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Pilot Vehicle Interface Improvements to the F/A-18 Weapon System

(Using Human Factors Solutions to Increase Efficiency)

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

Thomas B. Heck
May 2007

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ABSTRACT

The purpose of this study was to evaluate and provide recommendations for optimizing the Pilot Vehicle Interface for components of data link systems employed on and currently in design for the F/A-18 Hornet and Super Hornet. Data was gathered using human factors research methodologies including descriptive studies, experimental research, and evaluation research. Additionally, flight and lab tests were used to gather data on systems that were mature enough in development. Overall, the study revealed that the interfaces for the systems evaluated could be modified in order to provide more situational awareness to the operator, allow for more logical display of information, and improve the operator interface with the overall effect of increasing the efficiency of the weapon system as a whole. While hardware display improvements would solve many display limitation problems with the Situational Awareness format, there are potential software solutions that were assessed to be adequate and much more cost effective. The software solutions will aid in displaying, on the Situational Awareness and expanded formats, information that is currently omitted under certain conditions. Decluttering the Track Number search format and Helmet Mounted Display while displaying pertinent information in a more concise manner will increase the efficiency with which the operator processes it. Displaying information on the Close Air Support format in a more usable format with the appropriate level of detail will help reduce the potential for fratricide. Standardizing the push button labels associated with the "cease" command function on the RECALL and NETS formats will significantly reduce operator workload, errors, and required training.

PREFACE

Given the proper experience and training, it is fairly easy to take “something” and, through testing or using it, identify the interface designs that are less than optimal. The challenge lies in identifying those interface design deficiencies during the design phase while that “something” is still only a concept. It is much more cost effective to implement changes in the design phase than it is after production or software coding. For that reason this paper focuses mostly on systems that are in the design phase.

The roles of the author in the development of the systems evaluated in this thesis were test pilot, project officer, and design team member. Lab and flight test events referenced were performed by the author. Design modifications and other recommendations were developed by the author. The results, recommendations, and conclusions presented are the opinion of the author and do not necessarily reflect the opinion of the United States Navy or the United States Department of Defense.

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LIST OF ACRONYMS

CAS – Close Air Support
C2 – Command and Control
DDI – Digital Display Indicator
EGRS – Egress
FAC – Forward Air Controller
FRND – Friendly
HMD – Helmet Mounted Display
IP – Initial Point
JHMCS – Joint Helmet Mounted Cueing System
JTIDS – Joint Tactical Information Distribution System (synonymous with MIDS)
L-16 – Link 16 (synonymous with TADIL J)
LVT – Low Volume Terminal
MIDS – Multifunctional Information Distribution System (synonymous with JTIDS)
NM – Nautical Mile (6000 ft)
PB – Push Button
PPLI – Precise Participant Location and Identification
PVI – Pilot Vehicle Interface
RESRCH – Research (as in to search again)
SA – Situational Awareness
TADIL J – Tactical Digital Information Link (synonymous with L-16)
TN – Track Number
TUC – Target Under Cursor
VCS – Voice Call Sign

CHAPTER 1: INTRODUCTION

STATEMENT OF THE PROBLEM

The ultimate mission of tactical airborne platforms is to employ weapons on the correct target as expeditiously as possible. However, that target is most often not selected by the aircrew of the tactical aircraft and must be located and identified through communications with the person who has selected the target. Technological solutions and weapon systems have been developed over the history of aviation in order to aid aircrew in locating and identifying the correct targets. These weapon systems have the potential to greatly increase the situational awareness of the aircrew, allow for the rapid exchange of large amounts of precise data, and decrease the time required to employ weapons on the correct target. However, these systems are also complicated and, with designs that are less than optimal from a human factors standpoint, have the potential to overwhelm the operators and degrade their performance in a multi-task environment and/or require excessive operator training. For this reason it is extremely important that these systems have an optimized Pilot Vehicle Interface (PVI). Cluttered displays, omitting pertinent information from displays, non-intuitive system operation and providing information on a display that is not at the appropriate level of detail for the assigned task are human factors problems that need to be identified and ultimately avoided. While locating and identifying targets in order to employ weapons is the ultimate mission, it is seldom the highest priority task of the aircrew. Piloting the aircraft, avoiding hostile missile engagement zones, and scanning for visual cues of surface–to–air fire are tasks that are arguably higher in priority. Training can mitigate some aspects of poor system interfaces however, designing an optimal PVI is crucial to the efficiency of the system as a whole. With the recent employment of data links in the F/A-18 Hornet and Super Hornet, modifications are required for several existing PVI's, and for those in design, in order to significantly increase the efficiency with which aircrew can locate, identify, and employ weapons on the correct targets.

BACKGROUND

GENERAL

The F/A-18 is a twin engine tactical platform designed for air-to-air and air-to-ground missions. It is used by the U.S. Navy and Marine Corps as the primary carrier based strike-fighter aircraft. The F/A-18 cockpit has three displays, each with its own set of 20 push buttons (PB) arranged around the perimeter. Those PB's are referenced by a number from 1 to 20. PB 1 is the lower-most button on the left column of the display and the PB's increase sequentially in a clockwise direction ending with PB 20 located at the left-most PB on the bottom row. If a push button has a function the text is written on the display directly above, below, or beside the PB and if there is no function associated with a PB then it will be blank and pressing the PB does nothing. The displays, referred to as Digital Display Indicators (DDI), and the push button reference system are used throughout this thesis. An example of a generic DDI with the PB numbering system is shown in Figure 1.

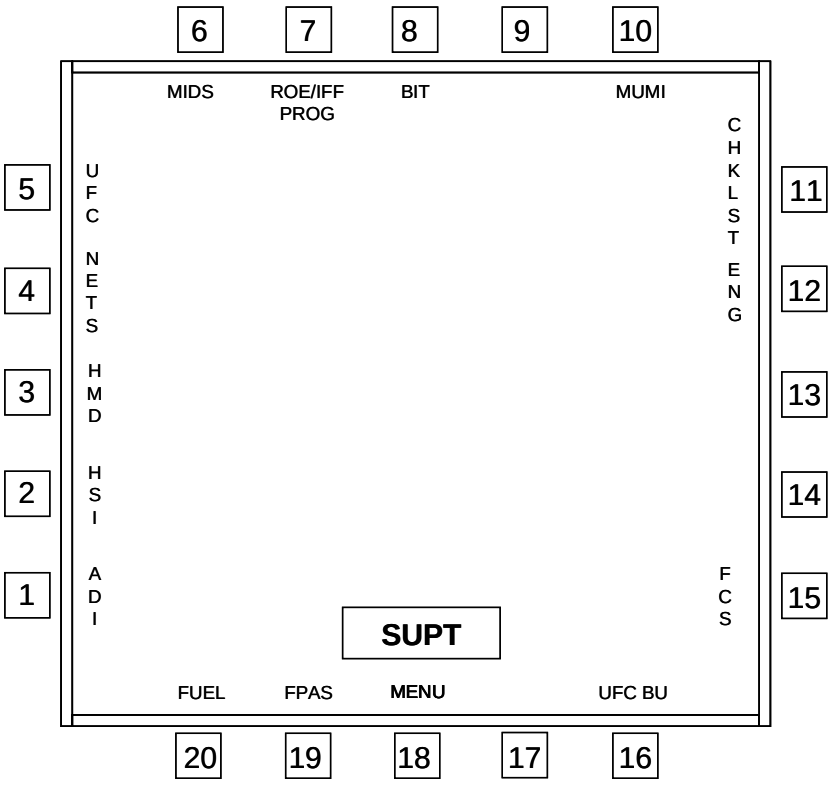


Figure 1
Generic Digital Display Indicator

The F/A-18 Hornet employs a Tactical Digital Information Link (TADIL J), or Link-16 (L-16), network capability through the use of a Low Volume Terminal (LVT)—also referred to as Multi-functional Information Distribution System (MIDS) and Joint Tactical Information Distribution System (JTIDS). For more information on MIDS and LVT see reference 1 [Global Security, 2005]. For more specific information on L-16 and TADIL J message structure see reference 2 [Cruz, 2004] and reference 3 [Abrams/Smith/Rhodes/Kinnan, 2000].

SITUATIONAL AWARENESS (SA) FORMAT

The F/A-18 uses the Situational Awareness (SA) format to display graphical L-16 information to the aircrew. Certain colors and symbols are used to differentiate between types of tracks and their allegiance. An example of a ground scenario presented on the SA format is shown in Figure 2.

The SA format was designed to display the position of friendly units, assuming they are L-16 equipped, and their proximity to the ownship's designated target. Tracks can be designated as targets and used to cue aircraft sensors. Situational awareness to other potential targets, threats, and lines of battle was also designed to be provided to the aircrew. The existing display hardware and software mechanization allow for the display of a limited number of ground tracks and threats on the SA format.

