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14. ABSTRACT
The AH-1Z provides the Marine Air Ground Task Force (MAGTF) Commander with a capable attack helicopter to utilize in the joint warfighting environment. Increasing its capability on the battlefield by increasing aircrew situational awareness and minimizing the risk associated with operating in degraded visual environment are essential to instill confidence in the commander. Marine Helicopter Light Attack (HMLA) squadrons are in the process of transitioning to the AH-1Z Viper from its predecessor, the AH-1W Super Cobra. The AH-1Z provides aircrew with an enormous capability shift in terms of how information is provided to the operator by providing a cockpit that is “under-glass.” Mechanical flight instruments have yielded to digital flight displays that have increased the amount of information that is presented to aircrew at any one time. This increase in information capability has increased systems functionality in the aircraft. With an increase in the functionality comes an increase in task load for aircrew unless the human machine interface (HMI) is streamlined. Without a streamlined or optimized HMI aircrew situational awareness is degraded because of an excessive mental workload. The HMI should be optimized to afford aircrew the appropriate situational awareness in all operating environments. It should be designed to maximize aircrew efficiency, effectiveness, and safety by providing at-a-glance information critical to mission success and safe employment of the aircraft. In order to accomplish this, a complete workload study of tasks performed by aircrew in the AH-1Z must be completed in the near future in order to understand design flaws and guide future design and integration of increased capability. Additionally, employment of material solutions to provide aircrew with the appropriate situational awareness under all operating conditions is detrimental to the safety of the aircrew and aircraft. Finally, increasing the effectiveness and efficiency of

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the aircrew through enhanced situational awareness that supports mission accomplishment is crucial.

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MASTER OF MILITARY STUDIES

Modifications to Optimize the AH-1Z Human Machine Interface

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
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Executive Summary

Title: Modifications to Optimize the AH-1Z Human Machine Interface

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Thesis: Aircrew situational awareness in the AH-1Z can be improved by optimizing the human machine interface (HMI) to reduce mental workload and increase effectiveness, efficiency, and safety.

Discussion: Situational awareness is a key component in aviation. The H-1 Upgrade Program was designed to provide an upgraded light attack capability to the Marine Corps. The aging UH-1N was replaced by the UH-1Y and the AH-1W was replaced by the AH-1Z. Due to the commonality considering the HMI in the upgrades aircraft the AH-1Z will be used for analysis. The Marine Corps' premier attack helicopter, the AH-1Z Viper completed successful Operational Evaluation in the spring of 2010 and was deemed initially operationally capable on 24 February 2011. Currently Marine Helicopter Light Attack squadrons are in the process of transitioning to the AH-1Z from its predecessor, the AH-1W Super Cobra. One of the largest changes between the AH-1Z and AH-1W, besides design changes in the airframe structure, is that the AH-1Z offers an information processing capability far greater than that of the AH-1W, simply because it has evolved to provide digitally displayed information through incorporation of an integrated avionics system (IAS). The AH-1Z provides aircrew with an enormous capability shift in terms of how information is provided to the operator by providing a cockpit that is "under-glass." Mechanical flight instruments have yielded to digital flight displays that have increased the amount of information that is presented to aircrew at any one time. Also, overall capability afforded to the operator has increased through functionality. This increase in information capability has increased systems functionality in the aircraft. With an increase in the functionality comes an increase in task load for aircrew unless the HMI is streamlined. Without a streamlined or optimized HMI aircrew situational awareness is degraded because of an excessive mental workload. Additionally, the HMI should be optimized to afford aircrew the appropriate situational awareness in all operating environments. Finally it should be designed to maximize aircrew efficiency, effectiveness, and safety by providing at-a-glance information critical to mission success and safe employment of the aircraft. With an increase in capability it would only follow that the AH-1Z HMI take advantage of new technologies to incorporate solutions to reduce aircrew mental workload, increase effectiveness and efficiency of aircrew, and increase safety.

Conclusion: The AH-1Z provides the MAGTF Commander with a capable attack helicopter to utilize in the joint warfighting environment. Increasing its capability on the battlefield by way of the aircrew and minimizing the risk during a degraded visual environment are essential to instill confidence in the commander. In order to accomplish this, a complete workload study of tasks performed by aircrew in the AH-1Z must be completed in the near future in order to understand design flaws and guide future design and integration of increased capability. Additionally, employment of material solutions to provide aircrew with the appropriate situational awareness under all operating conditions is detrimental to the safety of the aircrew and aircraft. Finally, increasing the effectiveness and efficiency of the aircrew through enhanced situational awareness that supports mission accomplishment is crucial.

DISCLAIMER

Illustrations

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Preface

This report was written primarily to fill the requirements of the Marine Corps Command and Staff Master of Military Studies program. I was previously involved in developmental and operational testing and evaluation of the AH-1W and AH-1Z at Naval Air Weapons Station (NAWS), China Lake. I was a member of the AH-1Z Operational Test Team which was formed to determine if the AH-1Z was operationally effective and suitable. As a pilot transitioning from the AH-1W to the AH-1Z, I was amazed at the technological leap that was made between the two aircraft. At the same time it was clear that this increase has an impact to aircrew situational awareness simply because of the sheer volume of information available. Material and non-material solutions offered in this paper to adjust how information is controlled and presented are a look at what is possible. That being said, the intent of this paper is not to suggest that these designs are the only relevant options to improve aircrew situational awareness. However, the intent is to provide an understanding of how aircraft functionality and display design effects situational awareness and how situational awareness can be improved through the human machine interface.

I would like to take an opportunity to acknowledge LtCol Victor Argobright, Major Rory Feely, and Mr. Robert Portilla for their expert advice, willingness to provide detailed information, and contributions to the H-1 community. Finally, I would like to thank Dr. Matthew Flynn at Marine Corps University's Command and Staff College for his guidance in execution of this project.

The shift from mechanical aircraft power and performance flight instruments to a digital cockpit with instrumentation "under glass" over the last two decades has brought vast challenges to the man / machine interface and opened the door to constantly increasing capabilities. The paper map and mechanical flight instruments are essentially a thing of the past. Much of the literature surrounding the AH-1Z professes increased capability and operator situational awareness (SA) superior to that of its predecessor, the AH-1W. However, an increase in capability has the potential to increase the mental workload of the operator because of the amount of information available, and an increase in task and/or procedure complexity if the interface between aircrew systems and aircrew is not optimized. With a flood of performance, mission, and environmental information constantly available, aircrew can easily be prone to information saturation that produces a high cognitive tax resulting in decreased SA. To avoid task saturation the human machine interface (HMI) between the operator and the aircraft must be streamlined to create a complete picture of performance and position in a three dimensional environment while demanding the least amount of cognitive load and control manipulation for task execution. Increasing SA through HMI optimization in the AH-1Z is essential to increasing aircrew effectiveness, efficiency, and safety.

The purpose of this paper is to examine potential solutions to streamline the HMI in the AH-1Z to provide the operator with increased SA by reducing cognitive load and providing aircrew appropriate SA information to increase effectiveness, efficiency, and safety. Incorporation of solutions to reduce operator cognitive load, decrease the potential of task saturation, exploit the ability of capability growth inherent to a platform that provides integrated information processing, and remedy flight operations in a degraded visual environment (DVE) are critical to operations now and in the future. A secondary purpose is to trigger an all-encompassing aircraft workload study to further identify shortfalls in the AH-1Z HMI design in regards to situational awareness. To accomplish this end the paper is broken down into an overview of the aircraft, key elements of the AH-1Z HMI, a discussion on the relevance of SA in HMI design, and three main sections that introduce solutions to optimize the AH-1Z HMI. Each section provides an overview of its relevance towards advancing SA in the AH-1Z and offers two design solutions and recommendations to improve the AH-1Z HMI to increase SA. Section One is focused on reducing aircrew mental workload through design improvements to the Helmet Mounted Sight and Display (HMSD) symbology for faster cognition. Furthermore, it provides the introduction of a low-cost trainer (simulation) as a solution to freeing up cognitive capacity through practice of aircraft functionality and procedures. Section Two centers on exploiting the aircraft's increased capability in terms of growth potential from past designs and provides three HMI solutions: a selectable earth/aircraft referenced heading tape for display in the HMSD, an ability to display virtual targets and waypoints in the HMSD, and a picture in picture capability within the HMSD field of view (FOV). The third section is dedicated to enhancing safety by providing an HMI solution to enhance SA in a DVE and a call for mission grip and hands on collective and stick (HOCAS) redesign. This structure best advances the view that improvement to the AH-1Z HMI should be made even in times of potentially staunch financial duress.

