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AIR COMMAND AND STAFF COLLEGE

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AN INVESTIGATION OF THE NON-DISTRIBUTED FLIGHT REFERENCE (NDFR) OWNSHIP STATUS SYMBOLOGY

by

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Abstract

Air Force tactical aircraft, such as the F-15, F-16, and future fighter/attack aircraft, will all be equipped with helmet-mounted displays (HMD) to maintain superior air combat capability in future conflicts. HMDs allow the pilot to point weapons and to quickly slew sensors at visual range targets in either an air-to-air or air-to-ground environment. Further improvements include combining HMDs with panoramic Night Vision Goggles to allow pilots to operate HMD displays in environments with increasingly degraded visual conditions (night/weather). Increased use of HMDs does have a downside, however. Because pilots spend more time with their “eyes outside the cockpit,” the potential for spatial disorientation, a major cause of Class A mishaps, may increase significantly. Research studies have indicated that if flight and weapons parameters commonly displayed on a heads-up display (HUD) can be provided on HMDs, pilots can remain "heads-out" of the cockpit for longer time periods while maintaining better situational awareness. The Air Force Research Laboratory is currently developing a Non-Distributed Flight Reference (NDFR) symbology set to better support HMD operations in this environment by combining information traditionally distributed across the display into one compact display configuration. The purpose of the NDFR is to allow quick crosscheck of basic ownship information (heading, airspeed, altitude and attitude) while simultaneously providing for an uncluttered display, thus freeing up “display real-estate” for tactical weapons displays. The objectives of this project were to gather data to validate the usability of the NDFR for off-

boresight attitude information and collect qualitative data to determine pilots' opinions on the new symbology.

Part 1

Introduction

Air Force aircraft, such as the F-15, F-16, and future fighter/attack aircraft, will all be equipped with helmet-mounted displays (HMD) to maintain superior air combat capability in future conflicts. HMDs can allow the pilot to point weapons and to quickly slew sensors at visual range targets in either an air-to-air or air-to-ground environment. Flight and weapons parameters commonly displayed on a heads-up display (HUD) can be provided on HMDs, allowing the pilot to remain "heads-out" of the cockpit for longer time periods while maintaining better situational awareness. Further improvements include combining HMDs with panoramic Night Vision Goggles. This will give pilots the ability to operate with HMD displays in environments with increasingly degraded visual conditions (night/weather). Air Force Research Laboratory (AFRL) engineers are currently developing a Non-Distributed Flight Reference (NDFR) symbology set to better support HMD operations in this environment. The NDFR symbology combines information traditionally distributed across the display into one compact display configuration. The purpose of the NDFR is to allow quick crosscheck of ownship information (heading, airspeed, altitude and attitude) while simultaneously providing for an uncluttered display, thus freeing up “display real-estate” for tactical weapons displays. The NDFR is intended to improve overall pilot situational awareness in hopes of reducing the USAF accident rate attributed to spatial disorientation while remaining unobtrusive to HMD combat displays. However, there is little qualitative data to substantiate that the NDFR symbology provides improved performance over the Military Standard HUD and Visually Coupled Acquisition and Targeting System (VCATS) display sets.

The next section of this paper provides a brief history of the development of HMDs, establishes the importance of reducing spatial disorientation accidents, and outlines the theoretical basis for the NDFR. The next two parts describe the test procedures used in the current study and discuss qualitative and quantitative data collected during this project to validate the usability of the NDFR for off-boresight attitude information. In the final part, the paper summarizes the current effort and makes recommendations for future studies.

Part 2

Background of HMD Systems, Safety Considerations and HMD Display Symbology

Description of HMD Systems

Currently, USAF fighter aircraft are at a disadvantage to many of their adversaries in the within visual range (WVR) arena. For example, the former Soviet Union fielded the MiG-29 Fulcrum with a capable off-boresight system composed of a helmet mounted cueing system and an off-boresight capable AA-11 missile. Other nations have also fielded capable WVR off-boresight systems such as the Israeli DASH helmet system, which utilizes the high off-boresight Python missile. However, the USAF has yet to field an operational helmet mounted sight in its fixed wing aircraft despite "helmet-mounted sights having been flown by the Air Force and Navy as early as 1969 on F-4B, F-101 and F-106B aircraft."[1]

To counter the threats discussed above, the USAF Armstrong Laboratory has been developing and demonstrating HMD systems for over thirty years. An early HMD technology demonstrator was the Vista Sabre II program which used the Kaiser Electronics Agile Eye Plus helmet system. This HMD was installed on two F-15Cs at Nellis AFB and underwent rigorous operational testing which demonstrated the improved combat effectiveness gained from employing an HMD targeting system. The next generation of helmet systems to be tested under the lead of Armstrong Laboratories was the Visually Coupled Acquisition and Targeting System

(VCATS). Again, the 422 Operational Test and Evaluation Squadron was selected to evaluate the VCATS HMD system. Not only was the VCATS HMD system improved over the Agile Eye Plus, but it was also combined with an improved high-off boresight angle (HOBA) missile. The VCATS program allowed for "the evaluation of critical human factors engineering criteria such as the effects of system accuracy, latency and aircraft buffet on pilot HOBA missile cueing performance".[2] In short, the VCATS program focused on evaluating a High Off-Boresight System (HOBS) in use by combat pilots during combat simulation flights. Figure 1 provides a quick overview of the components of the VCATS system.

Figure 1. Visually Coupled Acquisition and Targeting System

The Joint Helmet Mounted Cueing System (JHMCS), the newest USAF HMD system, is currently being tested at Edwards AFB and Eglin AFB in conjunction with the AIM-9X HOBS missile program. The JHMCS is the system that will be incorporated into the operational USAF and USN fleet: F-15s, F-16s, F-18s and F-22s. The JHMCS directly leveraged the research and development of both the Vista Sabre and VCATS programs. With regard to display symbology, the JHMCS symbology for the F-15 (the planned first USAF aircraft to be equipped with the helmet system) closely resembles the conventions developed for the VCATS program. Specifically, the JHMCS primary attitude display very closely mirrors the VCATS system.

The VCATS helmet system and symbology sets were designed primarily to meet and defeat the potential adversaries (i.e., the MiG-29) in WVR aerial combat. Typically, USAF fighter crews practice WVR combat using stringent safety rules, which regulate minimum cloud clearances and visibility requirements. These restrictions are applied in order to reduce the occurrences of mid-air collisions and accidents due to pilot disorientation. As a result, combat crews may undervalue the importance of attitude information on the HMD. However, future developments of the HMD system will expand the capabilities of the helmet system beyond the limited role of daylight, blue-sky WVR air-to-air engagements.

HMD systems of the future will increasingly be used under conditions of reduced visual acuity such as night and/or poor weather. An example of these future developments is the panoramic night vision goggles (PNVG). The PNVG concept demonstrator currently provides 100-degree horizontal by 40-degree vertical field of view (FOV). This panoramic display shown in Figure 2 is compatible with the VCATS HMD system and fits into the helmet's universal connector. This connectivity results in a seamless combination of the night vision goggles and the VCATS display and provides the future fighter pilot with a night visual capability in combination with the off-boresight pointing capability of the VCATS system.[3] As with the previous VCATS system, the PNVG is currently being operationally evaluated by the 422 TES at Nellis AFB. Tasks being evaluated include target search and identification, low altitude navigation, dive-toss bombing, formation flight, and blacked out runway landings.

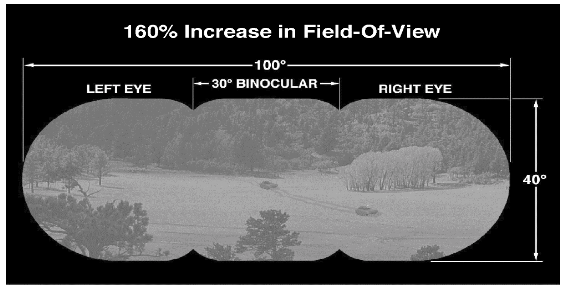


Figure 2. Panoramic Night Vision Goggle (PNVG) Display

While the current VCATS and JHMCS are primarily designed for air-to-air operations, the HMD is quickly evolving into an air-to-ground tool. The HMD can be used to designate air-to-ground targets or as a pointer to guide the pilot's eyes onto ground targets and points of interest outside of the HUD FOV. When the HMD is combined with the PNVG capability for operations in conditions of reduced visibility (night), the potential for pilot disorientation is greatly increased from the typical blue-sky WVR air-to-air engagements where HMD systems are currently being employed. As noted by Drewery, Davy and Dudfield,[4] HMD systems encourage pilots to spend more time looking off-boresight. Currently, pilots remain off-boresight for as short a time as possible before cross-checking the HUD for basic flight information. The extended time off-boresight creates a particularly important "safety issue … in the low-level regime, where too long looking off-boresight can quickly become fatal."[5] The objective of the Non-Distributed Flight Reference is to prevent the pilot from becoming spatially disoriented during these demanding operations where in-flight visibility does not allow the pilot to use outside-the-cockpit horizon references.

Safety Importance of Helmet Mounted Display Attitude

The USAF's emphasis on safety has resulted in saving an immense number of combat assets as well as lives. Despite this emphasis, however, accidents still result in significant aircraft losses. HMDs have the potential to decrease the rate of accidents due to spatial disorientation (SD) in particular. However, just as significantly, poorly designed HMDs may actually become a distraction to the pilot and thereby increase the rate of SD accidents. In fact, despite previous advances in display technologies, SD remains a major contributor to aircraft losses.

According to AFMAN 11-217, "SD is an incorrect perception of one's linear and angular position and motion relative to the plane of the earth's surface. Specifically, in the flight environment, SD is an erroneous perception of any of the parameters displayed by aircraft control and performance flight instruments."[6] Performance parameters are heading, airspeed, and altitude. These parameters need to be constantly cross-checked by the pilot to maintain situational awareness (SA). "If pilots are to maintain situational awareness, they must constantly monitor aircraft attitude and a few performance indications to maintain spatial orientation, even during high threat situations. Maintaining spatial orientation is a 100% mission requirement."[7]

Spatial disorientation can be categorized into three major types: Type I (unrecognized), Type II (recognized) and Type III (incapacitating).[8] With Type I, the pilot's interpretation or belief of the aircraft orientation does not match reality. In pilot's terms, he dies relaxed. Type II SD is characterized by a conflict between what the pilot feels the aircraft is doing and what the flight instrumentation or "out-of-the-cockpit" view is telling him. In this case, the pilot dies confused. With Type III SD, the pilot experiences an incapacitating physiological response to physical or emotional stimuli associated with the disorientation event. In short, the pilot probably recognizes the disorientation but is unable to do anything about it. Again, in pilot terms, he dies tense.

When pilots fall victim to one of spatial disorientation's primary operating mechanisms, channelized attention, distraction, or task misprioritization, they lose track of their flight path often resulting in extreme aircraft pitch and bank angles.[9] The process of returning the aircraft from the unintended flight path to controlled flight is termed unusual attitude recovery. HMDs can provide the pilot with constant access to critical flight information, which can aid the pilot by preventing Type I SD and serving as an a unusual attitude recovery aid for Type II and Type III SD. This access is particularly important in the tactical air-to-air and air-to-ground combat environment where there are huge demands on pilot's attention. Historically, the demands of the tactical environment have resulted in a significant number of SD accidents resulting in aircraft and pilot losses.

Two studies provide proof of the extensive costs and loss of combat capability from SD accidents, lending credence to the importance of investigating HMD symbology to prevent SD accidents. Erocoline, DeVilbiss, and Lyons examined trends in spatial disorientation accidents from 1958 through 1992.[10] Similarly, Davenport, from the Life Sciences Branch of the Air Force Safety Center examined the costs and rates of Class A SD mishaps from 1991 through 1998.[11]

From the period of 1958 to 1971, there were an average of 380 Class A mishaps per year. Of these, 23 mishaps were related to SD, or 6% of the total. From the period of 1972 to 1992, an average of 77 Class A mishaps occurred yearly with 16 percent (12 mishaps) attributed to SD. When these rates are normalized per 100,000 flying hours, the Class A mishap rates have decreased dramatically from 5.36 (1958 through 1971) to 2.22 (1972 though 1992). However, the Class A accident rate due to SD remained almost constant at 0.32 (1958 through 1971) and 0.35 (1972 through 1992) per 100,000 flight hours. These statistics suggest that the "USAF will experience one SD accident for every 300,000 flight hours. The 'smart' development of helmet-mounted display technology and symbology provides an opportunity to decrease SD-potential in some of the more demanding operational environment."[12] As a point of reference, from 1992 to 1999, the USAF (active duty, Air National Guard, and Air Force Reserve) averaged 2,354,857 flight hours a year.[13]

Davenport examined the SD Class A rates from FY 1991 through FY 1998, illustrating the cost of spatial disorientation. In his cost determinations, he did not include Mid-Air collisions, some of which could have been caused by SD or had SD as a contributing factor. Even with this omission, though, the costs of spatial disorientation losses are staggering to the USAF. The following data only includes accidents where SD was rated as a causal or major contributor by the flight surgeon/human factors safety investigator. During the period of interest, the USAF experienced 270 Class A mishaps costing $4.6 Billion and 280 lives. The mishap rate per 100,000 flight hours was 1.36. Of this total number, 56 of the accidents, or 20.7 %, were SD related. The costs of these SD related accidents were $1.3 Billion and 50 lives. The mishap rate per 100,000 flight hours was 0.29.

The trend toward overall safety continued in the period of 1991 to 1998. Specifically, from the early overall Class A mishap rates of 5.36 (1958 through 1971) and 2.22 (1972 through 1992), the 1.36 overall rate compares favorably and represents a 74 percent and a 39 percent improvement respectively. In contrast, the 0.29 spatial disorientation accident rate was only a 9.4 percent and 18.75 percent improvement over the 1958 through 1971 and the 1972 through 1992 periods, respectively. As can be seen in Figure 3, while the USAF has achieved a dramatic reduction in overall accident rates, the accident rate due to spatial disorientation factors has remained essentially flat.

