and Pro-attitude Concepts

The By-Exception and Pro-Attitude Concept, whereby Attitude Cues are presented by exception only and are retrievable, on demand, for situations where visual contact with the ground has been lost, has tremendous potential and should be developed to the point where boundary values for Pitch and Roll cueing, filtering, and hysteresis have been optimized.

5.2.2.3 Investigate Intensity Differentials

Potential applications for Intensity Differentials, whereby key symbol elements are highlighted by increasing their brightness relative to the whole symbol set, should be investigated to determine suitability and effectiveness.

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BIBLIOGRAPHY

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APPENDICES

APPENDIX A
TABLES

Table A-1

ANVIS-6 Characteristics

PARAMETER	**VALUE**
Gain	25000:1
Field of View	40
Resolution	20/40
Magnification	1:1
Weight	16 oz.
Focus Range	10 in. to
Diopter Adjustment	+2 to -6 diopters
Inter-Pupillary Adj	51-72 mm
Brightness	1.0 mLux
Photocathode Material	GaAs (Gallium Arsenide)

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

Table A-2

TESTS AND TEST CONDITIONS (0)

PHASE	SUBPHASE	MANEUVER	ALT (FT AGL)	AIRSPEED (KIAS)	REMARKS
BASELINE	TEST READY	EMC SOFT/FAM	ON DECK	N/A	HUD FAMILIARIZATION
FORWARD FLIGHT (1)	FAMILIAR-IZATION (8)	TAKEOFF	0-75	0-80	NORMAL TAKEOFF
		CLIMB OUT	75-500	80	NORMAL CLIMBOUT
		LEVEL ACCEL	500	80-VNE	10 KNOT INCR
		LEVEL DECEL	500	VNE-60	10 KNOT INCR
		QUICK STOP	500	VNE-0	RAPID DECEL
		RECOVERY	500	0-VNE	SLOW ACCEL
		LEVEL TURNS	500	100	AOB=10,20,30,45,60 deg
	FORMATION	COMBAT SPREAD	200-500	100	(2),(3)
		TAC TURNS	200-500	100	(2),(3)
		BREAKUP/REND	200-500	100	(2),(3)
		COMBAT CRUISE	200-500	100	(2),(3)
		CRUISE	200-500	100	(2),(3)
		PARADE	200-500	100	(2),(3)
	UNUSUAL ATTITUDES (8)	PITCH UP/ PITCH DOWN	1500-1000	VNE-0	ENTER AT 1500 FT RECOVER BY 1000 FT
		ROLL LFT/ ROLL RT	1500-1000	VNE-0	ENTER AT 1500 FT RECOVER BY 1000 FT
		COMBINATION	1500-1000	VNE-0	ENTER AT 1500 FT RECOVER BY 1000 FT
	TERRAIN FLIGHT (8)	LOW LEVEL	150-200	70-VNE	(2)
		NAVIGATION	150-200	80-VNE	USE OF GPS NAV DATA (2)
		CONTOUR	50-150	40-70	(2)
		NOE	10-50	0-40	(2)
	URBAN OPERATIONS (8)	D.C LOW LEVEL ROUTE/ EAST YUMA	50-200	60-VNE	EFFECTS OF DENSE CULTURAL LIGHTING

NOTES:
- (0) BUILD UP APPROACH TO BE USED; FLY IN ORDER LISTED.
- (1) PILOT/EVALUATOR ON NVG W/ HUD; PILOT AT CONTROLS (PAC). OTHER SEAT PILOT ON NVG ONLY-NO HUD; PILOT-NOT-AT-THE-CONTROLS (PNAC).
- (2) IN ACCORDANCE WITH REFERENCE (18)
- (3) ANVIS HUD/EVALUATOR TO FLY WINGMAN POSITION ONLY. LEAD ACFT WAS UH-1N, AH-1W, AND AH-1J.
- (4) ORDNANCE LOADING: TWO LAU 68, GAU 16 W/500 RDS OF .50 CAL, GAU-2B W/3000 RDS 7.62 MM.
- (5) ANVIS HUD/EVALUATOR TO FLY BOTH LEAD/WINGMAN POSITION.
- (6) IN CONJUNCTION WITH INDEPENDENT DYNAMIC INTERFACE (SHIPBOARD) TESTING SCHEDULED FOR FY 94. DUE TO FUNDING CONSTRAINTS/VESSEL AVAILABILITY, THIS SUBSET OF TESTING WAS NOT COMPLETED.
- (7) BOTH PILOTS EQUIPPED WITH ANVIS HUD. CONTINUED USE OF HUD DURING NIGHT/NVG FLIGHT TESTING.
- (8) MANEUVERS TO BE PERFORMED AT YUMA PROVING GROUND (YPG) PRIOR TO DEMO FLIGHTS IN SUPPORT OF PROJECT SUPPORT PLAN (GEN PROJ U0101/93).

Source: NAWCAD *Test Plan No. UH-1N U004/93 RW*, UH-1N AN/AVS-7 Night Vision Goggle Head Up Display Evaluation, dated 28 August 1993.

Table A-3

TESTS AND TEST CONDITIONS CON'T (0)

PHASE	SUBPHASE	MANEUVER	ALT (FT AGL)	AIRSPEED (KIAS)	REMARKS
LOW AIRSPEED (1)	MANEUVERS (8)	APPROACHES	500-0	VNE-0	NORMAL, STEEP and PRECISION APPROACHES
		CONFINED AREA LANDINGS	500-0	VNE-0	QUANTICO AND YUMA RESTRICTED AREAS
		PEDAL TURNS	5-10	0	30 DEG/SEC MAX
		FWD & AFT SLIDES	10-20	0-30	CAUTION-OFF AXIS
		LEFT & RIGHT SLIDES	10-20	0-35	CAUTION-OFF AXIS
	UNUSUAL ATTITUDES	PITCH UP/ PITCH DOWN	1000-500	0-40	ENTER AT 1000 FT RECOVER BY 500 FT (3)
		ROLL LFT/ ROLL RT	1000-500	0-40	ENTER AT 1000 FT RECOVER BY 500 FT
		COMBINATION	1000-500	0-40	ENTER AT 1000 FT RECOVER BY 500 FT
ORDNANCE (1)	FORWARD FLIGHT	DIVING FIRE	500-150	40-VNE	(2),(4)
		RUNNING FIRE	100-50	40-VNE	(2),(4)
	LOW AIRSPEED	HOVER FIRE	10-20	N/A	(2),(4)
DYNAMIC INTER-FACE (1)	LOW ALTITUDE	FORMATION	50-200	100	SUBSET OF FORMATION (5)
	OVER WATER	LEVEL TURNS	25-150	100	ALTITUDE CUEING
	LHA CLASS OPERATIONS	C/D PATTERNS BREAK ENTRY	300-DECK	100-0	(6)
	LPD CLASS OPERATIONS	C/D PATTERNS BREAK ENTRY	200-DECK	100-0	(6)
EMER-GENCY PROC-EDURES (1)	WAVEOFF (8)	WAVEOFF	10-200	0-80	SIMULATED DUST OUT DECLUTTER FUNCTIONALITY
	POWER LOSS	SIM S.E. FAILURE	200-0	100-0	ALT CUES TO TOUCHDOWN
	AUTO-ROTATIONS	LOW AIRSPEED	5-0	0-10	HOVER AND TAXI
		FWD FLIGHT	1000-10	VNE-0	POWER RECOVERY
FOT&E (7)	TWO PILOT HUD OPS	ALL	N/A	N/A	CONTINUED USE OF HUD - NIGHT NVG FLIGHT.