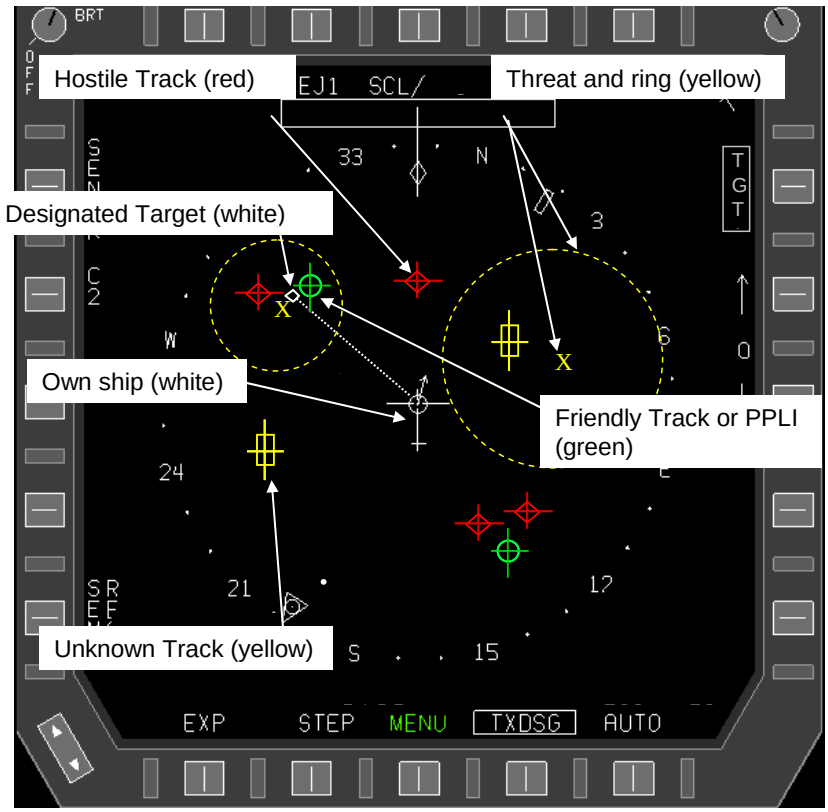


Figure 2
SA Format Overview

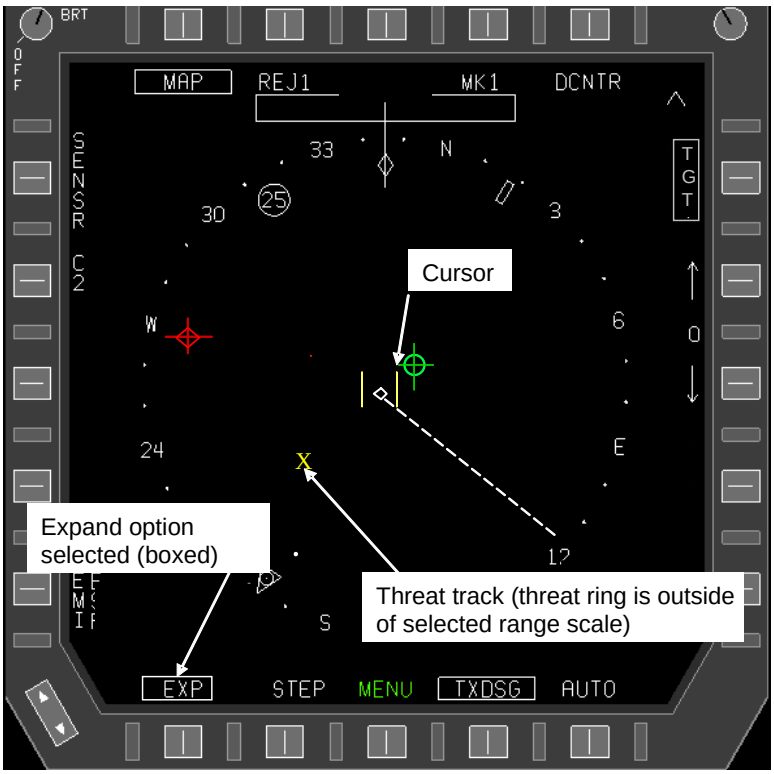


Figure 3
Expanded SA Format

SA Format Expand Function

The "expand" option on the SA format provides a capability to select a location on the SA format using a cursor and center the display on that location while decreasing the range scale. This function was designed to be used as a type of magnifying glass for the SA format. When tracks are closely spaced relative to the range scale selected, the expand function was designed to be used to differentiate between tracks and to provide a better indication of how many there are in a specific location. When actuated, the expand function defaults to a 5 nautical mile (nm) scale and can then be increased if desired. Figure 3 shows an expanded SA format about the ownship's target designation from Figure 2.

MULTIPLE TRACK NUMBER (TN) SEARCH FORMAT

Every L-16 track has a track number (TN) associated with it. That number is a 5 character alpha-numeric, octal identification. The first two characters can be letters or numbers and the last three characters must be numbers. The numbers must be between 0 and 7 (Cruz, 2004). Operationally, tracks are referenced and identified using their TN. For example, a controlling agency may verbally task a tactical platform to employ air-to-ground weapons on TN 12345. This posed a problem in the F/A-18 when

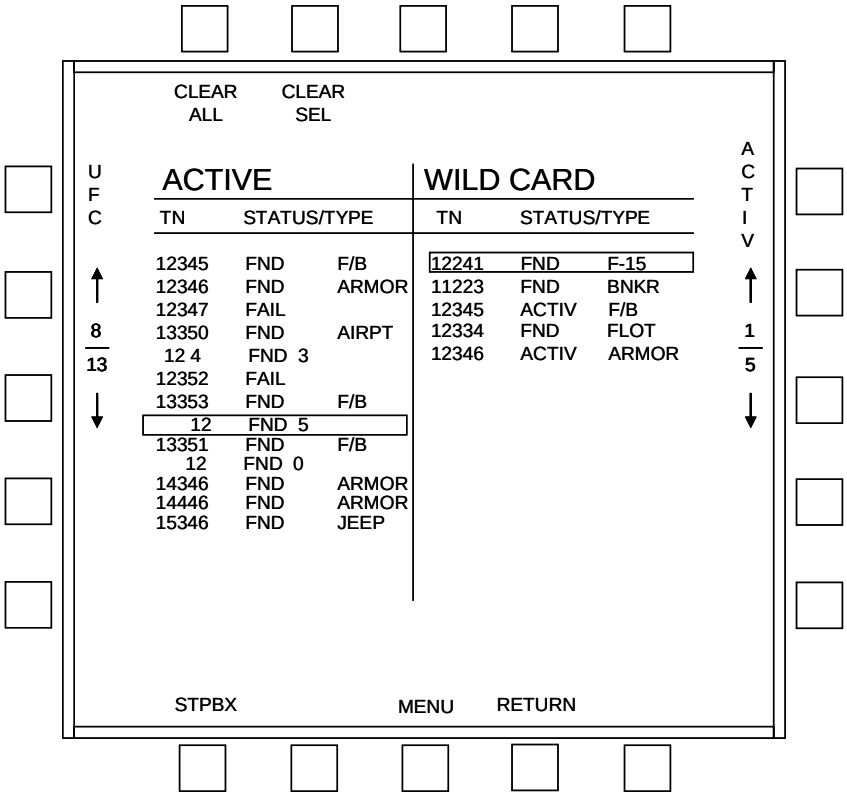


Figure 4
Proposed Multiple TN Search PVI

the track was not displayed due to display limitations—the tasking could not be carried out. As a result, the U.S. Navy requested a capability to search for a TN and, if found, to raise that TN in priority in order to ensure display on the SA format. Initially a capability to search for a single TN was implemented. The capability to search for and manage multiple TN's is now being designed. The contractor's proposed PVI for this multiple TN search capability is shown in Figure 4.

To initiate a TN search, UFC (Up Front Control) would be pressed at PB 5 and the data entry pad on the UFC used to enter the desired TN for the search. Provided a full 5 character TN was entered, it would be displayed in the "ACTIVE" column along with the status and description if available. If the TN was found in the network within the allotted time, then FND would be displayed for the status on the multiple TN search format. In addition, the track symbol associated with the found TN would be automatically highlighted on the SA format with a box and the cursor positioned at the location of the track. If the track symbol was located outside of the currently selected range scale on the SA format, the range scale would be automatically increased so as to display the track and highlight box. If the TN was not found, then FAIL would be displayed and no change made on the SA format.

If a partial TN were entered it would be considered a "wildcard" search. There are two types of wildcard searches: one where the characters entered must be in the same location in the found TN and another where the location of the entered characters would not matter – any TN found with the entered characters (located anywhere within the TN) would be displayed. The partial TN entered for the wildcard search would be displayed in the "ACTIVE" column with the number of matching TN's found placed next to it. If the selection box was positioned over that partial TN by using the arrows at PB 3 and PB 4, the "WILDCARD" column would populate with the TN's that match that wildcard search. The selection box is on the 8th TN in the ACTIVE list in Figure 4. Another selection box, located in the wildcard column, could be positioned over a desired wildcard result by using the arrows at PB 12 and PB 13. PB 11 (ACTIV) could then be used to move a wildcard search result TN to the ACTIVE column. Tracks in the ACTIVE list would be raised in priority against other tracks so that the existing priority scheme for display on the SA format would be applied to those TN's in the ACTIVE list prior to others. Additionally, stepping the selection box over a TN in the ACTIVE column would force display of that TN on the SA format, regardless of where it ranked in the priority scheme. Stepping the selection box in the ACTIV column list would behave similarly to initially finding a TN in that the SA format range scale would automatically increase to display the track and highlight box if required. The force display of that TN would persist as long as the selection box was not moved on the multiple TN search format or the cursor was not moved on the SA format. There are two options that would allow deletion of TN's from the ACTIVE list. One method would use PB 7 (CLEAR SEL) and would delete only the TN in the selection box. The other method would use PB 6 (CLEAR ALL), which would delete all TN's in the ACTIVE list.

CLOSE AIR SUPPORT (CAS) FORMAT

The Close Air Support (CAS) format was designed for use in the F/A-18 with the Variable Message Format (VMF) transmit and receive capability. This format allows for digital display and use of the standard "9-line CAS brief" for Close Air Support tasking. The CAS format aids in rapidly finding the desired target by integrating information traditionally passed via voice communications directly into the aircraft's systems for use in cueing sensors. For more information on VMF and the CAS mission see reference 4 [Bigalk, 2002]. Since its design and implementation, the CAS format has been adapted for use with L-16. However, L-16 does not have the capability to support all of the functions on the CAS format. The United States Navy requested upgrades to the L-16 CAS format functions and the contractor responded with a proposed design.

L-16 CAS Additions

New additions to the CAS format include line 1 Initial Point (IP), line 8 closest friendly (FRND), and line 9 egress direction/point (EGRS). The information for these three lines would all be displayed in coordinate format (either latitude/longitude or grid). Existing mechanization, for display of the closest friendly, results in a blank line if an invalid value is received. The sender enters the closest friendly information as a range and bearing from the target. An example of when the closest friendly line would be displayed as blank in the F/A-18 is when the maximum value for range is exceeded in the

information received. The proposed PVI and display for the updgraded L-16 CAS format is shown in Figure 5.

MULTIPLE TARGET FORMATS

The capability to transmit and receive digital tasking with multiple targets embedded via L16 and VMF has been designed for the F/A-18. Included is the ability for the F/A-18 to take a multiple target mission that it has received from a Command and Control (C2) platform and parse it out to other tactical aircraft. With this parsing ability, the need to send a "cease mission" command was identified and included in the design. The "cease" command informs the receiver that the associated mission command is no longer valid and instructs them to abort that particular mission. The formats used for the "cease" command function include the NETS and the RECALL formats. The PVI design proposed for the multiple targets capability will allow for aircrew to send a cease command using three options.