The body of work utilized for this paper relies heavily on my personal experience as an AH-1Z pilot involved in both Developmental and Operational Test and Evaluation and the experience of other AH-1Z aircrew. There is a significant body of literature concerning cognitive load, automaticity, skills acquisition, and perceptual motor skills that support the importance of providing improved situational awareness to the aircrew through the HMI design and overcoming preconditions that lead to unsafe acts. Other research includes reports and information obtained from the H-1 Weapons Systems Support Activity (WSSA) Integrated Product Team (IPT), Naval Air Systems Command (NASC) Air Combat Electronic Program Office (PMA-209), and NASC H-1 Program Office (PMA-276). It is also necessary to review preconditions and acts described in the DoD-HFACS and how they relate to SA in the aviation domain and provide a broad overview of the AH-1Z and key components that support its HMI. In doing so the analysis is grounded in experience and theory. Ultimately, this paper is driving towards enhancing aircrew SA in the AH-1Z while simultaneously stimulating an all-encompassing aircrew workload study of the AH-1Z. Only through understanding the aircrew workload in the AH-1Z and how it impacts SA, and providing solutions to the HMI to bolster SA, can the H-1 community design systems to reduce the potential of human error.

AH-1Z Overview

The AH-1Z provides the Marine Corps a rotary wing attack capability and is employed by the marine helicopter light attack squadrons (HMLA) to conduct offensive air support (OAS), utility support, assault support escort, and airborne supporting arms coordination during day or night under all weather conditions in support of expeditionary, joint, or combined operations.[1] The Bell Helicopter AH-1Z (Viper) attack helicopter is the replacement for the AH-1W (Super Cobra) and underwent successful Operational Test (OT) in the spring of 2010.

> The AH−1Z is an armed, tactical helicopter manufactured by Bell Helicopter Textron. Tandem seating is provided for a forward (FWD) and aft crewmember. This helicopter is capable of operating from prepared or unprepared areas, from amphibious shipping, other floating bases and austere shore bases, day or night, and in visual meteorological conditions (VMC) or instrument meteorological conditions (IMC) [*sic*].[2]

The significance of the aircraft is that it provides the Marine Air Ground Task Force (MAGTF) Commander with an organic and critical rotary wing battlefield capability.

The AH-1Z incorporates an integrated avionics system (IAS) "[T]hat interfaces the helicopters' glass cockpits and provides the capability...to communicate, navigate, process and present data, manage crew station systems, detect and counter threats, acquire and track targets, employ guided and unguided munitions, provide various sensor input..."[3] The IAS utilizes two synchronized mission computers that provide information processing and control. The mission computers are essentially the brain of the aircraft. The forward (FWD) and aft (AFT) crew stations each contain a crew management system (CMS) that provides for the interface between aircrew and aircraft systems and avionics and consists of display systems, a keyboard for data input, and HOCAS switches (Figures 1 and 2). A mission grip is also provided in each cockpit to control aircraft systems. Aircraft displays for both crew stations consist of two multi-function displays (MFD), a dual function display (DFD), and a keyboard display unit (KDU) which allow aircrew to monitor, manage, and operate aircraft systems (Figure 3).[4]

Increasing the aircraft's processing capability, in theory, provides an enhanced rotary wing platform to the Marine Corps. While the aircraft now has the capacity to process mass amounts of information the information is useless unless it can be translated and correctly interpreted by aircrew. The flood of information the aircraft provides has the potential to negatively tax aircrew and impact their SA, creating a dilemma in determining what information is most critical, when. Aircrew must then use that information to apply procedure while staying ahead of the aircraft and situation. The brain can think but is limited in execution. A necessity for the execution of aircraft functionality while simultaneously gaining and maintaining SA is a streamlined or optimized HMI.

HMSD, HOCAS, and Mission Grip Overview

The AH-1Z incorporates a Helmet Mounted System Display (HMSD). It consists of the Optimized TopOwl Version II (OTO V2) helmet and helmet mounted display (HMD) to provide a heads-up display of aircraft power and performance information to the aircrew. An HMD is a "display which projects video imagery symbolic and/or alphanumeric information on a medium into one or both eyes of the crewmember."[5] It is a see through display that provides virtual information overlaid on the visual scene allowing the pilot to remain heads up (Figure 4). There are two different display modules: a day display module (DDM) and a night display module (NDM). In effect the HMSD provides the operator the ability to monitor aircraft performance and position, and conduct targeting while simultaneously monitoring the environment external to the aircraft. While valuable information is provided to the operator through the use of the HMSD it is in need of optimization to increase aircrew situational awareness.

The mission grip in the AH-1Z is part of the crew station management system and consists of a hand held controller with 13 switches that perform 36 functions. The mission grip provides a critical interface between aircrew and the aircraft and provides the aircrew the capability to target, deliver ordnance, and manipulate and generate waypoints for navigation and targeting. Functionality is expected to grow in future aircraft software builds. A full list of mission grip switches and functionality is listed in figure 5.

The HOCAS allows the crewmember at the controls to select functions without removing hands from the controls.[6] Collective and cyclic head switches and functionality are listed in figures 1 and 2. Using the HOCAS, aircrew can complete 50 functions through the use of 17 switches. This is a vast amount of functionality that needs to be committed to the "muscle memory" of aircrew.

HOCAS and mission grip switches are divided up between three surfaces (collective head, cyclic head, and mission grip). The switches are in close proximity to one another. Some of the switches perform benign functions while others provide more critical, irreversible ones. The point is that aircrew can rapidly find themselves in a dilemma if the wrong switch is utilized.

The HMSD in the AH-1Z was designed to provide a heads up display to aircrew to increase situational awareness and reduce heads down time. The inconsistency with other displays concerning how information is presented in terms of character color creates a situation where aircrew must learn, decode, and differentiate between data that is displayed in the cockpit to data that is displayed through the HMSD creating a potential cognitive load dilemma. Additionally, the HMSD must include increased technological advancements in display design and synthetic vision that are detrimental to facilitating a true heads up capability and provide a solution to the number one killer in rotary wing aviation – DVE. Examination of the mission grip and HOCAS will focus primarily on "redesign" limited to a discussion of functionality required to make them complete hands on interfaces. Also, investigation of a low-cost simulation based on Serious Games (SG) is introduced to bridge the gap between preparation and execution and create automaticity of task execution.

These are aspects of the HMI that require exploitation to reduce cognitive load and increase mission efficiency and effectiveness and increase safety. Once this is accomplished, increased SA to aircrew operating the AH-1Z will be achieved.

Situational Awareness

Human error is a causal factor in Naval aviation mishaps 80-90% of the time and present in 50-60% of all Naval aviation mishaps making it the greatest single mishap hazard.[7] The Department of Defense Human Factors Analysis and Classification System (DoD-HFACS)

(Figure 6) is a taxonomy designed to identify hazards and risks and describes four main tiers of failures or conditions: acts, preconditions, supervision, and organizational influences.[8] By examining the breakdown of acts and preconditions into their components it is clear that most of the elements involved can be directly attributed to a loss of SA. A high level of aircrew SA is critical in aviation and directly impacts every aspect of aircrew skill, perception, and decision making. It is important that aircraft system design supports these acts in order to overcome preconditions that may degrade SA. Providing an effective human machine interface, or the way in which the aircrew interacts with the aircraft and its systems through controls and displays, to target certain preconditions is the key to enhancing aircrew SA.

Gaining and maintaining SA is essential to aircrew to operate their aircraft efficiently, effectively, and safely. There are volumes of research and numerous articles written on the topic of SA. Dr. Mica Endsley is a foremost expert in the study of SA. Endsley "… is recognized as a pioneer and world leader in the study and application of situation awareness in advanced systems...and has authored over 200 articles and reports on SA."[9] She describes SA as an internal mental model of the current flight environment and defines it as, "perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."[10] Aircrew must continuously fight to gain and maintain a high level of SA during every second of flight to make appropriate decisions. To effectively make calculated decisions and act based on those decisions aircrew must be competent in operating their aircraft; understand flight rules, procedures, and tactics; and have a constant, current picture of the state of the aircraft and environment.[11] The continuous flood of information available to aircrew at any one time makes gaining and maintaining SA an extremely daunting task. Once aircrew get behind the SA power curve it is difficult to recover the required SA to effectively do business.