NOTES:
(0) BUILD UP APPROACH TO BE USED; FLY IN ORDER LISTED.
(1) PILOT/EVALUATOR ON NVG W/ HUD; PILOT AT CONTROLS (PAC). OTHER SEAT PILOT ON NVG ONLY-NO HUD; PILOT-NOT-AT-THE-CONTROLS (PNAC).
(2) IN ACCORDANCE WITH REFERENCE (18)
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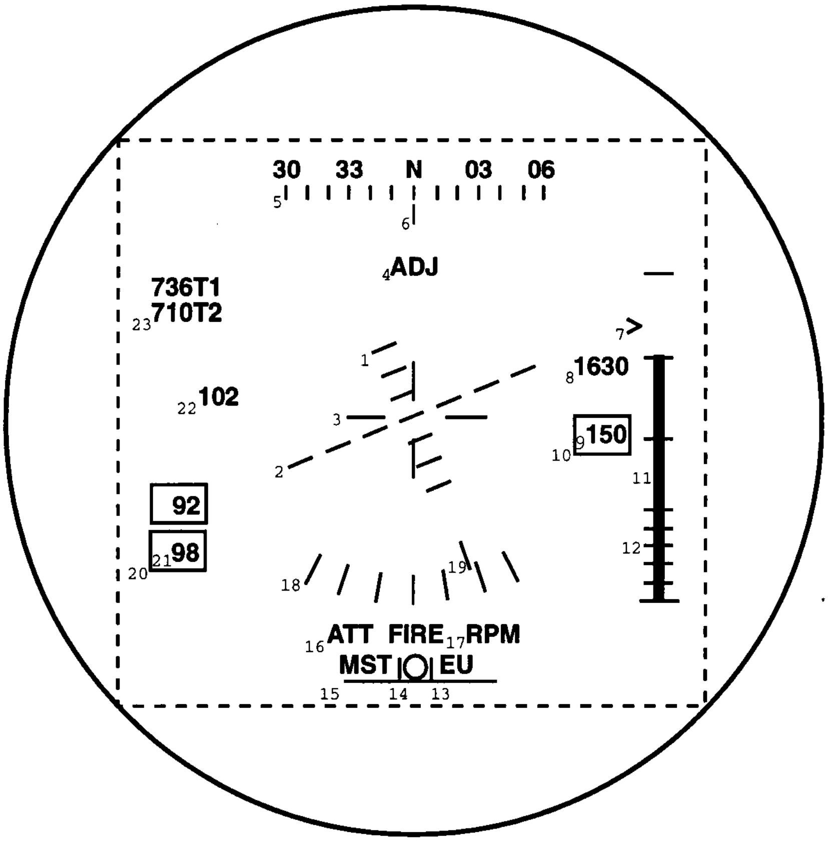
(7) BOTH PILOTS EQUIPPED WITH ANVIS HUD. CONTINUED USE OF HUD DURING NIGHT/NVG FLIGHT TESTING.
(8) MANEUVERS TO BE PERFORMED AT YUMA PROVING GROUND (YPG) PRIOR TO DEMO FLIGHTS IN SUPPORT OF PROJECT SUPPORT PLAN (GEN PROJ U0101/93).

APPENDIX B
FIGURES



No.	Symbol Name/Function	Comments
1	Pitch Ladder - Pitch Angle (Moving)	+/- 30 degrees
2	Virtual Horizon Line	+/- 45 degrees pitch
3	Plus Sign - Attitude Reference (Fixed)	"Aircraft Wings"
4	Program/Adjustment Message - Mode Status	PROG = Program Mode
5	Magnetic Heading Tape - Compass	0-359 degrees
6	Magnetic Heading Benchmark - Reference	Fixed Reference Mark
7	VSI Pointer - Rate of Climb/Descent	+/- 2000 FPM
8	Barometric Altitude (MSL)	-1,500 - 20,000 ft
9	Radar Altitude Numerical - (AGL)	0-1000 ft
10	Low Altitude Box - Warning	Flashing Box
11	Radar Altitude Thermometer - (AGL)	0-200 ft
12	Radar Altitude/VSI Scale	0-200 ft AGL, +/- 2000 FPM
13	SDC Failure Mode Message - Failure Alert	
14	Inclinometer - Trim Ball	+/- 2 ballwidths
15	Master Caution Message - Anomaly Alert	
16	Warning Messages - Sensor Failure Alert	
17	Low RPM Warning Message	< 91 +/-2% Nr
18	Roll Scale - Roll Angle	+/- 30 degrees
19	Roll Angle Pointer	+/- 30 degrees
20	High Torque Box - Limit Exceedence	88% Transmission Torque
21	Torque Numerical - Transmission Torque	0-190% Transmission Torque
22	Airspeed Numerical - Indicated (KIAS)	0-220 knots
23	ITT Numerical - Turbine Gas Temperatures	0-999 degrees Celsius

Figure B-1
UH-60A/L BASELINE SYMBOL SET (FUNCTIONAL DESCRIPTION)

Photo: *Gary Hammett, NAWCAD Patuxent River, MD*

UH-1N Helicopter (BuNo 158768)

Photo: *Gary Hammett, NAWCAD Patuxent River, MD*

UH-1N Helicopter (BuNo 160457)

Figure B-2
USMC UH-1N HELICOPTER

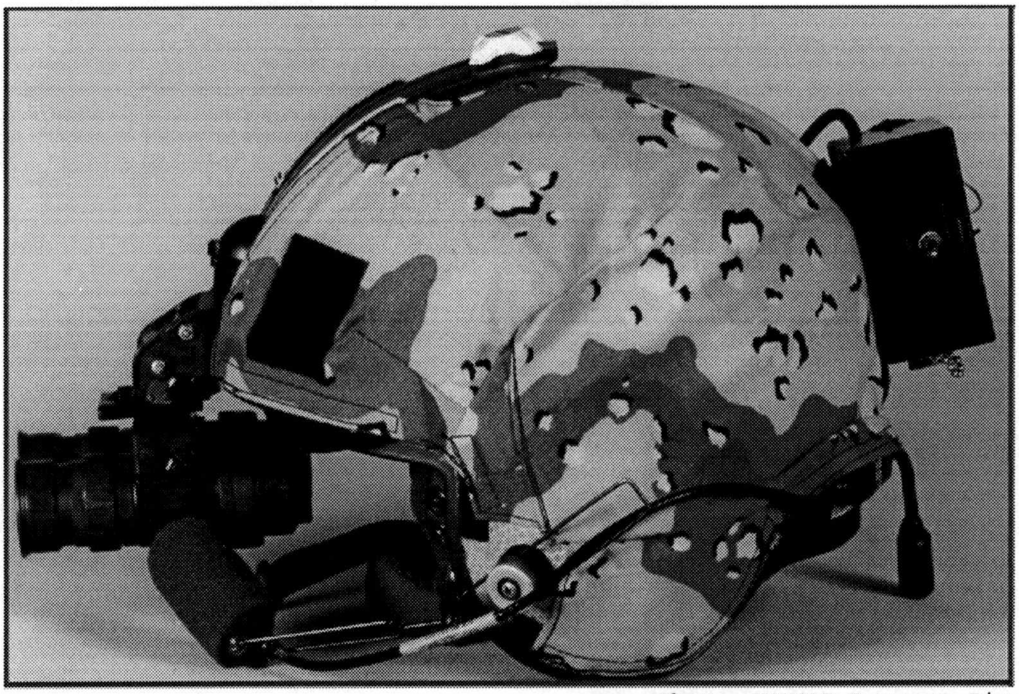


Photo: *NAWCAD Patuxent River, MD*

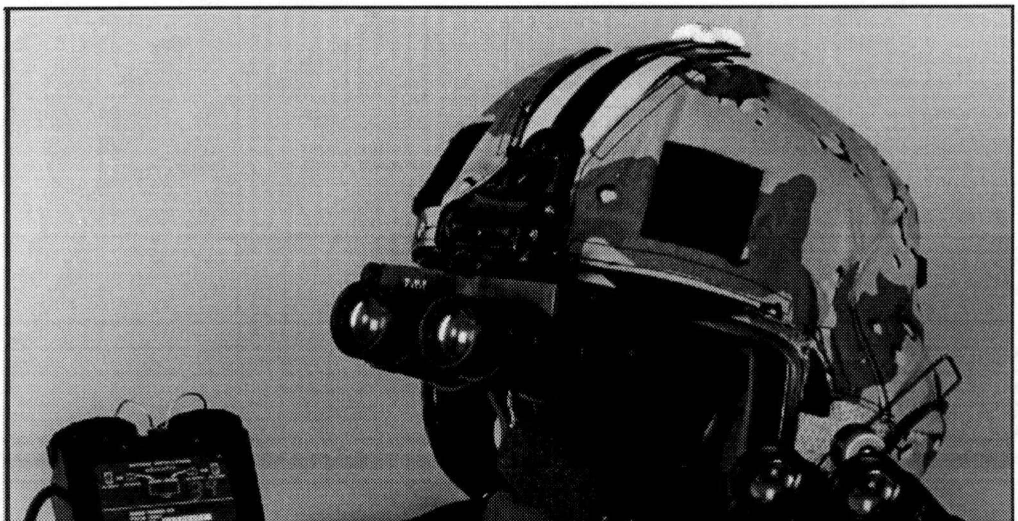


Photo: *NAWCAD Patuxent River, MD*

Figure B-3
AN/AVS-6 "ANVIS" NIGHT VISION GOGGLES (NVGs)

