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An Evaluation of the AH-64 Night Vision Systems for use in 21st Century Urban Combat

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To the Graduate Council:

I am submitting herewith a thesis written by John Kevin Heinecke entitled "An Evaluation of the AH-64 Night Vision Systems for use in 21st Century Urban Combat." I have examined the final electronic 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.

Richard Ranaudo, Major Professor

We have read this thesis and recommend its acceptance:

U. Peter Solies, Rodney Allison

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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recommend its acceptance:

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Rodney Allison______________

Acceptance of the Council:

Linda Painter________________
Interim Dean of Graduate Studies

(Original signatures are on file with official student records.)

An Evaluation of the AH-64 Night Vision Systems for use in 21st Century Urban Combat

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

John Kevin Heinecke
December 2006

DEDICATION

This paper is dedicated to the memory of those AH-64 pilots who served during the completion of this study and were later killed in action.

CW4 Richard “Matt” Salter	December 26, 2005	Cypress, TX
CW2 Isaias E. Santos	December 26, 2005	Ancon, Panama
CW3 Rex C. Kenyon	January 16, 2006	El Segundo, CA
CW2 Ruel M. Garcia	January 16, 2006	Wahiawa, HI
CW3 Michael L. Hartwick, Jr.	April 1, 2006	Albany, NY
CPT Timothy J. Moshier	April 1, 2006	Orrick, MO

These men heroically patrolled the skies of Iraq to protect and defend the lives of those Americans serving in our Armed Forces.

ACKNOWLEDGEMENTS

I wish to thank Mr. Clarence E. “Ed” Rash, of the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, for his technical review, patience and mentoring in the completion of this project. His efforts and contributions over the last three decades towards the study of enhanced vision systems provided much needed insight for the author and served as a benchmark for this study.

I also wish to thank Professor Richard Ranaudo (University of Tennessee Space Institute, Tullahoma, TN) and Dr. (Col.) Keith L. Hiatt (USAARL) for their continued support over the past year.

Lastly, I wish to thank all my fellow AH-64D aviators who put up with me and took the time to participate in this study amidst all that was going on.

ABSTRACT

Currently one of the most arduous and dangerous aviation missions for the military attack helicopter pilot is the night combat mission. The mission entails flight at close proximity to the ground and obstacles such as wires, trees, and buildings in an effort to avoid detection by enemy air defense and insurgent small arms fire. Night flight requires the use of augmented vision systems and enhanced aircraft stability and control systems to allow pilots to effectively see and negotiate those hazards that would otherwise be visible during daylight.

The U.S. Army currently fields two variants of augmented visionics, the Aviator Night Vision Imaging System (ANVIS) and the Pilot Night Vision System/Target Acquisition and Designation System (PNVS/TADS). ANVIS is a portable Image Intensification (I^2) system usable by all Army airframes whereas PNVS and TADS are both forward looking infrared (FLIR) subcomponents attached to the nose of the AH-64 attack helicopter. Since aviators began using augmented vision systems complaints have been registered regarding loss of static and dynamic cues, presence of visual illusions and other visual symptoms. Currently the mission has grown to encompass urban and suburban reconnaissance and security operations using systems designed in the late 1970's for transitioning to a "battle position" and near stationary engagement of heavy armor forces.

This study evaluated both systems in use by AH-64D aviators serving in and around Baghdad, Iraq from November 2005 thru October 2006. Whereas previous studies concentrated solely on visual symptoms and complaints associated with IHADSS use, this was the first study of both the FLIR and I^2 used in combination by AH-64 cockpit crews.

In the constant-moving environment of aerial reconnaissance and security, I^2 is preferable to the IHADSS by a majority of AH-64D pilots. Additionally, results showed a predominant favoring of the ANVIS over the PNVS/TADS for wire and aircraft avoidance due in large part to the enhanced visual acuity (20/25) of the ANVIS as compared to the 20/60 visual acuity of the IHADSS. The visual acuity disparity led to

consistent reporting of insufficient visual cues by IHADSS users. The primary benefit, as seen by pilots, of the PNVS/TADS system was the flight symbology cues provided through the helmet mounted display. Through training and education the data is received as stimuli and converted into usable 3-D cues for improved situational awareness. As with all previous studies, visual symptoms associated with IHADSS use were present.

DISCLAIMER

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GLOSSARY OF TERMS AND ABREVIATIONS

AO	Area of Operation
ADL	Aircraft Datum Line
AGL	Above Ground Level
AH	Attack Helicopter
ANVIS	Aviator Night Vision System
CAP	Combat Air Patrol
C^2	Command and Control
CONUS	Continental United States
CPG	Copilot/Gunner
CRT	Cathode Ray Tube
DAP	Display Adjustment Panel
DEU	Display Electronics Unit
DVE	Degraded Visual Environment
EO	Electro-optical
FLIR	Forward Looking Infrared
FOV	Field of View
HAT	Height above touchdown
HF	Human Factors
HDU	Helmet Display Unit
HMD	Helmet Mounted Display
I^2	Image Intensification
IED	Improvised Explosive Device
IR	Infrared
LOS	Line-of-Sight
LED	Light Emitting Diode
MFD	Multi-function Display
NIR	Near-Infrared
nm	Nanometer
NOE	Nap of the Earth
NVD	Night Vision Device
NVG	Night Vision Goggle
OIF	Operation Iraqi Freedom
OPTEMPO	Operational Tempo
PNVS	Pilot Night Vision System
SDU	Symbology Display Unit
SEU	Sight Electronics Unit
SHP	Shaft Horsepower
SSU	Sight Surveying Unit
TAS	True Airspeed
TEDAC	TADS Electronic Display and Control
UCE	Usable Cueing Environment
USAARL	U.S. Army Aeromedical Research Laboratory

VDU	Video Display Unit
VMC	Visual Meteorological Conditions
VSI	Vertical Speed Indicator

1. INTRODUCTION

Currently one of the most arduous and dangerous aviation missions for the military attack helicopter pilot is the night combat mission. The mission entails flight at close proximity to the ground and obstacles such as wires, trees, and buildings in an effort to avoid detection by enemy air defense and insurgent small arms fire. Night flight requires the use of augmented vision systems and enhanced aircraft stability and control systems to allow pilots to effectively see and negotiate those hazards that otherwise are visible during daylight. The U.S. Army has been using the Boeing AH-64D Apache attack helicopter (Figure 1) for this mission. Presently the mission has grown to encompass urban and suburban reconnaissance (recon) and security operations using systems originally designed for transitioning to a "battle position" and near stationary engagement of heavy armor forces. Issues of night system visual acuity, perceived effectiveness, and general pilot opinion while functioning in the urban and suburban reconnaissance and security mode need to be explored to improve the effectiveness of the airframe in its modern role.

Figure 1. AH-64D Apache Helicopter.

The U.S. Army fielded the AH-64 Apache attack helicopter in the early 1980's to meet the requirement for a day and night attack platform. The AH-64 Apache attack helicopter is a tandem-seated, four-bladed, twin engine rotorcraft that uses as its primary night visionics the Integrated Helmet and Display Sighting System (IHADSS). The IHADSS (Figure 2) uses Forward Looking Infrared (FLIR) sensor technology to enhance, for the pilot, the night visual environment.

The IHADSS has two major functions, viewing and line of sight maintenance, with each having subcomponents specific to them. Viewing is accomplished when video imagery is sent through the Display Electronics Unit (DEU) to the Display Adjustment Panel (DAP) into the Helmet Display Unit (HDU). The imagery is presented on a miniature (1-inch diameter) cathode ray-tube (CRT) and reflected off a beamsplitter into the eye (Figure 3, right). Line of sight is maintained through a pair of lead sulfide photodiode sensors on the helmet that track helmet position through movement within an IR generated "motion box". The motion box is created by the Sensor Surveying Units (SSU) (2 each). Movement is transmitted to the Sight Electronics Unit (SEU) facilitating movement of weapons system and Target Acquisition and Designation System (TADS/PNVS) and Pilot's Night Vision System (PNVS) sensors. A boresight module is mounted within each pilot station and is used at the beginning of each flight to calibrate the line of sight. Figure 2 illustrates the major components of the IHADSS.

The AH-64 airframe is currently up to the "D" version, which uses a glass cockpit (multifunction display-equipped) design, improved engines, enhanced navigation capability, and an added millimeter wave radar targeting system. With the exception of one attack helicopter battalion, the D model continues to use the original IHADSS for fire control (weaponry) and general piloting data imagery. Pilotage information is provided in the format of symbology viewed through a monocle (beamsplitter) in daytime or symbology overlaying the FLIR video feed from the PNVS sensor (night or day, when selected). The copilot views FLIR imagery from the TADS sensor. Either sensor system may be used from either crewstation by toggle selection on the collective handgrip (left of and at the bottom of pilot's seat). The backup night vision system currently being used is the Aviator Night Vision System (ANVIS) (Figure 3, left) which is commonly referred

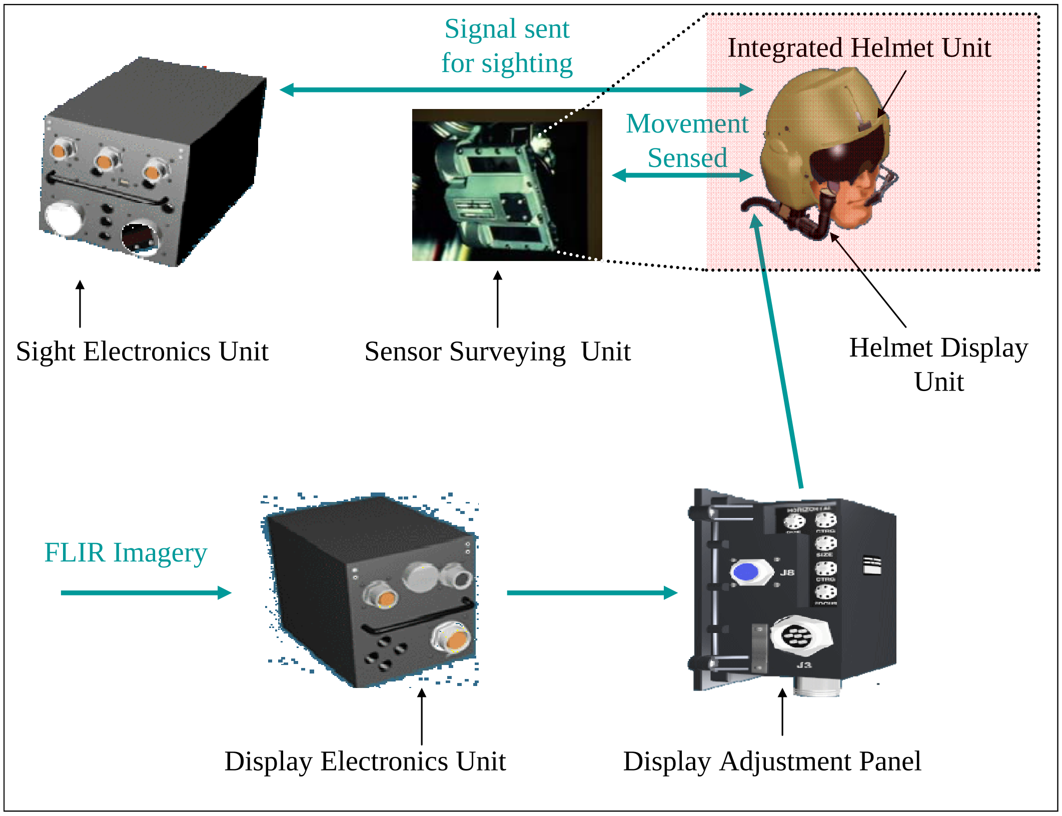

Figure 2. IHADSS Major Components.

Figure 3. Apache Pilot wearing ANVIS (L) and IHADSS (R).

to as Night Vision Goggles (NVGs) (Department of the Army, 2005).

NVGs utilize the concept of image intensification (I^2) and currently are the only night vision system option for U.S. Army non-Apache helicopter airframes. The use of NVGs as a backup to the IHADSS resulted from the recognized limitations of the legacy FLIR to consistently identify other aircraft, detect powerlines and wires.

Subsequent to the fielding of the Apache aircraft, several studies were completed to address pilot complaints of visual issues, (LeDuc et al., 2005, Rash et al., 2004), and pilot subjective opinion of their use of the IHADSS (Behar et al., 1990, Rash et al., 2001, Hiatt et al., 2004). Of the reports cited, only Hiatt et al., 2004, addresses issues related within the combat environment, but not specifically the urban environment. This paper addresses the AH-64D augmented vision systems use within the Operation Iraqi Freedom (OIF) urban combat environment.

The use of night vision technology has been driven by the Army's ever-expanding mission and subsequent nighttime operational needs. This requirement for increased visual augmentation is provided by two basic sensor technologies: I^2 and FLIR. The physics of these two technologies are different; therefore their benefits and limitations also differ. I^2 sensors operate on the principle of light application, and their performance is a function of the level of ambient illumination. FLIR sensors operate on temperature differences between adjacent objects or regions. FLIR sensors do not require visual illumination. Their performance is a function of the ambient temperature gradient.

Initially, only FLIR sensor imagery was available for display, via the IHADDS, to AH-64 pilots. In the AH-64's original tank-engagement mission role, FLIR sensor technology was optimal at detecting the infrared emission of tanks and other vehicles at long stand-off distances. However, with the transition of the AH-64's mission into one of close-quarter urban engagement, there may be situations where I^2 sensors are better suited. For this reason, currently, both night vision sensor technologies are employed in the AH-64.

The following operational research questions are based on the need to validate this recent decision to place both sensor technologies in the AH-64 cockpit:

1. Is there a significant difference in each system’s performance for aircraft, wire and obstacle detection and avoidance?
2. Is there a significant difference in effectiveness between the IHADSS/PNVS and the NVG (ANVIS) sensors for night urban (and suburban) reconnaissance/security?
3. Is there a significant difference in each system’s ability to provide situational awareness?

A questionnaire was developed and used to collect data on AH-64 pilot opinion of dual sensor operations and IHADSS visual symptoms in urban combat as previously touched upon in the 2004 OIF study. The pilots surveyed served on a joint U.S. – Iraqi airfield northwest of Baghdad, from December 2005 through November 2006. The Baghdad municipal area served as their primary area of operation. Other reference material for this project includes the multitude of reports published by the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, and other relevant studies in the field of human factors (HF).

2. BACKGROUND

2.1 Helicopter Obstacle Avoidance during Low-Level Maneuvering

The primary sense for coordinated movement is the human eye. Through the eye we are able to detect and avoid objects, judge and adjust speed based on closure rates and generally guide our movements with a purpose. David N. Lee of Edinburgh University described a theory of guided movement and referred to it as “General Tau Theory” (Lee et al., 1999). This theory described the concept of “Tau-Coupling,” explaining how our nervous system continuously receives visual data and couples a target’s distance to its rate of closure. By constantly computing the changing values, referred to as “Tau Gaps,” our nervous system allows us to successfully grasp objects and to avoid obstacles. Constantly maintaining a specific ratio value allows us to maintain control, e.g., decreasing distance should accompany a decreasing closure rate. In recent years, this theory of guided movement has resulted in several papers dealing specifically with helicopter operations in the nap-of-the-earth (NOE) environment (Padfield et al., 2001) and in the degraded visual environment (DVE) (Clark 2003). NOE is defined as varying airspeed and altitude to avoid obstacles and is usually performed below 25 feet AGL and below 40 knots airspeed (Department of the Army, 2005).

Under visual flight rules (full illumination) the pilot relies on static and dynamic cues for speed and altitude control, terrain slant (slope) determination, glideslope control, and depth perception (Foyle et al., 1992). The successful and safe completion of any helicopter low-level mission requires the pilot to receive all static and dynamic cues available. These cues in turn allow the pilot to perform the basic functions of piloting: (1) navigating the route, (2) guiding the aircraft, and (3) keeping the aircraft stable (Padfield et al., 2001). Navigating requires the pilot to reconcile where he/she is with where they want to go via maps, navigation equipment and changing scenery. This task has the longest lead time and can, when needed, be corrected without incident (i.e., you get lost so you turn around). Guidance and stabilization, on the other hand, are more time critical, with extreme penalties for error. Guidance requires the pilot flying close to the earth to reassess obstacle and hazard avoidance every few seconds for a given distance span, this being measured in tens of meters (Clark, 2003). The more cues available, the better guidance can be accomplished by the pilot. Stabilization, being the most time response stringent, is a closed-loop function that requires constant instantaneous corrections resulting in the greatest pilot workload. Tau-coupling is critical for safe operation of the aircraft at close proximity to the ground.

During NOE, the same principle of distance versus rate of closure is applied to the man-helicopter system as an entity. The pilot manipulates the controls in such a manner as to successfully stop, turn, climb, and move laterally, etc., as he/she views the changing scenery below and in front of the aircraft (Figure 4). This is easily accomplished in full daylight, and with constant practice the pilot can achieve a level of expertise to facilitate safe completion of a combat mission. This is not the case during nighttime operations, which requires the use of augmented vision systems.

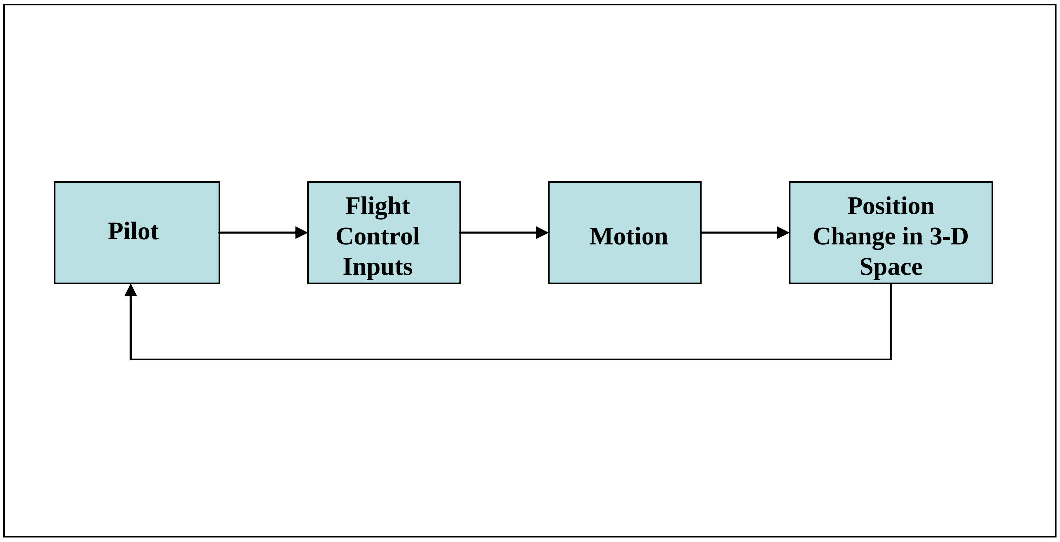

Figure 4. Simplified Pilot-in-the-Loop Flight Control System.

2.2 Bringing Back the Day: Night Flight Past and Present

In the earliest days of flying, the primary safety concern for pilots was the visual loss of the horizon or the ground, and hopefully, not both. The issues of vertigo and spatial disorientation, although not well understood by the general population at the time, were well recognized by early aviation instrument pioneers like William Ocker (1880-1942) (University of Texas, 2001). Spatial disorientation is the apparent conflict between the vestibular and visual systems, the difference between what you see yourself doing and what your inner ear organs tell you is happening (U.S. Air Force Research Laboratory, 2003). Early pilots did not consider flight instruments important to flying, and most aircraft were minimally instrumented, if instrumented at all. In fact, Wilbur and Orville Wright equipped their first plane with only three instruments, an anemometer for airspeed indication, an engine revolution counter for engine performance, and a stopwatch (Mraz, 2003). The flight took place in daylight under good visual conditions and did not have a need for instrumentation to help with horizontal and lateral position; the ground and horizon provided sufficient visual cues. The overall absence of flight instruments during early aviation led to many fatalities when pilots lost sight of the ground or horizon and trusted their vestibular senses (University of Texas, 2001). Intentional night flight was even more dangerous.

For aviation to be an asset to the military, night flight would have to be an option (McFarland, 1997). Military use of night air combat operations can trace its lineage back to World War I when the Germans used Zeppelins to bomb England under the cover of darkness. The British retaliated by using fighter aircraft to hunt down and destroy the Zeppelins (Feltus, 2003). But again, these aircraft had only the basic instrumentation: engine revolutions per minute (RPM), compass, altitude and airspeed gauges (Figure 5).

The successful use of “radio intercepts, ground observers, searchlights and blind luck” (McFarland, 1997) played a heavy role in the British success over their airspace in 1915. It wasn’t until the end of the war and several years later that research and development would assist the pilot in regaining the loss of horizon and directional cues.

During the post-war period Ocker would upgrade and patent Elmer Sperry’s turn

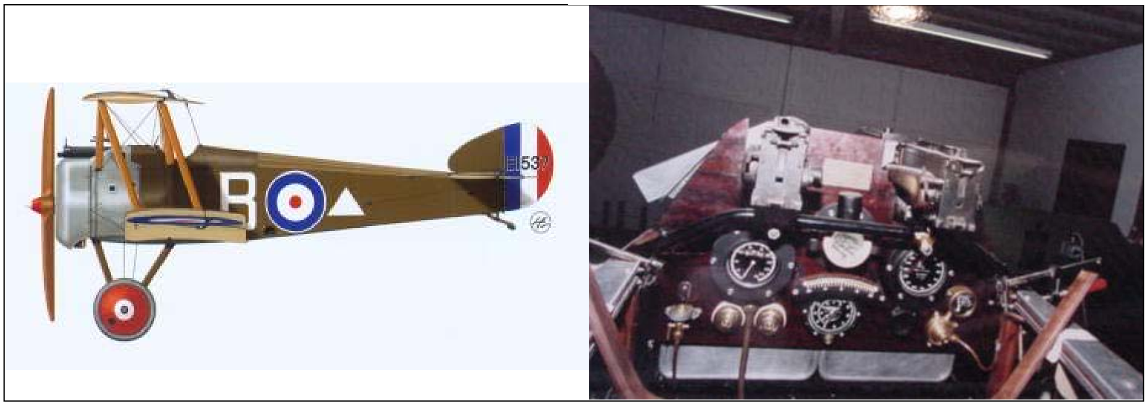

Figure 5. Sopwith Camel, WWI Fighter.

Source: University of Tennessee Space Institute Course AS515: Human Factors Engineering; R. Ranaudo.

indicator, one of the original flight instruments used, turning it into a turn and bank indicator (Mraz, 2003). Following this, further research and development would introduce cockpit instruments such as the altimeter by Paul Kollsman and the directional gyro and artificial horizon invented, again, by Elmer Sperry. All of these advancements led to the “blind flight” aircraft trials of 1929–1933 (Glines, 1993) and eventually to the U.S. Army incorporating instrument flight training into its flight curriculum in 1943 (University of Texas, 2001). These flights, flown by the legendary Jimmy Doolittle, showed the utility and relative safety of flying aircraft without any visible contact with the horizon or ground. But being able to fly in darkness and inclement weather still did not aid combat aviation in attacking and thwarting enemy air assaults.

In World War II, searchlights were modified to allow transmission of infrared (IR) radiation in the range 700 – 1200 nanometers (nm). Allowing the transmission of near-IR (NIR) energy, combined with the use of an image converter tube, increased the ability to view and target the enemy. Unfortunately, conventional and near IR searchlights were active in nature, meaning that the enemy, when similarly equipped, were afforded the same advantage (McLean et al., 1998). It wasn’t until the 1960s that passive systems were designed to allow for ambient light levels to be “intensified” for undetected viewing. NVGs such as the ANVIS Type 6, the current generation of such intensifying systems, are a passive system (Figure 6).

The ANVIS NVG operates by focusing ambient light onto a photocathode (sensitive to both visible and NIR energy). The photons of light, by means of the photoelectric effect, produce electrons that undergo multiplication as they pass through a micro channel plate. The ANVIS operates by "intensifying ambient light 2,000 to 3,500 times" (Department of the Army, 1988). The intensified imagery is presented on a phosphor screen and viewed through an eyepiece. The imagery visible has a green color due to the choice of phosphor used. The system is less effective in rain, fog, sleet, snow, and smoke due to the requirement for ambient light to be present (Department of the Army, 2004).

NVGs for use by pilots were not approved until 1971 (Department of the Army, 1988). Since that time period the technology has gone through several improvements. The ANVIS system, itself, constitutes a 3rd generation image intensification system (Figure 4). This system became operational in 1982 but was not fielded until 1989 (McLean et al., 1998). The ANVIS is designed to operate in the 625 – 950 nm range (Figure 7), allowing the operator to identify terrain features as low as 200 feet AGL while traveling at speeds of 150 nautical miles per hour (McLean et al., 1998).

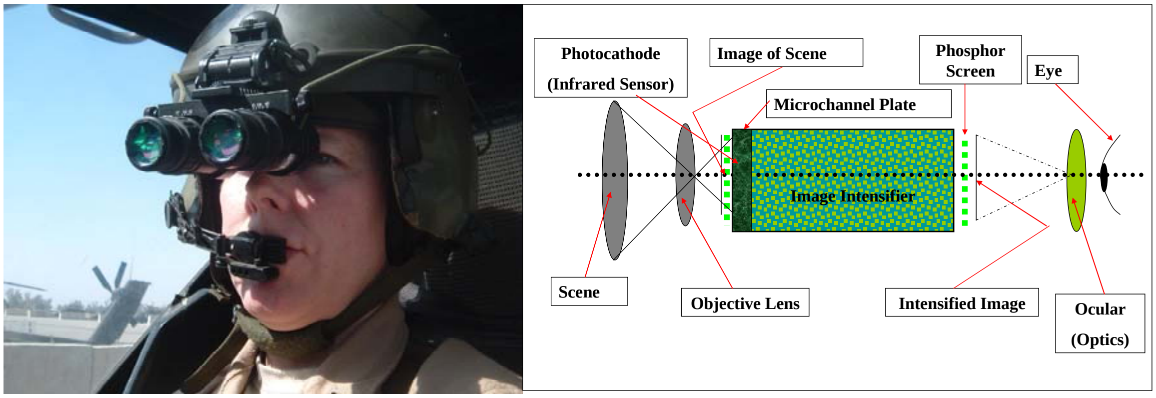

Figure 6. NVGs and Concept of Operation.

Source: U.S. Army TC 1-204: Night Flight Techniques and Procedures.

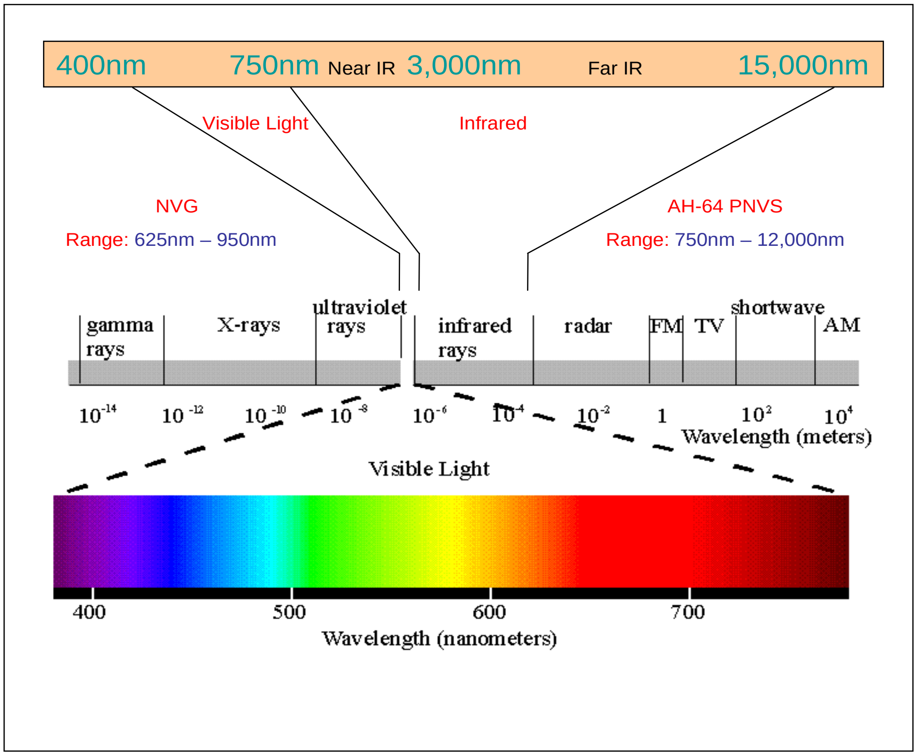

Figure 7. Electromagnetic Spectrum with Augmented Visionic System Ranges.
Source: U.S. Army TC 1-204: Night Flight Techniques and Procedures.

The 625 – 950 nm range puts ANVIS system in the upper visible to NIR spectrum (Department of the Army, 1988). The ANVIS system has a 40-degree circular field of view (FOV) with Snellen visual acuity up to 20/25 (personal communication, W.E. McLean, USAARL, Ft. Rucker, AL, July 18, 2006). The pilot's ability to see objects in azimuth and elevation is limited only by the aircraft cockpit structure (bulkheads and canopy) and his/her physical ability to look left, right, up and down.

Shortly after Army Aviation began experimenting with NVGs, the competition trials for fielding the Army's new advanced attack helicopter, the AH-64 Apache, had begun. Part of the trials included a competition for a targeting and sensor system. The Advanced Attack Helicopter sensor competition was between Martin Marietta Corporation and Northrop Grumman Corporation, with both companies submitting proposals in 1976 (Goebel, 2003). Martin Marietta (the winner) proposed the thermal imaging approach using FLIR sensors, the TADS/PNVS design, and was awarded the contract in 1980 (Goebel, 2003). Unlike ANVIS, thermal imaging sensors require no ambient light to operate effectively. IR sensors at the time were generally considered "less affected by weather conditions than I^2 systems" (Department of the Army, 1988), while also allowing for better acquisition of enemy targets at greater distances. The TADS/PNVS system covers a wider range over the electromagnetic spectrum than the I^2 systems (Department of the Army, 1988) (Figure 7), this range allowing for both near and far IR. In essence, the system allows the pilot to see what is normally invisible to the naked eye.

Since the TADS/PNVS is attached to the nose of the AH-64 Apache helicopter, it has elevation and azimuth limits but suffers from no physical obstructions to the pilot's view as is the case with NVGs. The PNVS can look up 20 degrees and down 45 degrees, while looking 90 degrees left or right of the aircraft datum line (ADL) (U.S. Army Aviation School [USAAVNS], 1999). The TADS, being primarily for target acquisition, can look upwards 30 degrees and downwards 60 degrees while looking 120 degrees left or right of the ADL (USAAVNS, 1999). Both TADS and PNVS provide their respective pilot with a 30-degree horizontal by 40-degree vertical FOV. The PNVS has a slew rate up to 120-degrees per second with the TADS slew rate advertised as "noticeable slower than the PNVS" (USAAVNS, 1999). The system provides a 20/60 Snellen visual acuity (Green, 1988).

The PNVS FLIR basic design is more complicated than the NVG system and is illustrated in Figure 6. The system receives IR energy and reflects it onto an IR imager which provides the 30 by 40-degree FOV as it rotates the received IR energy 90 degrees. The imager folds the image 90 degrees for entry into a "focus wedge" which then focuses the IR energy onto an IR detector strip. The IR detector sends the IR image to the video electronics section where it is converted into electrical signals. This video electronics section can be manually adjusted from the cockpit for improving visual acuity. The electrical signals are converted into visible light by the light-emitting diode (LED) array. Once the IR signal is captured, it is converted to an electronic video signal by the Electro-Optical (EO) Multiplex (MUX) and transmitted to the cockpit. Figure 8 illustrates the basic concept of the AH-64 FLIR system. In the cockpit, the image is presented through

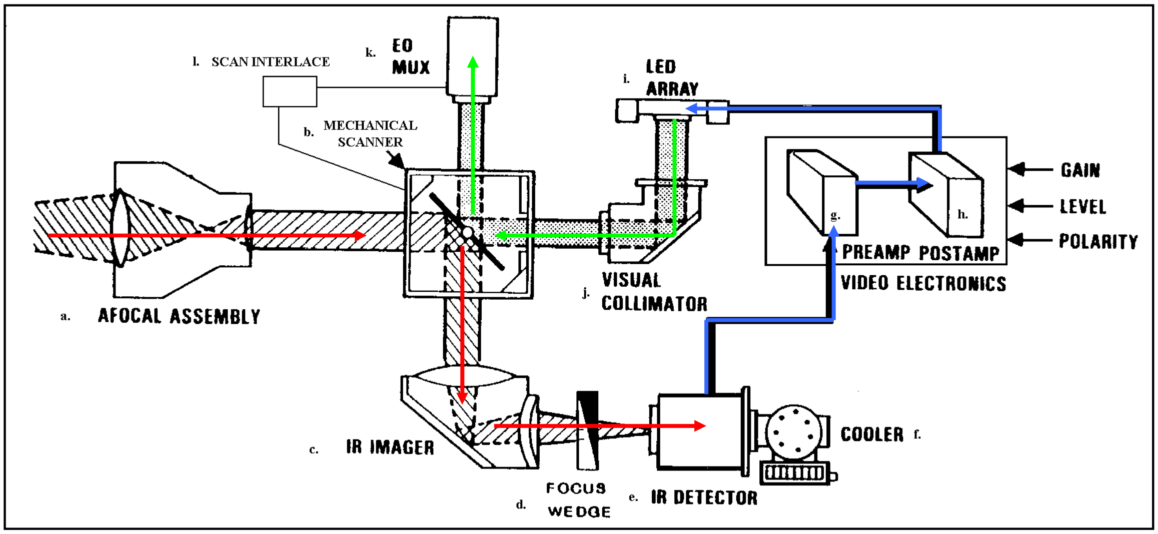

Figure 8. AH-64 FLIR Operation.

