NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

DECISION AIDS IN AIRBORNE COMMAND AND CONTROL PLATFORMS

by

Karl E. Hines

June 1998

Principal Advisor: Orin Marvel
Associate Advisor: Gary Porter

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1998	Master's Thesis

4. TITLE AND SUBTITLE
DECISION AIDS IN AIRBORNE COMMAND AND CONTROL PLATFORMS

5. FUNDING NUMBERS

6. AUTHOR(S)
Hines, Karl E.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

As a result of dramatic growth in the capabilities of C4I systems, commanders have an immense amount of information available to them. Increased bandwidths and improved speeds in our communications systems can overload our commanders with data. One solution is improved methods of presenting information to the commander.

The same advances that threaten to overload the commander with data provide a solution. Improved technology now allows us to present the information in an easily assimilated graphical, 3D or "picture" form. These new types of displays can present the information in an intuitive style that eases the commander's cognitive workload and speeds comprehension. Recent studies comparing different types of displays support this theory.

Because commanders in airborne command and control platforms require a detailed understanding of a three dimensional environment, they should adopt some type of 3D display. Perspective or 2½D displays are not perfect for absolutely every situation the commander will face; but the added understanding of the action, tactics and intentions of friendly and enemy forces demand its adoption.

14. SUBJECT TERMS
Decision Aids, Command and Control (C2), Display, E-2C Hawkeye, Three Dimensional Displays

15. NUMBER OF PAGES
98

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFI- CATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

Approved for public release; distribution is unlimited.

DECISON AIDS IN AIRBORNE COMMAND AND CONTROL PLATFORMS

Karl E. Hines

Lieutenant, United States Navy

B.S., United States Naval Academy, 1990

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
(Command, Control and Communications)

from the

NAVAL POSTGRADUATE SCHOOL
June 1998

Author: ______________________
Karl E. Hines

Approved by: ______________________
Orin Marvel, Principal Advisor

____
Gary Porter, Associate Advisor

____
Dan Boger, Chairman
C4I Academic Group

ABSTRACT

As a result of dramatic growth in the capabilities of C4I systems, commanders have an immense amount of information available to them. Increased bandwidths and improved speeds in our communications systems can overload our commanders with data. One solution is improved methods of presenting information to the commander.

The same advances that threaten to overload the commander with data provide a solution. Improved technology now allows us to present the information in an easily assimilated graphical, 3D or ``picture'' form. These new types of displays can present the information in an intuitive style that eases the commander's cognitive workload and speeds comprehension. Recent studies comparing different types of displays support this theory.

Because commanders in airborne command and control platforms require a detailed understanding of a three dimensional environment, they should adopt some type of 3D display. Perspective or 2½D displays are not perfect for absolutely every situation the commander will face; but the added understanding of the action, tactics and intentions of friendly and enemy forces demand its adoption.

TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

This thesis investigates new and improved C2 decision aids for airborne tactical and operational commanders. The specific focus is on the E-2C Hawkeye.

As a result of dramatic growth in the capabilities of C4I systems, commanders have an immense amount of information available to them. Increased bandwidths and improved speeds in our communications systems can overload our commanders with data. One solution is improved methods of presenting information to the commander.

Among other things, a C2 system should present the information in an easily assimilated form. Displays should present the information in an intuitive style that eases the commander's cognitive workload and speeds comprehension.

In fact, as speeds and volumes of information of data continue to increase, the limiting factor of the Hawkeye as a C2 platform becomes not the human but the human machine interface.

Depictions in science fiction movies and novels of humans with a receptacle in their head through which the computer and the human communicate would be the ideal HMI. Our goal is to become as close to this ideal as possible. All calculations and conversions that do not require human judgment or decisions are done by the computer. This greatly reduces the cognitive load of translating and manipulating less processed information and data. By doing

this much, more of his mental ability is available to maintain situational awareness and make key tactical and operational decisions. The focus of C2 system designers should be on how to more efficiently instill understanding, not improve how to show data or information.

In that aim, the use of text should be limited. A picture says a thousand words is still true today, and recent studies in cognitive analysis shows evidence for why this is true.

