8-2000

Evaluation of the joint helmet-mounted cueing system as a control for cueing high off-boresight weapons and sensors

Terry Scott Barrett

To the Graduate Council:

I am submitting herewith a thesis written by Terry Scott Barrett entitled "Evaluation of the joint helmet-mounted cueing system as a control for cueing high off-boresight weapons and sensors." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Frederick W. Stellar, Major Professor

We have read this thesis and recommend its acceptance:

Frank S. Collins, R. Richards

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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Associate Vice Chancellor and
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EVALUATION OF THE JOINT HELMET-MOUNTED CUEING SYSTEM AS A CONTROL FOR CUEING HIGH OFF-BORESIGHT WEAPONS AND SENSORS

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

Terry Scott Barrett
August 2000

DEDICATION

This thesis is dedicated to:

My wife Kelly

ACKNOWLEDGEMENTS

There are many people to whom I am grateful for making my time at the University of Tennessee so rewarding.

ABSTRACT

The F/A-18 High Off-Boresight System (HOBS) is a critical component for surviving in future air-to-air combat in the Within Visual Range (WVR) arena The HOBS system is comprised of the pilot, F/A-18 Strike/Fighter aircraft, Joint Helmet-Mounted Cueing System (JHMCS), F/A-18 air-to-air Radar, and the AIM-9X Sidewinder launch and leave, short-range missile. The primary focus of this thesis is an evaluation of the Joint Helmet-Mounted Cueing System as a control for cueing high off-boresight weapons and sensors.

The author of this thesis is the current HOBS (JHMCS and AIM-9X) project pilot. While performing other HOBS developmental test flights in parallel, the author flew 16 ACM test missions from October 1999 to February 2000. The results from these flights have been compiled for use in this thesis.

The HOBS showed tremendous tactical utility in the WVR arena. The HOBS allowed the pilot to monitor critical aircraft-state information such as airspeed, altitude, and load factor while simultaneously keeping sight of the target at high off-boresight angles. The JHMCS proved effective as a controller for cueing the Sidewinder and Radar. The system showed excellent capability for obtaining multiple Sidewinder acquisitions on targets at high off-boresight angles. The mechanization for transitioning from one JHMCS cueing mode to another was less than optimum and showed the greatest need for improvement.

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LIST OF ABREVIATIONS

AC	Alternating Current
ABC	Automatic Brightness Control
ACM	Air Combat Maneuvering
AIM	Air Intercept Missile
AMRAAM	Advanced Medium Range Air to Air Missile
AOA	Angle-of-Attack
AOC	Angle-of-Coincidence
BIT	Built-In-Test
BST	Boresight
C/UC	Cage / Uncage
CP	Control Panel
CRT	Cathode Ray Tube
CU	Cockpit Unit
CVRS	Cockpit Video Recording System
DC	Designator Controller
DDI	Digital Display Indicator
DT&E	Developmental Test and Evaluation
ETI	Elapsed Time Indicator
EU	Electronic Unit
FLIR	Forward Looking Infrared
FOR	Field-of-Regard
FOV	Field-of-View
HACQ	Helmet Acquisition
HDU	Helmet Display Unit
HMD	Helmet-Mounted Display
HOBS	High Off-Boresight System
HOTAS	Hands on Throttle and Stick
HRC	Helmet Release Connector
HUD	Head Up Display
HVI	Helmet Vehicle Interface

LIST OF ABREVIATIONS

HVPS	High-Voltage Power Supply
ILS	Inertial Landing System
INS	Inertial Navigation System
IRC	In-line Release Connector
JHMCS	Joint Helmet-Mounted Cueing System
L&S	Launch and Steer
LAR	Launch Acceptability Region
LED	Light Emitting Diode
LOS	Line-of-Sight
MC	Mission Computer
MC1	Mission Computer #1
MC2	Mission Computer #2
mr	Milliradian
MRU	Magnetic Receiver Unit
MTU	Magnetic Transmitter Unit
NIRD	Normalized In-Range Display
nm	Nautical Mile
NORM	Normal Rejection Level
OFP	Operational Flight Program
PRF	Pulse Repetition Frequency
QDC	Quick Disconnect Connector
Radar	Radio Detection and Ranging
REJ1	Reject Level One
REJ2	Reject Level Two
RWS	Range While Scan
SPS	Seat Position Sensor
SUPT	Support
TAC	Tactical
TD	Target Designator
TDC	Throttle Designator Controller
TLL	Target Locator Line
USAF	United States Air Force

LIST OF ABREVIATIONS

USMC	United States Marine Corps
USN	United States Navy
VACQ	Vertical Acquisition
VCATS	Visually-Coupled Acquisition and Targeting System
VISTA	Variable-Stability In-flight Simulator Test Aircraft
WVR	Within Visual Range

CHAPTER 1

Introduction

Background

The United States Navy (USN) and United States Air Force (USAF) developed a requirement for a high off-boresight, air-to-air weapon system to enable the warfighter to regain the combat advantage in the air-to-air, Within Visual Range (WVR) arena. The services teamed together to develop the High Off-Boresight System (HOBS) to meet this requirement. The HOBS is planned for integration on the F/A-18, F-15, F-16, and F-22 fighter aircraft. The lead development platforms are the F/A-18 (USN) and the F-15 (USAF). The current HOBS is comprised of the pilot, F/A-18 or F-15 fighter aircraft, Joint Helmet-Mounted Cueing System (JHMCS), F/A-18 or F-15 air-to-air Radar, and the AIM-9X Sidewinder launch and leave, short-range missile.

In addition to its HOBS capability, the JHMCS will provide the aircrew with the capability to cue on-board weapons and sensors to the pilot's Line-of-Sight (LOS), visually confirm seeker and sensor position, and monitor aircraft-state information such as altitude and airspeed. In the air-to-ground role, the JHMCS will enhance lethality and survivability by reducing target acquisition time.

Scope

While the HOBS is a multi-platform system, the scope of this thesis will only encompass its integration on the USN F/A-18. While a broad overview of the HOBS is presented, a more detailed description of the system is outlined to support the human factors evaluation of the JHMCS as a controller for cueing the F/A-18 Helmet Acquisition (HACQ) Radar mode and the Sidewinder missile during WVR, air-to-air combat.

Method of Research

The author of this thesis is the current HOBS (JHMCS and AIM-9X) project pilot and the only USN test pilot flying and evaluating the HOBS for its utility in the WVR combat environment. Training and test missions designed to simulate the WVR arena are known as Air Combat Maneuvering (ACM) missions. ACM missions involve multiple aircraft and the rules-of-engagement allow for role swapping between shooter and target. ACM missions flown for this evaluation involved one test aircraft versus one target aircraft. The test aircraft was an F/A-18 equipped with the HOBS. The target aircraft was an F/A-18 or F-15 equipped with the HOBS or an existing weapon system. While performing other HOBS developmental test flights in parallel, the author flew 16 ACM test missions from October 1999 to February 2000. At the end of each ACM mission, a flight summary was compiled which evaluated the current system performance (as designed) for its utility in the WVR arena. Each flight summary was submitted to the program for review along with recommendations for software and hardware fixes. These results have been compiled to support the human factors evaluation of the HOBS for the fighter pilot's mission. The SHEL model [1] was used as the framework for both the HOBS description and human factors evaluation. The SHEL model is a method of describing a complex system according to its Software, Hardware, Environment and Liveware components. Additionally, the SHEL model provides a systematic approach for describing and evaluating the integration of system components.

CHAPTER 2

System Description

Liveware

Combat Pilot

USN combat pilots employing the HOBS will vary greatly in skill and experience. Experience levels will vary from junior pilots who have just joined their first squadron to Commanding Officers with 15 years of experience. While the HOBS must be designed to accommodate the entire population, the primary focus must be on the lowest common denominator (the junior pilot). A junior pilot is ready to go to combat upon arrival at his or her first squadron. The junior pilot will have just completed primary aircraft training in the F/A-18 and may have as little as 400 total flight hours with only 200 in the F/A-18. The junior pilot's total experience against air-to-air targets may consist of as little as 20 training flights.

The combat pilot population is comprised of both males and females. These pilots vary greatly in body and head size. Head length, width and diameter are critical JHMCS design issues. The JHMCS must be able to accommodate the entire F/A-18 pilot population using current production USN helmet sizes [5].

Test Pilot

The current HOBS project test pilot and author of this thesis has amassed over 1700 flight hours (1200 in the F/A-18) and flown over 25 different aircraft. As one of only two USN test pilots conducting Developmental Test and Evaluation (DT&E) for the HOBS project, the author has flown over 80% of the developmental test missions and all of the ACM missions Evaluations, conclusions and recommendations discussed in this thesis have been the sole work of the HOBS project test pilot.

The test pilot evaluates a system's performance and ease of use compared to an ideal system. An ideal system is a system that a junior pilot could operate proficiently without additional training. Pilot actions required to operate the ideal system would be so intuitive and well integrated into the F/A-18 that they would need no explanation. While the ideal system does not exist, it is a benchmark for comparison.

Environment

Overview

The HOBS is a multiple service, multiple platform system, used for both air-to-air and air-to-ground missions during day and night conditions [2]. The HOBS was designed to assist the pilot during visual acquisition of both air-to-air and air-to-ground targets.

Within Visual Range Combat Arena

The HOBS was designed primarily for the WVR combat arena. The WVR arena is defined by an air-to-air engagement that has degraded to the point where both fighter and enemy aircraft are within approximately five miles of each other (within visual sight). This particular scenario usually requires dynamic flight, involving high load factors and extreme aircraft maneuvering. Prior to the HOBS it was necessary for the pilot to point the nose of the aircraft directly at the target before employing its weapons. This required both a highly maneuverable aircraft, and the necessity to focus entirely on positioning the aircraft. The advent of the HOBS will allow the pilot to cue air-to-air weapons towards a target by merely looking at them. While dynamic maneuvering may still be necessary, the HOBS capabilities serve to relax the maneuvering required to obtain weapons launch capability. The HOBS must not impede the pilot's ability to fly at increased load factors where any additional weight (added by the JHMCS to the helmet) will be multiplied, by up to nine times, to the pilot's neck and head Additionally, the need to continuously see an airborne target during an engagement dictates the requirement to maximize the pilot's field of view (FOV). The HOBS, with its additional hardware, must not further impede FOV.

Specific Engagement Scenarios

While it is important for the HOBS to operate throughout the entire WVR envelope, there are two specific scenarios where HOBS was designed to excel. The HOBS was designed to give the pilot first-shoot capability in the one-circle and two-circle engagement, figure 1.

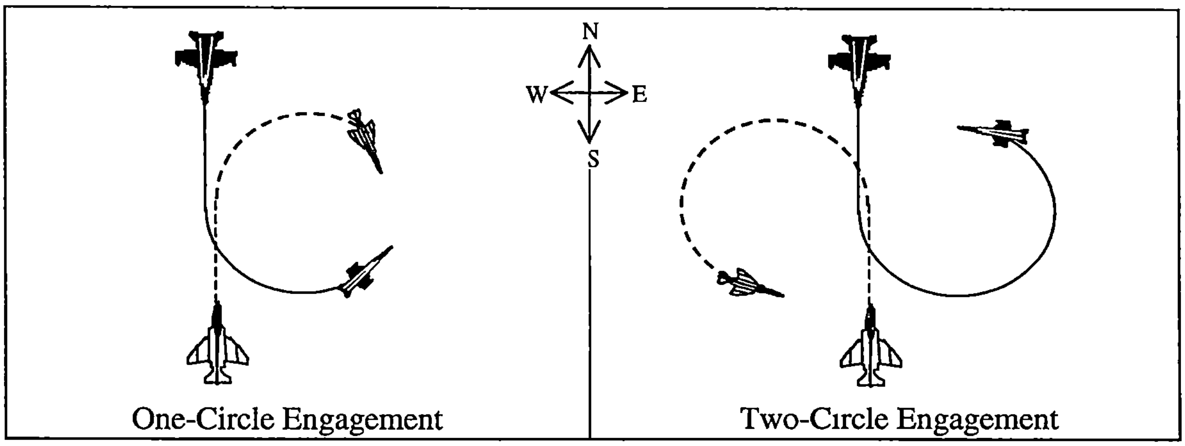

Figure 1. One-Circle and Two-Circle Engagements

These engagement scenarios usually begin with two aircraft approaching each other from a distance of greater than five miles. Inside of five miles the aircraft see each other visually and fly their aircraft to pass as close as possible at the merge. After the merge, each aircraft turns to engage the other. Both aircraft turning towards the same direction (east) will result in a one-circle engagement. Both aircraft turning towards opposite directions (one east, one west) will result in a two-circle engagement. The aircraft whose weapon has the highest off-boresight capability will win the fight. Almost all engaged maneuvering in the WVR environment involves some form of the one or two-circle engagement

Cockpit

All of the USN F/A-18 aircraft targeted for the HOBS are single-pilot, single-seat fighter aircraft. The cockpit, maximized for the WVR environment, contains a bubble canopy for maximum FOV (approximately 340 degrees). The only visual obstruction within the canopy FOV is the portion of the seat behind the pilot's head. A cockpit anti-g system connects to the pilot's g-suit and increases the pilot's load factor capability. Each cockpit is pressurized, air conditioned, and heated via an environmental control system.

Hardware

Joint Helmet-Mounted Cueing System

Overview

The JHMCS is a controller, which provides to the pilot the capability to visually cue weapons and sensors to the helmet LOS. The JHMCS also acts as a display by presenting weapon and sensor LOS as well as aircraft-state information. The JHMCS, figure 2, is comprised of a Helmet-Mounted Display, an Electronics Unit, a Cockpit Unit, a Control Panel, a Magnetic Transmitter Unit, a Seat Position Sensor, and a Helmet Vehicle Interface [3].

