

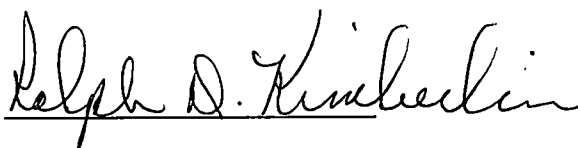
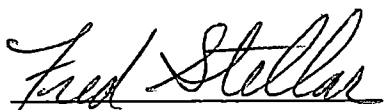
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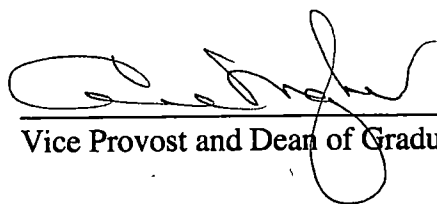


Dr. Solies, Major Professor

We have read this thesis and
recommend its acceptance:



Accepted for the Council:



Vice Provost and Dean of Graduate Studies

**Aircraft Heads Up Display Design and Optimization
as Applied to the AV-8B Harrier**

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

Charles Sean Gray
December 2001

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DEDICATION

This thesis is dedicated to my wife and children

Kelly

Ryan and Gillian

And to my parents

Ove and Rosa Steffensen

ACKNOWLEDGEMENTS

I am grateful to the staff of the University of Tennessee for their support and patience during my time in the graduate program. I would also like to thank the aircrew and engineering staff of the AV-8B Joint System Support Activity for their participation and involvement in support of the preparation of this thesis.

ABSTRACT

Though the advent of the Heads Up Display (HUD) has dramatically changed the way information is presented to aircrew during flight, the requirement to select and discern the pertinent information applicable to the task at hand has not. Much like the proliferation of gauges and switches in a 60's and 70's era military cockpit interfered with a quick and efficient scan of the instruments, so to do the number of pieces of information being presented in a HUD.

With the selection of the AV-8B to be the lead platform in implementation of the Open System Core Avionics Requirement (OSCAR), a rehosting of the Operational Flight Program (OFP), has come the opportunity to optimize the HUD design of the AV-8B.

This thesis focuses on an attempt to simplify and standardize the current HUD displays and improve the tailoring of reject sub-modes that are designed to decrease the amount of data being displayed. The potential benefits of HUD modes that could be instructor configured and selectable in-flight to facilitate the development of the proper scan and reduce the time required for pilots to gain proficiency are also addressed.

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LIST OF ABBREVIATIONS

AA	Air-to-Air
ADC	Air Data Computer
AG	Air-to-Ground
ALTER	Alternate
AMC	Advanced Mission Computer
AMC&D	Advanced Mission Computer and Displays
AOA	Angle of Attack
ATHS	Automatic Targeting Handoff System
AMRAAM	Advanced Medium Range Air-to-Air Missile
APG	Airborne Radar Gun or Searchlight Directing
ARBS	Angle Rate Bombing System
ATR	Airborne Transportable Rack
AUTO	Automatic
CAS	Close Air Support
CL	Conventional Landing
COM	Communication
DC	Display Computer
DMT	Dual Mode Tracker
FLIR	Forward Looking Infrared
FNSL	Fixed Nozzle Slow Landing
FOV	Field-of-View
GPPM	General Purpose Processor Module
GPS	Global Positioning System
HOL	Higher Order Language
HUD	Heads Up Display
INS	Inertial Navigation System
JDAM	Joint Direct Attack Munition
JPT	Jet Pipe Temperature
KCAS	Knots Calibrated Airspeed
LERX	Leading Edge Root Extension
MAGR	Miniaturized Airborne GPS Receiver
MSC	Mission Systems Computer
MPCD	Multipurpose Color Display
MUXBUS	Multiplex Data Bus
NRAS	Nozzle Rotation Airspeed
NWTSCL	Naval Weapons Test Squadron China Lake
OFP	Operational Flight Program
OSCAR	Open Systems Core Avionics Requirement
OVRD	Override
PRIM	Primary
RPM	Revolutions per Minute

RVL	Rolling Vertical Landing
RWR	Radar Warning Receiver
SAAHS	Stability Augmentation Attitude Hold System
STO	Short Takeoff
STOL	Short Takeoff and Landing
UFC	Up-Front Control
VL	Vertical Landing
VMC	Visual Meteorological Conditions
VNSL	Variable Nozzle Slow Landing
VSI	Vertical Speed Indicator
V/STOL	Vertical/Short Takeoff and Landing

CHAPTER 1

INTRODUCTION

BACKGROUND

The advent of the Heads Up Display (HUD) has dramatically changed the way information is presented to the pilot during flight. Now, instead of having to glance below the glare shield to gather the necessary information to accomplish in-flight tasks, the pilot can continue to look through the windscreen and is merely required to change his focus. Though the requirement to look inside the aircraft has been minimized, the requirement to identify and discern the pertinent information applicable to the task at hand has not been reduced. Much like the proliferation of gauges and switches in a 60's and 70's era military cockpit interfered with a quick and efficient scan of the instruments, so to do the number of pieces of information being presented in a HUD. Further complicating the task is a lack of standardization of the symbology developed and used in HUD configurations¹. Additionally, HUD clutter often forces pilots to look around the HUD in order to locate and identify ground and airborne targets, an option counter to the purpose of a HUD and not available with the next generation of information display technology, the helmet mounted display.

The AV-8B Harrier is not immune to this problem and is particularly susceptible in the takeoff and landing regime and during the delivery of air-to-ground weapons, where a pilot can rapidly find himself task saturated. Though the AV-8B has separate

HUD modes, each tailored to a specific phase of flight², the amount of data presented in the primary modes can become distracting and complicate the execution of specific tasks. Two levels of reject sub-modes are provided in an attempt to decrease the amount of data being displayed, but in most cases, these reject levels only change the way the information is displayed and in some cases remove so much data from the HUD that they are no longer useful. Improved tailoring of the reject sub-modes is necessary to ease scan requirements, reduce opportunities for confusion and enhance task execution.

The problem of developing and executing a proper scan has always been particularly difficult to overcome in the early stages of training in an aircraft. Again, the AV-8B is particularly susceptible in the takeoff and landing regime, where students are not only learning to use a HUD for the first time, but are also being exposed to an entirely new regime of flight. The air-to-ground environment is no less challenging for students who have never delivered ordnance through the use of a HUD or executed dive deliveries at night. Tailored reject sub-modes that could be instructor configured and selectable in-flight show potential for facilitating development of the proper scan and reducing the time required for students to gain proficiency. Once proficient, the introduction of the additional HUD data would not negatively impact task performance.

With the selection of the AV-8B to be the lead platform in implementation of the Open System Core Avionics Requirement (OSCAR), a rehosting of the Operational Flight Program (OFP) involving a hardware independent, layered software architecture, based on object oriented design using a Higher Order Language (HOL), has come the opportunity to optimize the HUD design of the AV-8B³. This effort would not only yield

immediate benefits in the areas of safety and mission execution, but would also lead to more effectively accomplishing the eventual transition to helmet mounted displays.

SCOPE

This thesis focuses on an attempt to simplify and standardize the current HUD displays and improve the tailoring of reject sub-modes that are designed to decrease the amount of data being displayed. Only the takeoff and landing and the air-to-ground master HUD mode are addressed, except for a brief mention of the air-to-air master mode, due to the sensitivity of air-to-air mode information and displays and the relative simplicity and associated low cockpit tasking associated with the navigation mode. The potential benefits of HUD modes that could be instructor configured and selectable in-flight to facilitate the development of the proper scan and reduce the time required for students to gain proficiency are also presented. Though this thesis specifically investigates the AV-8B, the general concepts and ideas are applicable to all HUD aircraft. Research and studies completed for displays of other aviation platforms were considered while developing proposed revised HUD designs for the AV-8B aircraft.

METHOD OF RESEARCH

Research and evaluation of proposed HUD designs was accomplished through the use of two control groups. The first group consisted of 10 military pilots, all with over 1000 hours of HUD experience in either the F/A-18 Hornet or the AV-8B Harrier. The second group also consisted of ten individuals, though they were either flight test

engineers or former military pilots with no HUD experience now working in flight test but in non-aviation capacities.

Both groups were used in evaluating the effect of simplifying displays by presenting them with snapshots of HUD presentations and evaluating the accuracy with which they could discern information. Additionally, the participants were asked to accomplish tasks using the AV-8B radar test bench involving the monitoring and manipulation of one, two and three dynamic variables on the HUD. The inclusion of the non-HUD experienced group allowed for the evaluation of simplified HUD designs for initial development of efficient HUD scans.

CHAPTER 2

SYSTEM DESCRIPTION

AV-8B HARRIER II PLUS AIRCRAFT

The AV-8B Harrier II Plus, shown in figure 2-1, is a single seat, single engine, transonic Vertical/Short Take-Off and Landing (V/STOL) light attack aircraft built by McDonnell Aircraft and Missile Systems, a division of the Boeing Corporation. The aircraft has a shoulder mounted super critical swept wing with a fully conformal Leading Edge Root Extension (LERX), trailing edge flaps and ailerons, and a lift improvement device for vertical operations. The aircraft is equipped with an integrated weapons system including the airborne gun or searchlight directing radar (APG-65) and is capable of carrying up to 9,000 lb. of conventional ordnance on seven external weapon stations. A Rolls-Royce Pegasus F402-RR-408 twin spool, axial flow turbofan engine with an uninstalled, sea level, static short lift wet thrust rating of 23,400 lbs, powers the aircraft. A more detailed description is available in the aircraft flight manual².

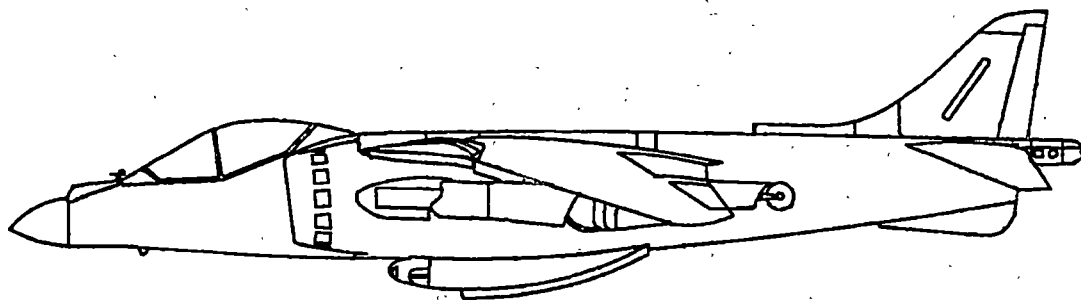


Figure 2-1. AV-8B Harrier II Plus Aircraft

The uniqueness of the V/STOL environment, combined with the multiple sensor management required in the execution of the various missions of the Harrier, impose a high level of task loading on the pilot. This task loading, epitomized by the requirement to operate in the low-altitude arena with night vision goggles while managing radar, digital moving map, forward-looking infrared (FLIR) and laser targeting sensors, make the optimization of the HUD critical to safe and successful mission execution⁴.