Endsley breaks SA into three levels: Level one – "perceiving critical factors in the environment," Level two - "understanding what those factors mean when integrated into the aircrew's goals," and Level three – "understanding what will happen with the system in the near future."[12] Using these three levels as a base she provides a model that effectively describes how situational awareness is affected by internal and external factors (individual and task/system factors) and how those factors impact decision making and performance. The performance of actions then feeds back into the state of the environment and back into the levels of SA, essentially completing a cycle that describes how SA is gained, maintained, and effected (Figure 7).

The DoD-HFAC taxonomy falls short in that it does not provide a direct link between preconditions and acts (decisions) to determine how or if SA impacts decision making in cases involving human error. The preconditions portion of the taxonomy reflects the system/task and individual factors in Endsley's model. A clear link between SA and decision making is observable when considering Endsley's model. It also demonstrates that decision making impacts how individual factors and system/task factors relate to SA in the overall decision making and performance of acts. While the DoD-HFAC does not provide a depiction of how SA impacts human error it provides preconditions for an act that are similar to the task/system and individual factors in Endsley's model. During an investigation of an aviation mishap the investigating authority must attempt to first and foremost determine if the mishap was due to a mechanical failure or if an individual committed or failed to commit an act. The investigator then must further classify the act as an error or violation. If it was determined that the act was an error, the error must be further categorized. The three errors attributed to an unsafe act are skill based errors, judgment or decision making error, and misperception errors. Once an error is determined the investigator must consider if any preconditions inspired the act.[13] These preconditions; environmental factors, individual factors, and personal factors, are broken down further into factors that reflect and support Endsley's model of SA.

By examining both models a link between SA and human error is evident. Through system design some of the preconditions such as the technological issues, perceptual issues, and cognitive issues can be remedied to provide enhanced SA, minimizing the potential for a mishap. A high level of situational awareness can be achieved by designing systems to reduce mental workload, increase effectiveness and efficiency, and increase safety. Endsley's research expertly shows how SA is impacted by preconditions and how preconditions effect decision making and acts. By understanding this information, we can better understand how to impact SA through situational design.

Section 1: Reducing Aircrew Mental Workload through Design and Practice to Improve SA

How much information is too much information? Is more information displayed appropriately to achieve a broader picture desirable? What information should be displayed in order to yield timely and effective decisions? Does skill level and experience in performing specific tasks relate to information overload or saturation? All of these questions are relevant concerning the increased technology of controls and displays in the Marine Corps AH-1Z.

During a standard flight aircrew can expect to view, hear, and digest information from four different displays at-a-glance, two radios, an aural alert system, the seat-of-the-pants feel, and the external environment simultaneously. Recognizing the current situation and acting accordingly can become problematic when conducting complex tasks to affect multiple aircraft systems. Reducing aircrew mental workload is essential to overcome potential information overload or saturation that creates a negative impact on aircrew SA causing the aircrew to get behind the "power curve".

Excessive mental workload can be caused by time pressures and task complexity. Time pressures are generally derived from the external environment, whereas task complexity is inherent to the HMI between the aircrew and aircraft. A limited workload study of the AH-1Z funded by PMA-276 provides a comprehensive explanation of how task complexity can lead to an excessive mental workload:

> Task complexity can arise from demands of sensory input (attending to visual or auditory stimuli), cognitive operations (remembering, transforming, translating, calculating, etc.), or response generation (e.g., movements of the hands, speech, etc.), or any combination of these three types of activities. This type of mental workload can be increased by a poorly-designed user interface. For example, a poorly-designed control-display relationship can make it difficult to point a sensor directly at an object of interest, leading to increased errors and increased workload. Similarly, a poorly-designed graphical user interface (GUI) with inconsistent labeling and non-intuitive icons can lead to increased errors (incorrect selections), increased task performance time, and increased workload.[14]

An excessive mental workload is similar to cognitive overload; which is the amount of cognitive or mental activity that the working memory is processing at any one time.[15]

Dr. John Sweller is a Professor of education at the University of New South Wales and the developer of the cognitive load theory. He argues,

> [T]he cognitive load theory attempts to account for outcomes of the limitations of the human information-processing system for the design of instructional procedures and learning… and that the human mind is made up of a working memory with limited capacity, and a long-term memory without capacity. One of the functions of the long term

> memory is to store automatized schemata… [which are] complex, cognitive constructs that permit the learners to categorize information in simple, easily retrievable units. [16]

Once information is absorbed by the long-term memory automaticity is achieved. The main point of the theory is that through practice the cognitive tax that comes with task completion is less because the task becomes automatized.[17]

Automaticity is essentially committing information to long term memory so that the retrieval of that information is automatic. Automatic processing of information is "…..fast, autonomous, effortless, and unavailable to conscious awareness in that it can occur without attention."[18] An automatic cognitive retrieval of information and task execution increases situational awareness since the mind is then free to process other information.

Automaticity can be applied to mental tasks triggered by stimuli (retrieving and processing information). Shiffrin and Schneider offer a dual process theory that demonstrates that there are two different types of information processing: automatic detection and controlled search. They argue that controlled search requires more time and is highly demanding on attention capacity, and strongly dependent on information load, whereas automatic detection is well learned, resides in the long-term memory, is demanding on attention only when triggered, and is unaffected by load.[19] Applying this theory to visual stimuli one can deduce that presenting the aircrew visual information that triggers an automatic response is more favorable than displaying information that requires a controlled response. Information that initially provides a controlled response can be committed to long term memory through practice making it feasible to display inconsistent information among display mediums, however, the mental load increases when trying to respond to the same information that is displayed differently and simultaneously.

Automaticity can also be applied to skills acquisition. Fitts and Posner break down complex skills learning into three phases: Cognitive- "…an understanding of the knowledge required to perform a skill", Associative – "…an understanding of procedure", and Autonomous- "…performance of tasks automatically."[20] This theory implies that a learner has some base level of knowledge that can be applied to procedural tasks and that over time and through practice the conduct of the complex skill is automatic. Research conducted by Ciaverelli, Platte, and Powers synthesized the relationship between perceptual motor learning (Fitts and Posner) and cognitive learning, that follows a similar phased progression (Anderson), and reasons that "… the typical learner transitions from state of *knowledge about* a subject or skill, to a state of *rule application,* and finally the learner progresses to a level of *automaticity* or skilled task performance that is executed with minimum conscious monitoring or interruption."[21] This is how experts understand how cognitive load affects SA and how the problems with it can be overcome. Currently there is limited means available to H-1 aircrew to practice or hone complex skills as it relates to non-flying pilot complex skills.

A high task complexity and subjection to massive amounts of information is inherent to flying a highly capable military aircraft. However, the cognitive or mental workload of the aircrew can be minimized through intuitive display design and providing a measure for aircrew to commit task performance and procedure to memory. Colorization of display symbology in the AH-1Z is for the most part intuitive; however, it is inconsistent between the MFDs and HMSD and there is currently limited means available to achieve automaticity of complex tasks associated with the mission grip.

Colorized HMSD

Creating consistency in sensory stimuli through a display that uses intuitive color schemes to encode information is essential to reducing objective mental workload and reinforcing conscious automaticity to increase SA. Human beings use color as part of the process in attempting to define, understand, and interpret information. Green, red, and yellow (amber) hues are often associated with safety status in United States culture.[22] These hues in particular offer meaning to U.S. citizens in everyday life (e.g., stoplights). The OTO HMD display technology relies upon a monochromatic depiction of information in the display color schemes. Providing color to a heads up display provides the operator the ability to understand how the aircraft is performing, the position of the aircraft, and the operating environment at-a-glance and is consistent with other aircraft displays.

The HMSD in the AH-1Z does provide visual performance instrument indications other than numbers to define where the aircraft is within the operating limitation in the form of temporal flashing to cue the operator that a limitation is being reached. While this is effective to streamline information interpretation it is limited in its application. Using color to display information in the HMSD DDM would increase SA to the operator and reduce information saturation, therefore, increasing operator efficiency and effectiveness. The National Aeronautics and Space Administration's (NASA) Color Usage Research Lab created a hierarchy of color usage guidelines states that "To succeed in using an information interface the user must find the needed information, read it, and understand it."[23] Finding graphically displayed information should be accomplished with "little cognitive effort under all operating conditions."[24]The AH-1Z HMD provides the operator with the information regardless of the use of a monochromatic design or a design that incorporates specific hues. Reading and understanding the information is where color differentiation comes into play.