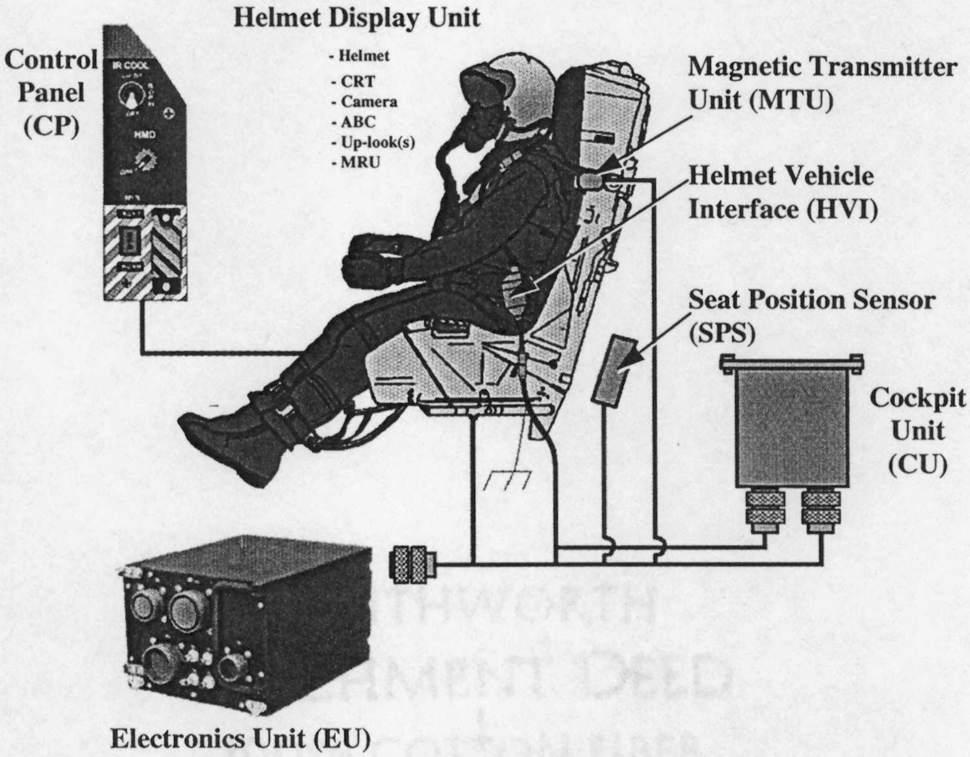

Figure 2. JHMCS System Segments

Helmet-Mounted Display

The Helmet-Mounted Display (HMD), figure 3, includes the helmet shell, universal connector, helmet cabling, visor, and the Helmet Display Unit. The helmet shell is based upon the lightweight, HGU-55/P helmet shell, weighing approximately two pounds [3]. The universal connector attaches the Helmet Display Unit to the helmet shell. The helmet cabling (part of the Helmet Vehicle Interface) attaches the helmet shell to the aircraft. The HMD weighs approximately four pounds.

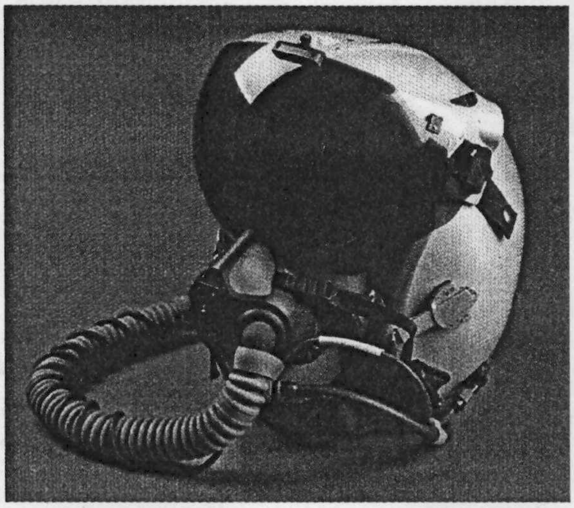

Figure 3. Helmet-Mounted Display

Visor

The visor acts as the optical element for displaying symbology to the pilot. The main display, a monocular 20-degree FOV image, will be displayed onto the visor in front of the pilot's right eye. The left uplook cursor will be displayed above and to the left of the pilot's left eye, while the right uplook cursor will be displayed above and to the right of the pilot's right eye. There are currently two visors available, one tented visor for day use and one clear visor for night use [3]. The visors are coated with neutral density reflective material. The reflective material is only applied to the visor in the location at which the main display and uplook cursors will be displayed [2].

Helmet Display Unit

The Helmet Display Unit (HDU) is a removable assembly that is attached to the top of the helmet shell via the universal connector, figure 4. The HDU contains a Cathode Ray Tube and Optics assembly, black and white video camera, Automatic Brightness Control Sensor, two uplook cursors, and a Magnetic Receiver Unit [3]. While the Magnetic Receiver Unit is part of the HDU it will be discussed separately from the other HDU components.

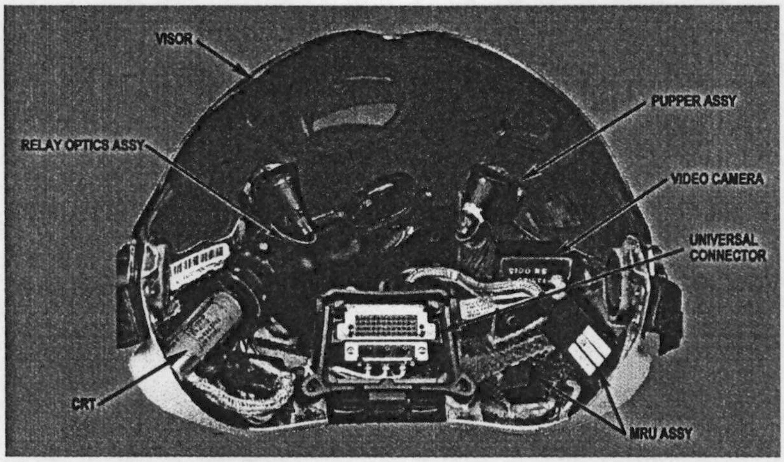

Figure 4. Helmet Display Unit Components

Cathode Ray Tube Display and Optics Assembly

The ½ inch Cathode Ray Tube (CRT) projects a collimated display directly on to the visor [2]. It is designed to position the CRT image (on the visor) in front of the pilot's right eye with a 20 degree FOV [2,3]. The ½ inch CRT was chosen for use on the HMD because it exhibited the best tradeoff between weight and optical performance [8].

Video Camera

The video system is an off-the-shelf black and white video camera [2]. The camera's FOV coincides with the HMD's 20 degree circular FOV so that the graphics processor in the Electronic Unit can properly overlay symbology on to the video. The composite video of the outside scene and the HMD symbology is output for recording purposes [4].

Automatic Brightness Control Sensor

The Automatic Brightness Control Sensor is used to determine ambient light and automatically adjust the CRT brightness to maintain a constant display ratio [4].

Uplook Cursor

The uplook cursor is a Light Emitting Diode (LED) which, when activated, illuminates a reticle on the visor over each eye outside the FOV of the HMD main display. The uplook cursors provide additional cueing capability (compared to helmet LOS) for earlier target acquisition in the WVR arena. The uplook cursors will allow for enhanced utility of off-boresight sensors beyond the range of human head motion [5]. The HDU contains two uplook cursors, both left and right, which are displayed (one at a time) symmetrically about the HMD boresight, figure 5.

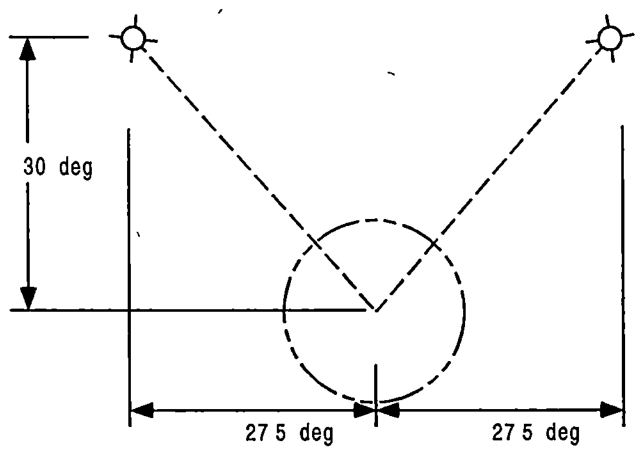

Figure 5. HMD Uplook Cursor Position

When the uplook cursors are activated, either the left or right uplook cursor is displayed based on horizontal head position. The HMD will switch from one uplook cursor to the other when the horizontal head position has moved past aircraft boresight plus the hysteresis band [3], figure 6.

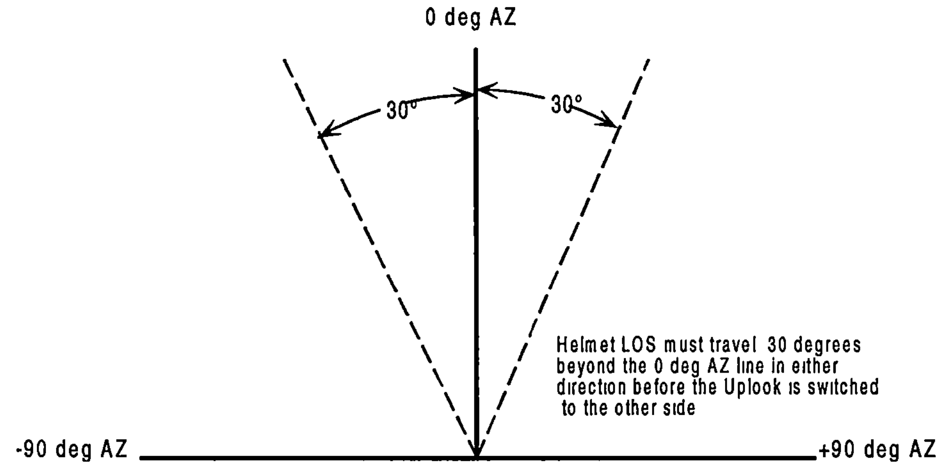

Figure 6. HMD Uplook Cursor Hysteresis

Control Panel

The Control Panel (CP) is located on the right side of the instrument panel. The CP contains a dual function, rheostat type, ON/OFF Brightness knob. Turning the knob clockwise turns the JHMCS system on and increases the HMD brightness. Turning the knob counter-clockwise decreases the HMD brightness and turns the system off [3].

Electronic Unit

The Electronic Unit (EU) interfaces between the JHMCS system components and the aircraft's Mission Computers via a digital 1553 bus. The EU is located in the upper equipment bay behind the pilot's seat, figure 7. The EU contains the necessary power and processing to drive the HMD [4]. It consists of the four following distinct electronic cards: a low voltage power supply, a line-of-sight module, a series of central processor cards, and a graphics processor/display driver [3]. The EU performs line-of-sight computations, graphics processing and display, and provides externally selectable video generation [4].

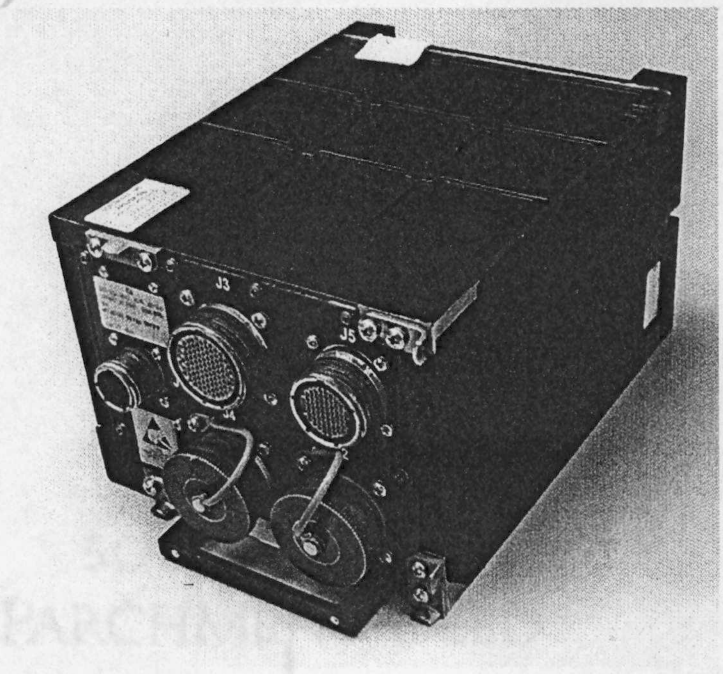

Figure 7. Electronics Unit

Magnetic Transmitter Unit

The Magnetic Transmitter Unit (MTU) is mounted in the canopy sill, figure 8. The MTU contains three orthogonal wound coils that represent the "baseline" X, Y and Z-axes of the system. The MTU produces three orthogonal Alternating Current (AC) magnetic fields in the cockpit. The magnetic fields flood the cockpit and are sensed by the Magnetic Receiver Unit located in the HDU. The resultant signals are amplified, digitized, and then transmitted to the EU, which computes helmet LOS by comparing the resultant signal with the "baseline" signal [4]. The amount that the resultant signal is altered by existing metal in the cockpit must be measured so that it can be accounted for during the LOS computations. These measurements are compiled to form the cockpit magnetic map, which is stored in the MTU and loaded into the EU during system power-up.

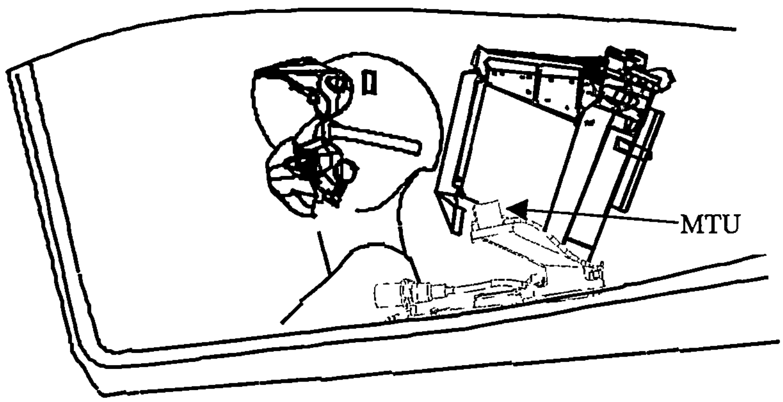

Figure 8. Magnetic Transmitter Unit

Magnetic Receiver Unit

The Magnetic Receiver Unit (MRU) coil assembly is a miniature version of the MTU assembly The MTU-produced magnetic field induces a signal into the MRU. The MRU transmits this signal to the EU. The EU computes the helmet LOS by comparing the MRU signal to the "baseline" MTU magnetic field [4].