APPLICABLE AIRCRAFT COMPONENTS

Heads Up Display

The HUD in the AV-8B is located on top of the main instrument panel, as shown in figure 2-2, and is the primary flight control and weapon delivery instrument. The

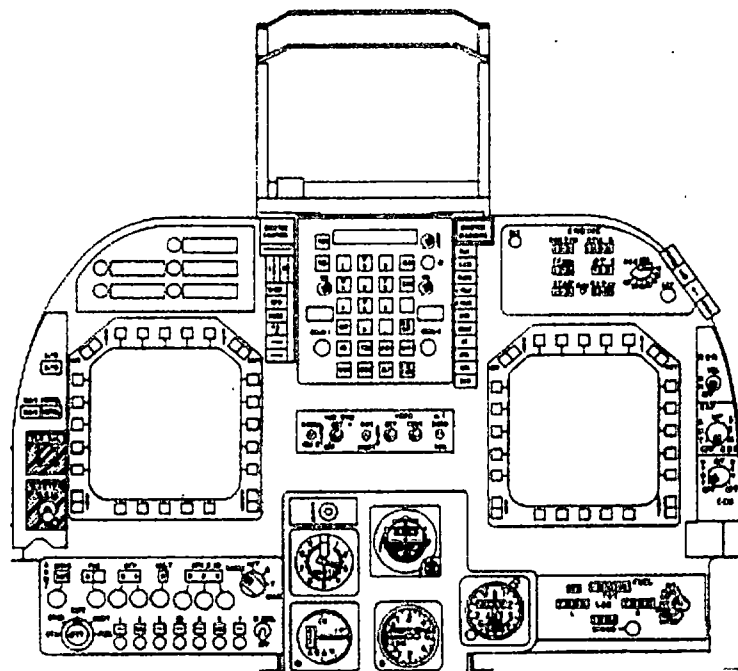


Figure 2-2. HUD and Instrument Panel Layout

HUD receives navigation and attack information via the Display Computer (DC) from the Mission Systems Computer (MSC) and projects the appropriate symbology on a combining glass for heads-up viewing in the pilot's forward field-of-view (FOV).

The HUD presently incorporated in the Night Attack and Radar variant of the AV-8B has a 22 deg total-field-of-view and a 16 by 20 deg instantaneous FOV that is visible to the pilot at any specific time and shown in figure 2-3. Additionally, Forward-Looking Infrared (FLIR) imagery can also be displayed on the combining glass, though with a reduced FOV, also shown in figure 2-3. In the event of a HUD failure, the DC can display the same symbology on either of two Multipurpose Color Displays (MPCD).

HUD power is controlled through a combination on/off and brightness control knob located on the aircraft Up-Front Control (UFC). An adjacent three-position switch

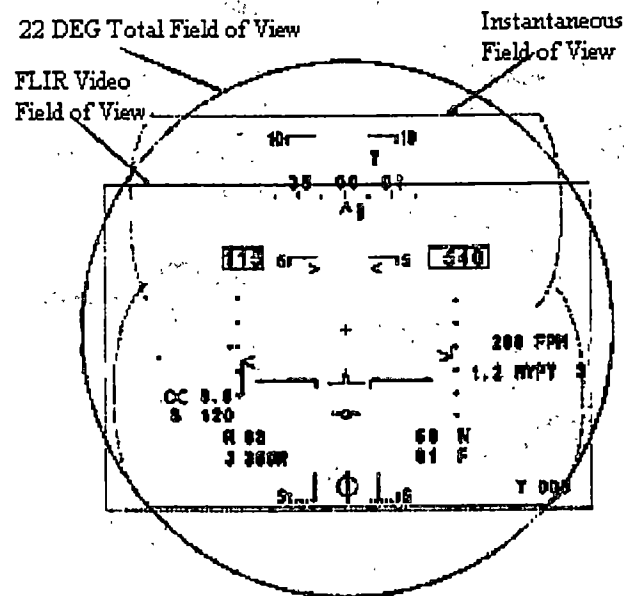


Figure 2-3. HUD Field-of-VIEWS

toggles the HUD display between the Normal, Reject 1 and Reject 2 levels of information displays. Push buttons on the left instrument panel allow for transition between the four master mission modes of display; Navigation, Vertical/Short Takeoff and Landing (V/STOL), Air-to-Ground (AG) and Air-to-Air (AA). AG and AA master modes can also be displayed on the HUD via selection of the associated weapons.

A two-position switch also located on the UFC control allows for selection of either the radar or barometric altimeter as the altitude source for display in the HUD.

Mission Systems Computer

The MSC is referred to as a standard general purpose stored program real-time computer with core memory. It is the central controlling computer for all aircraft systems operations. It is controlled by a three-position switch on the pedestal between the rudder pedals, behind the control stick. The AUTO position allows the MSC to assume control of the multiplex data bus (MUXBUS) under normal conditions and provides the display computer as a backup mode of operation in case of an MSC failure. The OFF position secures power to the MSC and utilizes the DC for a backup mode of operation. Selection of the override (OVRD) position inhibits the backup mode of operation if the MSC is functioning properly. If in the backup mode at the time of selection, OVRD will reapply power to the MSC in an attempt to reset MUXBUS control to the MSC from the DC.

Advanced Mission Computer

An assessment of the current capabilities of the hardware installed on the AV-8B, specifically related to the increased air-to-air radar functionality that the OSCAR upgrade was to bring, indicated that the current operational flight program, with existing functionality, was already running within the last 5-10% of the capacity of the processors. This finding led to a requirement for the Advanced Mission Computer (AMC) to replace the current MSC. Though the display computer was not included in the higher order language upgrade, software modifications were required to accommodate changes driven by the AMC and associated added weapons functionality.

The AMC being incorporated was initially the F/A-18 MC replacement that was part of the Advanced Mission Computer and Displays (AMC&D) Program for the F/A-18. Part of the decision process that led to the selection of the AMC to upgrade the MC capability was driven by the desire to purchase a common mission computer for both the AV-8B and the F/A-18, thereby hopefully realizing some cost savings. The AMC is intended to provide the excess processing performance and functionality to accommodate the increased requirements of advanced medium range air-to-air missile (AMRAAM) support and displays and follow-on upgrades and weapon systems such as the Joint Direct Attack Munition (JDAM). As currently configured, the AMC is a full Airborne Transportable Rack (ATR) chassis incorporating a General Purpose Processor Module (GPPM), an Input/Output module, three dual redundant 1553 multiplex data bus channels, two power supply modules and five spare card slots.

Display Computer

The display computer drives the HUD and MPCD via mutually redundant display channels. It also provides a backup mode of operation for aircraft avionics and weapons systems in the case of an MSC failure. A two-position switch drives the DC display channels. The primary (PRIM) position randomly selects one of the two channels for operation at power-up. If there is a channel failure, the computer will automatically select the alternate channel. The alternate (ALTER) position manually selects the alternate display channel for operation if an automatic reversion does not occur.

As previously mentioned, the display computer was not selected for upgrade under the open systems core avionics requirement program. The initial software modification effort was to be directed at accommodating the DC interface with the AMC and the added weapons functionality. However, the added weapons functionality and associated displays pushed the DC beyond its limits of performance. Exhausting the capabilities of the DC turned an opportunity to redesign the HUD displays into a necessity in order to reduce HUD write-time requirements on the DC and leave processing capability for future weapons and displays.

Bus Architecture

Figure 2-4 depicts the avionics bus structure of the AV-8B. The architecture incorporates two buses plus a third bus on Radar equipped AV-8B's. The MC (being replaced by the AMC) provides control for the systems using Bus 1 and Bus 2 and interfacing with the

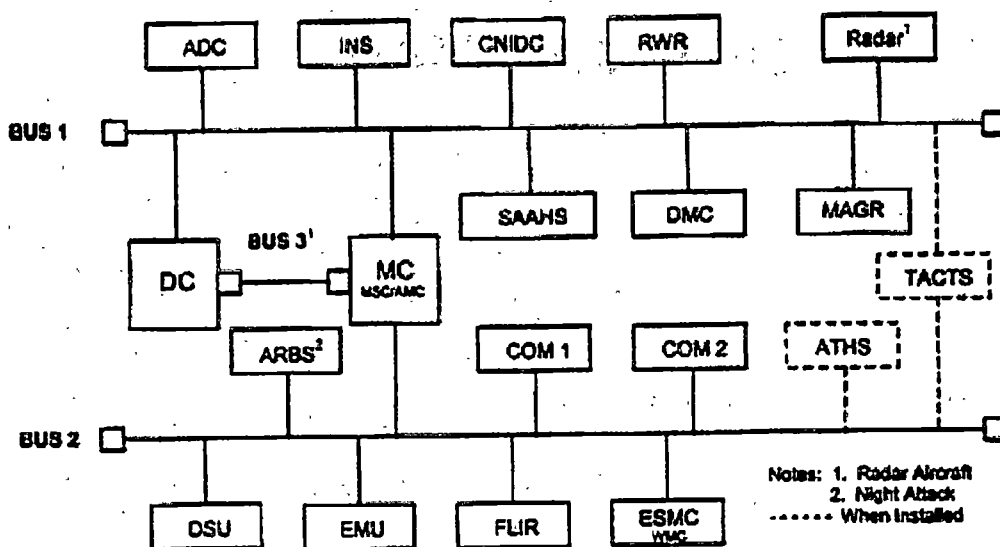


Figure 2-4. AV-8B Bus Architecture

aircraft remote terminals. Bus 3 allows for direct communication between the MC and the DC.

LABORATORY FACILITIES

The AV-8B simulation and test bench facilities at the AV-8B Joint Systems Support Activity (JSSA), Naval Weapons Test Squadron China Lake (NWTSC), California were used in developing and evaluating proposed HUD designs. The test bench facilities can be configured to represent all variants and integrate all avionics aspects of the AV-8B aircraft, to include radar, FLIR and laser targeting imagery. The test bench facilities also allow the DC software to be modified and manipulated as the displays are projected on a HUD, thus allowing for a real time comparison and

assessment of the display designs. The simulation facilities integrate actual aircraft cockpit controls and displays with the avionics test benches and provide a limited out-of-the-cockpit scene simulation with a HUD display overlay. This facility was used in evaluating aircrew proficiency at using the displays based on different HUD designs and quantity of data presented.