The information must be presented to the operator in a manner which it can be found and read, and the colors utilized "…shall allow the user to understand the information with little cognitive effort and minimum risk of error under all operational conditions."[25] Understanding the information presented through the display is critical to interpreting the performance and position of the aircraft, environment, and what, if any, operator corrections or inputs to the aircraft or systems are necessary to affect the situation. The monochromatic nature of the HMD however, does not provide a colorized breakout of warnings and cautions. Colorizing display information beyond a single color provides an at-a-glance capability to the aircrew, reducing the time required to interpret information and maintain a continuous scan of the display and environment with little cognitive effort. This is not limited to warnings and cautions concerning aircraft position and performance indications already incorporated into the display. Colorizing HMD information is also applicable to any information used to relay safety of flight information.

One issue that comes to light from using color schemes in digital displays is that color should be used sparingly to retain its meaning.[26] Using the same color scheme to relay different meaning throughout aircraft systems could increase cognitive workload. Although the proposed color schemes are used in encoding other systems information an information decoding dilemma for the operator is not created because the systems that use these hues use them to describe a safety condition. The proposed colors are then easily interpreted because of how they have manifested themselves in U.S. culture.

Another factor of importance using color to encode information in the AH-1Z HMD is consistency with other cockpit displays. Performance instruments displayed on the AH-1Z Multi-Function Displays (MFD) are color coded for green, red, and yellow (amber). Green indicates that aircraft systems are within operating limits (normal operating limits), yellow indicates that the aircraft is approaching operating limitations (caution range), and red relays that operating limitations have been exceeded. Weapons status is also colorized within aircraft MFDs. When a weapon is selected and the aircraft is placed in the stand-by (STBY) position the weapon selected for front or rear seat pilot is reflected in yellow (caution, weapon selected) when the aircraft is in an ARM state (ready to fire) the selected weapon indication is red. One of the guidelines developed by the NASA Color Research Lab to using color where discrimination and identification are critical is to use color coding consistently across displays and pages.[27] This is recommended to avoid increases in cognitive effort because the operator must remember different information encoding schemes in different contexts. This is a valuable design element that aids in combating information saturation. The aircraft MFDs make effective use of colors to encode information and the HMSD should as well to provide consistency in information interpretation to the aircrew. By using a recognized color scheme consistently the aircrew cognitive process is streamlined and information is understood rapidly.

Low-Cost Individual Simulation

A capability to reinforce skills acquisition to achieve specific tasks utilizing mission grip or HOCAS functionality in the AH-1Z other than in the aircraft or simulator is missing. With looming defense budget cuts that are sure to affect squadron flight hour programs coupled with a lack of AH-1Z simulators there is limited means available to reinforce automaticity of task execution for aviators that are new to the platform. The AH-1Z Training and Readiness Manual outlines requirements that aviators must meet to progress in the AH-1Z syllabus. There is no a single sortie in the AH-1Z Training and Readiness (T&R) manual that specifically focuses on mission grip utilization. Instead certain tasks and procedures are integrated into the broader scope of the sortie. After all, the mission grip and the HOCAS are part of the HMI in which the operator interacts with the aircraft to accomplish an objective and not the focus of aircrew training. However, this becomes problematic if aircrew are not proficient in utilization of mission grip functionality prior to execution of a sortie, and contributes to an excessive mental workload if they have to stumble through mission grip or HOCAS functions to complete time critical tasks. It also decreases situational awareness since the incompetency in execution of tasks or procedure will demand the aircrew's complete attention. Currently, there are only two simulators to source eight HMLA squadrons (one to source five squadrons on the west coast and one to source three squadrons on the east coast.) There is an existing gap between operator preparation and conducting a flight event in either the simulator or aircraft. A measure of effectiveness and individual performance as it relates to mission grip and HOCAS utilization is also not available other than overall performance in a specific flight event.

A low-cost trainer is essential to bridge the gap between flight preparations for syllabus events and provide a means of measuring individual performance and progression in task application through the use of the mission grip and HOCAS to enhance automaticity of skills. The low-cost trainer concept would serve to increase skills acquisition through simulation and provide a means to measure performance. The concept would incorporate an interactive Serious Game (SG) that hosted specific scenarios requiring specific actions via a mock-up of the mission grip or HOCAS by the operator. The link between prep and execution hinges on this tool that greatly improves and reinforces perceptual and psycho motor skills.

SGs provide a level of entertainment while teaching and reinforcing critical perceptual motor skills as well as procedural skills. Essentially, SGs "…use the artistic medium of games to deliver a message, teach a lesson, or provide an experience."[28] The low-cost trainer concept could consist of a computer and monitor with a mock-up of controls or utilize any current gaming system. SGs "can extend the value of training films and books by allowing the player to not only learn, but also to demonstrate and apply what he or she has learned."[29] Through repetition, and introduction to specific scenarios and objectives the cognitive and motor skills required for performing specific tasks are solidified through objective achievement and measures of individual performance provided. Practice is essential to honing skills required in the execution of complex tasks and “Practice environments can greatly decrease the time to achieving mastery level, and they are necessary even for the acquisition of procedural knowledge.”[30] Through practice it is more likely that aircrew will achieve the mastery level and reach a stage of automaticity concerning skill. Ultimately, this provides increased SA by freeing up critical information processing capability while simultaneously increasing effectiveness and efficiency in task execution. These games could be utilized to expose new pilots to a plethora of tactical scenarios; introduce tactics, techniques, and procedures; accomplish learning objectives; and above all automatize mission grip and HOCAS utilization to execute procedures.

Section 2: Exploiting Increased Capability

The AH-1Z was designed with increased capability in mind and offers the ability of integrated growth which was not available in its predecessor, the AH-1W. Through software, increased capability can be incorporated into system design, and increase the effectiveness and efficiency of the aircrew by increasing SA. As previously stated, the HMSD provides a heads-up capability to aircrew, and allows them to simultaneously monitor certain performance and position indications while maximizing a scan outside the aircraft. As aircraft software continues to update and provide increased capability to the aircrew the HMSD should as well. HMSD design should reflect the increased capabilities of the aircraft and expand what tasks can be performed “heads-up”. These solutions should be incorporated in the HMI to provide SA that previously was completely absent in the HMSD.

Selectable Earth/Aircraft Reference Heading tape

The HMSD provides the operator a digital heading tape at the top of the display that presents current aircraft heading. Even when the pilot looks off-axis from aircraft heading the present aircraft heading is displayed instead of the heading the aircrew is actually looking towards. This is problematic in an attack aircraft platform during targeting, target hand-offs to other aircraft, and maneuvering to arrive within a prescribed final attack heading. In order to achieve these tasks the operator must scan inside the cockpit to determine their relation to a specific point in space by referencing the moving map display. This can lead to errors while attempting to locate an object, determining relative bearing to an object, and maneuvering the aircraft correctly into a final attack heading directed during close air support fire mission. With an earth referenced heading tape the aircrew would have the ability to reference bearing to and from a specific point without maneuvering the aircraft to a “nose-on” position. An aircraft referenced heading tape is still desirable during certain situations such as when operating in the take-off and landing environment. The aircrew requires the ability to switch between an earth or aircraft referenced heading tape to increase situational awareness depending on the situation.

Virtual targets/waypoints/threats

The heading tape displayed in the HMSD also provides the operator with cueing to the next waypoint or target, depending upon what is selected. What it does not provide is a visual indication of where that target or waypoint is located in the three dimensional environment and only provides cueing to what point is selected as the “TO” point. In order to display other waypoint or target information in the HMSD the operator must utilize hard key functionality on the MFDs to select a new “TO” point. Increasing the capability of the HMSD to support virtual waypoint and target depictions in the field of view (FOV), congruent to their position in the external environment reduces heads down time and increases SA. Also, the amount of time required to determine aircraft relation to a point in space is decreased therefore decreasing information interpretation and mental workload.