1. Select a recipient on the NETS format and send a "cease" command for a specific multiple target mission, selected via the RECALL format, to that recipient.
2. Select a recipient and send a "cease" command for all multiple target missions previously sent to that recipient.

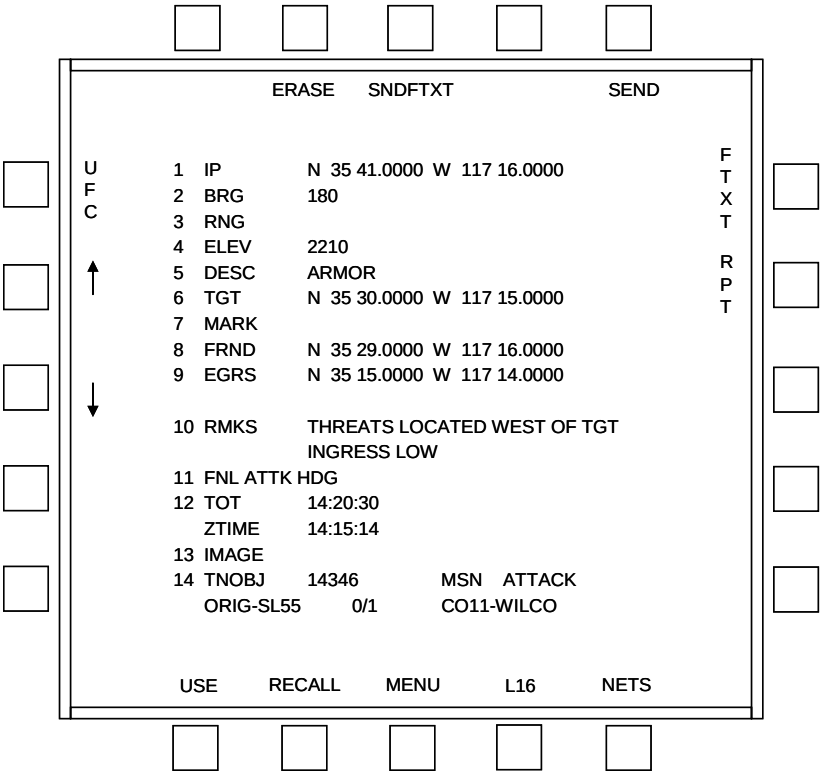


Figure 5
Proposed PVI for Upgraded CAS Format

3. Select a multiple target mission and send a “cease” command to all recipients of that command.

Cease Selected Mission to Selected Recipient

PB 9 (CEASE VCS/TN) on the RECALL format would be used to transmit a “cease mission” command for the selected mission on the RECALL format to the selected recipient on the NETS format. The proposed PVI for the RECALL format is shown in Figure 6, where PB 9 is labeled “CEASE CO11”. In this example, CO11 is the Voice Call Sign (VCS) of the selected recipient on the NETS format and the selected mission is “1”, or the one with the selection carat “>” next to it on the RECALL format. If the VCS is not available for the recipient then the 5 character TN would be displayed.

Cease Selected Mission to all Recipients

PB 10 (CEASE MSN) on the RECALL format would be used to transmit a “cease” command for the selected mission on the RECALL format to all recipients that have previously received the selected mission. As shown in Figure 6, PB 10 is labeled “CEASE MSN” and the selected mission is the one with the “>” next to it (mission 1).

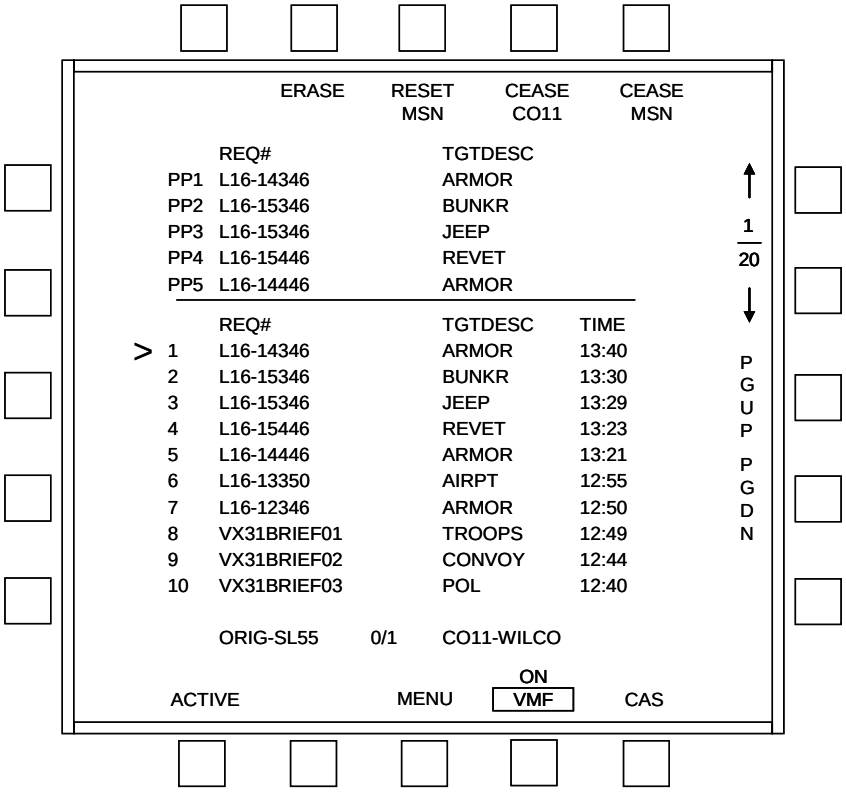


Figure 6
Proposed PVI for RECALL Format

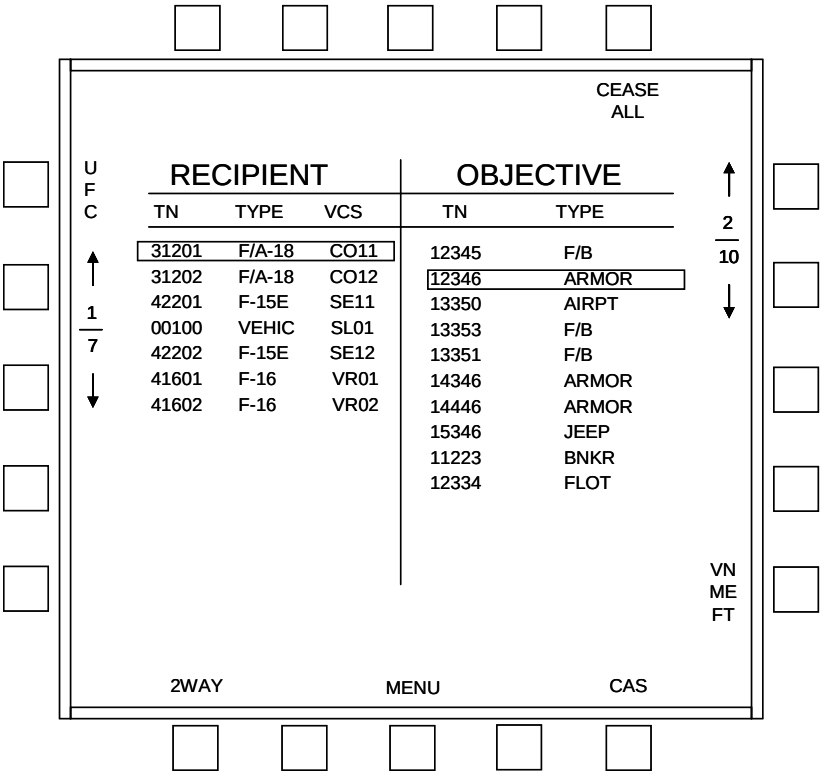


Figure 7
Proposed PVI for NETS Format

Cease all Missions to Selected Recipient

PB 10 (CEASE ALL) on the NETS format would be used to transmit a "cease" command for all missions previously sent to the selected recipient on the NETS format. The proposed PVI for the NETS format is shown in Figure 7 where PB 10 is labeled "CEASE ALL". In this example the selected recipient is the one with the selection box around it—TN 31201 with a VCS of CO11.

L-16 TRACKS IN HELMET MOUNTED DISPLAY (HMD)

A Helmet Mounted Display (HMD) presents information to aircrew by overlaying information onto the inside of the helmet's visor. The information displayed often includes, but is not limited to, the information found in the Heads Up Display (HUD). The HMD allows aircrew to see vital information while not having to look forward through a fixed display, such as a HUD, or point the aircraft in a certain direction. The Joint Helmet Mounted Cueing System is the specific HMD that has been implemented in the F/A-18. For more information on the JHMCS see reference 5 [Global Security, 2005].

The capability to display L-16 tracks in the JHMCS was requested by the U.S. Navy and a proposed design was provided by the contractor. The display would include

offboard Hostile, Unkown, and Friendly tracks as well as Flight Members and Donors. The F/A-18 has the capability to select up to three Precise Participant Location and Indications (PPLI's) as flight members, which then allows for the sharing of additional data and mission status over L-16 as well as a means to easily identify wingmen on current displays (such as the SA format). Flight members are assigned a letter, typically A, B, C, or D, which corresponds to a position in the flight. Up to seven PPLI's can be selected as donors, which allows for the sharing of additional data over L-16.

Offboard Tracks

Tracks that are generated by an offboard source and received by the ownship are referred to as "offboard tracks." For offboard tracks, the existing symbols for hostile, unknown, and friendly tracks would be used in the JHMCS with the addition of an upper and lower window for textual information display next to the symbol (Figure 8). The upper window would display information for track type, Target Under Cursor (TUC), and designated target if applicable. The upper window is limited to an 8 character string. The lower window would display range from ownship in nm to the nearest tenth.

Members and Donors

For flight members and donors, a circle would be used for the symbol (Figure 8). The upper window would display information for VCS, flight member letter, TUC, and designated target if applicable. The lower window would display range from ownship in nm. An example of the proposed HMD display, including some L-16 tracks, is shown in Figure 9.