CHAPTER 3

VERTICAL/SHORT TAKEOFF AND LANDING HUD MODE

NORMAL MODE DISPLAY LEVEL

The HUD mode used during takeoff and landing is referred to as the Vertical/Short Takeoff and Landing (V/STOL) mode. The primary V/STOL mode is referred to as the normal mode with subsequent reject sub-levels referred to as Reject 1 and Reject 2. The V/STOL normal mode, shown in figure 3-1, provides all data required for successful accomplishment of takeoff and landing tasks. Altitude and airspeed are

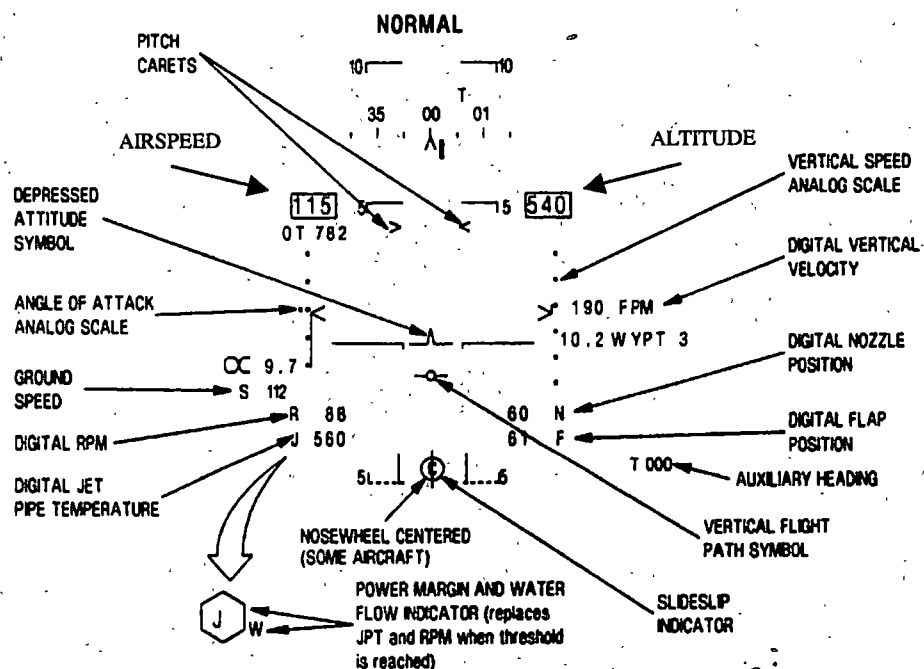


Figure 3-1: Vertical/Short Takeoff and Landing HUD Mode (Normal)

presented in a larger font size than the rest of the parameters in an effort to facilitate their recognition⁵. In addition, though there is little evidence to suggest that duplication of information in various formats increases pilot performance⁶, some of the information is provided in multiple formats. A total of 19 different parameters are provided to the pilot. Of these, aircraft heading is provided by a heading tape located across the top of the HUD display and by a numerical display located at the bottom right hand corner of the HUD. Similarly, aircraft angle of attack (AOA) is displayed through an analog scale and through a numerical display, though these are collocated on the left of the HUD display. Aircraft vertical velocity is displayed through an analog scale vertical speed indicator (VSI) and a numerical display, both collocated on the right side of the HUD, and when below 60 KCAS through the conversion of the vertical flight path symbol to an additional VSI scaled to the degrees above or below the horizon multiplied by 100. This brings to 22, the total number of items that compete for the pilot's attention during the takeoff and landing phase.

Further complicating the display is the dynamic nature of various parameters. Though visual performance can be significantly improved by object motion or flashing⁷, the opposite effect can be easily induced and little consideration appears to have been given in the design of the AV-8B HUD. Multiple parameters may flash at different rates, transform in nature and appear or disappear based on predetermined conditions. The vertical flight path symbol will flash upon reaching the upper or lower boundaries of the HUD display. The engine revolutions per minute (RPM) and jet pipe temperature (JPT) indications will transition from a digital readout to a hexagonal analog display as upper

limits are reached and the box around the airspeed readout will appear as the proper speed at which to lower the nozzles is reached during the takeoff roll. Reject sub-modes 1 and 2 are an attempt to reduce the number of items that attract or distract the pilot's attention, thereby facilitating scan and task execution.

REJECT 1 MODE DISPLAY SUB-LEVEL

Selection of the Reject 1 mode, shown in figure 3-2, still provides the same number of parameters to the pilot, though clutter is reduced through the elimination of duplication of VSI and AOA information. In Reject 1 mode, only the analog scales are provided for these parameters. Eliminating the conversion of the RPM and JPT digital

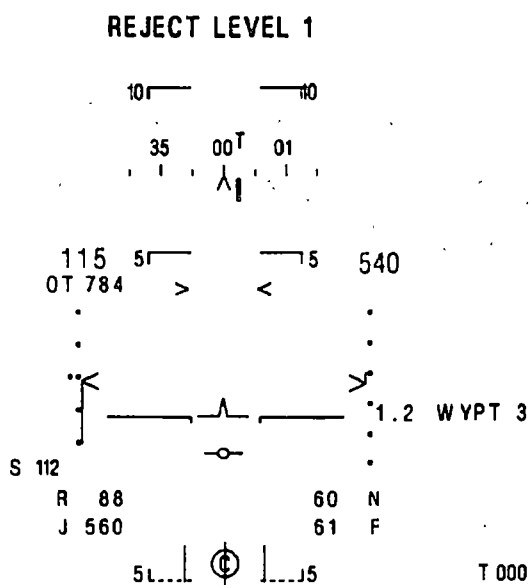


Figure 3-2. Vertical/Short Takeoff and Landing HUD Mode (Reject 1)

readouts to a hexagonal analog display as the upper limits are reached also reduces the dynamic nature of the display.

A further attempt to reduce the clutter present in the normal mode is the elimination of the boxes that frame the airspeed and altitude readouts. A dangerous result of this change is the confusion that can occur when a pilot is executing a takeoff in a HUD mode other than that to which he is accustomed. In the Reject 1 mode, below the airspeed at which the nozzles should be rotated down during takeoff roll, the pilot will see a box surrounding the airspeed display. If the pilot mistakenly believes he is in the Normal mode, he will rotate the nozzles (in normal mode, the appearance of the box being the signal that nozzle rotation airspeed (NRAS) has been reached) before sufficient wing lift is being generated and will cause the aircraft to momentarily become airborne with a subsequent bounce back to the runway as a result of insufficient wing lift being generated to sustain flight. The rate of descent experienced during this bounce combined with the unpredictable directional response of the aircraft as it returns to the runway can easily lead to damaging the fragile outriggers or departing the runway surface. If inadvertently flying in the Normal mode, when Reject 1 mode is believed to have been selected, the same sequence of events can take place. A simple solution is to remove the boxes from both modes, other than on the ground prior to nozzle rotation airspeed being reached. Removal decreases HUD clutter and standardizes the function of the disappearing box as the indication that NRAS has been reached during the takeoff roll. This recommendation would also serve to reduce HUD write-time requirements on the display computer.

Further proposals applicable to the Reject 1 mode are to eliminate the numerical heading indicator in the lower right corner of the HUD to decrease clutter and to eliminate the aircraft flight path symbol as the airspeed is reduced below 60 KCAS. At different points during decelerations to a hover in the simulation facility, subject aircrew were asked if the flight path symbol was currently functioning as a VSI or flight path symbol. Over 80% responded flight path symbol without ever referencing KCAS, thus pointing at a prevalent assumption that is never correct below 60 KCAS. However, subjects also reported use of the analog tape along the right side of the HUD as the primary source of vertical velocity. The apparent lack of attention paid to the flight path symbol during this phase of flight serves to reduce the occurrence of risk caused by possible misinterpretation of the flight path symbol and simultaneously advances the case for its removal.

REJECT 2 MODE DISPLAY SUB-LEVEL

The Reject 2 mode, shown in figure 3-3, further attempts to reduce the amount of HUD clutter by eliminating multiple parameters from the display. Unfortunately, many task essential parameters are removed, precluding execution of takeoff and landing tasks solely by scanning the HUD and forcing the pilot to look inside the cockpit to acquire the necessary information. All of the changes resident in Reject 1 exist in Reject 2. In addition, flap and nozzle angle indications are removed from the lower right of the display, and RPM, JPT and groundspeed are removed from the lower left. Clutter and the dynamics of the display are reduced through the elimination of the flight path symbol.

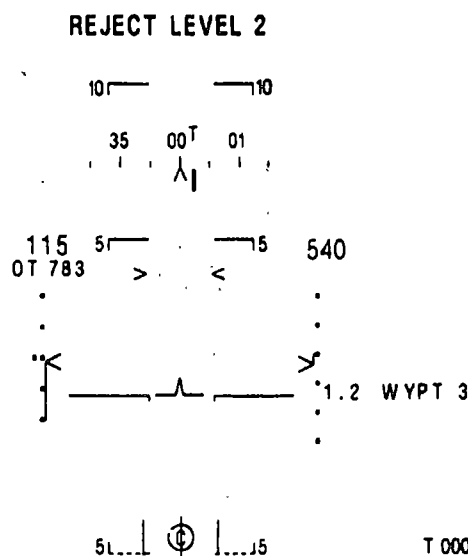


Figure 3-3. Vertical/Short Takeoff and Landing HUD Mode (Reject 2)

The removal of nozzle angle from the HUD forces the pilot's scan to be momentarily directed inside the cockpit during the critical takeoff and landing phases of flight. During a short takeoff, after initial application of the nozzles to the short takeoff (STO) position, the nozzles must be rotated aft to no less than 25 degrees before the flaps must be taken out of the short takeoff and landing (STOL) mode. During landing, nozzle angle is the determining factor of closure rates during hovering approaches and of ground speed during rolling vertical landings (RVL's). During fixed nozzle/variable throttle slow landings (FNSL's) and variable nozzle/fixed throttle slow landings (VNSL's), nozzle angle will determine the ratio of lift being generated between the wings and engines. A better alternative would be to leave nozzle angle in the HUD, though flap angle could be removed since it is simply a function of nozzle angle in the takeoff and landing regimes.

The removal of both RPM and JPT also forces the pilot's scan to be directed inside the cockpit. During both takeoff and landing, engine performance will be limited either by RPM or JPT, depending on the current ambient conditions. During decelerating approaches to vertical landings (VL's), the determination of whether or not the landing can be completed is based on performance margin present as the aircraft decelerates through 60 KCAS. At this critical point, as the aircraft is transitioning from wing-borne to thrust-borne flight, requiring the pilot to scan inside the cockpit to locate and determine the limiting performance parameter, either RPM or JPT, disrupts the outside scan critical to safely transitioning to hovering flight. A preferable solution would be to only display the more limiting parameter. This would not only reduce clutter in the HUD, but would also relieve the pilot from having to determine the limiting parameter during this critical phase of flight.

Finally, removal of groundspeed from the HUD eliminates the only source of this information available to the pilot. Since RVL's are based on a 60 kt groundspeed approach (for short field and unprepared surface landings while still maintaining some wing lift), RVL's cannot be performed in Reject 2 mode. This limitation makes it more desirable to maintain a groundspeed display in the Reject 2 mode.

An improved and more useful Reject 2 mode is made more important by the possibility that if HUD write -time requirements are not reduced to a level manageable by the display computer, triggers may be inserted that automatically revert the HUD to a lower reject level in order to maintain an acceptable refresh rate on the HUD display.

The limited utility of the current Reject 2 mode would result in tremendously reduced mission capability in the event of a triggered reversion.

CHAPTER 4

AIR-TO-GROUND HUD MODE

NORMAL MODE DISPLAY LEVEL

The HUD mode utilized during the execution of ordnance delivery is the Air-to-Ground (AG) mode. As with the V/STOL modes, the primary mode is referred to as the normal mode with the subsequent reject sub-modes referred to as Reject 1 and Reject 2. The AG normal mode, shown in figure 4-1 in the auto delivery configuration, provides the pilot with the information required for successful execution of ordnance delivery.