Source: Infrared (IR) Theory and Pilot Night Vision System (PNVS) Operations (Student Handout, 1998, pg. D-9). Reprinted by permission.

the Helmet Display Unit (HDU) attached to the aviator’s helmet (Figure 3, right). The system “makes visible” the 7.5 to 12.0 micron range of the IR spectrum in the outside scene (Figure 7).

The TADS/PNVS design allows the pilots to not only see in the dark and under degraded visual conditions, but it provides symbology that augments the visible cues for improved situational awareness. Vision scientists found that by augmenting the external scenery via flight symbology viewed through an HMD, pilots could use augmented cues in place of the absent or diminished cues present (Foyle et al., 1992). Primary piloting data are provided in the form of a directional heading tape, true airspeed (TAS) indicator, vertical speed indicator (VSI), radar altimeter, velocity vector and an acceleration cue (Figure 9). A field of regard box is visible at the base of the image showing the viewer where their FOV is in relation to their permissible azimuth and elevation limits. Figure 9 illustrates the view seen by the pilot through the IHADSS beamsplitter. The velocity vector and acceleration cues provide a visual representation of the direction the aircraft is translating and where it will go if it continues its present acceleration, respectively. The

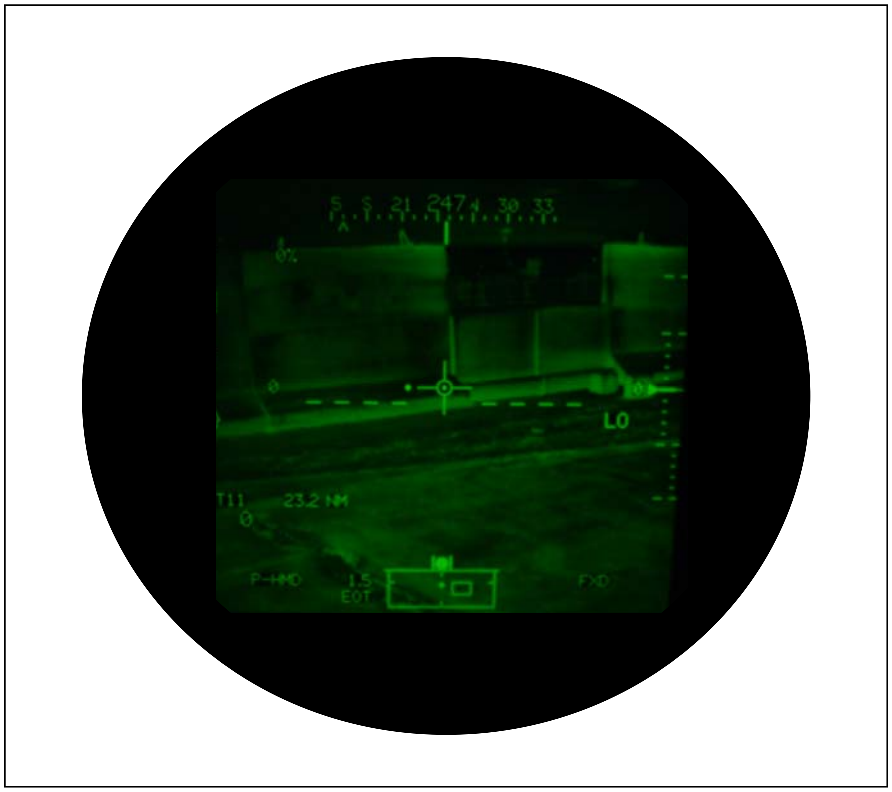

Figure 9. IHADSS Symbology with FLIR.

heading tape is presented on the top, the radar altimeter and VSI are to the right, and the TAS indication is on the left. The Figure 9 image is representative of an aircraft that is stationary; hence, airspeed is zero and there is no velocity vector or acceleration cue displacement. However, the acceleration cue is visible in the center of the pilot's line-of-site (LOS) reticule with a cueing dot to its left advising the pilot the direction of the ADL of the aircraft from where the pilot is viewing.

The TADS as a targeting and acquisition system proved itself immediately upon introduction of the AH-64A into the U.S. Army fleet. The system however was never intended as the primary source for piloting the aircraft, the PNVS was designed for that purpose. The PNVS had a 120-degree per second slew rate as compared to the much slower TADS (USAAVNC, 1999). Issues of latency while slewing one's head left or right and reports of a poorer image quality plagued the system (discussed in Section 2.3).

In the late 1980s the U.S. Army began acknowledging the potential safety issues related to piloting the AH-64 via the TADS. Until 2004 the AH-64A/D aircrew training manuals only authorized the copilot/gunner station (the primary user of TADS) to use NVGs for navigation and obstacle avoidance (Department of the Army, 2004). It was specified that the pilot in the backseat would always use PNVS except when training with an instructor pilot (IP) using PNVS from the front seat. PNVS and TADS may both be toggle selected for use from either cockpit's collective handgrip. In 2004 the U.S. Army authorized the use of NVGs in either cockpit of the AH-64D (U.S. Army Research, Development and Engineering Command, 2004) with at least one pilot using either PNVS or TADS.

Currently the Army is fielding a modernized TADS/PNVS (Modernized Target Acquisition Designation Sight [MTADS]) with Generation III FLIR for a total of 611 systems for use on A- and D- model Apaches. The last units are scheduled for procurement in 2009 (Table 1), meaning that for the foreseeable future, deployments will continue to be conducted with the current system.

Table 1. Modernized TADS/PNVS Upgrade Procurement Schedule.

Fiscal Year	Contract Year	Order Quantity
2006	Basic	211
2007	Option Year 1	182
2008	Option Year 2	91
2009	Option Year 3	128

Source: FBO Daily, March 2, 2005, FBO#1192. Modernized Target Acquisition Designation Sight (MTADS)/Pilot Night Vision Sensor (PNVS) http://www.fbodaily.com/archive/ 2005/03-March/02-Mar-2005/FBO-00759671.htm

The U.S. Army has temporarily authorized the use of an improved version of NVGs modified for use with a symbology display unit (SDU). The SDU mounts to the pilot's visor and provide the NVG wearer with full flight symbology representation identical to that provided by the IHADSS. An additional feature of the SDU design is that it allows for line-of-sight acquisition use of the aircraft's onboard weapons system (U.S. Army Research, Development and Engineering Command, 2005). This system is only authorized for use by units operating in the combat theater and at the discretion of the individual commands.

2.3 Enhanced Vision System Problems

From the initial use of the IHADSS' helmet-mounted display (HMD), AH-64 Apache pilots have registered complaints regarding degraded visual cueing, the presence of visual illusions, and general physical discomfort (headaches and blurred vision) (Hiatt et al, 2004). During the initial design phase, vision scientists felt the monocular design of the AH-64 IHADSS could pose a problem due to the binocular nature of the human visual system, but these concerns were never proven valid (Rash, 2007 [in press]). Several studies were conducted to evaluate the validity of reports and to determine the possible source(s) of the complaints.

Steven Hale and Dino Piccione (Hale & Piccione, 1989) completed their "Pilot Assessment of the AH-64 Helmet Mounted Display System" using subjective data gathered from 52 AH-64 pilots stationed at Fort Hood, Texas, in 1988. The study identified issues related to size-distance perception, FLIR image quality, and effects of monocular viewing on pilot physiology. The size-distance perception issue was seen as a problem associated with proper adjustment of the HDU combiner lens image, via the display adjustment panel (Figure 2). When properly adjusted, the HDU image presents a 30-degree vertical by 40-degree horizontal one-to-one (unity magnification) depiction of the outside world. By adjusting the image to make it smaller (allowing for clearer perception of the symbology) pilots were making objects appear farther away. PNVS FLIR image quality was noted as being better when viewed on the AH-64's cockpit video display unit (VDU)/ multi-function display (MFD), located on the instrument console, rather than through the HDU. The VDU/MFD receives the video signal directly from the display processor whereas the HDU has the image sent from the display processor through the DAP, then through the HDU cabling to the pilot's right eye (Figure 2). "IR crossover" was addressed as an issue associated with poor FLIR quality. Since FLIR works by making visible an object's relative heat, the period of time in the evening and in the early morning when all items have generally the same temperature (IR crossover) presents a problem. Regardless of the amount of adjustments attempted, the image quality still remains insufficient. Monocular viewing and the binocular function of the human vision system were identified as the possible problem with respect to pilot physical discomfort. After 1 – 1.5 hours of flight, CRT luminance on the right eye causes fatigue. This fatigue and the general fatigue associated with long duration flights, made right-eye concentration difficult. Binocular rivalry would begin when "intentional" control of the eye became difficult. Following the publishing of the report by Hale and Piccione, the U.S. Army Aeromedical Research Laboratory at Fort Rucker, Alabama, conducted a 3-part study of the AH-64 HMD and issues related to its use.

USAARL Report No. 90-15, "Visual Survey of Apache Pilots" (Behar et al., 1990), included an anonymous survey (Part I of the study) of 58 AH-64 instructor pilots stationed at Fort Rucker in 1990. Of the pilots surveyed, 80% had at least one visual complaint associated with use of the AH-64 HMD. Part II of the study entailed a battery of visual function tests for 10 volunteers and did not produce any salient issues. Part III entailed HMD diopter measurements for 11 AH-64 Student pilots and 9 AH-64 instructor pilots. A diopter is a unit of measurement that determines how much a lens should be modified to bend or refract light rays. Without the correct adjustment, adequate focus cannot be achieved. The measurements were completed on the flightline at Fort Rucker, Alabama, with the AH-64 pilots adjusting the HMD for effective viewing. The diopter measurement data ranged between 0 to -5.25 with a mean of -2.28 (Behar et al., 1990). Normally a one-to-one representation for an individual with 20/20 vision would result in a diopter measurement of "0". The minus (-) 2.28 diopter mean measurement by the investigators meant that pilots were focusing in closer than what should have been required thus causing there eyes to make a "positive" accommodation to constantly view the object. This problem centered on the improper focusing of the IHADSS prior to flight. The investigators felt that the positive accommodation required by the AH-64 pilot's right eye to offset these "negative" focus settings during long flights was most probably the cause for ocular discomfort. In the following year (1991), USAARL completed an extensive survey of all the services concerning visual illusions under NVG and PNVS (Crowley, 1991).

Crowley explored Night Vision Device (NVD) (NVG and IHADSS) visual illusions based upon 242 completed questionnaires spread over all of the military services. Of those respondents 221 were NVG users who reported some visual effect due to their use, and 21 were IHADSS users who reported some form of visual illusion or effect due to IHADSS use. The report noted a frequent misjudgment by pilots regarding aircraft drift, ground and obstacle clearance, height-above-touchdown (HAT), and aircraft attitude. The investigators concluded that contributing factors in all cases were pilot inexperience, crewmember division of attention during normal piloting tasks, and overall fatigue. No obvious differences were noted between NVG and IHADSS users and included input from fixed-wing pilots. Table 2 shows a breakdown of the results of 1991 report. This all inclusive NVD report was followed up in 2000 and 2003 with surveys conducted specifically on AH-64 pilot IHADSS users.

The U.S. Army Aeromedical Research Laboratory conducted a "Visual Issues Survey of AH-64 Apache Aviators" in 2000 (Rash, 2001) and a field study of AH-64 pilots serving in Operation Iraqi Freedom (OIF) in 2003 (Hiatt, 2004). The CY 2000 survey was web-base, had 216 respondents, and concentrated on reports of visual complaints, helmet fit, and general helmet acoustics. Of those responding to this survey 92% reported at least one visual complaint during or after flight (Rash et al., 2001, p. 23, Figure 22). Hiatt and Rash's OIF study in 2003 encompassed vision history, helmet fit, and aviator visual complaints. The effort was aimed at ascertaining if the frequency of reported complaints varied from the training environment and the battlefield.

Hiatt and Rash (Hiatt et al., 2004) found that the most frequently reported complaint was visual discomfort and headache which was consistent with previous

Table 2. Cumulative Results: Crowley's 1991 Report on Human Factors of NVD.

Degraded visual cues	RW - NVG (n = 212)		FW - NVG (n = 9)		AH-64 PNVS (n = 21)	
	%	(n)	%	(n)	%	(n)
Degraded resolution/insufficient detail	33	(70)	66	(6)	14	(3)
Loss of visual contact with horizon	15	(31)	-		10	(2)
Impaired depth perception	11	(24)	11	(1)	10	(2)
Decreased field-of-view	10	(20)	22	(2)	10	(2)
Inadvertent IMC	8	(16)	22	(2)	5	(1)
Whiteout/brownout	6	(13)	-		-	
Changing acuity due to shadows	3	(7)	-		-	
Blurring of image with head movement	<1	(1)	22	(2)	-	
Static Illusions						
Faulty height judgment	16	(33)	56	(5)	19	(4)
Trouble with lights	8	(17)	-		5	(1)
Sense of landing in a hole	5	(10)	-		-	
Faulty clearance judgment	3	(7)	11	(1)	-	
Faulty slope estimation	3	(7)	11	(1)	-	
Bending of straight lines	3	(7)	-		-	
Faulty attitude judgment	3	(6)	-		-	
Dynamic Illusions						
Undetected aircraft drift	18	(38)	-		24	(5)
Illusory aircraft drift	14	(30)	-		24	(5)
Disorientation (“vertigo”)	12	(25)	-		14	(3)
Faulty closure judgment	6	(13)	-		10	(2)
No sensation of movement	2	(4)	11	(1)	-	
Faulty airspeed judgment	1	(2)	-		-	
Illusory rearward flight	1	(2)	-		-	
Illusions of pitch	1	(2)	-		-	
Sensation of stars falling	<1	(1)	-		-	
Illusory sideward flight	<1	(1)	-		-	

studies. The USAARL report concluded with a recommendation for a future study encompassing AH-64 pilots operating in the urban combat environment in a further effort to understand the frequencies of visual complaints associated with NVD use. It is this recommendation and the use of dual sensor technology in the AH-64 that motivated the current study.

2.4 OIF Urban Combat Flight Profiles In and Around Baghdad, Iraq

Combat flights in and around Baghdad, Iraq, varied between low-level, contour, and nap-of-the-earth (NOE) flight. The U.S. Army makes the following distinction for flight profiles: Low-level flight refers to maintaining a constant airspeed and altitude (usually defined as no lower than 200 feet above the ground (AGL)); Contour flight is the varying of altitude while maintaining a near constant airspeed along the "contour" of the terrain; and NOE refers to flight where the pilot varies airspeed and altitude as close to the "the earth's surface as vegetation, obstacles, and ambient light will permit" (Department of the Army, 2005).

The U.S. Army has reviewed these modes of flight for "environmental relevance", providing aviators a "factor" that can be applied to one hour of non-day flight. This factor realistically quantifies the equivalent cumulative stress and fatigue on the pilot during non-day, non-straight-and-level flight. Table 3 details the environmental relative factor portion of the U.S. Army's "Crew Endurance Guide" (Department of the Army, 1997). Note the fact that night vision device use is associated with an increased stress and fatigue factor of 2.3 (in bold).

Table 3. U.S. Army Environmental Relative Factors.

Flight Condition	Environmental Relative Factor
Day	1.0
Day Contour and Low Level	1.3
Low Level Instrument	1.3
Night	1.4
Day NOE	1.6
Night Terrain	2.1
Night Vision Devices	**2.3**
Chemical Protective Gear	3.1

3. **DATA, DISCUSSION, AND FINDINGS**

3.1 Methodology

A questionnaire/survey was distributed and completed on Taji Airfield, northwest of Baghdad, Iraq, between March 15, 2006 and April 8, 2006. Flights were conducted under visual meteorological conditions (VMC) during the non-rainy season with relatively little overcast conditions. Apache pilots surveyed were asked to voluntarily fill out the questionnaire. Respondents were permitted to take the survey to their quarters to complete with no time limit given. The Aviation Brigade being surveyed maintained a 24 hour operation with 3 shifts rotating on a 30 day cycle. In several instances individuals completed the survey in the Mission Planning Room immediately upon receipt of the survey, but in most cases participants elected to complete it at their leisure.

The survey was broken into five (5) sections: (1) “Demographics and flight experience”, (2) “Visual history”, (3) “Helmet fit and IHADSS utility”, (4) IHADSS vision, and (5) “IHADSS versus NVG mission effectiveness during this OIF rotation”. The first section addressed individual pilot flight experience, age, and gender. Flight experience questions covered overall experience, combat time, number of sorties flown and number of rotations into a combat zone with Operation Enduring Freedom (OEF) (Afghanistan) rotations inclusive. Section (2) covered use of corrected vision (or absence of) and eye preference prior to initiation into right monocle IHADSS use. Time since last helmet fitting, IHADSS field of view, symbology viewing effectiveness and general system utility were queried in Section (3). Section (4) inquired regarding “before” and “after” flight visual symptoms, degraded visual cues, dynamic and static illusions, and physical limitations of the IHADSS with reference to the mode of flight during said limitation. Sections (1) through (4) constitute the “first part” of this study and were designed to parallel previous HMD reports and studies in format and design while exploring ongoing visual symptoms associated with IHADSS use. The end goal was the ability to compare to previous results and identify any trends or possible salient differences. The last section, Section (5), serves as the “second part” of this study and was used to compare dual sensor operations in the AH-64 cockpit. Perceived effectiveness was questioned regarding security and reconnaissance missions. Tabular data is represented in histogram (bar chart) format and compared to the previous OIF study through chi-squared analysis. Chi-squared analysis for this and the previous OIF study identifies statistical significance to the .05-level (5%). Where subjective results were requested in Sections (2) through (5), a Likert scale of 1 to 5 was used. Comparisons of response patterns for Likert scale data is accomplished via the Mann-Whitney U-test. Respondents were offered the opportunity to reply “N/A” but in all cases opted to respond. Participants were encouraged to make anecdotal comments throughout the survey with their comments being included throughout the report. The Appendix includes complete survey questions and compiled results detailing all data collected via the questionnaire.

3.2 Demographics, Flight Experience and Visual History

Survey data was collected for age, total flight hours (all airframes), total AH-64 hours, combat hours in the area of operation (AO), NVS time, NVG time, combat sorties, average length of sortie, longest sortie, and number of deployment rotations completed. Both male (35, 92%) and female (3, 8%) Apache pilots responded to the survey.

Respondent age ranges from 23 to 43 years with a mean of 33.6 years and a median of 33.5 years, the standard deviation was 5.4 years. Figure 10 depicts a histogram of the age distribution. The most common age of respondent (mode) is 33 years with a frequency of 4. With the exception of the three (3) respondents with ages of 43 years, the distribution is somewhat symmetrical about the mean and it indicates a fairly young aviation force being represented in this study. Of those queried 61% (23) are junior warrant officers (Warrant Officer 1 and Chief Warrant Officer 2) or company grade commissioned officers (2nd Lieutenant, 1st Lieutenant, or Captain). These individuals fly the majority of missions with battalion level and brigade level staff pilots flying part-time.

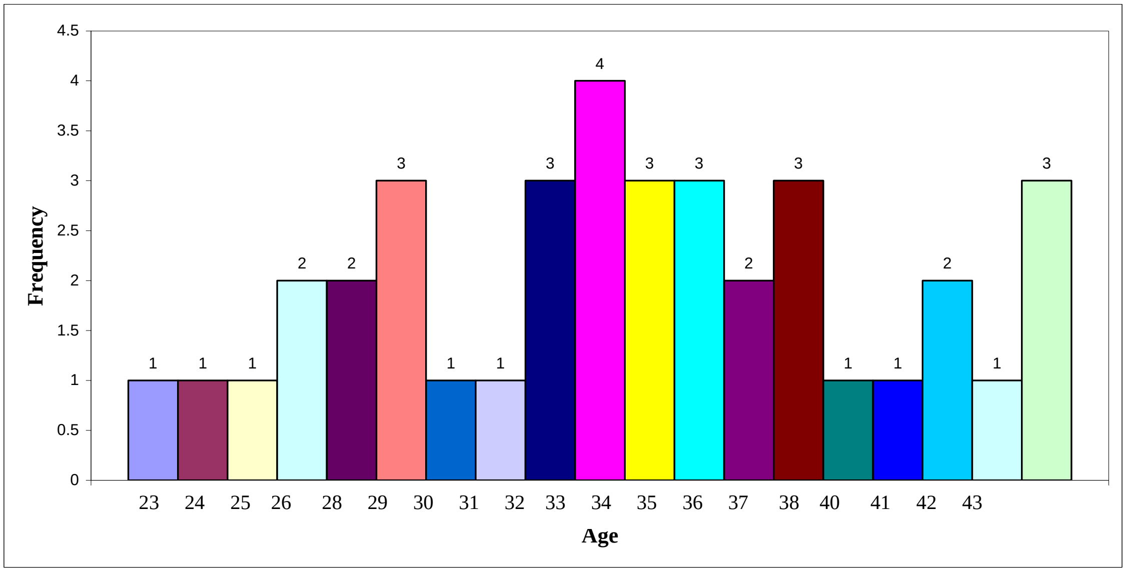

Figure 10. Surveyed Pilot Age Distribution.

Total flight hours across all airframes have a mean of 1483.0 hours with a median of 1150 hours. The range is between 500-4000 hours, with a standard deviation of 911.0 hours. Overall, AH-64 time ranges from 300-3850 hours with a mean of 1139.1 hours and a median of 900 hours. The standard deviation for total AH-64 hours is 845.3 hours.

The close proximity of the ranges of total flight hours and AH-64 hours reflects the fact that more aviators in this survey have only logged AH-64 flight time with the exception of their TH-67 training helicopter time during U.S. Army rotary-wing flight school. AH-64 aviators in earlier studies had previous AH-1 Cobra and UH-1 Huey experience. Respondents have a mean NVS usage time of 440.2 hours, with a median of 311.5 hours. The NVS time ranges from a low of 22 hours (reflecting aviators serving directly out of flight school) to a high of 1500 hours (reflecting senior instructor pilots and previous combat aviators). The standard deviation for NVS time is 360.5 hours. NVG time has a mean of 160.1 hours with a median of 119.5 hours. The NVG time ranges from 30 to 650 hours, with a standard deviation of 130.4 hours. The mean of 160 hours reflects the fact that NVGs are not the primary night pilotage system for this airframe and are used as a backup.

Combat sorties during this rotation, for the 4 months completed prior to this survey, have a mean of 62.9 hours with a median of 67.5 hours. Staff aviators logged as few as 11 sorties, whereas attack company pilots logged as many as a 100. The standard deviation for combat sorties is 20.1 sorties. Combat sorties have a median length of 4.3 hours with a range of 3.8-5.0 hours. The standard deviation is 0.3 hours. The "longest sortie" ranges between 5.0-8.0 hours with a mean of 6.4 hours and a median of 6.2 hours. The standard deviation is 0.7 hours. Of the pilots responding to this survey, 17 (44.7%) are on their second tour in Iraq, with 4 (10.5%) having served in Afghanistan in addition to 2 tours in Iraq. Table 4 provides a tabular breakdown of data.

Of the 38 respondents 6 (15.8%) reported requiring corrective vision, with 100% of those 6 using single (mono) vision glasses while off duty. These individuals use single vision contact lenses while in flight, with 4 (10.5%) respondents using glasses while in flight. Preferred sighting eye is predominantly the right eye, with 29 (76.3%) responses total. The reported "telescope viewing eye" for most respondents, 29 (76.3%), is also the right eye. Figure 11 illustrates the preferred and telescopic sighting eye responses. When asked regarding the present condition of their "better" eye since using the IHADSS, 26 (68.4%) felt that their vision with this eye was the same, but 12 (31.6%) reporting that they felt their vision with this eye had degraded.

Table 4. Age and Flight Experience Data for Respondents.

	Mean	Median	Range	Std. Dev.
Age (years)	33.6	33.5	23-43	5.4
Total flight hours	1483.0	1150	500-4000	911.0
Total AH-64 flight hours	1139.1	900	300-3850	845.3
Combat hours in AO	256.8	255	120-750	106.1
NVS hours	440.2	311.5	22-1500	360.5
NVG hours	160.1	119.5	30-650	130.4
Combat sorties (thru March '06)	62.9	67.5	11-100	20.1
Average length of sortie	6.4	6.2	5.0-8.0	0.7
OIF rotations (including current)	1.4	1	1-2	0.5
OEF rotations	0.1	0	0-1	0.3

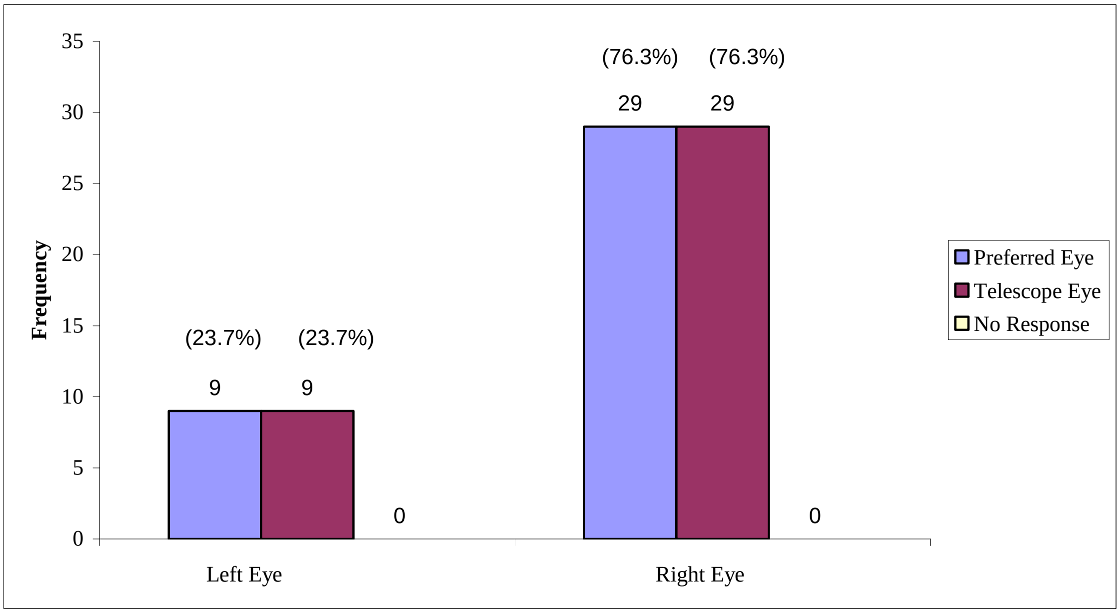

Figure 11. AH-64 Aviator Preferred and Telescopic Sighting Eye.

As stated previously, the U.S. Army Aeromedical Research Laboratory conducted a similar survey in 2000 (Rash et al., 2001) and a field study of AH-64 pilots serving in Operation Iraqi Freedom (OIF) in 2003 (Hiatt et al., 2004). Of current respondents, 5 (13.2%) indicated that they were asked to participate in the 2000 survey and 1 (2.6%) indicated that he/she had participated in the 2003 survey. One respondent for the current study participated in both the 2000 and the 2003 surveys.

3.3 Helmet Fit and IHADSS Utility

Helmet fit translates directly to IHADSS effectiveness and perceived utility. Recall that line of sight is maintained through a pair of lead sulfide photodiode sensors on the helmet that track helmet position through movement within an IR generated motion box. Pilotage imagery and symbology are viewed off of the beamsplitter having a 10-millimeter exit pupil, which must be centered at the pilot's eye to maintain full FOV. Since the beamsplitter is integral to the HMD portion of the IHADSS, the improper fitting of the helmet will cause minor slippage while looking left or right, resulting in weapon system line of sight errors and CRT beamsplitter misalignments (Rash et al, 1987). The beamsplitter misalignments result in flight symbology and pertinent data moving out of the pilot's FOV. The questionnaire inquired regarding length of time since last helmet fitting, nuclear biological and chemical (NBC) mask usage and fitting, FOV effectiveness, ability to maintain symbology within FOV, and lastly, frequency of readjustment of the combiner (focus) lens during flight.

Time since helmet fitting ranged from the previous month up to 24 months before the survey (Figure 12). Regulations require an annual fitting to address slippage issues. The mean time since last fitting is 7.9 months with a median of 2.5 months and a standard deviation of 6.6 months. When asked regarding NBC mask fitting with the helmet, 36 (94.7%) answered that fitting was not performed with the mask. Only 1 (2.6%) of the respondents wore the mask in flight during this rotation and that occurrence was conducted in a simulator to meet compliance with annual familiarization.

Overall 23 (60.5%) of respondents reported to be somewhat satisfied with their helmet fit versus 6 (15.8%) who stated they were completely satisfied (Figure 13).

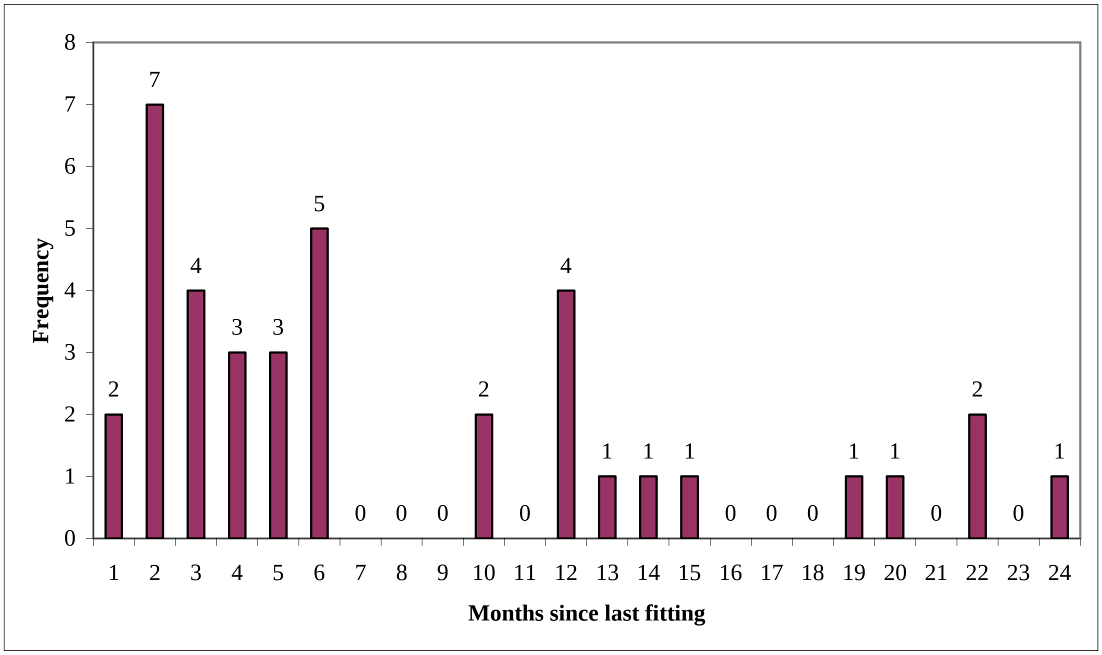

Figure 12. Helmet Fit Distribution.