As computers become faster and more powerful, we can depict the scene graphically, even in three dimensions, and instantly provide the user a firm understanding of his environment.

Recent experiments comparing perspective and other forms of three dimensional displays with current two dimensional displays show better performance with the 3D displays. A greater reliance on the graphical representation may allow the user to manipulate the picture, for example, use a different viewpoint, take a vertical or horizontal slice, rotate the world slowly and perhaps back and forth to glean more detailed relative information. For the more rare case of highest accuracy, the text-based information can still be viewed. The key is that the user has the option of using the more easily digestible picture and resorting to text only when necessary. Omitting the pictorial capability because it lacks exactness for specific tasks robs the user of understanding in cases where text is not necessary, or the picture is more quickly and easily assimilated into situational awareness.

The results of this thesis should convince the operators of C2 platforms that the three dimensional display is the best choice now in the evolution towards the ideal HMI.

The following is a list of assumptions made:

- Speed and bandwidth increases will continue to provide more and more information to commanders.
- Sensor sophistication and capabilities will continue to improve resulting in a greater amount of, and more detailed, information.
- Weight and space restrictions on airborne C2 systems will persist.

Joint Pub 6-0 states ``..information should be relevant, essential, timely and **in a form that warriors can quickly understand and can use to act.**''

Because commanders in airborne command and control platforms require a detailed understanding of a three dimensional environment, they should adopt some type of 3D display quickly. Perspective displays are not perfect for absolutely every situation the commander will face; but the added understanding of the action, tactics and intentions of friendly and enemy forces demand its inclusion.

ACKNOWLEDGMENTS

I would like to thank Professor Orin Marvel for his guidance as my thesis advisor. His knowledge and enthusiasm were essential. Professor Gary Porter's assistance was also invaluable. Others without whom this thesis would not have been possible are Professor Susan Hutchins, Jeff Morrison of SPAWAR San Diego, Eric Olsen and others at Monterey Technologies and James Broyles of SPAWAR San Diego.

I would also like to acknowledge the outstanding support of my family.

I. INTRODUCTION

This thesis will investigate new and improved C2 decision aids for airborne tactical and operational commanders. The specific focus will be on the E-2C Hawkeye.

A. DEFINITIONS

Since the term ``decision aid'' is in the title, the author will address the definitions of this term, and others, immediately. Complete agreement on the use and definition of these terms across many professions and backgrounds is difficult to reach. The author selected the most widely accepted definitions or those most applicable to this thesis. ``Decision aid'' refers to a system designed to assist the decision maker by presenting information to the user in a way to ease or speed his understanding. The term Human Machine Interface (HMI) is a generic term for any interface between a human and a machine, not limited to displays. Some other forms of an HMI are a keyboard or mouse. A display is a device that gives information in a visual form, as on a cathode ray tube. (The American Heritage Dictionary, 1982)

Before describing the problem we must distinguish between data, information and understanding.

``Information is data collected from the environment and processed into usable form. Combining pieces of information with context produces ideas or provides knowledge. By applying judgment, knowledge is transformed into understanding.'' (Joint Pub 6-0, 1995) See Figure 1.

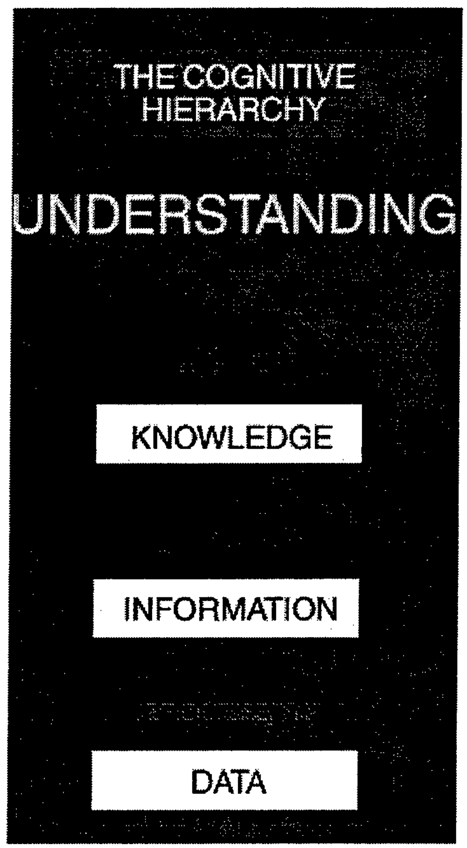


Figure 1 Transition of Data to understanding (Joint Pub 6-0, 1995)