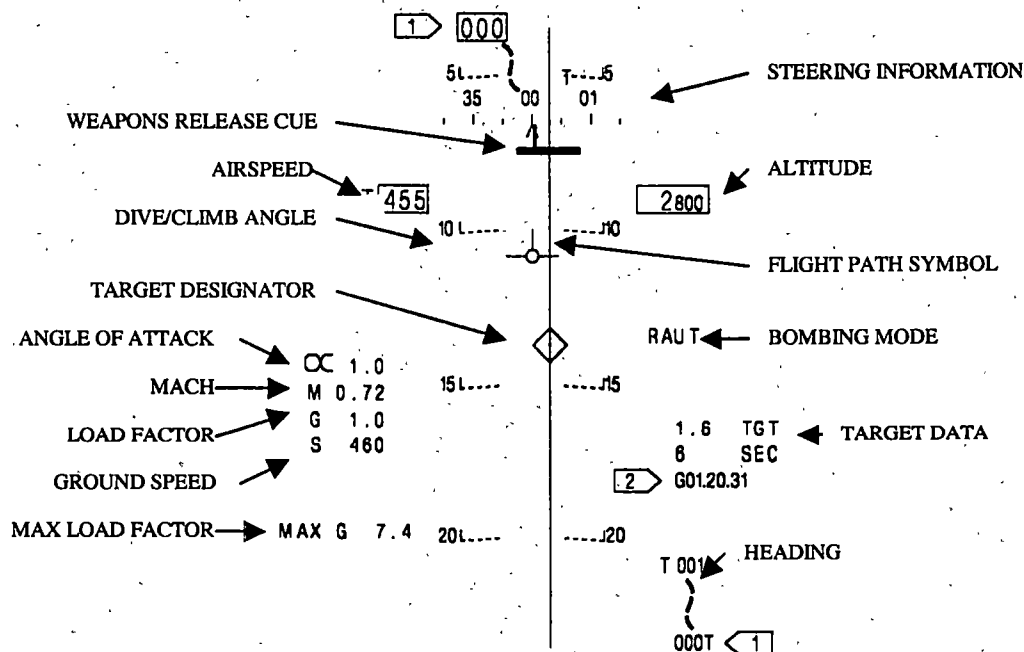


Figure 4-1. Air-to-Ground HUD Mode (Normal)

A total of 18 different parameters are presented, but unlike the V/STOL normal mode which provides many parameters in redundant formats, the only data redundancy is in the display of heading, both through the heading tape and by a numerical display at the bottom right hand corner of the display. Similar to the V/STOL normal mode, the AG normal mode also incorporates boxes around the altitude and airspeed readouts.

Improvements to the normal mode that should be considered include reducing HUD clutter by removing the secondary heading display in the lower right corner and also removing the boxes around the airspeed and altitude readouts. This deletion of the boxes would provide consistency of display if the boxes were also removed from the V/STOL mode in order to reduce clutter and confusion about NRAS cueing. A secondary benefit would be alleviation of HUD write-time requirements. A further effort to reduce clutter would be the removal of the MAX G readout after a specified period of time. The MAX G readout is not present until the pilot has applied greater than 4.5 g's to the aircraft. After meeting that initial threshold, the display will remain in the HUD permanently and be updated if the displayed value is exceeded. The intent is to notify the pilot that he may have pulled near to the maximum allowable load of 8 g's. Displaying the data for only a specified period of time after the event (approximately 30 seconds), would serve to alert the pilot of the load excursion and then clear the HUD display.

Additional parameters not displayed in figure 4-1, that can be displayed on all the AG modes and add to the dynamic nature of the AG display are an automatic targeting handoff system (ATHS) message, a pull-up cue, a weapon inhibit cue, a hot gun cross, an out of field of view dashed designation diamond and an arrow showing target direction.

REJECT 1 MODE DISPLAY SUB-LEVEL

Selection of the Reject 1 mode, shown in figure 4-2, only provides 1 less parameter to the pilot, real time. In the normal mode this is displayed on the lower right hand side, beneath the distance and time to target readouts. An additional reduction in clutter is the removal of the boxes surrounding the airspeed and altitude readout. A final change is the displaying of AOA in an analog tape instead of a numerical readout.

Similar to the normal mode, removal of the redundant heading readout at the lower right hand corner of the display would reduce clutter and aid in alleviation of HUD writ-time problems.

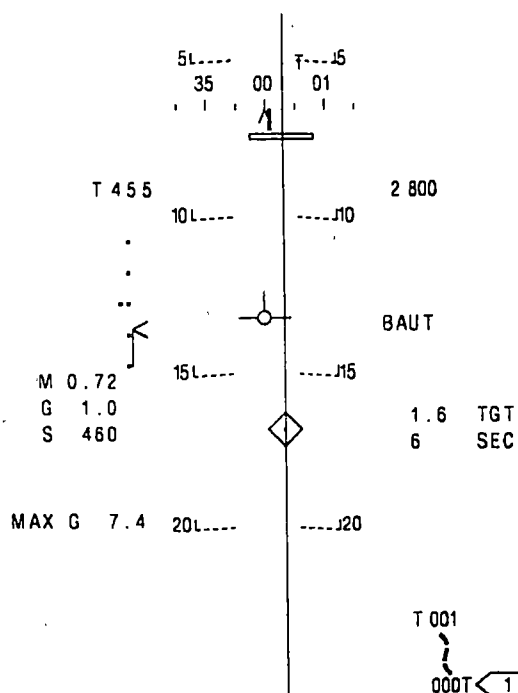


Figure 4-2. Air-to-Ground HUD Mode (Reject 1)

REJECT 2 MODE DISPLAY SUB-LEVEL

The Reject 2 mode, shown in figure 4-3, further attempts to reduce the amount of HUD clutter by eliminating multiple parameters from the display. All changes resident in Reject 1 apply to Reject 2. In addition, both the heading tape and numerical readout are removed, as are AOA, Mach number and groundspeed displays.

Removal of the heading tape greatly reduces the amount of data presented at the top of the display, though simultaneously deleting the numerical heading indication from the lower right effectively eliminates all heading information from the HUD. During the delivery of laser-guided weapons or the performance of close-air-support (CAS) missions, restricted run in headings are commonly imposed on the pilot. Lack of any

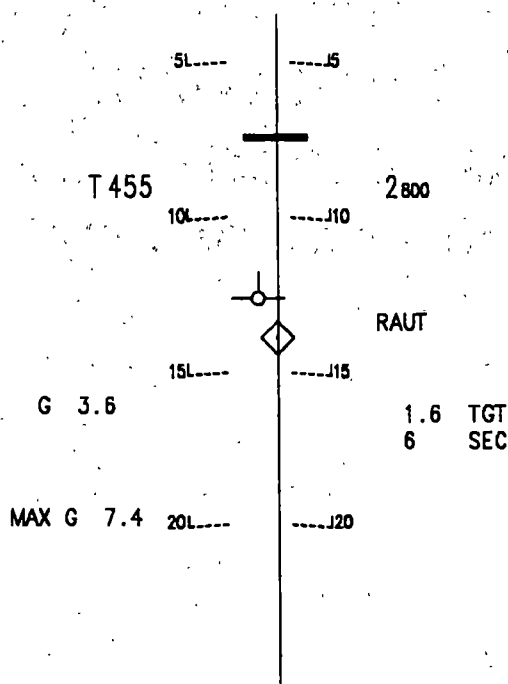


Figure 4-3. Air-to-Ground HUD Mode (Reject 2)

HUD presentation of aircraft heading would require the pilot to focus his scan inside the cockpit in order to discern heading before continuing with the weapons delivery. Though the elimination of the heading tape does reduce clutter at the top of the HUD, in this case, maintaining the numerical heading at the lower right corner of the display would permit the pilot to maintain his scan on the HUD and target area.

AOA, Mach number and groundspeed are not required data during weapons delivery, and though Mach number and groundspeed may be of some use during target ingress, and AOA may be of use in post flight weapons delivery assessment, they do not preclude accurate delivery of ordnance or lead the pilot to scan inside the cockpit. Their removal does allow the pilot to monitor g applied during the pull out more effectively as this now becomes the only numerical parameter in the lower left portion of the HUD, eliminating any distracters.

As with the V/STOL Reject 2 mode, the threat of an uncommanded or triggered degrade to a reject sub-level favors the addition of data, the heading tape, to the reject sub-level in order to increase its utility to the pilot.

TARGET DESIGNATIONS

All three display levels in the air-to-ground mode incorporate a diamond to designate a surface target for which an inertial navigation system (INS) driven targeting solution has been generated. This diamond is fixed to the horizon, so that as the aircraft rotates, the diamond remains oriented as a diamond in relationship to the earth and the horizon bars in the HUD. Similarly, a square is used to designate a surface target for

which a dual-mode tracker (TV or Laser) targeting solution has been generated. This square is also fixed to the horizon, and remains a square, relative to the horizon bars, regardless of aircraft orientation. This mechanization presents information to the pilot in an instinctive and unambiguous manner⁴. Figure 4-4 below illustrates both an INS designation with the aircraft level and turning and a TV designation with the aircraft level and turning, as shown by the orientation of the aircraft symbol.

The air-to-air mode originally only incorporated a square to identify targets for which there was a radar track. This square, unlike the air-to-ground mode, is not fixed to the horizon, but rotates with aircraft attitude, matching the aircraft symbol. Figure 4-5 illustrates the aircraft with a radar track in both level and turning flight. Allowing the square to rotate, though not consistent with air-to-ground designation mechanization was

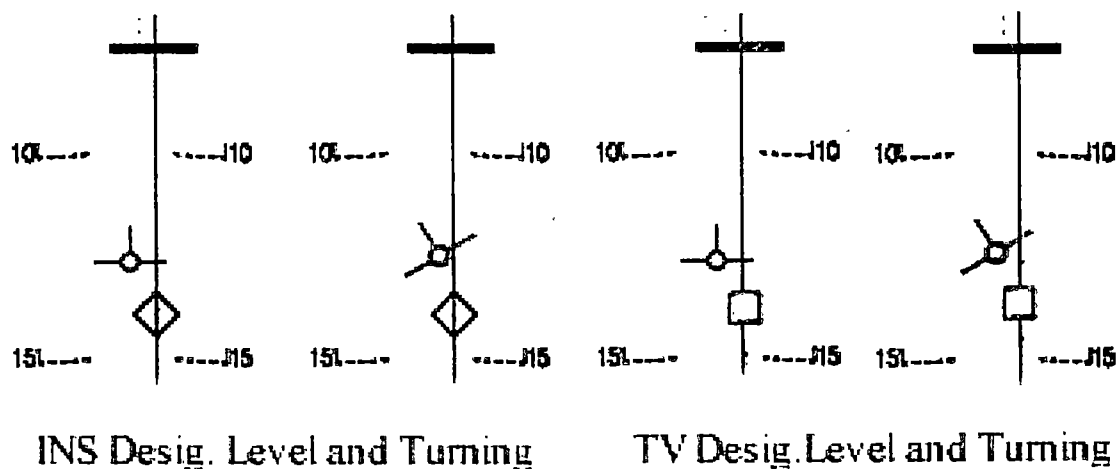


Figure 4-4. Level and Turning INS and TV Designation Symbology

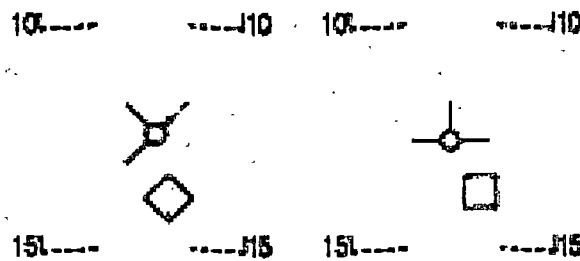


Figure 4-5. Turning and Level Radar Track Designation Symbology

considered acceptable since regardless of the symbol orientation, it could only be interpreted as airborne target location.