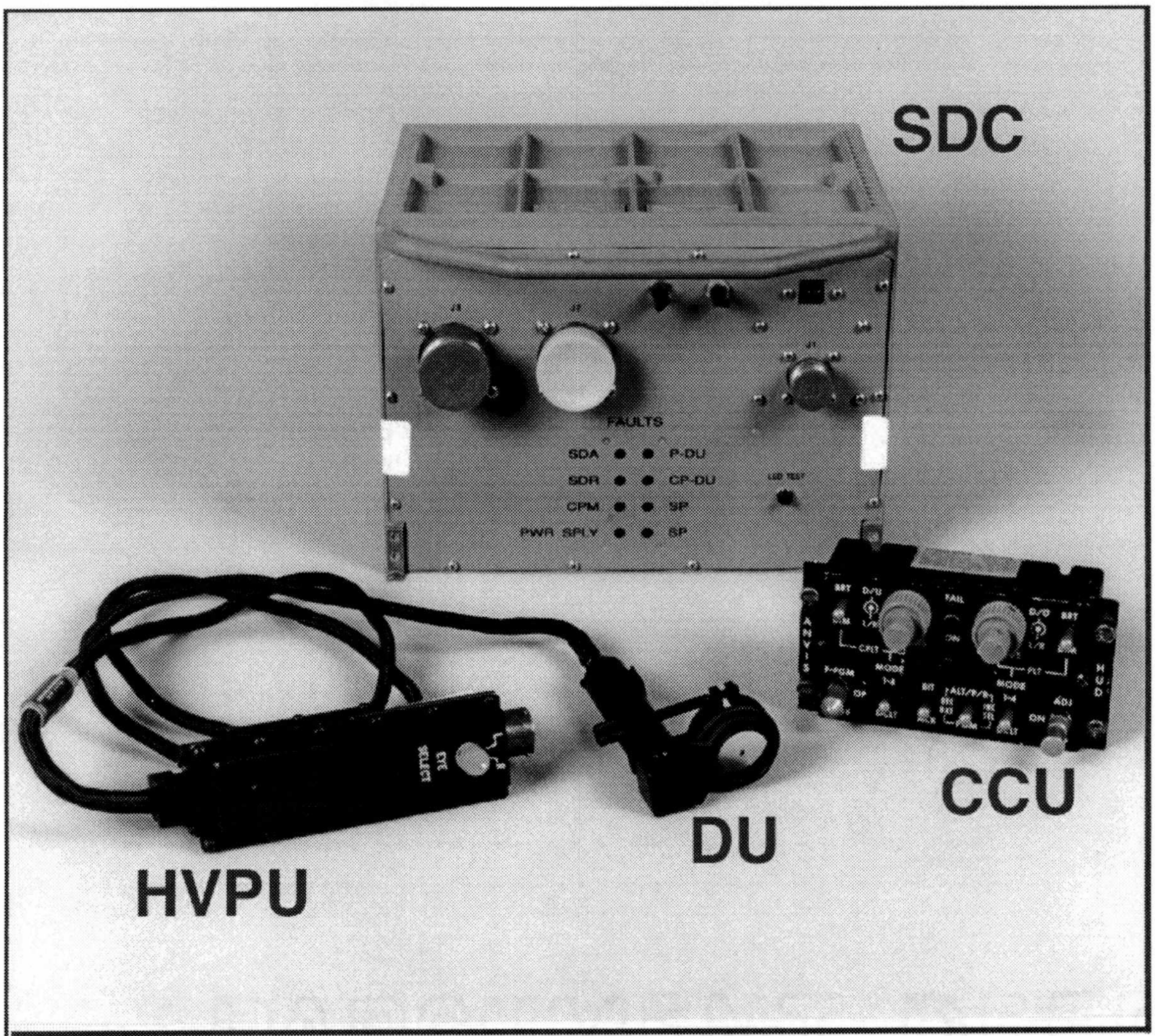


Photo: *NAWCAD Patuxent River, MD*

Figure B-4
AN/AVS-7 ANVIS HUD SYSTEM

Photo: *Gary Hammett, NAWCAD Patuxent River, MD*

Figure B-5
HELMET DISPLAY UNIT (HDU)

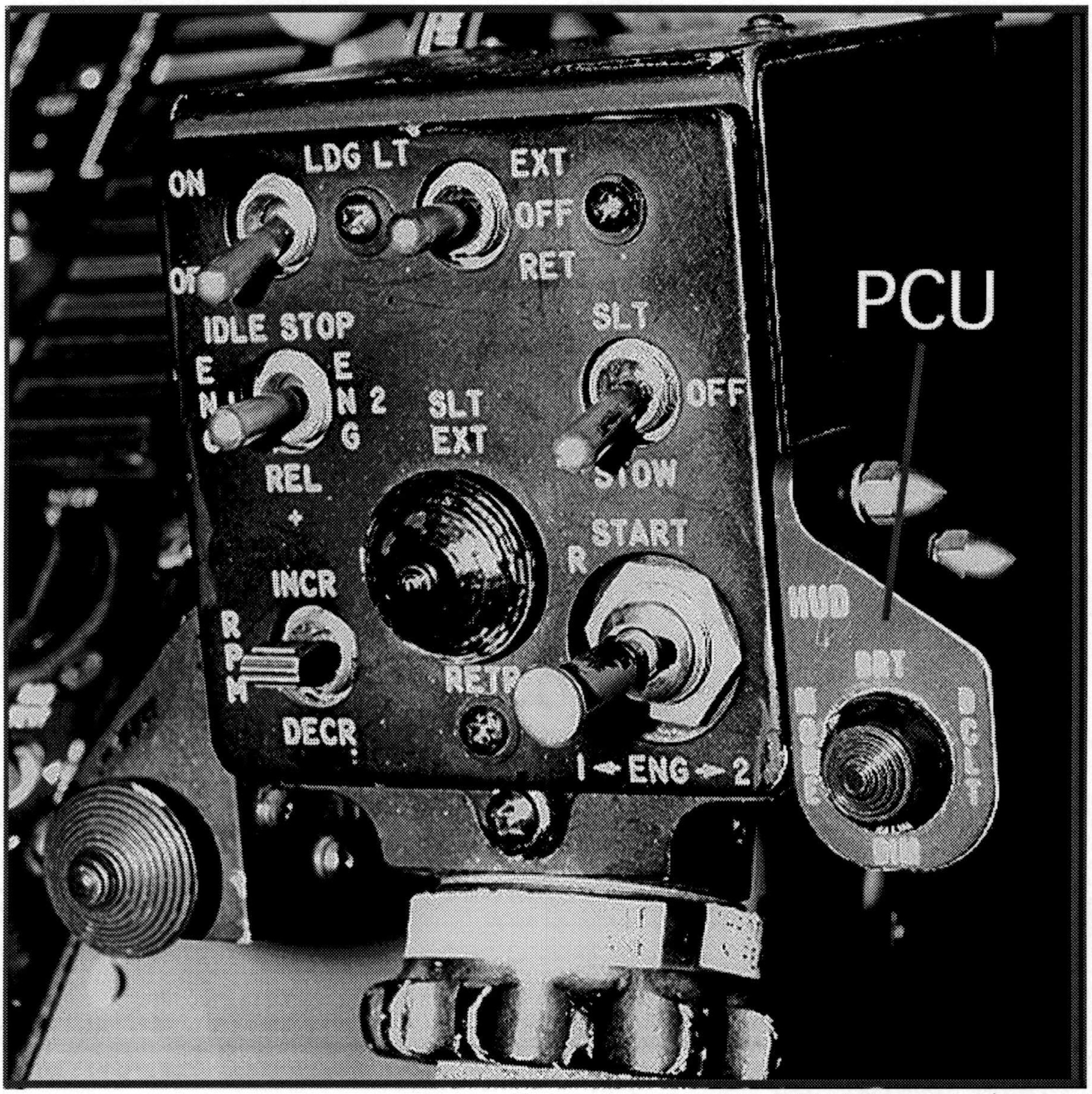


Photo: *Gary Hammett, NAWCAD Patuxent River, MD*

Figure B-6
PILOT CONTROL UNIT (PCU)