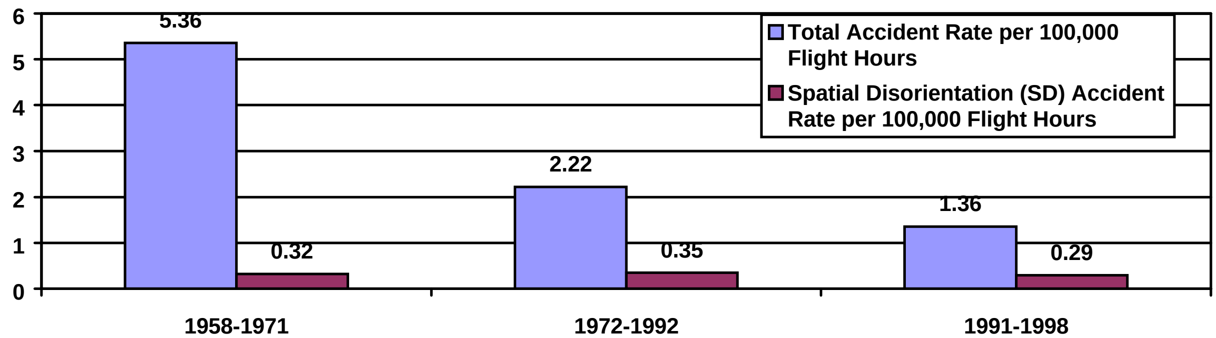


Figure 3. Accident Rate Comparison between Total Rate and Spatial Disorientation Rate

While the 0.29 SD mishap rate is a slight improvement over the previous rates, the trend within the 1991 through 1998 period is not positive. As can be see in Figure 4 below, the SD accident rates finished this eight-year period at 0.38. The slope of a linear curve fit shows a projected increase rate of almost .01 per year. This trend contributes to the conclusion that accident rates due to spatial disorientation have remained essentially constant since the late 1950's despite the enormous USAF safety efforts that have resulted in the dramatic reduction in overall aircraft accident rates. Of the first 30 accidents in 1999, 3 were spatial disorientation mishaps, which resulted in the loss of $79,809,190 in equipment. The accident rates discussed have included all aircraft types (bomber, tanker, transport and fighter). Marking the particular importance of SD accidents to the fighter/attack community, tactical aircraft accounted for 80 percent of the Class A SD accidents during the eight-year period of 1991 to 1998.

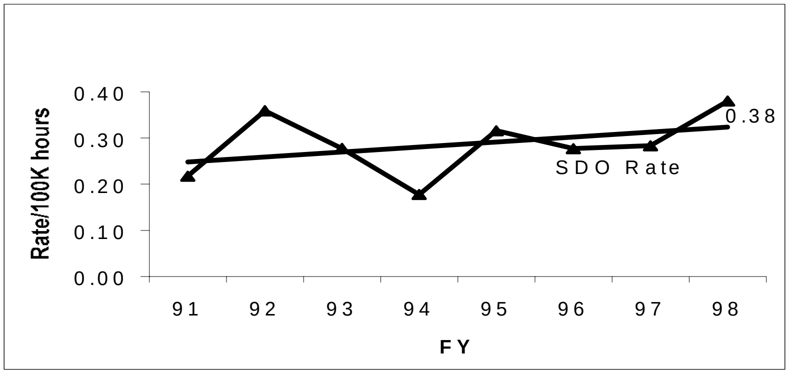


Figure 4. Period 1991 Through 1999 Spatial Disorientation Accident Rate per 100,000 Flight Hours

As HMDs enter the tactical aircraft fleet, they offer a significant opportunity to increase pilot situational awareness and decrease this costly accident rate. For example, a study conducted as part of the Spatial Disorientation Countermeasures Task at Armstrong Laboratory's Attitude Awareness Laboratory at Brooks Air Force Base looked to determine the impact of HMDs on unusual attitude recoveries. The Brooks investigation used a combination arc-segmented pitch ladder display in an HMD compared to no HMD available and measured the time required for unusual attitude recovery. Investigators concluded that spatial orientation information was valuable on HMDs. Their findings "clearly demonstrated that some minimal flight symbology, visible during off-axis viewing, can improve the pilot's awareness of spatial orientation information."[14] Three possible HMD attitude symbology sets are described below which could possibly be used to increase pilot situational awareness.

Mil Std HUD, VCATS and NDFR Symbology Description

Mil Std HUD

The Military Standard (Mil-Std) Heads-Up Display (HUD) symbology is designed to provide complete attitude information for instrument flight and unusual attitude recovery from any attitude. The design of this symbology was not constrained by having to share display space with combat attack symbology. The resulting display was optimized for use in fixed Heads-Up Displays as a stand-alone primary instrument flight reference. While current combat aircraft such as the F-15, F-16 and A-10 use elements of the Mil-Std HUD, it is not fully implemented in any USAF tactical combat aircraft.

A detailed description of the Mil-Std HUD symbology is provided in Military Standard 1787B.[15] Briefly, the Mil-Std HUD symbology provides altitude, heading and airspeed information in both digital and analog formats. Airspeed is presented on the far left of the display and altitude information is presented on the far right of the display, both in a digital format. In addition, a circle of 10 dots rings the digital airspeed and altitude. Inside the ring of dots is a wiper, which spins corresponding to change in altitude. One complete cycle of the analog wiper (spin from 12 o'clock position to 12 o'clock position) represented a change of altitude of 1000 feet, providing the pilot with rate of change information. With pure digital information, pilots have difficulty assessing the rate of change in altitude. Heading information is presented in an analog format at the top of the HUD symbology. Twenty degrees of a heading scale scrolls left and right with the changing heading. Current heading is read in the center of the display, which is marked by a lubber line.

Attitude (pitch and bank) information is presented by pitch ladder. Bank is presented by the rotation of the pitch ladder in a manner identical to the standard flight instrument attitude direction indicator (ADI). Pitch is represented in reference to the aircraft flight path marker. The flight path marker (velocity vector) is marked by an inverted T symbol representative of aircraft wings and tail. The position of the flight path marker within center of the pitch ladder represents the angular climb and dive of the aircraft. The Mil-Std HUD pitch ladder represents angles above and below the horizon with two sets of displays. For angles above the horizon, pitch angles are presented in 10-degree increments by a square bracket (pitch bar) parallel with the horizon. At the left end of the bracket, the value of the pitch bar is presented digitally. As pitch increases, the size of the pitch bar reduces providing a further analog representation of pitch. For example, at 80 degrees of pitch, the width of the pitch bar is 60 percent of the pitch bar width at 20 degrees. Additionally, the positive pitch bars (above the horizon) had small tick on the outside of the lines, which always point to the horizon. In contrast, for negative pitches (below the horizon), the pitch bars were changed from solid lines to dashed lines to represent nose low attitudes. The horizon pointed ticks mentioned earlier were moved from the outside of

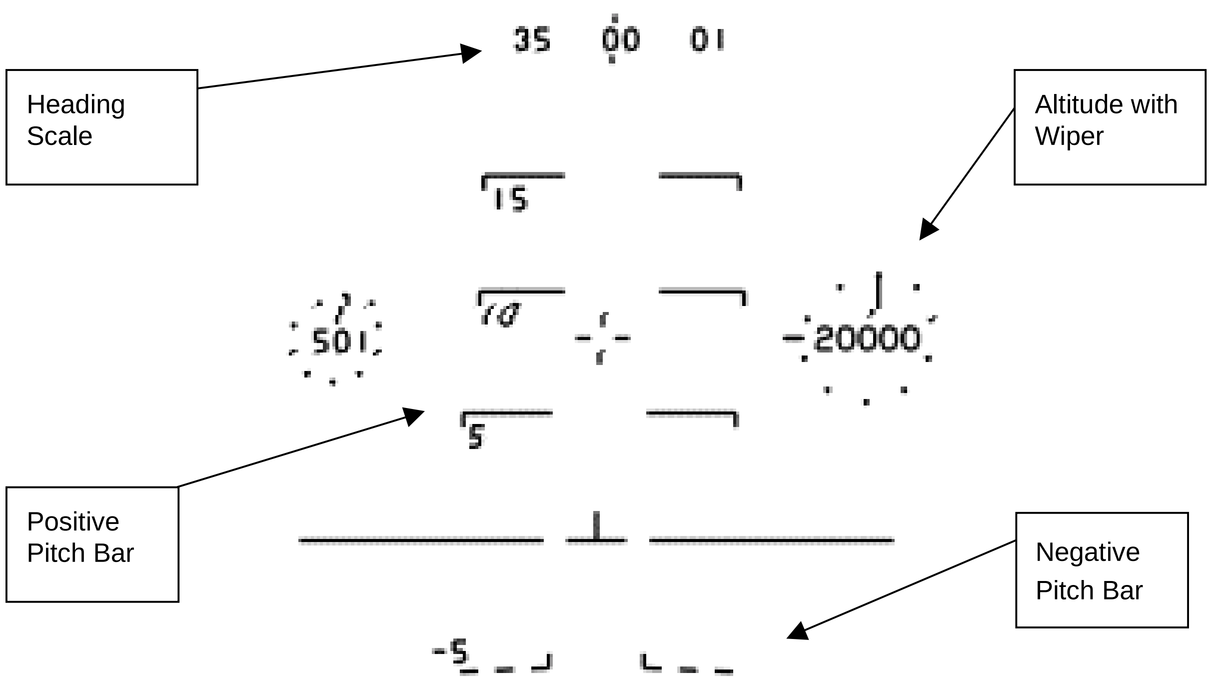


Figure 5. Military Standard HUD Ownship Symbology

the pitch line to the inside of the pitch line. While straight lines always represented the positive pitches, pitches below the horizon are bent into chevrons with the inside of the chevron always closer to the horizon. The angle of the chevron bend is one half of the dive angle. For example, at 40 degrees of dive, the pitch bar will be bent 20 degrees, dashed, and have horizon pointer ticks on the inside of the chevron. A sample Mil-Std HUD symbology is shown in Figure 5.

Visually Coupled Acquisition and Targeting System Ownship Symbology

Like the Mil-Std HUD, VCATS ownship information display presents the required primary flight information (heading, altitude, airspeed, and attitude). However, where the Mil-Std HUD symbology was designed to provide a stand-alone primary flight reference, the VCATS ownship display was designed as a situational awareness aid. This reduced the clutter of the display and occlusion difficulties providing more space on the display for tactical weapons symbology. In designing the display, the basic format of the F-15 HUD display was maintained (heading at the top, airspeed left, and altitude right). However, to reduce the clutter and occlusion with the combat displays, the analog references for altitude and airspeed were removed. The analog tapes (method used in the F-15 HUD) were replaced with a pure digital display enclosed with an accent box for quick location by the pilot.

Attitude information is presented by a radically abbreviated ADI symbology set. The pitch ladder is removed from the display and replaced by single horizon bar at the bottom of the display. Additionally, the digital pitch indicators have been removed from the display resulting in only analog climb and dive information. Roll is presented identically with the Mil-Std HUD as the horizon bar rotates around the climb/dive angle marker. It is important to note that the attitude display is forward referenced. This means that regardless of head position, the attitude information is displayed as if the head was position pointing forward. "This is done to reduce the potential of disorientation caused by coupling head and aircraft movement with attitude display changes. Forward referenced displays are also easier to "look around" versus information that is superimposed over the outside world."[16] Climb and dive is similarly displayed as in the Mil-Std HUD. However, in the Mil-Std HUD, the horizon line is a non-changing straight line. In the VCATS display, the horizon bar changes to represent the corresponding climb dive. Additionally, the horizon line does change in a manner consistent with the Mil-Std HUD. Climbs are represented by a straight solid line with horizon pointer ticks on the outside forming a bracket. Bent dashed chevrons represent dive angles with the angle of bend determined by one-half the dive angle. Horizon pointer ticks are placed on the inside of the horizon line. Similar to the Mil Std HUD, when climbs are indicated, the horizon bar shrinks from a maximum width of 0.053 radians at zero pitch to 0.025 radians at 90 degrees of pitch using the following formula: *Width = (53-((14xPitch in degrees)/45)))/1000 radians*.[17] To further indicate the magnitude of dive and climb, the horizon bar moves above and below the climb/dive marker in proportion to the magnitude of the climb and dive. Figure 6 shows typical VCATS symbology.