The upgraded radar functionality brought about by the OSCAR program has increased air-to-air functionality, causing a square or diamond to now be displayed based on radar targeting information. However, the mechanization of this display currently still allows for the square, and now diamond, to rotate with aircraft orientation. This mechanization introduces ambiguity, making interpretation of the symbol a difficult task, further complicated by the contrasting mechanization existent in the air-to-ground mode.

During laboratory simulations, subjects were asked to evaluate the existing air-to-air radar track mechanization and to compare it to the current air-to-ground mechanization. The subjects were then shown the same air-to-air displays, but with the square or diamond fixed to the horizon as in the air-to-ground implementation. A consensus was reached that having the symbols fixed to the horizon successfully removed

ambiguity as to the nature of the symbol, diamond or rotating square. A further benefit is the consistency between both the air-to-ground and air-to-air mode mechanizations.

CHAPTER 5

TRAINING HUD MODES ASSESMENT

GENERAL

Though the HUD has shown great utility in the presentation of information to pilots, this utility has led to a perceived lack of need for training in its proper and optimum usage. Current military training for pilots in the use of the HUD is almost non-existent both in terms of initial and recurrent training⁸. The potential utility of tailored reject sub-modes for facilitating development of the proper scan and reducing the time required for students to gain proficiency in HUD usage was evaluated through the use of two control groups. The first group consisted of 10 military pilots, all with over 1000 hours of HUD experience in either the F/A-18 Hornet or the AV-8B Harrier. The second group consisted of ten flight test engineers or former military pilots with no in-flight HUD experience, currently working in flight test but in non-aviation capacities. The two groups were subject to both static and dynamic HUD evaluation exercises.

Static evaluation exercises involved displaying snapshots of HUD presentations and evaluating the accuracy with which the information could be discerned. Dynamic evaluation exercises utilized the AV-8B simulation facility and involved the monitoring and manipulation of one, two and three dynamic variables on the HUD. Additionally, a collateral non-flight control associated task was introduced to serve as a typical in-flight distracter during the exercise.

STATIC EVALUATIONS

Method of Evaluation

Static evaluations were accomplished by creating a simplified HUD image that contained three numeric parameters (altitude, nozzle angle and engine RPM), one analog parameter (angle of attack) and two graphical parameters (aircraft pitch attitude and sideslip). A sample slide is included in Appendix A, with a representative HUD presentation shown in figure 5-1. A sample image was provided to all participants for familiarization prior to the evaluation. Twenty slides were created with varying values for each of the parameters. Prior to each slide being shown, a slide delineating the three parameters to be identified was shown, followed by the subject slide being presented on a screen for 3 seconds. Subjects were asked to write down the three required parameters from each slide.

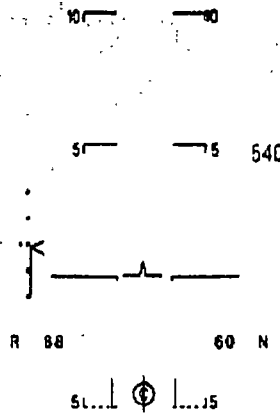


Figure 5-1. Simple HUD

Fourteen days following the simplified HUD image exercise, the subjects were again presented with a sample slide of a HUD image for familiarization, but this slide was representative of the V/STOL reject 1 sub-mode currently employed in the AV-8B. A sample slide is included in Appendix A, with a representative HUD presentation shown in figure 5-2. The method of test was the same as for the simplified HUD image, but subjects now had to discern the three delineated parameters from a greater number of competing and potentially distracting numeric, analog and graphical parameters. A two week delay between the exercises was included in an attempt to minimize the effect of learning experienced during the initial simplified HUD evolution from impacting the results of the follow on exercise.

Results

Post exercise review of the data showed the non-HUD experienced group to have identified and annotated the delineated parameters with an accuracy of 87% for the

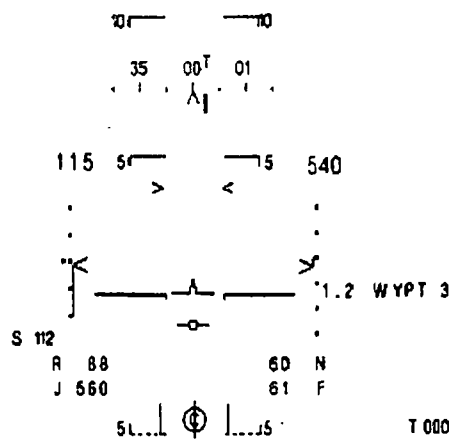


Figure 5-2. Complete Reject Level 1 V/STOL HUD

simplified HUD image and 73.5% for the more complete HUD image. The HUD experienced group demonstrated 97.67% accuracy for the simplified HUD and 88.5% accuracy for the more complete HUD image. Results are graphically depicted in figure 5-3 with the raw data included in Appendix B. Though the expected result of the non-HUD experienced group achieving greater accuracy with the simplified HUD display served to provide a level of validation for the implementation of training HUD modes, the trends in accuracy and learning during the execution of the exercise provided an insight into the possible values of these training modes and of their likely diminishing returns as aircrew gain experience and proficiency with a HUD.

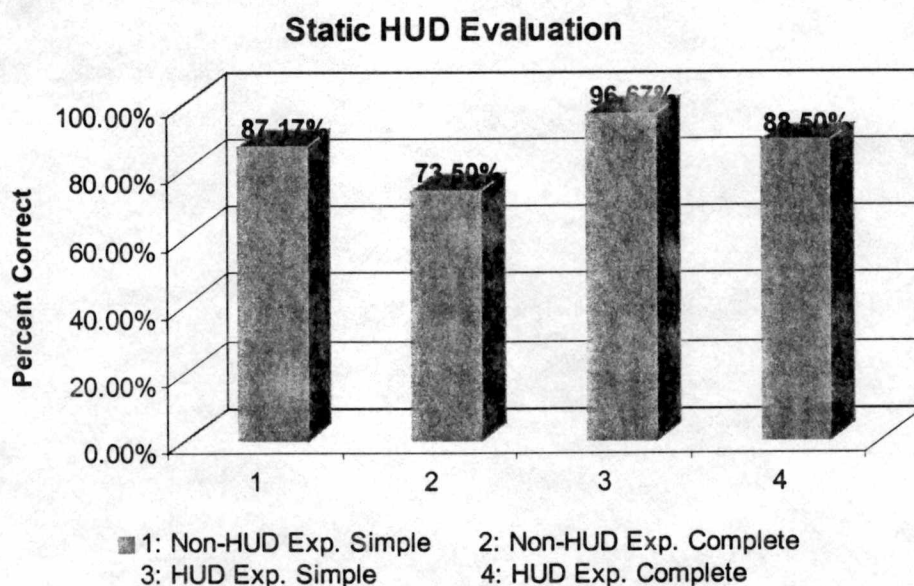


Figure 5-3. Static HUD Evaluation Results

The HUD experienced group demonstrated a fairly constant level of proficiency throughout the presentation of the 20 slides in each category as shown by figure 5-4. The absence of a marked increase in proficiency as the evaluation progressed, both with the simplified and complete HUD image, is likely an indication of the near maximum level of proficiency of HUD interpretation already attained by these aircrew. Though barely discernable, the slopes of the increase in proficiency for each type of HUD image were nearly equal, with values of .0036 for the simple HUD and .0044 for the complete HUD, as calculated by the inclusion of linear trend lines, Appendix C. This leads to the possible conclusion that once aircrews reach a certain level of proficiency, learning may

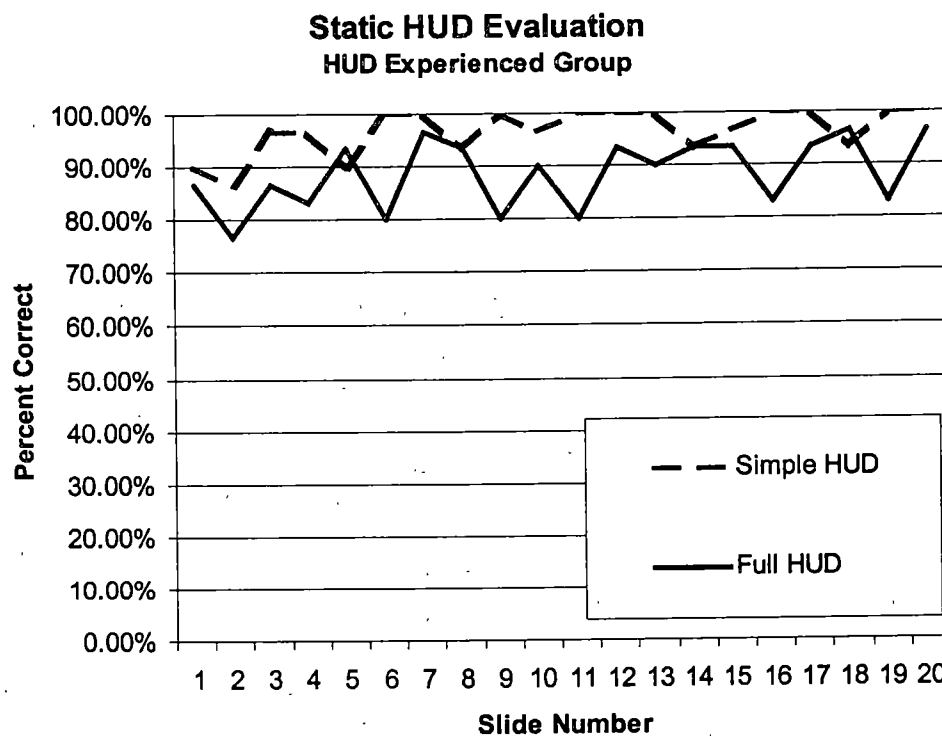


Figure 5-4. HUD Experienced Group Results

not be aided by reduction of HUD parameters. However, even at this level of proficiency and familiarity, the lower level of accuracy achieved by the experienced aircrew with the complete HUD image, 88.5% instead of 96.67% for the simplified HUD, serves to underscore the value of eliminating unnecessary parameters from HUD imagery for operational accuracy.