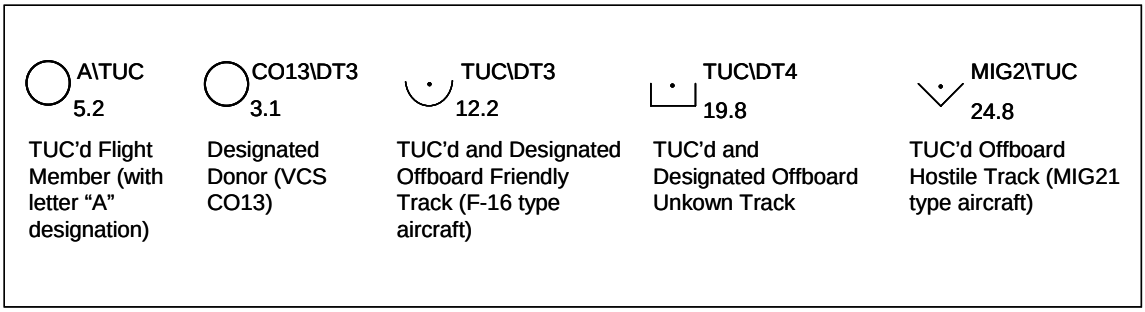


Figure 8
Proposed HMD L-16 Track Symbology

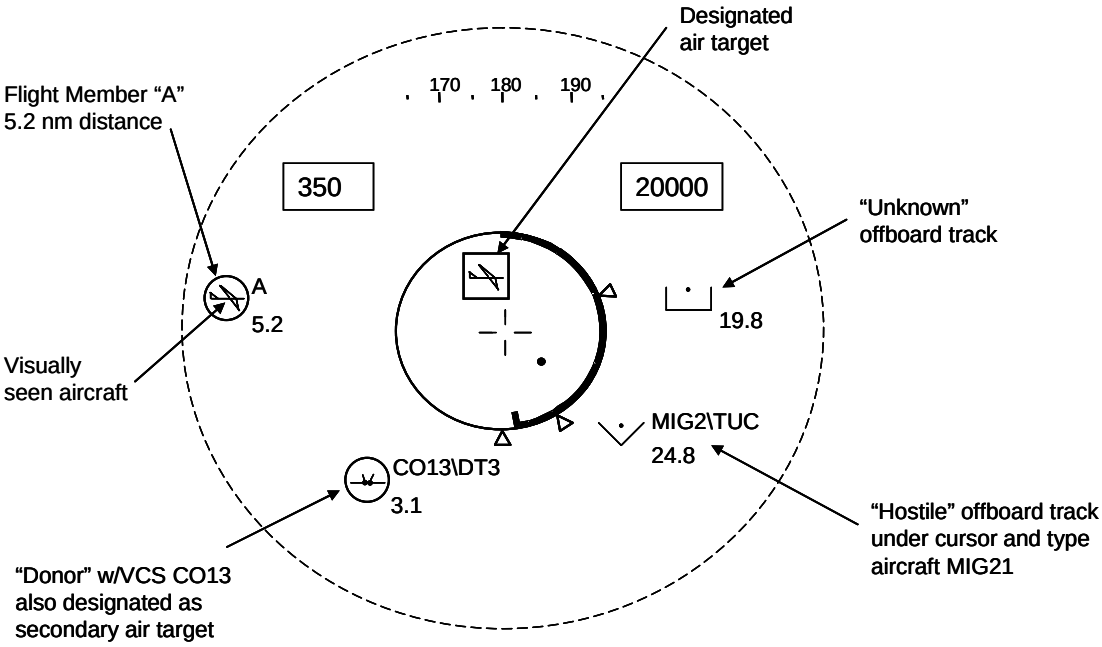


Figure 9
Proposed HMD Display with L-16 Tracks

CHAPTER 2: METHODOLOGY

GENERAL

F/A-18 weapons systems are evaluated by test squadrons for suitability for the end users. The end users are the operational F/A-18 squadrons – also referred to as the "Fleet". The methods used by the author to evaluate the F/A-18 systems' PVI described in the background section and to develop deficiency corrections included human factors research methodologies and the systems engineering process.

Additionally, flight tests were flown and a weapons laboratory was used to acquire data for the existing systems. Developmental flight and lab tests for the weapons systems of interest were conducted by the author from March 2005 to January 2007 and consisted of approximately 10 laboratory hours (including simulations) and 100 flight hours. In many cases, a design existed only for the system under evaluation, so descriptive documents or laboratory simulations had to be used for evaluation. The Human Factors Military Standard (MIL-STD 1472D) was referenced as a validation tool for the recommendations provided.

HUMAN FACTORS RESEARCH METHODOLOGIES

DESCRIPTIVE STUDIES

Descriptive studies are generally used to gather information on a population in terms of certain attributes [Sanders/McCormick, 1993]. In the case of this study, the population was a group of operators (or aircrew), with similar aviation backgrounds. Specifically, the population consisted of pilots and Weapon Systems Officers (WSO's) with approximately 10 years of flying experience and 7 years of experience in the F/A-18. Also included in the population were F-14 Radar Intercept Officers (RIO's) that have transitioned to the F/A-18 as WSO's and who have approximately 10 years flying experience and two years of experience in the F/A-18. Ten aircrew, including the author, comprised the population of operators and were independently interviewed. The interviews gathered opinions on existing deficiencies and operational problems and, to a larger extent, anticipated deficiencies and problems based on the experience of the aircrew and the presentation of the design. Questions included "likes" and "dislikes" of the newly designed displays and how information was presented. Additionally, the subjects were asked to perform such tasks as choosing a correct PB to activate in order to complete a task or picking out a specific piece of information from a display.

EXPERIMENTAL RESEARCH

Experimental research is generally used to test the effects of some variable on behavior [Sanders/McCormick, 1993]. Many of the systems could not be evaluated using experimental methods because they simply did not exist yet. However, for existing systems, such as the SA format, variables were controlled and the results measured directly from the display through observation.

SA Format Display Limitations

The SA format display limitations were evaluated during flight test by fixing the SA format to a 40 nm scale and introducing L-16 tracks within that range. A simulated C2 platform consisting of a lab ground station with a MIDS LVT was used to generate the L-16 tracks. When the maximum displayable tracks were present on the SA format, additional tracks were introduced outside of the selected range scale. The resulting number of displayed tracks on the SA format was then recorded.

EVALUATION RESEARCH

Evaluation research is somewhat of a mix of descriptive and experimental research with the purpose of evaluating the affects of a system and seeking to describe the performance and behaviors of the operators in comparison to the end goal (or mission) [Sanders/McCormick, 1993]. For the purposes of this study, the end goal is to quickly and accurately locate and identify correct targets. Simulated combat scenarios were utilized during flight test and simulator events in order to collect data on the use of the SA format and L-16 tracks in the JHMCS for the end goal.

SYSTEMS ENGINEERING PROCESS

The systems engineering process was used to break down the system into smaller, more manageable pieces. In this study, the goal of quickly and accurately locating and identifying correct targets was broken down into the goal of optimizing the PVI of the technologies added to the F/A-18. The optimization of the PVI can be measured using the variables of time, accuracy, and cost. Alternatives to existing mechanization or design, which would improve one or more of the variables, were then developed, analyzed, and decided upon. Testing some of the alternatives was possible, however other systems were still in the design phase and could not be tested.

CHAPTER 3: RESULTS OF EVALUATION

SA FORMAT

SA FORMAT DISPLAY LIMITATIONS

Due to hardware display limitations and existing software mechanization, the SA format is limited to displaying a maximum number of ground tracks and threats. It was discovered during flight testing that the tracks selected for display are independent of the range scale selected on the SA format. The tracks selected for display are determined by applying an existing priority scheme to all available tracks based on range from ownship. Precise Participant Location and Identification (PPLI) tracks are ranked first in the priority scheme. Therefore, when too many PPLI's were located outside of the selected SA range scale (40 nm as shown in Figure 10), the resultant SA format was relatively blank in regards to the ground picture as shown in Figure 10. This SA format was found to provide little situational awareness to the operator and, in fact, provided false indications that there were no ground tracks located within 40 nm of ownship.

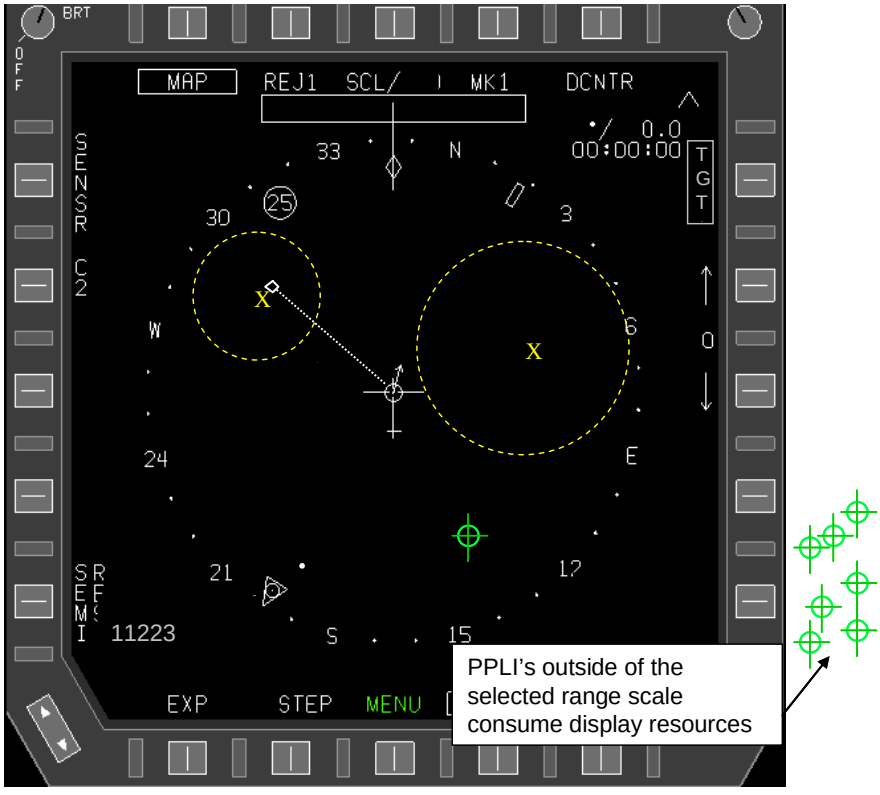


Figure 10
Blank SA Format

SA FORMAT EXPAND FUNCTION PRIORITY DEFICIENCY

A deficiency in the expanded SA format function was discovered during a simulated combat scenario. The priority scheme for displaying tracks on the expanded SA format ranks tracks for display based upon range from ownship, which is identical to the non-expanded SA format. However, since the expand function is typically used to expand about a point at a significant distance from ownship, the expanded SA format was often blank because the tracks that were selected to consume display resources were outside of the range scale on the expanded SA format. During the simulated combat scenario, the F/A-18 was tasked to attack a target. The target was designated and the SA format expanded about that target. The SA format displayed no tracks around the designated target and the decision was made to employ a simulated air-to-ground weapon. A friendly unit located in close proximity to the target, but not displayed on the SA format, was assessed to have been destroyed by friendly fire during the scenario. The U.S. Navy requested an improvement to the expanded SA format design and the contractor responded with a proposal. However, this proposed design placed caveats as to whether the closest friendly to the designated target would be displayed. Eighty percent of the subjects identified having caveats as a potential operational problem. Additionally the proposed design did not take into account the fact that there might be numerous friendly tracks around the target that could consume all of the display resources. Ten percent of the subjects thought this would be a deficiency.