Cockpit Unit

The Cockpit Unit (CU) is located in the F/A-18's left equipment bay, figure 9. The CU contains a High Voltage Power Supply (HVPS), which generates the high voltage needed to power the CRT display in the HDU [4].

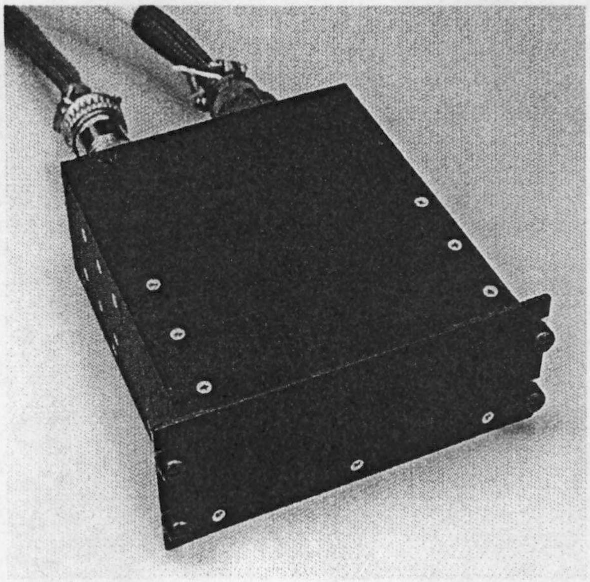

Figure 9. Cockpit Unit

Seat Position Sensor

The Seat Position Sensor (SPS) is located on the lower right side of the cockpit behind the ejection seat [2]. The SPS is a linear potentiometer, whose output is proportional to seat position [4]. The effect seat position has on the magnetic map must be taken into account by the EU during helmet LOS computation [4].

Helmet Vehicle Interface

Overview

The Helmet Vehicle Interface (HVI) system provides the cabling between the helmet and the aircraft's avionics. The system is comprised of an upper HVI cable and a lower HVI cable, figure 10. The universal connector provides the capability to remove the HDU from the helmet shell. The upper HVI is attached to the helmet and integrates with the pilot's flight gear. The lower HVI cable originates in the aircraft [4].

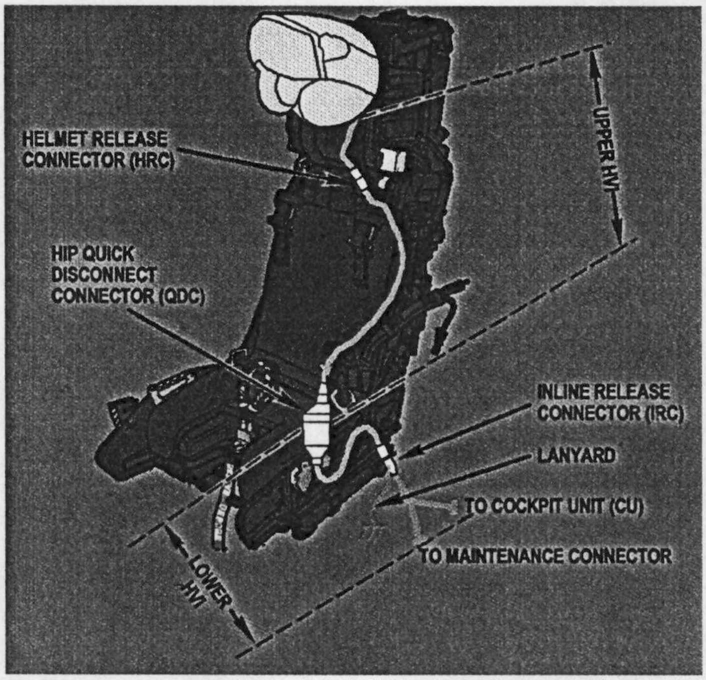

Figure 10. Helmet Vehicle Interface

Upper HVI Cable

The upper HVI cable is attached to the rear of the helmet shell. It is comprised of the Helmet Release Connector (HRC) and the upper half of the Quick Disconnect Connector (QDC), figure 11. The HRC provides a one-time disconnect in the event of helmet loss during ejection [4]. The QDC is the primary day-to-day interface between the pilot and the aircraft, which provides the capability to connect and disconnect via a release button located on the upper half of the QDC [2]. Additionally, the QDC is the primary disconnect component during an ejection or ground egress. The upper half of the QDC is attached to the left side of the pilot's torso harness via a mounting bracket. During ejection or egress the mounting bracket will absorb any disconnect loads, preventing injury to the pilot's head or neck [3].

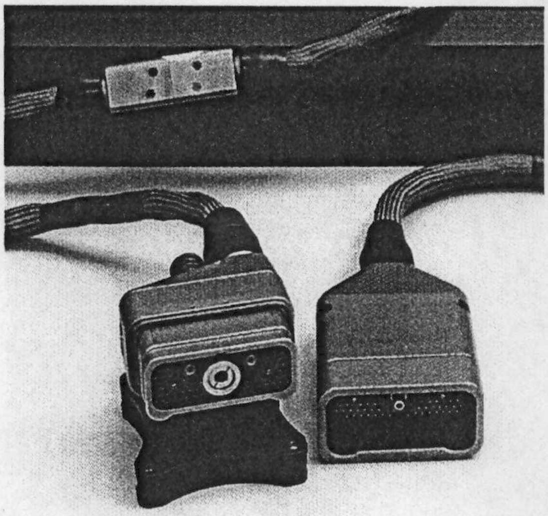

Figure 11. QDC and HRC

Lower HVI cable

The lower HVI cable is attached to the pilot via the lower half of the QDC, figure 11. A steel lanyard mounted to the aircraft structure will disengage the QDC locking mechanism during an ejection or emergency egress. The lower HVI cable is attached to the aircraft via the In-line Release Connector (IRC). The IRC will provide a one-time disconnect as emergency back up for the QDC [3].

F/A-18

Aircraft

The F/A-18 is a twin engine strike fighter designed for use by the USN and United States Marine Corps (USMC). The F/A-18 has been in the United States inventory since 1987, figure 12. Operationally, the USN uses a single seat carrier based version of the aircraft while the USMC uses both the single and dual seat versions. The

USN and USMC employ the F/A-18 in both the air-to-air and air-to-ground combat mission. The F/A-18 is capable of performing both of these missions on the same flight.

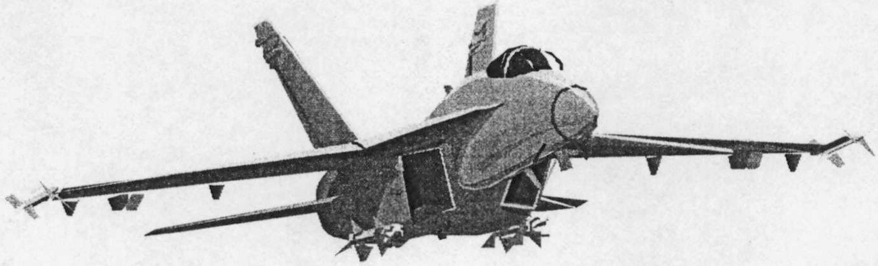

Figure 12. F/A-18 Strike Fighter

The F/A-18 is a highly maneuverable, highly flexible weapons carriage and delivery platform. It contains a nose-mounted 20 millimeter cannon with both air-to-air and air-to-ground capability. The F/A-18 can carry the AIM-9M/X Sidewinder, AIM-7 Sparrow, and the AIM-120 AMRAAM air-to-air missiles. For the air-to-ground combat mission, the F/A-18 can carry a large assortment of gravity bombs and smart weapons [3]. It can also carry targeting and navigation sensors such as the Forward-Looking Infrared (FLIR).

The F/A-18 can operate in one of three master modes: navigation, air-to-air, and air-to-ground. When a particular master mode is selected, the aircraft automatically tailors on-board systems to maximize the aircraft's capability for that mission. The F/A-18 utilizes two onboard Mission Computers (MC) to communicate and control aircraft avionics. Mission Computer #1 (MC1), referred to as the Navigation Computer, performs processing for navigation, control and display management, aircraft Built-In-Test (BIT), and status monitoring. Mission Computer #2 (MC2), known as the Weapon

Delivery Computer, performs processing for air-to-air and air-to-ground, tactical control and display, and backup navigation should MC1 fail [3].

The F/A-18 is comprised of many displays and controls capable of controlling a multitude of weapons and sensors. Only the displays and controls relative to the HOBS will be discussed.

Displays

The aircraft contains three integrated controller/displays that are used by the JHMCS. These displays are the Heads Up Display (HUD) and the left and right Digital Display Indicators (DDI). The HUD, figure 13, displays aircraft-state information including altitude, airspeed and load factor. It also provides weapon and sensor position information.

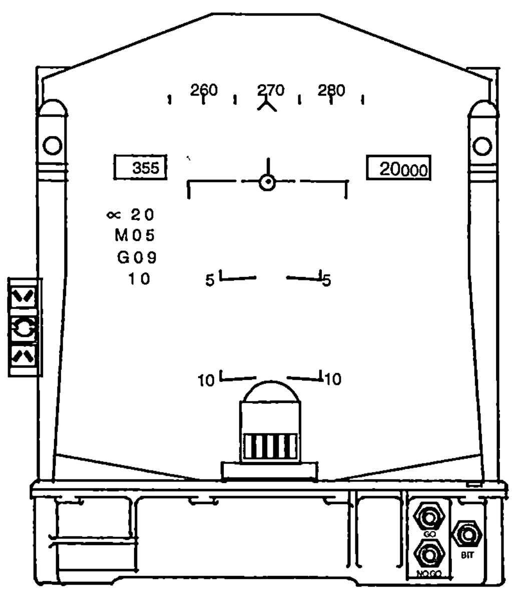

Figure 13. Heads Up Display

The aircraft's two DDIs, figure 14, provide JHMCS configuration information as well as an indication of system health.

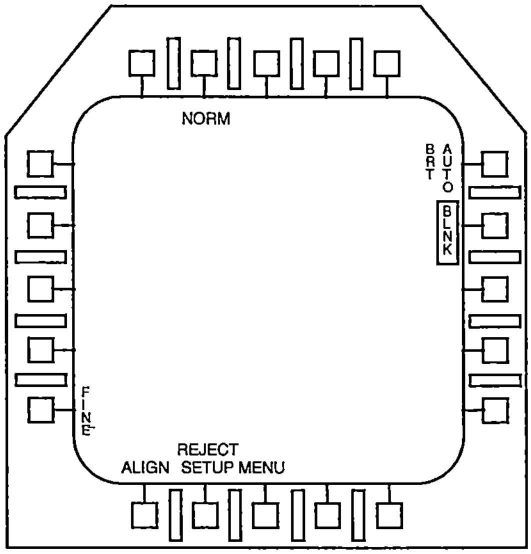

Figure 14. Digital Display Indicator

Controllers

The aircraft's HUD functions as a controller for slaving weapons and sensors, as well as designating air-to-ground targets. The aircraft's two DDIs provide a means for programming HOBS configuration. By pressing pushtiles, which surround the DDI, the pilot can perform functions such as HMD symbology rejection, as well as select sensors and weapons for cueing.

The Dual Throttle Control contains two HOBS related controllers, the Target Designator Controller (TDC) and the Cage/Uncage (C/UC) button, figure 15. The TDC is used during the HMD alignment process. The C/UC button is used for controlling the Sidewinder slaving source as well as commanding or breaking a Sidewinder track. Both the TDC and the C/UC button are well positioned and mechanized for ease of use in high workload scenarios.

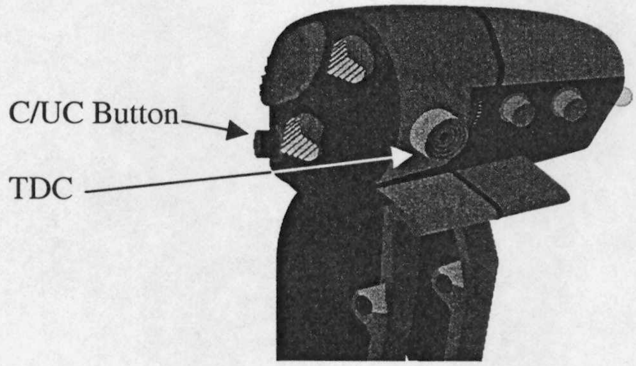

Figure 15. Dual Throttle Control

The Flight Control Stick, figure 16, contains the following three HOBS related controls: the Weapon Select Switch, the Sensor Control Switch, and the trigger. The Weapon Select Switch can select one of the following five air-to-air weapons: AIM-9M, AIM-9X, AIM-7, AIM-120, and the air-to-air gun. The Sensor Control Switch has a multitude of functions. When the JHMCS is operating, pushing forward on the Sensor Control Switch puts the Radar in HACQ mode. Pulling aft on the Sensor Control Switch (if already in HACQ) selects the uplook cursors. All three of the Flight Control Stick, HOBS related controls are well-positioned and intuitive to use.

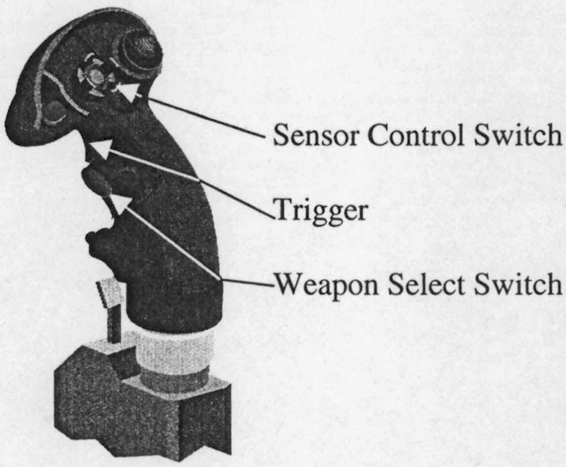

Figure 16. Flight Control Stick

F/A-18 Air To Air Radar (APG-73)

The APG-73 Radar is a multiple Pulse Repetition Frequency (PRF), multi-mode attack Radar system with sophisticated electronic counter-countermeasure features mounted in the nose of the F/A-18. The Radar provides rapid acquisition of short-range targets and excellent head-on capability against long-range, high closing rate targets. Features which enhance the APG-73's capability in the WVR combat arena are: tail-aspect, look-down capability, high antenna angular track rates, frequency agility to alleviate scintillation effects at close range, and rapid automatic acquisitions modes [3]. The Radar is capable of supporting the AIM-120 and AIM-7 Radar guided air-to-air missiles as well as provide slaving cues to the AIM-9M/X launch and leave, short-range missiles.