The non-HUD experienced group, though demonstrating a lower level of accuracy, figure 5-5, demonstrated a greater increase in proficiency during the execution of the evaluation. Slopes of linear trend lines associated with the data, Appendix C, were .0161 and .0101 for the simple and complete HUD images, respectively. The steeper learning slopes resulting from the non-HUD experienced group were to be expected, and

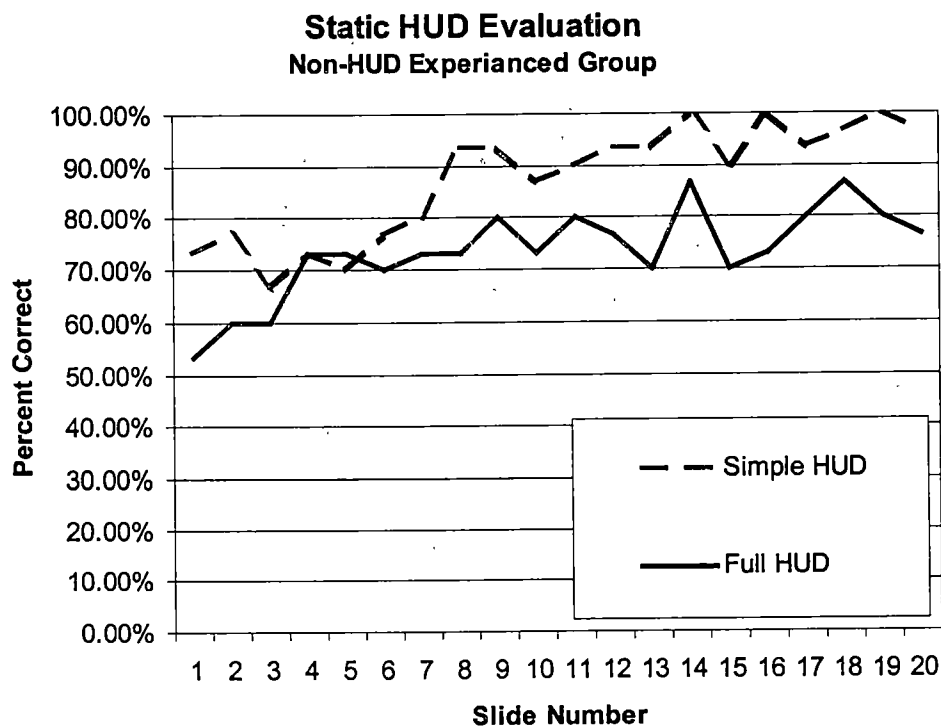


Figure 5-5. Non-HUD Experienced Group Results

serve only to reaffirm the fact that the untrained group has the greater potential for improving performance. Of greater interest is the 60% steeper slope in the increase in proficiency of the non-HUD experienced group when utilizing the simple HUD image as compared to the complete HUD image. This result serves to validate the potential that simplified and tailored HUD training modes could have in increasing the quality of training and reducing the time to train.

Finally, the smaller difference in performance between the two control groups when presented with the simple HUD instead of the complete HUD, 9.5% versus 15%, further reinforces the belief that simplified and tailored training HUD modes can have a positive impact in the initial phases of flight training.

DYNAMIC EVALUATIONS

Method of Evaluation

Dynamic evaluation exercises utilized the AV-8B radar test bench and involved the monitoring and manipulation of one, two and three dynamic variables on the HUD. Additionally, a collateral non-flight control associated task was introduced to serve as a typical in-flight distracter during the exercise.

The simplified HUD configuration used for the dynamic evaluation was similar to that used for the static evaluation. Parameters presented were altitude, airspeed, heading, ground track and aircraft predicted flight path. A representative HUD presentation is shown in figure 5-6. The complete HUD configuration used for the dynamic portion was

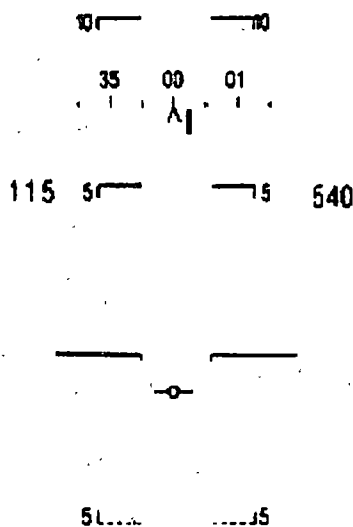


Figure 5-6. Dynamic Evaluation Simplified HUD

the same as used for the static evaluation. These displays were programmed into the display processor of the AV-8B radar test bench. The test bench was then coupled to the simulation station and allowed subjects to control the applicable parameters through actual cockpit controls and displays representatively arranged to include accounting for design eye position of the HUD⁹. Out-of-the-cockpit scene simulation was limited to green earth with blue sky to provide a discernible horizon reference.

Subjects were first asked to maintain a constant altitude with the simple HUD display. Constant airspeed was then introduced as the second task and constant ground track was added as the final task. A crosswind was then introduced into the simulation increasing the workload required to maintain a constant ground track. Finally, the subjects were presented with written information and were asked to read out loud while

maintaining all parameters constant in an effort to further increase their workload. This same process was then repeated with the complete HUD configuration after a two-week delay. As with the static evaluation, the delay between the exercises was included in an attempt to minimize the effect of learning experienced during the initial simplified HUD evolution from impacting the results of the follow on exercise.

Results

Results from the dynamic evaluation served to reinforce some of the conclusions drawn from the static evaluation. For the non-HUD experienced group, deviations from altitude when it was the only parameter required with the simple HUD, averaged 10 to 20 ft. This is within the level of accuracy achievable with the control response in the simulation facility. The introduction of airspeed did not significantly impact altitude deviations, and subjects were able to maintain airspeed within approximately 5 kts of the specified value. The addition of ground track control did not initially impact the magnitude of altitude or airspeed deviations and subjects were able to maintain ground track within 1 to 2 degrees of the specified parameter. However, the introduction of a crosswind into the ground track requirement caused observed altitude deviations of as much as 80 ft from the specified value. The added task of verbalizing written information did not noticeably increase the magnitude of altitude deviations, but did create a nearly continuous sinusoidal variance, as the majority of subjects were unable to capture altitude, but rather made constant periodic corrections to it.

Airspeed control did not vary noticeably. This was likely a result of the thrust axis not being impacted by the small heading and altitude corrections being utilized. Once airspeed was captured in the initial phase of the evaluation, subjects rarely needed to apply throttle corrections. A better involvement of the thrust axis may have been achieved by requiring subjects to change altitudes, thus requiring associated throttle corrections to maintain airspeed within tolerance.

The introduction of a crosswind appeared to lead subjects to concentrate on maintenance of the ground track parameter, as this was the only parameter being externally impacted. This may explain the minimal deviations seen from ground track. This emphasis on ground track, combined with the apparently disassociated airspeed maintenance task, forced the use of the resulting deviations of altitude as the only performance gauge for the exercise.

The subsequent evaluation of the non-HUD experienced group with the complete HUD initially yielded very similar results. Initial observed altitude deviations averaged 10 to 20 ft when altitude was the only required parameter. The introduction of airspeed did not noticeably impact altitude management and airspeed maintenance never became an issue for reasons previously mentioned. The introduction of ground track maintenance again did not have an initial impact on parameter deviations, but as before, the introduction of a crosswind into the ground track maintenance task increased altitude deviations. Excursions of as much as 70 to 80 ft were observed. The only significant difference between the exercises was observed when the reading task was introduced. Where as with the simplified HUD configuration, subjects were able to maintain the

deviations within approximately 80 ft of the prescribed value, deviations of as much as 210 ft were noted with the complete HUD. After the subjects' focus was drawn off the HUD presentation to accomplish the reading task, a longer delay was experienced in reacquiring and reacting to the displayed data on the more complete HUD leading to deviations of greater magnitude. These deviations support the development of simplified HUD designs to improve operator accuracy by allowing more rapid recognition and interpretation of the data pertinent to the specific situation.

The HUD experienced group initially exhibited similar performance with the simplified HUD. Initial altitude deviations were in the order of 10 to 20 ft and airspeed maintenance did not become an issue. The introduction of ground track control did not perceptibly impact parameter deviations. A difference in performance from the non-HUD experienced group was noted with the introduction of crosswind. With the HUD experienced group, the effect of crosswind on the magnitude of parameter deviations was negligible. Also, the inclusion of the reading task failed to produce any noticeable change in performance.

Introduction of the complete HUD to the experienced group yielded comparable results to that of the simplified HUD up to the point of inclusion of the reading task. When using the simple HUD display, even the inclusion of the reading task did not prevent precise altitude control that could be best described as altitude capture. With the introduction of the reading task to the complete HUD display evaluation, though the deviations remained minor, maximum observed deviation were 30 to 40 ft, they became more frequent, again indicating a delay in the reacquisition and reaction to pertinent

information when distracted from the display. However, as in the static evaluation, the reduced magnitude and significance of these deviations by the HUD experienced group points to both the diminishing returns of simple training HUD modes for experienced aircrew and the likely minimal impact of including additional HUD data to displays once aircrew have completed initial training and developed proper scan patterns. The remaining chapters address potential training HUD modes for the takeoff and landing and air-to-ground environments.

CHAPTER 6

V/STOL TRAINING HUD MODES

GENERAL

During training of pilots in the takeoff and landing regimes of flight encountered by the AV-8B, the greatest challenge can be developing the proper scan for the takeoff or landing being performed. Though the V/STOL HUD mode provides all information required for all landings, different information must be prioritized as landing and takeoff type are varied. HUD modes tailored to specific takeoff and landing types by removal of non-essential data may have the potential to provide an accelerated scan development and improved task performance by removing distractions¹⁰. Reduction of HUD imagery will also allow for greater concentration on the external environment, which can be easily overlooked as HUD imagery competes for the pilot's attention¹¹. The following are examples of proposed training modes using the V/STOL Reject 1 mode as the basis.

CONVENTIONAL LANDING

The conventional landing is accomplished with the nozzles in the aft position and the flaps in the AUTO setting. In this configuration, with the gear down, the flaps will remain at 25 degrees. These set of conditions remove the requirement for nozzle or flap indications. Additionally, power settings encountered are such that the upper limits of the RPM or JPT are not encountered, eliminating the need for an RPM or JPT display.

Assuming that landing pattern training will take place in visual meteorological conditions (VMC), the requirement for heading indications can be eliminated as can distance to the selected waypoint or tacan. Since pitch carets are only used as an aid for setting takeoff attitude, these too can be removed.

It can also be argued that rate of descent readout throughout the approach is not required since altitude will be scanned, and that airspeed is not required due to the proper execution of the conventional landing being based on an AOA instead of airspeed. Groundspeed, however, should be retained to ensure that touchdown does not take place above 180 kts, the tire limit.