The term ``Situational Awareness'' (SA) will be used a fair amount in this paper and a simplified definition for SA is one's level of understanding of the surrounding environment.

Situational awareness can be broken down into specific tasks that must be done at any given time. A measure of SA is whether or not the individual performs them and how well he performs them. The list of tasks are (Shrestha et al, 1995):

- maintain an accurate perception of the surrounding environment(both internal and external to the unit the individual is on)
- identify problems and/or potential problems
- recognize the need for action
- note deviations in the mission
- maintain awareness of tasks performed.

B. BACKGROUND

As a result of dramatic growth in the capabilities of C4I systems, commanders have an immense amount of information available to them. Increased bandwidths and improved speeds in our communications systems can overload our commanders with data. One solution is improved methods of presenting information to the commander.

Among other things, a C2 system should present the information in an easily assimilated form. Displays should present the information in an intuitive style that eases the commander's cognitive workload and speeds comprehension.

The author will discuss and focus on tasks or decision aid capabilities that have not been addressed in planned updates, or even visions, of the Hawkeye in 2005 or 2010. Much of the focus in upgrades and follow-on aircraft is on a more powerful computer system while too little attention is paid to the interface between the computer and the user. In fact, as speeds and volumes of information of data continue to increase, the limiting factor of the Hawkeye as a C2 platform becomes not the human but the human machine interface.

Depictions in science fiction movies and novels of humans with a receptacle in their head through which the computer and the human communicate would be the ideal HMI. Our goal is to come as close to this ideal as possible. The assumption in this case, is that along the input medium the raw data is transformed to an ideal form that provides instantaneous understanding for the human. All calculations and conversions that do not require human judgment or decisions are done by the computer. This greatly reduces the cognitive load of translating and manipulating less processed information and data. By doing this much, more of his mental ability is available to maintain SA and make key tactical and operational decisions. The focus of C2 system designers should be on how to more efficiently instill understanding not just to improve how to show data or information.

In that aim, the use of text should be limited where possible. A picture says a thousand words is still true today and recent studies in cognitive analysis shows evidence for why this is true. The standard range and bearing method of describing a track's position is an attempt to paint a picture with text. As computers become faster and more powerful, we can depict the scene graphically, even in three dimensions, and instantly provide the user a firm understanding of his environment. An example of current efforts in this area is Force Threat Evaluation and Weapons Assignment (FTEWA).

A greater reliance on the graphical representation may allow the user to manipulate the picture, for example, use a different viewpoint, take a vertical or horizontal slice, rotate the world slowly and perhaps back and forth to glean more detailed relative information. For the more rare case requiring the highest accuracy and ample decision time, text-based information can still be viewed. The key is that the user has the option of using the more easily digestible picture and resorting to text only when necessary. Omitting the pictorial capability because it lacks exactness for specific tasks robs the user of understanding in cases where text is not necessary. This is because the picture is more quickly and easily assimilated into situational awareness.

Current systems and those being designed are incorporating more graphics than before. The step needed now is to demote the text-based data and information to supplementary screens and further improve pictorial representations especially three dimensional displays for use as the primary tool of the commander.

Some may argue that the bird's eye view screen used in most DOD command centers and ships, shore and aircraft is pictorial and sufficient. Bird's eye (2D) displays are rudimentary and require a large amount of cognitive resources to keep track of associated text-based information (especially altitude) not displayed graphically to maintain SA.