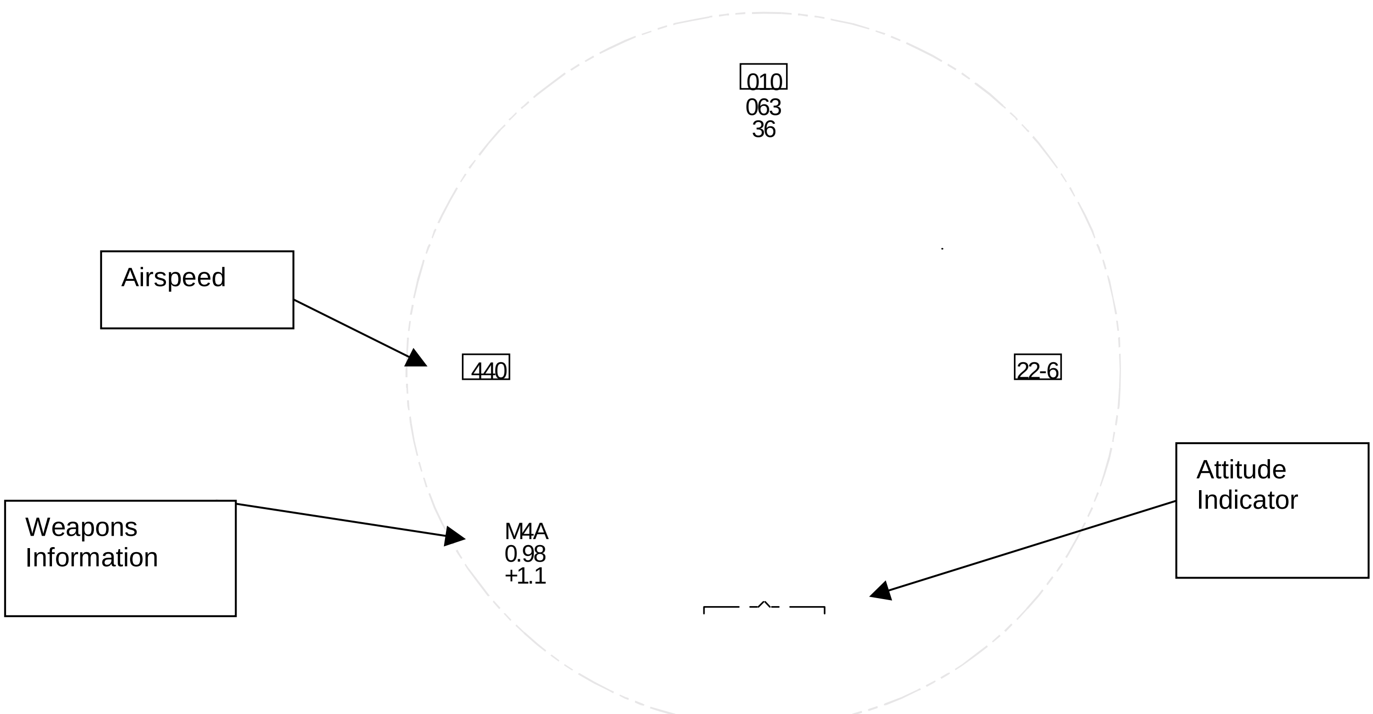
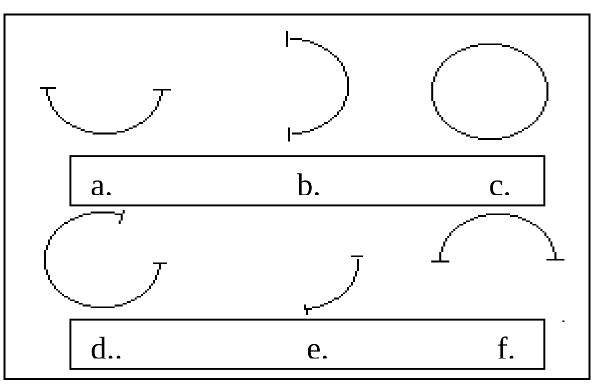


Figure 6. Visually Coupled Acquisition Targeting System Ownship Symbology

Non-Distributed Flight Reference Ownship Symbology

Unlike the Mil-Std HUD and VCATS, the NDFR departs from the pitch ladder concept to display analog attitude information. Instead, attitude is indicated by the use of a sky arc. The sky arc is also known as an arc segmented attitude reference or orange peel. The orange peel was developed by researchers in the German Air Force to aid pilots with maintaining situational awareness.[18] This novel attitude symbology uses an arc surrounding a climb/dive marker. As indicated in Figure 7, the arc rolls around the climb/dive marker to indicate bank. The length of the arc segment indicates pitch and is always oriented toward the earth. With the flight vector on the horizon, the arc forms a semi-circle. With the flight vector 45 degrees above the horizon, the arc forms a quarter circle. In contrast, a three-quarter enclosed circle represents a flight vector 45 degrees below the horizon. At the extremes, a flight vector pointed straight up would be represented by an absence of an arc while a flight vector straight down would be represented by a full circle. Similar to the VCATS ownship symbology, the NDFR uses a digital-only format to present airspeed, altitude, and heading information. Unlike the VCATS scheme, however, this digital information is moved from the perimeter of the display to inside the analog attitude indicator, making for a compact, transferable display. A typical NDFR display is shown in Figure 8. Figure 9 demonstrates the relative size of the NDFR and VCATS displays.



a. Level Flight, Zero Bank
b. Level Flight, 90 Right Bank
c. 90 Nose Low
d. 45 Nose Low, 45 Left Bank
e. 45 Nose High, 45 Right Bank
f. Level Flight, Inverted

Figure 7. Sky Arc Sample Interpretation

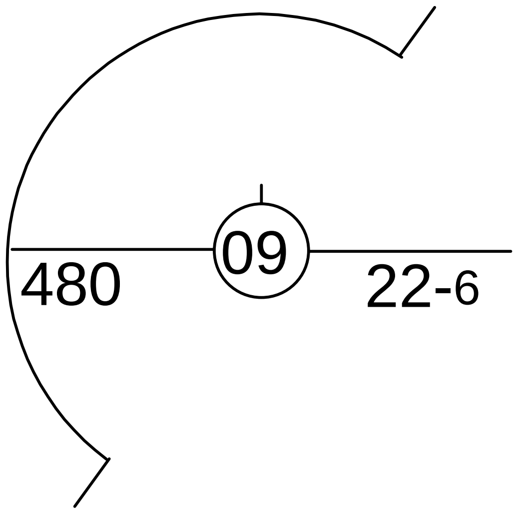


Figure 8. Non-Distributed Flight Reference

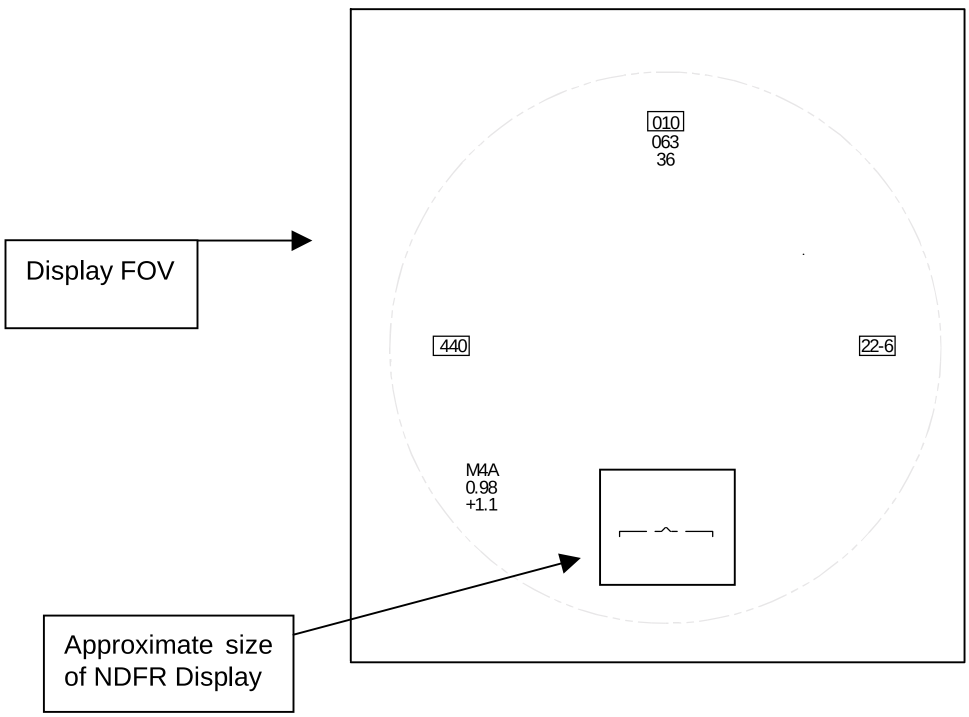


Figure 9. HMD Display Comparing/NDFR Size Relationship Overlaid on VCATS Display

Non-Distributed Flight Reference Rationale

HMD systems are currently employed in good weather conditions. However, as these systems continue to mature and are married with panoramic night vision goggles, HMDs will be employed in adverse weather conditions. Unfortunately, the attitude reference which pilots with HMDs currently rely on to compensate for increased time away from the primary flight references will not be available. This problem will be further amplified in the air-to-ground role where pilots may spend large portions of their crosscheck searching for targets in poor visibility and night conditions. The impact of HMDs on overall pilot SA is unknown. However, with pilots spending more time looking away from their primary flight instruments and HUD, the potential exists for an increase in instances of spatial disorientation as more HMD systems are employed. "Because HMD equipped pilots tend to look farther off-boresight for longer periods of time versus HUD only pilots, it follows that the HMD should contain some of the information the pilots would otherwise scan when looking forward into the cockpit."[19] Additionally, this information must be presented in a manner so that it is not distracting from the primary purpose of the HMD, combat employment.

Researchers at the Air Force Research Laboratory at Wright Patterson Air Force Base, Ohio, developed the Non-Distributed Flight Reference (NDFR) to provide ownship status information including airspeed, altitude, heading and attitude to the pilot in helmet mounted cueing systems. The primary purpose of the HMD in fixed wing aircraft is to provide weapons cueing in both air-to-air and air-to-ground combat; however, as mentioned earlier, the HMD also provides the opportunity to increase pilot SA by providing the pilot ownship status information regardless of the pilot's head position. While designing the NDFR, the AFRL researchers assumed that the HMD ownship information would only be used for general situational awareness and unusual attitude recognition, so the symbology was designed to prevent spatial disorientation as opposed to being a primary flight reference. Stated another way, the NDFR was not intended as an aid for recovery from an unusual attitude, but rather is designed to help the pilot recognize the unusual attitude situation. The pilot should transition to the aircraft's primary flight references and HUD for the actual recovery. The researchers also leveraged earlier research, which indicated the following conclusions:[20]

1. HMD presented information enhances pilots' ability to look far off-boresight for long periods of time during air-to-air tasks.
2. Increased line of sight (LOS) duration and angle off-boresight occur independent of HMD information functionality (targeting versus ownship status information).
3. Pilots prefer that off-boresight ownship information be included within the HMD symbology set.
4. Specific symbology formats should be designed to minimize occlusion and clutter.

Display space is critical on the HMD. First, the pilot must look through the display at all times. The more lines on the display, the more difficult it is for the pilot to look through the display to the real world. If the display is overly cluttered, the pilot's vision is inhibited. This greatly increases target acquisition times and, in effect, reduces pilot situational awareness of the tactical environment. In an effort to reduce clutter, the NDFR uses digital information to represent airspeed, heading and altitude rather than analog tapes or analog dials. This digital information is formatted in the standard instrument flight T-crosscheck which all pilots are trained in airspeed, on left, heading center, altitude right. The NDFR also puts all the performance information in close proximity as opposed to spreading or distributing the information across the HMD display, hence the name Non-Distributed Flight Reference. The tight display is intended to reduce overall display clutter by isolating the ownship information. Most importantly, however, the tight display reduces the crosscheck distance, which allows the pilot to view all ownship information with minimal eye movements.

By comparison, the VCATS display and Mil-Std HUD shown earlier in Figures 5 and 6 respectively, required the pilot to look at the top of the display for heading, far left of the display for airspeed and the far right of the display for altitude. Additionally, as Geiselman notes, the

VCATS display does not maintain the basic instrument T by presenting attitude information below the heading reference. "An active scan is required to view the required information that is now located around the periphery of the FOV."[21] Finally, the tight grouping of ownship information allows for easy symbology repositioning which minimizes occlusion with attack symbology and the real world (actual outside window targets). For example, during air-to-air engagements, the primary display area of interest is generally the top of the display. Therefore, when an air-to-air combat mode is selected, the NDFR would be placed at the bottom of the HMD display. The converse is true for air-to-ground where the primary display area of interest is typically the bottom of the display. In this case, the NDFR ownship information would be placed at the top of the display. Additionally, based on head position, the NDFR could be displaced left and right to further prevent any problems of occlusion. In distributed symbology schemes, the information is spread to the limits of the display and cannot be moved to prevent occlusion without changing the basic crosscheck of the display.

The sky arc was designed to provide a more intuitive display leading to faster reaction times and more accurate reaction inputs. Previous tests demonstrate the effectiveness of the sky arc attitude display leading to its selection for the NDFR. In a test conducted at the Northrop Grumman Advanced Technology and Development Center, pilots determined that the Sky Arc was superior to the standard HUD for attitude information.[22] The sky arc was found to provide more rapid recoveries from unusual attitudes. The total times for recovery, as well as the time to first stick correction, were demonstrated to be better with the sky arc display opposed to the Mil-Std HUD. Additionally, the sky arc resulted in improved recovery correctness as well as a reduction in pilot induced oscillation (PIO) tendencies. In other words, pilots made fewer errors during the recovery, such as not rolling the shortest direction to the horizon during the recovery with the sky arc. According to Northrop's report, when the recovery was completed, pilots using the Mil-Std HUD tended to enter an oscillation in pitch, which had to be consciously damped. This tendency was not observed when pilot used the sky arc attitude reference.

In addition to the HMD applications, the NDFR can be viewed as an information postage stamp, which can be placed on Heads-Down Displays (HDD). This application could provide the advantage of commonality to the pilot. Once proficient at interpreting the display, the same symbology format can be used on all displays providing the pilot with display consistency. For example, the NDFR could easily be placed in the corner of a terrain following radar display, moving map display or air-to-ground radar display, thereby contributing to overall pilot situational awareness. "The NDFR should be unobtrusive, but the information will be available to keep the pilot in contact with aircraft status information without an otherwise required scan of primary flight instruments or a head-up look out of the cockpit."[23] In short, using the NDFR on HMD and HDD multifunction displays will provide the pilot with constant ownship status information and may keep the pilot from becoming spatially disoriented. As discussed earlier, the cost of pilot spatial disorientation is very high. Even small improvements in symbology designed to keep pilots oriented without distracting them from their combat displays can yield large dividends for the USAF in both life and materiel.

NDFR Compliance to Human Factors Guidelines

The Man-machine Integration Department of the Defence Research Agency at Farnborough, UK offered a series of guidelines for the development of HMD systems.[24] Some of these guidelines, such as the importance of eliminating clutter and symbology occlusion, have already been discussed in the design rationale for the NDFR. The first of these additional guidelines is that HMDs must support spatial awareness. The guidelines point out that with HUDs, most disorientation is caused by the attitude display not presenting a global view of the spatial environment as seen with the standard ADI. Additionally, HUD pitch ladder displays often exhibit instability. Finally, with the HUD pitch ladder attitude symbology, the zero-pitch line (horizon line) on the HUD pitch ladder disappears from view during large positive and negative pitch attitudes. While display symbology instability cannot be addressed with the NDFR, the segmented arc attitude display used in the NDFR does provide a global view very similar to the standard ADI display. Additionally, the arc segment attitude display provides continuous horizon information negating the difficulties caused by the disappearing horizon line found in the pitch ladder format.