The resulting display, shown in figure 6-1, would force the student to focus on aircraft altitude, attitude and AOA, by eliminating most other data from the HUD, while not compromising safety. Altitude, attitude and AOA are the critical parameters that

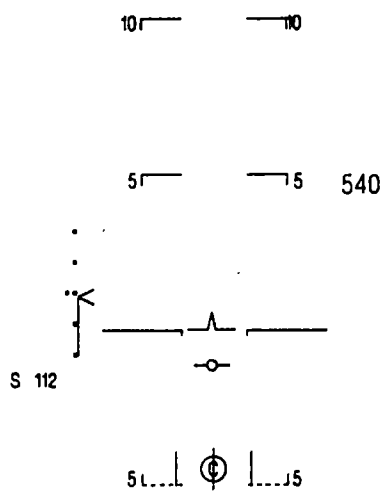


Figure 6-1. Conventional Landing Training Mode

must be monitored and controlled during the execution of a conventional landing. The display of sideslip would ensure that coordinated flight was being maintained throughout the approach, and the display of groundspeed would indicate if there was a possibility of exceeding the maximum allowable tire speed.

FIXED NOZZLE AND VARIABLE NOZZLE SLOW LANDING

The fixed nozzle slow landing and variable nozzle slow landing are accomplished through the manipulation of, in addition to the throttle, the nozzle lever. Depending on airspeed, nozzle setting and flap mode, since these landings can be accomplished in STOL or AUTO flap settings, the flap angle will vary. Due to these variables, nozzle and flap angle must be retained on the HUD. In addition, depending on nozzle setting and ambient conditions, RPM or JPT limits may be approached, requiring that at least the parameter whose limits are closest to being reached be displayed.

As in the previous example, VMC training will be assumed, eliminating the requirement for heading indications and distance to the selected waypoint or tacan. Pitch carets used as an aid for setting takeoff attitude will also be removed.

Again, rate of descent readout throughout the approach is not required since altitude will be scanned, and airspeed is not required due to proper execution of the fixed nozzle slow landing and variable nozzle slow landing being based on an AOA instead of airspeed. Groundspeeds encountered will be well below the 180 kt limit, allowing for deletion of this parameter from the HUD.

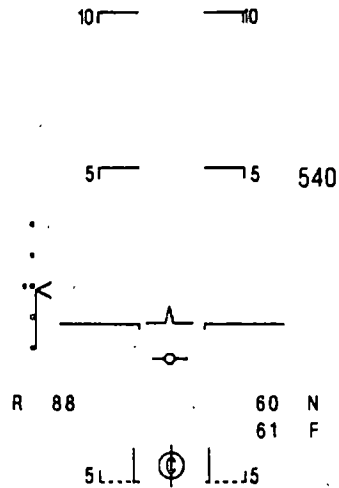


Figure 6-2. Fixed Nozzle/Variable Nozzle Landing Training Mode

The resulting display, shown in figure 6-2, would again force the student to focus on the critical parameters while not compromising safety. Inclusion of nozzle and flap angle would introduce the student to monitoring and managing these flight control parameters, while inclusion of engine RPM or JPT would introduce monitoring of critical performance parameters.

ROLLING VERTICAL LANDING

The rolling vertical landing is performed similarly to the fixed and variable nozzle slow landing except for the only allowable flap setting being the STOL position and the final portion of the approach being based on a groundspeed and glideslope instead of AOA. These differences would lead to two changes to the FNSL/VNSL training mode. The requirement for flap angle display would be eliminated, as these would be at a fixed

setting, but groundspeed would have to be included. Though the final portion of the approach is based on glideslope and groundspeed, AOA will have to be retained as the initial portion of the approach is based on a 10 degree AOA approach until nozzles are lowered to approximately 70 degrees and the groundspeed/glideslope profile is intercepted.

The resulting display, shown in figure 6-3, would reduce the need to scan both nozzle and flap angle but introduce the groundspeed parameter as a variable, instead of just as a limit as used during conventional landings.

VERTICAL LANDING

For a vertical landing, the aircraft is configured as it is for the rolling vertical landing. The difference in execution occurs as the aircraft rolls into the final portion of the approach, the nozzles are brought to the hover stop position instead of to the

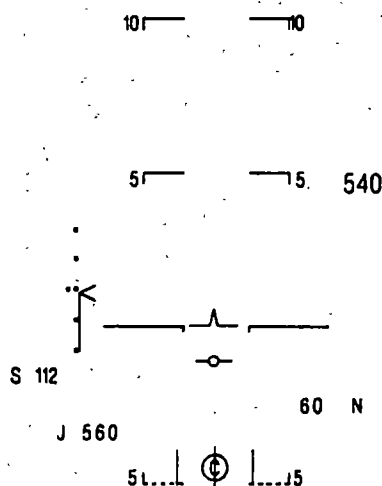


Figure 6-3. Rolling Vertical Landing Training Mode

approximately 70 degree nozzle setting. At this point, the aircraft decelerates rapidly and transitions from wing-borne to thrust-borne flight. Scan requirements will be similar as far as nozzle setting, performance parameters and proper attitude and AOA as the final approach is commenced. Ground speed will also have to be retained in order to accurately assess excess performance status as the aircraft decelerates through 60 kts and wing lift is lost. The resulting display would be the same as used for rolling vertical landings, previously shown in figure 6-3.

CHAPTER 7

AIR-TO-GROUND TRAINING HUD MODES

GENERAL

Much like the V/STOL HUD mode provides a variety of data that is not applicable to every situation, the AG HUD modes also provide parameters that though likely applicable during the execution of a tactical missions, will distract the pilot attempting to learn the basic mechanics of ordnance delivery and weapons employment. Of further importance during the execution of dive deliveries is the requirement to quickly react to continuously changing information in order to not exceed safety thresholds associated with weapon fusing, ordnance fragmentation and terrain avoidance. Reduction of HUD information, to only essential elements, permits for faster reaction time by reducing the delay in recognizing and assimilating critical information¹². The following is an example of a training mode that could be used to accelerate the development of the scan required for successful basic ordnance delivery.

AG TRAINING MODE FOR AUTO DELIVERIES

Using the Reject 2 mode for auto deliveries as the basis, few changes would be required. Though distance to target would be required in order to determine the appropriate attack cone distance, time to target does not provide any benefit to the mechanics of bomb delivery and could be eliminated. As already stated in the

assessment of the AG modes, the max g display should incorporate a time out function so that it is not present at roll-in and during the dive delivery. All other parameters are justifiable as safety of flight or weapons delivery parameters. The resulting display would provide initial conditions through airspeed, altitude and distance readouts. The delivery would be executed through the use of the azimuth steering line, weapons release cue, flight path indicator and target designation. Abort parameters of altitude, airspeed and dive angle would be present, as would normal load factor applied for the dive recovery. The proposed display is shown in figure 7-1.

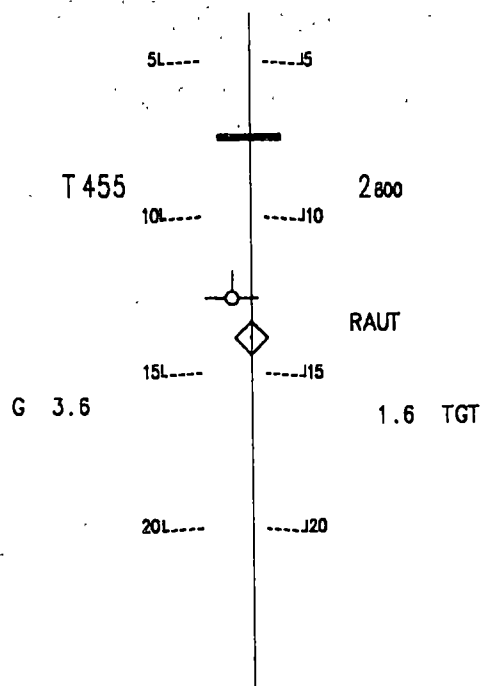


Figure 7-1. Air-to-Ground Training Mode

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Though the Heads Up Display provides a tremendous decrease in workload and corresponding increase in capability to execute flight related and mission tasks, refinement of existing HUD modes in the AV-8B is required to provide greater safety and efficiency in the accomplishment of these tasks. As the number of weapons systems and sensors available for carriage has increased, the amount of information presented on the HUD has correspondingly increased with little or no effort being applied to the nature of the presentation. This has led to display clutter being reported by pilots to be a major problem¹³. The amount of data presented often interferes with the pilots' ability to discern critical parameters, and leads to an increased amount of time focused on the HUD and not on the surrounding environment¹¹. This situation becomes particularly critical when the surrounding environment is the target area or the landing pattern. Any increase in the efficiency of HUD scan will directly relate to an increase in combat capability, situational awareness and in the landing pattern, general safety. The evaluation of both HUD experienced pilots and non-HUD experienced pilots and flight test personnel directly demonstrated the value of simplified HUD designs through the greater levels of accuracy achieved during both static and dynamic assessments when using a simplified HUD vice a complete HUD.

Further reduction of data displayed in the HUD, to that necessary to accomplish only the most basic aspects of weapons delivery and takeoff and landing, though not tactically suitable, shows potential in increasing the efficiency with which pilots are trained. Presenting only the required data to accomplish these tasks will rapidly develop the proper scan and improve performance and decrease time to train. This was demonstrated during the static evaluation by the 60% greater increase in learning exhibited by the non-HUD experienced group when presented with a simplified HUD rather than a complete HUD.

As tactical aircraft transition from console mounted HUD symbology to helmet mounted displays, consideration must be given for the continued improvement of display design¹⁴. The helmet mounted display, though seen as the next generation of information display technology, will be subject to the same drawbacks of image clutter as the conventional HUD. In transitioning to this technology designers must focus on optimum design and presentation of information and not merely settle for a rehosting of existing displays on a new medium.

RECOMMENDATIONS

Takeoff and Landing Modes

- Remove the boxes around the airspeed and altitude readouts in both the Normal and Reject 1 modes of display. The box around airspeed may remain while on deck and be removed as the aircraft reaches nozzle rotation airspeed.
- Remove the numerical heading indicator in the lower right hand corner of the Reject 1 mode.

- Eliminate the aircraft flight path symbol in Reject 1 mode as airspeed is decreased below 60 KCAS.
- Add nozzle angle to the Reject 2 mode.
- Display the priority limiting parameter of JPT or RPM in the Reject 2 mode.
- Display groundspeed in the Reject 2 mode.

Air-to-Ground Modes

- Remove the boxes around the airspeed and altitude readouts in the Normal mode.
- Remove the numerical heading indicator in the lower right hand corner of the Normal and Reject 1 modes.
- Remove the maximum G readout after a specified time delay in the Normal, Reject 1 and Reject 2 modes.
- Display a numerical heading indication in the Reject 2 mode.

Target Designations

- Display air-to-air target track symbology referenced to the horizon.

Training HUD Modes

- Develop configurable HUD modes for initial phases of flight training.