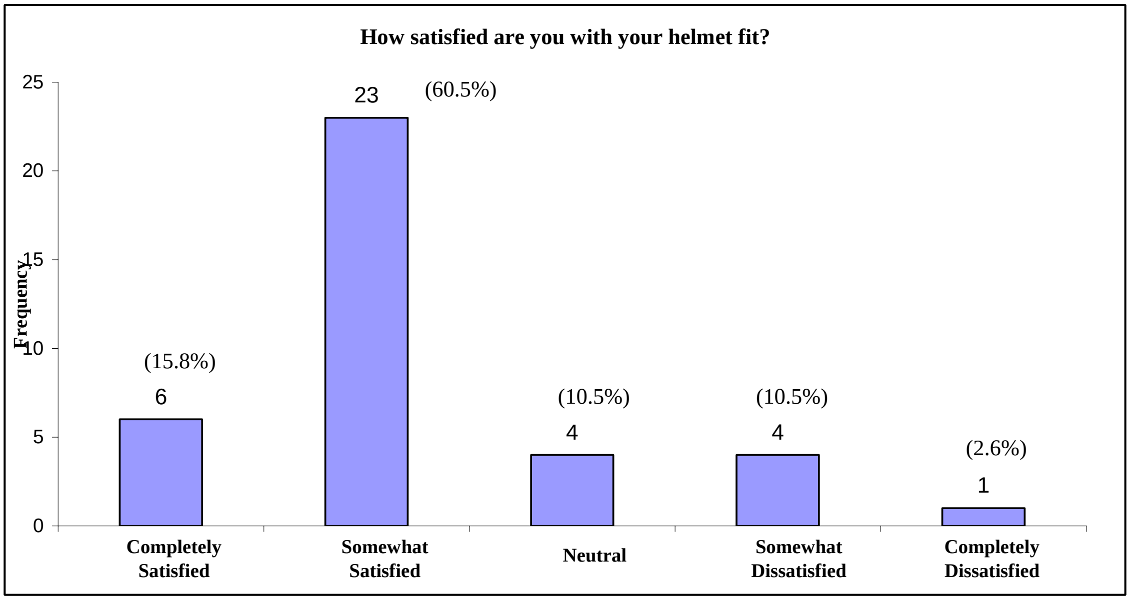

Figure 13. Helmet Fit Satisfaction.

Neutral respondents to the question of satisfaction numbered 4 (10.5%); somewhat dissatisfied respondents numbered 4 (10.5%) and completely dissatisfied respondents numbered 1(2.6%). When asked whether IHADSS imagery was impacted by helmet fit respondents are divided evenly, 19 (50%) reported “Yes” and 19 (50%) reported “No”. As to the general question of achieving full FOV, 35 (92.1%) report that, yes, they do achieve a full FOV, with 3 (7.9%), stating they do not. When asked regarding loss of IHADSS symbology in flight, 28 (73.7%) of respondents report they have lost symbology while looking full left, while 25 (65.8%) report they have lost symbology while looking full right. Of these individuals 16 (42.1%) report that they cannot provide effective ordnance delivery while looking full left or right. With the exception of those times when the HMD wire harness (located on the right) gets snagged while looking to the left, the loss of symbology when looking left or right indicates an improperly fitted helmet.

Previous studies concur with this report and have reported general satisfaction with quality of fit of the IHADSS helmet. In the earliest study (Behar et al, 1990) 86% of respondents reported reasonable or complete satisfaction with IHADSS fit. In the 2000 study (Rash et al, 2001), there was a decrease to 68% for respondents reporting a similar level of satisfaction. This decrease was attributed to an expanded use of the IHADSS system. The first OIF study (Hiatt et al, 2004) reported a similar proportion of satisfaction with 62.5% of respondents being somewhat or completely satisfied with their helmet fit. In the current study, approximately 76% of respondents report being either somewhat or completely satisfied with the quality of fit (Figure13).

Regarding physical limitations of the IHADSS, to include FOV effectiveness, bleaching of the imagery edges, and frequency of the need to adjust the combiner lens, report are mixed. When queried about the effectiveness of the IHADSS's 30-degree vertical by 40-degree horizontal FOV, over half of respondents report a lack of effectiveness (Figure14). When asked regarding problems of maintaining a full 30X40 FOV 14 (36.8%) respondents report they have some frequency of problem with 24 (63.2%) respondents being either neutral or reporting the problem occurs infrequently. Combiner lens frequency of adjustment responses are split 16 (42.1%) pilots report some level of frequency, 9 (23.7%) are neutral, and 13 (34.2%) report the problem is infrequent.

Although a majority of Apache aviators report they are comfortable with their helmet fit, the extended periods of time between fittings may contribute to FOV problems that in turn lead to degraded engagement of the weapon systems. Rash et al. (1989) found in a study on the IHADSS helmet fitting program that the need for subsequent adjustments after the initial aviator helmet fitting is essential to maintaining fit quality. Questions still need to be answered regarding whether proper helmet fitting will improve the perception of adequate FOV or whether the standard 30 X 40 FOV really needs to be expanded.

Representative comments regarding common problems with the IHADSS are:

"Turning my head in excess of 45 degrees sometimes causes me to lose symbology."

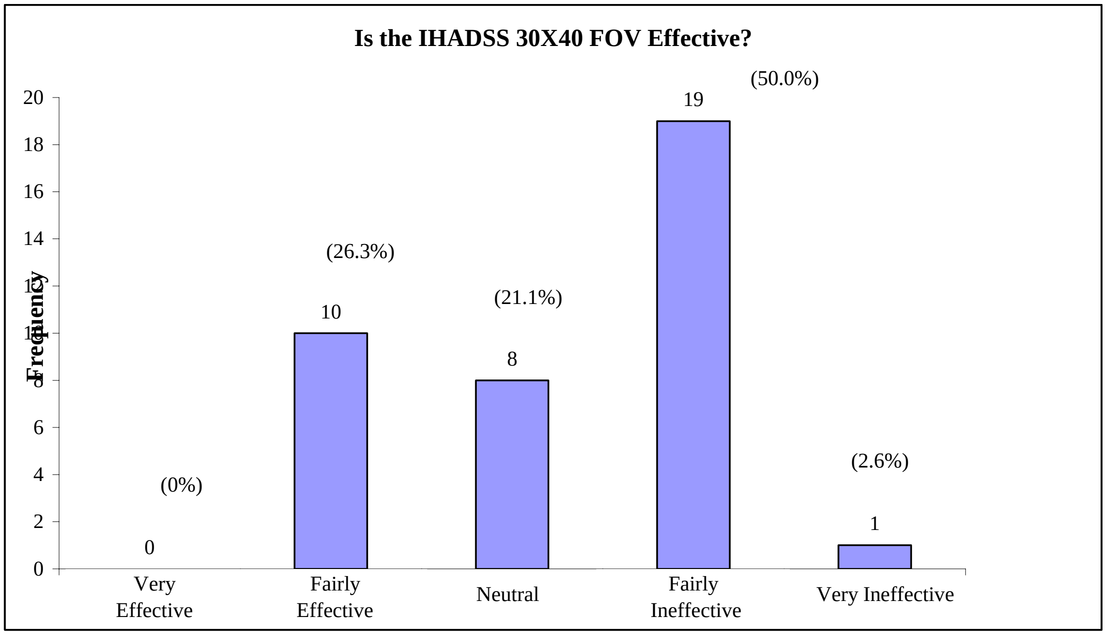

Figure 14. IHADSS FOV Effectiveness.

"After 2.5 hours, helmet slips and needs adjusting."

"IHADSS imagery is difficult to view without a properly fitted helmet."

"Some HDU (Helmet Display Unit) don't fit right without twisting the helmet a bit."

"When the helmet slips the HDU moves and affects the HDU."

"Mainly when mounting NVGs to Helmet, IHADSS shifts position. Also the chord effects my head movement."

3.4 IHADSS Vision

The IHADSS serves as the AH-64 pilot's primary visual reference for the combat scene during night and degraded visual environment (DVE) flight. Previous studies (Hale & Piccione, 1989; Behar et al., 1990; Crowley, 1991; Rash et al., 2001; Hiatt et al., 2004) of AH-64 pilots have documented the presence of physical symptoms, degraded visual cues, and illusions of flight during and after different phases of IHADSS night system operations. The survey used for this thesis asked respondents if they experienced the same symptoms as were reported in the earlier studies while performing aviation combat duties in and around the city of Baghdad, Iraq. The symptoms in question included visual discomfort, headache, double vision, blurred vision, spatial disorientation, and afterimages. Degrees of unintentional alternation of the eyes and decreased control over purposeful alternation of left eye to right eye and vice versa were also addressed. Other issues previously studied and explored within this report include the presence of degraded visual cues, cognitive tunneling, static illusions and dynamic illusions.

3.4.1 Physical Symptoms

General visual discomfort is the most common physical complaint with 33 (86.7%) of respondents acknowledging the condition exists sometimes or always. Headache is present sometimes or always in 22 (57.9%) of respondents. Both general visual discomfort and headache have been previously attributed to improper focus of the HDU (Hale & Piccione, 1989; Behar et al., 1990; Crowley, 1991; Rash et al., 2001; Hiatt et al., 2004). Behar et al., (1990) recommended that a detent be placed on the HDU focus ring to identify, for the pilot, the physical point of focus equivalent to zero diopters. Without this physical aid AH-64 aviators continue to rely on their own “best judgment” when focusing the HMD. The visual discomfort and headache result after fatigue sets in and the eye can no longer accommodate the improper focus (Behar et al., 1990). Double vision resulted in the least number of positive responses with only 4 (10.5%) aviators reporting this condition sometimes. Blurred vision is present for 16 (42.1%) respondents sometimes or always. Both double vision and blurred vision may be attributed to improper fit and aircraft vibration resulting in a relative motion between the viewer and the viewed image (Hart, 1988).

The respondents for the current study report that physical symptoms occurred after a mean flight time of 2.4 hours. The median time to onset of symptoms was 3.5 hours; standard deviation was 1.1 hours; and the range was 0.1 to 4.5 hours. Symptoms of disorientation and afterimages had 11 (28.9%) and 19 (50%) positive responses of “Sometimes” or “Always,” respectively. Figure 15 illustrates the distribution of reports

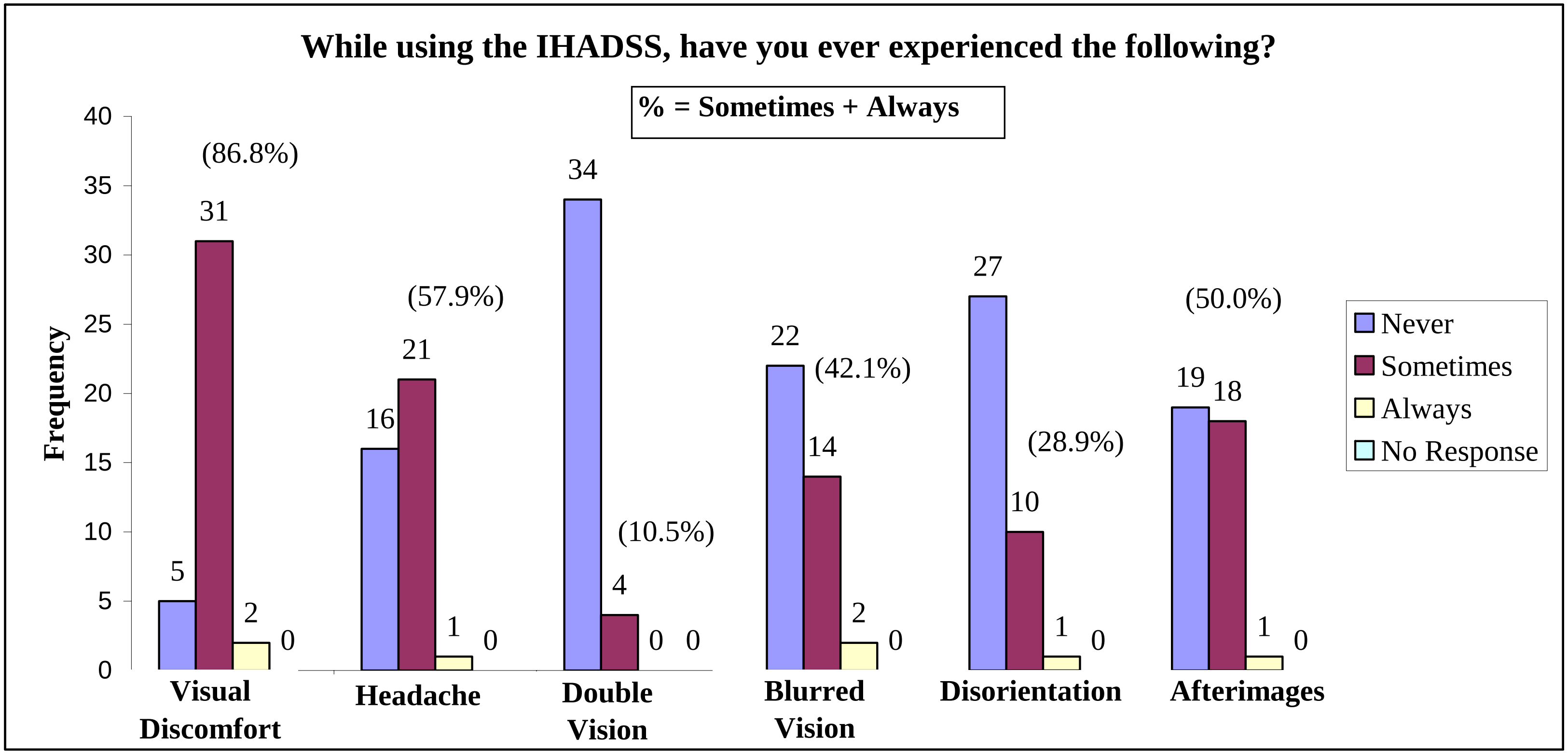

Figure 15. Physical Symptoms while using the IHADSS.

of the various physical symptoms. The 1990 VISAA report (Behar et al, 1990), the Visual Issues Survey of AH-64 Apache Aviators (Rash et al, 2001), and the first OIF study (Hiatt et al, 2004) all reported varying degrees of the same visual complaints both *during* and *after* flight. The majority of reported symptoms for this study were visual discomfort, headache, and afterimages which mirror both the 2000 and 2003 studies.

As previously described, the monocular design of the IHADSS lends itself to binocular rivalry with the left eye viewing the outside world “unaided” and the right eye viewing a visually enhanced scene via the HMD. Competition ensues between the eyes (binocular rivalry). Issues of binocular rivalry are usually related to *unintentional* alternation between the right and left eyes and the degree to which the pilot can *intentionally* (i.e., on demand) switch his/her viewing eye while flying a mission with the HMD. Of respondents, 24 (63.2%) report having experienced *unintentional* alternation between the eyes, with all subjects (38 [100%]) reporting the ability to switch viewing eyes easily or with some difficulty when desired. The 1990 VISAA study (Behar et al., 1990) also reported unintentional alternation of eyes for 3 (5%) respondents “Always”, 3 (5%) respondents “Usually”, 34 (59%) respondents “Sometimes” and 18 (31%) respondents “Never.” The Appendix details a complete list of pilot comments related to *intentional* and *unintentional* alternation between the eyes.

Another problem specific to HMDs is that of cognitive or “attentional” tunneling. One definition of attentional tunneling is the allocation of attention to a particular channel or source of information for a duration that is longer than optimal, resulting in the neglect of events from other sources (Wickens, 2005). When fixating under HMD use, cognitive tunneling manifests itself as the inability to process the external scene or other symbology (than the source of fixation) (Foyle et al., 1992). Studies have shown that placement of the symbology at least 8 degrees outside of the tracked viewing path decreases the incidence of cognitive tunneling (Dowell et al., 2002). The presence of cognitive tunneling was reported during day flight by 8 (21.1%) respondents and also reported by 15 (39.5%) during night system flight.

Representative comments related to cognitive tunneling include:

"Generally I focus in on one [symbology or scenery] or the other."

"[I accomplish it] with proper adjustment of symbology while looking out at least 90 ft."

"With a proper infinity focus the symbology appears overlaid on the external scene."

"It takes training and constant use."

"[I] view through the symbology."

"I focus the symbology to be clear while I look past it."

"Sometimes if [the] sun is low it is difficult due to smoked visor/HDU [being] too dark.

Further studies need to be conducted to investigate cognitive tunneling issues and to identify potential issues related to symbology brightness, image brightness and image contrast to see if they are contributory in nature to the perception of a problem.

3.4.2 Degraded Visual Cues

The presence of degraded visual cues during night system flight requires that aviators impose operational limitations on speed, altitude, and maneuvering especially when in close proximity to the ground. The pilot serves as the primary "guidance system" for the aircraft and is required to maintain flight path control, obstacle avoidance, and translational rate situational awareness to avoid collision (Hart, 1988). To accomplish this task the pilot uses "static" and "dynamic" visual cues to evaluate the outside environment and the relationship of the aircraft to this environment. Static cues include object texture, shading, and colors which change appearance based upon resolution, which in large part is based upon illumination. Dynamic cues, such as motion parallax and optic flow, are also dependent upon resolution but are more effected by fields of view, or lack there of. This function of providing guidance to the aircraft is most affected when the pilot is forced to work with reduced visual cues (Clark, 2003). A by-product of poor visual acuity for the helicopter pilot is the tendency to slow down and "take in" more cues while climbing higher to avoid undetected obstacles. Aviators forced to operate in the DVE will ultimately "fly slower, higher, and with less extreme maneuvers" (Hart, 1988) which ultimately affects maneuvering flight in and around the aircraft “bucket speed”. Bucket speed is a term that refers to the airspeed on an aircraft’s performance chart where the most under utilized power exists (U. S. Army Aviation Center [USAAVNC], 2003). When the airspeed is slowed below the bucket speed the aircraft does not have enough forward energy (momentum) to tradeoff for a lateral defensive maneuver, consequently the aircraft descends abruptly. In combat aerial reconnaissance and security the presence of degraded visual cues impacts defensive and offensive maneuvering and is an important consideration for the pilot.

At least one degraded visual cue was reported by 31 (81.6%) of the respondents. Degraded cuing due to brownout/whiteout ranked the highest with 31 (81.6%) respondents having experienced it at sometime. Brownout refers to the condition where the visible horizon is obscured by dust associated with a landing (or takeoff) into (or out of) an area with high amounts of loose soil. Whiteout refers to the same obscuration of the visible horizon in a snowy environment. Degraded visual resolution and impaired depth perception are reported by 30 (78.9%) respondents each. Decreased FOV and a general blurring of images had been experienced by 28 (73.7%) respondents at some point. Lost contact with the visible horizon affected 26 (68.4%) of pilots surveyed, with the more drastic event of inadvertent IMC affecting 15 (39.5%) of those asked. Figure 16 displays the results for loss of visual cues.

Representative comments related to loss of visual cues include:

“While flying with TADS, I fly mostly symbology and accept that I cannot clearly see where I am going.”

“FLIR I technology is a very poor picture versus technology today.”

“At some point through the years flying I’ve experienced all of the symptoms.”

“[These degrade visual cues are present during] FLIR crossover in particular. However, some nights certain systems are just unflyable.”

“All ‘yes’ [responses] are [a] function of FLIR quality or environmental factors – we are trained to detect and deal with.”

“Just the basic degraded vision due to the optics.”

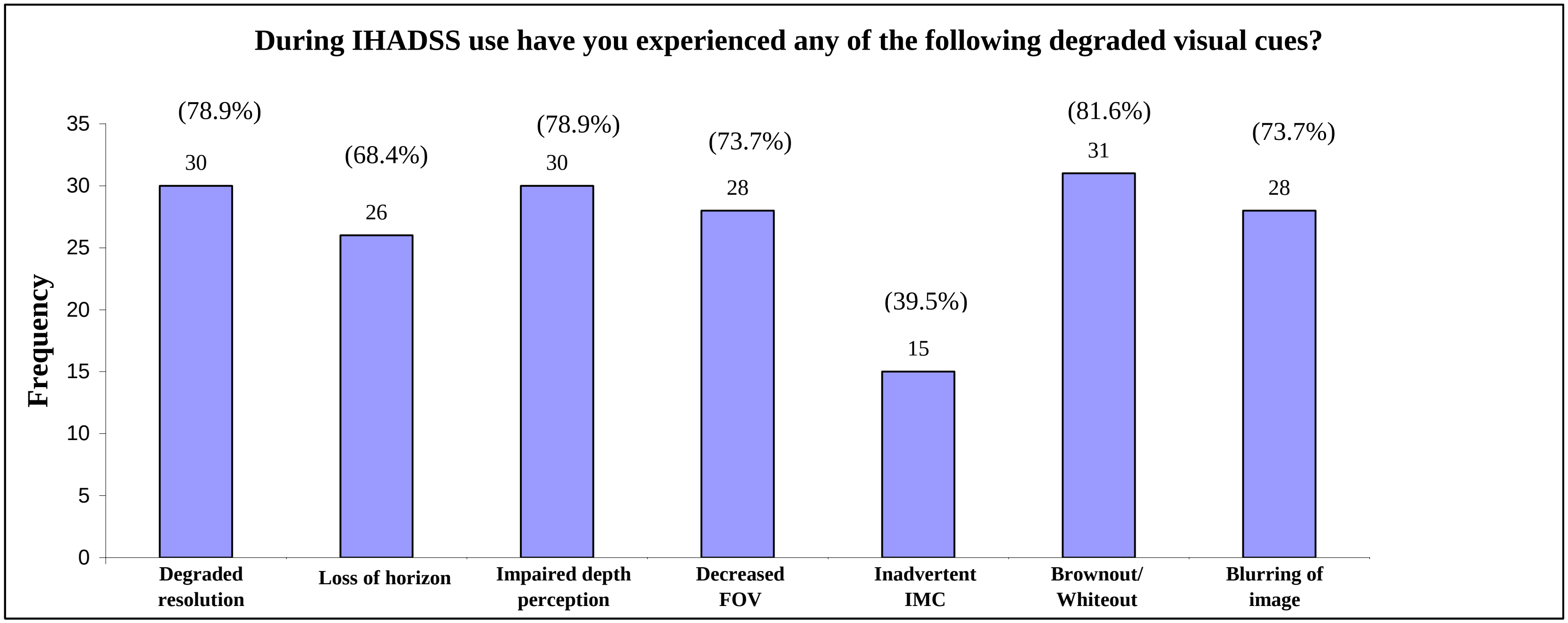

Figure 16. Incidents of Diminished or Lost Visual Cues.

Incidents of diminished visual cues were present in the two most recent Apache IHADSS studies (Rash et al, 2001, Hiatt et al, 2004), with both studies reporting varying degrees of the same visual complaints *during* and after *flight*. A comparison of percentage response by cue for ‘during flight’ is provided in Table 5. Degraded resolution assessments improved from the 2000 Study, thru the 2004 OIF Study to the current OIF Study. Percentages of 90.3, 85.0 and 78.9 reflect the younger (mean age of 36.5, 32, and 33.6, respectively) aviation force surveyed in the two OIF studies. Depth perception assessments also appeared to have improved from the 2000 study to the 2004 OIF study but worsened in this study. The improvement from 2000 to 2004 may reflect the decrease in respondent age whereas the increase in the current study may represent the fact that this study was conducted in the urban environment with night vision goggles (ANVIS) in use accentuating perceived IHADSS issues. “Decreased FOV” was statistically significant to the .05-level and is represented in bold. The significant increase relates only to the 2004 OIF Study but is remarkably close to the 2000 Study.

Table 5. Degraded Visual Cues ‘During Flight’ Result Comparison.

Diminished Cue	2000 Internet Study (n = 216) (%)	2004 OIF Study (n = 40) (%)	Current OIF Study (n = 38) (%)	p-value for OIF Studies
Degraded resolution	90.3	85.0	78.9	0.6892
Loss of horizon	75.9	72.5	68.4	0.8875
Depth perception	84.7	70.0	78.9	0.5169
Decreased FOV	81.0	47.5	73.7	**0.0331**
Inadvertent IMC	38.9	20.0	39.5	0.1016
Whiteout/brownout	75.5	87.5	81.6	0.6801
Blurring of images	75.5	62.5	73.7	0.4166

The reported presence of brownout is relatively the same for both OIF studies and higher than the 2000 Study due to the inherent dusty environment associated with desert operations versus training within the continental United States (CONUS).

3.4.3 Visual Illusions

Visual illusions are the result of diminished references to the inertial plane one is operating in and can induce spatial disorientation (Department of the Army, 1988). Many types of illusions exist during day and night unaided flight, e.g., altered planes of reference (sloping ridgeline misinterpreted as level horizon), false horizons (sloping cloud formations), ground light misinterpretation (as star light or horizon), and relative motion (interpreting another's movement as one's own). Previous IHADSS studies have shown the frequency of static and dynamic illusions reported by AH-64 pilots (Hale & Piccione, 1989; Behar et al., 1990; Crowley, 1991; Rash et al., 2001; Hiatt et al., 2004). With aircraft systems designed to augment vision and improve cueing in the DVE, it is important to identify those illusions present and attempt to mitigate the hazard to pilots. Visual illusions during flight have induced spatial disorientation with catastrophic consequences in pilots flying unaided aircraft. Fortunately for HMD users in the rotary-wing environment, Rash et al. (2003) showed that accident data for the Army's AH-64 Apache found no specific correlation between IHADSS/PNVS use and flight-related accidents. The current study's reports of visual illusion (Figure 17) are similar in type and frequency to the previous studies.

Nearly half the respondents, 17(44.7%), experienced at least one static illusion. Faulty height judgment, attitude judgment, and clearance judgment ranked the highest in frequency of occurrence. There were 17 (44.7%), 10 (26.3%), and 11 (28.9%) positive responses to this query, respectively. Aviator problems with slope estimation and trouble discerning cues from ground based lights provided 17 (44.7%) and 16 (42.1%) positive responses, respectively. The least number of positive responses were related to the pilot's sense of "landing in a hole" and the visual illusion of linear objects appearing to bend. There were 5 (13.2%) and 4 (10.5%), positive responses in these categories, respectively. These results are provided in Figure 17.

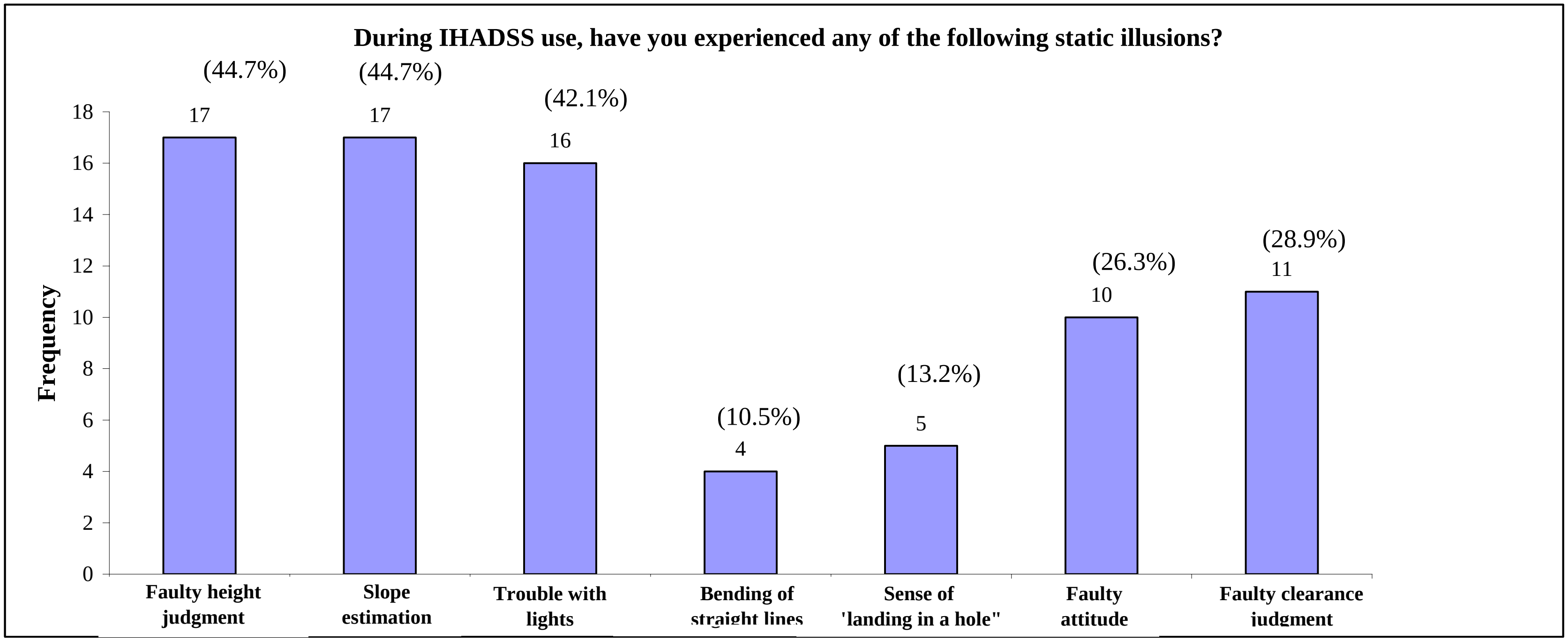

Figure 17. Static Illusions.

Representative comments related to the presence of static illusions were:

"[Illusions were a result of] poor TADS imagery [and] AC coupling."
"Front seat TADS AC coupling causes loss of visual cues & disorientation."
"The FLIR imagery doesn't give enough visual cues to avoid these illusions."
"Training has made me aware [that] these things can happen, so I am prepared to overcome these known deficiencies."
"Illusions have declined with greater experience due to [my] ability to recognize and compensate."
"Improper registration, boresight inaccuracies, and helmet movement (especially tilt) can all affect these [illusions]."
"[The] symbology helps provide depth & 3rd dimension cues. Failure to clear [the aircraft] & slope judgment [illusions] are pilot error."

Static illusions during flight were reported in the previous two studies (Rash et al, 2001, Hiatt et al, 2004). Faulty height estimation was the most frequently reported static illusion by Rash et al. (2001) with 173 (80.1 %) responses. Faulty slope estimation had the highest number of positive responses in the OIF study in 2004 (Hiatt et al, 2004). A tabular comparison of the two previous studies and the present study are presented in Table 6. A comparison between the data from the current OIF study and year 2004 OIF show consistency between responses for "Height judgment", "Slope estimation", "Landing in a hole", "Attitude judgment" and "Clearance judgment" and both reflect a decrease in reported illusions from the year 2000 study. "Trouble with lights", a common NVG problem, has increased reporting in the present study due to the constant operation in and around the highly illuminated Baghdad municipal area. The differences between this study and the 2004 OIF Study show no statistical significance to the .05-level.

Dynamic illusions in flight are greatly impacted by limited fields of view. The IHADSS's 30 degree vertical by 40 degree horizontal FOV requires constant head movement by the pilot to cover a 180 degree span. The PNVS sensor can move at 120 degrees per second but still cannot maintain the normal speed of the human reflexive

Table 6. Tri-Study 'Static Illusion' Results Comparison.

Static Illusion	Year 2000 Study (n = 216) (%)	2004 OIF Study (n = 40) (%)	Current OIF Study (n = 38) (%)	p-value for OIF Studies
Height judgment	73.6	45.0	44.7	0.8415
Slope estimation	80.1	57.5	44.7	0.3681
Trouble with lights	60.2	27.5	42.1	0.2636
Bending of lines	20.4	5.0	10.5	0.6242
"Landing in a hole"	41.2	20.0	13.2	0.6101
Attitude judgment	N/A	27.5	26.3	0.8875
Clearance judgment	60.2	22.5	28.9	0.6985

system (USAAVNS, 1999). The decreased FOV issue coupled with this inherent latency can cause dynamic illusions which may result in spatial disorientation for the pilot. Previous IHADSS studies have documented dynamic illusions reported by AH-64 pilots (Hale & Piccione, 1989; Behar et al., 1990; Crowley, 1991; Rash et al., 2001; Hiatt et al., 2004). It is not surprising to note the presence of many of the same illusions during urban combat operations.

Motion parallax is the illusion of one's own movement while viewing another's movement (Department of the Army, 1988). Illusions of drifting, while not specific to motion parallax, result in the same spatial disorientation when viewing external scenery through enhanced vision systems. Helicopter operations cover 6 degrees of motion: forward, backward, upward, downward, leftward, and rightward. The "sense" of drifting can occur in any axis. Questions asked in the current survey specific to aircraft motion and drift were related to general undetected drift, movement without the sensation of movement, the general illusion of drifting while stationary, and the specific illusion of drifting rearward. Of these illusions, "Undetected drift" (i.e., actual aircraft movement with respect to the ground) resulted in the highest number of positive responses, 16 (42.1%). “Illusory aircraft drift,” “Illusory rear drift” and “No sensation of movement” resulted in 10 (26.3%), 7 (18.4%) and 8 (21.1%) positive responses, respectively. Other dynamic illusions which were reported with positive responses included “Faulty velocity judgment”, 10 (26.3%), “Faulty [rate of] closure judgment”, 16 (42.1%), “Illusions of [erroneous] pitch [attitude rate],” 7 (18.4%), and “General disorientation,” 4 (10.5%). The distribution of dynamic illusions reported by the respondents is shown in Figure 18. Representative comments specific to dynamic illusions were:

“[The answer is the] same as [for] above.” [“The FLIR imagery doesn’t give enough visual cues to avoid these illusions.”]
“Poor picture does not provide enough cues to rely upon must always trust symbology.”
“[The] use of symbology cures all.”
“[These illusion are] mostly due to loss of peripheral sight.”