C. SCOPE

This thesis will investigate new and improved C2 decision aids for airborne tactical and operational commanders. The specific focus will be on the E-2C Hawkeye. Chapter II will give background information on the E-2C and its missions. In Chapter III, Tactical Decision Making Under Stress (TADMUS) will be described and analyzed for its potential contributions to a solution for the E-2C. Monterey Technologies' New Millennium Electronic Surveillance Interface System (NEMESIS) is a NAVAIR supported effort to hypothesize about the future E-2C CIC. This project will be described and analyzed in Chapter IV.

Chapter V will provide a background on three dimensional displays and analyze applications to the E-2C CIC. As a result of this discussion, conclusions and recommendations (Chapter VI) will be made for program offices of the E-2C and other airborne C2 platforms such as AWACS, ABCCC and JSTARS. The discussion on 3D is included to support the author's proposal to increase the use of three dimensional displays in airborne command and control platforms.

This thesis will not include an experiment nor create data. Results will not address nor will they likely be directly applicable to cockpit displays. Reference may be made to artificial intelligence or neural networks, but they will not be discussed in detail in order to limit the breadth of work. Because this thesis' intended audience is operators of command and control platforms, and those that acquire these systems, a focused discussion of the challenge is presented. This audience is familiar with DOD missions and systems and therefore a minimum of descriptions of these terms will be used.

The results of this thesis should convince the operators of C2 platforms that the three dimensional display is the best choice now in the evolution towards the ideal HMI.

D. ASSUMPTIONS

The following is a list of assumptions made:

- Available speed and bandwidth will continue to increase and thus will enable more and more information to be provided to commanders.
- Sensor sophistication and capabilities will continue to improve resulting in a greater amount of, and more detailed, information.
- Weight and space restrictions on airborne C2 systems will persist.

II. E-2C HAWKEYE BACKGROUND INFORMATION

A. CURRENT DISPLAYS IN THE CIC OF THE HAWKEYE

Why does the crew in the E-2C need an improved HMI? What is it about the job they do and the tasks they complete in a normal mission that require improved displays? The Combat Information Center Officer (CICO) and his crew as a team in a tactical or operational command and control platform must make decisions within severe time restrictions and while being bombarded with information and requests from numerous sources. The current displays used in the CIC of the E-2C are antiquated and do not support naturalistic decision making. Some readers that are not familiar with the E-2C mission may suggest that applications such as Global Command and Control System (GCCS) and the Common Operating Picture (COP) or Common Operating Environment (COE) could be adapted for use in the E-2C CIC. These applications or standards are sufficient at higher levels of command but wholly unsuited for the operators in the E-2C Hawkeye. GCCS and the COP lack the level of detail and responsiveness required.

B. E-2C HAWKEYE DESCRIPTION

A brief description of the E-2C Hawkeye follows. If further details are desired, references such as Jane's or the E-2C NATOPS manual would be a good start for a more detailed description.

An E-2C could be described simply as a miniature AWACS that flies from an aircraft carrier. This description is not completely accurate, but provides a general understanding. Dimensions of the aircraft are provided in Figure 2.

Aircraft Data

- Combat Weight..........48,000 lb.
- Wing Span..................80' 7''
- Length........................57' 6 3/4"
- Rotodome Diameter...24'
- Two Turbo Prop Engines
- About 4-5 hr. On-Station Time
- Max Speed.................300 KIAS

Figure 2 Aircraft Data

A broad brush description of systems on board is a necessary prelude to discussing capabilities and missions.

The B-band radar uses a rotating antenna depicted in Figure 3 and provides a range of about 300 miles for 360 degree coverage of the air and surface. Also incorporated in the dome with the radar antenna is the IFF antenna.