Picture in Picture (PIP)

The HMSD in the AH-Z currently does not have the ability to display a sensor picture within the display FOV. Typically the non-flying pilot is manipulating the Target Sighting System (TSS) and the flying pilot is focused, of course, on flying the aircraft. The flying pilot can view what the TSS is looking at through one of their two MFDs. However, in order to view the page the operator must look inside the cockpit to interpret the environment in which the TSS is looking, or the environment that the non-flying pilot is targeting. The HMSD does provide a reference symbol that the operator can use to determine where the TSS line of sight (LOS), however, it does not provide a capability to assist or monitor targeting heads-up. Dedicating a portion of the HMSD FOV to integrating a picture in picture (PIP) capability or virtual environment is essential to flying pilot SA. Projecting the TSS forward looking infrared (FLIR) picture or future DVE solution picture in the background of the HMSD would allow the flying pilot to remain heads up while interpreting the environment that the TSS is surveying.

A PIP capability in the HMSD FOV would allow the flying pilot to simultaneously monitor the external environment while maintain situational awareness during targeting, aid the non-flying pilot in target or object detection, recognition, and identification, and reference FLIR imagery during DVE operations and terrain flight (TERF). PIP increases SA by allowing the flying pilot to maintain an outside scan during the tasks listed and increases efficiency and effectiveness by shedding the transition of attention inside and outside of the cockpit. Also, the potential of a dual heads-down situation where both the flying and nonflying pilot are looking into the aircraft and not monitoring the external environment is avoided adding an increased element of safety.

Section 3: Enhanced Safety

The big three in terms of aviation are aviate, navigate, and communicate. These three items make their way into every flight brief to remind aviators of the most important items to focus on in the event of an emergency. These three elements are critical during every phase of flight and during all operating conditions.

The AH-1Z supports expeditionary operations and operations ashore, both day and night, during VMC and IMC conditions from improved or unprepared surfaces. Operating in all types of conditions includes operating in a DVE. A DVE is one where the visual scene is degraded because of night time operations or operations were obscurants such as sand, snow, smoke, fog, or haze a present which may induce spatial disorientation or perception issues and a loss of situational awareness potentially affecting both aviation and navigation. A DVE that is inherent to rotary wing platforms, brown out or whiteout, is caused by downwash created by the turning rotor system and can cause the disruption of obscurants that can severely degrade or restrict aircrew visual reference during landing or takeoff creating causing loss of SA and spatial disorientation because of a lack of visual cues. Spatial disorientation "is the situation occurring when the aviator fails to sense correctly the position, motion, or attitude of his aircraft or of himself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical."[31] Spatial disorientation during critical phases of flight such as takeoff, landing, and nap of the earth (NOE) flight can have disastrous results. A DVE clearly creates a situation ripe for an aviation mishap. The AH-1Z currently does not possess a material solution to DVE operations.

Similarly, communication is a key ingredient to safety of flight. It is essential to every aspect of operations and is critical to all aspects of the flight. The inability to communicate effectively during time critical situations can have multiple disastrous results that may affect aircrew autonomous to the aircraft, other aircraft, or elements operating on the ground. It can result in mishaps, lost targeting opportunities, or potential fratricide. The AH-1Z already has an effective communication system; however, communication can be stifled during critical moments because of the current HMI.

HMSD Synthetic Vision

During Operation IRAQI FREEDOM (OIF) and Operation ENDURING FREEDOM (OEF) from 2001 to 2009 there were 375 rotor craft loses with 496 fatalities. Of those loses 79 percent were attributed to loss of situational awareness and other human factors. The primary causal factors were CFIT and brown out.[32] An Urgent Universal Needs Statement (UUNS) forwarded by HMLA-469 October 12, 2012 details this capability gap by citing that,

> Currently, Marine Corps helicopters operate without systems to assist in avoiding obstacles during takeoff, enroute and landing when operating in Degraded Visual Environment (DVE) conditions**.** Consequently, more than half of combat helicopter fatalities and loss of aircraft have occurred during “brown-out” landings or Controlled Flight into Terrain (CFIT). This is a problem common to all helicopters and tilt rotor aircraft. In DVE situations, aircrew may lose the ability to recognize obstacles (such as terrain or high-tension power lines) in the flight path of the aircraft. There are numerous occurrences where aircrew flew a fully functional helicopter into terrain or obstacles during combat operations in DVE situations resulting in loss of life and equipment.[33]

The UUNS effectively argues the necessity to procure a DVE operating capability in the AH-1Z that utilizes current aircraft systems in concert with new systems designed to provide a synthetic vision of the external environment, a terrain and collision avoidance technology, and mature automatic flight control system capable of assisting DVE during the takeoff, landing, and enroute phases of flight. Of primary importance to this portion of the paper is the benefit of integrating synthetic vision into the HMSD.

There are currently examples of a sensor fused synthetic vision that effectively create a three dimensional picture of the external environment taking advantage of the IR and millimeter wave portions of the electromagnetic spectrum. When a material synthetic vision solution is provided for the AH-1Z it is critical that it be displayable in the HMSD. A sensor fused image of the three dimensional scene in line with aircraft vector, overlaid by selectable symbol sets (HMSD declutter modes dependent upon current phase of flight) would vastly increase aircrew SA in a DVE. Selectable symbols sets would vary from current HMSD symbology and could be selectable through declutter functionality that already exists for the HMSD. A synthetic vision symbol set would incorporate "intuitively displayed aircraft state parameters such as acceleration, velocity and orientation...such as: velocity vector and acceleration cue in the horizontal plane; an acceleration cue in the vertical axis; and a flight path vector."[34] This functionality would allow the aircrew to "see through" obscurants, detect obstacles to flight during DVE operations.

Mission Grip and HOCAS

Issues regarding safety and survivability are present with the current mission grip design and HOCAS communication and a countermeasure dispensing capability. When employing the mission grip the soul source of communication for the non-flying pilot is a foot switch. The AH-1Z has two radios that the operator can use to communicate. The Cockpit Communication System (CCS) is the control for switching between radio one and two when using the foot switch. Once a radio is selected on the CCS the operator depresses the foot switch and talks. In order to switch between the two radios the operator is required to take his hand off of the mission grip. This becomes a safety of flight issue if the non-flying pilot observes a situation that is critical to other aircraft in the flight or area or personnel on the ground reaction time to warn other members is excessive. Similarly, the Counter Measures Dispensing Switch is independent of the mission grip and in order for the operator to manually dispense expendables they must remove their hand away from the mission grip. This is time consuming in a critical environment, especially at night where the operator is required to use tactile feel to find the dispensing switch.

The HOCAS switchology presents an issue along the same lines; however, the flying pilot does have the capability to talk and dispense flares without removing their hands from the controls while flying. The problem is that the flying pilot cannot dispense flares and talk simultaneously because of the location of the switches. This is critical to survivability and safety. The first step in evasive maneuvers for launch of an infrared surface-to-air missile / air-to-air missile against the aircraft is to dispense flares (countermeasures) while simultaneously making a "FLARES, FLARES, FLARES" call to notify the flight of the threat.[35]

Mission grip and HOCAS redesign was investigated in an informal design review conducted by PMAs-209 and 276 with the involvement of fleet and test community AH-1Z pilots. The redesign effort cited communications, survivability, and future growth as issues that required exploration.[36]These same issues were also raised in the AH-1Z OT final test report. Other pilots have complained about the ergonomics of the mission grip and HOCAS themselves. The problem with this is that there will always be pilots who do not like the ergonomics no matter what the design is. In a mission grip or HOCAS redesign "the focus of effort should be determined on what tasks the aircrew is required to execute and exact a design were the aircrew does not have to remove their hands from the controls to complete tasks."[37] With the exception of utilizing hard and soft keys to interface with the MFDs there are other tasks that could be incorporated or made available to the mission grip

Conclusion / Implications

The AH-1Z provides aircrew with an enormous capability shift in terms of how information is provided to the operator by providing a cockpit that is “under-glass”. Mechanical flight instruments have yielded to digital flight displays that have increased the amount of information that is presented to the aircrew at any one time. Also, overall capability afforded to the operator has increased through functionality. This increase in information capability has enhanced systems functionality in the aircraft. With an increase in functionality comes an increase in task load for aircrew and a decrease in aircrew SA unless the HMI is streamlined.