Hiatt et al. (2004) and Rash et al, (2001) both reported the presence of dynamic illusions during flight. The earlier study reported “Undetected drift,” 169 (78.2%), and “Faulty closure judgment,” 163 (75.5%), as the two most frequent complaints. Both OIF studies also reported “Undetected drift” and “Faulty closure judgment” as their two most frequent complaints. The 2004 OIF study and the current OIF study reported “Undetected drift,” 22 (55%) and 16 (42.1%), and “Faulty closure judgment,” 21 (52.5%) and 21 (42.1%), respectively. A comparison of the two previous studies and the current study is presented in Table 7 with no statistical significance present to the .05-level. Based on visual acuity reports and complaints of diminished IHADSS FOV (Appendix question (f)) the current and previous findings tend to validate that insufficient optical flow field and diminished FOV both are contributory in dynamic illusions.

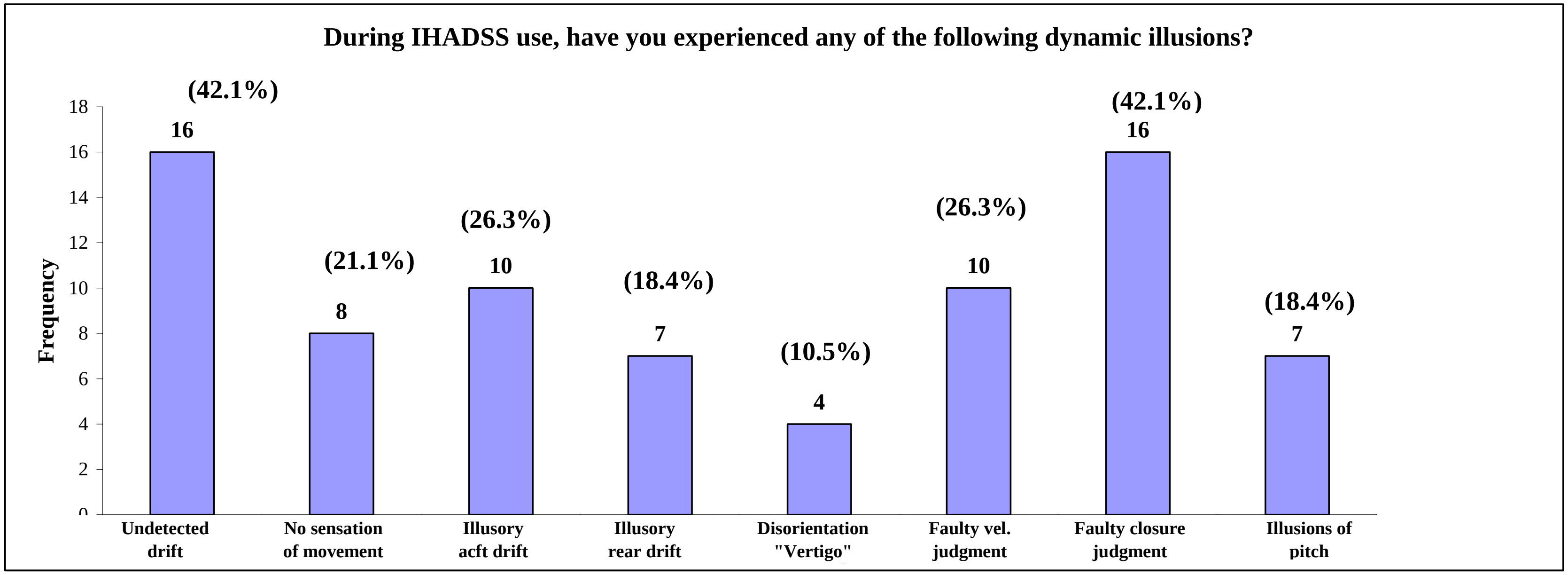

Figure 18. Dynamic Illusions.

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Table 7. Tri-Study 'Dynamic Illusions' Results Comparison.

Dynamic illusion	Year 2000 Study (n = 216) (%)	2004 OIF Study (n = 40) (%)	Current OIF Study (n = 38) (%)	p-value OIF Studies
Undetected aircraft drift	78.2	55.0	42.1	0.3623
No sensation of motion	55.6	15.0	21.1	0.6892
Illusory aircraft drift	71.3	30.0	26.3	0.9203
Illusory rearward drift	55.6	22.5	18.4	0.8625
Disorientation (vertigo)	38.0	25.0	10.5	0.1703
Faulty airspeed judgment	64.8	22.5	26.3	0.8875
Faulty closure judgment	75.5	52.5	42.1	0.4884
Illusions of pitch	44.9	12.5	18.4	0.6801

3.5 IHADSS and NVG System Mission Effectiveness

One of the current roles of the AH-64 Apache attack helicopter is as an aerial platform to provide reconnaissance and security to the ground elements of the U.S. Army. Within this mission, the primary night system flight issues that remain are obstacle, aircraft, and wire avoidance. Visual acuity effects on these flight issues with respect to IHADSS use have been well documented in previous studies (Hale & Piccione, 1989; Behar et al., 1990; Crowley, 1991; Rash et al., 2001; Hiatt et al., 2004), but never documented in comparison to ANVIS use. The U.S. Army's decision to allow the use of ANVIS (I^2) with IHADSS (thermal FLIR) during operations in OEF and OIF has provided the opportunity to evaluate the benefits of each system while providing a gage to individual effectiveness.

Baghdad, Iraq is located in central Iraq with the Tigris River bisecting the city from northwest to south east. The Euphrates River transitions from the west-southwest of Baghdad to south-southeast below the city. This area includes the "Triangle of Death" to the south of Baghdad and the “Merchant’s Triangle” to the north. The Triangle of Death has received much media attention with reports of numerous AH-64 aircraft shot down.

The AH-64D can takeoff with 3000 pounds of fuel for a little over three hours of flight time with fueling points scattered throughout the area of operation. An AH-64 aerial reconnaissance team works in groups of two, four, and more aircraft if needed. Constant coordination and overlapping of teams provide for full-time coverage for the U.S. and Iraqi ground units. The attack helicopter operation is a 24 hour, continuous mission. With the exception of extremely inclement weather precluding safe flight, there is never a moment when AH-64 Apache aircraft are not patrolling the skies of Iraq.

Reconnaissance and security for the Baghdad municipal and surrounding areas occurs before and during ground convoy operations and during combat air patrols (CAP). Apache pilots scout the routes looking for abandoned vehicles, disturbed earth, dead animals or any object that may conceal an improvised explosive device (IED). Freshly disturbed earth looks different under NVG and FLIR and so do people. Humans, for example, who recently exerted themselves at 0230 hours in the morning with a shovel in their hands, provide brighter returns or “hot spots” when viewed with FLIR. However, the brightness associated with higher than normal body temperatures are not apparent when viewed with NVGs. Altitude, airspeed, and the scanning techniques of two AH-64 crewmembers working in concert with different night systems determines what is seen and left unseen.

CAP missions are continuously ongoing providing the ground force commanders immediate access to aerial firepower and reconnaissance assets. Routes within and around the city vary in their ability to be observed with ANVIS or FLIR from differing altitudes and airspeeds under various ambient conditions. This fact in conjunction with insurgent efforts to shoot down coalition aircraft makes the decision to fly low (NOE) or high (low-level or contour) a decision based upon one’s overriding concern for wires or insurgent weapons fire, respectively.

The following operational research questions were formulated to validate this decision to place use both sensor technologies in concert with one another within the same aircraft, basically providing dual-sensor input (but not to the same pilot):

1. Is there a significant difference in each system’s performance for aircraft, wire and obstacle detection and avoidance?
2. Is there a significant difference in effectiveness between the IHADSS/PNVS and the NVG (ANVIS) sensors for night urban (and suburban) reconnaissance/security?
3. Is there a significant difference in each system’s ability to provide situational awareness?

3.5.1 Aircraft, Wire, and Obstacle Recognition and Avoidance.

The operational question regarding aircraft, wire, and obstacle detection and avoidance relates directly to night low level, contour, and NOE flight. To be effective, an augmented vision system must provide sufficient cues to provide adequate reaction time for impact avoidance. Pilots were asked separately about aircraft/obstacle avoidance and wire avoidance. Regarding individual sensor effectiveness for avoidance reaction time, NVG elicited 36 (86.9%) responses for effectiveness as compared to 16 (42.1%) responses for IHADSS effectiveness. With respect to IHADSS there were 10 (26.4%) responses for ineffectiveness whereas no responses of ineffectiveness for NVG. The distribution of opinions by NVD regarding their effect on obstacle avoidance are distinctly different (U=1133, p=.00002) with NVG centered on “Fairly effective” and IHADSS centered on “Neutral” (Figure 19).

Aircraft operate in close proximity to one another during quick reaction force (QRF), MEDVAC security, and air assault missions. Diminished visual cues make it difficult to assess the flight path of other mission aircraft. Complicating the problem are congested radio communications that place a higher reliance on superior night vision systems to assist the pilot with aircraft identification, proximity, and relative rates of closure. When asked which system was preferred for aircraft recognition and reaction time 31 (81.6%) of respondents chose ANVIS, 4 (10.5%) chose IHADSS, and 3 (7.9%) felt both systems the same (Figure 20).

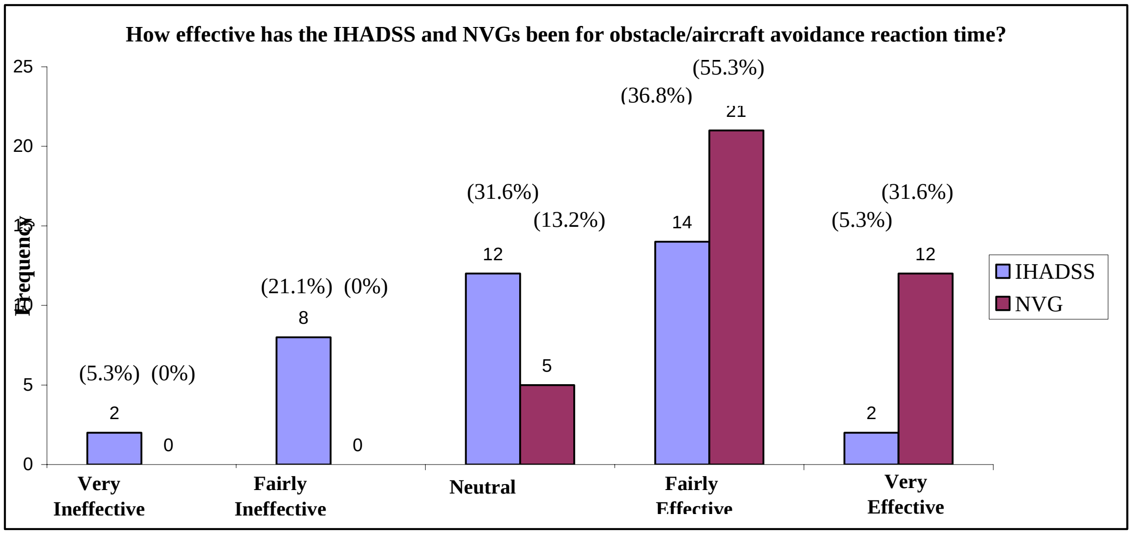

Figure 19. Night System Obstacle/Aircraft Awareness Effectiveness.

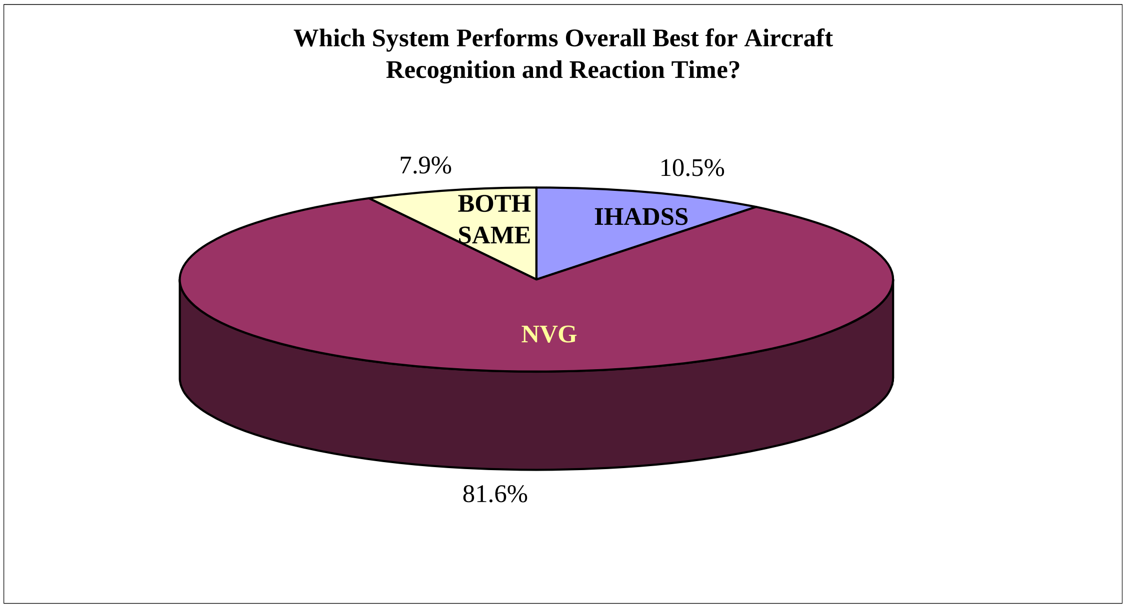

Figure 20. Preferred System for Aircraft Recognition and Reaction Time.

When asked regarding the frequency with which other aircraft were not detected or identified expeditiously in high volume traffic points, IHADSS had a higher amount of reported incidents. The distribution of opinions by NVD regarding their effect on failure to acquire and recognize are significantly different (U=1052.5, p=.00056) (Figure 21) contributing to the preference of NVG over IHADSS. IHADSS had 19 (50.0%) responses for "Very" or "Fairly" frequently as compared to NVG's 8 (21.1%), a ratio of more than 2:1. When asked regarding infrequency of occurrence NVG has 25 (65.7%) responses as compared to 10 (26.3%) for IHADSS, again a 2 to 1 ratio.

To assess the relative preference of the IHADSS and NVG systems for aircraft recognition and avoidance reaction times respondents were asked to identify those characteristics that influenced their decision. "Resolution" provided 21 (55.3%) positive responses and "Object recognition" provided 26 (68.4%) positive responses. For IHADSS, "Resolution" and "Object recognition" are both reported by one subject each (2.6%). Other reported characteristics receiving positive responses were 4 (10.5%) for "Contrasting objects," 2 (5.3%) for "Azimuth and elevation acquisition," and 3 (7.9%)

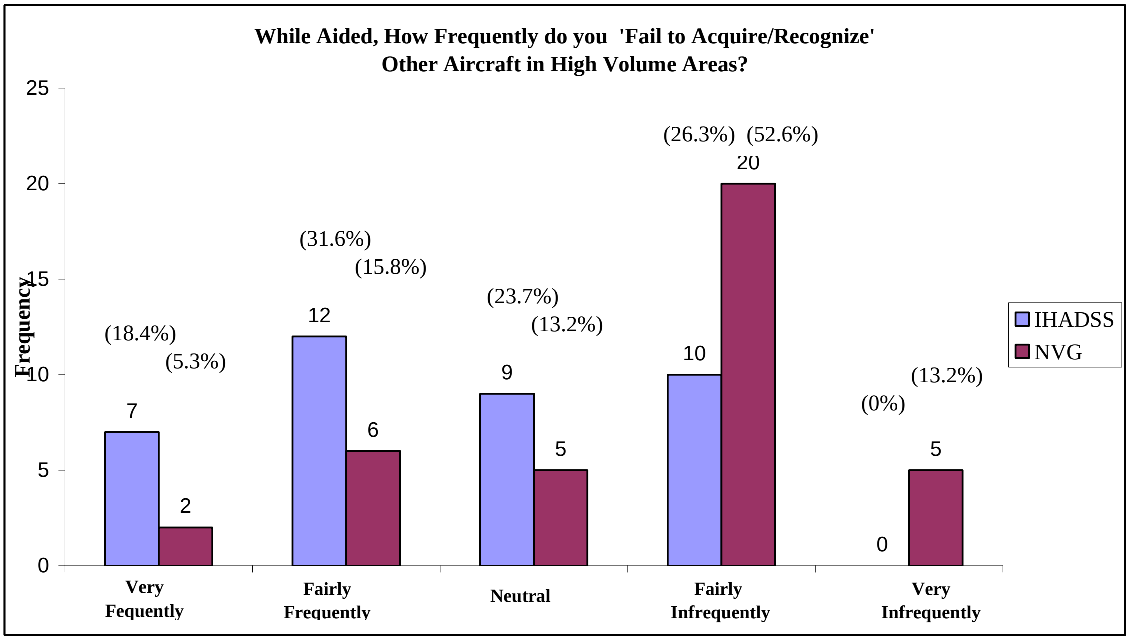

Figure 21. Frequency of "Failure to Recognize" another Aircraft.

for “Overall comfort.” There were no reports (0%) for responses of “Same”. Resolution and the ability to recognize an object are directly related to visual acuity. The superior nature of the ANVIS visual acuity of 20/25 as compared to the IHADSS visual acuity of 20/60 is evident in both of these responses. NVGs, for this tasking, are succinctly identified as the better system. A histogram depiction of the complete results is displayed in Figure 22.

Wire recognition effectiveness is critical to safely operating in and around population centers, reconnoitering routes, and providing security within NOE and low-level flight profiles. To address the operational question regarding system performance for wire detection, pilots were asked the fundamental question: “How frequently have you realized you were passing over wires, after it was too late to react?” This question was formulated through consultation with several instructor pilots, seasoned aircraft commanders, and novice pilots alike. Aircraft are operated at high speeds to make weapons targeting and acquisition by the enemy difficult while at the same time allowing for timely response to ground commander needs over a wide area of terrain. Past

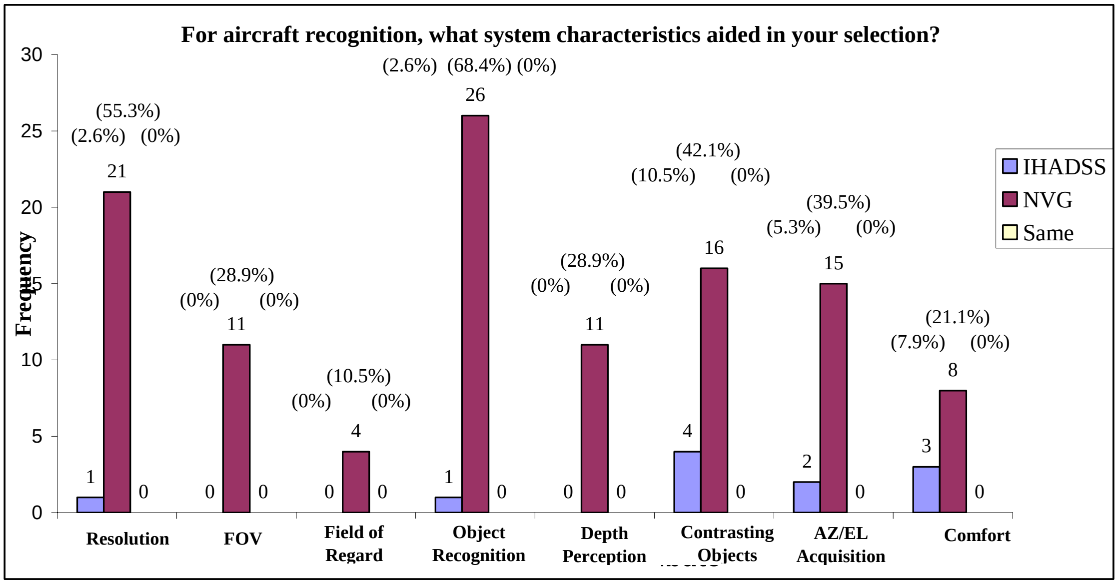

Figure 22. System Favorable Characteristics for Avoidance Reaction Time.

experience and success with one or both systems was likely the primary influence for the response to this question.

When answering the question regarding the identification of wire hazards *after passage* IHADSS had 2 (5.3%) responses for "Very frequently", 16 (42.1%) for "Fairly frequently", 8 (20.5%) for "Neutral", 6 (15.6%) for "Fairly infrequently" and 6 (15.6%) for "Very infrequently". NVG had 0 (0%) responses for "Very frequently", 6 (15.6%) for "Fairly frequently", 4 (10.5%) for "Neutral", 22 (57.9%) for "Fairly infrequently" and 6 (15.6%) for "Very infrequently" (Figure 23). The ability to identify wires prior to passage favors the ANVIS and validates the present day use of the system. The distribution of opinions by NVD regarding delayed recognition of passage of wires are distinctly different (U=996, p=.00424) with NVG frequency centered on and primarily infrequent as compared to IHADSS which is centered on and primarily frequent. A significant difference in overall failure to recognize wires is evident between the two systems.

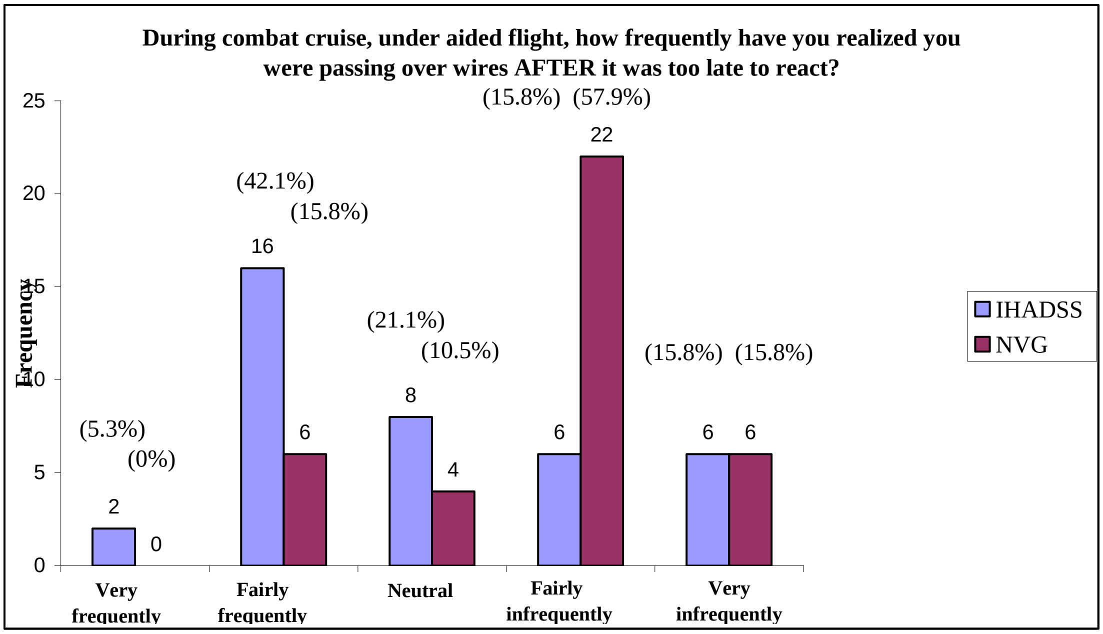

Figure 23. Delayed Wire Recognition Frequency.

When asked to choose the best system overall for wire recognition and avoidance 21 (55.3%) respondents chose NVG, 9 (23.7%) respondents chose IHADSS, and 8 (21.1%) reported that both systems operate about the same (Figure 24). To understand these choices respondents were asked to identify those characteristics that aided in their decision. For NVG there were 21 (55.3%) positive responses for resolution, 9 (23.7%) for FOV, 4 (10.5%) for field of regard, 19 (50%) for object recognition, 8 (21.1%) for depth perception, 10 (26.3%) for contrasting objects, 11 (28.9%) for azimuth and elevation acquisition, and 5 (13.2%) for comfort. By comparison, IHADSS received 5 (13.2%) positive responses for resolution, 3 (7.9%) for FOV, 2 (5.3%) for field of regard, 4 (10.5%) for object recognition, 3 (7.9%) for azimuth and elevation acquisition, and 5 (13.2%) for comfort (Figure 25). There were no responses for "same".

In summary, results from the aircraft, obstacle, and wire avoidance survey questions show that the NVG system is preferred over IHADSS for acquiring and avoiding obstacles in flight. Resolution of the object and the ability to recognize the item being viewed played the largest role in choice with 55% and 50% NVG positive responses, respectively, directly correlating with the question of preferred system. The difference in Snellen visual acuity between IHADSS and ANVIS (20/60 versus 20/25) is also a factor in these results. The visual acuity differences are even more apparent when the systems are being compared with each other. Another key factor regarding visual acuity and resolution for ANVIS versus IHADSS users is the nature of the image viewed (Brickner, 1989). The ANVIS image has an almost "black and white TV quality" versus the unnatural "thermal signature" produced by the PNVS. The ease with which a pilot recognizes the object being viewed under ANVIS or IHADSS relates directly to perceived effectiveness and in turn biases preference. Recall that IHADSS users are trained to identify objects under FLIR.

The choice to allow use of the ANVIS system in conjunction with IHADSS for aircraft, obstacle and wire avoidance appears to be validated with the positive results for increased acuity and decreased frequency of failing to identify hazardous obstacles.

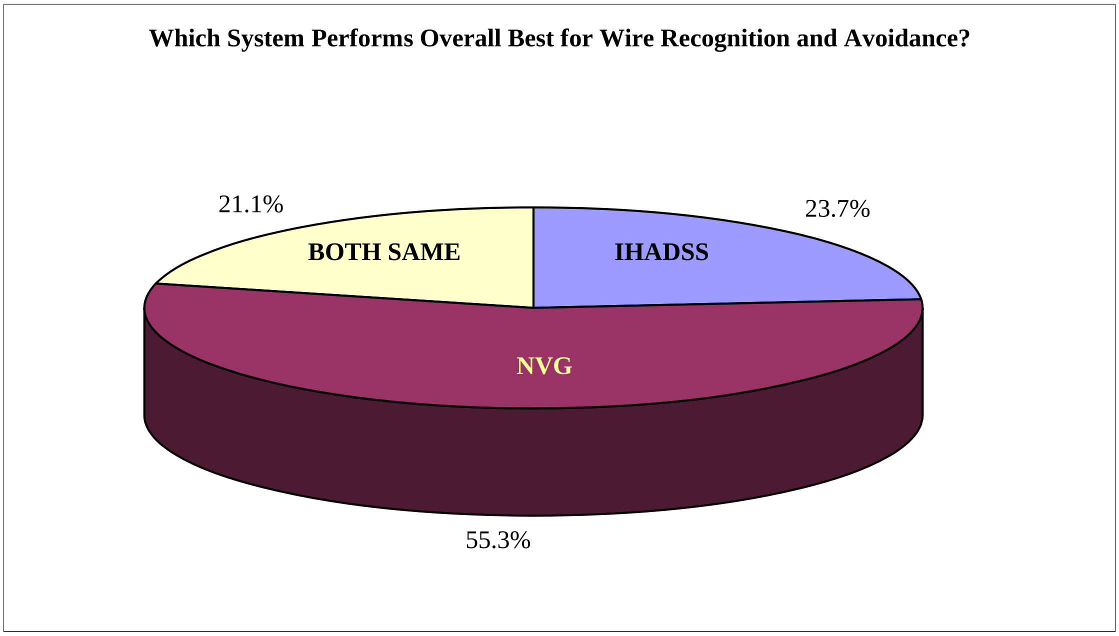

Figure 24. Preferred System for Wire Recognition.

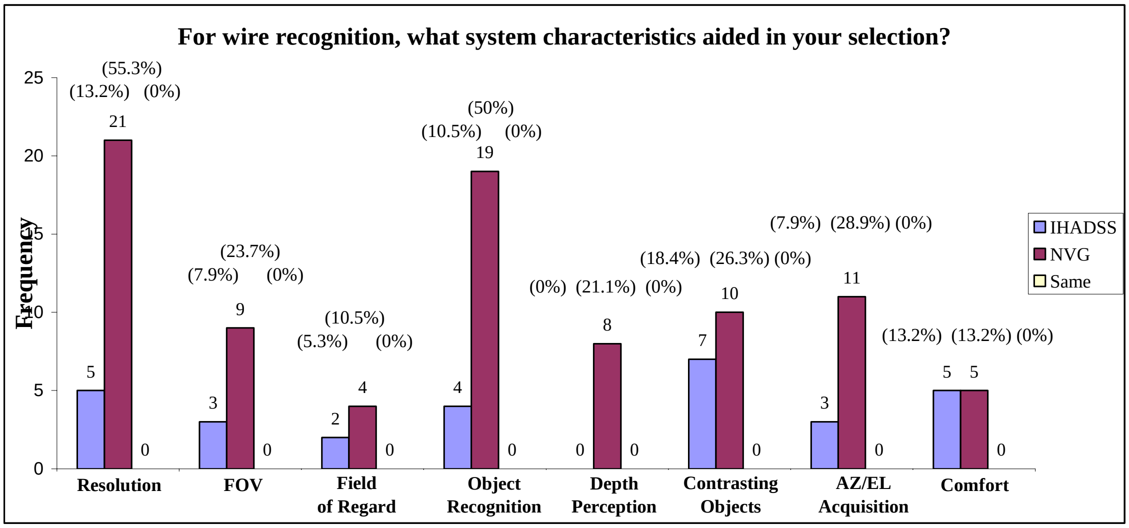

Figure 25. System Favorable Characteristics for Wire Recognition.

3.5.2 Reconnaissance Effectiveness.

Reconnaissance effectiveness is measured by the ability to discern and gather intelligence from scenery unfolding on the battlefield. Aircraft, obstacle, and wire recognition are safety of flight issues that lend themselves to general piloting duties for the helicopter pilot; reconnaissance effectiveness is directly related to mission accomplishment. When asked how *effective* the IHADSS and NVG were for reconnaissance IHADSS received 52.7% positive responses for effectiveness compared to ANVIS which received 86.8% positive responses for effectiveness (effectiveness defined, in this case, as the sum of 'fairly' and 'very'). IHADSS and NVG both received 18 (47.4%) and 16 (42.1%) positive responses for "Fairy effectively", respectively and 2 (5.3%) and 10 (26.3%) for "Very effective", respectively. When asked how *ineffective* the IHADSS and NVG were for reconnaissance 1 (2.6%) and 2 (5.3%) stated the systems are "Very ineffective", respectively. IHADSS and NVG received 8 (21.1%) and 1 (2.6%) responses for "Fairly ineffectively", respectively. IHADSS had 9 (23.7%) "Neutral" responses and ANVIS' had 2 (5.3%) responses for neutral. The distribution of opinions by NVD regarding their effect on reconnaissance are distinctly different (U=1054, p=.00053) with NVG responses primarily on the right side of the graph and IHADSS distributed throughout (Figure 26). Figure 26 illustrates the significant difference between IHADSS and NVG as relates to reconnaissance effectiveness.

The overall effectiveness results supported the choice of ANVIS (NVG) as the preferred system for reconnaissance. The breakdown of preferred system for reconnaissance is 22 (57.9%) for NVG, 6 (16%) for IHADSS and 10 (26.3%) for "Same". Figure 27 provides a pie chart analysis o f these results. Although IHADSS had greater than 50% reported effectiveness (Figure 26), the 23.7% reported ineffectiveness most likely contributed to the mid-teen percentage (15.8%) preference for its use during reconnaissance operations. To help qualify preference for reconnaissance visionic system pilots where asked to identify those system characteristics that aided in their decision of preferred system.

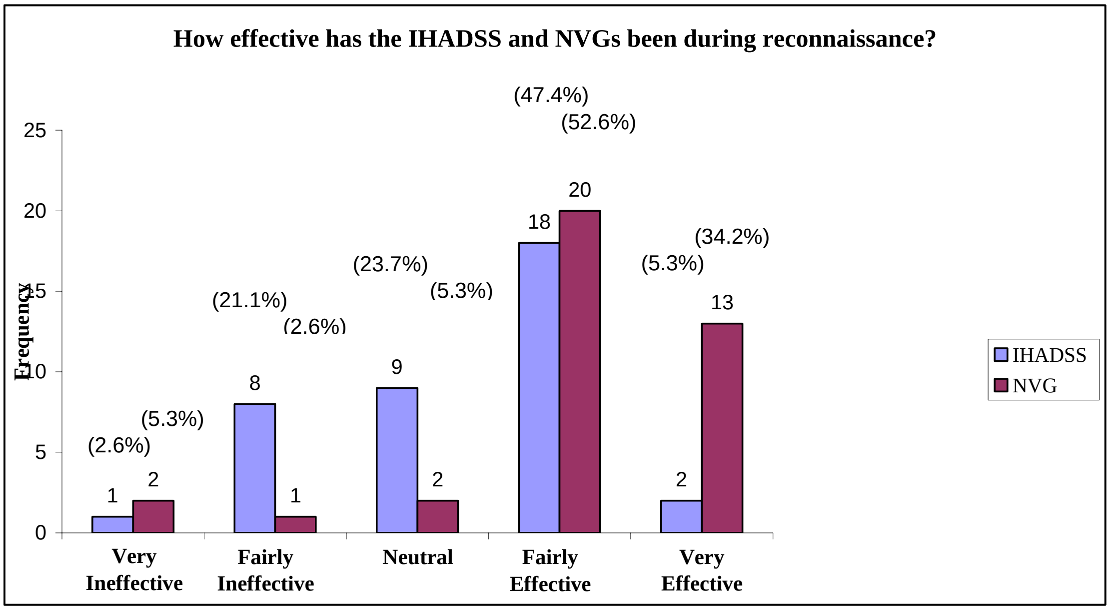

Figure 26. Reconnaissance Effectiveness by Visionic System.