MULTIPLE TN SEARCH FORMAT

WILDCARD SEARCH DISPLAY AMBIGUITY

Through analysis of the proposed design it was found that the two different types of wildcard search methods have the potential to appear the same in the ACTIVE column. Referencing Figure 4, there are three wildcard searches where two of the three (the 8^{th} and 10^{th} on the list) appear as three blanks followed by the digits “12”. However, one of them was entered as just “12” – meaning that all TN’s containing “12” anywhere in them will match the search. The other was entered as 3 spaces followed by “12” – meaning that all TN’s containing “12” in the last two character places will match the search. There is no difference in the way the two are displayed on the ACTIVE list. There were no interviewed subjects that could determine which wildcard search method had been used without examining the TN’s on the WILDCARD list. Using this method, it took the subjects 5 to 10 seconds to correctly determine the wildcard search method used for the “12” example in Figure 4.

CLUTTERED ACTIVE AND WILDCARD COLUMNS

The proposed design displays FND in the wildcard search column next to all TN’s found that are not in the active list (Figure 4). Interviewed subjects reported this as redundant information that added clutter to a display that already had a large amount of textual information. Sixty percent of the subjects complained that the clutter made it more difficult to quickly ascertain which wildcard results were already in the ACTIVE column. The fact that the wildcard column contains a TN, by default, means that it was found and therefore the FND indication is not needed. Additionally, the FND and FAIL

indications on the ACTIVE list were assessed by 10% of the subjects to be similar and difficult to quickly differentiate.

SA FORMAT SEARCH DISPLAY MANAGEMENT

The proposed design provided no indication on the multiple TN search format as to which TN's were consuming a display resource, which made it difficult for aircrew to efficiently manage the tracks displayed on the SA format. While TN information is available on the SA format by placing the cursor over a track symbol, doing this for each track and then comparing the information to that displayed on the TN search format was not assessed as an effective means to manage displayed tracks on the SA format. All subjects abandoned the task of trying to force the display of desired tracks on the SA format by deleting tracks on the ACTIVE list of the TN search format.

SELECTION BOX SCROLLING

With the force display function that the selection box in the active and wildcard columns invoked on the SA format, coupled with the auto-increasing SA format range scale, it was anticipated by 50% of the subjects that there would have been undesirable effects on the SA format. During rapid selection box scrolling, the SA format would have had the potential to quickly and automatically toggle the range scale, causing some confusion to the operator. Additionally, whenever the selection box was rapidly scrolled through the ACTIVE list a common result would have been that the operator would be required to decrease the SA format range scale to the desired setting after scrolling the selection box. This would be due to the fact that while the SA range scale would automatically increase to accommodate display of the TN under the selection box in the ACTIVE list, it would not automatically decrease. Therefore, it would be likely that at least one of the TN's that the selection box was scrolled past would have been at a range that was greater than the desired SA range scale.

L-16 CAS FORMAT

COORDINATE DISPLAY

Lines 1 (IP), 8 (FRND), and 9 (EGRS) were all displayed as a latitude and longitude (or grid coordinates), which is identical to the method of displaying the target in line 6 (TGT) (Figure 5). The CAS format typically contains a large amount of information for aircrew to comprehend in a multi-task environment. Displaying multiple lines with the same coordinate format as the intended target produced clutter and made it difficult for the subjects to quickly pick out information that the interviewer requested. Additionally, there were 2 occasions where the incorrect information was retrieved by the subjects after being tasked. Aircrew are trained to refer to line 1 (IP) using a name of a prearranged geographical location (or in some cases a bearing and range from the target), line 8 (FRND) as a subcardinal direction and range from the target, and line 9 (EGRS) as a subcardinal direction from the target and/or name of a prearranged geographical location. All of the subjects found the method of display in the proposed design to be non-intuitive based on their previous experience and training.

INVALID CLOSEST FRIENDLY DISPLAY MECHANIZATION

For the existing mechanization, if an invalid range is received via datalink for closest friendly to the target, then line 8 FRND would be blank on the CAS format. During flight test, this was found to occur when the ground operator (FAC) inadvertently included an extra digit when entering the range for closest friendly. The correct range was 1700 m and the FAC entered 17,000 m by accident—the error was not immediately noticed. In the existing mechanization, 17,000 m exceeds the maximum value for valid range and so line 8 (FRND) was left blank in the receiving F/A-18. This provided a false indication to the aircrew that there were no friendly forces close to the target. The aircrew did not discover that there were friendly forces close to the target until post flight review.

CEASE COMMAND FUNCTION

NON-INTUITIVE PB LABELS

The labels for the "cease" command function push buttons on the NETS and RECALL formats were found to be non-intuitive and not very descriptive as to what their functions were. CEASE MSN ceases *a* mission for *all* recipients while CEASE ALL ceases *all* missions for *a* recipient. These labels, as shown in Figure 6 and Figure 7 were confusing to the subjects and they had difficulty remembering their functions. Each subject interviewed either made an error when asked to perform a task involving the CEASE MSN and CEASE ALL PB or they requested a review of the PB functions prior to making their selection.

DISPERSED INFORMATION

The information associated with the "cease" command push buttons on the RECALL and NETS formats were dispersed on those displays. When transmitting a "cease" command for a specific mission, the operator needed to know for which mission the "cease" command would be sent when PB 9 or 10 was actuated on the RECALL format (Figure 6). That information was available on the RECALL format, however 60% of the subjects complained that there was a lot of information on that format and locating the desired specifics was time consuming. The same applied for the NETS format when transmitting a "cease" command for all missions to the selected recipient—the operator needed to know to whom that command would be sent when the CEASE ALL push button was actuated on the NETS format. While that information was available on the NETS format, it was not located near the push button that was being used which forced the operator to search the display for the desired information.

FALSE RECIPIENT INDICATION

The VCS or TN of the recipient selected on the NETS format was displayed under CEASE at PB 8 on the RECALL format regardless of whether that recipient had received the selected mission (Figure 6). This gave a false indication to the operator that the selected mission had been sent to that recipient. It also forced the operator to remember or write down every recipient of sent missions. The opinion of all of the subjects was that this was unacceptable added workload.

L-16 TRACKS IN HMD

EXCESSIVE INFORMATION

Displaying “TUC” in the upper window to indicate which track is currently under the cursor (TUC’d) was excessive and cluttered the display (Figure 8). Displaying “DT2”, “DT3”, or “DT4” to indicate the track as a designated target was excessive and also added to the clutter of the display. The subjects tended to dislike excessive information presented in a text format on a tactical display, such as the JHMCS and 80% complained about the TUC and DT2, specifically.

MISSING INFORMATION

There were instances discovered where desired information was omitted in the proposed design. For example, as shown in Figure 8, when an offboard track with a known aircraft type was TUC’d, the last character of the aircraft type was omitted. In this example, the type of aircraft was a “MIG21” but the displayed information was “MIG2\TUC”. The display provided false information and misled the operator into thinking the aircraft associated with that particular symbol was a “MIG2” instead of a “MIG21” (if such an aircraft existed). This problem was further compounded by the existing mechanization that limits aircraft type display information to 5 character strings. With hundreds of possible aircraft types, each character in the displayed information was vital for accurate operator interpretation. All subjects disliked the truncation of the aircraft type information. Another example from Figure 8 is the friendly track that is TUC’d and designated as DT3. Due to the 8 character string limitation, the “TUC” indication replaced the aircraft type information – “F-16”. With the proposed design, there was no way to simultaneously display the TUC indication, aircraft type information, and the designated target information in the upper window. Fifty percent of the subjects noticed the omission of aircraft type with a “TUC” and “DT#” indication and identified it as a deficiency

CHAPTER 4: RECOMMENDED DESIGN IMPROVEMENTS

GENERAL

The recommendations provided in this chapter are those of the author and have not been evaluated to the extent that the existing systems and proposed designs in the background chapter were evaluated. However, all subjects polled about the recommendations tended to agree that they would result in an overall improvement. More specific rationale and justification for each recommendation can be found in the "Discussion of Improvements" chapter.

SA FORMAT IMPROVEMENTS

SA FORMAT RANGE FILTER

A design improvement is recommended for the SA format which would require a relatively inexpensive software update. This update should include a filter which will take into account the range scale selected on the SA format. Ground tracks that fall outside of that range should be filtered out so as to not consume one of the few display resources. Additionally, the threat rings should be decoupled from the center threat track so that the ring can be displayed while the threat track, located outside of the selected range scale, would not consume a display resource. An example of a potential ground picture on an improved SA format with the range filter is shown in Figure 11.

SA FORMAT EXPAND FUNCTION PRIORITY

Ensuring the display of the closest friendly track to the designated target on the expanded SA format, with no caveats, is recommended. However, only the one closest friendly track should be displayed with the rest of the display resources given to other tracks.

MULTIPLE TN SEARCH FORMAT IMPROVEMENTS

DISPLAY OF WILDCARD SEARCHES

The method for displaying wildcard searches in the ACTIVE column should be modified so that entered blanks are displayed with a dash as shown in Figure 12 with the 5^{th} and 10^{th} TN in the ACTIVE list. The method of displaying wildcard partial TN's with no criteria for position within the found TN should be retained as a right-justified character string with preceding blank spaces as shown by the 8^{th} TN in the ACTIVE list of Figure 12. Notice that the 5^{th} and the 10^{th} TN were entered using the same wildcard method.