WORKS CONSULTED

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APPENDICES

APPENDIX A
STATIC EVALUATION HUD CONFIGURATIONS

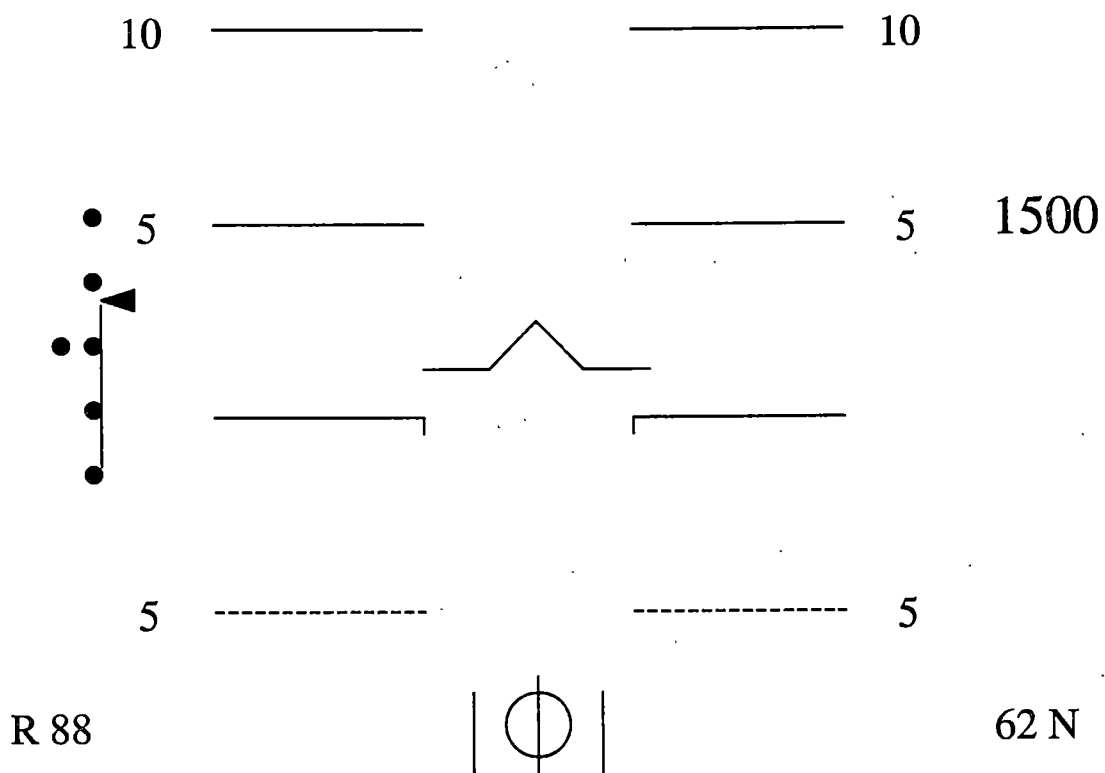


Figure A-1. Simplified HUD Configuration

APPENDIX B
STATIC HUD EVALUATION RAW DATA

Table B-1. Non-HUD Experienced Group with Simple HUD

Non-HUD Experienced - Simple HUD			
Slide #	Total Ans.	Corr. Ans.	Percent
1	30	22	73.33%
2	30	23	76.67%
3	30	20	66.67%
4	30	22	73.33%
5	30	21	70.00%
6	30	23	76.67%
7	30	24	80.00%
8	30	28	93.33%
9	30	28	93.33%
10	30	26	86.67%
11	30	27	90.00%
12	30	28	93.33%
13	30	28	93.33%
14	30	30	100.00%
15	30	27	90.00%
16	30	30	100.00%
17	30	28	93.33%
18	30	29	96.67%
19	30	30	100.00%
20	30	29	96.67%
	600	523	87.17%

Table B-2. Non-HUD Experienced Group with Complete HUD

Non-HUD Experienced - Complete HUD			
Slide #	Total Ans.	Corr. Ans.	Percent
1	30	16	53.33%
2	30	18	60.00%
3	30	18	60.00%
4	30	22	73.33%
5	30	22	73.33%
6	30	21	70.00%
7	30	22	73.33%
8	30	22	73.33%
9	30	24	80.00%
10	30	22	73.33%
11	30	24	80.00%
12	30	23	76.67%
13	30	21	70.00%
14	30	26	86.67%
15	30	21	70.00%
16	30	22	73.33%
17	30	24	80.00%
18	30	26	86.67%
19	30	24	80.00%
20	30	23	76.67%
	600	441	73.50%

Table B-3. HUD Experienced Group with Simple HUD

HUD Experienced - Simple HUD			
Slide #	Total Ans.	Corr. Ans.	Percent
1	30	27	90.00%
2	30	26	86.67%
3	30	29	96.67%
4	30	29	96.67%
5	30	27	90.00%
6	30	30	100.00%
7	30	30	100.00%
8	30	28	93.33%
9	30	30	100.00%
10	30	29	96.67%
11	30	30	100.00%
12	30	30	100.00%
13	30	30	100.00%
14	30	28	93.33%
15	30	29	96.67%
16	30	30	100.00%
17	30	30	100.00%
18	30	28	93.33%
19	30	30	100.00%
20	30	30	100.00%
	600	580	96.67%

Table B-4. HUD Experienced Group with Complete HUD

HUD Experienced - Complete HUD			
Slide #	Total Ans.	Corr. Ans.	Percent
1	30	26	86.67%
2	30	23	76.67%
3	30	26	86.67%
4	30	25	83.33%
5	30	28	93.33%
6	30	24	80.00%
7	30	29	96.67%
8	30	28	93.33%
9	30	24	80.00%
10	30	27	90.00%
11	30	24	80.00%
12	30	28	93.33%
13	30	27	90.00%
14	30	28	93.33%
15	30	28	93.33%
16	30	25	83.33%
17	30	28	93.33%
18	30	29	96.67%
19	30	25	83.33%
20	30	29	96.67%
	600	531	88.50%

APPENDIX C
STATIC EVALUATION LINEAR TREND LINES

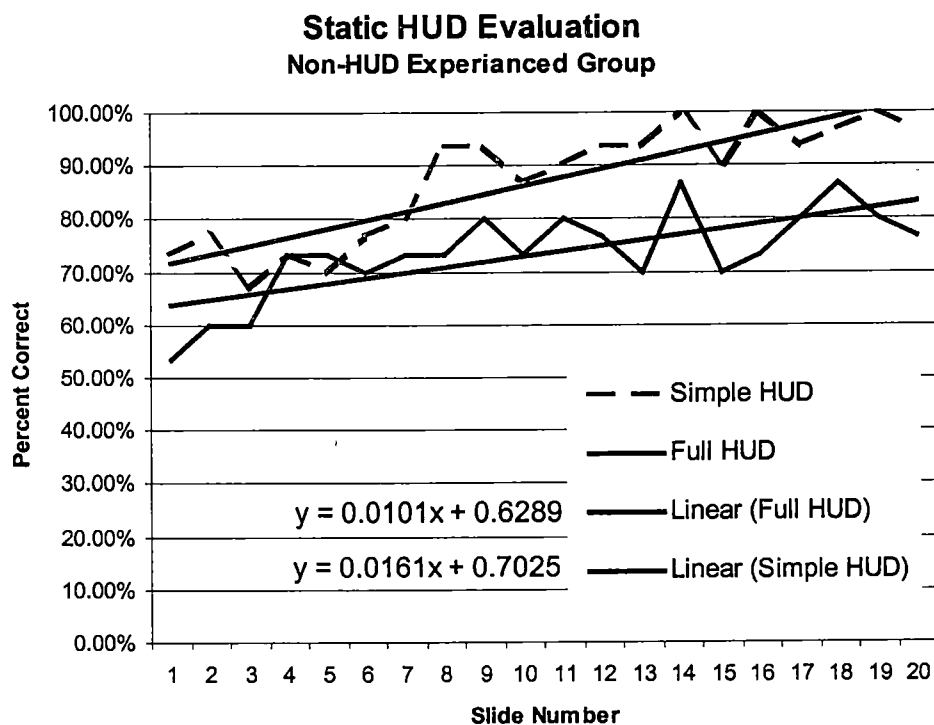


Figure C-1. Non-HUD Experienced Group Data Linear Fit

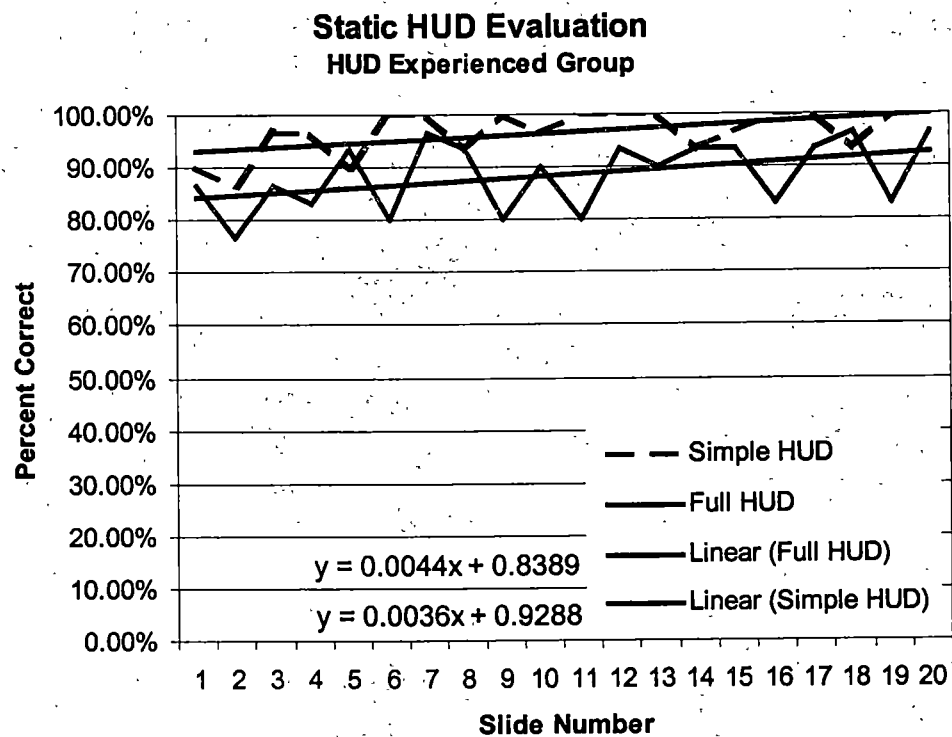


Figure C-2. HUD Experienced Group Data Linear Fit

VITA

Charles Sean Gray was born in Paramonga, Peru on 06 January 1967. His family moved to the United States in 1973 and settled in New Jersey, where he graduated from Metuchen High School in June 1985. He entered the United States Naval Academy in July 1985 and graduated in May 1989 with a Bachelor of Science degree in Aerospace Engineering. He was commissioned a Second Lieutenant in the United States Marine Corps and reported to The Basic School in Quantico, Virginia, for six months of initial training. Upon completion he reported to Pensacola, Florida, for flight training and received his wings in June 1992. After completion of AV-8B Harrier training in Cherry Point, North Carolina, he served three years with VMA-513, based in Yuma, Arizona before reporting back to Cherry Point as an AV-8B instructor pilot. Following completion of his instructor tour he was selected to attend the United States Naval Test Pilot School in Patuxent River, Maryland. Upon graduation from test pilot school he was assigned to the Naval Air Warfare Center, Weapons Division at China Lake, California. He initially served as the Military Deputy for Test and Evaluation of the AV-8B Joint Systems Support Activity and as the project officer for the Open Systems Core Avionics Requirement upgrade program for the AV-8B before being assigned to his current billet as Operations Officer of Naval Weapons Test Squadron China Lake.