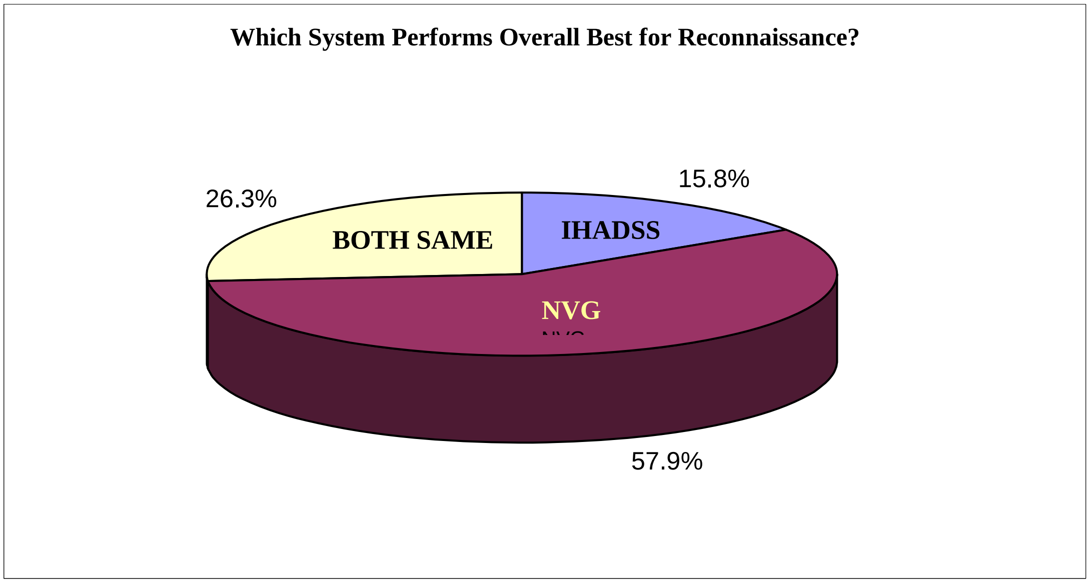

Figure 27. Preferred Visionic System for Reconnaissance.

IHADSS responses for characteristics that aided in its choice as a preferred system for reconnaissance were: 4 (10.5%) for resolution, 3 (7.9%) for FOV, 3 (7.9%) for field of regard, 1 (2.6%) for object recognition, 2 (5.3%) for contrasting objects, 4 (10.5%) for azimuth and elevation acquisition, and 3 (7.9%) for comfort (Figure 25). Similarly, NVG responses were 21 (55.3%) for resolution, 13 (34.2%) for FOV, 4 (10.5%) for field of regard, 19 (50%) for object recognition, 8 (21.1%) for depth perception, 12 (31.6%) for contrasting objects, 7 (18.4%) for azimuth and elevation acquisition, and 8 (21.1%) for comfort. Responses for "same" were 3 (7.9%) for resolution, 3 (7.9%) for FOV, 1 (2.6%) for field of regard, 3 (7.9%) for object recognition, 1 (2.6%) for contrasting objects, and 1 (2.6%) for comfort" (Figure 28).

Overall the perception of reconnaissance effectiveness numerically favors NVG use over IHADSS with the impact of ALL characteristics being greater for NVGs than for IHADSS. A majority of respondents, 22 (57.9%), chose the ANVIS system over the IHADSS with their primary deciding criteria spread over all characteristics listed. "Resolution" and "Object recognition", again, had the highest responses with 21 (55.3%) and 20 (52.6%) positive replies, respectively. Another major factor in favor of NVG was the perceived effectiveness and ineffectiveness of both systems. NVG had 26 (68.4%) of

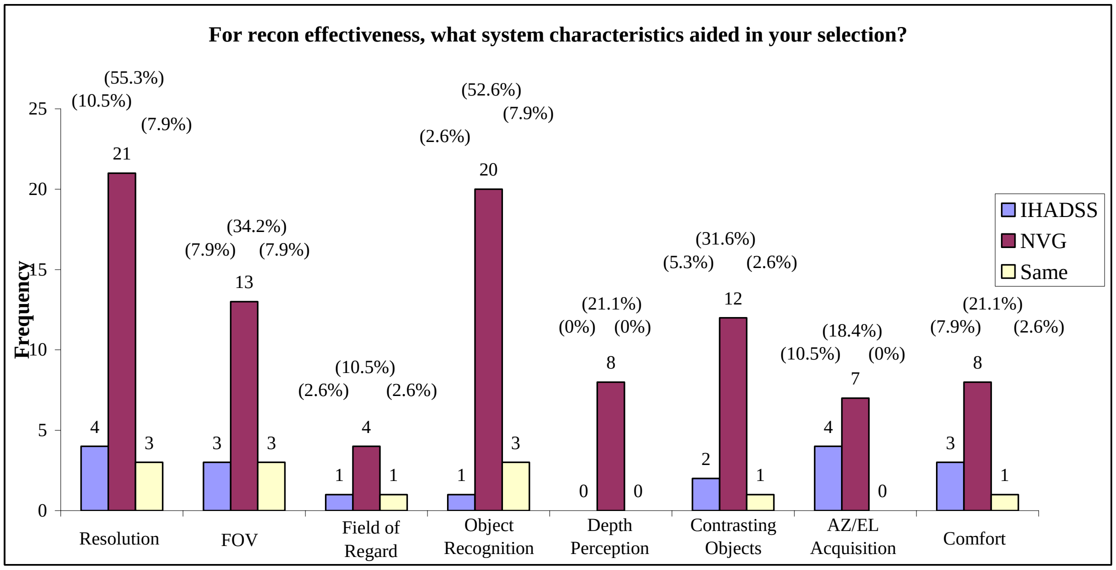

Figure 28. System Favorable Characteristics for Reconnaissance Effectiveness.

respondents who report the ANVIS system is either “Very effective” or “Fairly effective” as compared to the 20 (52.6%) positive responses for effectiveness of IHADSS. IHADSS had 9 (23.7%) positive responses for “Very ineffective” or “Fairly ineffective” compared to the 3 (8.3%) positive responses for ineffectiveness of NVG.

It is interesting to note that the “Resolution” and “Object recognition” characteristics for wire recognition and reconnaissance effectiveness were almost identical. This similarity seems to confirm the preference for the 20/25 visual acuity of NVG over the 20/60 visual acuity of IHADSS. The U.S. Army’s decision to include the use of NVG in conjunction with IHADSS provides for improved reconnaissance and security capabilities in the urban combat environment.

3.5.3 Situational Awareness, Static and Dynamic Cues.

Situational awareness, having knowledge of one’s position in 3-D space, is directly affected by the quantity and quality of visual and audio cues received by the brain. Too many or too few cues leave the pilot with a diminished ability to assess “the situation”. In-flight scenery is constantly changing requiring timely evaluation of the data available. The subjects were queried regarding static and dynamic cueing with respect to viewing objects through ANVIS and FLIR. The IHADSS system provides the AH-64 Apache pilot symbology for added situational awareness therefore the questions asked spoke to visual cueing with and without symbology. The ANVIS system in use during this study did not provide flight symbology to the pilot, but the potential to provide this symbology has been investigated. The AH-64A possessed the ability to “turn off” symbology, the AH-64D does not have this feature. With regard to evaluating best overall cues without symbology, respondents were asked to respond only to the visual cues present and not the flight data information provided by the system symbology

When queried regarding best overall static cues provided by ANVIS and IHADSS *with symbology*, IHADSS positive responses were: 28 (73.7%) for altitude, 13 (34.2%) for slope angle, 29 (76.3%) for attitude, 28 (73.7%) for pitch, 10 (26.3%) for clearing obstacles, and 3 (7.9%) for differentiating objects. When queried regarding best overall static cues provided by ANVIS and IHADSS *without symbology*, IHADSS positive responses are: 3 (7.9%) for altitude, 2 (5.3%) for slope angle, 1 (2.6%) for attitude, and 3 (7.9%) for pitch.

ANVIS positive responses for static cuing as compared to IHADSS with symbology, were 10 (26.3%) for altitude, 25 (65.8%) for slope angle, 9 (23.7%) for attitude, 10 (26.3%) for pitch, 28 (73.7%) for clearing obstacles, and 35 (92.1%) for differentiating objects. When compared with IHADSS video imagery and no symbology, respondents reported 35 (92.1%) for altitude, 36 (94.7%) for slope angle, 37 (97.3%) for attitude, and 35 (92.1%) for pitch. Figure 29 presents these results in histogram format.

When asked regarding best overall dynamic cues provided by ANVIS and IHADSS *with symbology*, IHADSS positive responses were: 32 (84%) for sensing aircraft drift, 32 (84.2%) for sensing airspeed, 23 (60.5%) for sensing closure rate, 27 (71.1%) for sensing pitch rate, and 29 (76.3%) for sensing bank rate. When asked regarding best overall dynamic cues provided by ANVIS and IHADSS *without symbology*, IHADSS positive responses were: 2 (5.3%) for sensing aircraft drift, 2 (5.3%) for sensing airspeed, 1 (2.6%) for sensing closure rate, and 6 (15.8%) for sensing pitch rate.

ANVIS positive responses as compared to IHADSS with symbology, were 6 (15.8%) for sensing aircraft drift, 6 (15.8%) for sensing airspeed, 15 (39.5%) for sensing closure rate, 11 (28.9%) for sensing pitch rate, and 9 (23.7%) for sensing bank rate. When queried regarding best overall dynamic cues provided by ANVIS and IHADSS *without symbology*, ANVIS positive responses were: 36 (94.7%) for sensing aircraft drift, 36 (94.7%) for sensing airspeed, 37 (97.4%) for sensing closure rate, 32 (84.2%) for sensing pitch rate and 38 (100%) for sensing bank rate. Figure 30 provides complete data for the referenced dynamic cueing with and without symbology.

IHADSS with symbology responses favored IHADSS. Visual cueing from imagery alone favored NVGs. The fact that AH-64 pilots have been trained to convert flight data stimuli into cues is evident when given the choice between systems. When symbology is discounted the majority of pilots favored the NVG system for cues.

To further understand the need for symbology stimuli for cueing, pilots were asked what flight symbology (if any) was their primary source while using NVG. The

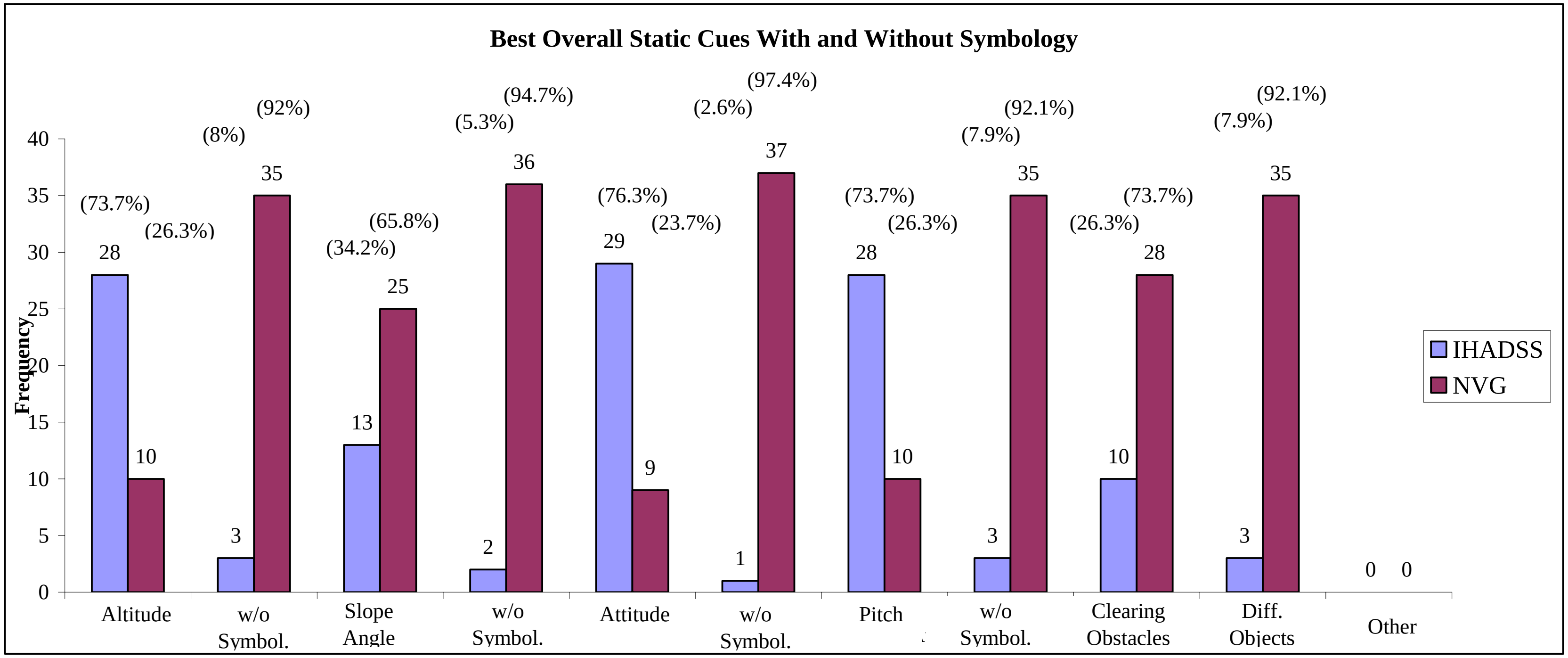

Figure 29. Static Cues

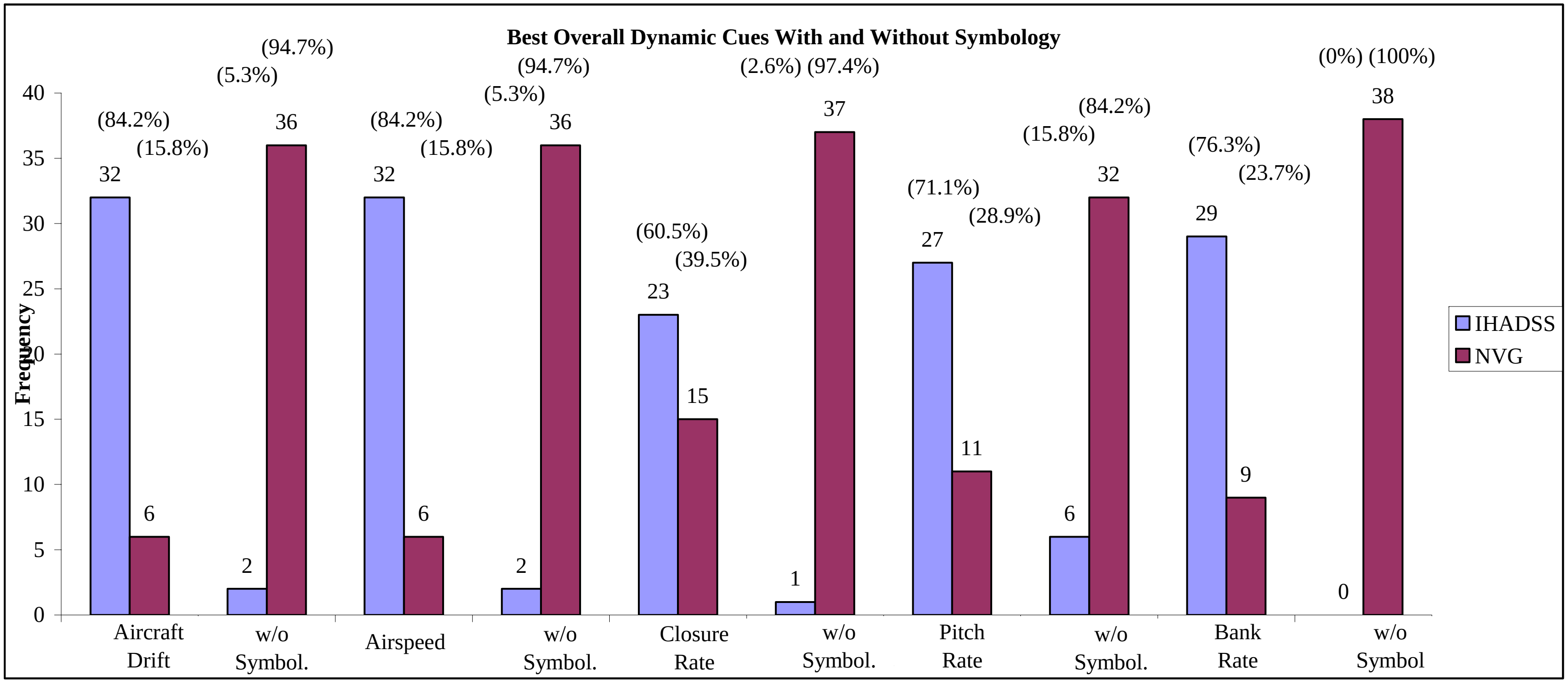

Figure 30. Dynamic Cues.

AH-64D attack helicopter uses a glass cockpit (multifunction display-equipped) design which allows for selection of flight page symbology on either page in the rear station or any of the three displays in the front station. The front stations center MPD is referred to as the TEDAC (TADS electronic display and control). When asked regarding their primary source of flight symbology data 25 (65.7%) of respondents stated that they use the left MPD, 9 (23.7%) the right MPD, 2 (5.3%) the center TEDAC, and 2 (5.3%) reported that they do not use any symbology while using NVG (Figure 31).

To further understand the use of MPD displayed flight symbology, pilots were asked to state the ease with which they could view the data while using ANVIS. Recall that pilots wearing the ANVIS system must look below/under the HMD to view the aircraft's MPD. The responses are nearly evenly split between "Fairly easy", 12 (31.6%), and "Fairly difficult", 10 (26.3%). Of the remaining responses 5 (13.2%) respondents report viewing is "Very easy", 5 (13.2%) report a "Neutral" response, 3 (7.9%) report viewing is "Very difficult", and 3, (7.9%) report they do not use symbology, up from two reported on the previous survey question. Figure 32 shows the complete results for this survey question.

With the inclusion of ANVIS into the AH-64 cockpit the issue of frequency of voluntary use becomes relevant when defining performance. Having been given a choice

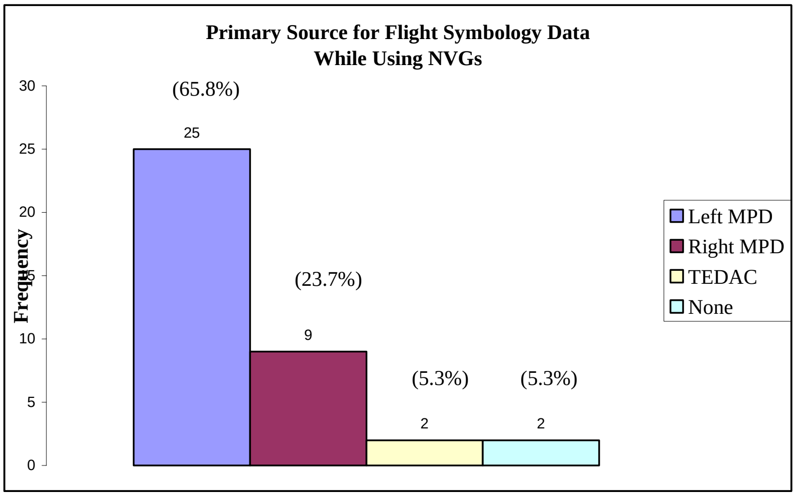

Figure 31. Flight Symbology Source while using NVG.

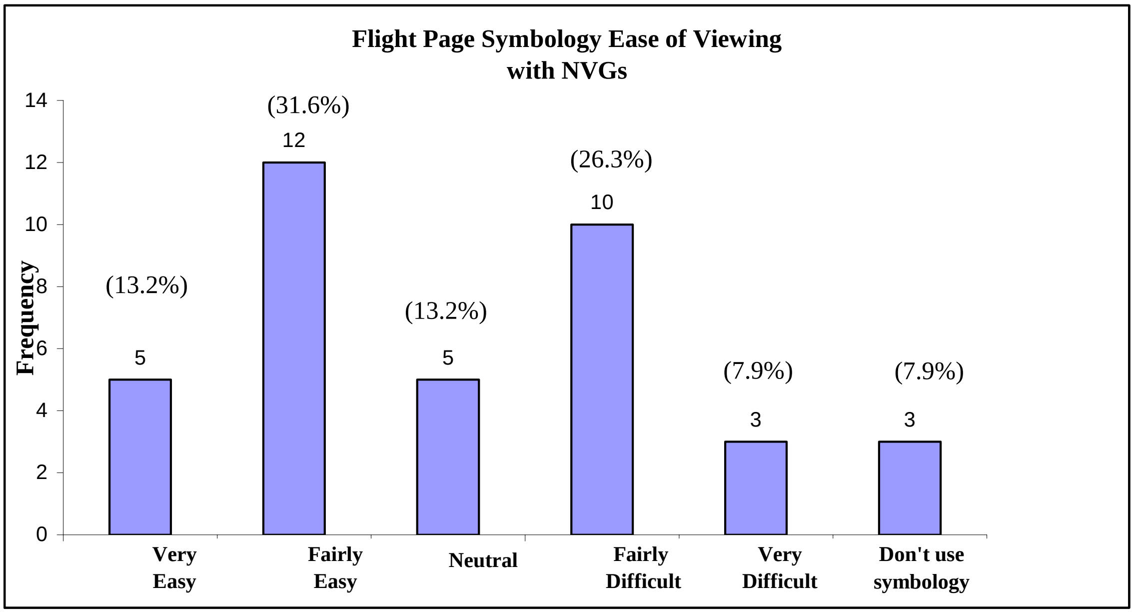

Figure 32. MPD Flight Symbology Ease of Use with NVG.

in augmented visionics it is important to determine how frequently AH-64 pilots "choose" to use the ANVIS instead of IHADSS. When asked how frequently one found themselves flying greater than 50% of a mission with NVG, 8 (21.1%) reported they did so "Very frequently", 14 (36.8%) "Fairly frequently", 5 (13.2%) of the respondents were "Neutral", 10 (26.3%) "Fairly infrequently", and 1 (2.6%) reported they did so "Very infrequently" (Figure 33). When asked how frequently one found themselves flying an entire mission with NVG, 3 (7.9%) "Very frequently", 6 (15.8%) "Fairly frequently", 6 (15.8%) were "Neutral", 14 (36.8%) "Fairly infrequently", and 9 (23.7%) reported they did so "Very infrequently" (Figure 34).

The survey questions and answers related to static cues, dynamic cues, and symbology use with and without the IHADSS attempts to answer the question of whether one system provides better situational awareness that the other. It has been established that flight symbology stimuli is converted to cues which the AH-64D pilots choose to use even while using NVGs. This fact is evidenced by the percentage of pilots utilizing a MPD with flight symbology while using night vision goggles. Considering that both

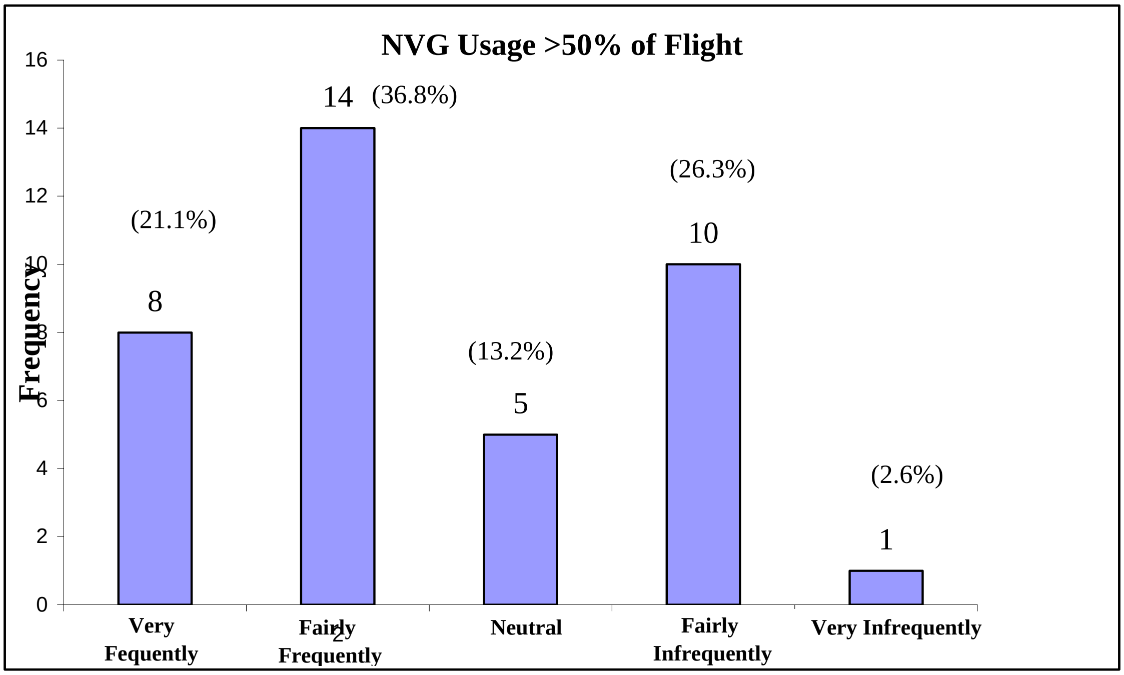

Figure 33. Frequency of Flying >50% of Flight with NVG.

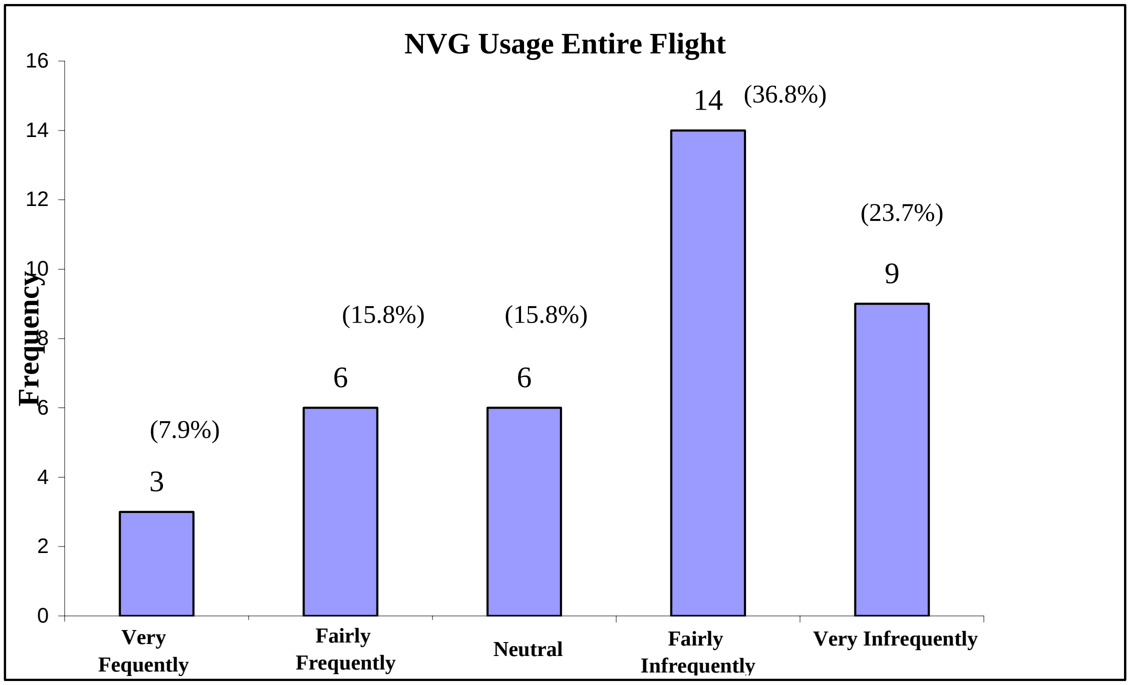

Figure 34. Frequency of Flying an Entire Flight with NVG.

systems have benefits in different ambient conditions, the fact that 22 (57.9%) respondents choose to use the NVG over the IHADSS for greater than 50% of a flight shows that pilots feel that the visual cues (overall) are better in the ANVIS system. Coupled with the fact that 9 (23.7%) of respondents frequently choose to use only the ANVIS system makes it evident that NVG has the better visual acuity for in-flight situational awareness. When asked if they would prefer NVG with symbology overlaid 36 (94.7%) respondents report "Yes", 0 (0%) said "No", and 2 (5.3%) report it does not matter (Figure 35).

The need for visual acuity and flight symbology data integration are evident by pilots' decisions to use ANVIS with a MPD displaying flight information. The fact that pilots are drawn "heads down" in the cockpit to view flight information while transiting enemy terrain poses safety hazards. The U.S. Army decision to allow NVG use in the cockpit has improved pilot situation awareness and reinforced the need for flight symbology data to the pilot. As stated in the introduction, the U.S. Army has authorized for use in combat a version of ANVIS which provides symbology and weapons

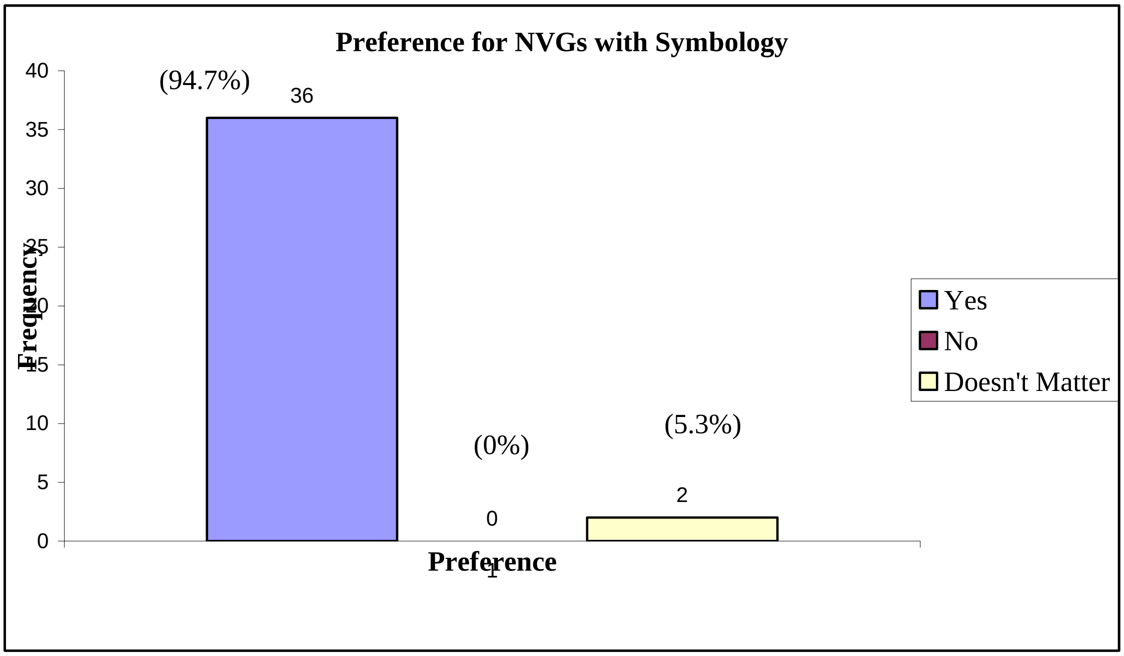

Figure 35. Preference for NVG with Symbology.

engagement capabilities. The system should be made mandatory and not voluntary to ensure the fullest implementation.