When the aircraft is in the air-to-air master mode, the Radar has short-range acquisition modes known as ACM modes. When the aircraft is in the ACM condition, the ACM modes are selectable using the Sensor Control Switch. There is one set of

ACM modes when the JHMCS is either not installed or not operating, and another set of ACM modes when the JHMCS is operating. Without the JHMCS, pushing forward on the Sensor Control Switch puts the aircraft in the ACM condition and selects Radar Boresight (BST) mode. In BST mode, the Radar is commanded to the aircraft's LOS and can track targets up to 10 nm in range. Selecting aft on the Sensor Control Switch selects the Vertical Acquisition (VACQ) Radar mode. In VACQ, the Radar scans an area 50 degrees above to 10 degrees below aircraft boresight. The scan is six degrees wide and can track targets up to five nm in range. When the JHMCS is operating, pushing forward on the Sensor Control Switch puts the aircraft in the ACM condition and selects Radar HACQ mode. HACQ slaves the Radar to the helmet LOS. Selecting aft on the Sensor Control Switch activates the HMD uplook cursors [3].

Helmet Acquisition Mode

The Helmet Acquisition mode (HACQ) is selected by pushing the Sensor Control Switch forward when the JHMCS is operating and the aircraft is in the air-to-air master mode. In HACQ, the Radar is commanded to the HMD LOS and is able to lock aircraft up to 10 nm in range. HACQ uses a medium PRF frequency (different from the BST Radar mode), that is tailored for HMD slaving. When HACQ is selected, a 3.3 degree dashed circle is displayed on the HMD. The system is designed to allow the Radar to automatically transition to track as soon as a target is placed within the dashed circle.

AIM-9M/X Sidewinder, Short Range Air-to-Air Missile

Overview

The AIM-9M/X Sidewinder is a launch and leave, short range, air-to-air missile that will be carried on USN, USAF and USMC aircraft. The AIM-9M missile is currently in service throughout the United States Armed Forces. While it can be integrated with the JHMCS, it has limited off-boresight capability. The AIM-9X missile, figure 17, is a major modification to the AIM-9M with improved acquisition range, off-boresight capability, maneuverability, background discrimination, probability of kill, and counter-countermeasure performance. The AIM-9X is currently undergoing developmental test in parallel with the JHMCS as part of the HOBS. The AIM-9X seeker may be slaved by a host of sensors including the Radar and the JHMCS. The generic term Sidewinder will apply to all variants of AIM-9M/X. Subjects pertaining to a particular variant (such as AIM-9X) will be stated explicitly.

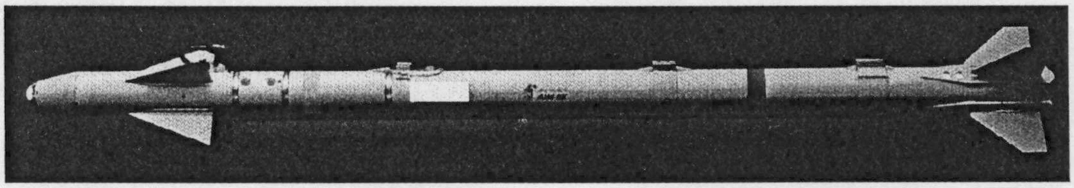

Figure 17. AIM-9X missile

Sidewinder Tones

The AIM-9M/X Sidewinder has three audible tones. The white noise tone is transmitted when there is no target in the Sidewinder seeker field-of-regard (FOR). The Acquisition tone is a medium pitch growl that is transmitted when there is a trackable target in the Sidewinder seeker FOR. When the Sidewinder has transitioned to a track, a high-pitched track tone is transmitted. Before the Sidewinder will transition to track, the system performs an Angle-of-Coincidence (AOC) check between the Sidewinder and the cueing source. This ensures that the Sidewinder only tracks what is being cued [3].

Sidewinder Acquisition Modes

The Sidewinder has two acquisition modes, which are AUTO and the default manual mode. In manual mode, when the Sidewinder has a target in the seeker FOR, and the acquisition tone is being transmitted, the pilot must press the C/UC button to command the Sidewinder to track. The AUTO mode will allow the Sidewinder to automatically transition to track whenever a trackable target is in the Sidewinder FOR. The pilot can cycle back and forth between the AUTO and the manual mode by pressing the C/UC button for more than 0.8 seconds at a time. AUTO is displayed at the bottom of the HUD and HMD when it is selected [3].

Software

Overview

While software encompasses a large group of topics including regulations, written documents and system requirements, the primary focus will be the computer software required to operate and control the JHMCS.

15C System Configuration Set

The 15C System Configuration Set (SCS), is the software build that controls most of the F/A-18's display functionality. The aircraft's two mission computers MC1 and

MC2 execute the 15C SCS software The MCs (via the software) control the orientation and format of symbology displayed on the aircraft's two DDIs and HUD. The DDIs display symbology in a menu/page format that is controlled by pressing the menu pushtile (positioned bottom/center on either DDI). The Tactical (TAC) page and Support (SUPT) page are the two top-level pages. The pilot can cycle back and forth between these two pages by selecting the menu pushtile. Sub-levels (pages), relative to a particular system, are selected via pushtile from the TAC or SUPT page. Pages associated with the JHMCS are accessed from the SUPT menu and are only available when power has been applied to the JHMCS via the ON/OFF/Brightness knob.

Software Configuration Menu

The software configuration page displays the software loaded into the different aircraft sub-systems, figure 18. The three software loads required for JHMCS operation are the MC1 and MC2 subsets of 15C SCS, and the EU's Operational Flight Program (OFP) test tape. The EU is developmental hardware; therefore its associated software is developmental and not currently part of the 15C SCS suite. The software configuration page is accessed from the SUPT page by pressing the BIT pushtile followed by the CONFIG pushtile (SUPT/BIT/CONFIG).

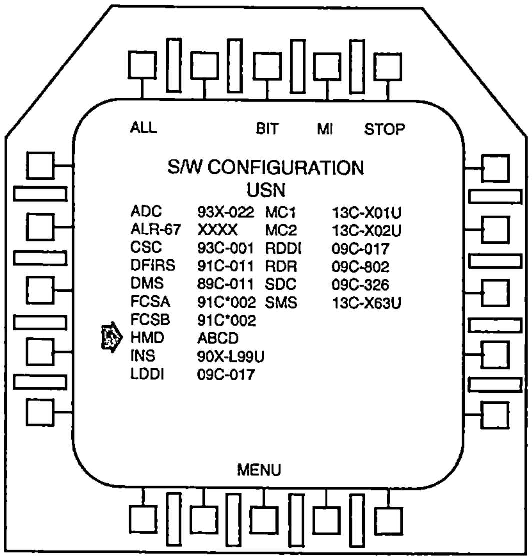

Figure 18 Software Configuration Page

Display BIT Sublevel

The Display BIT Sublevel provides information on system health and is accessed by pushing pushtiles (SUPT/BIT/DISPLAYS), figure 19.

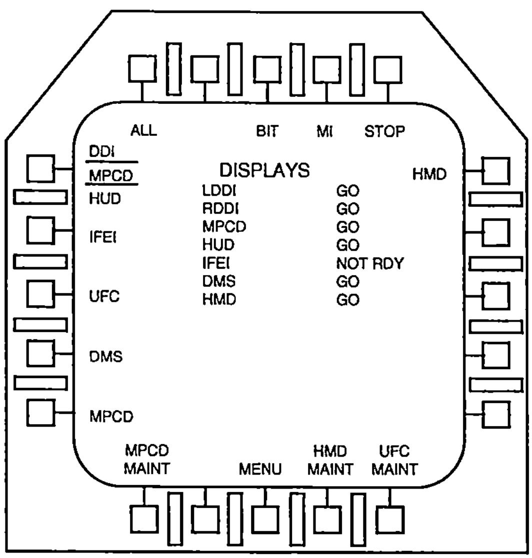

Figure 19. Displays Bit Sublevel

Pressing the HMD pushtile performs an initiated BIT. While the BIT is in progress, IN TEST will be displayed next to HMD on the BIT page. When the BIT is complete, a GO will be displayed if system health is good. Additional messages may be displayed if the system is degraded (DEGD, OVRHT, etc.). Following the BIT, a series of four test patterns will be sequentially displayed on the HMD. The test patterns allow the evaluation of HMD display quality and will continue to be displayed until the STOP pushtile is pressed [3].

Pushing the HMD MAINT pushtile displays the HMD software configuration page on the HMD while simultaneously enabling two new options (STEP LINE and STEP PAGE) on the BIT page, figure 20. Pushing STEP PAGE will replace the HMD software configuration page with the HMD Error Log page. A new Error Log page is created whenever the JHMCS power is cycled. The system can store up to 23 pages. Pushing STEP LINE will cycle through each line of the configuration page or the Error Log page [3].

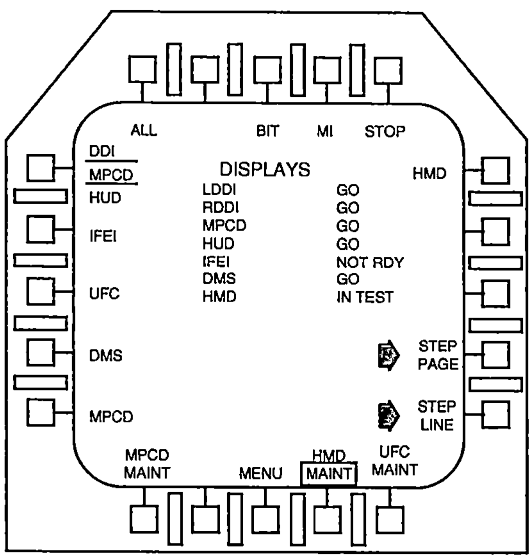

Figure 20. HMD Maintenance Options

HMD Format Page

The HMD format page is accessed by selecting pushtiles (SUPT/HMD). The HMD format page, figure 21, allows the pilot to perform the following actions: align the HMD, enable or disable HMD blanking, select the HMD brightness mode, select symbology reject levels and display the reject programming sublevel [3].

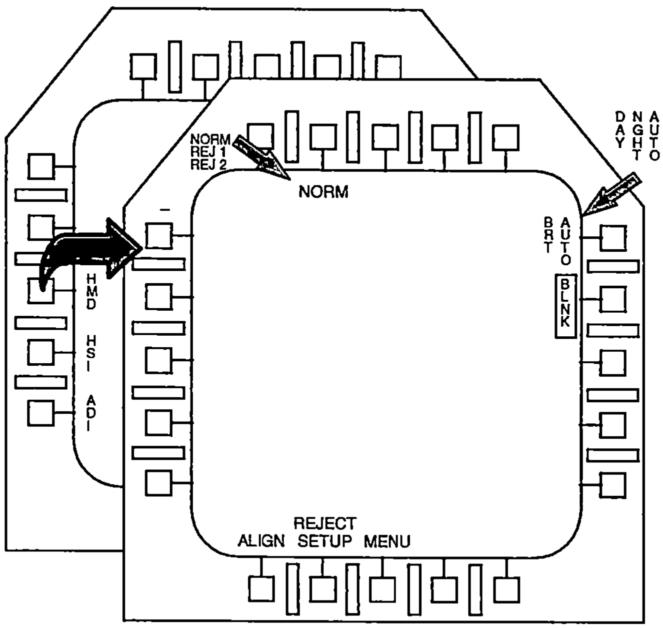

Figure 21. HMD Format Page

HMD Alignment

Performing an HMD alignment orients the JHMCS relative to aircraft boresight. This is necessary for accurate cueing of weapons and sensors. The system must be aligned with the HMD donned, visor fully down and locked, and the canopy fully closed. The two types of alignments are a course alignment and a fine alignment. A course alignment must be performed (at a minimum) to ensure acceptable HMD pointing accuracy. To initiate an HMD course alignment the pilot selects the ALIGN pushtile on the HMD format page, figure 22.

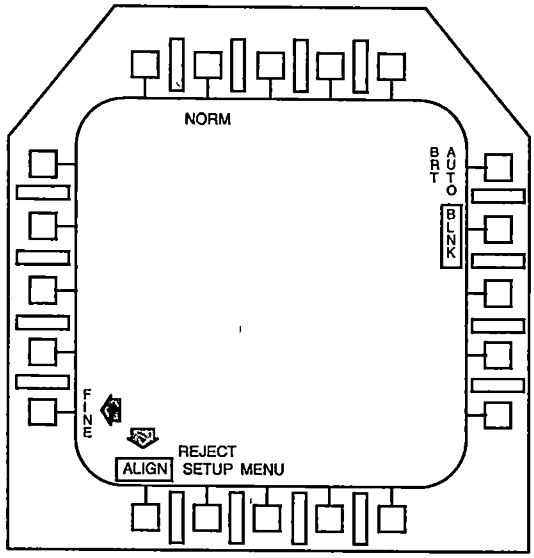

Figure 22. Course Alignment Selection

The HMD main display will change from displaying the normal HMD symbology to displaying the course alignment cross and the course alignment status. Additionally, an alignment cross is displayed, centered on the HUD, figure 23.

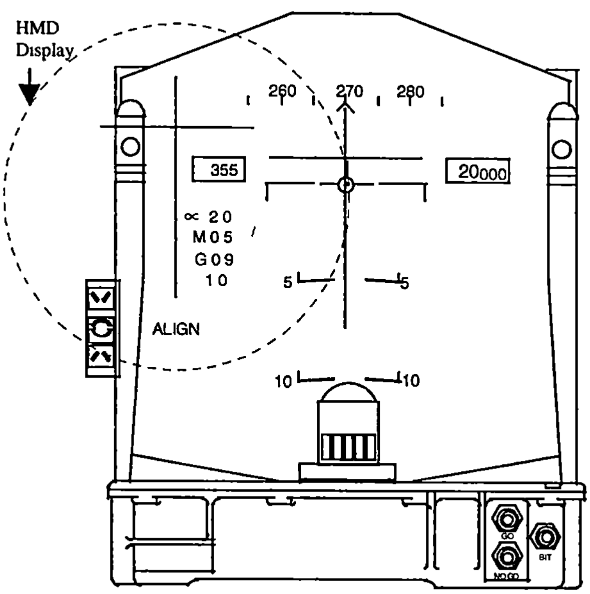

Figure 23. HMD Course Alignment

The pilot superimposes the HMD alignment cross over the HUD alignment cross and presses the C/UC button on the throttle until the HMD displays an ALIGN OK status (approximately 2 seconds). If the C/UC is released early, ALIGN FAIL will be displayed. If the system is degraded LOS FAIL will be displayed. When the pilot releases the C/UC button with an ALIGN OK, the system automatically transitions to the fine alignment mode [3].