DECLUTTER OF WILDCARD STATUS COLUMN

The FND indication in the WILDCARD column should be removed to make it less cluttered and easier to identify which TN's from the WILDCARD column are also in the ACTIVE column (Figure 12). It is also recommended that color be used to help differentiate FND TN's (green) from FAIL TN's (red) in the ACTIVE column.

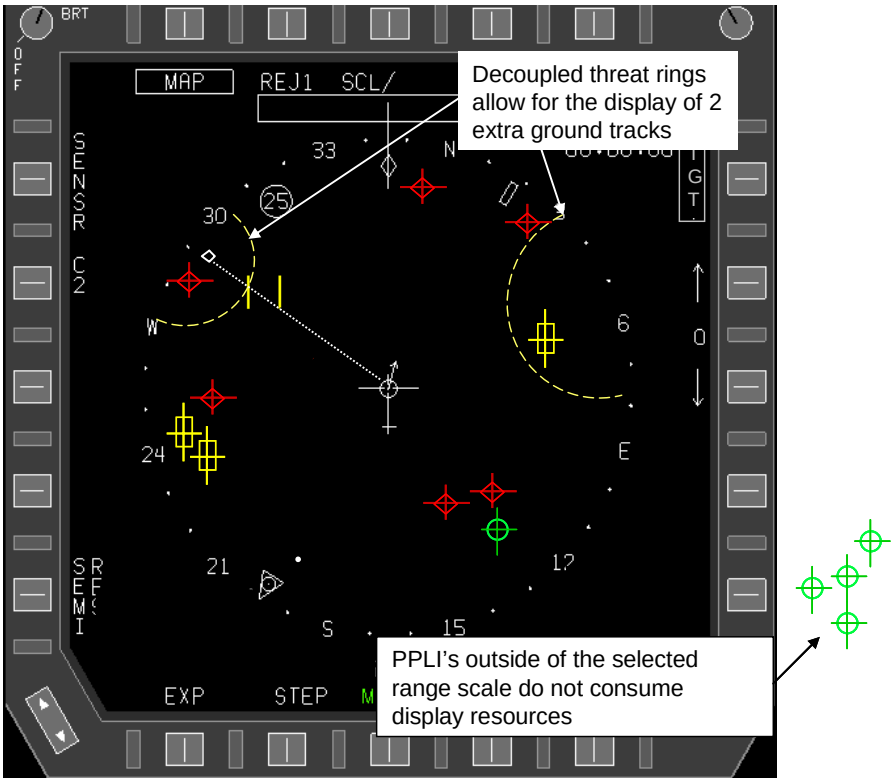


Figure 11
SA Format with Range Filter

ADDITION OF TN DISPLAY INDICATION

To aid in the track display management on the SA format, an indication on the multiple TN search format that identifies which TN's are currently consuming a display resource on the SA format is recommended. That indication should be a symbol, such as an asterisk "*", located to the left of the TN in both the ACTIVE and WILDCARD search lists when that TN is using a display resource. An example of this type of indication is shown in Figure 12.

CLEAR FAILED SEARCHES ADDITION

The proposed design offered no capability to quickly delete all failed searches without also deleting all other searches. A capability should be added to the design that would allow aircrew to delete just the failed searches by using PB 8 (CLEAR FAIL), as shown in Figure 12. Additionally, the proposed design required re-entry of the TN, via the UFC, to initiate another search on a failed TN. It is recommended that the design be altered to allow the operator to quickly re-initiate a search on a failed TN by using PB 19 (RESRCH). The RESRCH PB should only be displayed and active when the selection box is positioned over a failed TN search, as shown in Figure 13.

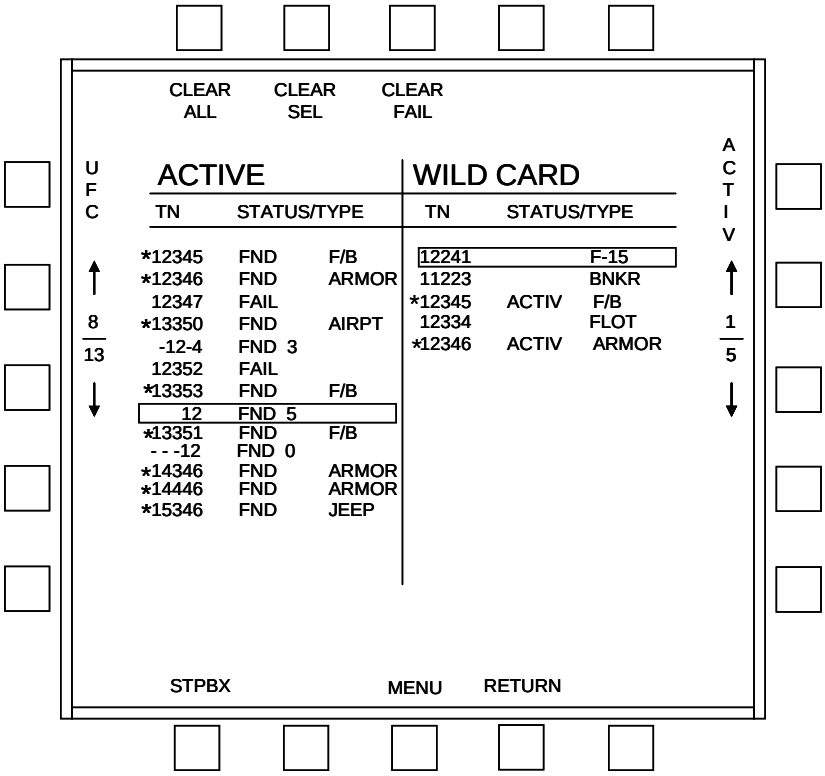


Figure 12
Modified Multiple TN Search PVI

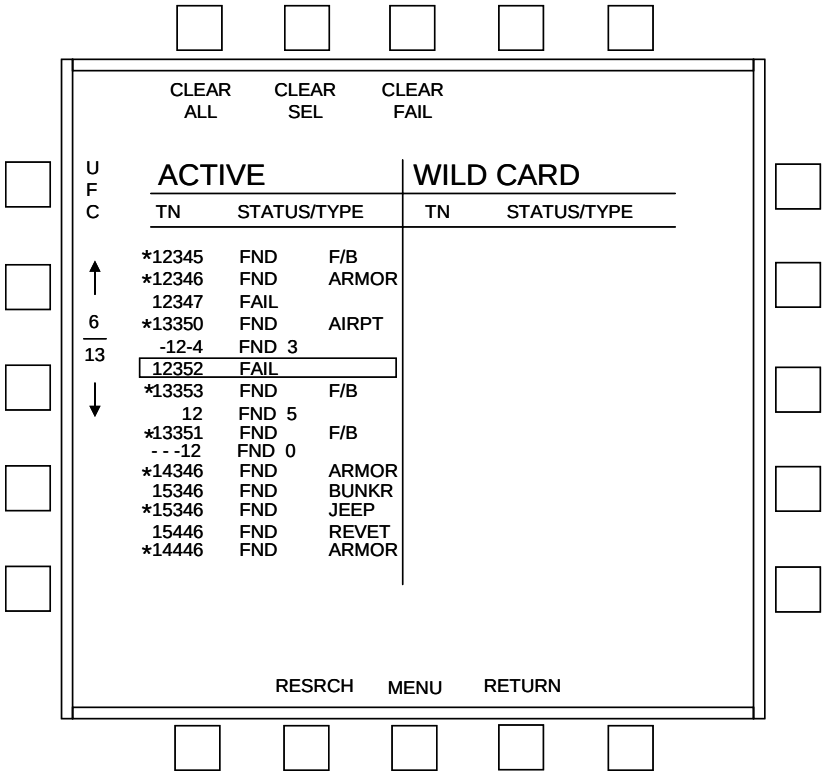


Figure 13
Modified TN Search PVI with RESRCH Option

L-16 CAS FORMAT IMPROVEMENTS

LINE 1 IP

The F/A-18's system can currently store up to 250 preplanned or entered waypoints. A name and number can be assigned to specific waypoints when the preflight mission planning system is used. Waypoints entered by aircrew while in the aircraft only have a number (no name) associated with them. The upgraded CAS format design should be modified so that line 1 (IP) will be displayed as a waypoint name and number or as a bearing and range from the target. When the IP is sent via L-16, it is sent as a coordinate in latitude and longitude format. This coordinate should be compared, by the aircraft's Mission Computer (MC), with those in the waypoint database of the aircraft. If there is a match, with a tolerance of approximately 100 ft, then that waypoint's name and number should be displayed in line 1 (IP) on the CAS format (Figure 14). In the Figure 14 example, the IP is a pre-coordinated geographic location named "horse," where the received coordinates have been matched to waypoint number 22 in the aircraft's database. If a match is not found then a bearing and range from the target coordinates to the IP coordinates, calculated by the MC, should be displayed in line 1 IP (Figure 15). In this example, the IP is not a pre-coordinated geographic location but has been defined by the FAC as a point 10 nm north of the target and sent to the F/A-18 in coordinate format.