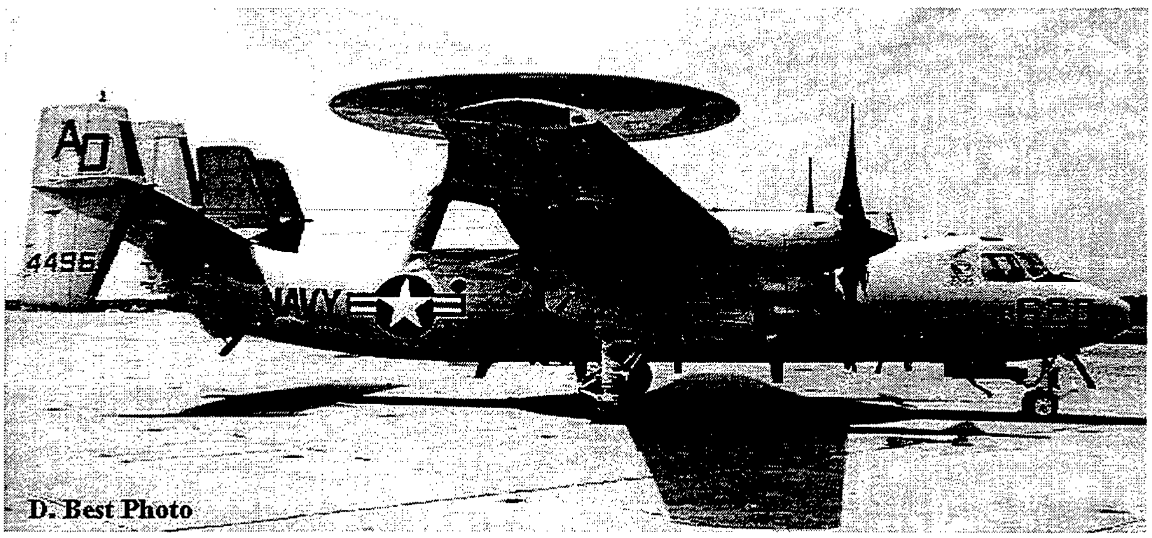


Figure 3 Grumman E-2C Hawkeye

The communications gear includes six UHF capable radios, three of which are also VHF and Havequick capable. Two of these six are also Link-11 and UHF relay capable. One is Link-4 capable and three are secure voice capable. The aircraft is also equipped with two HF radios which can support plain and secure voice and Link-11. A recent addition to the communications suite is a SATCOM radio. Some E-2Cs in various steps of upgrades may have additional capabilities like Link-16 and Cooperative Engagement Capability (CEC).

Another system on board is the Passive Detection System (PDS). This system is operator intensive but covers a large range of frequencies. Proposed systems for future version of the E-2C or Airborne Early warning (AEW) version of the Common Support Aircraft (CSA) are Tactical Receive Equipment (TRE) and an Infra-Red Sensing system (IRST).

C. E-2C MISSIONS

The missions performed are carried out primarily by the three operators in the small CIC.(Figure 4) These mission include Command and Control(C2), Anti-Air Warfare (AAW), Airborne Early Warning (AEW), Strike Warfare (STW) which may include Battlefield Air Interdiction (BAI), Airborne Command Control and Communication (ABCCC), Close Air Support (CAS), Electronic Support (ES), Surface Warfare (SUW), Airborne Command Element (ACE), Undersea Warfare (USW), Search and Rescue (SAR), Counter Drug (CD) and Hummer Controlled Approach (HCA) - a method to use the E-2's radar to get aircraft aboard the carrier in the event of catastrophic damage to the ship's radar systems.