Currently, the HMI in the AH-1Z is not optimized to enhance SA. Advanced technology has provided capabilities to the aviation community limited only to money and the imagination. However, with this increase in capability the design of the HMI must be streamlined in order to avoid an excessive mental work load or levy a huge cognitive tax on aircrew receiving, interpreting, and acting upon information. Similarly, HMI design must also support task accomplishment in that the design and method of learning how to manipulate the design through the task execution does not induce an excessive mental workload upon aircrew. Exploiting increased capability will increase the effectiveness and efficiency of the AH-1Z as a warfighting means in the joint environment. Integration of material solutions that provide enhanced safety to aircrew and the aircraft to combat the number one killer of rotary wing aircraft are available and must be applied to the AH-1Z. Although a limited work load study of the AH-1Z has been performed, an all-encompassing study must be performed to realize design flaws and apply appropriate design to future implementation.

The Marine Corps must seek to improve the effectiveness and efficiency, and safety of the AH-1Z platform and aircrew through increased SA to provide a highly capable aircraft to enhance the joint warfighting effort. Yet, solutions to streamline or optimize the HMI are really the tip of the iceberg. There are many other concepts that are applicable to the AH-1Z and are exploited by other joint operations. The bottom line is that AH-1Z, and the missions it performs, is critical to the MAGTF commander's warfighting capability. The AH-1Z provides the MAGTF commander with a capable attack helicopter to utilize in the joint warfighting environment. Increasing its capability on the battlefield by targeting aircrew SA, exploiting growth potential, and minimizing the risk during a DVE are essential to instill confidence in the commander in this air asset. If a platform is consistently ineffective in performing its mission essential tasks, or suffers a high mishap rate while performing those tasks, the commander's options to employ that platform become limited. Providing the commander with a platform that consistently meets or exceeds mission requirements increases their confidence, and provides another capability for the commander to consider during planning.

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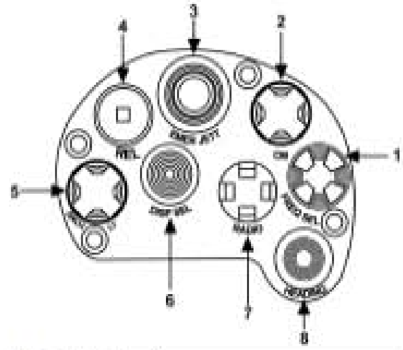
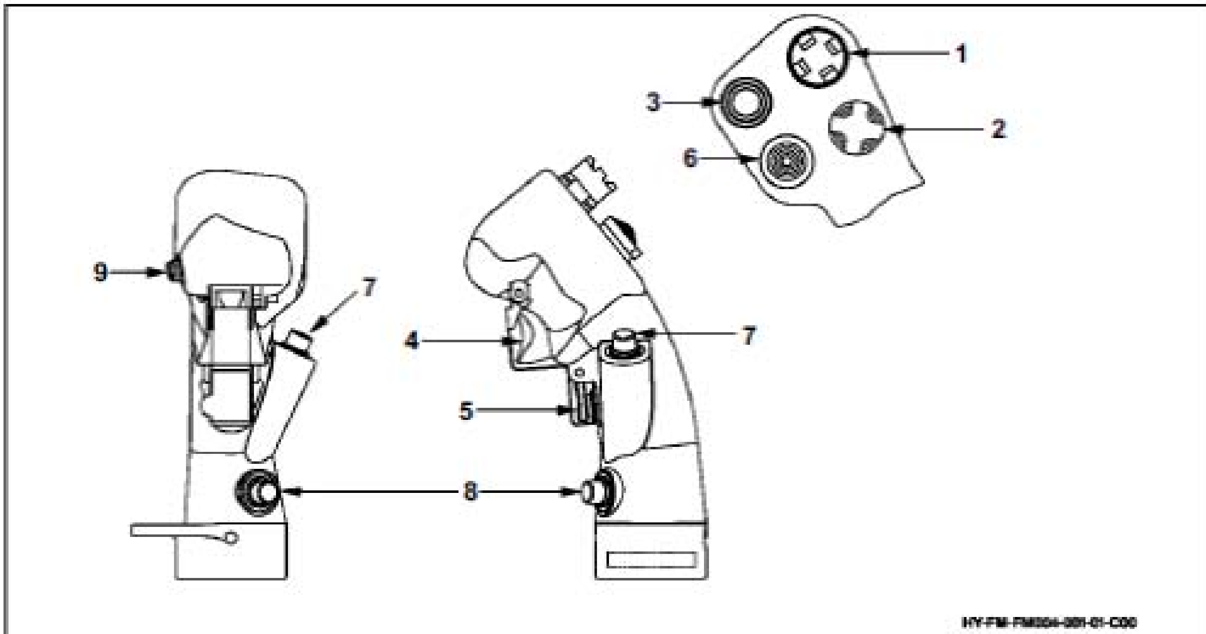
Collective HOCAS Switches



SWITCH NUMBER	SWITCH POSITION	FUNCTION
1. FREQ SEL	Forward	Call up Mission List for display on DFD Scroll–up preset frequencies
	Aft	Call up Mission List for display on DFD Scroll–down preset frequencies
	Left	Last frequency selected
	Right	Tune active radio to designated frequency
	Center press	Toggle active radio
2. CM	Forward	Normal Mode — Manual Program 1, 2, 3, or 4 Dispense Bypass Mode — Chaff Bypass Program Dispense
	Aft	Normal Mode — Semi–Auto Dispense Bypass Mode — Flare Bypass Program Dispense
	Left	Normal Mode — Manual Program 5 Dispense Bypass Mode — Both Bypass Program Dispense
	Right	Normal Mode — Manual Program 6 Dispense Bypass Mode — Mixed Bypass Program Dispense
	Center press	Normal Mode — Toggle Auto/Semi–Auto Bypass Mode — No Function
3. EMER JETT	Center press	Emergency jettison stores at stations 2, 3, 4, and 5
4. REL	Left	Eng 1 idle stop release
	Right	Eng 2 idle stop release
5. SRCH LT	Forward	Extend searchlight
	Aft	Retract searchlight
	Left	Slew searchlight left
	Right	Slew searchlight right
	Center press	Toggle searchlight on/off
6. DISP SEL	Forward	EW Page
	Aft	TSS Video
	Left	WCA Page
	Right	SYS Page
	Center press	Return to last non–HOCAS screen selected
7. RADIO	Forward	Transmit on COMM 1
	Aft	Transmit on ICS
	Left	Transmit on COMM 2
	Right	Not used
	Center press	Not used
8. HEADING	Forward	At cruise speed: Engage/disengage cruise hold At low speed: Engage/disengage hover hold
	Aft	Release collective force trim for altitude or power adjustment (when altitude hold engaged); Reengage altitude hold
	Left	Adjust helicopter heading left (when heading hold engaged)
	Right	Adjust helicopter heading right (when heading hold engaged)
	Center press	Not used