4. CONCLUSIONS

The AH-64 Apache, now in its “D” version, continues to be the world’s premier attack helicopter. Its design has allowed the U.S. Army to dominate the battlefield during day and night operations and with an ever changing doctrine has allowed the airframe to assume pure reconnaissance operations. The success of the aircraft over the years during night operations owes itself to the IHADDS design and the PNVS/TADS ability to turn ‘day into night’. This success, though, is tempered by consistent reporting over the years of visual complaints associated with the HMD use. Included with visual complaints were issues of poor visual acuity at times diminishing mission effectiveness. Incidents of reported visual complaints have been well documented over the past 20 years by the U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama. The U.S. Army countered these problems by allowing the use of NVGs in the AH-64 cockpit while scheduling a modernization of the IHADSS’ infrared imaging system, in essence allowing the AH-64 pilot the ‘best of worlds’, image intensification and infrared. This thesis revisited the presence of visual illusions for comparison to past studies and made a comparison of NVGs to IHADSS for the 21st century urban combat attack helicopter role. This study reflects VMC flight under minimal overcast conditions and does not extrapolate to other than those conditions specified.

The major conclusions to be drawn from this OIF study are:

- Although anecdotal comments state that both systems (FLIR and I^2) have benefits based upon ambient conditions (Appendix, question 5(f)), I^2 was preferable 81.6% to 10.5% for aircraft recognition and avoidance, 55.3% to 23.7% for wire avoidance and recognition, and 57.9% to 15.8% for reconnaissance (Figure 36). In the constant-moving environment of aerial reconnaissance and security the ANVIS is preferable to the IHADSS by a majority of AH-64D pilots. Although functionally effective, the legacy IHADSS is not intended for the level of detail

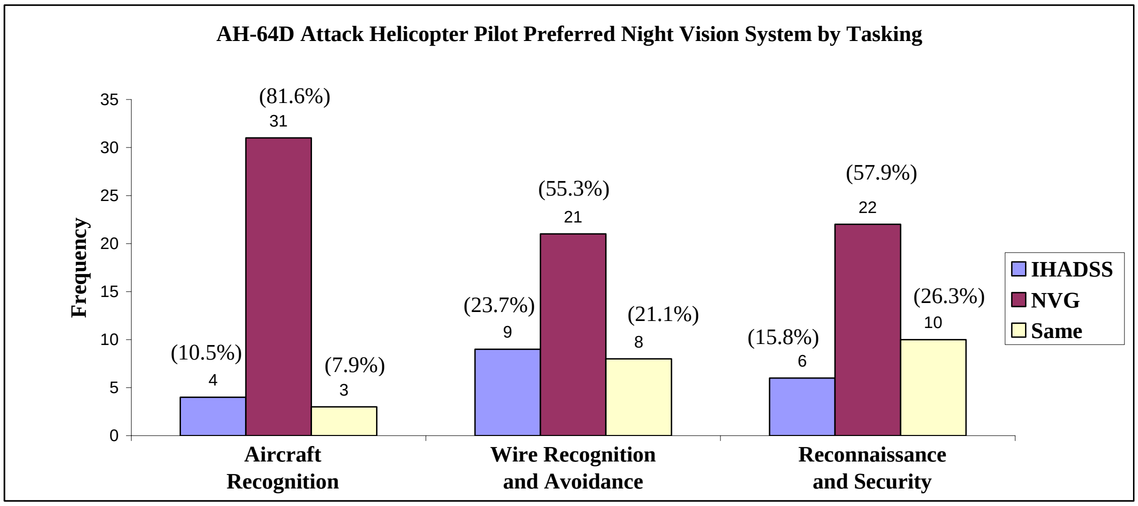

Figure 36. Night Vision System Preference by Tasking.

and in-flight terrain observation that is being required in the urban environment. The decision by the U.S. Army to allow ANVIS in the AH-64D cockpit has added a level of safety and increased mission effectiveness mitigating much of the risk associated with IHADSS limitations during different phases of flight.

- Physical symptoms are present in this study as with all previous studies of the AH-64 and the IHADSS (Figure 37). Visual discomfort, headache, and after-images (brown-eye) are the most common. The first two issues stem from improper focus of the HDU when performing the “infinity focus” procedure. Brown-eye is the result of using day (photopic) and night (scotopic) vision at the same time. Day vision use is present during HMD operation whereas the unaided left eye is night adapted. The right eye needs to night adapt after removal of the HMD which leaves the pilot with “brown-eye” for 30-45 minutes after a flight.

  It is important to note, when reviewing Figure 37, that the 1990 Study results may reflect a more experienced aviator population, hence the large difference in responses.

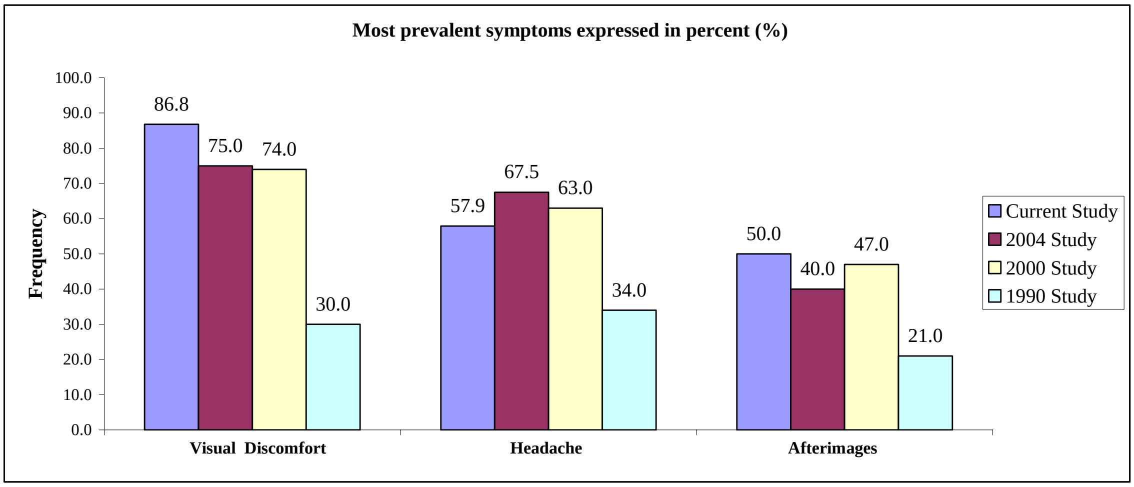

Figure 37. Most Prevalent Physical Symptoms from IHADSS use.

- The loss of visual cues in this study (Figure 16) and the presence of static and dynamic illusions (Figures 17 and 18) are similar in frequency to previous studies (Tables 5, 6, and 7, respectively) but may have been accentuated by the available comparison to ANVIS in as much as ANVIS had not been used as extensively in previous studies as was the case in this study. Another factor to consider when reviewing the loss of cueing and subsequent illusions is the functional requirements of each system. Whereas ANVIS intensifies the ambient light condition, FLIR relies on the difference in temperature between the item viewed and its surroundings. The temperature changes that may occur over 4-5 hour block of a night mission and the fact that re-optimization is not always feasible in a timely manner may also factor into perceived utility. Insufficient re-optimization of the FLIR system may contribute to the loss of cues and the presence of illusions.

- Based on present and past visual acuity reporting (Figure 16 and Table 5) and complaints of diminished IHADSS FOV in conjunction with illusion reporting, current and previous findings tend to validate that insufficient optical flow field and diminished FOV both are contributory in dynamic illusions.

- The presence of symbology and its effective use by AH-64 pilots combined with the requirement for no ambient illumination remains the primary reason for reliance on the IHADSS. The effective translation of the visual cueing data and digital flight data received into improved situational awareness is evident in the pilot reliance on MPD flight symbology data *while using NVG* visual cues. Pilots choose to use the ANVIS over the IHADSS at different phases of the mission and make adjustments to transition inside the cockpit for needed flight symbology.

- Helmet fit is predominantly satisfactory (76.3%) with most complaints centering on physical obstructions within the cockpit when looking full left or right. FOV issues also centered on looking full left or right and may be related to slippage but also may relate to 30-degree X 40-degree as being insufficient.

5. RECOMMENDATIONS

Based on the findings of this study, the following *recommended actions* are suggested:

- The U.S. Army should address the infinity focus issue that is the most likely causal factor for IHADSS user headache and eye discomfort. Efforts should be made to comply with previous recommendations for the addition of a zero-diopter HDU focus detent.

- Progress should be continued with the scheduled modernization and fielding of the upgraded TADS/PNVS.

- Consideration should be given to exploring an HMD design that provides for increased FOV.

- The AH-64D community should continue to use ANVIS while awaiting FLIR system scheduled upgrades. It is further recommended that they use the ANVIS with the symbology display unit modification (AN/AVS-7) as designed for use by the AH-64A/D.

Based on the findings of this study, the following *future research studies* are suggested:

- A study should be initiated to evaluate possible crew coordination issues related to cockpit crews using distinctly different night vision systems with an emphasis on synergetic utilization of the two systems.

- A separate study should be initiated to evaluate the modernized TADS/PNVS (once fielded) against NVGs (ANVIS with symbology, preferably).

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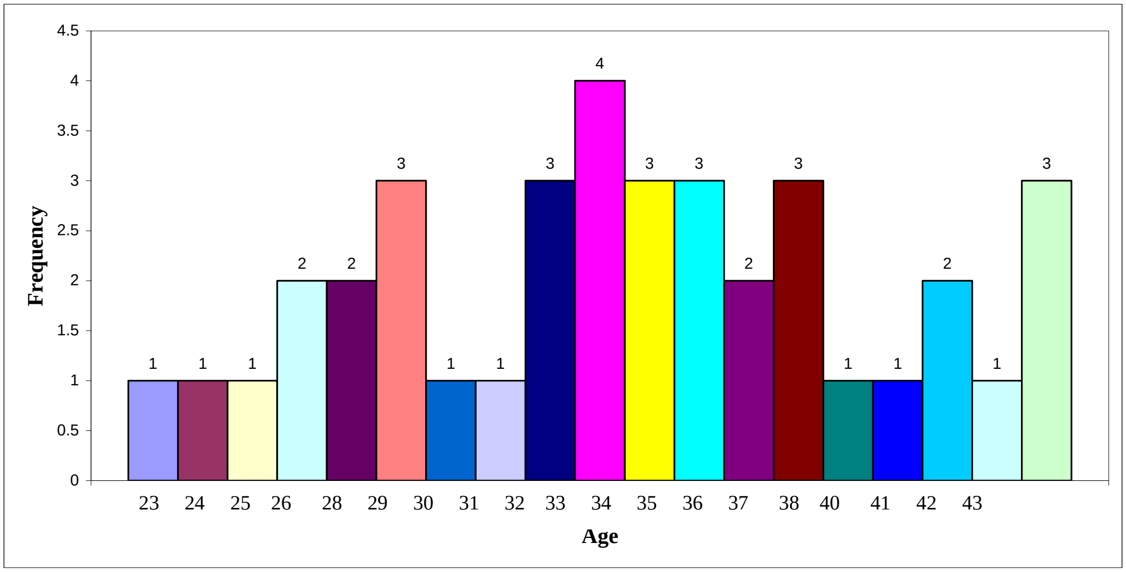
APPENDIX

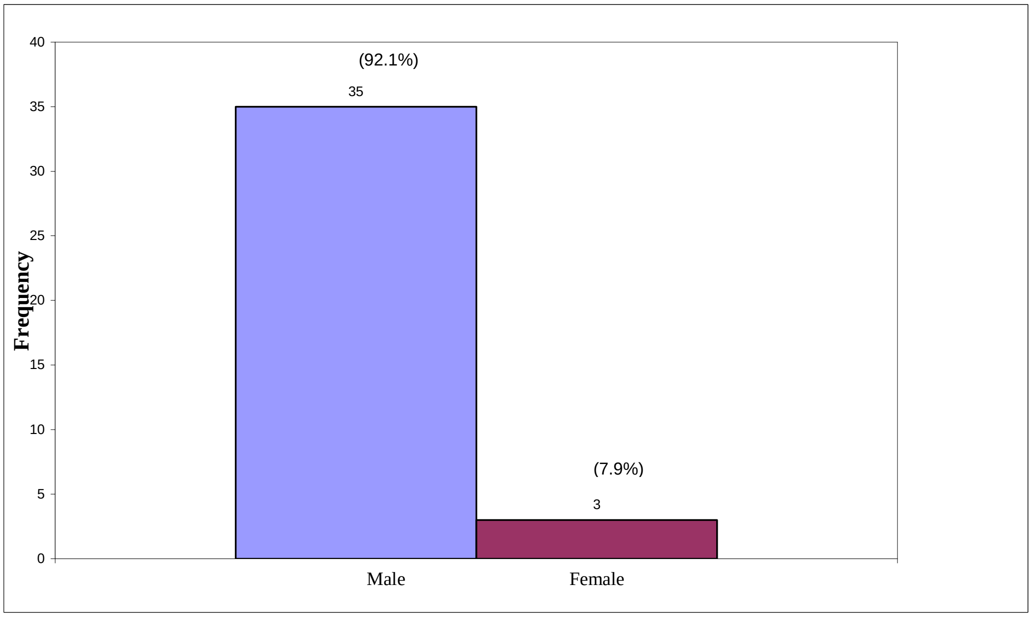
1. Demographics and flight experience:

a. Age (Years):



Mean (33.6) Median (33.5) Std. Dev. (5.4) Range (23-43)

b. Sex:



Male (35, 92.1%) Female (3, 7.9%)

c. Total flight hours in all Army aircraft:

Mean (1483.0) Median (1150.0) Std. Dev. (911.0) Range (500-4000)

d. Total flight hours in AH-64:

Mean (1139.1) Median (900.0) Std. Dev. (845.3) Range (300-3850)

e. Combat hours during this OIF rotation:

Mean (256.8) Median (255.0) Std. Dev. (106.1) Range (120-750)

f. Total NVS time (hours):

Mean (440.2) Median (311.5) Std. Dev. (360.5) Range (22-1500)

g. Total NVG time (hours):

Mean (160.1) Median (119.5) Std. Dev. (130.4) Range (30-650)

h. Do you maintain NVG currency for use as a backup?

Yes (38, 100%) No (0, 0%)

i. Estimated number of sorties in Iraq (November ’05 – March ’06):

Mean (62.9) Median (67.5) Std. Dev. (20.1) Range (11-100)

Average length (of sortie) (in hours):

Mean (4.3) Median (4.3) Std. Dev. (0.3) Range (3.8-5.0)

Longest length (of sortie) (in hours):

Mean (6.4) Median (6.2) Std. Dev. (0.7) Range (5.0-8.0)

j. Primary flight position while serving in OIF:

PIC (Both Seats):	(20, 52.6%)
PIC (Backseat):	(4, 10.5%)
CPG (Front Seat):	(14, 36.8%)

k. Operation Iraqi Freedom (OIF)/Operation Enduring Freedom (OEF) tours (including this one):

OIF:	Mean (1.4)	Median (1.0)	Std. Dev. (0.5)	Range (0-2)
OEF:	Mean (0.1)	Median (0.0)	Std. Dev. (0.3)	Range (0-1)

l. Your Warrant Officer (WO) or Commissioned Officer Grade is:

Junior Warrant (WO1 – CW2)	(17, 44.7%)
Senior Warrant (CW3 – CW4)	(12, 31.6%)
Master Warrant (CW5)	(0, 0%)
Company Grade Commissioned Officer (2LT – CPT)	(6, 15.8%)
Field Grade Commissioned Officer (MAJ – COL)	(3, 7.9%)
Choose to non-disclose	(0, 0%)

2. Visual history:

a. Do you wear any type of vision correction when not flying?

Yes (6, 15.8%) No (32, 84.2%)

If "Yes" check all that apply:

(1) Glasses: Single vision (6, 15.8%) -Bifocals (0, 0%) -Trifocals (0, 0%) -Progressive (No Line) (0, 0%)

(2) Contacts: Single (mono) vision (6, 100%) -Bifocal (0, 0%)

b. Do you wear any type of vision correction when flying?

Yes (6, 15.8%) No (32, 84.2%)

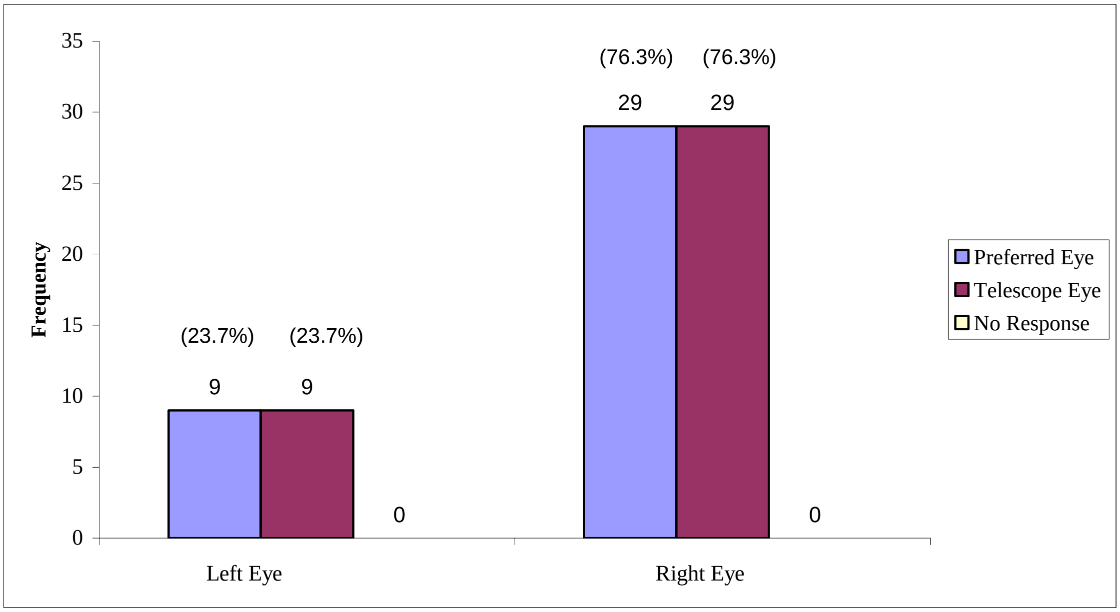
If "Yes" check all that apply:

c. Glasses: Single vision (4, 10.5%) -Bifocals (0, 0%) -Trifocals (0, 0%) -Progressive (No Line) (0, 0%)

d. Contacts: Single (mono) vision (6, 15.8%) -Bifocal (0, 0%)

e. Which is your preferred sighting eye? LEFT (9, 23.7%) RIGHT (29, 76.3%)

f. Which eye would you use with a telescope? LEFT (9, 23.7%) RIGHT (29, 76.3%)



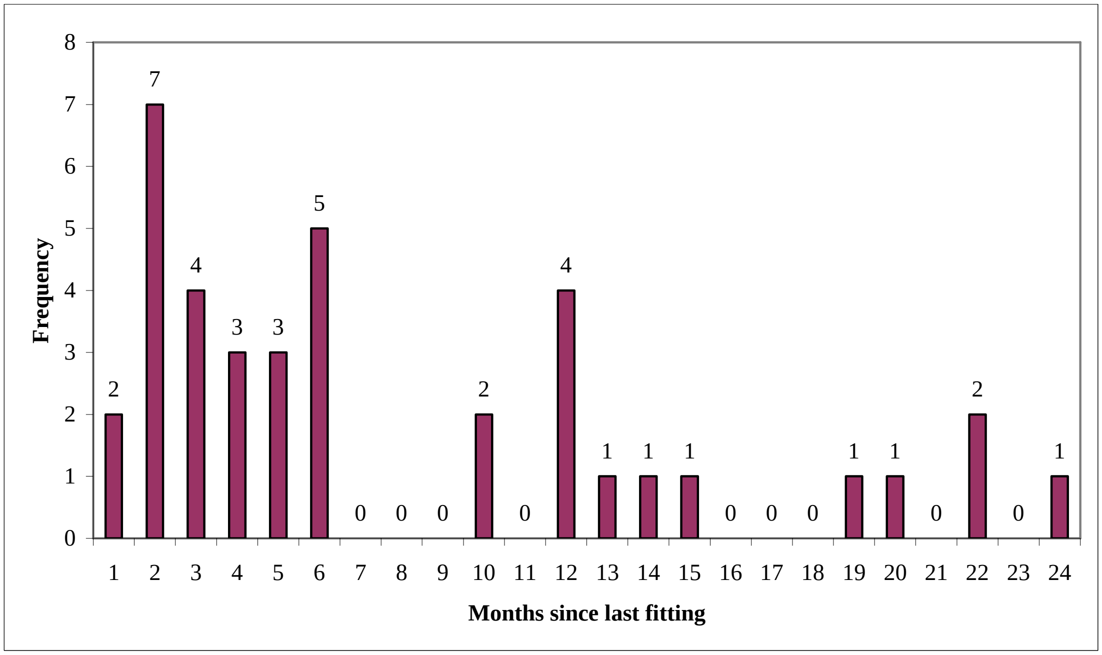
g. Is your better eye the same now (after AH-64 training and experience) as it was prior to your AH-64 experience?

Yes (26, 68.4%) No (12, 31.6%)

3. Helmet fit and IHADSS utility:

a. How long since your last helmet fit (months):

Mean (7.9) Median (2.5) Std. Dev. (6.6) Range (1-24)



b. Was your helmet fitted with the NBC mask?

Yes (2, 5.3%) No (36, 94.7%)

c. Did you fly with the NBC mask during this OIF rotation?

Yes (1, 2.6%) No (37, 97.4%)

If **YES**, approximate number of hours: (0.5 hours, once in simulator)

Did you experience incompatibility with the HDU and the mask?

Yes (2, 5.3%) No (0, 0%) N/A (36, 94.7%)

If **YES,** please explain:

“[It is] hard to see all of the HDU display.”

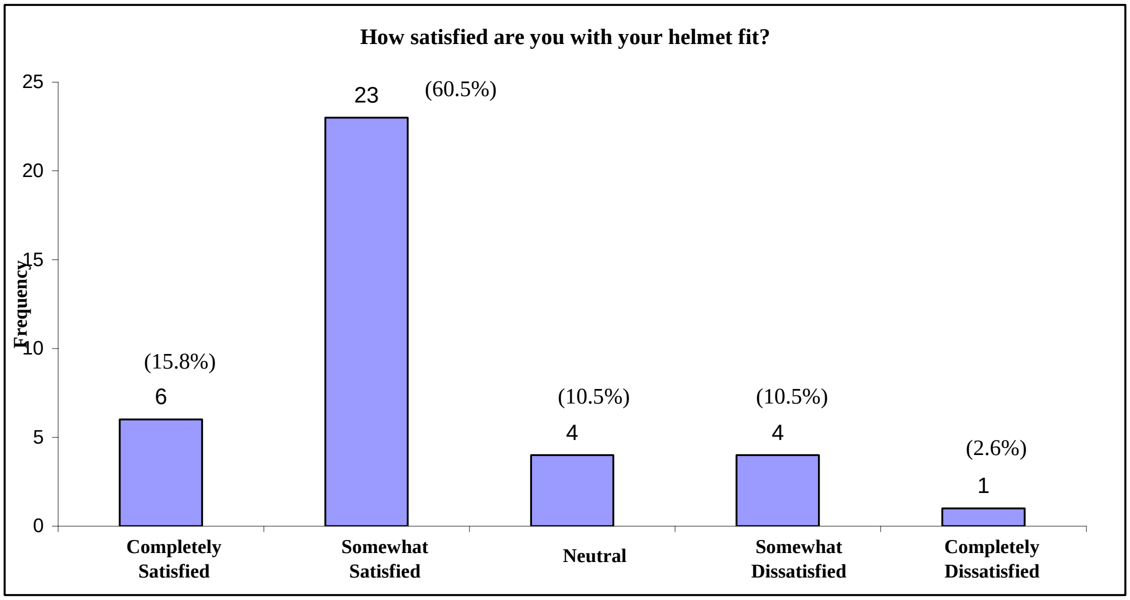
“No matter what adjustments were made I could still not see through [the] HDU.”

“The picture is barely visible. By which I mean you only see the upper left portion of the picture [which is] maybe 60% of normal.”

“[I] was unable to wear my helmet with mask during NBC training. [I] had to go 1 size larger which made HDU impossible to use.”

“[I] haven’t flown with [the] mask.”

d. Rate satisfaction with current helmet fit:



e. Is your ability to view IHADSS imagery impacted by your helmet fit (e.g., helmet slippage impacts ability to maintain field of view)?

Yes (19, 50%) No (19, 50%)

Comments;

“Cord will pull helmet resulting in helmet movement and misalignment with eyes”

“Turning my head in excess of 45 degrees sometimes causes me to lose symbology.”

"After 2.5 hours, helmet slips and needs adjusting."

"Poor fitting puts the HDU in the wrong spot."

"I'm using an extra-large helmet when I'm supposed to have a large. Not enough equipment in the inventory."

"IHADSS imagery is difficult to view without a properly fitted helmet."

"Helmet shifts during flight under hot/high temp cockpit conditions."

"Due to hot spots, I end up having to readjust my helmet – then adjust everything else."

"[A] poorly fitted helmet causes the loss of picture when [my] head is turned left or right."

"Different HDU do not fit the same, you have to shift helmet."

"The HDU mount must be positioned correctly in order to see all symbology."

"If [my] hair grows too long, [the HDU] picture becomes more difficult to properly boresight."

"Some HDU don't fit right without twisting the helmet a bit."

"[The helmet] needs to be a snug fit. New helmet system needed. HGU56!!"

"When the helmet slips the HDU moves and affects the HDU."

"Improper fit ruins IHADSS sight picture."

"Mainly when mounting NVGs to Helmet, IHADSS shifts position. Also the chord effects my head movement."

f. Do you achieve a full field of view?

Yes (35, 92.1%) No (3, 7.9%)

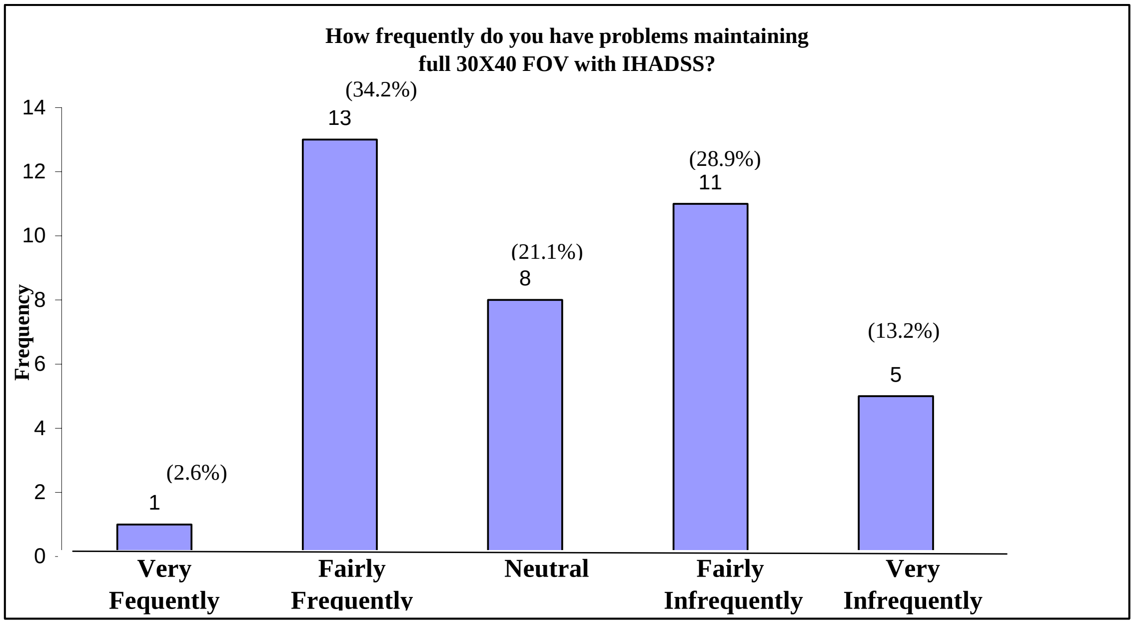
g. Have you ever lost IHADSS symbology while looking full left or full right?

Full left?	Yes (28, 73.7%)	No (10, 26.3%)
Full right?	Yes (25, 65.8%)	No (13, 34.2%)

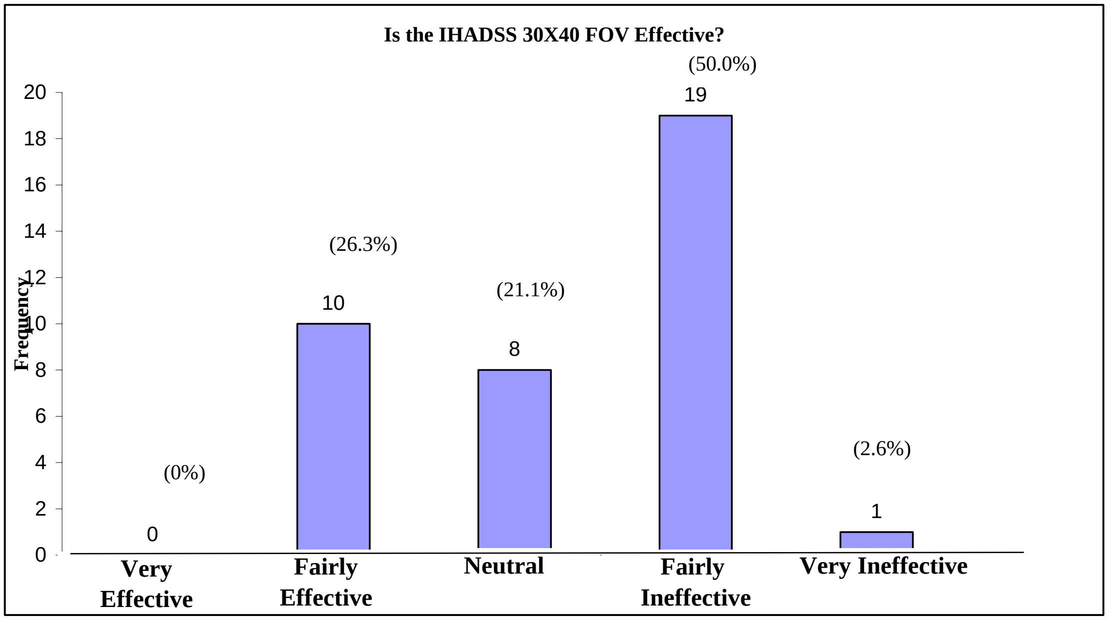
h. Do you feel you could still provide effective ordnance guidance while looking full left or right?

Full left?	Yes (22, 57.9%)	No (16, 42.1%)
Full right?	Yes (22, 57.9%)	No (16, 42.1%)

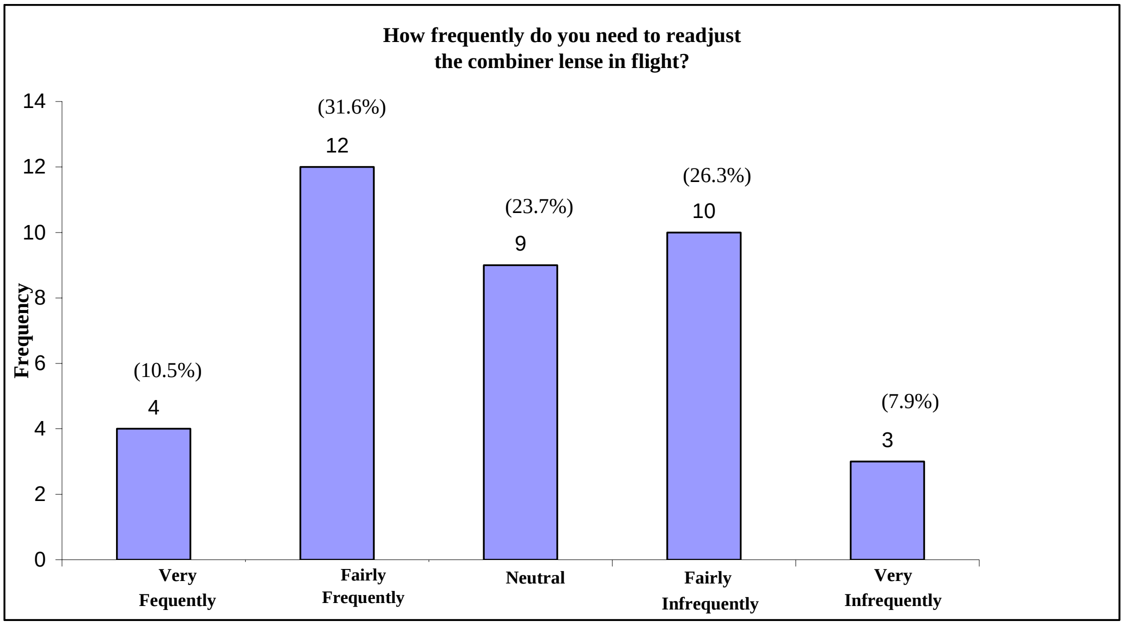
i. How frequently do you have problems with maintaining full 30X40 FOV with IHADSS (i.e., bleaching of the edges)?



j. Is the IHADSS 30X40 FOV effective?