The fine alignment mode may be entered by completing a course alignment or by manually selecting the FINE pushtile on the HMD format page. Upon entering the fine alignment mode the HMD display will change from displaying the course alignment cross to displaying two space stabilized alignment crosses, and the course alignment status will change from ALIGN OK to ALIGN DX/DY, figure 24.

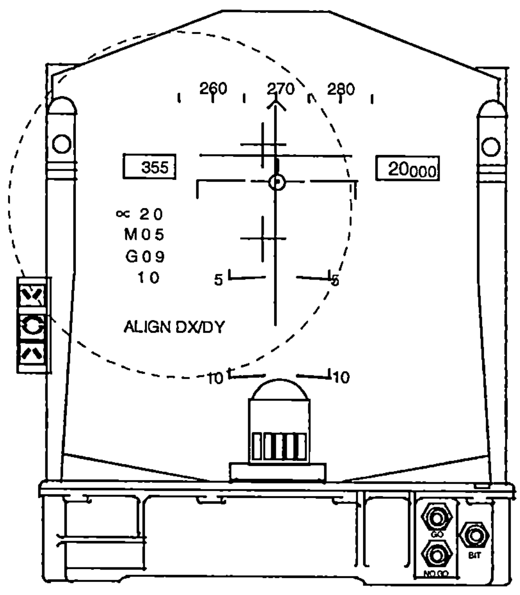

Figure 24. HMD Fine Alignment Symbology

During fine alignment, manipulating the aircraft TDC on the throttle up/down/left/right will slew the HMD space stabilized alignment crosses. The pilot will vertically and horizontally align the top HMD alignment cross so that it is coincident with the HUD alignment cross and press the C/UC button. The course alignment status will immediately change from ALIGN DX/DY to ALIGN DROLL. In this mode, manipulating the TDC left and right will rotate the lower HMD alignment cross counter-clockwise and clockwise respectively (pivoting around the upper HMD alignment cross). The pilot will align the vertical section of the lower HMD cross with the vertical section of the HUD alignment cross and press the C/UC button. Following the C/UC the alignment status will immediately change back to ALIGN DX/DY. If during alignment the HMD display is moved greater than 10 degrees away from aircraft boresight, alignment status will change to CENTER DISPLAY until the HMD display is returned [3].

To exit either course or fine alignment, the pilot can do one of the following: deselect the ALIGN option, select an air-to-air weapon, select the menu option, or change the position of the castle switch. Exiting alignment mode removes the alignment crosses from both the HMD and the HUD [3].

HMD Display Blanking

The HMD displays much of the same information displayed on the HUD. To prevent a double image when looking through the HUD and reduce clutter when looking at cockpit instruments, the HMD incorporates an automatic blanking feature. Selecting BLNK (the default) on the format page enables automatic blanking, and removes most of the HMD symbology when looking through the HUD or into the cockpit-blanking region. In the air-to-air master mode all of the HMD symbology is removed except the Sidewinder seeker circle, Radar HACQ circle and aiming cross [3].

HMD Brightness Control

The HMD Brightness Control provides three brightness control options: day, night and automatic brightness mode. The day and night modes provide brightness scheduling for the CRT to allow sufficient brightness for day use and appropriate sensitivity for night use. Selecting the AUTO mode utilizes the Automatic Brightness Control (ABC) sensor in the HDU. The HMD registers external brightness (via the ABC) and attempts to maintain the registered contrast between the external brightness and the displayed symbology. The ABC is disabled when the pilot changes HMD brightness via the brightness knob on the control panel [3].

HMD Reject Level Operation

The symbology displayed on the HMD can be rejected independently of the symbology on the HUD. Reject selection is accomplished via the reject pushtile on the HMD format page. Pressing the pushtile cycles the reject option between NORM, REJ1 and REJ2, with NORM being the default value. With Norm selected no HMD symbology is rejected. When REJ1 is selected all symbology programmed at reject level one is rejected. When REJ2 is selected all symbology programmed at reject level one and two is rejected [3].

HMD Reject Level Programming

HMD reject levels (REJ1 and REJ2) are programmable by the pilot. This allows the pilot to tailor, according to personal preference, the HMD symbology. Selecting the

REJECT SETUP pushtile on the HMD format page displays the HMD reject programming sub-level, figure 25. This displays the list of items that may be rejected. To program the reject levels, the pilot moves the selection box (using the up/down/left/right arrows on the HMD reject programming page) around the appropriate item and presses On, 1 or 2. Selecting "On" programs the HMD symbology to be displayed whenever NORM is selected as the reject level. Choosing "1" assigns the item to reject level one. Choosing "2" assigns the item to reject level two. When reject programming is finished the pilot returns to the HMD format page by selecting RETURN [3].

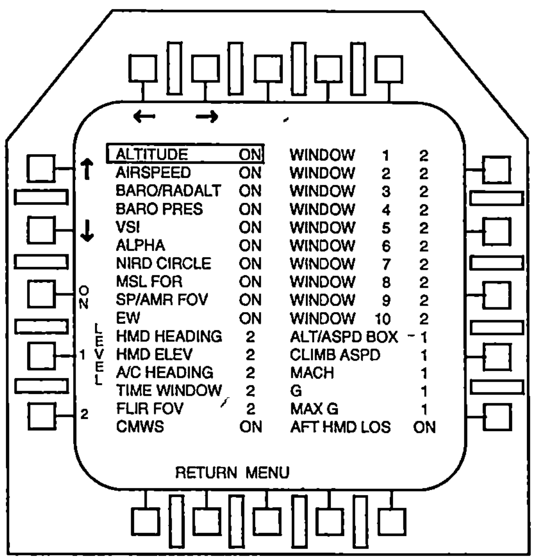

Figure 25. HMD Reject Programming Format

Electronic Unit Software

The EU OFP is compatible with the F/A-18, F-15, F-16, and F-22. The same EU could be installed into any of the four aircraft [4]. The symbology initiation file is loaded into the EU, from the host aircraft's MCs, the first time the EU is installed in the aircraft. The symbology initiation file will remain stored in the EU as long as the EU is installed in the aircraft. The EU (utilizing the symbology initiation file) will display the appropriate symbology format and orientation on the HMD [3]. The HMD Software Configuration display, figure 26, shows all of the separate hardware modules associated with the HMD on the left-hand side of the display. Adjacent to each module is its associated serial number, software version, firmware version, and elapsed time indication.

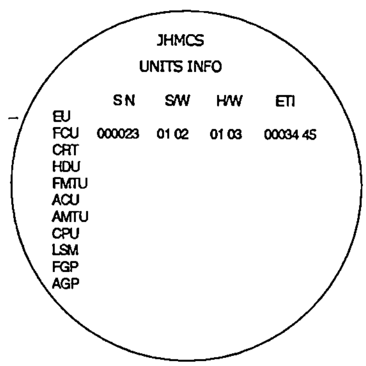

Figure 26. HMD Software Configuration

Helmet-Mounted Display Symbology

Symbology displayed on the HMD has been replicated as closely as possible to the symbology displayed on the aircraft's HUD, figure 27. This consistent format and orientation between the HMD and HUD presents a familiar display to the pilot that reduces aircrew workload and training [3].

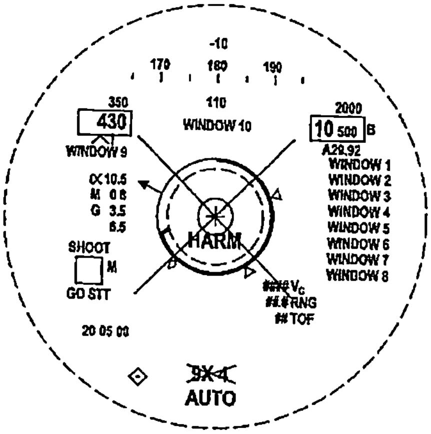

Figure 27. Maximum HMD Symbology

HUD Symbology Not Replicated on HMD

Some HUD symbology is not presented on the HMD in order to minimize disorienting the pilot. Most of the symbology that is aircraft referenced or referenced along the aircraft's boresight is omitted from the HMD [2]. Symbology not displayed on the HMD includes aircraft attitude data such as the aircraft pitch ladder, horizon bar, velocity vector, and waterline indicator. Landing aid symbology including bank angle cues, ILS cues, and the angle-of-attack bracket are omitted. Symbology used to employ weapons along the aircraft's boresight, including gun symbology and air-to-ground weapon release symbology is not displayed on the HMD [3].

HMD Symbology - Master Mode Independent

Helmet Line of Sight Data

The HMD LOS heading scale displays the HMD LOS azimuth angle relative to the aircraft in either magnetic or true heading. This data provides the pilot with a quick angular reference for visual targets. The HMD LOS elevation is displayed relative to the horizon. Figure 28 shows the pilot looking 180 degrees south, at 10 degrees below the horizon [3]

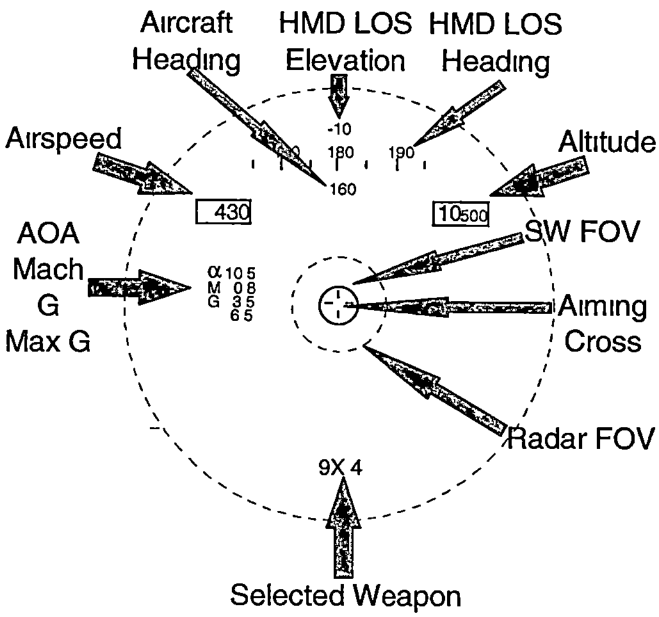

Figure 28. Typical HMD Display

Aircraft Data

Aircraft heading is displayed below the HMD LOS heading scale. This digital number displays the aircraft heading presented on the HUD [3].

Out of Motion Box Data

The HMD displays "MOTION BOX" if the pilot moves the helmet to a position that places the helmet MRU outside the boundaries of the cockpit magnetic map volume [2]. If this happens the system can not accurately determine the location and orientation of the helmet and the pilot should move the helmet towards the center of the cockpit until "MOTION BOX" disappears [3].

Helmet Video

Helmet video is provided so those events which take place during a flight may be recorded and played back for debrief [3]. The following symbology is only displayed on the recorded video and is used for debrief purposes, figure 29.

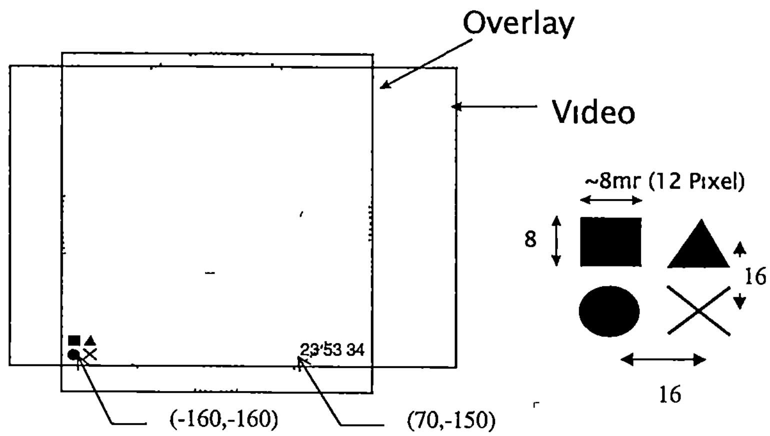

Figure 29. HMD Video Event Markers

Uplook Cursor Event Markers

The uplook cursors are outside the HMD FOV and are not recorded on HMD video Event markers are overlaid and recorded on to the HMD video to denote which uplook cursor is selected. A square displayed at the lower left corner of the HMD video denotes the left uplook cursor is selected. A triangle displayed at the lower left corner of the HMD video denotes the right uplook cursor is selected [3].

HUD Event Marker

A circle is displayed at the lower left corner of the HMD video when the trigger is squeezed to the second detent or when the weapons release button is depressed

Mission Time

Mission time is displayed at the lower left corner of the HMD video.

HMD Symbology - Air-to-Air Master Mode

Dynamic Aiming Cross

The dynamic aiming cross is the main cueing reference for the pilot. Selected weapons and sensor are commanded to the dynamic aiming cross LOS [3]. The dynamic aiming cross is normally displayed in the center of the HMD FOV. When a pilot looks up (raising helmet LOS) the dynamic aiming cross moves vertically from the center to the top of the HMD FOV, figure 30. This provides additional slaving angle to aid in earlier acquisitions The dynamic aiming cross reaches its maximum deflection of 9 degrees above HMD center when the pilot's head reaches 30 degrees of lookup [2].