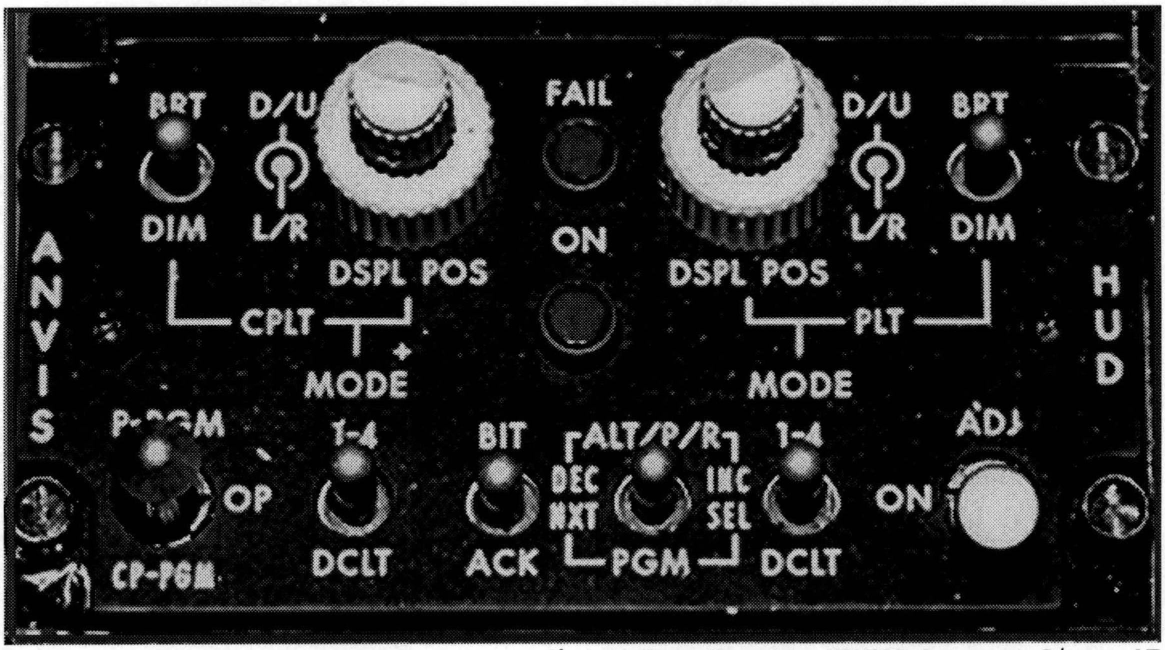


Photo: *Gary Hammett, NAWCAD Patuxent River, MD*

Figure B-7
CONVERTER CONTROL UNIT (CCU)

FLIGHT REPORT

PRNC-NATC-3760/5

DAILY REPORT No. AN/AVS-7-25

AIRPLANE MODEL	BUNO	APPLIES TO CARD NO.	ENGINEER	
UH-1N	160457	CAMPEN 1/2	N/A	
PILOTS/CREW CAPT MITCHELL - EVALUATOR / CAPT MANNELLA - PILOT		DATE 14 DEC 1993	TAKE-OFF TIME 1715	LANDING 1945
WEATHER CONDITIONS RELATIVE TO TEST CLR 7, 55% RH,no precipitation, 97% MOON			BIS-PTR PATUXENT RIVER	
LOADING CONDITIONS FULL INT, 2/3 AUX	T.O. GROSS WEIGHT 9250 lbs	T.O. C.G. % MAC N/A - LIMIT OF BASIC AIRCRAFT		

EXTERNAL CONFIGURATION

1. ANVIS 7 ANVIS HUD EQUIPPED AIRCRAFT. HUD EVALUATOR IN RIGHT SEAT. AIRCRAFT AN/AAQ-22 LRF FLIR CONFIGURED WITH TFU AND CEU REMOVED.

SPECIAL INSTRUMENTATION

2. BUNO 160457. SYMBOL SET = UH-60A/L BASELINE. VIDEO ENCRYPTION PALLET W/ TELEMETRY ANTENNA.

CHANGES SINCE LAST FLIGHT

3. NONE

PURPOSE OF FLIGHT

4. INTRO FLIGHT/QUALITATIVE EVALUATION FOR FLEET PILOTS. DATABASE EXPANSION.

SCOPE

5. SINGLE FLIGHT. FAM MANEUVERS IN PICACHO WASH. LIMITED SECTION MANEUVERING.

METHOD

6. DIRECT COMPARISON TO SHIP SYSTEM TRUTH DATA. QUALITATIVE EVALUATION.

RESULTS AND DISCUSSION

7. AMBIENT CONDITIONS:

	1800 LOCAL OBS:	CLR/7 SM T=57 DEG F/REL HUM=55%
	1900 LOCAL OBS:	CLR/7 SM T=57 DEG F/REL HUM=55% LUNAR ILLUM 97%, >.0022 LUX

8. PILOT INFO:

RANK: CAPT, USMC — AGE: 34
NAME: JOHN MITCHELL
AIRCRAFT TYPE: UH-1N
TOTAL TIME: 2900
TIME IN MODEL: 2400
NVG TIME: 350

9. QUESTIONNAIRE:

A. DID THE ANVIS HUD AID OR IMPAIR PILOTS ABILITY TO CONDUCT THE FOLLOWING NVG OPERATIONS?

Figure B-8
EXAMPLE OF DAILY FLIGHT REPORT

1) HOVER: NEUTRAL.

2) PEDAL TURNS: NEUTRAL.

3) SLIDES: AIDED. WITH ALTITUDE AND TORQUE.

4) TOUCHDOWNS: NEUTRAL.

5) NORMAL APPROACHES: AIDED. AIDED IN BALL, TORQUE, ALTITUDE CONTROL AND AIRSPEED.

6) QUICK-STOP: AIDED. SEE #5) ABOVE.

7) URBAN OPERATIONS: IMPAIR. ENSURE BRIGHTNESS IS UP PRIOR TO URBAN OPERATIONS. (DENSE AMBIENT LIGHTING).

8) OVERWATER FLIGHT: OUTSTANDING!!

a) LEVEL - EXCELLENT REFERENCE UNDER VERY DARK CONDITIONS. ALLOWS FOR NEAR IMC FLIGHT WITH A VISUAL SCAN.

b) LEVEL TURNS -.LENDS ITSELF TO INCREASED PERFORMANCE, A HUGE REDUCTION IN WORKLOAD AND HIGH COMFORT LEVEL.