Figure 1.
Referenced from the 2010 AH-1Z NATOPS

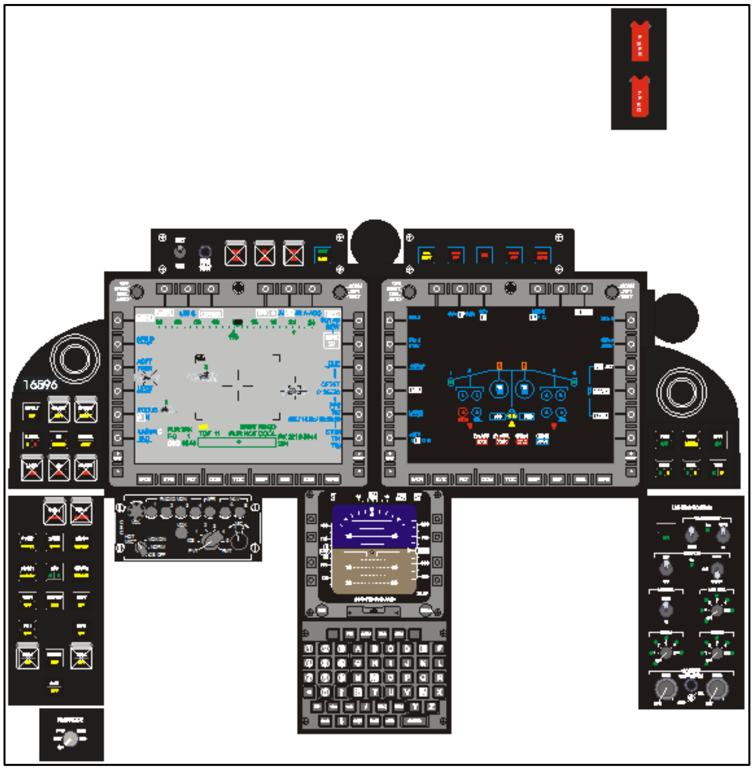
Cyclic HOCAS Switches



SWITCH NUMBER	SWITCH POSITION	FUNCTION
1. WPN SEL	Forward	Select gun
	Aft	Select Hellfire missile
	Left	Select rockets, bombs, or flares
	Right	Select AIM–9 missile
	Center press	Deselect all
2. HMD SEL	Forward	Increase symbol brightness/contrast
	Aft	Decrease symbol brightness/contrast
	Left	Symbology Mode Select, toggles between Normal Mode or Blank All Mode symbology
	Right	Cycles thru successive declutter levels – 0, 1, 2, 3, 4
	Center press	Activate boresight and boresight checking
3. CGE/UNCGE	Center press	Cage/uncage air–to–air missile
4. WPN FIRE	Press	Fire selected weapon
5. QUICK DRW	Press	Slew gun/air–to–air missile to HMSD line–of–sight
6. FRC TRIM	Fwd/Aft/Left/Right	Adjust forward, aft and lateral trim
7. TRIM REL	Press	Momentary release of Force Trim
8. SCAS REL	Press	Disengages all AFCS functions and SCAS channels
9. HOVER	1st Press	Places hover aid graphic on FLT page
	2nd Press	Marks present position with a box on hover aid graphic
	3rd Press	Resets present position box on hover aid graphic

Figure 2.
Referenced from the 2010 AH-1Z NATOPS

AH-1Z Forward and Aft Crew Stations



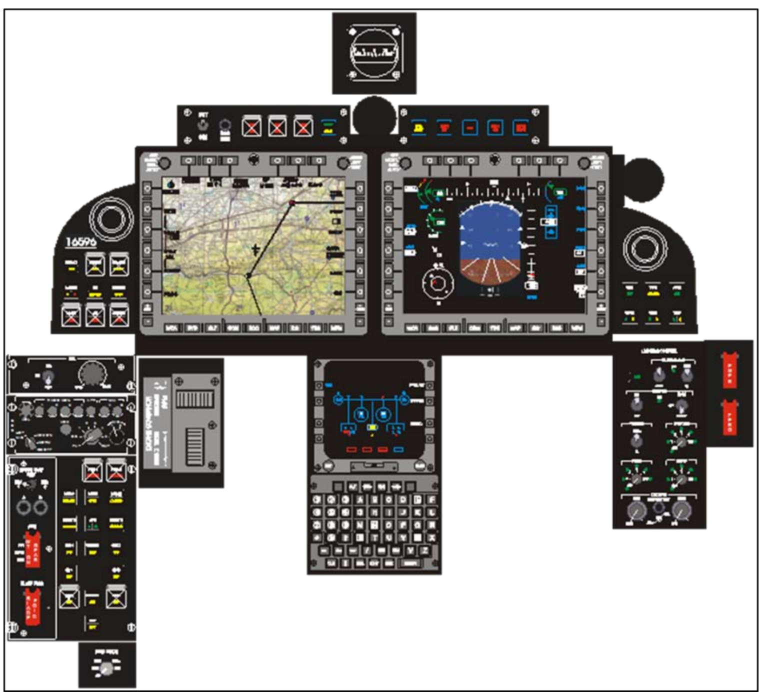


Figure 3.
Referenced from the 2010 AH-1Z NATOPS

HMSD in Normal Mode Declutter 0

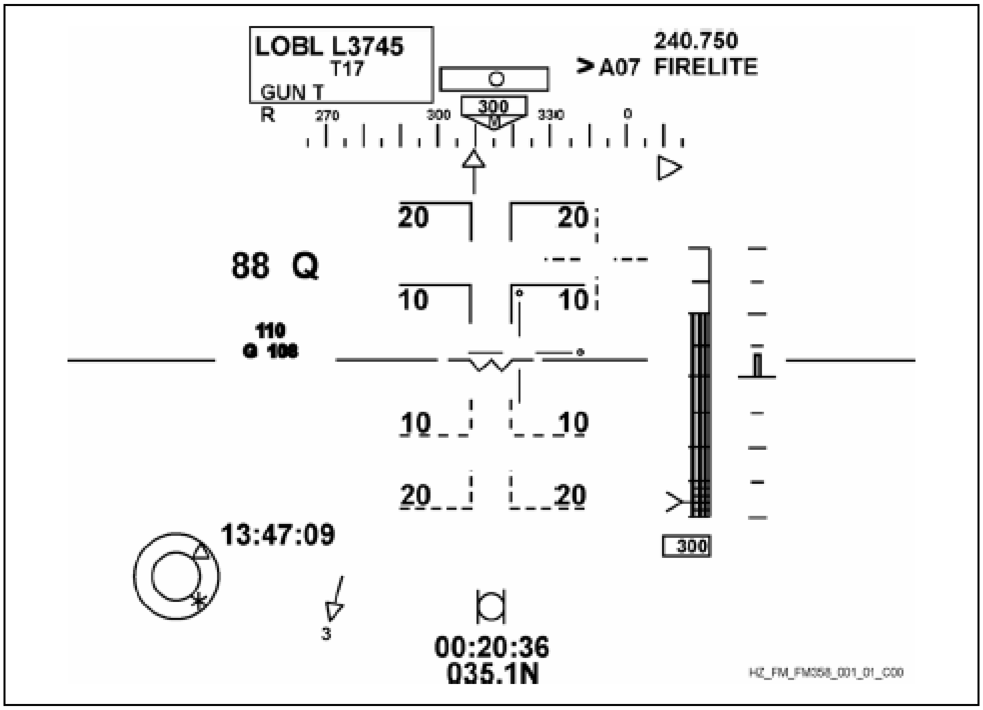
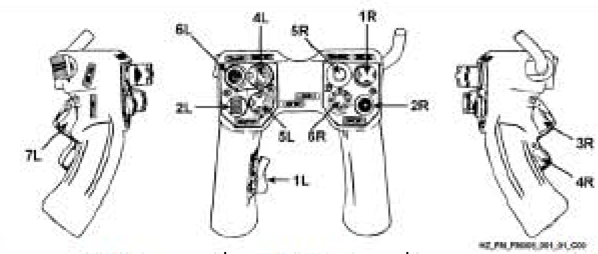


Figure 4.
Referenced from the 2010 AH-1Z NATOPS

Mission Grip Switches



SWITCH NUMBER	NAME	POSITION	FUNCTION
1L CURSOR SEL	Track/Manual Acquire and Break Track (Cursor Select)	Up	TSS mode — Rejects track on current target and removes it from the track list Map/Nav mode — Provides hook and drop function
		Down	TSS mode — 1st press engages track on an individual target — 2nd press saves the track, allows further manual cueing Map/Nav mode — Provides hook and drop function
2L TRK/OFFSET	Aim Point Control	Up	1st press changes tracker mode, slew inputs redefine aim point 2nd press completes the action and allows further manual cueing
		Down	1st press allows slew controller to define offset point 2nd press returns LOS to target
3L HMD LOS	TSS to HMSD Acquire Select/Fixed Forward	Fwd	TSS to fwd crew station HMSD LOS
		Aft	TSS to aft crew station HMSD LOS
		Center press	TSS fixed forward (ADL, 2D or 3D)
4L VIDEO ADJ	Video Adjust	Fwd/Aft	FLIR gain/TV contrast
		Left/Right	FLIR level/TV brightness
		Center press	Auto adjust
5L TGT SEL	Next Priority Target	Fwd	Go next active
		Aft	Go previous active
		Left	Go next inertial
		Right	Go previous inertial
		Center press	Go active/Go direct
6L POL/FOV	FLIR/TV FOV Select Sensor polarity	Fwd	FOV/zoom in
		Aft	FOV/zoom out
		Left	FLIR select
		Right	TV select
		Center press	Reverse polarity
7L LASER	Laser Fire	1st Detent	Range only
		2nd Detent	Range and designate
1R WPN SEL	Weapons Select	Fwd	Gun
		Aft	Air–to–ground missile
		Left	Rocket or flare
		Right	Air–to–air missile
		Center press	Deselect All
2R HMD SEL	HMSD Flight Mode Declutter and Boresight	Fwd	Symbology mode select
		Aft	Cycles levels of declutter
		Left	Increase symbology brightness
		Right	Decrease symbology brightness
		Center press	Activate boresight
3R WPN FIRE	Weapon Fire	Press	Fire selected weapon, HF, AIM–9, or gun only
4R QUICK DRW	Quick Draw/Action Bar	Press	Slew gun or missile seeker to TSS line of sight
5R CGE/UNCGE	Cage/Uncage	Press	Cage/uncage AIM–9 missile
6R SLEW	TSS/Cursor Slew	Fwd/Aft/Left/Right	Directional control