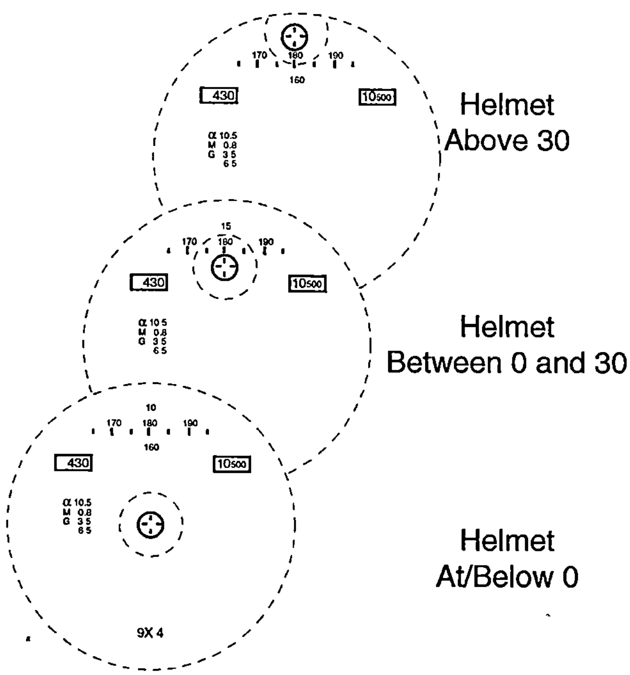

Figure 30. HMD Dynamic Aiming Cross

Radar in ACM mode (HACQ)

When HACQ is selected, the Radar is slaved to the HMD LOS and will automatically lock the first detected target. A 3.3 degree FOV dashed HACQ circle is displayed on the HMD, but not on the HUD. The HACQ circle is not removed from the HMD when display-blanking logic is activated. If the pilot attempts to slave the Radar beyond the gimbal limits of the Radar antenna, the HACQ circle will flash and be repositioned from around the dynamic aiming cross to the edge of the HMD FOV, figure 31. When the uplook cursors are active the dynamic aiming cross will disappear and the HACQ circle will be repositioned from around the dynamic aiming cross to center of the HMD FOV [3].

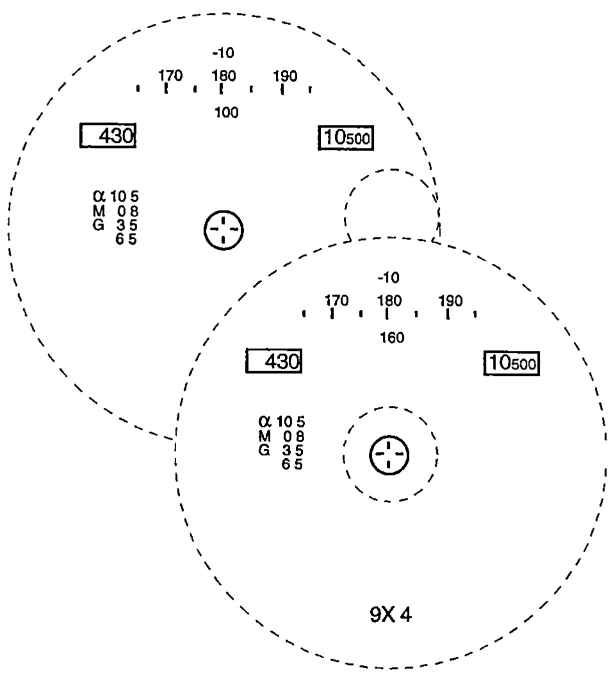

Figure 31. HMD Display of Gimbaled HACQ Circle

Launch and Steer Target

The launch and steer (L&S) specific symbology (figure 32) displayed on the HMD is identical to the symbology displayed on the HUD, therefore this symbology is blanked from the HMD when blanking logic is activated. When a target is created, the Target Designator (TD) box is displayed on the HMD adjacent to the target. The TD box will flash when it is outside the HMD FOV and a Target Locator Line (TTL) will be displayed. The TLL is a variable length pointer that points in the direction of the target. The TLL is displayed (60mr long) when the angular difference between the HMD LOS and the target is greater than 10 degrees and grows to a maximum of 125 mr when the angular difference reaches 90 degrees.

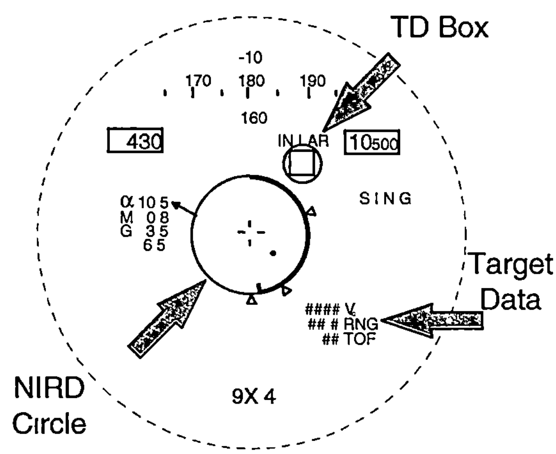

Figure 32. HMD Display With L&S Target

AIM-9 M/X Sidewinder Selected

Sidewinder is selected by pushing down on the Weapon Select Switch on the flight control stick. When this occurs, the air-to-air master mode is selected and the Sidewinder seeker circle is displayed on the HMD.

Sidewinder Seeker Circle

With Sidewinder selected, the HMD displays the Sidewinder seeker symbol at the missiles reported position. The Sidewinder seeker symbol is a displayed circle whose size is based on the AIM-9 variant selected. When AIM-9M is selected, the displayed Sidewinder seeker circle is 1.5 degrees. When AIM-9X is selected, the displayed seeker circle is the same size (in degrees) as the AIM-9X seeker FOV. When the Sidewinder transitions from slave to track the Sidewinder seeker circle remains at 1.5 degrees for the AIM-9M and transitions to 1.5 degrees for the AIM-9X The Sidewinder seeker circle is displayed on both the HMD and the HUD simultaneously, but is not removed from the HMD when display-blanking logic is activated.

Uplook Cursors

While the CRT does not display the uplook cursors on HMD, they are the primary cue for slaving the Sidewinder to high off-boresight targets. During high off-boresight acquisition attempts, head movement (usually when looking up) may limit the pilot's ability to place the dynamic aiming cross over the target. The uplook cursors can provide additional cueing angle for earlier target acquisition The uplook cursors bridge the gap between attainable HMD LOS (using the dynamic aiming cross) and the Sidewinder gimbal limits. When the uplook cursors are activated they are displayed and the Sidewinder is slaved to the uplook cursor LOS. The uplook cursors remain displayed until the Sidewinder obtains a track or the uplook cursors are deactivated. The uplook cursors flash when the Sidewinder is being slaved to its gimbal limits.

Helmet LOS Beyond Sidewinder Gimbal Limit

If the pilot attempts to slave the Sidewinder beyond its gimbal limit, the Sidewinder seeker circle will flash and be repositioned from around the dynamic aiming cross to the edge of the HMD FOV. In addition to the flashing seeker circle, the missile FOR line, figure 33, is displayed on the HMD. This provides a real-time reference to the pilot for determining the gimbal limits of the selected Sidewinder. The FOR line is based on the FOR of the AIM-9 variant selected.

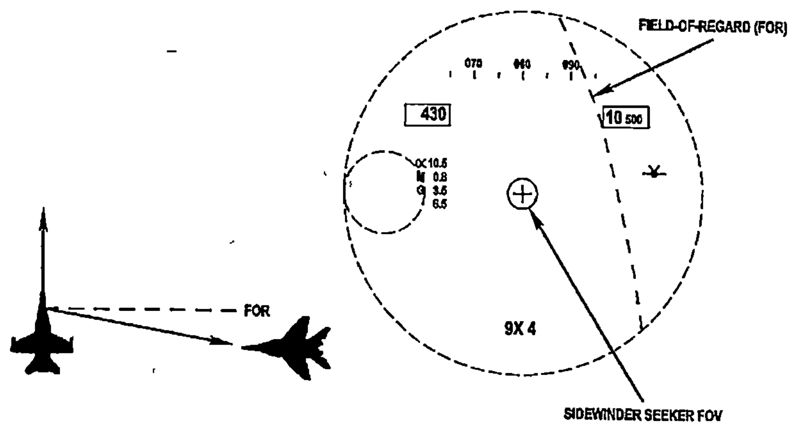

Figure 33. Sidewinder FOR line

Sidewinder LOS Beyond HMD FOV Limit

The Sidewinder seeker circle is flashed when it is outside of the HMD FOV. This can happen if the HMD LOS is beyond the Sidewinder gimbal limits, the Sidewinder is being slaved to a L&S target that is outside the HMD FOV, or the Sidewinder is tracking a target outside the HMD FOV [3].

AIM-7/AIM-120 Selected

Similar to the HUD, the AIM-7 or AIM-120 FOV circle is displayed on the HMD, figure 34. The AIM-7 and AIM-120 seekers are not slaved to the HMD LOS, but are being displayed for weapon selection information only [3].

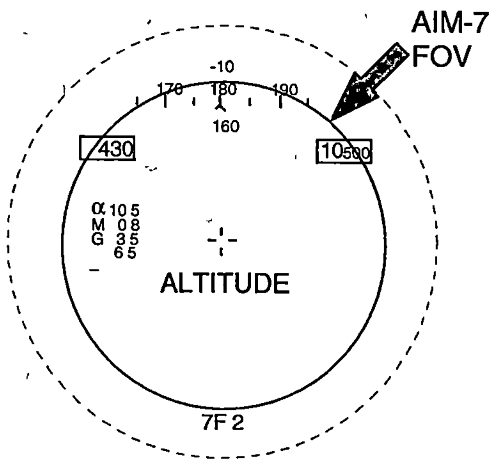

Figure 34. HMD Display With AIM-7 Selected

HMD Symbology - Air-to-Ground Master Mode

When air-to-ground master mode is selected and the JHMCS is operating, the HMD provides the pilot with the capability to visually designate A/G targets. When HMD priority has been selected by pushing the Sensor Control Switch forward, the HMD will display either the A/G aiming reticle, figure 35, or the aiming cross and TD diamond, figure 36. Additionally, the HMD will display the A/G data windows that are displayed on the HUD.

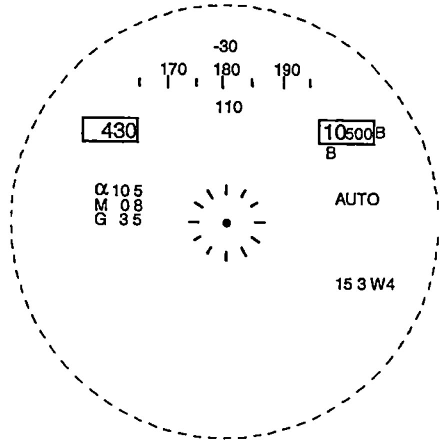

Figure 35. HMD Display Without An A/G designation

The aiming cross will be displayed at the center of the HMD FOV when an air-to-ground designation has been made. It will not move dynamically as mechanized in the air-to-air master mode. Weapon steering cues for the employment of air-to-ground weapons are not displayed on the HMD.

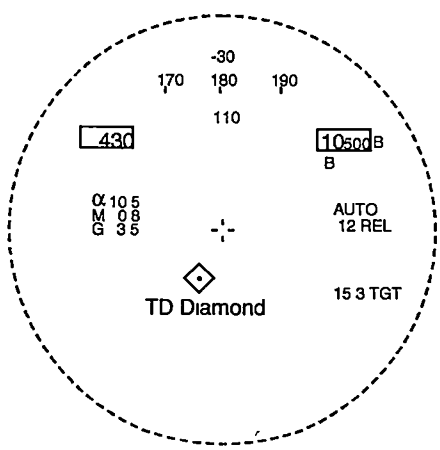

Figure 36. HMD Display With A/G designation

HMD Symbology - Navigation Master Mode

In navigation master mode the HMD will display the standard aircraft-state information, figure 37. If an air-to-air L&S or air-to-ground TD diamond exist, they will be displayed on the HMD. If either the L&S or TD diamond is HMD FOV limited, a

TTL will point towards the appropriate symbol. If both are HMD FOV limited the TLL will point towards the L&S.

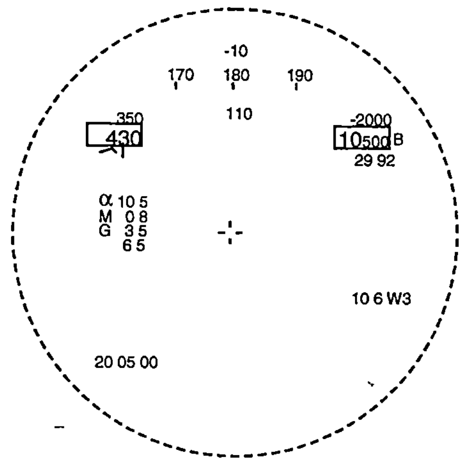

Figure 37 HMD Display in Navigation Master Mode

CHAPTER 3

System Integration

Liveware to Hardware

Pilot to JHMCS

Pilot-Helmet Fit

To achieve satisfactory performance the helmet should fit snugly and comfortably. The HGU-55/P helmet shell is fitted with a foam ZETA® liner made by the Oregon Aero Company. The ZETA liner is secured inside the helmet using Velcro strips. The ZETA liner is available in five different widths to accommodate different head sizes. Correctly positioning the HMD display over the pilot's right eye is the most critical step in the fitting process. The HMD display is positioned laterally by adjusting an Inter-pupil distance adjustment located on the top of the HDU. The HMD display is positioned vertically by adjusting the thickness of the ZETA liner.

System Start-up

The following are the minimum steps required for operating the JHMCS. Upon entering the cockpit, the pilot mates the upper half of the QDC (attached to the pilot's flight harness) to the lower half of the QDC (attached to the aircraft). The upper half of the QDC is attached to the mounting bracket on the pilot's torso harness. When the HDU is attached to the helmet the system is ready for power-up. After the aircraft generators have come on-line, the JHMCS can be powered up by rotating the On/Off Brightness knob clockwise, off the detent. Start-up requires from 10 seconds to 2 minutes after which the symbology in figure 38 is displayed on the HMD.