B. WAS THE SYMBOLOGY READABLE? YES.

C. WAS SYMBOLOGY BRIGHT ENOUGH? YES.

D. WAS SYMBOLOGY EFFECTIVE? YES. EASY TO READ AND UNDERSTAND.

E. WAS SYMBOLOGY ACCURATE? YES. IMPROVED SOFTWARE WOULD MAKE IT BETTER.

F. DID FIXATION OCCUR? **YES. WITH BLINKING SYMBOLS.**

G. WAS IT EASY TO CHANGE MODES? YES.

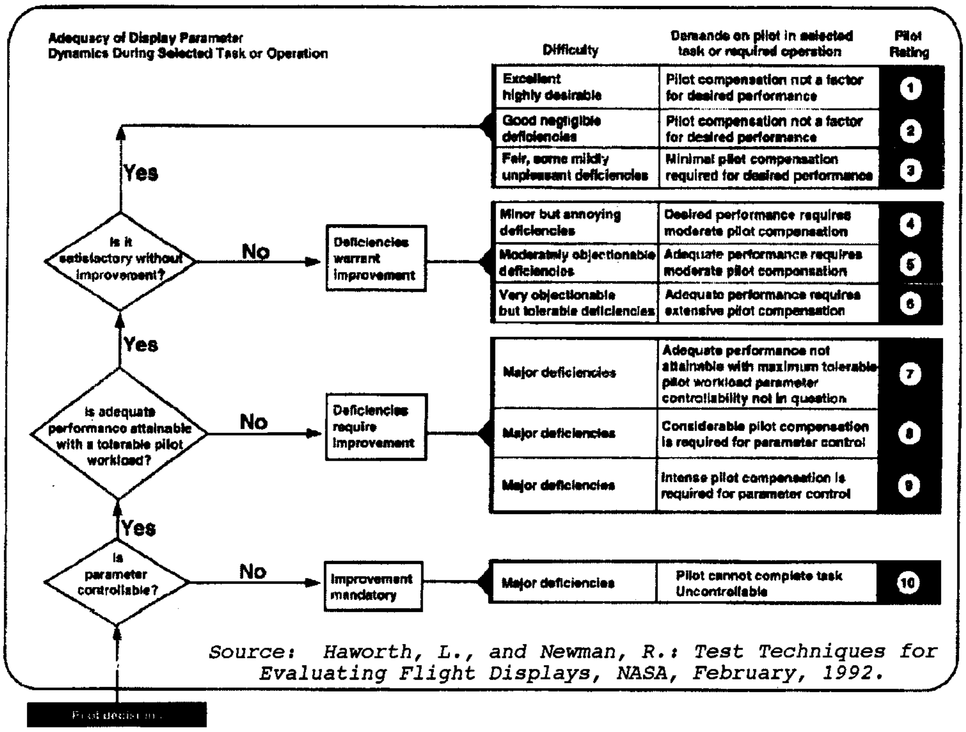
H. DID THE ATTITUDE SYMBOL ELEMENTS PROVIDE GOOD OR BAD CUES (DESCRIBE)? PITCH/ROLL REFERENCE - BAD! **THE PLUS SIGN CONFUSED ME IN TURNS.** IN GENERAL THERE WAS TOO MUCH IN THE CENTER FOV.

I. WERE THERE ANY SYMBOL ELEMENTS YOU DIDN'T CARE FOR (DESCRIBE)? **ANYTHING THAT FLASHED! IT CAUSED FIXATION. THE ATTITUDE SYMBOLOGY. SEE #H. ABOVE.**

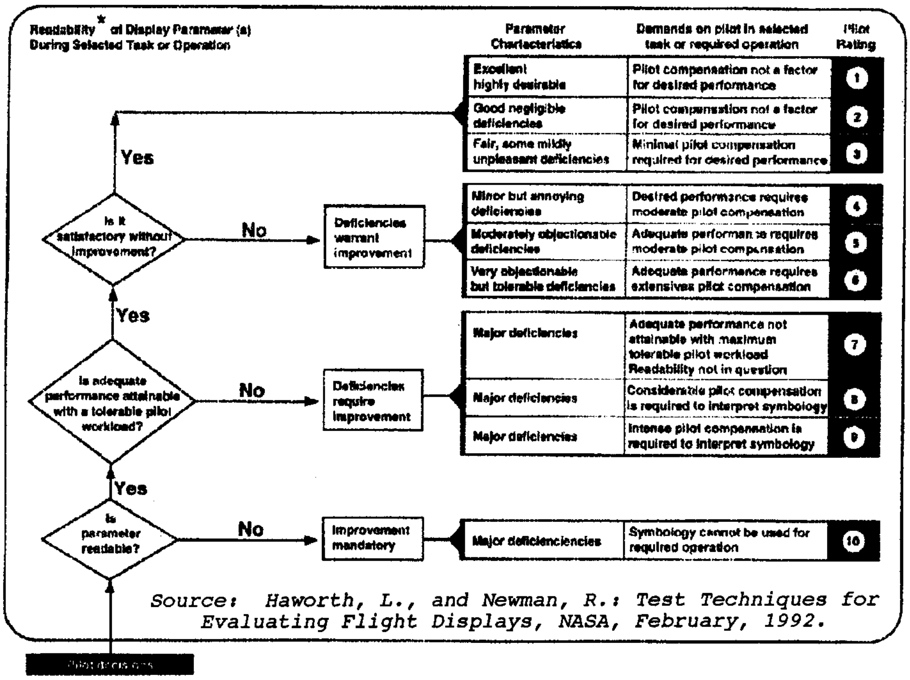
ADDITIONAL COMMENTS

10. OVERALL USE OF THE SYSTEM WAS EASY AND TRANSPARENT TO THE USER IN-FLIGHT. THE SYMBOLOGY, AS FLOWN, IS A STEP IN THE RIGHT DIRECTION. **IT'S BETTER THAN NO SYMBOLOGY (NO HUD).** HOWEVER, SEVERAL ITEMS WERE DETERMINED TO BE NOT-SO-GOOD. FIRST ANY FLASHING SYMBOL ELEMENT CAUSED FIXATION AND THE ONLY WAY TO GET AROUND THE PROBLEM WAS TO DECLUTTER THE SYMBOL ELEMENT. **I FOUND THE ATTITUDE REFERENCE CONFUSING WHILE IN TURNS. I THINK THE BALL-TORQUE-AIRSPEED-ALTITUDE-ONLY MODE WAS EXCELLENT.** THE HEADING TAPE WAS ALSO VERY HELPFUL. **THE LOWER HALF OF THE FOV SHOULD BE FREE OF CLUTTER/SYMBOLS AS MUCH AS POSSIBLE. AIRCRAFT SPECIFIC SYMBOLOGY WILL BE REQUIRED TO ACCOMPLISH THE MISSION ASSIGNED TO THE AIRCRAFT.**

Figure B-9
EXAMPLE OF DAILY FLIGHT REPORT (CON'T)