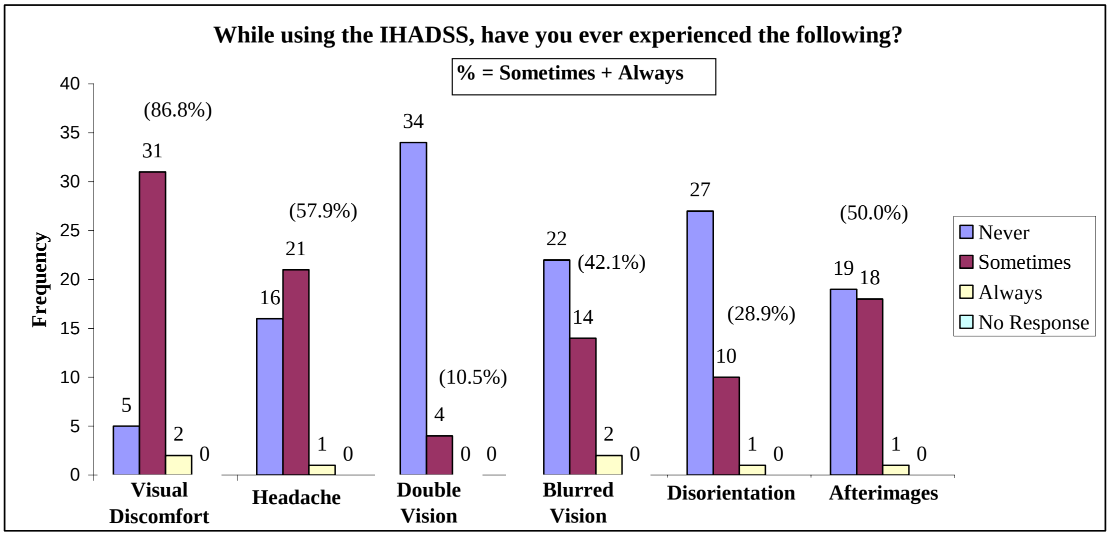


k. How frequently do you have problems with the combiner lens requiring readjustment in-flight?



4. IHADSS vision:

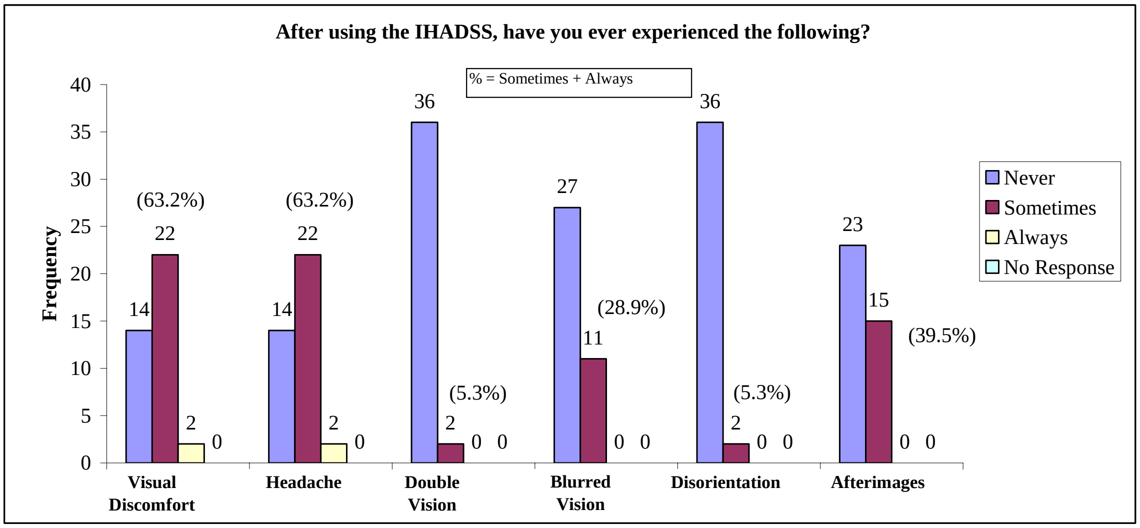
a. ***While*** using the IHADSS, have you ever experienced the following?



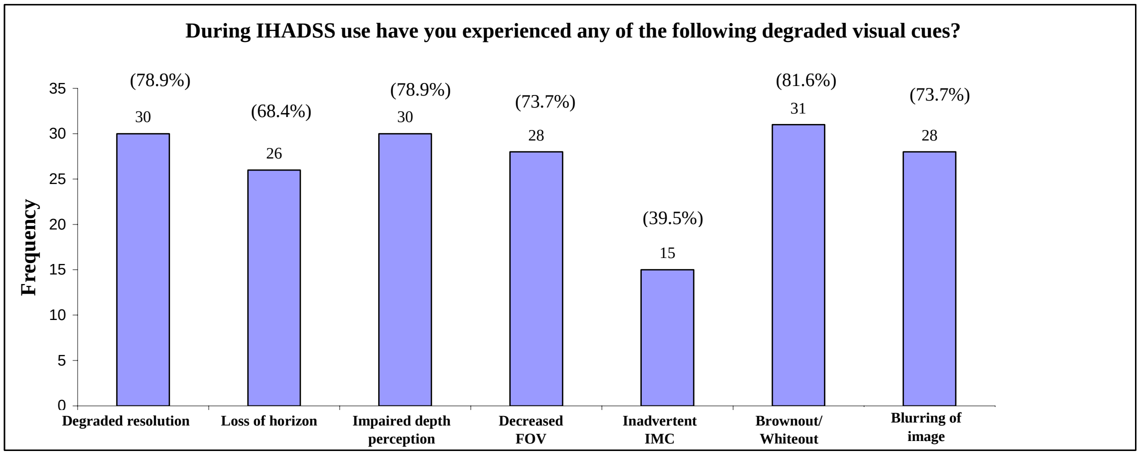
b. If symptoms were reported in (a) above, please comment on length of time IHADSS was in use before symptoms occurred:

Mean (2.4) Median (3.5) Std. Dev. (1.1) Range (0.1-4.5)

c. ***After*** using the IHADSS, have you ever experienced the following?



d. During IHADSS use have you experienced any of the following degraded visual cues?



Comments:

"[The above illusions occur] usually with improperly adjusted HDU or inoperative HDU."

"…..front seat with TADS in NVS mode."

"….IMC in snow/blizzard."

"While flying with TADS, I fly mostly symbology and accept that I cannot clearly see where I am going."

"I don't think this is an IHADSS issue more than it's a TADS FLIR issue."

"FLIR I technology is a very poor picture versus technology today."

"…brownout conditions [are] unavoidable."

"At some point through the years flying I've experienced all of the symptoms."

"[These degrade visual cues are present during] FLIR crossover in particular. However, some nights certain systems are just unflyable."

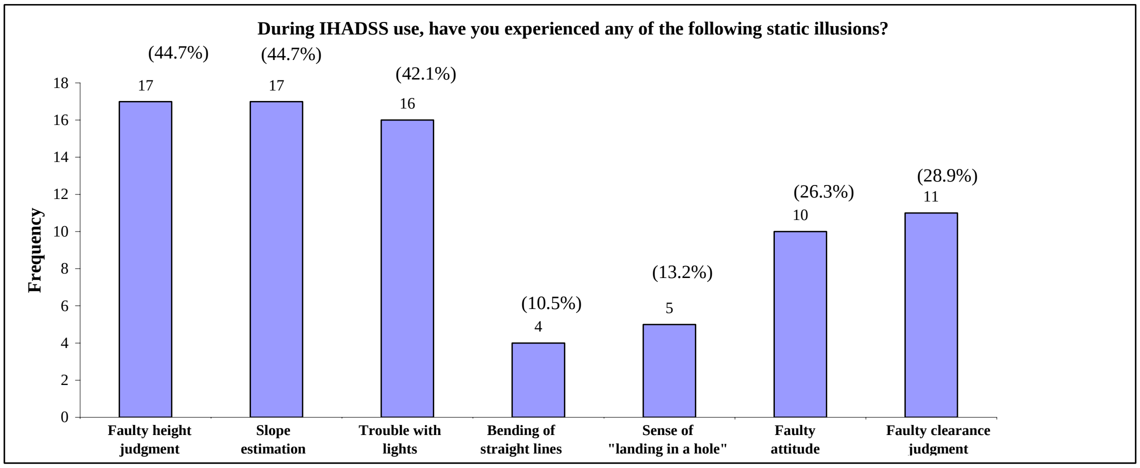
"I cannot recall having 'decreased FOV'."

"Just the basic degraded vision due to the optics."

"All 'yes' [responses] are [a] function of FLIR quality or environmental factors – we are trained to detect and deal with."

“With NVS is necessary to drive the “brightness” and “contrast” down to [the] lower half of the “greyscale” otherwise it is too bright to concentrate.”

e. During IHADSS use, have you experienced any of the following illusions?



Comments:

“[Illusions were a result of] poor TADS imagery [and] AC coupling.”

“Front seat TADS AC coupling causes loss of visual cues & disorientation.”

“The FLIR imagery doesn’t give enough visual cues to avoid these illusions.”

“Training has made me aware [that] these things can happen, so I am prepared to overcome these known deficiencies.”

“Binocular rivalry……”

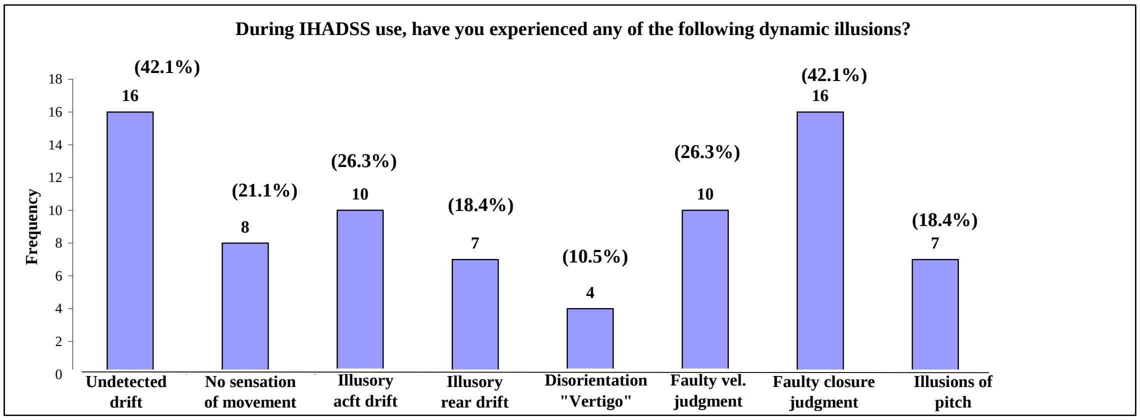
“Illusions have declined with greater experience due to [my] ability to recognize and compensate.”

“Improper registration, boresight inaccuracies, and helmet movement (especially tilt) can all affect these [illusions].”

“[I just get] the normal [illusions] that everyone gets used to after a few hours [of] using IHADSS.”

“Loss or lack of resolution is the general fault.”

"[The] symbology helps provide depth & 3rd dimension cues. Failure to clear [the aircraft] & slope judgment [illusions] are pilot error."



Comments:

"AC coupling is the primary problem [of these illusions]."

"[The answer is the] same as [for] above." ["The FLIR imagery doesn't give enough visual cues to avoid these illusions."]

"Poor picture does not provide enough cues to rely upon. [The pilot] must always trust [the] symbology."

"[The] use of symbology cures all."

"[These illusion are] mostly due to loss of peripheral sight [FOV]."

"[I have] just the normal [illusions]."

f. Have you noted any change in your ability to see or interpret HMD symbology during any phase of flight? Yes (35, 92.1%) No (3, 7.9%)

Comments:

"If turning hard right or left cause some of symbology as helmet moves on head."

"[Problems with symbology interpretation occurs after] flights greater than 3.0 hours."

"My symbology tends to blur and require readjustment 3 or 4 times within a 4 hour flight."

"Symbology interpretation becomes increasingly difficult during moments of high workloads or when fatigue increases."

"Symbology is great."

"As experience increases, cross check is quicker and takes less mental energy [and] mental focus on scene contact."

"Due to faulty HDU, symbology sometimes blanks, gets blurry, et cetera….."

"Dusk/dawn – adjust greyscale/symbology brightness."

"Only after 5.0 hours of NVS or on extended missions due to maintenance. Eye fatigue would be an explanation."

"[Seeing the] Head tracker, cued LOS, flight path vector, [and] NAV (navigation) FLY to, all in the center of [the] FOV causes clutter, sometimes impeding ability to see aircraft you are following."

l. When viewing through the HDU, can you focus clearly on the external scene and the symbology simultaneously?

Daytime: Yes (30, 78.9%)   No (8, 21.1%)   "No" comments:

"Generally I focus in on one or the other."

"[I use a] proper infinity focus."

"[I accomplish it] with proper adjustment of symbology while looking out at least 90 ft."

"No problem in [the] day."

"With a proper infinity focus the symbology appears overlaid on the external scene."

"It takes training and constant use."

"Proper focus adjustment [helps]."

"[I] view through the symbology."

"I usually focus on one or the other."

"Depending on [whether] the DAP (display adjustment panel) focus is set correctly, 60% "no" and 40% "yes"."

"I focus the symbology to be clear while I look past it."

"As long as the infinity focus knob doesn't get caught on anything and rotate."

"[I] usually can't see through the HDU with right eye (if PNVS is off)."

"Sometimes if [the] sun is low it is difficult due to smoked visor/HDU [being] too dark.

Nighttime: Yes (23, 60.5%) No (15, 39.5%) "No" comments:

"[It is] hard for me to translate both at once."

"[I use a] proper infinity focus."

"[I find that] I close the distracting one."

"Internal/external rivalry – one is always more clear depending on [the] focus."

"[This answer is the] same as above." ["With a proper infinity focus the symbology appears overlaid on the external scene."]

"Proper focus adjustment [helps]."

"[I] must focus on either scene."

"[You] lose aircraft in high light areas [and] you have to find [the] aircraft and remain level otherwise…."

"I usually focus on one or the other."

"Same as above – ["Depending on [whether] the DAP (display adjustment panel) focus is set correctly, 60% "no" and 40% "yes"."]"

"As long as the infinity focus knob doesn't get caught on anything and rotate."

"[I] pick one or the other [but I] can't do both at once."

"[The] NVS picture prevents me from looking "through" [the] HDU to [the] external scene."

m. During flight, does your vision sometimes unintentionally alternate between the two eyes? Yes (24, 63.2%) No (14, 36.8%)

Comments:

"Lights will make my unaided eye focus and interfere with the flight."

"[I] just close [my] left eye when it does [this]. I am left eye dominant."

"Experiences have had a decreased frequency with [flight] experience."

"[This is a case of] Classic retinal rivalry."

"I find myself closing one eye or the other as needed."

"As fatigue increases the vision can unintentionally alternate (bright cockpit or city lights)."

"[I do] when I see a bright light with my left eye."

"[I do] during bright lights in the background."

"[The] lighting (outside & inside) draws your [left] eye [away]."

"Yes, [because of] binocular rivalry with bright lights at night."

"Yes, to gain SA inadvertently."

"Yes, during high background lighting."

"Yes, [with] bright lights."

"Sometimes I experience a "strobe" effect with my eyes."

"Yes, predominantly over well lit urban areas."

"[I] learned to fly aided and unaided at the same time."

"Yes, usually when the aircraft will not properly greyscale."

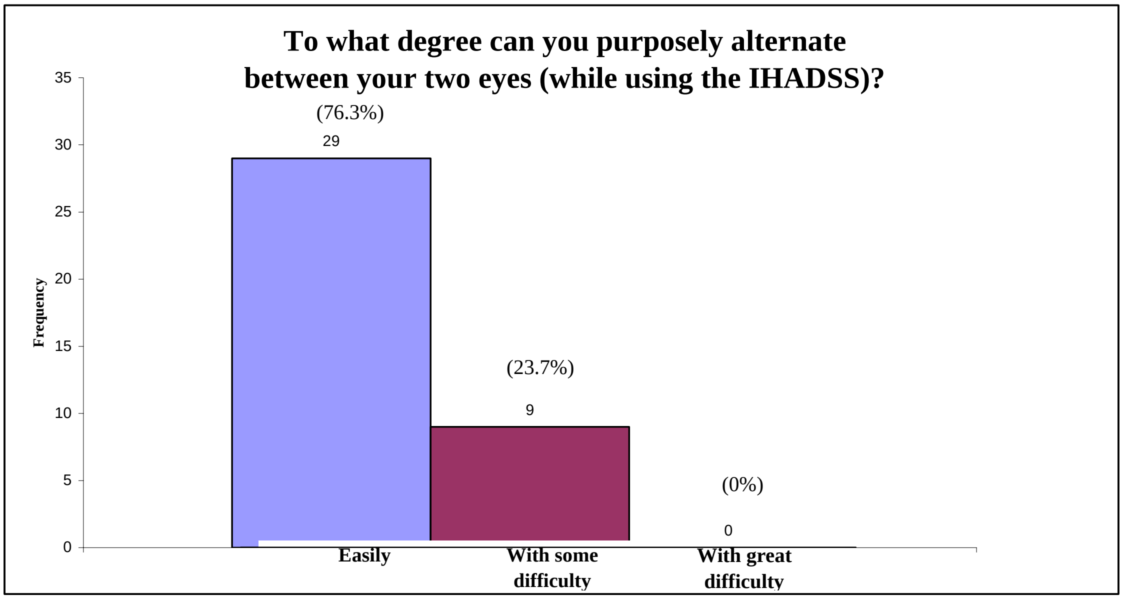
"It is difficult to maintain which eye has the focus especially around bright lights [because] the unaided eye normally takes over."

"Yes, the left eye [with] bright lights over the city."

"Yes, [with] the left eye focused on bright light. [It] just takes time to get used to it."

"I used to but no longer an issue – time/experience/training eliminates this."

n. To what degree can you purposely alternate between your two eyes?



Comments or technique:

“I close the eye I don’t want to use.”

“I close the left eye quickly to just concentrate on [the] FLIR picture or symbology.”

“I close the eye I don’t want to use.”

“I close the distracting one.”

“If I can’t mentally switch, then I close the opposite eye for a few seconds.”

“[I use] mental focus.”

“For the unaided eye I close the aided eye.”

“I close the one I don’t want to use.”

“It is only difficult over brightly lit urban areas.”

“I just learned through experience.”

“I close one eye.”

“[I] blink an eye.”

“I close both eyes for a second than open the one to be used.”

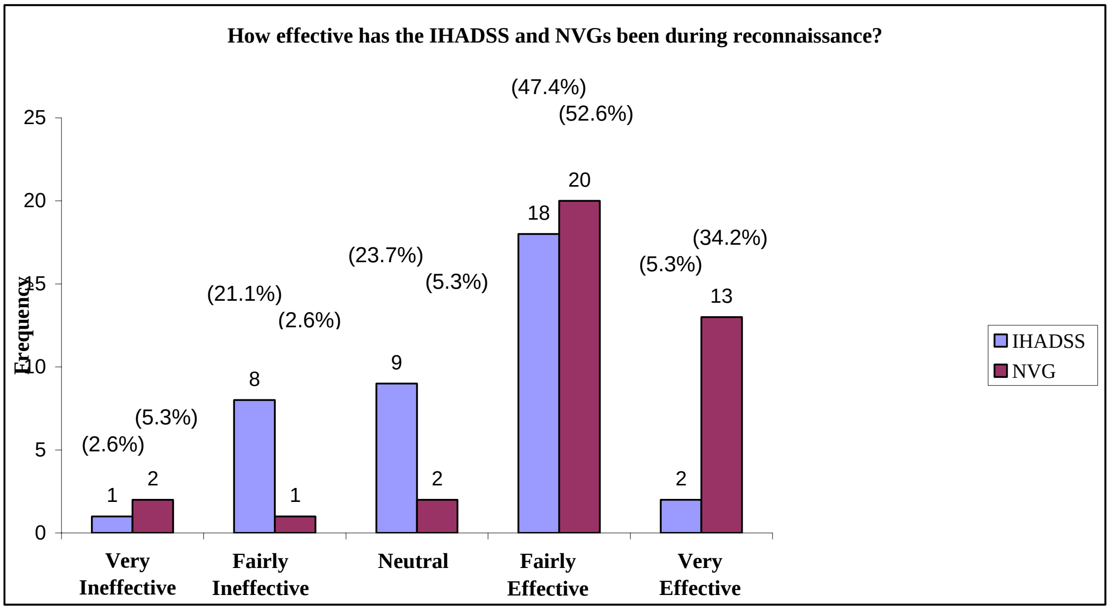
“[I use a] slight turn of the head to the right to concentrate with [the] left eye.”

“[I] focus attention on one or the other – if that fails [I] close the eye [I] don’t want to see [out of].”

5. IHADSS versus NVG effectiveness during this OIF rotation:

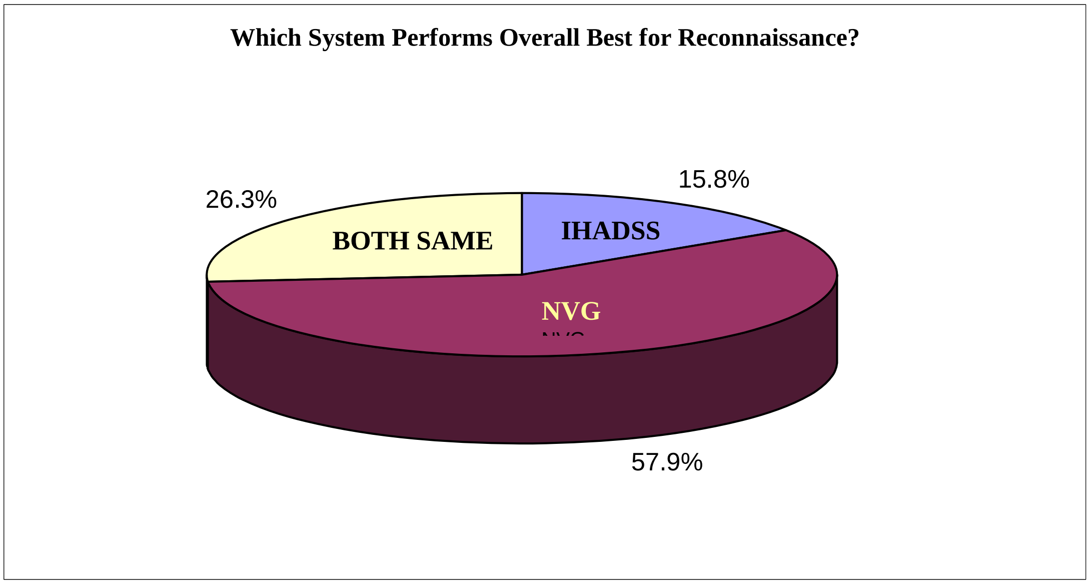
a. How effective has the IHADSS and NVGs been during reconnaissance?

b. How effective have NVGs been during reconnaissance?

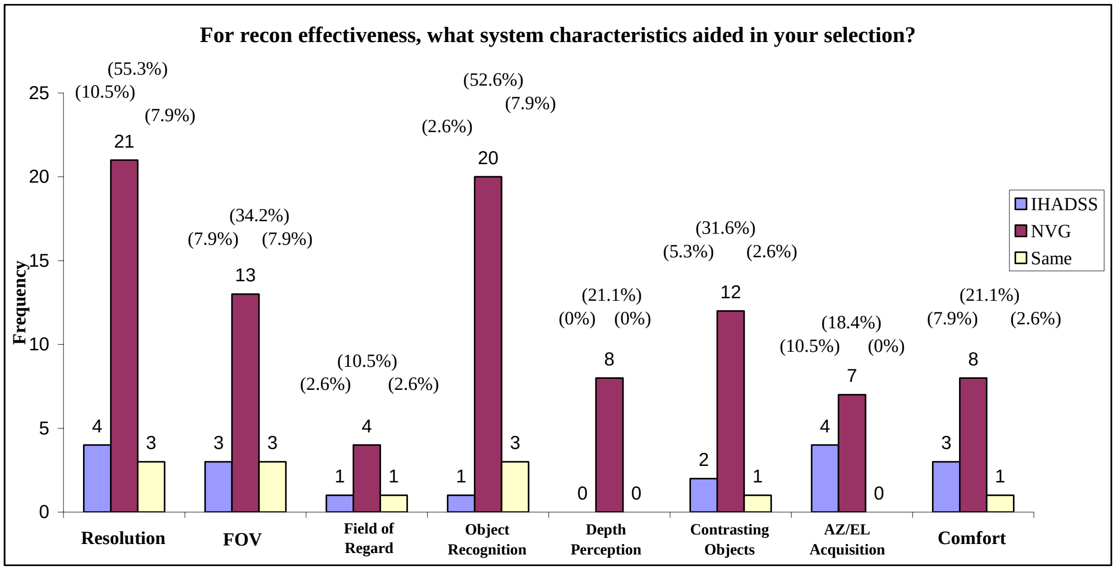


c. Which system performs <u>overall best</u> for Reconnaissance?

IHADSS (6, 15.8%) NVG (22, 57.9%) Both Same (10, 26.3%)

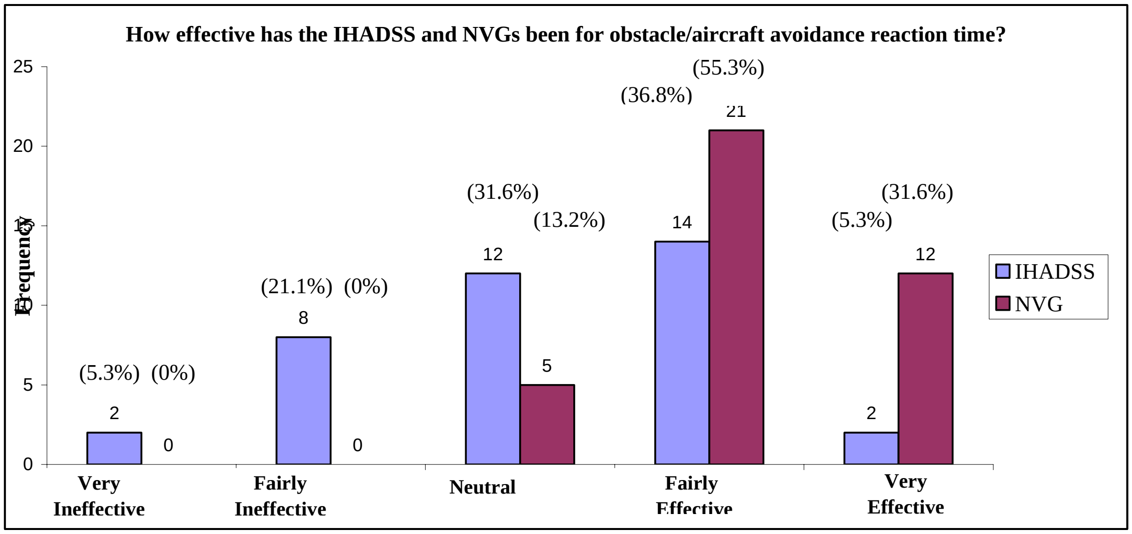


c.1 For the system you selected, choose the characteristics that aided in your selection:



d. How effective has the IHADSS been for obstacle/aircraft avoidance <u>reaction time</u>? (e.g., “no collision occurred, but NOT because I saw them in time)

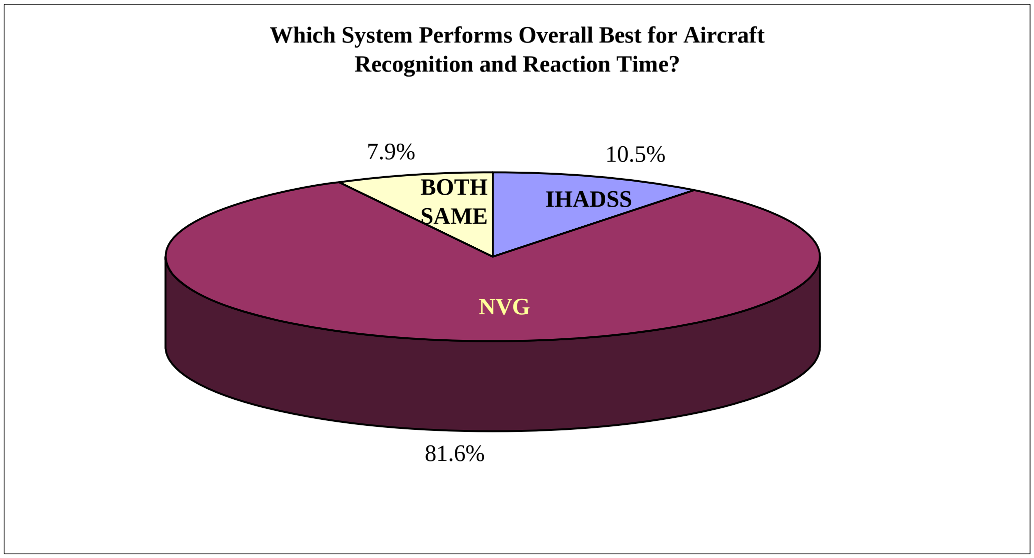
e. How effective have NVGs been for obstacle/aircraft avoidance reaction time? (e.g., "no collision occurred, but NOT because I saw them in time)



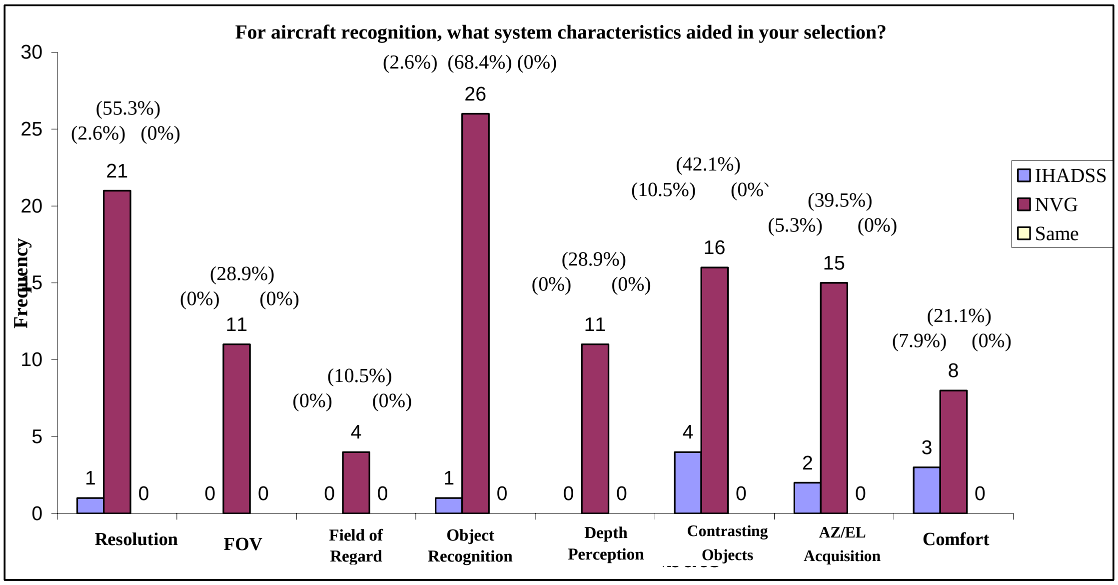
f. Which system performs overall best for collision avoidance reaction time?