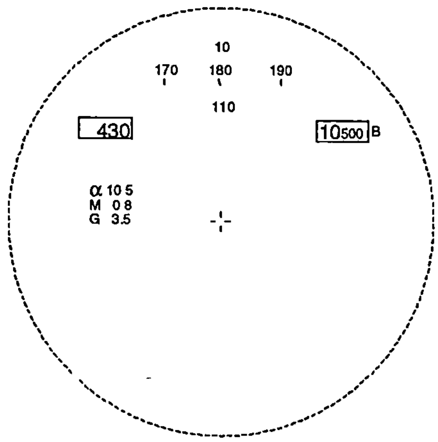

Figure 38. HMD Display After Start-up

If the display is not shown within two minutes of applying power, a system problem has probably occurred and the pilot should initiate an HMD BIT. An HMD BIT may help the pilot discover the source of the problem. When the system is operating correctly, the pilot will configure the JHMCS using the HMD format page and perform an alignment. A course alignment is the minimum that is required, but a fine alignment will increase system LOS accuracy. Following the alignment the system is ready for operation.

System Operation

While airborne the pilot can reference aircraft-state information and cue weapons and sensors without looking through the HUD. During dynamic air-to-air combat, the pilot can monitor critical aircraft parameters such as speed, altitude, and load factor on the HMD while simultaneously keeping sight of the target. Real-time awareness of speed, altitude and load factor are necessary for achieving maximum aircraft performance. The pilot can cue sensors and weapons in the air-to-air master mode using the dynamic aiming cross or uplook cursors. The pilot can cue weapons and sensors in the air-to-ground mode by creating an air-to-ground designation using the aiming reticle.

Air-to-Air Cueing

The pilot's primary aiming cue is the dynamic aiming cross. The aircraft computes the dynamic aiming cross LOS and commands the Radar and the Sidewinder to point in that direction. The time required for the aircraft to align the Radar/Sidewinder LOS with the pilot cued LOS, and then transmit back actual missile LOS for display on the HMD is called System Latency [11]. System latency, a result of display latency and mechanical slaving rates, causes the HACQ and Sidewinder seeker symbology to lag significantly behind the dynamic aiming cross. This lag prevents the use of the HACQ or Sidewinder circles as aiming cues. A recent study conducted for USAF Wright Laboratories showed that lag between pilot LOS and aiming cues increases acquisition time in a linear fashion [6]. The HACQ and Sidewinder symbology is displayed on the HMD primarily as an indication of system health.

Pilot to Sidewinder – HOBS

Sidewinder Cueing

The HOBS was designed to facilitate track and shoot functions on high off-boresight airborne targets in the WVR arena. The pilot can cue the Sidewinder in one of three ways: using the dynamic aiming cross, acquiring a Radar track in HACQ, or using the uplook cursors. When the JHMCS is powered-up and Sidewinder is selected, the Sidewinder will be automatically slaved to the dynamic aiming cross on the HMD. Any time the Sidewinder obtains a track, the pilot can easily break the track and slave the Sidewinder back to the dynamic aiming cross by pressing the C/UC button on the throttle. Pushing forward on the Sensor Control Switch will select the HACQ Radar mode, slaving both the Radar and the Sidewinder to the dynamic aiming cross When a HACQ Radar track has been obtained, the Sidewinder will be slaved to the Radar LOS in an attempt to gain a Sidewinder track. The pilot can easily cycle the Sidewinder back and forth between the Radar track LOS and the dynamic aiming cross by pressing the C/UC button While in HACQ the pilot can cycle back-and-forth between the uplook cursors and the dynamic aiming cross by pulling aft on the Sensor Control Switch. The C/UC button will not deselect the uplook cursors

Employing HOBS

If an air-to-air engagement has degraded to the WVR environment, the pilot will attempt to visually acquire and pass the target head-on. Prior to the pass, the pilot will select Sidewinder by pushing down on the Weapon Control Switch and select AUTO acquisition mode by pressing the C/UC button for more than 0.8 seconds. Following the pass, the pilot will turn the aircraft 180 degrees back towards the target. The pilot will select HACQ by pushing forward on the Sensor Control Switch and then select the uplook cursors by pulling aft on the Sensor Control Switch. The pilot will attempt to place the uplook cursors on the target as soon as possible. During normal operation the Sidewinder will transition to track when the uplook cursors are placed over the target and the target is within the Sidewinder FOR. When the Sidewinder transitions to track, the uplook cursor will disappear, and the Sidewinder track tone will be transmitted. If the Sidewinder does not quickly transition to track, the pilot should transition from the uplook cursors to the dynamic aiming cross by pulling aft on the Sensor Control Switch.

As the target transitions from high off-boresight to medium off-boresight, the dynamic aiming cross is a more effective aiming cue. With the uplook cursors deselected, both the Radar and the Sidewinder will be slaved to the dynamic aiming cross. If the Radar is capable of obtaining a track it will slave the Sidewinder to the Radar track LOS enabling the Sidewinder to acquire the target. When the Sidewinder transitions to track, the Sidewinder seeker circle size will be 1.5 degrees and the Sidewinder track tone will be transmitted. Once a good track is established the pilot pulls the trigger and shoots the Sidewinder

Hardware to Hardware

Aircraft to JHMCS

Aircraft Mission Computer to JHMCS Electronic Unit

Upon power up of the JHMCS, the EU reads the data stored in the HDU, MTU, and the CU. This provides the EU with the cockpit magnetic map, helmet characterization data, and JHMCS hardware serial numbers. If the HDU, MTU, and CU have not been replaced since the last power-up, system power-up could take as little as 10 seconds. However, if a piece of equipment has changed, the power-up time could take as long as two minutes. Once the EU has read the data from the external equipment the aircraft's MCs will provide the EU with any required data. If the EU is new to the aircraft, the MC will have to load the aircraft's symbology initiation file, which may be different for each F/A-18 variant. Following successful communication between the EU and the aircraft's MCs, the EU will compute HMD LOS and begin displaying symbology to the HMD.

Aircraft to JHMCS - Frames of Reference

JHMCS Frame of Reference

The JHMCS MTU and MRU operate in the body coordinate system of the aircraft. The positive X-axis is out the nose of the airplane and the positive Y-axis is out the right wing. The positive Z-axis is out the bottom of the aircraft with the origin centered at the Inertial Navigation System (INS). To produce a magnetic map of the cockpit, an MRU is mounted on a translatable fixture (a cockpit magnetic mapper) within the cockpit, figure 39. The MRU is then moved throughout the cockpit-planned area of operation to record the magnetic signature at each point. To accommodate for head motion, the orientation of the MRU is changed in order to characterize operation when the MRU is not aligned with the axes. In operation, the signal received by the MRU is compared to the cockpit magnetic map to determine helmet orientation [12].

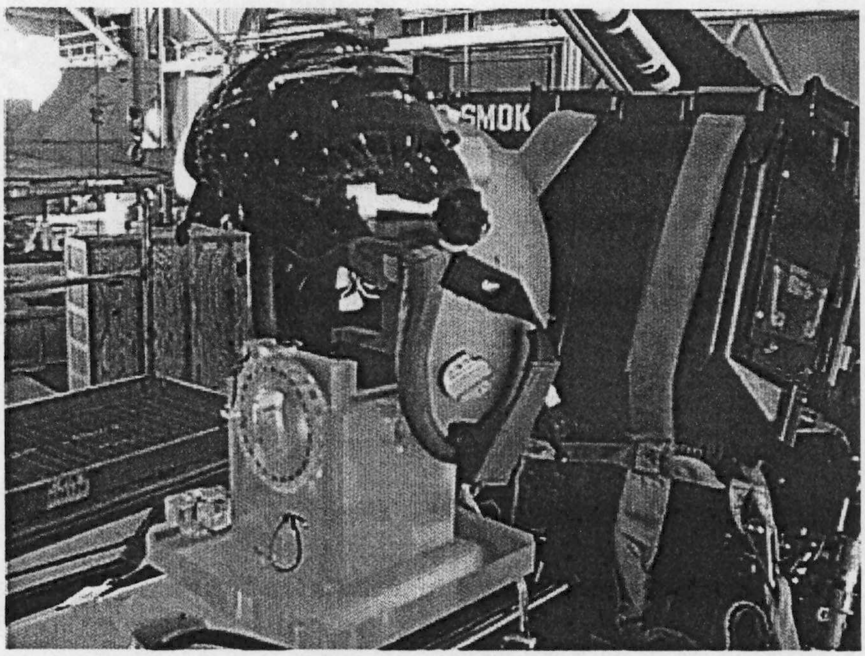

Figure 39. Translatable Fixture – Cockpit Mapper

Aircraft Frame of Reference

The INS in the aircraft determines aircraft position in the inertial coordinate system with North, East, and Down being the positive directions. Sensor and weapon systems such as the Radar and the Sidewinder also report position relative to the inertial frame of reference. To cue aircraft systems, the body axis LOS from the helmet system is passed to the aircraft MCs for conversion to the inertial frame of reference [12].

Helmet Line-of-Sight Orientation

Prior to sending the helmet LOS (in the body coordinate system) to the aircraft's MCs, the JHMCS EU applies a series of corrections to ensure the LOS accuracy. The first correction is based on vertical position of the ejection seat. As the seat moves through its adjustable range, its position affects the MTU generated magnetic field. These changes to the field must be compensated for to ensure an accurate LOS. Second, a correction is required to correct for refraction caused by the aircraft canopy. The EU contains the correction algorithm for both the F/A-18 and the F-15 [7]. A third correction is applied to compensate for the effects of additional metal and circuitry such as the oxygen mask bayonet fittings and earphones present in the pilot's helmet.

MTU to MRU

The EU performs the helmet LOS computations. The MTU (attached to the aircraft) and MRU (attached to the helmet) each contain three coils oriented in a X, Y and Z-axis configuration. By comparing three transmitted signals from the MTU (one from each axis) to the received signals in the MRU, the EU computes the helmet's orientation relative to the aircraft. As an example, the MTU transmits a magnetic field from the coil oriented in the X-axis. The magnetic field induces a signal, in varying strengths, in all three of the MRU's coils If the MRU detects the strongest signal in the coil oriented along the X-axis, the helmet and the aircraft are aligned. If the MRU receives the strongest signal in the coil oriented along the Y-axis, the helmet is oriented 90 degrees from the aircraft. Additionally, the time required for the signal to travel from the MTU to the MRU provides helmet distance information. The EU requires one MTU-transmitted magnetic field from each axis and their respective transmission times to compute helmet LOS.

CHAPTER 4

Human Factors Evaluation

General Comments

The HOBS was evaluated for the WVR combat mission using the SHEL model as a guide. Sixteen ACM test flights were performed accumulating a total of 15.5 flight hours, table 1. Approximately four ACM engagements were performed during each test flight. All of the ACM test flights were flown in the vicinity of China Lake, California over desert and mountainous terrain under day, visual meteorological conditions. The high workload and time critical requirements placed on the pilot during the ACM test flights uncovered many deficiencies that previously went unnoticed during earlier, less dynamic phases of flight testing. While many aspects of the HOBS were satisfactory, only the issues that were enhancing characteristics or deficiencies were listed in this chapter.

F/A-18 HOBS ACM Test Flights		
Target Aircraft	Number of Test flights	Number of engagements
F/A-18 - Non-HOBS equipped	9	38
F-15 – Non-HOBS equipped	3	11
F-15 - HOBS equipped	4	15

Table 1, F/A-18 HOBS ACM Test Flights

Liveware to Hardware

Helmet Fit

The HMD was evaluated for helmet fit in the WVR environment while performing dynamic maneuvers at high load factors. A medium HGU-55/P helmet shell was fitted with a size 3, foam ZETA® liner made by the Oregon Aero Company. The helmet remained secure on the pilot's head without any noticeable discomfort. The secure helmet fit combined with the lightweight characteristics of the HMD enabled the pilot to cue the Sidewinder under high load factor conditions, without an increase in head and neck fatigue. During all ACM engagements the HMD fit snuggly and comfortably with only minor helmet rotation. The HMD main display and the uplook cursor displays were not effected by the slight helmet rotation and display quality remained constant throughout the WVR environment. The satisfactory display quality during dynamic maneuvering allowed the pilot to monitor the aircraft state information (altitude, airspeed, load factor) crucial for achieving maximum aircraft performance.

Uplook Cursor Display Positioning

Uplook cursor display positioning was evaluated during one and two-circle engagements. In both of these scenarios the aircraft was in a 60-80 degree AOB turn towards the target, with the pilot looking over his shoulder in an attempt to place the uplook cursor on the target. Uplook display placement on the visor, both laterally and horizontally, was well suited for acquisition cueing. Only small adjustments to head movement were required to align the uplook cursor with the target. Additionally, the current system design for automatically switching from one uplook cursor to the other uplook cursor was very timely. The appropriate uplook cursor for the targeting situation was always displayed.

Uplook De-Selection Not Intuitive

Deselecting the uplook cursors in order to select the dynamic aiming cross as the primary aiming cue was evaluated during one and two circle engagements. Selecting the uplook cursors first required the pilot to select HACQ. After selecting HACQ, the pilot could select and deselect the uplook cursors by pulling aft on the Sensor Control Switch. If the pilot lost track of how many times the Sensor Control Switch had been pulled aft, the pilot had to visually confirm the display of the uplook cursors to determine if they were selected. Additionally, this mechanization resulted in having to use two different methods for selecting the dynamic aiming cross as the primary aiming cue. Selecting the dynamic aiming cross required pushing forward on the Sensor Control Switch if the uplook cursors were deactivated and pulling aft on the Sensor Control Switch if the uplook cursors were activated. This mechanization was not intuitive and required the pilot to know the pre-existing condition of the uplook cursors in order to correctly select the dynamic aiming cross as a cueing source.

Liveware to Software

Dynamic Aiming Cross Utility

The dynamic aiming cross (the primary cueing reference for HACQ and Sidewinder) was too small and unintuitive for quick reference. The pilot had to make a concerted effort to find it on the HMD. When the dynamic aiming cross moved to the top of the HMD, it blended in with the helmet heading symbology making it difficult to view. The merging of the dynamic aiming cross and helmet heading symbology occurred during approximately 80 percent of the (dynamic aiming cross-cued) acquisition attempts. Using the dynamic aiming cross in the WVR arena required removing (by programming REJ1 and REJ2) the helmet heading symbology from the HMD display. Unfortunately, the helmet heading symbology aided the pilot in obtaining a visual acquisition of the target aircraft and therefore had its greatest utility in the WVR environment.