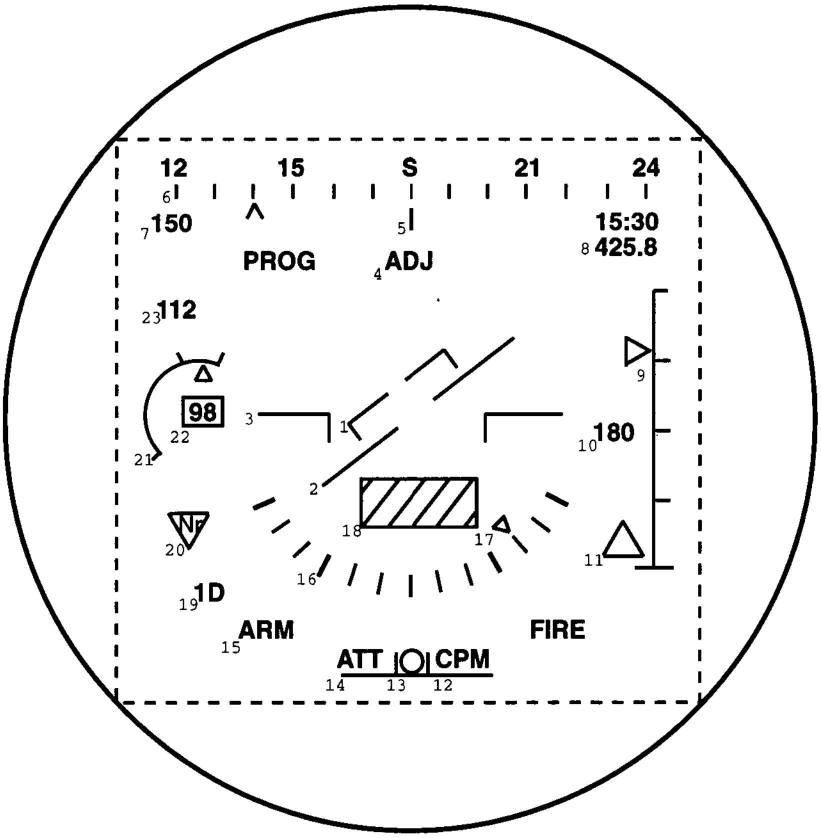


Display Controllability Rating Scale



Display Readability Rating Scale

Figure B-10
PILOT RATING SCALES



No.	Symbol Name/Function	Comments
1	Pitch Ladder - Pitch Angle (Moving)	20 degrees - one sense only
2	Virtual Horizon Line	+/- 60 degrees pitch
3	Attitude Reference (Fixed - "By Exception" only)	"Aircraft Wings"
4	Program/Adjustment Message - Mode Status	PROG = Program Mode
5	Magnetic Heading Benchmark - Reference	Fixed Reference Mark
6	Magnetic Heading Tape - Compass	0-359 degrees
7	Bearing to GPS Waypoint	Magnetic Track Required
8	Navigation Stack (Time/Distance to Waypoint)	Coupled to Bearing Info
9	Radar Altitude Ladder/Pointer - (AGL)	0-200 ft, 50 ft Increments
10	Radar Altitude Numerical - (AGL)	0-400 ft
11	Low Altitude Warning - Triangle	Up Collective Prompt
12	SDC Failure Mode Message - Failure Alert	
13	Inclinometer - Trim Ball	+/- 2 ballwidths
14	Warning Messages - Sensor Failure Alert	
15	ARM Status/FIRE Warning Messages	Master Arm On/Off
16	Roll Scale - Roll Angle	+/- 60 degrees
17	Roll Angle Pointer	+/- 60 degrees
18	Master Caution Message - Anomaly Alert	
19	Mode Status - Current Mode	(N - Normal, D - Declutter)
20	Low RPM Warning - Triangle with Nr	Down Collective Prompt
21	Torque Pointer - Transmission Torque	Tick Marks for 88 & 100%
22	Numerical Torque/High Torque Box - Exceedence	88% Transmission Torque
23	Airspeed Numerical - Indicated (KIAS)	0-220 knots

Figure B-11
UH-1N SPECIFIC SYMBOL SET (FUNCTIONAL DESCRIPTION)

APPENDIX C
KEY POINTS

KEY POINTS

1. GENERAL. Key Points are salient features or characteristics of the system, or it's use which were discovered during testing. A Daily Flight Report (form PRNC-NATC-3760/5) was completed following each flight evolution. Daily reports or "Dailies" are included as appendices D-F. The authors have added comments in the form of Key Points (highlighted in boldface), to the "Dailies", where appropriate to bring out important characteristics of the system. Key Points are numbered in the order they were documented and are, therefore, not necessarily grouped by category. In all, 36 Key Points have been documented. In some cases information presented in the Key Points has also been mentioned above. The following paragraphs chronicle those Key Points, by listing them, individually, with their associated Daily Report comments (Note: "Dailies" are written in bullet style. A degree of author's license has been added to the comments below, making them read slightly differently than their original references).

2. KEY POINT #1. A DYNAMIC AMBIENT LIGHT ENVIRONMENT MAY CAUSE HIGH PILOT WORKLOAD WITHOUT AN AUTOMATIC BRIGHTNESS CONTROL.

"The evaluator had difficulty in using the HUD as a primary flight reference when in and out of dense ambient lighting. It was especially difficult to perform a Quick Stop while approaching the tower side of OLF Webster at 500 ft AGL with the scene changing from lighted buildings to unlighted water and then back to lighted buildings etc... The symbol elements tended to blend with the lights causing critical parameters to be lost."

3. KEY POINT #2. THE RADALT SYMBOL IS A "MUST HAVE" FOR OVERWATER OPERATIONS.

"It was really nice having the RADALT (and altitude trend information) while flying low, over water. Comfort level was significantly higher."

4. KEY POINT #3. THE BALANCE BALL SYMBOL IS A "MUST HAVE" FOR ALL MODES.

"The ball display was outstanding at all times! It was great to have real-time input."

5. KEY POINT #4. ANALOG SYMBOLS ARE BETTER THAN DIGITAL FOR TREND INFO.

"The numerical torque value was not effective as a warning of impending limit approaching. It was hard to "find" when quick trend information was needed."

6. KEY POINT #5. THERE MAY BE PHYSICAL/PHYSIOLOGICAL/OPTICAL LIMITS TO FIELD OF VIEW AND HUD SCAN (GIVEN THE KNOTHOLE EFFECT).

"The magnetic heading tape may be located a bit too high, and just a bit out of the comfortable FOV to be readily scanned. About 1.0 hours into the flight, the pilot made the comment that it had about 3 degrees of jitter. That observation was made as the pilot was trying to hold a certain heading. That point in the flight may have been the first time heading was scanned."

WERE THERE ANY SYMBOL ELEMENTS YOU DIDN'T CARE FOR? (DESCRIBE) - "The altitude & RADALT appeared to be outside of the primary scan area. A definite eye scan was required to assimilate the data. Consider moving it inboard a small amount."

7. <u>KEY POINT #6</u>. SINGULAR SCENE CHANGES (SYMBOL MIPL, BOXING, OR SHAPE CHANGES) ARE MORE EFFECTIVE FOR ANNUNCIATION/WARNINGS THAN FLASHING SYMBOLS.

WERE THERE ANY SYMBOL ELEMENTS YOU DIDN'T CARE FOR? (DESCRIBE) - "The flashing box (around the RADALT numerical value). The pilot was quickly desensitized to it. During initial takeoff, the pilot barely noticed that it was flashing but did notice when it disappeared (stopped flashing)."

"The RPM warning flashed continuously from start up and could not be cleared (note: this is irregular). The flashing symbol was annoying at first but the operator quickly became desensitized to it (as the flight progressed). In fact, after approximately twenty minutes... the pilot wasn't sure if he recognized it anymore."

"The flashing box around the digital radar altitude display when below the pre-selected low limit was visually compelling and caused an aft drift in a hover when the pilot's eye was drawn to and concentrated on the flashing box vice maintaining a good outside visual scan. A single flash of the box will suffice in alerting the pilot of a low altitude condition, followed by a solid box around the digital display."

8. <u>KEY POINT #7</u>. MANEUVERS MAY BE FLOWN WITH MORE PRECISION AND AGGRESSIVENESS THAN WITHOUT A HUD, BUT NOT ON THE SAME PAR AS DAYTIME OR UNAIDED.

"At times the pilot lost outside situational awareness while performing a dedicated HUD nodal task. For example, when conducting a level quick stop (isolating the RADALT Ladder), pitch tolerances (of +/- 20 degrees) were easily exceeded. When conducting a quick stop without the HUD, overall situational awareness was much greater. The pilot scanned the HDIP, but relied on external peripheral cues which defined motion. When using the HUD for such a task, peripheral cues were greatly ignored."

9. <u>KEY POINT #8</u>. SYMBOLOGY DISPLAY ACCURACY WILL ONLY BE AS GOOD AS THE SIGNAL DRIVING IT.

"The magnetic heading tape had approximately 3 degree of jitter under all conditions. This may, in fact, represent the tolerance band of the discrete signal driven by the AN/ASN-89 COMPASS."

10. <u>KEY POINT #9</u>. IT'S BETTER TO CONFIGURE ALL NVGS WITH BRACKETS (IN THE SHOP) THAN TO ATTEMPT TO CHANGE BRACKETS ON THE FLIGHT LINE.

"The guide for the bracket which held the DU monocle was set at angle which was slightly less than needed. The pilot's head had to be tilted, in level flight, to overlay the virtual horizon line on the actual horizon line. Subsequently, there was a slight tendency to fly with a 1-3 degree bank angle in level flight."

11. KEY POINT #10. ROLL POINTER SENSING IS NEGATIVE (AS COMPARED TO THE HDIP) WITH THE SCALE LOCATED IN THE LOWER HEMISPHERE.