IHADSS (4, 10.5%) NVG (31, 81.6%) Both Same (3, 7.9%)

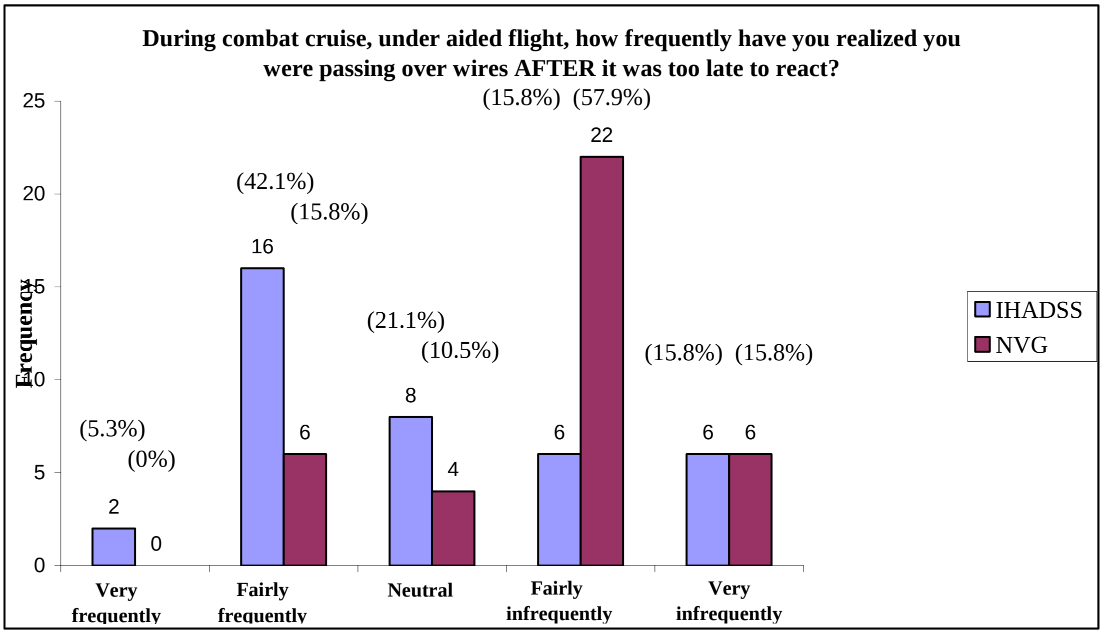
Comment: "Of course environmental conditions determine which of the two is better". (similar remark submitted 6 times)



f.1 For the system you selected, choose the characteristics that aided in your selection:

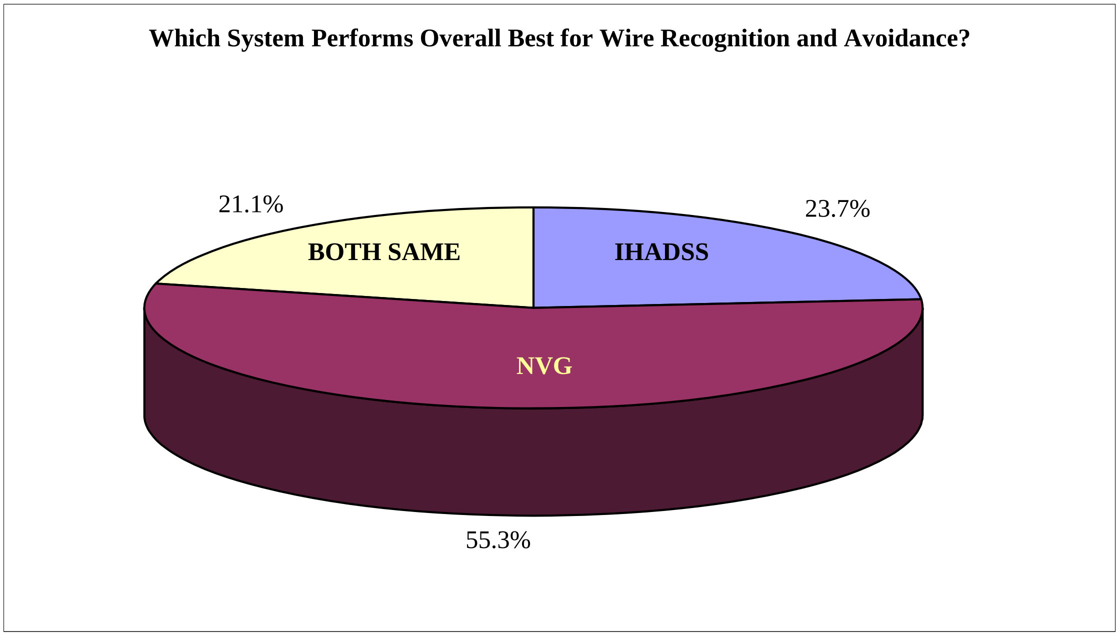


g. During combat cruise (> 100 KIAS), while using the IHADSS, how frequently have you realized you were passing over wires AFTER it was too late to react?

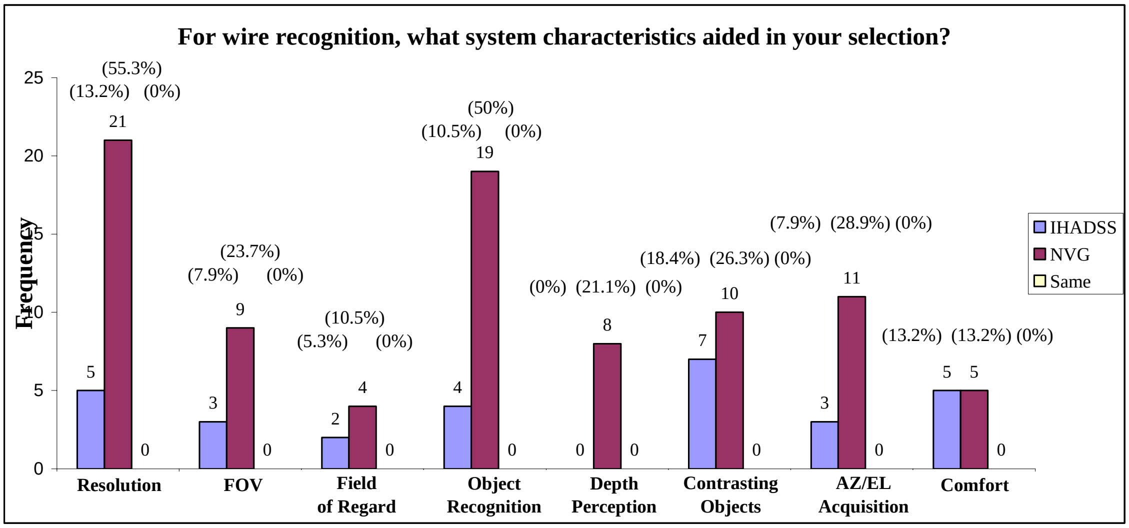


i. Which system performs better for wire recognition and avoidance?

IHADSS (9, 23.7%) NVG (21, 55.3%) Both Same (8, 21.1%)

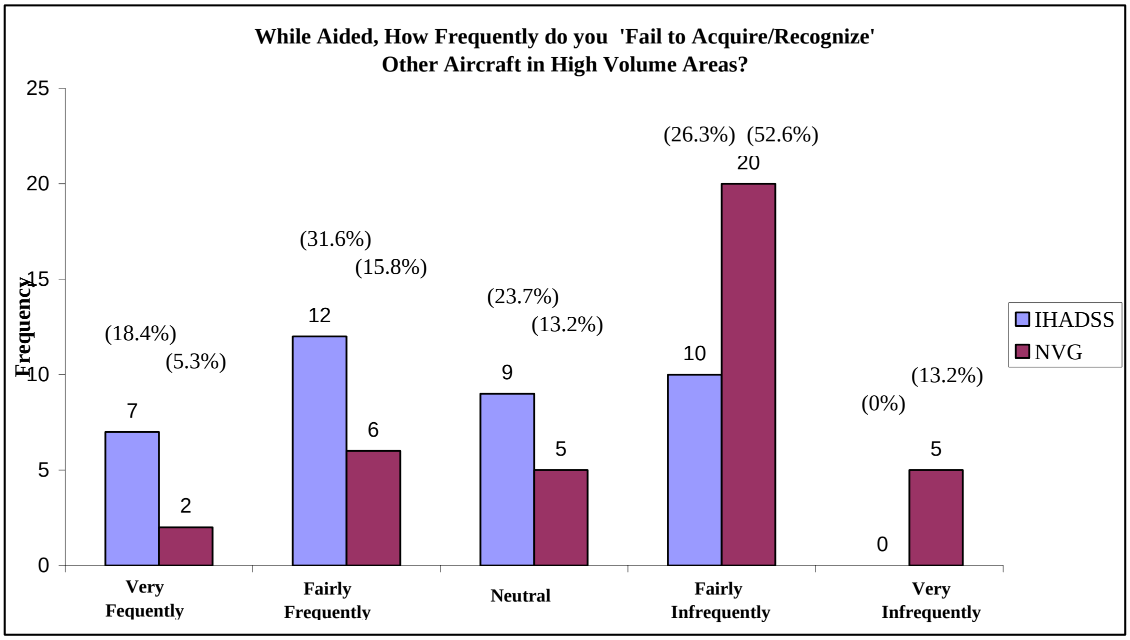


i.1 For the system you selected, choose the characteristics that aided in your selection:



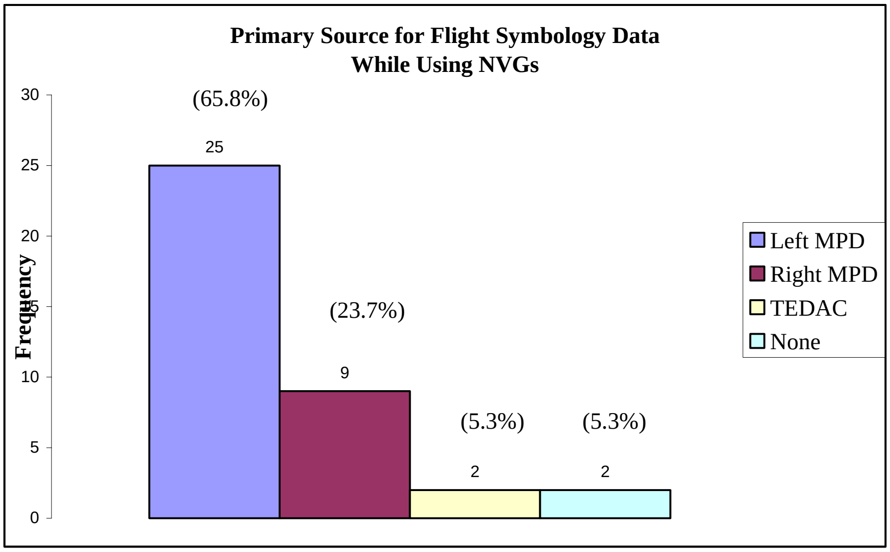
j. IHADSS: While providing security or reconnaissance services in the vicinity of high volume traffic points (CASH Pad, LZ, ect.) how frequently have you been "surprised" by a non-team ACFT?

k. NVGs: While providing security or reconnaissance services in the vicinity of high volume traffic points (CASH Pad, LZ, ect.) how frequently have you been "surprised" by the presence of a non-team ACFT?

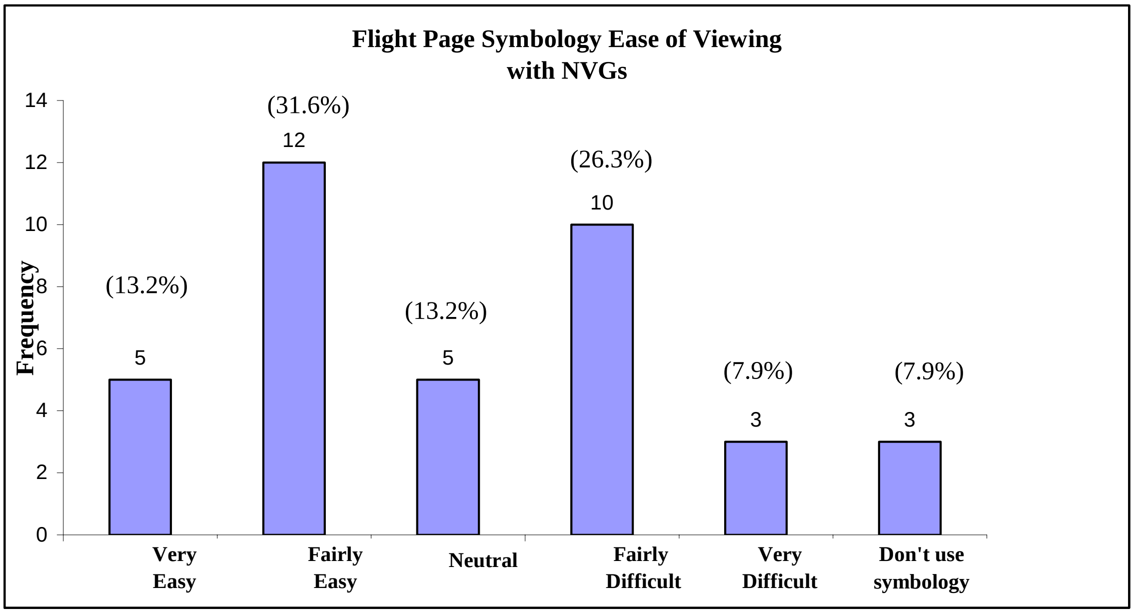


l. NVGs: What is your primary source of flight information while piloting and using NVGs?

Flight Page Left MPD (25, 65.8%) Flight Page Right MP (9, 23.7%) None (2, 5.3%)

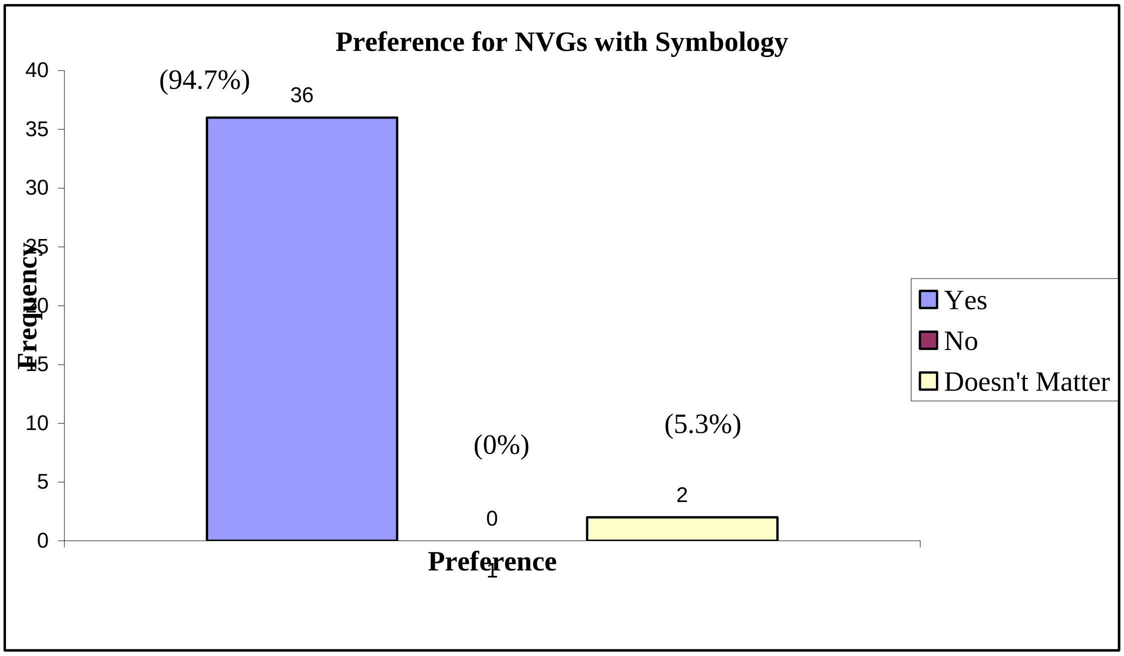


m. NVGs: IF your primary source is a FLIGHT PAGE, while operating NOE, how easy is it to see under the goggles?

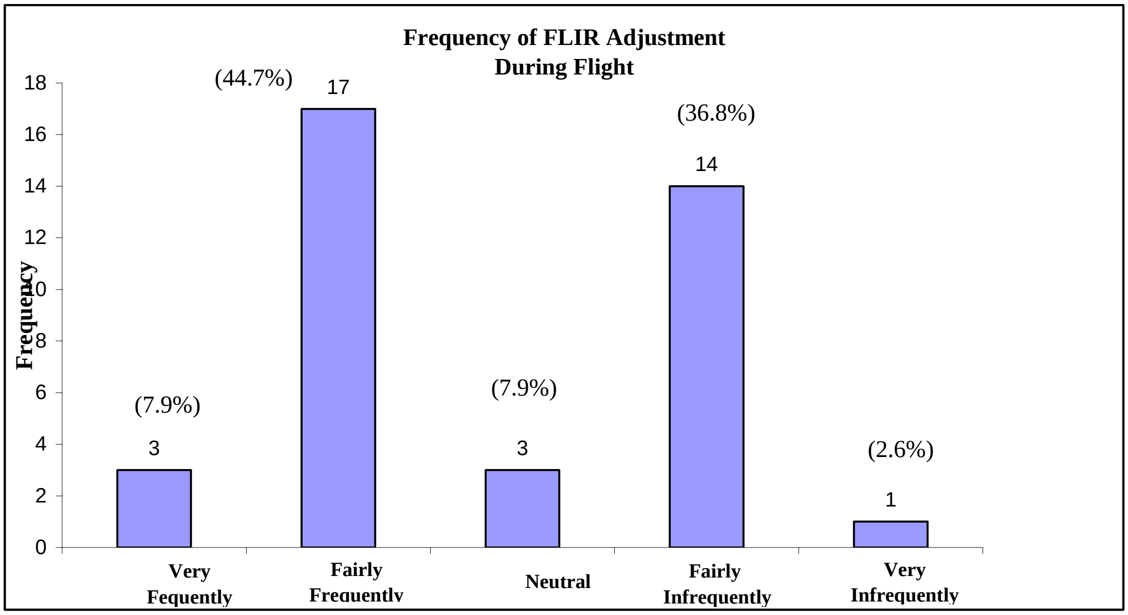


l.1 Would you prefer NVG with symbology overlaid?

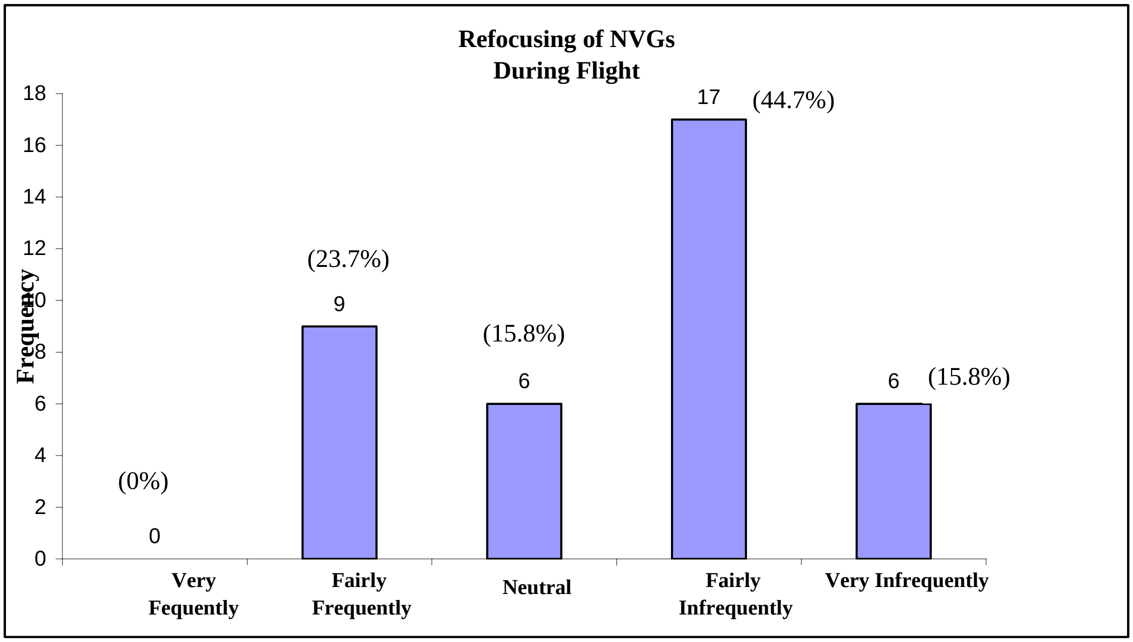
Yes (36, 94.7%) No (0, 0%) Doesn’t matter (2, 5.3%)



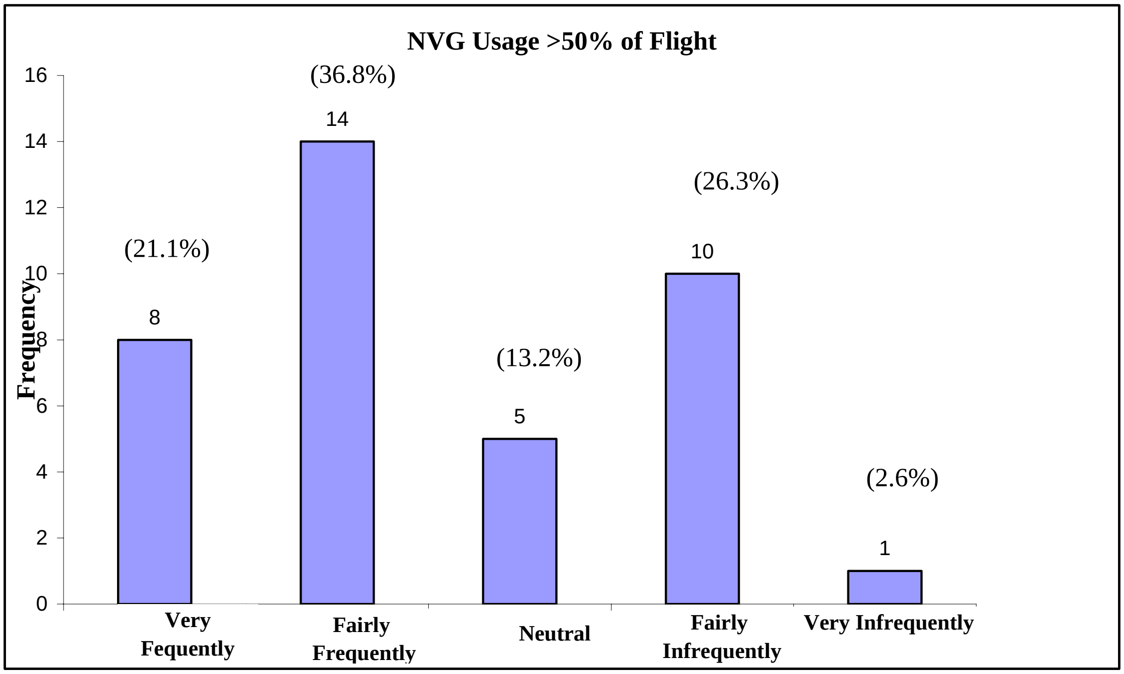
n. IHADSS: On a standard mission set (4 hours) how frequently do you have to re-optimize your FLIR?



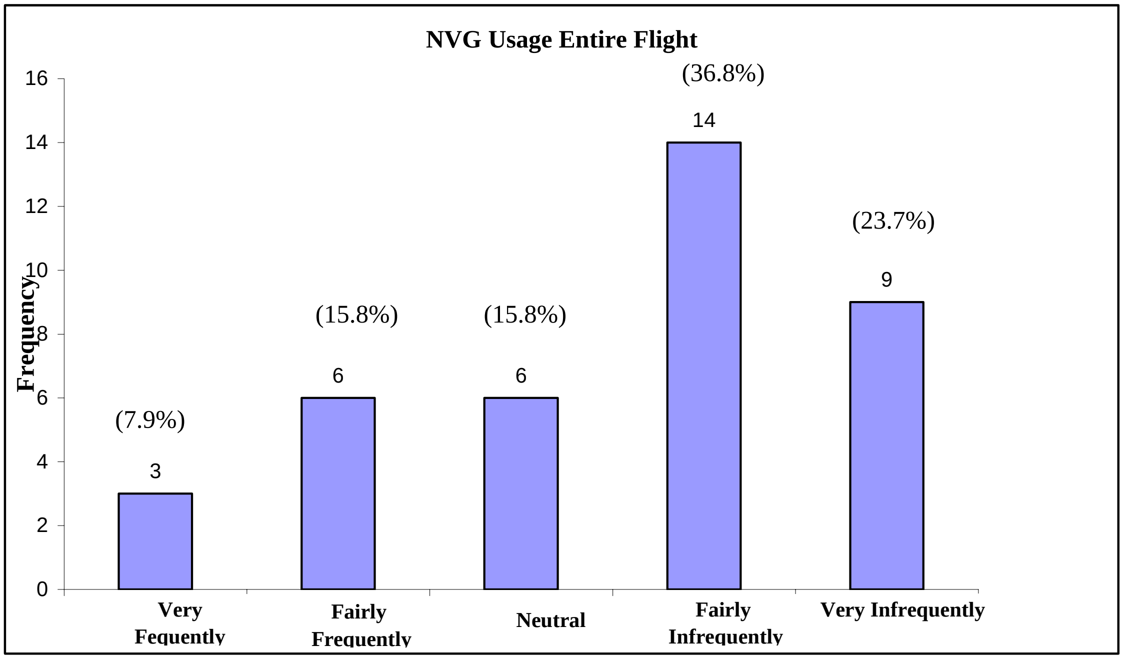
o. NVG: On a standard mission set (4 hours) how frequently do you have to refocus your goggles?



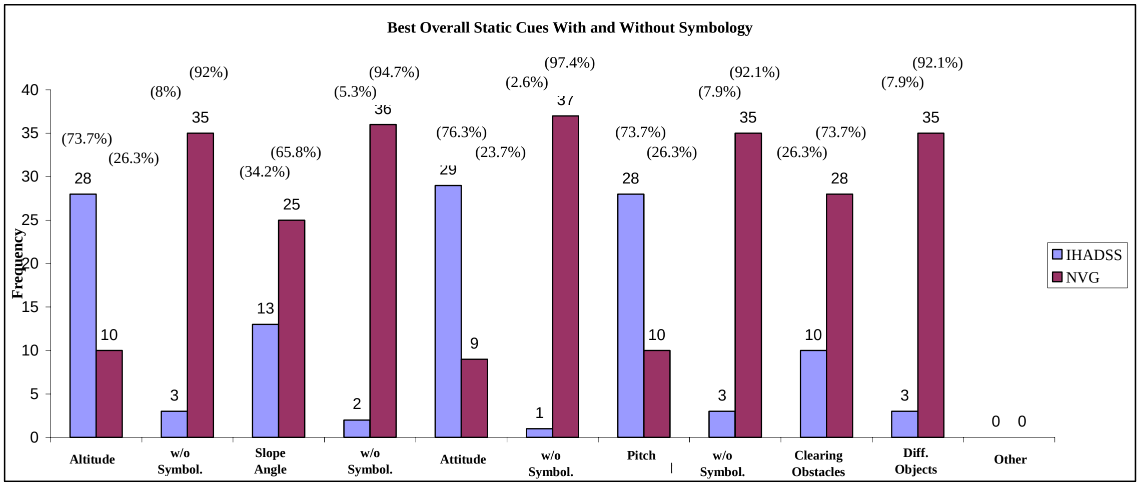
p. How frequently do you fly more than 50% of a night mission under NVG?

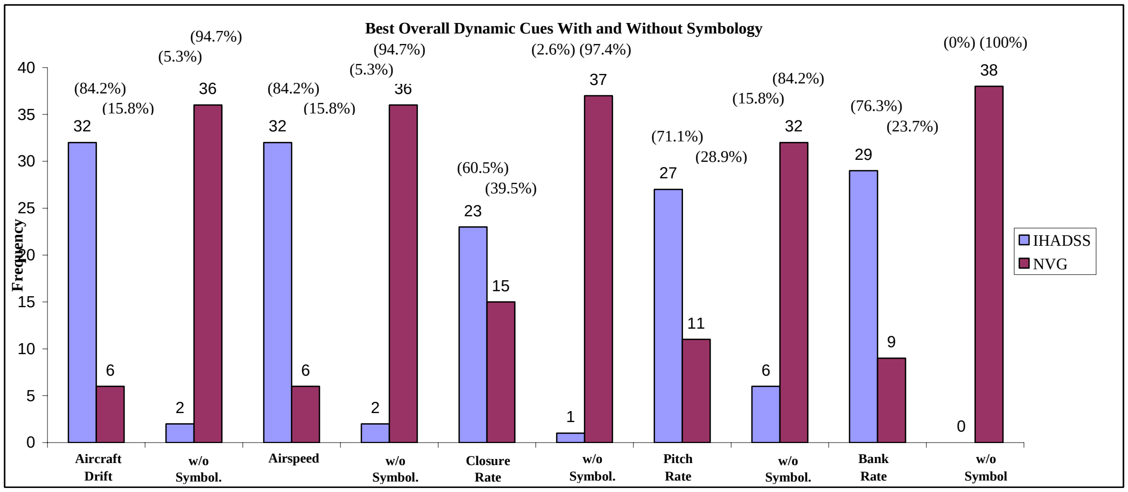


q. How frequently do you fly a complete mission under NVG?



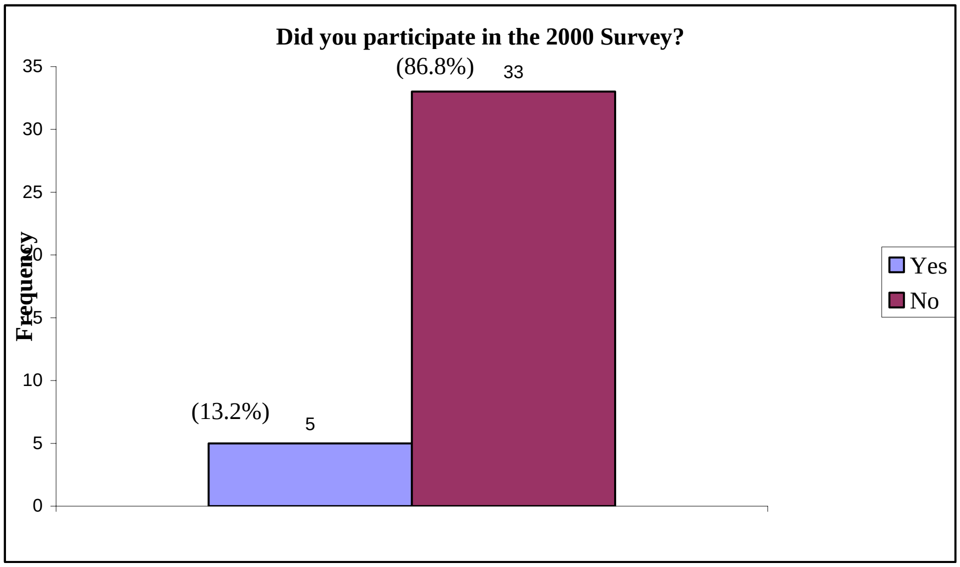
s. Cueing: Which system provides the best overall cues for these static and dynamic tasks?





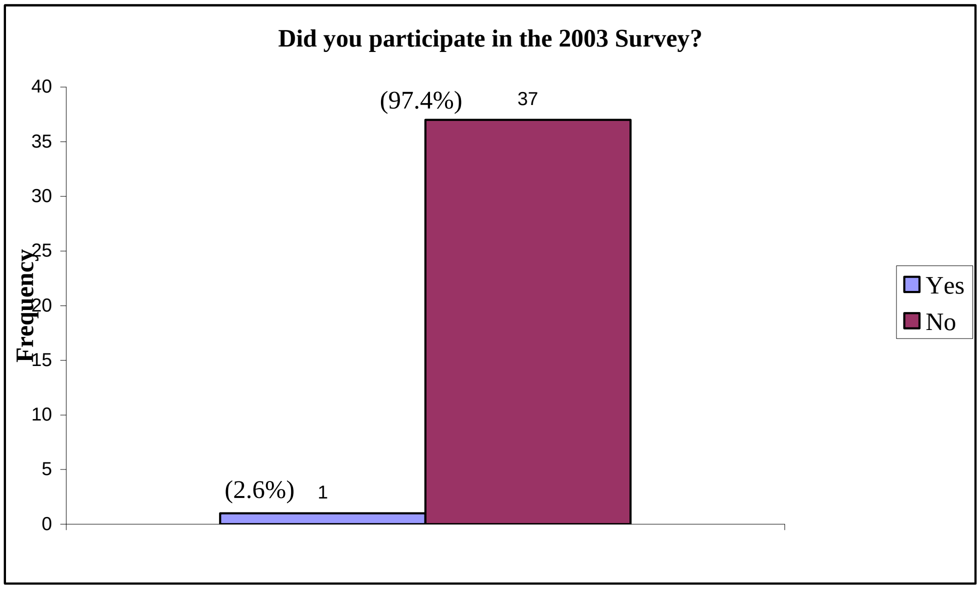
6. **In 2000, a web-based questionnaire similar to this one was conducted by USAARL, Fort Rucker. It was advertised in Flight Fax and offered over the internet.** Did you participate?

Yes (5, 13.2%) No (33, 86.8%)



7. **The 101st Airborne Division's Aviation Brigade participated in a similar survey in Northern Iraq in November 2003.** Did you participate in that survey?

Yes (1, 2.6%) No (37, 97.4%)



VITA

J. Kevin Heinecke was born and raised in Baltimore, MD and has a B.S. in mathematics from Towson University, Towson, Maryland. He is a commercial and military rated pilot in both airplanes and helicopters with over 2000 flight hours. Kevin is currently on active duty and has served tours as an attack helicopter pilot in the Republic of Korea, Bosnia Herzegovina, and Iraq. His aircraft qualifications include the AH-1 Cobra, C-12 Huron, OH-6 Loach, OH-58 Kiowa, UH-1 Huey, UH-60 Blackhawk, and both the AH-64A Apache and AH-64D Longbow Apache.