Another issue under the umbrella of supporting spatial awareness is that HMDs present a unique orientation problem for attitude representation. Prior to HMDs, attitude information was always fixed to the body reference of the aircraft. One option is conformal symbology. With conformal symbology, the horizon bar is always superimposed on the horizon as the pilot moves his head. Pitch and bank information for the aircraft is then referenced from this horizon line. Non-conformal symbology, on the other hand, does not conform to the outside horizon as the pilot moves his head. Instead, the horizon bar represents the horizon in front of the aircraft even as the pilot looks off boresight. A study conducted at the NASA Langley Research Center examined the relative benefits between HMD non-conformal versus conformal display formats. During combat simulations, the NASA group found that pilots made one third fewer pitch judgement errors with non-conformal symbology format over a conformal display.[25] The roll errors were approximately cut in half with a non-conformal format. The NDFR attitude display applies a non-conformal format supporting pilot spatial awareness.

The second design guideline applicable to the NDFR is that the display must enhance situational awareness (SA) and reduce workload. The premise behind the NDFR is to improve pilot SA by providing ownship information. To be effective, the display must further present the information in a cognitively compatible manner. The NDFR is particularly effective in exploiting the cognitive principles of proximity, similarity, and common fate. Proximity means that objects that are close together will be perceived as a whole. Similarity states that objects with similar properties will be grouped together. Finally, common fate implies that objects that move together will be grouped together.[26] The NDFR purposely groups all ownship information, which was previously spread around the HMD and HUD displays together in a single location. . Likewise, the grouping of ownship information locates all similar information together potentially avoiding confusion between ownship and tactical information. Finally, if a mechanization scheme is adopted that provides for the relocation of the grouped ownship data with differing combat modes, the principle of common fate should aid the pilot with ownship data location.

The final two guidelines for HMD symbology development offered by the Defence Research Agency report require that HMD symbology must be compatible with existing cockpits and be responsive to task demands. One element of compatibility is the degree with which HMDs are integrated with HUD displays. Specifically, the Man-machine Interface Department offers that HUDs and HMDs may be integrated successfully through segregation of types of information between the displays. Under this scheme, "the HMD could provide key information, such as off-boresight weapon aiming symbology and limited safety-critical information."[27] Bailey mirrors this advice stating that designers should avoid using HMDs as a primary flight reference (PFR) except with the virtual HUD concept, as it would only serve to create clutter and confusion degrading the situational awareness function of the HMD. Furthermore, using HMD symbology, which looks like PFR instrumentation, could contribute to misinterpretation when the pilot looks off axis due to control-display conflict, clutter and attention diversion. The NDFR conforms to these concepts. It does not attempt to provide all of the information required to be a primary instrument reference. Instead, the NDFR is designed to "keep the pilot aware of state changes in support of the primary HMD tactical functions. The display is intended to keep the pilot from entering an unusual attitude versus allowing the pilot to recover from an unusual attitude while off-boresight."[28] The role of primary flight reference is left to the HUD and HDDs. Additionally, the arc-segment attitude display is unique compared to the HUD PRF symbology set, further reducing the possibility of pilot confusion. The Man-machine Interface Department states that HMDs must be responsive to tasks. Specifically, the display should provide the pilot opportunity to select/deselect the symbology depending on the tactical situation. The "information stamp" styling of the NDFR display allows for a flexible display option. As mentioned in the NDFR rationale above, the NDFR display can be moved as a unit to different places on the HMD display as required, or if necessary, decluttered by pilot selection from the display.

NDFR and the Display Development Process

The build-up approach used for development of new displays consists of a four-step process: concept development, pilot-in-the-loop simulation, and concept refinement followed by flight test.[29] Bailey suggests that to reduce this iterative design process it is important to base the "design on past experience and with the inputs from all of the key players including display designers, engineers, human factors personnel, and pilots."[30] Human factors and display designers designed the NDFR. The NDFR conforms to HMD design guidelines that were determined from the lessons learned from HUD designs. The next step in the design process is pilot-in-the-loop simulation. This evaluation of the NDFR symbology set is a quantitative and qualitative assessment to determine if the NDFR can meet the following requirement learned during HUD symbology development. "Symbology should only be added if it measurably contributes to the primary objectives of the HMD, improves in the performance of the pilot-vehicle system or reduces pilot workload. The primary objectives of the HMD should be weapon-system critical functions and situational awareness."[31] Should the NDFR perform well in these simulations, it may merit further concept development and incorporation into flight test.

Notes

[1] Ronald F. K. Merryman, "Vista Sabre II: Integration of Helmet-Mounted Tracker/Display and High Off-Boresight Missile Seeker into F-15 Aircraft," *Proceedings of SPIE Conference Helmet- and Head-Mounted Displays and Symbology Design Requirements*, Vol. 2218 (5-7 April 1994): 173.

[2] Air Force Research Laboratory Pamphlet, "Helmet-Mounted Sensory Technologies," Air Force Research Laboratory, Visual Display Systems Branch, Crew System Interface Division, Human Effectiveness Directorate, 1-2.

[3] Jeffrey L. Craig and Eric E. Geiselman, "Further Development of the Panoramic Night Vision Goggle," *Proceedings of the 1998 SAFE Symposium*, (1998): 26.

[4] Chris C. Drewery, Eleanor C. Davy and Helen J. Dudfield, "Attitude Symbology for Helmet-Mounted Displays: Lessons Learned," *Proceedings of SPIE Conference Head-Mounted Displays II*, Vol. 3058 (21-22 April 1997): 98.

[5] Drewery et al., 98.

[6] Air Force Manual (AFMAN) 11-217, *Instrument Flight Procedures*, vol. 1, 1 April 1996, 167.

[7] William R. Ercoline, Carita A. DeVilbiss, and Terence J. Lyons, "Trends in USAF Spatial Disorientation Accidents – 1958-1992," *Proceedings of SPIE Conference Helmet- and Head-Mounted Displays and Symbology Design Requirements*, Vol. 2218 (5-7 April 1994): 257.

[8] Helen J. Dudfield, Thomas D. Hardiman and Stephen J. Selcon, "Human Factors Issues in the Design of Helmet-Mounted Displays," *Proceedings of SPIE Conference Helmet- and Head-Mounted Displays and Symbology Design Requirements II*, Vol. 2465 (18-19 April 1995): 136.

[9] Major Clark E. Davenport, "Class A Spatial Disorientation (SD) Mishaps" (background paper prepared at the Human Factors/Physiology Life Sciences Branch, HQ Air Force Safety Center, 1999), 4.

[10] Dudfield, 257-260.

[11] Davenport, 2.

[12] Dudfield, 257.

Notes

[13] "Equipment," *Air Force Magazine*, May 1999 USAF Almanac, Vol 82, No 5 (May 1999): 66.

[14] Carita A. DeVilbiss, "Effect of Arc Segmented Attitude Reference Symbology on a Helmet-Mounted Display During an Unusual Attitude Recovery Task," *Proceedings of SPIE Conference Helmet- and Head-Mounted Displays and Symbology Design Requirements II*, Vol. 2465 (18-19 April 1995): 261.

[15] Military Standard 1787B (USAF), *Military Standard Practice: Aircraft Display Symbology*, 20 October 1995.

[16] Eric E. Geiselman, "Development of a Non-Distributed Flight Reference Symbology For Helmet-Mounted Display Use During Off-Boresight Viewing," *Proceedings for the Fourth Annual Symposium and Exhibition on Situational Awareness in the Tactical Air Environment*, Naval Air Warfare Center – Aircraft Division (1999): 118.

[17] Paul A. Pecha, JHMCS Requirements Definition Document Helmet Mounted Display, Revision D, 19 March 1993, 56.

[18] DeVilbiss, 255.

[19] Geiselman, 28.

[20] Geiselman, 119.

[21] Geiselman, 120.

[22] Ted Voulgaris, Sam Metalis, and Scott Mobley, "An Integrated Primary Flight Display: The Sky Arc," *Proceedings of SPIE Conference Helmet- and Head-Mounted Displays and Symbology Design Requirements II*, Vol. 2465 (18-19 April 1995): 209-211.

[23] Geiselman, 120.

[24] Dudfield et al., 138-138.

[25] Denise R. Jones, Terence S. Abbott, and James R. Burley II, "Evaluation of Conformal and Body-Axis Attitude Information for Spatial Awareness," *Proceedings of SPIE Conference Helmet-Mounted Displays III*, Vol. 1692 (21-22 April 1992): 151.

[26] Dudfield et al., 137.

[27] Dudfield et al., 132.

[28] Geiselman, 120.

[29] Randall E. Bailey, "HUD Lessons-Learned for HMD Development," *Proceedings of SPIE Conference Helmet- and Head-Mounted Displays and Symbology Design Requirements*, Vol. 2218 (5-7 April 1994): 223.

[30] Bailey, 223.

[31] Bailey, 224.

Part 2

Test Description

Test Objective and Procedures

The objective of this evaluation was to compare the effectiveness of the NDFR with the VCATS and Military-Standard HUD symbology sets in providing both digital and analog information when the pilot has minimum time to assess the flight information. The basic assumption in this test was that the quicker and easier the pilot can interpret ownship information, the greater the symbology set's potential to increase pilot situational awareness. This display would then be presented to the pilot operationally in helmet-mounted displays as well as key heads down displays. Ultimately, the purpose of the NDFR attitude reference is to reduce the USAF accident rate due to loss of situational awareness.

The displays were evaluated using a personal computer (PC) based testing system. The measure of performance used to evaluate the display was a measurement of pilot error and assimilation rate of both digital (altitude, airspeed and heading) and analog information (pitch and bank). The geometry and sizing of the displays were presented consistent with the symbology size as would be presented in an actual HMD. This required the subject to be seated at a precise viewing distance from the PC monitor. This viewing distance was determined by using the display symbology angular sizing provided in the Joint Helmet Mounted Cueing System (JHMCS) requirement document.[1] Specifically, the overall height and width of the display as seen on the PC were compared to the JHMCS requirements, and the appropriate view distance was determined using the arc length formula.

The PC testing program allowed for the selection of symbology set (NDFR, VCATS, Mil-Std HUD), display duration and a test/training toggle. In the test mode, the program would display the selected symbology set for the selected duration. The test program randomly selected test points from the following display set providing specific analog and digital information. Once a test point was presented it would not be repeated. This ensured that for each symbology and duration, the subject was presented the entire display set. The test points in the display set were chosen to equally sample all pitch and bank quadrants in attitude and provide a realistic combat representation of altitudes and airspeeds. A complete listing of the 20 test points is given in Table 1.

All subjects completed a brief training session on the respective display immediately prior to evaluating the specific display. This training session consisted of three canned maneuvers: aileron roll, loop, and barrel roll. The subjects were allowed to view the display as many times as necessary to become comfortable with the display symbology. In addition to the particular display, the actual values of pitch and bank were displayed to the subject allowing the subject to ensure that the display was being properly interpreted during the training session.

All subjects first evaluated the Mil-Std HUD. Following the Mil-Std HUD symbology set, the VCATS and NDFR were alternately tested next. This resulted in half the subjects evaluating VCATS as the second display and half the subjects evaluating the NDFR as the second display. This was accomplished in an effort to eliminate any potential learning curve bias during the testing. For all symbology sets, the evaluations were conducted using 1000-

millisecond, 500-millisecond and 250-millisecond display durations. The displays were presented from longest to shortest duration, and the complete symbology set was evaluated for

Table 1. Display Set

Test Point	Heading	Airspeed	Altitude	Bank	Pitch
1	4	239	28.5	22.5	-45
2	8	359	30.1	22.5	-15
3	36	289	10.1	22.5	0
4	29	243	12.6	22.5	15
5	27	501	28.8	22.5	45
6	6	586	29.5	67.5	-45
7	28	209	20.4	67.5	-15
8	21	484	17.7	67.5	0
9	16	538	24.6	67.5	15
10	5	413	11.9	67.5	45
11	30	529	20	112.5	-45
12	30	370	15.5	112.5	-15
13	8	586	12.4	112.5	0
14	31	534	19.3	112.5	15
15	17	319	17	112.5	45
16	16	293	19.2	137.5	-45
17	22	286	14	137.5	-15
18	31	557	20.8	137.5	0
19	33	252	16.3	137.5	15
20	12	536	28.9	137.5	45

each duration prior to proceeding to the next duration. The test subject initiated the test point execution by a single depression of the PC keyboard spacebar. When the spacebar was depressed, the appropriate symbology set would display the randomly selected test point for the selected duration. The test subject would verbally call out to the test conductor as much of the following information as possible: airspeed, heading, altitude, pitch, and bank. The test subject was allowed to call information as soon as the display was visible. The test subject was not given a priority listing of the information to recall and was allowed to recall the information in any order or priority. Following the preset time of 1000, 500, or 250 milliseconds, the display was removed, and the subject was allowed whatever time necessary to recall the maximum amount of information. The test conductor manually recorded this information. The test software automatically recorded the truth data for later comparison to the manually recorded subject response data.

During and following the quantitative testing, each pilot provided comments on the respective displays, which were recorded by the test conductor. Additionally, each pilot was asked to evaluate both the VCATS and NDFR display sets using the questionnaire shown in Figure 10.