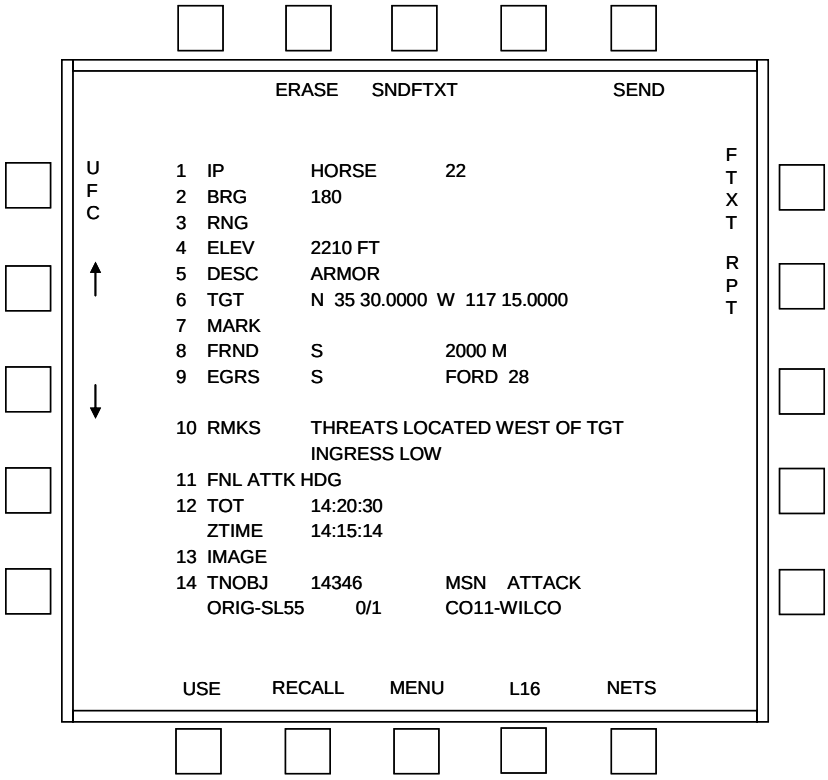


Figure 14
Modified CAS Format with Matched IP and EGRS Waypoints

LINE 8 FRND

The design for Line 8 (FRND) should be modified to prevent displaying the closest friendly location in coordinate format. The coordinates received should be used to calculate a bearing and range from the target. The bearing should then be converted to a sub-cardinal direction using the criteria shown in Table 1. The calculated sub-cardinal direction, followed by the range from the target in meters, should then be displayed in line 8 (FRND) to indicate the closest friendly to the target (Figure 15).

LINE 9 EGRS

The design for line 9 (EGRS) should be modified so that the egress point information is not displayed in a coordinate format. The bearing from the target to the egress point coordinate should be calculated by the MC and a sub-cardinal direction (determined by criteria from Table 1) should be displayed in line 9 (EGRS). The coordinates received by the aircraft for the egress point should also be compared to the aircraft's waypoint database by the MC. If a match is found, then the name (if it exists) and the number of the matching waypoint should be displayed in line 9 (EGRS), as shown in Figure 14. If a match is not found, then only the direction should be displayed as shown in Figure 15.

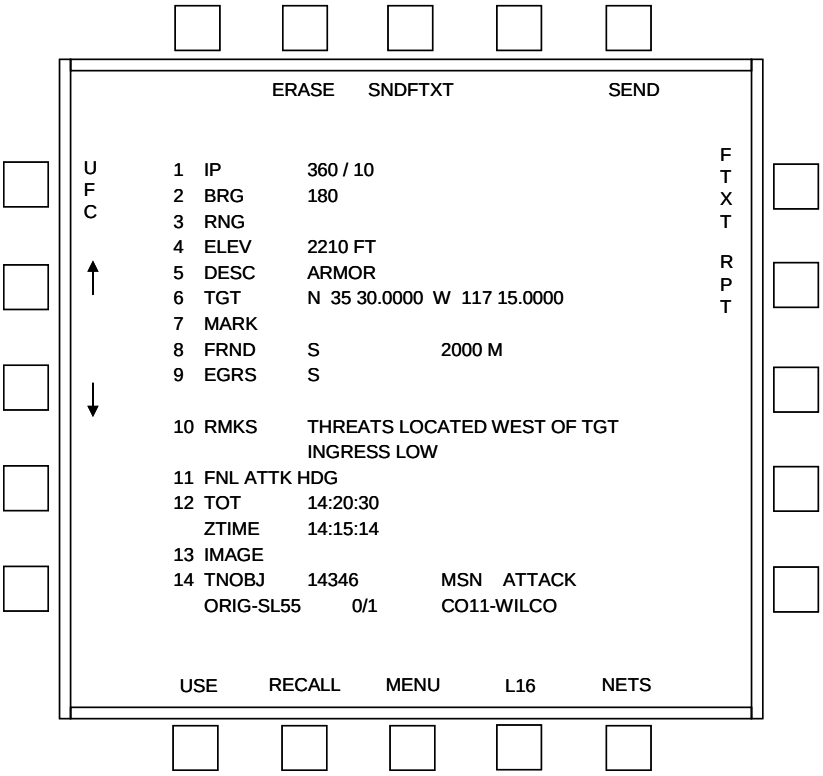


Figure 15
Modified CAS Format with no Matched IP or EGRS Waypoints

Table 1
Sub-Cardinal Direction Criteria

Calculated Bearing	Displayed Direction
≥ 337.5° to < 022.5°	North (N)
≥ 022.5° to < 067.5°	North East (NE)
≥ 067.5° to < 112.5°	East (E)
≥ 112.5° to < 157.5°	South East (SE)
≥ 157.5° to < 202.5°	South (S)
≥ 202.5° to < 247.5°	South West (SW)
≥ 247.5° to < 292.5°	West (W)
≥ 292.5° to < 337.5°	North West (NW)

DISPLAY OF INVALID CLOSEST FRIENDLY

It is recommended that if closest friendly data is received by the aircraft, regardless of whether the range is valid, the calculated direction should still be displayed.

CEASE COMMAND FUNCTION IMPROVEMENTS

CEASE SELECTED MISSION TO SELECTED RECIPIENT

It is recommended that PB 9 on the RECALL format be modified to read "CSE-### VCS/TN", where CSE is an abbreviation for CEASE and ### is the number of the mission as shown on the RECALL format (Figure 16). In this example, if PB 9 is actuated then a "cease" command for mission 001 will be sent to CO11. Also shown in the figure is the alternate label of the PB where the TN (31201) is displayed if the VCS of the recipient is not available. The number of the mission can be preplanned 1-5 (PP1-PP5) or 1-30. The PB labels are limited to two rows with seven characters each, which requires that CEASE be abbreviated to CSE.

CEASE SELECTED MISSION TO ALL RECIPIENTS

PB 10 on the RECALL format should be modified to read "CSE-### TO ALL", where ### is the selected mission and "TO ALL" means all previous recipients of

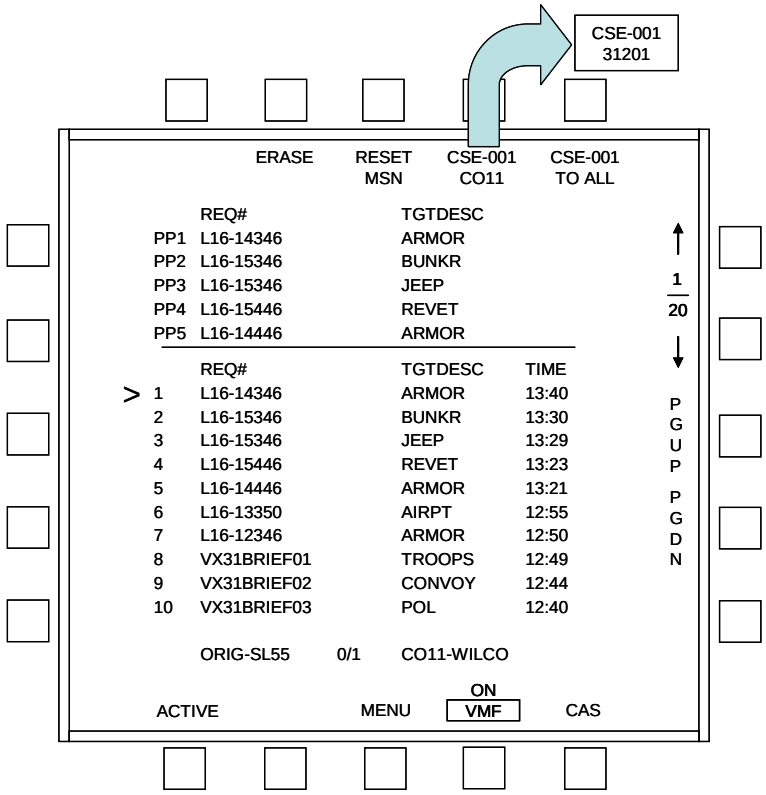


Figure 16
Modified PVI for RECALL Format

mission ###. In the example of Figure 16, if PB 10 is actuated then a "cease" command for mission 001 will be sent to all previous recipients of that mission.

CEASE ALL MISSIONS TO SELECTED RECIPIENT

PB 10 on the NETS format should be modified to read "CSE-ALL VCS/TN", where ALL means all missions sent to the selected recipient (VCS/TN). In Figure 17, if PB 10 is actuated then a "cease" command will be sent to CO11 for all missions previously sent by ownship. Also shown in Figure 17 is the alternate label for PB 10 where the TN (31201) is displayed if the VCS (CO11) of the selected recipient is not available

RECIPIENT INDICATION

The recipient indication associated with PB 9 on the RECALL format should be modified so that the VCS or TN of the selected recipient will only be displayed if that recipient has actually received the *selected* mission from ownship. Additionally, PB 10 on the NETS format should be modified so that the VCS or TN of the selected recipient will only be displayed if that recipient has received *any* mission from ownship.