"Roll pointer sensing was negative. When holding a steady 20 degree angle of bank, level turn, the pilot had a tendency to make the wrong input required to slave the pointer to the appropriate benchmark. Holding a steady angle of bank (+/- 2 degrees) in a level turn was difficult requiring dedicated concentration on the roll pointer and was aggravated by an occasional incorrect input (DCR 6)."

12. KEY POINT #11. FOR VMC FLIGHT, PRIMARY VISUAL SCAN, SECONDARY INSTRUMENT/HUD SCAN WORKS BEST. USE OF SUBTLE CUES IS RECOMMENDED.

USE OF THE HUD AS PRIMARY INSTRUMENT FLIGHT DEVICE. THERE WAS A BIG DIFFERENCE BETWEEN THE 40 DEGREE ANVIS-6 FOV AND THE 0.8 INCH HUD SYMBOLOGY SCAN RADIUS AND NORMAL FOV AND SCAN PATTERN UNAIDED.

POSITIVE ATTRIBUTES = CAN SEE MORE AIDED (NIGHT/VMC), SCAN TAKES LESS TIME, SCAN CAN BE SUBLIMINAL/SUBCONSCIOUS.

NEGATIVE ATTRIBUTES = CROSSOVER CONFUSION (NOT DEDICATED INSTRUMENT SCAN, NOT DEDICATED VISUAL SCAN), POTENTIAL HUD FIXATION AT THE EXPENSE OF OBSTACLE AVOIDANCE OR VISUAL CUE RECOGNITION. DEDICATED INSTRUMENT FLIGHTS NEEDED TO DETERMINE IMC FLIGHT POTENTIAL.

13. KEY POINT #12. AN OVERSIZED LENS CAP COVER THAT CAN ACCOMMODATE THE DU SHOULD BE PROVIDED.

"There is not a lens cap cover to fit over the Optical Unit when attached to the NVG monocular housing.. The Optical Unit will be damaged when mounted on the helmet prior to use. Normally the NVG lens cap covers are kept on the NVG monocular housings until the operator is ready to turn the NVGs on."

14. KEY POINT #13. THE PLUS-SIGN WAS CONFUSING AS AN ATTITUDE REFERENCE.

"Unusual attitude recovery without a visible horizon (looking straight down at the water) was difficult without the horizon line(pitch/roll) and the attitude reference indicator . Deleting the attitude reference indicator made pitch recovery difficult but had negligible affect on roll recovery. The attitude reference indicator in the center of the display is extremely cluttered when coupled with the horizon line and pitch scale. The pitch scale, attitude reference indicator and the horizon line were difficult to differentiate and caused some initial incorrect pitch control inputs (reverse sensing) when recovering to a level attitude. Suggest an attitude reference indicator on either side of the horizon line vice a cross in the middle."

13. KEY POINT #14. THE VSI WOULD BE MORE EFFECTIVE WITH GRADUATION MARKINGS.

"Difficult to interpret the VSI pointer location. Had to devote an inordinate amount of attention to interpret the VSI cursor in order to determine the rate of descent in steep approaches. Suggest that the 0 fpm mark be tagged along with a 500 and 1000 fpm."

14. KEY POINT #15. FOR MOST OPERATIONS, A LESS-CLUTTERED/ESSENTIAL-INFO ONLY DISPLAY WAS PREFERRED.

"Mode 3 and mode 4 were the most desirable symbology set-ups for conducting approaches. Modes 1 and 2 had an excessive amount of clutter in the middle of the display which obscured a clear view of the landing area."

15. KEY POINT #16. FOR MOST OPERATIONS, A LESS-CLUTTERED/ESSENTIAL-INFO-ONLY DISPLAY WAS PREFERRED.

"For most tasks, the pilot found attitude cues distracting. The virtual horizon tilted with the pilot's head and, during turns, was frequently not superimposed on the actual horizon unless forced there. The pilot tried ignoring the cues and look "through" the pitch Ladder with limited success. The pilot much preferred keeping the center FOV clear; to view the scene and to determine attitude from external cues."

"Mode 4 was the most desirable symbology set-up for conducting operations in an urban environment. Modes 1 and 2 had an excessive amount of clutter in the middle of the display which obscured a clear view of the man-made features."

"SYMBOLOGY-Mode 4 was the most desirable for formation flight in that the lead aircraft could be framed by the HUD symbology with no overlap. Symbology overlaid on the lead aircraft or the evaluation aircraft structure during cross-cockpit flying was easily read with no misinterpretations of symbology when looking off-axis. Full bright symbology intensity was used during TAC turns to accommodate bright background light (moon reflection off the water/urban lights)"

16. KEY POINT #17. BIT MUST BE SELECTED AFTER ACKNOWLEDGING AN ATTD FAILURE IN ORDER TO GET A LIGHT FOR SUBSEQUENT ATTD FAILURES.

"The ATTD failure light illuminated when the pilot's ATTD circuit breaker was pulled. The light could be extinguished by acknowledging the fault or resetting the circuit breaker. Next flight check to see if the ATTD light will illuminate again after being acknowledged if the fault persists or re-occurs. Also check to see if the system can be reset to indicate subsequent ATTD failures by going to BIT after acknowledging the ATTD fault light."

17. KEY POINT #18. DIGITAL DISPLAYS ARE EASILY CONFUSED WHEN PLACED IN CLOSE PROXIMITY. TRY TO DECONFLICT BY LOCATION, FONT, SIZE OR CHANGE TO SHAPE.

"TORQUE/OVERTORQUE WARNING: The flashing torque box (<88%) was not noticed on three occasions during TAC turns due to its location on the lower left side of the symbology presentation. The torque and airspeed symbols are in close proximity and are identical digital presentations which were occasionally confused with each other."

18. KEY POINT #19. THE HUD PRECLUDES THE NEED FOR A HEAD-DOWN OR HEAD-INSIDE INSTRUMENT SCAN/CROSS CHECK DURING AGGRESSIVE MANEUVERING.

"SITUATIONAL AWARENESS: The level of aggressiveness of TAC turn maneuvers at night with the HUD was the same as during daytime operations. The HUD was comforting in that altitude and torque information was immediately available. The heading tape and airspeed were invaluable in immediately assessing TAC turn geometry/roll out headings. Complete head out of the cockpit flying was possible without sacrificing performance parameter monitoring. The Co-Pilot could devote more attention to the outside tactical situation and performing other cockpit tasks vice maintaining constant vigilance on the gauges during maneuvering flight."

19. KEY POINT #20. WITH THE SYMBOLOGY SLIGHTLY OUT OF FOCUS, SCAN ASSIMILATION AND USEFULNESS WERE DEGRADED.

WAS THE SYMBOLOGY READABLE? "The pilot could not adequately focus the symbology through the full range of adjustment. (Author's note: the knurled knob used to adjust symbology focus was difficult to turn and at times appeared to have reached the stop (with travel still available)."

20. KEY POINT #21. SYMBOLOGY PROVIDES A COLLIMATED OPTICAL REFERENCE INSIDE OF THE NORMAL RESTING STATE OF FOCUS.

3) SLIDES: "UNDECIDED. During slide maneuvers, I believe, the symbology provides a contrast to the surface as the aircraft moves. This causes a "ground rush" sensation which is good in that it gives a cue for lateral velocity, but... is easy to fixate on. This is a big trade-off. The HUD data allowed for better AGL control in slides and improved situational awareness. Could lead to fixation, on the other hand."

21. KEY POINT #22. EYE DOMINANCE IS A CRITICAL FACTOR AND OPERATORS WILL NEED PROPER TESTING TO DETERMINE THEIR INDIVIDUAL FIT.

"I am left eye dominant and had some initial trouble "seeing" the HUD display in my right eye. This may or not be normal. I will look at switching eyes for testing in the H-60 to see what happens. (AUTHOR'S NOTE: This pilot did fly the remainder of flights with the HUD symbology on his left eye... without any anomalies)."

22. KEY POINT #23. HEAD UP SYMBOLOGY IS AN AID TO IMC FLIGHT (NO SURPRISE HERE).

"In general, the symbology was an aid to unusual attitude recoveries whenever the aircraft attitude cues were unambiguous."