PART ONE

1	2	3	4	5
Not Confident		Somewhat Confident		Very Confident

Using the scale above circle your response to the following questions:

1)	How confident are you that you could use VCATS for determining heading?	1	2	3	4	5
2)	How confident are you that you could use VCATS for determining airspeed?	1	2	3	4	5
3)	How confident are you that you could use VCATS for determining altitude?	1	2	3	4	5
4)	How confident are you that you could use VCATS for determining bank?	1	2	3	4	5
5)	How confident are you that you could use VCATS for determining pitch?	1	2	3	4	5
6)	How confident are you that you could use NDFR for determining heading?	1	2	3	4	5
7)	How confident are you that you could use NDFR for determining airspeed?	1	2	3	4	5
8)	How confident are you that you could use NDFR for determining altitude?	1	2	3	4	5
9)	How confident are you that you could use NDFR for determining bank?	1	2	3	4	5
10)	How confident are you that you could use NDFR for determining pitch?	1	2	3	4	5

PART TWO

1	2	3	4	5
VCATS Definitely Superior		Both About The Same		NDFR Definitely Superior

Using the scale above circle you response to the following questions:

1)	Which symbol set allows better determination of heading?	1	2	3	4	5
2)	Which symbol set allows better determination of airspeed?	1	2	3	4	5
3)	Which symbol set allows better determination of altitude?	1	2	3	4	5
4)	Which symbol set allows better determination of bank?	1	2	3	4	5
5)	Which symbol set allows better determination of pitch?	1	2	3	4	5
6)	Which symbol set allows better determination of unusual attitude recognition?	1	2	3	4	5
7)	Which symbol set would you prefer in a combat display? (AA information)	1	2	3	4	5
8)	Which symbol set would you prefer in a combat display? (AG information)	1	2	3	4	5

PART THREE

Answer the following questions:

1) What element of VCATS did you like the least?____________________
2) What element of VCATS did you like the most?____________________
3) What element of NDFR did you like the least?____________________
4) What element of NDFR did you like the most?____________________
5) What improvements would you make to VCATS?____________________
6) What improvements would you make to NDFR?____________________
7) How does the PC test compare to the HMD test for evaluation of display symbology?__________
   Any additional comments? (Use back if necessary)____________________

Figure 10. Questionnaire

Evaluation Methodology

The data was evaluated in terms of digital and analog information. Digital information consisted of altitude, heading and airspeed. Analog information consisted of bank and pitch. Each of the five items was evaluated using a two-point system. In accordance with the following table, each response was given a value of zero, one or two. A null answer always received a value of zero. Average scores were determined for the digital information for each subject pilot (three averages scores for heading, airspeed and altitude) for each display symbology (Mil Std HUD, VCAT, and NDFR) for each selected duration (1000, 500 and 250 milliseconds). These averages were in turn averaged again, resulting in an average digital score per display type, duration and pilot. The scores for bank and pitch (attitude information) were averaged in the same way.

Table 2. Response Evaluation Criteria

Value Received	2	1	0
Airspeed	Hundreds and Tens Digit Correct	Hundreds Digit Correct	Less than Hundreds Digit Correct
Altitude	Ten Thousands, Thousands, Hundreds Digit Correct	Ten Thousands and Thousands Digit Correct	Less than Ten Thousands and Thousands Digit Correct
Heading	≤ 10 degrees error	≤ 30 degrees error	>30 degrees error
Bank	≤ 15 degrees error	≤ 30 degrees error	>30 degrees error
Pitch	≤ 15 degrees error	≤ 30 degrees error	>30 degrees error

Once the average digital and analog values were determined for each display symbology and duration, these values were then averaged for each of the 10 subject pilots. This data reduction step resulted in an average digital and analog score for each display symbology and duration. A combined score (analog and digital score) was determined by averaging the average analog and average digital scores for each display symbology and duration.

To determine the relative improvement of the VCATS and JHMCS display, the Mil-Std HUD display was used as a baseline. Percent improvement of the VCATS and JHMCS was determined for the three categories of average digital score, average analog score and average combined score by the following formula: *Percent Improvement = ((Mil Std HUD Average*

Score – Display of Interest Average Score)/(Mil Std HUD Average Score))x100%. The final product was a percent improvement for the VCATS and NDFR displays for analog, digital and combined averages for each duration of 1000, 500 and 250 milliseconds.

The final data analysis was a mean correct response analysis. The average correct responses (graded value of 2) were plotted against the number of parameters recalled and symbology set. This data reduction was conducted for each of the durations (1000, 500, and 250 milliseconds). This analysis resulted in a plot representing the mean frequency of test subject correct responses for particular numbers of parameters for each display set and duration. For example, one data point would be the mean number of times at 500 milliseconds using the VCATS display the test subject was able to correctly identify 2 parameters. In this analysis, all information, heading, airspeed, altitude, bank and pitch were treated equally, and no division was made between digital and analog data.

The pilot responses in Part One of the pilot questionnaire were evaluated by averaging the scores for each question and determining the standard deviation. Additionally, the data was evaluated in terms of the number of pilots out of total, which rated each display above and below the neutral value (3). The pilot responses for Part Two were similarly averaged for each question. Again, the standard deviation was determined for these items. Additionally, the data was reduced to the number of pilots evaluating the NDFR as superior to VCATS, VCATS as superior to NDFR and the number of subject pilots evaluating the displays neutral for each Part Two question. Finally, the responses to the Part Three questions were combined with the subject comments provided during the evaluation. These comments were subjectively evaluated for trends regarding the VCATS and NDFR display performance.

Notes

[1] Paul A. Pecha, JHMCS Requirements Definition Document Helmet Mounted Display, Revision D, 19 March 1993, 56.

Part 3

Test Results

Ten experienced fighter pilots were used for the evaluation (see Table 3). As described in Part 2, each pilot evaluated the three displays (Mil-Std HUD, VCATS, NDFR) at three differing durations (1000, 500 and 250 milliseconds) for 20 test points. This resulted in each pilot generating 180 test points. With ten pilots, a total of 1800 test points were collected for data reduction. Of these 1800 test points, 16 were lost due to test subject errors in operating the test software, resulting in 1784 valid test points collected.

Table 3. Pilot Experience

Subject	**Hours**	**Aircraft Types**
1	2500	F111, F15E
2	2100	F16
3	1600	F16
4	2100	F111, F15C
5	2600	A10, F117
6	2900	F15E
7	2300	F15C
8	2700	F111, F15C
9	2100	F16
10	1650	F15C

Quantitative Data

Following is a summary of the quantitative results collected during the symbology evaluation. The NDFR was found to outperform both the Mil-Std HUD and the VCATS symbology sets for all tested durations, 1000, 500 and 250 milliseconds, and in all three evaluated categories, digital information, analog information and combined information. The VCATS display also performed favorably in comparison to the Mil-Std HUD. The VCATS display outperformed the Mil-Std HUD in all categories and durations except for analog information recall at 1000 milliseconds and analog information at 500 milliseconds. This information is presented in Table 4 and graphically in Figures 11 through 13. Using the Mil-Std HUD symbology as a baseline, the VCATS and NDFR percent improvements are presented in Figures 14 through 16. Percent improvement measurement indicates a significant improvement in pilot performance using the NDFR over the VCATS symbology set.

Table 4. Summary Table of Average Scores Sorted by Symbology Format and Exposure Duration

SHUD 1K		**SHUD 500**		**SHUD 250**	
DIGITAL	0.69	**DIGITAL**	0.47	**DIGITAL**	0.28
ANALOG	1.24	**ANALOG**	1.25	**ANALOG**	1.12
COMBINED	0.96	**COMBINED**	0.86	**COMBINED**	0.70

VCATS 1K		**VCATS 500**		**VCATS 250**	
DIGITAL	0.98	**DIGITAL**	0.72	**DIGITAL**	0.46
ANALOG	1.22	**ANALOG**	1.05	**ANALOG**	1.28
COMBINED	1.10	**COMBINED**	0.89	**COMBINED**	0.87

NDFR 1K		**NDFR 500**		**NDFR 250**	
DIGITAL	1.11	**DIGITAL**	1.11	**DIGITAL**	0.89
ANALOG	1.51	**ANALOG**	1.53	**ANALOG**	1.38
COMBINED	1.31	**COMBINED**	1.32	**COMBINED**	1.13

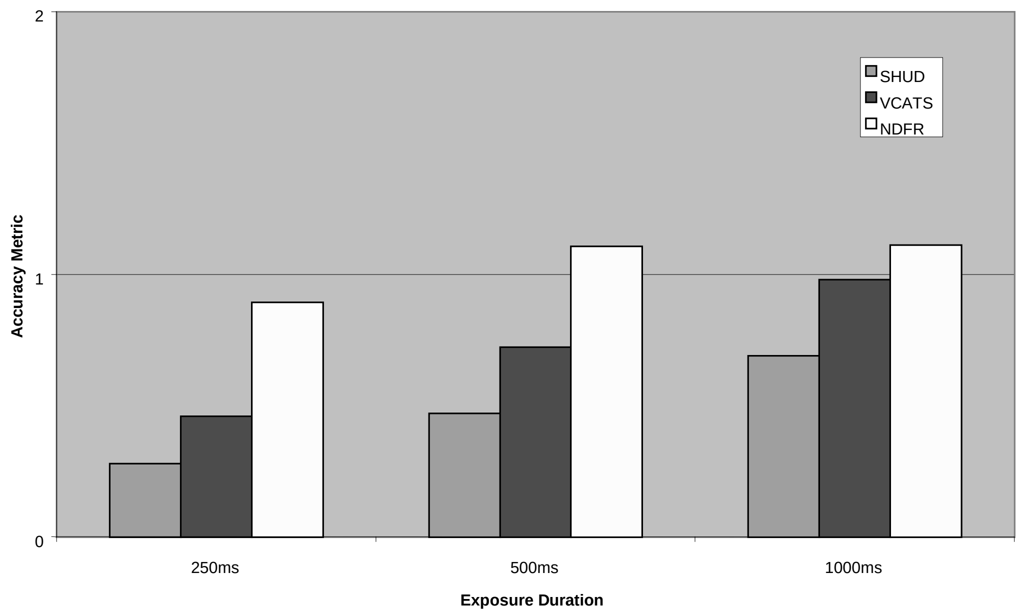


Figure 11. Digital Information Recall Accuracy as a Function of Symbology Format and Exposure Duration

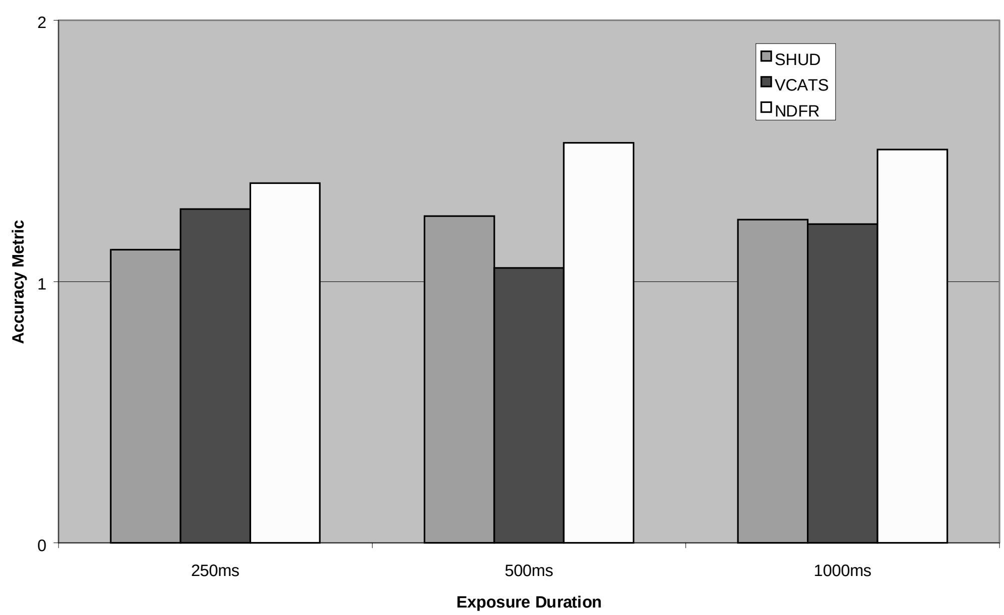


Figure 12. Analog Information Recall Accuracy as a Function of Symbology Format and Exposure Duration

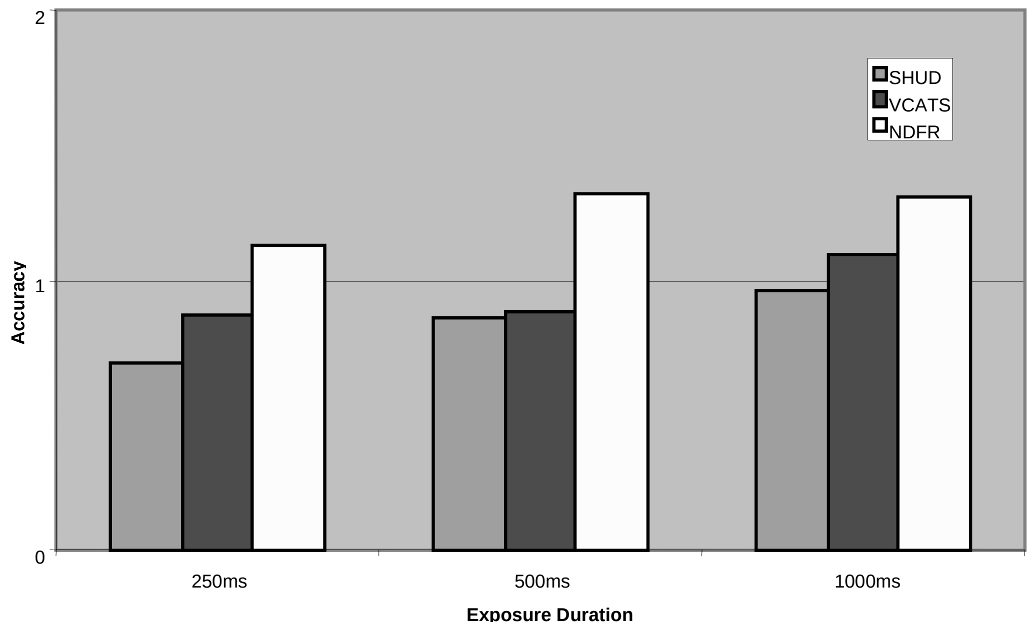


Figure 13. Combined Information Recall Accuracy as a Function of Symbology Format and Exposure Duration