The HACQ and Sidewinder circles on the HMD display were distracting and contributed to the difficulty in utilizing the dynamic aiming cross. The HMD was designed to display the HACQ and Sidewinder circles at the reported Radar and Sidewinder seeker LOS. Due to system latency [11] the displayed HACQ and Sidewinder circles lagged so far behind the dynamic aiming cross (getting up to 180° out of phase) that they cluttered the HMD display and detracted from targeting. The HACQ and Sidewinder circles were not designed for use as aiming cues. The only reason for displaying actual Radar or seeker position (prior to a lock) was to give an indication of system health. While this was advantageous during developmental test and while performing pre-combat checks, it provided no useful information to the pilot while targeting an aircraft in the WVR environment. The pilot had the Sidewinder white noise tone and the Sidewinder and Radar BIT status to determine system health.

USN F/A-18 pilots were trained to use the AIM-9M seeker circle and the Radar BST circle as an aiming cue when employing their current weapon systems. It was extremely difficult for the pilot to deviate from this training and ignore the Sidewinder and HACQ circles (which were moving erratically on the HMD) and use the dynamic aiming cross as the primary aiming cue. When the pilot reverted to previous training during an engagement and attempted to cue using the HACQ or Sidewinder symbology, acquisition success was severely diminished. Results from the Wright Laboratory's Variable-Stability In-flight Simulator Test Aircraft (VISTA) NF-16D flight simulator showed that system latency greater than 0.1 seconds increased pilot workload when performing missile cueing, due to the pilots tendency to over correct [9]. Pilots agreed during the Visually-Coupled Acquisition and Targeting System (VCATS) / F-15 program that system latency, not accuracy, was 80 percent of the problem when performing missile cueing in a dynamic maneuvering environment [10].

Sidewinder Seeker Circle Displayed in HUD and HMD Caused Ghosting

When the HMD display was within the HUD blanking region, the system was designed to remove all HMD symbology except the Sidewinder seeker circle, Radar HACQ (dashed) circle, and dynamic aiming cross. When the JHMCS was in operation, the Sidewinder seeker circle was displayed on both the HUD and the HMD simultaneously. The HACQ circle was removed from the HUD during HMD operation. The dual display of the Sidewinder seeker circles resulted in increased clutter and ghosting when looking through the HUD. The increased clutter prevented long-range visual sightings of head-on targets. The only available method for de-cluttering the dual displayed symbology.was to turn off the JHMCS.

HMD Clutter Caused By Gimbaled/Flashing Symbology

When the Radar or Sidewinder was HMD display limited, the system was designed to flash the appropriate symbol on the edge of the HMD display. During acquisition attempts, the flashing symbol was distracting and decreased acquisition performance. However, when the Radar or Sidewinder was in track, the appropriate flashing symbol was useful in providing a directional cue towards the target.

AIM-9X FOR Line Does Not Reflect AIM-9X Actual FOR

The AIM-9X FOR line was designed to provide the pilot with a real-time indication of the AIM-9X seeker gimbal limit. This reference aided the pilot during AIM-9X acquisition attempts. If the target was just outside of the FOR, the pilot could estimate how far the aircraft's nose had to be repositioned to place the target inside of the AIM-9X FOR. The AIM-9X FOR display line only reflected actual AIM-9X FOR from 0 to 30 degrees up in elevation. Greater than 30 degrees up, the FOR display line was too conservative. Fortunately, the AIM-9X displayed seeker circle flashed at the actual AIM-9X FOR. While the flashing seeker circle gave the pilot an indication of the actual AIM-9X seeker gimbal limit, the seeker circle was much harder to monitor than the FOR line during dynamic maneuvering.

Hardware to Hardware

AIM-9X Slaving Priority

While employing the HOBS during one and two circle engagements, the AIM-9X slaving priority was not always given to the primary cueing source. At the beginning of an engagement the pilot would cue with the uplook cursors in an attempt to acquire the target at the highest off-boresight angle possible. The pilot would select AIM-9X, HACQ and then the uplook cursors. With the uplook cursors activated the Radar (in HACQ) would be slaved to center of the HMD FOV, while AIM-9X would be slaved 30 degrees higher to the uplook cursor LOS. The problem is that the Radar (while tracking) would remain the priority cueing source even when the Radar and the uplook cursor (what was being aimed at the target) were pointed in different directions. If the Radar obtained a false lock on the ground or another aircraft in the vicinity, the AIM-9X would no longer be slaved to the primary cueing source (the uplook cursors) but to the false target along the Radar LOS. To rectify the situation the pilot would first have to recognize that a false Radar and possibly AIM-9X lock had been obtained, then push the C/UC button to slave the AIM-9X to the HMD LOS, Castle FWD to re-select HACQ, and Castle back to re-select the uplook cursors. The number of steps required to reselect the uplook cursors after a false radar track prevented high off-boresight acquisitions.

HACQ Mechanization with Uplook Cursors Selected

HACQ mechanization reduced the chance of obtaining a Sidewinder acquisition while using the uplook cursors as a cueing source, and increased the difficulty of transitioning from the uplook cursors to the HMD dynamic aiming cross. When HACQ was selected and the uplook cursors were not selected, both the Radar and the Sidewinder were slaved to the dynamic aiming cross. This mechanization provided targeting redundancy. If the HMD cued Sidewinder failed to track the target, but HACQ was able to obtain a Radar track, the system would command the Sidewinder to the Radar LOS in an attempt to obtain a Sidewinder track. When the uplook cursors were selected, the system commanded the HACQ mode of the Radar to the center of the HMD FOV (30 degrees away from the uplook cursor LOS), and removed the dynamic aiming cross. This prevented the Radar from assisting the Sidewinder during an uplook cursor acquisition attempt. If the pilot was unable to acquire the target with the uplook cursors, the pilot had two options. First, the pilot could leave the uplook cursors selected, rotate the HMD 30 degrees towards the target and point the HACQ dashed circle without the aid of the dynamic aiming cross. Second, the pilot could deselect the uplook cursors, rotate the HMD 30 degrees towards the target and point the dynamic aiming cross (slaving both the Radar and Sidewinder). Using either option, it was difficult for the pilot to transition from looking at the uplook cursors to looking at the dynamic aiming cue on the HMD, while simultaneously repositioning the helmet and maintaining site of the target. This increased pilot workload resulted in significant acquisition delays.

Radar Mode Functionality After Lost HACQ Track

If a Radar track was obtained using HACQ, the Radar would not revert back to HACQ if the Radar track was lost. Following lost track, the Radar would revert back to the Range-While-Scan (RWS) mode and take the aircraft out of the ACM condition. During dynamic maneuvering in the WVR arena, there were many instances where a

Radar track on the target was obtained but the range between the aircraft and the target was too close to employ weapons. On most of these occasions the aircraft Radar broke track as the two aircraft passed each other. Following the pass, the two aircraft would turn to re-engage each other. With the current system mechanization, the pilot would have to reselect HACQ after every time the Radar broke track. On approximately one-quarter of the engagements the pilot would re-engage the target without HACQ (the optimum Radar mode) selected.

CHAPTER 5

Conclusions and Recommendations

General Conclusions

The HOBS showed tremendous tactical utility in the WVR arena The HOBS was able to consistently acquire targets at high off-boresight angles. The HOBS allowed the pilot to monitor critical aircraft-state information such as airspeed, altitude, and load factor while simultaneously keeping sight of the target at high off-boresight angles. Secure helmet fit combined with the lightweight characteristics of the HMD enabled the pilot to cue the Sidewinder at high load factors. While the presentation of the uplook cursors were advantageous, the dynamic aiming cross on the main display was difficult to utilize as the primary cueing source. The area with the greatest need for improvement was the HOBS mechanization for transitioning from one JHMCS cueing mode to another. This mechanization was not always intuitive and hampered the pilot during high-workload, dynamic maneuvering.

Liveware to Hardware

Helmet Fit

Conclusion

The secure fit achieved by the HGU-55/P helmet shell fitted with the foam ZETA® liner is an enhancing characteristic that will increase pilot comfort and HOBS performance. The lightweight HMD will not add to pilot fatigue during AIM-9X acquisition attempts at high load factors.

Uplook Cursor Display Positioning

Conclusion

The uplook cursors provide a tremendous tactical advantage during high off-boresight acquisition attempts. The well placed positioning of the uplook cursors are an enhancing characteristic, which will decrease both acquisition time and pilot workload during high off-boresight acquisitions.

Uplook De-Selection Not Intuitive

Conclusion

The unintuitive mechanization for deselecting the uplook cursors is a deficiency that should be corrected before deploying this system to the fleet. The current mechanization will increase the time required for transitioning from the uplook cursors to the dynamic aiming cross. This increase in transition time will decrease the off-boresight angle at AIM-9X acquisition, reducing the HOBS first shot capability.

Recommendation

The system should be mechanized so that the uplook cursors are deselected by castling forward on the sensor control switch. This would enable the pilot to select the dynamic aiming cross as a cueing source by pushing forward on the Sensor Control Switch and select the uplook cursors as a cueing source by pulling aft on the Sensor Control Switch - in all scenarios.

Liveware to Software

Dynamic Aiming Cross Utility

Conclusion

The difficulty in utilizing the dynamic aiming cross as the primary cueing source is a deficiency that must be corrected before deploying this system to the fleet. The poor visual characteristics of the dynamic aiming cross combined with the additional display clutter caused by the erratic movement of the HACQ and Sidewinder circles will increase AIM-9X acquisition time and reduce the HOBS first shot capability.

Recommendation

An option called "Tactical" should be made available on the HMD support page. Selecting "Tactical" would place the HACQ and Sidewinder circles coincident with and around the dynamic aiming cross. The circles should move up and down with the dynamic aiming cross, as currently mechanized. The HACQ circle and the AIM-9X circle should be the primary aiming cue for targeting. This would increase aircrew familiarity and reduce aircrew training. The HACQ circle and the Sidewinder circle should not reflect actual seeker position until the Radar or Sidewinder obtains a lock. This option should be selected as the default upon system power-up.

An option called "Maint" should also be available on the HMD support page. Selecting "Maint" would display the HACQ circle and Sidewinder circle on the HMD at their reported position (as currently mechanized). This option would provide the pilot with real time feedback of system health during a known system failure (failed BIT) or during pre-combat checks.

Sidewinder Seeker Circle Displayed in HUD and HMD Caused Ghosting

Conclusion

The simultaneous display of the Sidewinder seeker circle on both the HUD and HMD is a deficiency that should be corrected before deploying this system to the fleet. The increased display clutter, due to ghosting, will prevent long-range visual sightings of head-on targets.

Recommendation

The AIM-9X seeker circle should be removed from the HUD when the HMD is in operation.

HMD Clutter Caused By Gimbaled/Flashing Symbology

Conclusion

The current functionality of displaying the HACQ and Sidewinder circles when they are HMD display limited is a deficiency that should be corrected before deploying this system to the fleet. Displaying the HACQ and Sidewinder circles at the edge of an already small and cluttered display reduces HMD display readability and acquisition performance.

Recommendation

When there is no Radar or Sidewinder track and the HMD is being pointed beyond the Radar or Sidewinder gimbal limits, the Sidewinder and HACQ circles should be held space stabilized at their respective FORs until within the HMD FOV. If either the Sidewinder or Radar obtains a track, that symbol should be displayed as currently designed.

AIM-9X FOR Line Does Not Reflect AIM-9X Actual FOR

Conclusion

The conservative presentation of the AIM-9X FOR line is a deficiency that should be corrected in future HOBS configurations. While the AIM-9X FOR is a more intuitive presentation, the flashing Sidewinder seeker circle will give the pilot a usable reference for the actual AIM-9X FOR.

Recommendation

The system software should be corrected so that the AIM-9X FOR display line reflects the actual AIM-9X FOR.

Hardware to Hardware

AIM-9X Slaving Priority

Conclusion

The mechanization that gives the Radar primary slaving priority when the uplook cursors are activated is a deficiency that must be corrected before deploying this system to the fleet. The capability of the Radar to command the Sidewinder seeker to a target 30 degrees away from the pilot commanded uplook LOS will increase the probability of shooting the Sidewinder at friendly aircraft.

Recommendation

When the uplook cursors are activated and the Radar obtains a track, the system should perform an AOC check between the uplook cursor LOS and the Radar track LOS. Until AOC is satisfied, the AIM-9X should remain slaved to the uplook cursor.

HACQ Mechanization with Uplook Cursors Selected

Conclusion

HACQ mechanization during uplook activation is a deficiency that must be corrected before deploying this system to the fleet. Commanding the Radar to a LOS 30 degrees away from the uplook cursor LOS will always prevent the Radar from obtaining a track on the intended target.

Recommendation

The system should be mechanized so that when HACQ is selected, the Radar points along the uplook cursor LOS. As the pilot attempts an uplook acquisition (from high off-boresight to low off-boresight) the uplook LOS and the Radar LOS will converge as the target reaches the Radar FOR. This will provide the redundancy that is present when cueing with the dynamic aiming cross. Commanding the Radar to the uplook cursor LOS will increase the chance of obtaining high off-boresight acquisitions

Radar Mode Functionality After Lost HACQ Track

Conclusion

Transitioning from HACQ to RWS during a dynamic engagement in the WVR environment is a deficiency that should be corrected before deploying this system to the fleet. The current system mechanization will require the pilot to reselect HACQ every time the Radar breaks track during an engagement.

Recommendation

The system should be mechanized to revert back to the HACQ mode whenever a HACQ obtained Radar track is lost,

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Terry Scott Barrett was born in Atlanta, Georgia on January 18, 1963 He graduated from Lyman High School in Longwood, Florida in 1981 He earned a Bachelor of Science in Engineering (Computer and Information Sciences) from the University of Florida in May 1987. He worked as a Software Engineer for Lockheed Space Corporation from 1988 to 1989 After attending Aviation Officer Candidate School in October of 1989 he was commissioned as an Ensign in the United States Navy He then proceeded to Pensacola, Florida to start flight training, earning his Navy wings in 1992 He was assigned to fly the F/A-18 Hornet in Jacksonville, Florida where he served as a strike fighter pilot with the VFA-86 Sidewinders from 1993 to 1997 Following completion of his fleet tour he was selected to attend the U S. Naval Test Pilot School in Patuxent River, Maryland Upon graduation from test pilot school he was assigned to his current billet at the Naval Aircraft Warfare Center, Weapons Division at China Lake, California where he serves as the AIM-9X and Joint Helmet-Mounted Cueing System (JHMCS) project officer.