23. KEY POINT #24. AIRCRAFT SYMBOL AND PITCH LADDER SHOULD NOT BE MUTUALLY EXCLUSIVE. IF ONE IS DECLUTTERED, THE OTHER SHOULD BE AS WELL.

"MODE 2 represents a "Set Up" in that the pitch Ladder was displayed without the aircraft or "wings" symbol. When the background scene was purely homogeneous (such as overwater heading to sea), having the pitch Ladder by itself (without the aircraft symbol) was worse than no cue at all. The Ladder gave the immediate impression that cues were available and it took a second to search for and discover that the aircraft symbol was missing."

24. KEY POINT #25. SYMBOLOGY IS CONFORMAL BUT NOT HEAD-TRACKED... THE PILOT HAS TO COOPERATE (SLAVE HIMSELF) FOR THE SYMBOLOGY TO BE ACCURATE.

"The horizon line had good fidelity and could be used for head orientation. This HUD may very well condition pilots to keep their head in a normal (read perpendicular) position during turns. Leaning the head into or away from the turn (as many pilots do) caused the virtual horizon to be misaligned with the actual horizon."

25. KEY POINT #26. WELL DESIGNED ATTITUDE CUES MAY BE AS GOOD AS AN AVERAGE (OR BELOW AVERAGE) REAL LIFE VISUAL SCENE.

"With MODE 1, flight using primary attitude cues (pitch and roll symbols) was effective."

26. KEY POINT #27. INCOMPLETE INFORMATION FROM A WELL DESIGNED ATTITUDE CUE MAY BE MISLEADING AND VISUALLY COMPELLING TO THE POINT THAT THE REAL LIFE VISUAL CUES ARE NOT RECOGNIZED OR IGNORED. (see KEY POINT #26).

"With the "Plus Sign" removed, there was a greater dependence on secondary cues. The VSI pointer wasn't even noticed until switching to MODE 2 (in which the "Plus Sign" was removed)."

27. KEY POINT #28. CENTRALLY LOCATED SYMBOLOGY MAY OCCLUDE (PHYSICALLY OR ELSE) REAL LIFE OBSTACLES.

"The visual scene (horizon) wasn't noticed much with MODE 1, was noticed more with mode 2 and was really incorporated into the scan with MODE 4 (which had no attitude cues)."

28. KEY POINT #29. IF A POSITIVE ATTD CUE IS NOT AVAILABLE, HUD FLIGHT WITH POOR HORIZON CUES MAY NOT BE RECOMMENDED.

"During overwater flight (with poor actual horizon), nose low recovery was relatively easy in MODE 1 and very difficult in MODES 2 and 4. Without a horizon (actual or virtual), the pilot may be inclined to make either no input or an incorrect. Proprioceptive cues, during level descents, were strong enough that the pilot probably would make the correct input, however, the possibility for controlled flight into the water exists during low light level (poor visual horizon) conditions."

29. KEY POINT #30. VERTIGO SYMPTOMS MAY BE ENHANCED BY NVG HUD SYMBOLOGY.

"VISUAL EFFECT. The set up was a continuous left hand turn (<10 deg AOB), with two complete 360 degree revolutions (equilibrium re-established). Upon eye opening, the immediate sensation (of the-world-rushing-by) was as follows: as if the symbology rushed off the screen and then re-appearred."

30. KEY POINT #31. LIKE THE POLICY ESTABLISHED FOR NVG FLIGHT, USE OF THE HUD SHOULD BE A BOTH-PILOT OR NO-PILOT POLICY.

2) LEVEL TURNS - AIDED. "The comfort level while performing low (<150 ft AGL), overwater maneuvers was much higher than it would've been

without the HUD. It was especially important to have Airspeed and RADALT displayed. The other pilot, who was not on the HUD, stated his unease with having to bring his scan inside for RADALT."

31. KEY POINT #32. HEAD UP SYMBOLOGY MAKES THE TRANSITION FROM DECISION HEIGHT TO TOUCHDOWN EASIER.

"I used the HUD while doing GCAs (in VMC). It makes transitioning from instrument scan to visual scan (on short final) very easy. It required minimal pilot effort to establish visual scan (with external cueing) while constantly receiving instrument cues (attitude, altitude, airspeed etc...). (DRR 3). It was a relatively high illum night... but the relatively wide RADALT tape did not appear to be a distractor. I thought it might."

32. KEY POINT # 33. THE LAG IN CHANGING MODES MAY LEAD TO INCORRECT MODE SELECTION DURING CRITICAL MOMENTS.

WAS IT EASY TO CHANGE MODES? "The functionality of the mode/declutter works well with one exception. There is approximately 1/2 second lag between switch actuation and the decluttering/cluttering of display formats. Additionally, the touch cueing of the switch is weak, making the changeover/declutter point unpredictable. When attempting to declutter by actuating the switch to the left, I often thought that I had not pressed the switch far enough. Just as I was pressing the switch, for a second time, the first format would be changing. This required an additional 3 switch presses to get to the mode originally desired." (appendix D, page no. D-33, paragraph 16)

33. KEY POINT #34. THE HUD CORD MAY BE DETRIMENTAL TO POST-IMPACT EGRESS.

"POTENTIAL SAFETY CONCERN. For emergency egress; there are so many devices on helmets already (BOOM MIKE, VISORs/HOUSINGS, NVGs) plus aircraft interfaces such as the coiled ICS cord and shoulder straps that the chord associated with the NVG HUD really aggravates freedom of movement, jeopardizing egress. We may want to give consideration to a guide or sleeve of some sort that straps the aircraft's ICS and NVG HUD chords together (for at least some of the total length)."

34. KEY POINT #35. A NEW APPROACH TO DECLUTTERING THE CENTER FOV, WHILE STILL PROVIDING USEFUL CUES, MIGHT BE SYMBOL INTENSITY DIFFERENTIALS.

H. DID THE ATTITUDE SYMBOL ELEMENTS PROVIDE GOOD OR BAD CUES? (DESCRIBE): "It was OK, but the reference element (the pitch Ladder) needs to be differentiable (by pattern/color/intensity etc...). Perhaps by making the pitch Ladder independently adjustable." (appendix D, page no. D-36, paragraph 9)

35. KEY POINT # 36. THE HUD IS EASY TO USE, EVEN FOR A BEGINNER. HUD USE "AB INITIO" (OR NEARLY SO) WITH NVG TRAINING MAY WORK.

"Overall the HUD enhanced the flight. The HUD was easy to use, even for a beginner. (Author's note: this pilot had never used NVGs before. Use of the HUD was preceded by only 10 minutes of pure NVG training."

VITA

Marcus Gerard Mannella was born in Columbus, Ohio on 7 May 1961. He graduated from Purdue University, with a Bachelor of Science degree in Aeronautical Engineering in May 1983 and was commissioned a Second Lieutenant in the United States Marine Corps. In February 1986, then First Lieutenant Mannella was designated a Naval Aviator and Marine Corps Helicopter Pilot and transitioned to the UH-1N helicopter for his first operational assignment. Captain Mannella graduated from the Marine Aviation Weapons and Tactics Squadron One (MAWTS One) Weapons and Tactics Instructor (WTI) Course 1-89 in October 1989 and the United States Naval Test Pilot School (Class 100) in December 1990. Captain Mannella received the 1993 Admiral Clifford C. Duerfelt "Officer of the Year" award as the outstanding junior officer aboard NAS Patuxent River and was the Rotary Wing Aircraft Test Directorate "Test Pilot of the Year" for 1993. Major Mannella is currently serving as the project manager and lead engineering Test Pilot for the UH-1N Block Upgrade, a major airframe and systems upgrade to the Marine Corps Utility Mission aircraft. Major Mannella has logged over 3100 flight hours in 49 different types, models or series of aircraft, over 350 flight hours using head worn night vision devices, over 150 hours using infra-red imaging systems and holds an FAA commercial pilot license (airplane and helicopter) with multiengine and instrument ratings for both categories. Major Mannella is a member of the Society of Experimental Test Pilots.