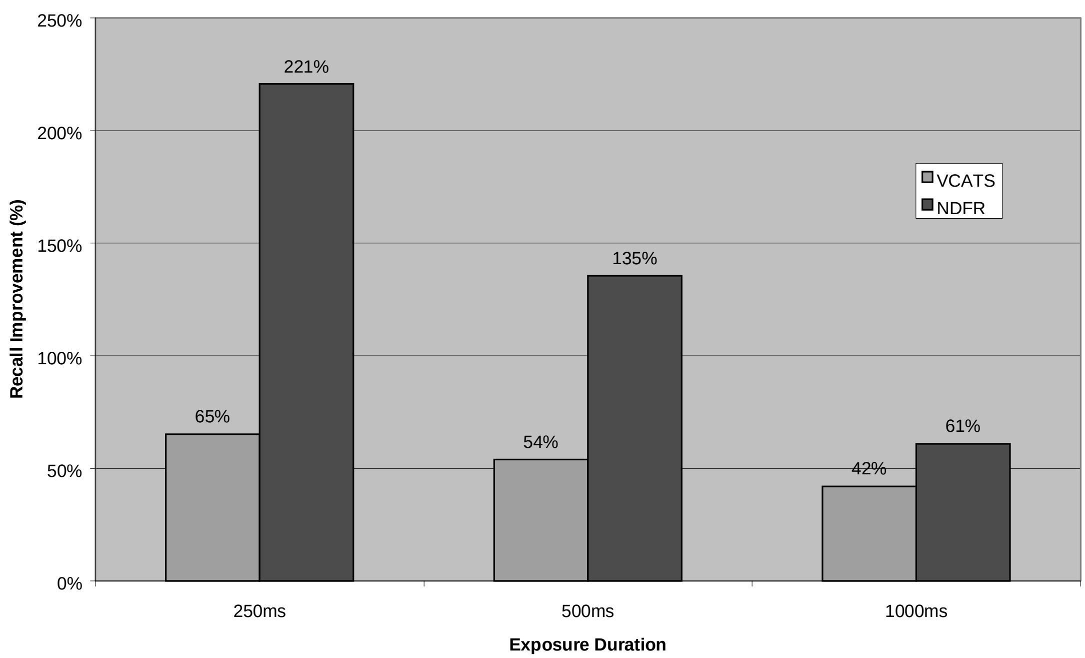


Figure 14. Digital Information Recall Accuracy Improvement Compared to Baseline Standard HUD Performance as a Function of Symbology Format and Exposure Duration

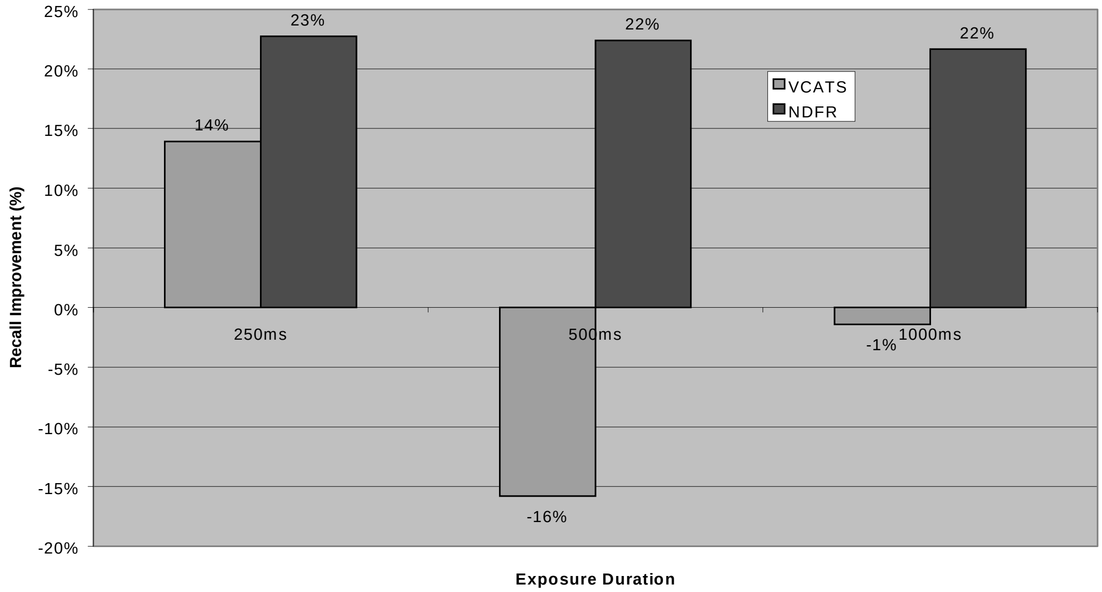


Figure 15. Analog Information Recall Accuracy Improvement Compared to Baseline Standard HUD Performance as a Function of Symbology Format and Exposure Duration

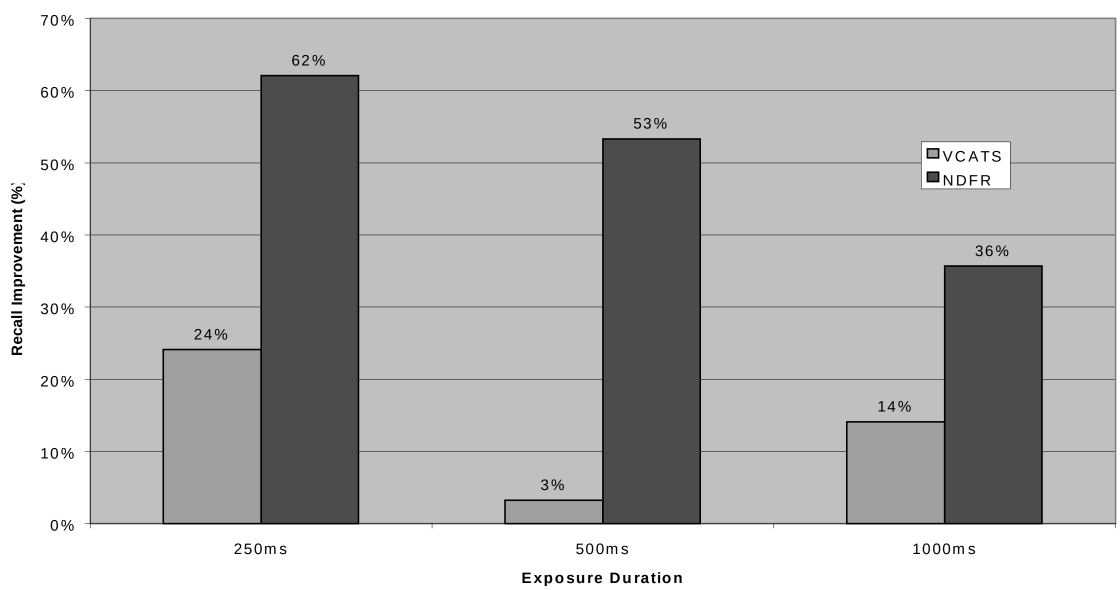


Figure 16. Combined Information (Digital and Analog) Recall Accuracy Improvement Compared to Baseline Standard HUD Performance as a Function of Symbology Format and Exposure Duration

Specifically, the NDFR showed a 221 percent, 135 percent, and 61 percent improvement for pilot accuracy in recall of digital information over the Mil-Std HUD for 250-, 500- and 1000-

milliseconds display times respectively. In comparison, the VCATS symbology set only offered 65 percent, 54 percent and 42 percent improvement for the same test conditions. For analog recall, the NDFR improvements were more consistent across the three tested durations at 23 percent, 22 percent and 22 percent improvement. The VCATS display performed significantly worse with analog information compared to its digital performance. For 500- and 1000-millisecond durations, the VCATS display was outperformed by the Mil-Std HUD with 16 percent and 1 percent degradation in pilot performance, respectively. However, at the 250-millisecond duration, the VCATS demonstrated a 14 percent improvement. The combined percent improvement in recall of analog and digital information, or total information recall accuracy, for the NDFR was 63, 53 and 36 percent for 250, 500, and 1000-milliseconds, respectively, over the Mil-Std HUD. The current VCATS display only provided a 24, 3 and 14 percent improvement under the same test conditions. The standard deviations are presented in Table 5. For the analog scores, the standard deviations ranged from a high of 0.38 to a low of 0.23. The standard deviations for the digital scores range from 0.68 to 0.16. Appendix A provides summary results for each pilot's performance for each display and duration combination.

In examining the mean frequency of correct responses, the NDFR was found to provide improved capability for the pilots to gather correct information. These results are presented in Figures 17, 18 and 19 for the specific durations. For example, at 250 milliseconds, pilots achieved a mean correct response score of 39.1. In contrast, the VCATS display mean correct frequency score was 19.4. At 500 and 1000 millisecond durations, the mean scores were 54.6 versus 22.7 for the NDFR and VCATS displays respectively. At 1000 milliseconds, the same analysis indicated a mean of 57.7 using the NDFR compared to only 36.7 for VCATS. The Mil-

Std HUD baseline symbology was also always outperformed by both the NDFR and VCATS displays.

Table 5. Summary Table of Average Scores with Standard Deviation

Symbol	Duration	Standard Deviation Digital Scores	Standard Deviation Analog Scores	Average Digital Score	Average Analog Score
VCAT	1000	0.31	0.57	0.98	1.22
SHUD	1000	0.28	0.49	0.69	1.24
NDFR	1000	0.38	0.25	1.11	1.51
VCAT	500	0.26	0.68	0.72	1.05
SHUD	500	0.36	0.57	0.47	1.25
NDFR	500	0.35	0.16	1.11	1.53
VCAT	250	0.23	0.55	0.46	1.28
SHUD	250	0.26	0.65	0.28	1.12
NDFR	250	0.33	0.39	0.89	1.38

Qualitative Data

The qualitative data collected from the test subjects consisted of pilot responses to the questions presented in Figure 10 found in the test procedure section of this report. Secondly, pilot comments were collected on the survey as well as during the testing procedures. Pilot responses to the questionnaire are presented in Table 6. Subject 8 did not return a questionnaire and was not included in the qualitative evaluation. For digital information, pilots indicated by a slight margin that they were more confident using NDFR. Specifically, of 27 possibilities (9 pilots times 3 questions evaluating digital information), pilots rated their ability to assess

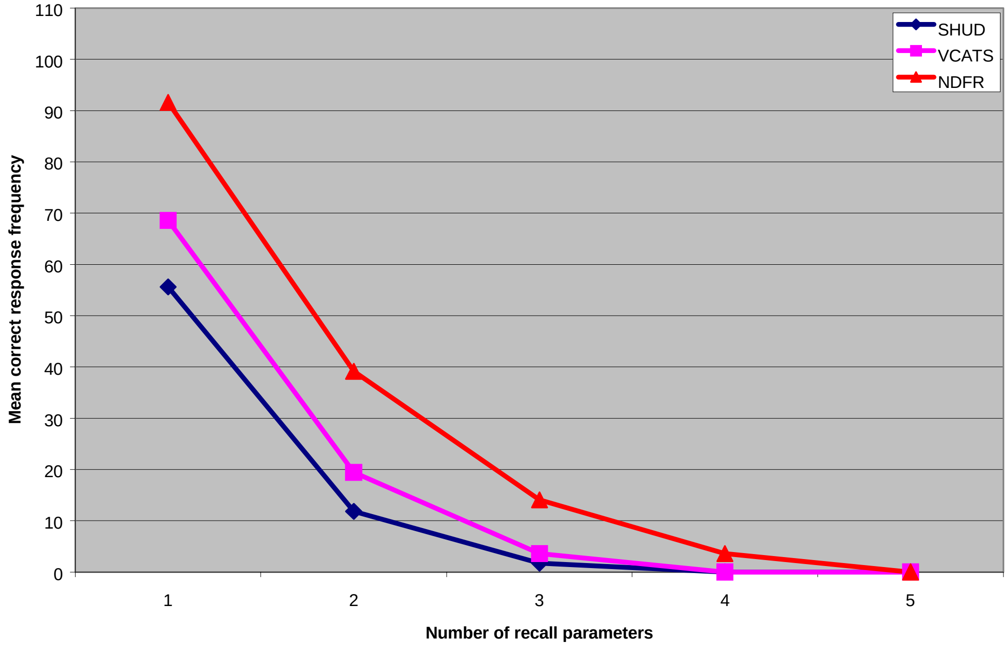


Figure 17. Mean Correct Response Frequency as a Function of Symbology Format and Number of Recall Parameters at a 250ms Exposure Duration

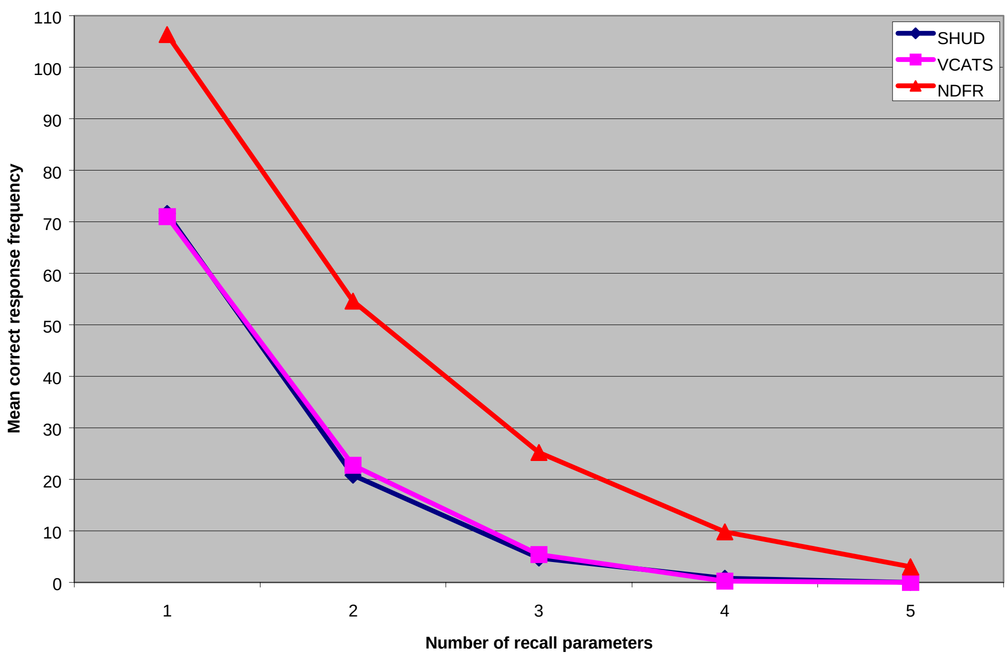


Figure 18. Mean Correct Response Frequency as a Function of Symbology Format and Number of Recall Parameters for the 500ms Exposure Duration