Figure 5.
Referenced from the 2010 AH-1Z NATOPS

DoD HFACS Model

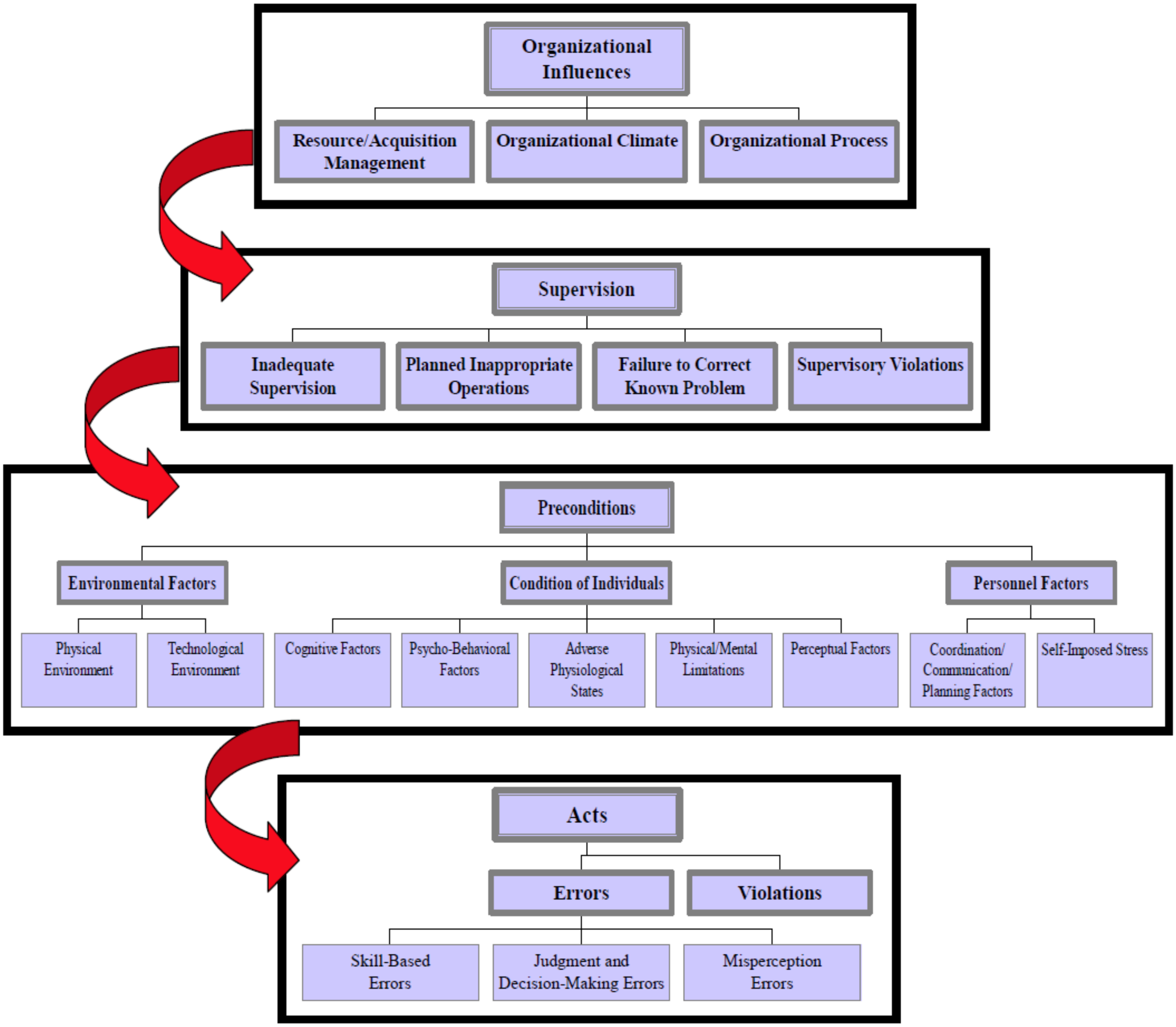


Figure 6.

Referenced from U.S. Department of Defense, *Department of Defense Human Factors and Classification System: A Mishap Investigation and Data Analysis Tool*, (Washington, DC: Department of the Navy, January 2005).

Model of Situational Awareness

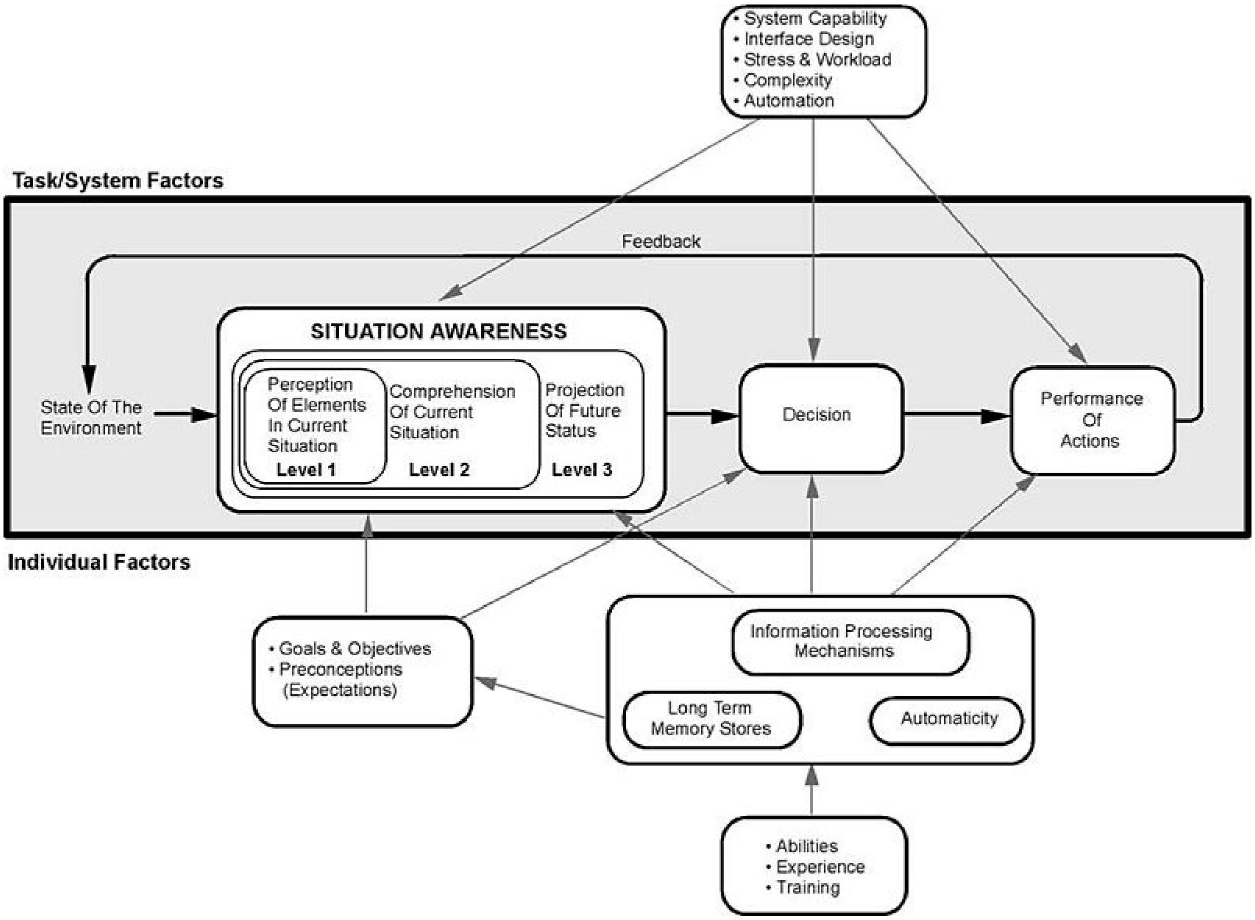


Figure 7.

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