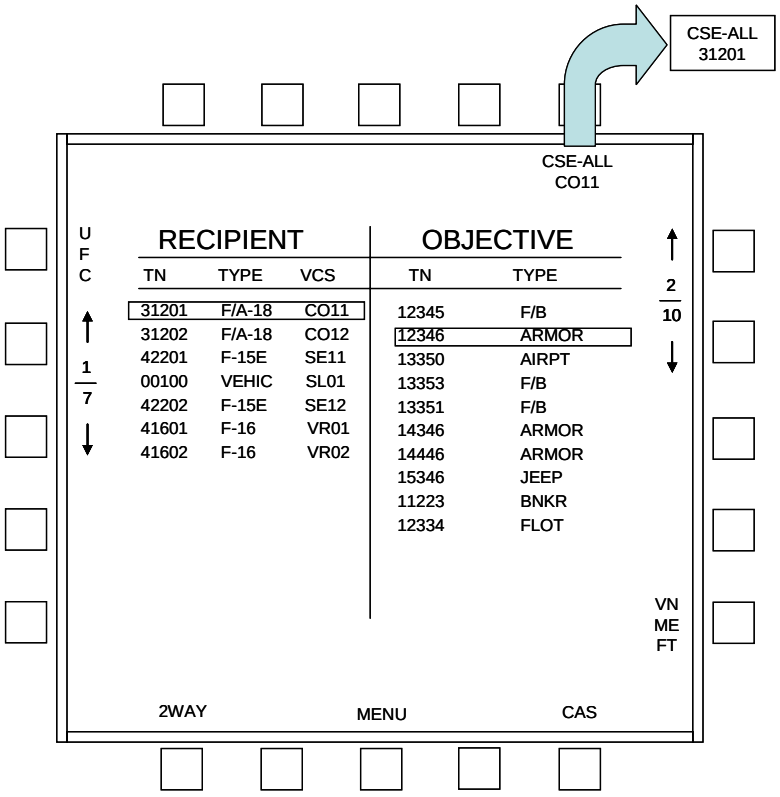


Figure 17
Modified PVI for NETS Format

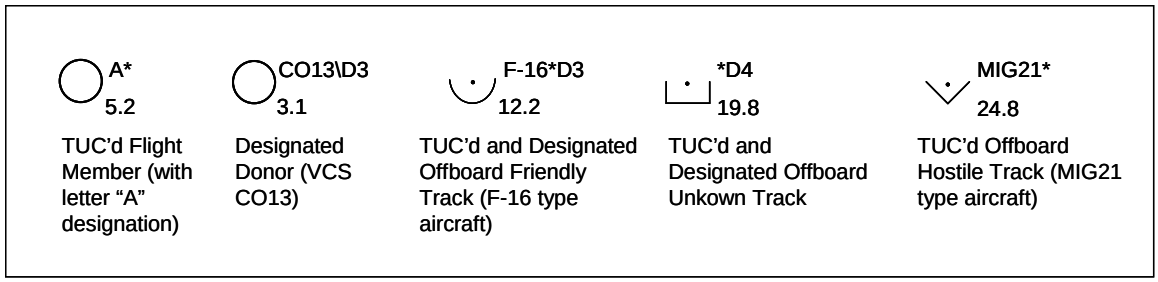


Figure 18
Modified HMD Symbology

L-16 TRACKS IN HMD IMPROVEMENTS

DISPLAY OF UPPER WINDOW INFORMATION

The upper window information should be modified to display a symbol "*" in place of "TUC" to indicate which track is TUC'd as shown in Figure 18. The indication for designated target should be shortened from DT2, DT3, or DT4 by omitting the "T". The resultant indication will be D2, D3, or D4 (Figure 18).

CHAPTER 5: DISCUSSION OF IMPROVEMENTS

GENERAL

Overall, there were many areas of improvement identified for the PVI of the systems evaluated in this study. The recommendations provided by the author should significantly enhance the efficiency of the F/A-18 weapon system as a whole by addressing specific PVI issues. Discussions for those specific PVI issues are provided below.

SA FORMAT

RANGE FILTER

Providing a range filter improvement to the Situational Awareness format would be a relatively inexpensive software upgrade that will prevent blank SA formats and greatly enhance operator situational awareness. There is a valid argument that the hardware components of the displays need to be upgraded in the F/A-18; however the range filter improvement recommended can be accomplished by updating the software load of the aircraft. This would be inexpensive relative to a hardware upgrade to the existing displays, while still significantly improving the effectiveness. This is illustrated by comparing the SA formats in Figure 10 and Figure 11.

EXPAND FUNCTION

Improving the expand function display of L-16 tracks as recommended would help prevent fratricide by increasing the situational awareness of the operator. While only displaying the one closest friendly track may not provide a complete picture as to where all of the friendlies are located, ensuring display of that one closest track provides enough information to the operator in order to make the decision to not employ weapons. Consequently, by not consuming excess display resources with other friendly tracks, the ability to display other tracks, such as hostile and unknown, is retained and operator situational awareness will be enhanced. Without incorporating the recommended improvement, the design would have posed a problem where the closest friendly was not always displayed and the friendly fire incident that occurred during the simulated combat scenario would have the potential to be repeated. Additionally, if there were multiple friendly tracks around the target, aircrew would not be given awareness of other tracks of significance (hostile or unknown tracks).

MULTIPLE TN SEARCH FORMAT

DISPLAY OF WILDCARD SEARCHES

Improving the display of wildcard searches in the active column list will eliminate ambiguities between different types of wildcard searches and decrease the amount of time required for the operator to differentiate between the two. This is illustrated by comparing the 8^{th} and 10^{th} TN's in the ACTIVE list of Figure 4 with those in Figure 12.

CLUTTERED ACTIVE AND WILDCARD COLUMNS

Decluttering the WILDCARD status column by removing the FND indication will improve the efficiency with which the operator processes the information contained there by eliminating unnecessary redundancy. Additionally, providing more contrast between FND and FAIL in the ACTIVE column will help the operator to more quickly differentiate between the two. Using the recommendation of different colors for FND and FAIL will aid in maximizing differences and reducing interference [Weiner/Nagel, 1988].

TN DISPLAY INDICATION

The absence of a desired track on the SA format is difficult to recognize. People simply do not easily notice the absence of things [Weiner/Nagel, 1988]. Providing an indication on the TN search format will allow the operator to see which TN's are consuming a display resource on the SA format and quickly determine why a desired track is not displayed on the SA format. This will effectively give the operator the means to manage, via the TN search format, the tracks that are displayed on the SA format by selecting an undesired track and removing it using PB 7 (CLEAR SEL) on the TN search format (Figure 12).

CLEAR FAILED SEARCHES

It is anticipated that the ACTIVE column of the TN search format will become full during normal operations. Providing a CLEAR FAIL option (Figure 12) will allow for quick removal and declutter of non-essential information in comparison to using the selection box and CLEAR SEL option (Figure 4).

SELECTION BOX SCROLLING

Modifying the selection box scrolling as recommended will reduce nuisance effects on the SA format and decrease time spent by the operator adjusting its range scale back to desired settings.

L-16 CAS FORMAT

COORDINATE DISPLAY

Modifying the method of display for lines 1, 8, and 9 on the CAS format, as recommended, will reduce errors, time required for operator processing, and the potential for fratricide. The original design (Figure 5) displayed lines 1, 8 and 9 information in a similar manner and provided potential for the operator to visually confuse one of those lines with the target and possibly employ weapons on unintended locations – even the friendly position. This is due in part to the vulnerability of the operator to fall victim to salience (or cue seeking) and confirmation biases. Decision makers do not necessarily process all of the information that is available to them, particularly when they are under stress, which may cause a tunneling of attention (salience bias). Additionally, this cue seeking behavior is likely guided by a hypothesis that may already have been chosen by the operator, who then seeks those sources of information that confirm what is already

believed to be true (confirmation bias) [Weiner/Nagel, 1988]. The recommended improvement for the display of lines 1, 8 and 9 (Figure 14) aligns more with the current convention for how that information is communicated during training and operations. Since the typical operator is already trained to recognize the manner in which the information is presented in the recommended improvement, the advantage of the representative heuristic can be realized in a positive way. "People typically try to understand a situation by matching in working memory the pattern of cues seen in the environment with a mental representation of the typical or representative pattern for a particular situation as recalled from long-term memory" [Weiner/Nagel, 1988, page 131].

DISPLAY OF INVALID CLOSEST FRIENDLY

Implementing the recommended modification to the display of invalid closest friendly information will provide an indication to the operator that friendly information was actually sent and deemed important enough by the sender that the operator should be made aware of that information. This indication will at least alert the operator that other means of communication are required in order to clarify the actual location of the nearest friendly forces, reducing the potential for fratricide.

CEASE COMMAND FUNCTION

Modifying the push button labels for the cease command function on the NETS and RECALL formats will significantly increase the efficiency of operator use by reducing operator errors and confusion. The recommendations shown in Figure 16 and Figure 17 will help reduce operator confusion by setting a standard where the top row always indicates which mission is selected (or will be "ceased") and the bottom row indicates who the recipient of that "cease" command will be. Additionally, only displaying a recipient VCS or TN on the bottom row when a valid recipient exists (one that has received the appropriate mission) will increase operator efficiency by not requiring memorization or recording of "who was sent what" by the operator.

L-16 TRACKS IN HMD

Improving the display method for information associated with L-16 tracks in the HMD will reduce clutter and eliminate the potential for missing information. Replacing "DT" with "D" for a designated track will reduce clutter and free up a character string. Using a symbol, such as "*" to replace the indication of "TUC", will not only reduce the amount of clutter in the display but will also eliminate the problem of omitting a character from the 5 character string aircraft type. This is illustrated by comparing Figure 8 and Figure 18. In the case of the friendly track with an aircraft type of "F-16" that is TUC'd and designated D3, all of the information and indications will be displayed in the upper window. This is true even if the aircraft type string has 5 characters instead of the 4 used in "F-16". Using the TUC symbol "*" to replace the "\" makes this possible.

CHAPTER 6: CONCLUSIONS

The research methods utilized in this study aided in identifying potential human factors deficiencies for systems that are in the design phase and aided in developing design improvement recommendations. Those design improvement recommendations should help reduce display clutter on the TN Search format and HMD, reduce the occurrence of omitted pertinent information on the SA and SA expanded formats, provide intuitive and standardized push button labeling for the “cease” command function, and provide information at a more appropriate level of detail on the CAS format.

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VITA

Thomas B. Heck was born in the Upper Peninsula of Michigan in 1974. He was raised in DeWitt, MI and graduated from DeWitt High School in 1992. He went directly to the United States Naval Academy and graduated from there in 1996 with a Bachelor of Science degree in Mechanical Engineering and received an officer commission as an Ensign in the United States Navy. He reported to Pensacola, Florida and began pilot training as a Student Naval Aviator. He completed flight school in 1999 at Naval Air Station Kingsville, Texas and was awarded his gold Naval Aviator wings. He then went on to Jacksonville, Florida and Virginia Beach, Virginia to train in the F/A-18 Hornet. From 2000 to 2003 he served in Strike Fighter Squadron One Zero Five (VFA-105) and completed two deployments while embarked on the USS Harry S. Truman aircraft carrier. He flew combat missions over Iraq in 2001 during Operation Southern Watch and in 2003 during the opening month of Operation Iraqi Freedom. He was selected to attend the United States Naval Test Pilot School and graduated from there in December of 2004 with class 126. Upon graduation he reported to Air Test and Evaluation Squadron Three One (VX-31) in China Lake, California. From 2005 to 2007 he worked at the F/A-18 Advanced Weapons Laboratory as the VX-31 MIDS and VMF project officer and test pilot for the F/A-18. He is currently serving his second operational tour as an F/A-18 pilot in Strike Fighter Squadron Eight Six (VFA-86) located in Beaufort, South Carolina.