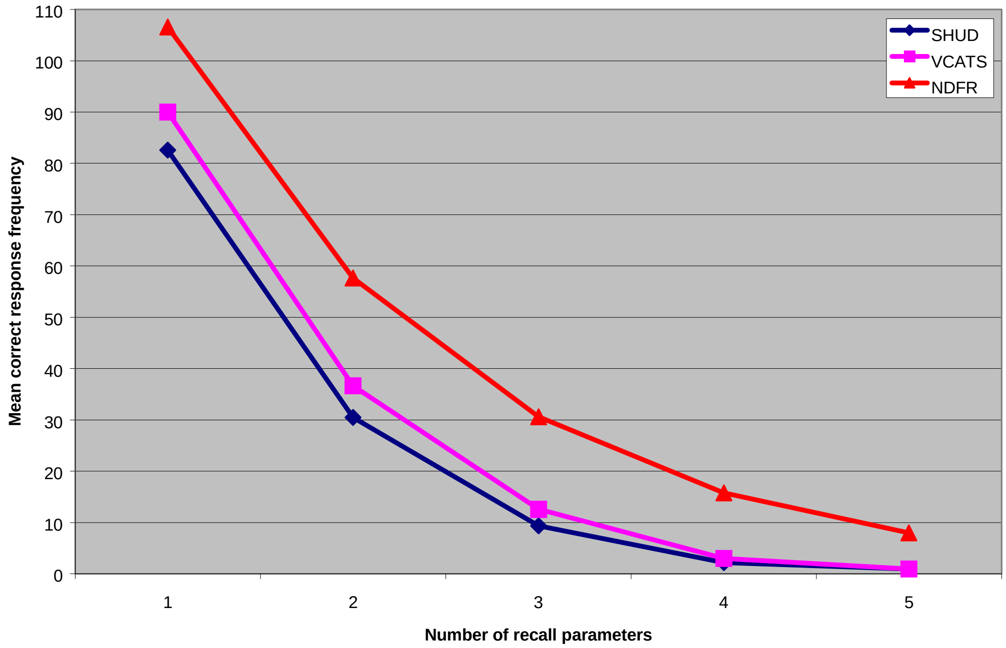


Figure 19. Mean Correct Response Frequency as a Function of Symbology Format and Number of Recall Parameters for the 1000 ms Exposure Duration

VCATS digital information 22 times as “Confident” to “Very Confident.” For the NDFR, 100 percent (27 of 27 possible responses) of the pilots rated their confidence in digital information assessment as “Confident” to “Very Confident.” When comparing only “Very Confident” ratings (maximum scores of 5), the VCATS display earned 16 maximum ratings while the NDFR received the maximum rating 21 out of 27 times. When these scores are averaged, the VCATS received a 3.8, 4.6 and 4.7 average for digital information (heading, airspeed and altitude, respectively). The NDFR average for the same conditions were 4.7, 4.9, and 4.9 indicating a 24 percent, 7 percent and 4 percent improvement, respectively, in pilot confidence for the NDFR digital format. The associated standard deviations are presented in Table 6.

The difference in pilot confidence in assessing analog information (pitch and bank) was more pronounced than the digital performance. Of 18 possible responses (9 pilots times two questions addressing pitch and bank), the VCATS display was rated “Confident” to “Very

Confident" in only 6 responses. Additionally, the display for analog information was rated below "Somewhat Confident" (rating of 1 or 2) in 5 of 18 possible responses. Of the 5 low VCATS analog responses, 4 were directed toward pilot confidence in assessing aircraft pitch. In contrast, 12 pilots evaluated the NDFR as "Confident" to "Very Confident" in 12 of the 18 possibilities. Additionally, the NDFR received only one rating below "Somewhat Confident" (also a pitch assessment rating). When examined in terms of averages, the VCATS received ratings of 3.3 and 2.6 for pitch and bank pilot confidence. The NDFR received ratings of 3.8 and 3.9. In terms of percent difference, the NDFR demonstrated a 15 percent improvement in bank assessment confidence and a 50 percent improvement in pitch assessment confidence. As with the digital information, the associated standard deviations are presented in Table 6. Again, the NDFR outperformed the VCATS in pilot confidence for analog information. Most importantly, the pilots were generally not confident in their ability to accurately assess pitch using the VCATS display.

When the pilots were asked to directly compare the VCATS to the NDFR for digital information, of the 27 comparisons (9 pilots times three questions comparing heading, airspeed and altitude), 14 ratings indicated the NDFR as "Superior" to "Definitely Superior" to the VCATS display (rating of 4 to 5). Only 3 ratings below "About the Same" were received (favoring the VCATS over the NDFR display). A single pilot provided these ratings for each category of heading, altitude, and bank. When these ratings are averaged, the NDFR was favored for both bank and pitch with ratings of 4.0 and 4.1 respectively on a five-point scale.

The subject pilots were further asked to evaluate the operational utility of the NDFR and VCATS displays for unusual attitude recognition, air-to-air combat display compatibility, and air-to-ground display compatibility. With regard to unusual attitude recognition, 7 of 9 pilots rated the NDFR as superior to the VCATS display. Two pilots felt the VCATS would provide superior unusual attitude recognition. The average rating on a five-point scale was 4.1 favoring the NDFR. Similarly, 7 of 9 pilots preferred the NDFR display for use in Air-to-Air combat symbology. One pilot rated the displays neutral and one pilot preferred the VCATS display. The average rating with regard to Air-to-Air combat symbology was 4.2. The preference of the NDFR over the VCATS display was slightly favorable for Air-to-Ground symbology compatibility. Specifically, 6 of 9 pilots preferred the NDFR while 2 pilots were neutral and 1 pilot preferred the VCATS display. The resulting average rating on the five-point scale was 3.8.

A summary of collected pilot comments is presented in Table 7. One pilot commented that the closeness of the digital information may lead the pilot during a quick glance to confuse data (misinterpret airspeed for altitude). However, five of nine responding pilots specifically noted that the closeness of the digital information was an asset. In particular, they felt that the compactness of the display allowed them to glean more information. Additionally, the arc-segment attitude indicator display received positive comments from five of the subjects. In general, these pilots noted that the orange peel allowed them to take a quick mental snapshot of the aircraft attitude that could easily be remembered and interpreted. These comments conform to the significant quantitative improvement in NDFR attitude (analog) information recall.

Table 6. Subject Survey Results

SUBJECT	1	2	3	4	5	6	7	9	10	AVG	STD DEV
Part I											
1	5	5	3	4	1	5	5	3	3	3.8	1.39
2	5	5	5	4	4	5	5	3	5	4.6	0.73
3	5	5	5	4	4	5	5	4	5	4.7	0.50
4	4	3	4	3	1	3	4	4	4	3.3	1.00
5	2	3	2	2	1	3	3	4	3	2.6	0.88
6	5	4	5	5	5	5	5	4	4	4.7	0.50
7	5	5	5	5	5	5	5	4	5	4.9	0.33
8	5	5	5	5	5	5	5	4	5	4.9	0.33
9	4	4	4	3	3	5	4	3	4	3.8	0.67
10	4	5	4	2	4	5	5	3	3	3.9	1.05
Part II											
1	3	2	5	4	5	3	5	5	3	3.9	1.17
2	3	2	5	4	4	3	4	3	3	3.4	0.88
3	3	2	5	4	4	3	4	5	3	3.7	1.00
4	3	5	5	4	4	5	4	2	4	4.0	1.00
5	3	5	5	4	5	5	4	4	2	4.1	1.05
6	5	5	5	2	5	4	5	4	2	4.1	1.27
7	4	4	5	3	5	5	5	5	2	4.2	1.09
8	4	4	5	3	5	2	3	4	4	3.8	0.97

With regard to the VCATS display, all nine of the pilots commented negatively on the pitch representation. In general, the lack of pitch reference made it difficult for the test subjects to determine pitch extremes accurately. Additionally, the VCATS comments indicated that the abbreviated pitch ladder was not conducive to quick snap shot looks for pitch determination with most negative comments resulting from the size modification scheme of the horizon bar to indicate pitch angle. Additionally, two pilots noted that the small horizon pointer ticks were difficult to catch at a quick glance. As a result, 135 degrees of bank could easily be misinterpreted as 45 degrees of bank. Three pilots also commented that they felt the distributed format for heading, altitude and airspeed made it more difficult to see the required information in the short duration test points. In general, the trend of pilot comments strongly favored the NDFR over the VCATS display.

Table 7. Summary of Pilot Comments

PILOT	DISPLAY	COMMENTS
1	NDFR	CLEARLY BEST FOR ATTITUDE INFORMATION; JUST A GLANCE AND YOU COULD RETAIN A MENTAL PICTURE
1	NDFR	DISPLAY MAY BE TOO CLUTTERED; LOSE A LARGE SEGMENT OF THE VIEWING AREA
1	SHUD	TOO MANY LINES ON DISPLAY TO QUICKLY INTERPRET INFORMATION
1	VCATS	DIFFICULT TO INTERPRET PITCH; ALSO EASY TO CONFUSE 135 WITH 45 DEGREES BANK
1	VCATS	PITCH INTERPRETATION WORST ELEMENT OF THE DISPLAY
2	NDFR	HEADING DIFFICULT TO PICK OUT OF THE CIRCLE
2	NDFR	CLOSENESS OF THE NUMBERS MAY CAUSE CONFUSION WITH A QUICK LOOK
2	NDFR	BUNCHED DISPLAY MAY BECOME AN EYE MAGNET VERSUS THE OPEN DISPLAY OF VCATS
2	VCATS	SKY POINTER DIFFICULT WITH HORIZON POINTER; DIFFICULT TO QUICKLY TELL 45 FROM 135 IN BANK FOR EXAMPLE
2	VCATS	DIFFICULT TO DETERMINE LARGE PITCH ANGLES WITH THE SIZING SCHEME WHEN YOU ARE MOST INTERESTED IN THE INFORMATION
2	VCATS	DID NOT LIKE THE WIDE DIGITAL BOX SPREAD; TO MUCH DISTANCE BETWEEN DIGITAL INFORMATION
2	VCATS	DID LIKE THE DIGITAL INFORMATION IN STANDARD PLACES
3	NDFR	EASIER THAN MIL STD TO GET ATTITUDE; DON'T HAVE TO FOCUS; CAN STARE AT NUMBERS THEN INTERPRET ATTITUDE W/O FOCUSING EYE
3	NDFR	LIKED ABILITY TO BUILD A MENTAL PICTURE OF ATTITUDE PARTICULARLY PITCH
3	NDFR	ADD TICKS TO THE ENDS OF THE HORIZON BAR TO MAKE THE HORIZON EASIER TO INTERPRET
3	VCATS	PITCH WAS TOUGH TO INTERPRET
3	VCATS	NEED TO CONSOLIDATE DATA AND MAKE PITCH EASIER TO COMPREHEND
4	NDFR	LIKED THE COMPACTNESS THE MOST
4	VCATS	VERY DIFFICULT TO TELL PITCH
4	VCATS	LIKED THE PITCH SYMBOLOGY WORST
4	VCATS	DID LIKE THAT THE LAYOUT WAS CONSISTENT WITH OLD HUD SYSTEM
5	NDFR	THIS IS VERY GOOD; WOULD LEARN TO LIKE MOST; FAVORATE OF THE THREE DISPLAYS
5	NDFR	VERY USEFUL ATTITUDE INFORMATION
5	NDFR	LIKED THE INFORMATION ALL BEING CLOSE TOGETHER
5	NDFR	NOT EVEN LOOKING AT ATTITUDE REFERENCES BUT STILL GET A MENTAL PITCURE
5	NDFR	BANK A BIT CONFUSED BUT MORE BECAUSE OF UNFAMILARITY
5	NDFR	ALL INFORMATION WAS CLOSE BUT READABLE
5	NDFR	LOCALITY OF DIGITAL INFORMATION ALLOWS YOU TO CONSCIOUSLY READ NUMBERS AND SUBCONSCIOUSLY NOTE ADI REFERENCE

Table 7. Summary of Pilot Comments (Cont)

5	SHUD	HAD TO PRIORITIZE ATTITUDE; AS I THOUGHT ABOUT NUMBERS THE ATTITUDE IMAGE GOES AWAY IN THE MIND
5	VCATS	INFORMATION TOO FAR AWAY FROM EACH OTHER TO SEE BOTH NUMBERS (DIGITAL INFORMATION) AND ATTITUDE
5	VCATS	NO WAY TO READ ATTITUDE ACCURATELY
5	VCATS	DIDN'T LIKE ATTITUDE DISPLAY; ALTITUDE AND AIRSPEED OK
5	VCATS	ATTITUDE REFERENCE UNUSABLE AT A SNAPSHOT
5	VCATS	NEEDS MORE UNDERSTANDABLE ADI REFERENCES
6	NDFR	LIKED ALL THE INFORMATION IN ONE PLACE
6	NDFR	LETTERING WAS A LITTLE SMALL
6	NDFR	ORANGE PEEL HAS A LOT OF POTENTIAL ESPECIALLY FOR AIR TO GROUND OPERATIONS
6	VCATS	INFORMATION WAS TOO SPREAD OUT
6	VCATS	DISLIKED THE ABILITY TO INTERPRET PITCH THE MOST
6	VCATS	WOULD LIKE THE NUMBERS AVAILABLE FOR PITCH LIKE THE SHUD
7	NDFR	LIKE BEING ABLE TO GET ALL THE INFORMATION AT ONCE
7	VCATS	DID NOT LIKE THE SEPARATION OF DATA
7	VCATS	DID NOT LIKE ABILITY TO TELL PITCH
7	VCATS	NEED NUMBERS ON THE PITCH
9	NDFR	LIKE THIS THE BEST FOR AIR TO AIR
9	NDFR	LIKED THE CLIMB/DIVE INFORMATION THE MOST OF THIS DISPLAY
9	SHUD	NEED TO HAVE THE HEADING AT THE BOTTOM
9	VCATS	DID NOT LIKE THE SIZE REFERENCE FOR PITCH UP; PERHAP NEED TO BEND PITCH LINES LIKE NOSE LOW INFORMATION
9	VCATS	TOUGH TO TELL HOW NOSE HIGH YOU ARE
9	VCATS	EASY TO DIGEST INFORMATION QUICKLY
9	VCATS	CAN'T DIGEST ALL THE INFORMATION QUICKLY; HAVE TO THINK HOW TO INTERPRET DISPLAY
9	VCATS	ADD 0 PITCH TICS SO SHRINKING HORIZON BAR MEANS SOMETHING
10	NDFR	EYES DIDN'T HAVE TO MOVE AROUND; COULD TAKE A SINGLE SNAPSHOT
10	NDFR	LIKED THE PROXIMITY OF THE SYMBOLOGY
10	NDFR	HAD DIFFICULTY INTERPRETING PITCH
10	VCATS	LIKE THE SIMILARITY TO THE HUD DISPLAY
10	VCATS	LIKED THE LACK OF MORE THAN ONE PITCH BAR THE LEAST
10	VCATS	NEED TO ADD PITCH BAR ABOVE AND BELOW HORIZON

Part 4

Conclusion

The future of tactical aviation will involve the use of helmet mounted displays. These displays will be incorporated in increasing challenging visual environments including night operations and low visibility environments. Studies have indicated that these displays enable pilots to spend more time looking outside the cockpit away from the aircraft's primary flight references. These two elements combine to create the potential for increased occurrences of pilot spatial disorientation. Despite the USAF's successful emphasis on safety and the general decline in the rate of Class A mishaps per hour flown, the mishap rate attributed to SD continues to hold steady. However, HMD ownship symbology displays may potentially mitigate the dangers of the pilot spending increased time away from the primary flight references as well as potentially reducing the overall risks of spatial disorientation by providing the pilot with constant access to ownship information.

The objective of the NDFR is to optimize the ownship information to the pilot while not being obtrusive to combat displays. According to the results of this evaluation, the NDFR concept affords better information interpretation for the exposure durations investigated. The symbology comparison of interest was between the NDFR and the VCATS. In most all cases, recall accuracy was best with the NDFR for both digital and analog information. Additionally, the subjective ratings completed by the subjects were consistent with the objective performance results. Subjects indicated more confidence in the ability of the NDFR symbology to provide information compared to the VCATS symbology particularly with regard to the analog information, pitch and bank. While the current attitude display being operationalized in the Joint Helmet Mounted Cueing System (JHMCS) uses the non-distributed format for digital information, it retains the VCATS attitude indicator format. This attitude indicator was the worst rated element of the VCATS display. Test results indicate that a JHMCS transition to the arc segment attitude display would be valuable for improving pilot attitude recognition.

However, as the design process progresses through the steps of concept development, pilot-in-the-loop simulation, and concept refinement, the next evaluations of the NDFR need to include dynamic testing. The test methodology used in this effort demonstrated the ability of the NDFR to be quickly interpreted but it is not often in the cockpit that the pilot must quickly interpret a static presentation of the symbology. Instead, it is more likely that the pilot will conduct a quick scan of the ownship information in order to gain a sense of both the present status as well as the trends of change in order to predict the future ownship state. With this in mind, a follow-on PC-based study should be conducted to compare interpretation performance for the present symbologies under conditions of dynamic maneuvering. This test should be sponsored by AFRL. As with this test, ACSC students provide an excellent source for test subjects. In fact, a cooperative relationship between the ACSC Department of Research and Communication Studies and AFRL could provide yearly source of technically oriented human factors research projects as well as solving AFRL problems of contacting pilots with recent operational experience. Should the NDFR perform as well under dynamic conditions as it has in this static test, simulator testing should be conducted to address the second portion of the NDFR objective, an unobtrusive display. Specifically, the following questions should be addressed in combat simulations prior to incorporation into flight test:

1) Does the NDFR occlude required combat symbology?
2) Will the NDFR be an “eye magnet” distracting the pilot unnecessarily during combat employment?
3) Does the NDFR size interfere with the pilot’s ability to “look outside” and detect visual targets?

Appendix A

Summary Data

Table 8. Summary of Average Individual Scores

Subject	Duration	Session	Average Heading Score	Average Airspeed Score	Average Altitude Score	Average Bank Score	Average Pitch Score	Average Digital Score	Average Analog Score	Symbol Set
1	1000	4	0.00	1.80	0.85	0.80	0.65	0.88	0.73	VCAT
2	1000	7	0.00	2.00	0.00	1.70	1.90	0.67	1.80	VCAT
3	1000	4	0.90	1.75	0.10	1.35	1.90	0.92	1.63	VCAT
4	1000	7	1.65	2.00	0.05	0.85	0.55	1.23	0.70	VCAT
5	1000	4	0.63	2.00	1.11	0.00	0.00	1.25	0.00	VCAT
6	1000	7	0.10	1.35	0.80	1.30	1.70	0.75	1.50	VCAT
7	1000	4	0.10	1.90	0.95	0.75	1.60	0.98	1.18	VCAT
8	1000	7	0.10	0.70	1.00	1.50	1.80	0.60	1.65	VCAT
9	1000	4	1.90	1.95	1.00	1.35	1.70	1.62	1.53	VCAT
10	1000	7	0.10	1.80	0.80	1.35	1.65	0.90	1.50	VCAT
1	1000	1	0.00	1.90	1.60	0.30	0.05	1.17	0.18	SHUD
2	1000	1	0.40	0.65	0.70	1.70	1.90	0.58	1.80	SHUD
3	1000	1	0.40	1.00	0.40	1.25	1.55	0.60	1.40	SHUD
4	1000	1	0.40	0.60	0.40	0.40	1.45	0.47	0.93	SHUD
5	1000	1	0.00	0.35	0.80	1.60	1.90	0.38	1.75	SHUD
6	1000	1	0.00	0.75	0.25	1.35	1.90	0.33	1.63	SHUD
7	1000	1	0.10	1.30	0.70	1.25	1.55	0.70	1.40	SHUD
8	1000	1	0.00	1.05	1.25	0.75	1.00	0.77	0.88	SHUD
9	1000	1	0.40	1.70	1.15	1.20	1.40	1.08	1.30	SHUD
10	1000	1	0.65	1.35	0.45	0.85	1.40	0.82	1.13	SHUD
1	1000	7	0.00	1.50	0.75	1.25	1.75	0.75	1.50	NDFR
2	1000	4	0.00	1.90	1.10	1.95	1.90	1.00	1.93	NDFR
3	1000	7	0.80	1.25	0.20	1.45	1.65	0.75	1.55	NDFR
4	1000	4	1.44	1.83	0.22	1.06	1.06	1.17	1.06	NDFR
5	1000	7	1.70	2.00	0.90	1.45	1.35	1.53	1.40	NDFR
6	1000	4	0.20	0.90	0.80	0.55	1.80	0.63	1.18	NDFR
7	1000	7	2.00	1.95	1.15	1.50	1.95	1.70	1.73	NDFR
8	1000	4	1.85	1.35	0.25	1.40	1.95	1.15	1.68	NDFR
9	1000	7	1.90	1.75	1.05	1.20	1.90	1.57	1.55	NDFR
10	1000	4	0.75	1.50	0.30	1.25	1.75	0.85	1.50	NDFR
1	500	5	0.00	1.75	0.85	0.35	0.85	0.87	0.60	VCAT
2	500	8	0.00	1.95	0.00	1.80	1.85	0.65	1.83	VCAT
3	500	5	0.00	1.00	0.00	0.00	0.00	0.33	0.00	VCAT
4	500	8	0.20	2.00	0.15	0.10	1.20	0.78	0.65	VCAT
5	500	5	0.20	1.85	1.05	0.00	0.00	1.03	0.00	VCAT
6	500	8	0.00	0.40	1.05	1.35	1.65	0.48	1.50	VCAT
7	500	5	0.00	1.85	1.10	1.05	1.80	0.98	1.43	VCAT
8	500	8	0.00	0.15	1.00	1.65	1.65	0.38	1.65	VCAT
9	500	5	0.40	1.85	0.90	1.40	1.50	1.05	1.45	VCAT
10	500	8	0.00	1.60	0.40	1.25	1.60	0.67	1.43	VCAT
1	500	2	0.00	1.90	1.00	0.00	0.00	0.97	0.00	SHUD
2	500	2	0.10	1.70	0.10	1.70	1.70	0.63	1.70	SHUD

Table 8. Summary of Average Individual Scores (Continued)

Subject	Duration	Session	Average Heading Score	Average Airspeed Score	Average Altitude Score	Average Bank Score	Average Pitch Score	Average Digital Score	Average Analog Score	Symbol Set
3	500	2	0.00	0.10	0.00	1.45	1.90	0.03	1.68	SHUD
4	500	2	0.80	0.20	0.00	0.20	1.20	0.33	0.70	SHUD
5	500	2	0.00	0.00	0.00	1.60	2.00	0.00	1.80	SHUD
6	500	2	0.00	0.10	0.50	1.60	2.00	0.20	1.80	SHUD
7	500	2	0.00	1.40	1.05	1.05	1.35	0.82	1.20	SHUD
8	500	2	0.00	0.50	0.35	1.10	1.30	0.28	1.20	SHUD
9	500	2	0.00	1.60	1.35	0.80	1.25	0.98	1.03	SHUD
10	500	2	0.75	0.20	0.40	1.25	1.55	0.45	1.40	SHUD
1	500	8	0.10	1.40	0.75	1.50	1.55	0.75	1.53	NDFR
2	500	5	0.10	1.85	1.00	1.80	1.90	0.98	1.85	NDFR
3	500	8	1.10	1.60	0.00	1.50	1.30	0.90	1.40	NDFR
4	500	5	1.75	1.80	0.00	0.95	1.80	1.18	1.38	NDFR
5	500	8	1.85	2.00	0.95	1.30	1.30	1.60	1.30	NDFR
6	500	5	0.10	1.20	0.80	1.45	1.85	0.70	1.65	NDFR
7	500	8	1.80	1.90	0.75	1.45	1.50	1.48	1.48	NDFR
8	500	5	1.80	0.60	0.50	1.50	1.85	0.97	1.68	NDFR
9	500	8	2.00	1.90	1.00	1.15	1.85	1.63	1.50	NDFR
10	500	5	0.25	1.70	0.65	1.45	1.65	0.87	1.55	NDFR
1	250	6	0.00	1.80	0.00	1.05	1.00	0.60	1.03	VCAT
2	250	9	0.00	1.95	0.00	1.45	1.70	0.65	1.58	VCAT
3	250	6	0.00	0.00	0.00	1.75	2.00	0.00	1.88	VCAT
4	250	9	0.00	1.39	0.00	0.00	1.50	0.46	0.75	VCAT
5	250	6	0.00	1.65	0.45	0.00	0.00	0.70	0.00	VCAT
6	250	9	0.00	0.00	0.65	1.20	1.60	0.22	1.40	VCAT
7	250	6	0.00	1.95	0.00	1.10	1.75	0.65	1.43	VCAT
8	250	9	0.10	0.00	0.75	1.55	1.60	0.28	1.58	VCAT
9	250	6	0.00	1.95	0.00	1.60	1.60	0.65	1.60	VCAT
10	250	9	0.00	0.00	1.15	1.35	1.75	0.38	1.55	VCAT
1	250	3	0.00	1.80	0.00	0.70	0.00	0.60	0.35	SHUD
2	250	3	0.00	1.30	0.00	1.50	1.40	0.43	1.45	SHUD
3	250	3	0.00	0.00	0.00	1.60	1.95	0.00	1.78	SHUD
4	250	3	0.78	1.22	0.00	0.00	0.00	0.67	0.00	SHUD
5	250	3	0.00	0.10	0.00	1.60	0.00	0.03	0.80	SHUD
6	250	3	0.00	0.00	0.00	1.39	1.89	0.00	1.64	SHUD
7	250	3	0.00	0.20	0.10	1.15	1.70	0.10	1.43	SHUD
8	250	3	0.00	0.11	0.39	1.00	0.00	0.17	0.50	SHUD
9	250	3	0.00	1.70	0.00	1.55	1.85	0.57	1.70	SHUD
10	250	3	0.00	0.00	0.65	1.45	1.70	0.22	1.58	SHUD
1	250	9	0.00	1.90	0.00	1.50	1.80	0.63	1.65	NDFR
2	250	6	0.00	1.45	0.15	1.80	1.80	0.53	1.80	NDFR
3	250	9	1.30	1.45	0.00	1.55	1.45	0.92	1.50	NDFR

Table 8. Summary of Average Individual Scores (Continued)

Subject	Duration	Session	Average Heading Score	Average Airspeed Score	Average Altitude Score	Average Bank Score	Average Pitch Score	Average Digital Score	Average Analog Score	Symbol Set
4	250	6	1.50	1.89	0.00	1.17	1.61	1.13	1.39	NDFR
5	250	9	1.70	1.95	0.10	1.60	1.40	1.25	1.50	NDFR
6	250	6	0.20	1.55	0.85	1.40	1.50	0.87	1.45	NDFR
7	250	9	1.58	1.79	0.21	1.42	0.00	1.19	0.71	NDFR
8	250	6	1.20	0.00	0.65	1.25	1.75	0.62	1.50	NDFR
9	250	9	1.94	1.94	0.17	1.28	0.00	1.35	0.64	NDFR
10	250	6	0.00	0.25	1.05	1.40	1.85	0.43	1.63	NDFR

Glossary

ADI	Attitude Direction Indicator
FOV	Field of View
HDD	Heads Down Display
HMD	Helmet Mounted Display
HOBA	High Off-Boresight Angle
HUD	Heads Up Display
JHMCS	Joint Helmet Mounted Cueing System
Mil-Std	Military Standard
PC	Personal Computer
PFR	Primary Flight Reference
PIO	Pilot Induced Oscillation
PNVG	Panoramic Night Vision Goggles
NDFR	Non-Distributed Flight Reference
SA	Situational Awareness
SD	Spatial Disorientation
VCATS	Visually Coupled Acquisition and Targeting
WVR	Within Visual Range
USAF	United States Air Force

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