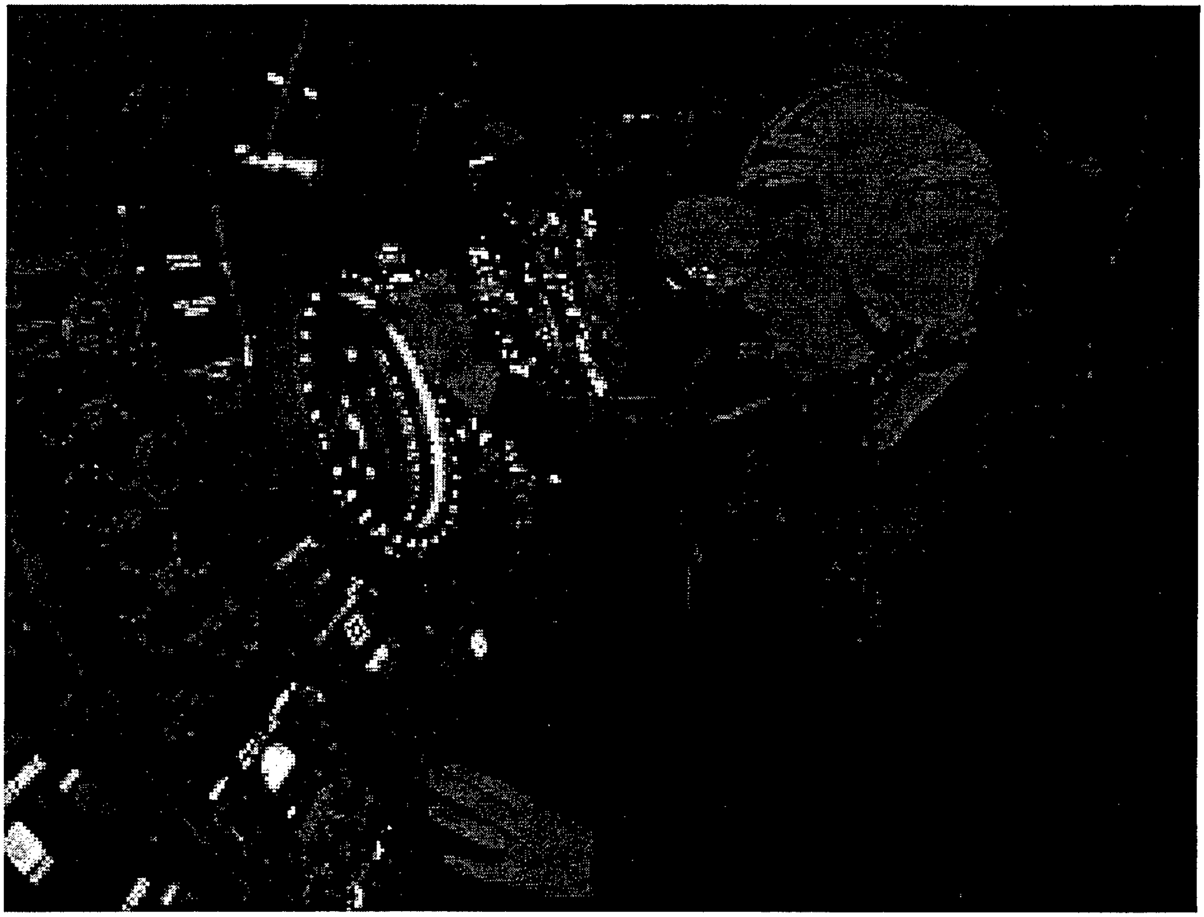


Figure 4 E-2C CIC

The crew normally performs many of these missions simultaneously during a single flight. They may also have to rapidly change missions in reaction to events affecting the task force. Additional missions are added to their load when another C2 is unable to perform their assigned mission. The crew is very busy and it is obvious that they need decision aids. As an E-2C commander, the author knows first hand how important a 3D display would be.

D. COMMUNICATIONS

A description of a representative flight from a carrier follows. The terms Radar Operator (RO), Air Control Officer (ACO) and CICO usually refer to the seat or scope position in the CIC, but do not always imply the job done by the person sitting at that station. The CICO, as the mission commander, runs the CIC. He must supervise newer Naval Flight Officers (NFOs) who are controlling multiple aircraft searching for and identifying surface contacts. The CICO must also request and provide information to the ACO who is controlling four F-18s on Combat Air Patrol (CAP) or running intercepts. Communication amongst the three team members in the CIC is done over the Internal Communications System (ICS). Other methods of communicating among the three are the use of functions and symbols on their screens, gestures, and even poking/grabbing in extreme cases. The pilot and copilot also communicate to the CICO and CIC via the ICS. They might request updates on stationing and ownship traffic, as well as inform the CICO of any factors that could affect the mission or time on station. This is not an all-inclusive list of ICS communications but gives a representative case of communications within the airplane.

Interaction with platforms outside of the aircraft by the CICO include monitoring information sent out on data links such as Link 4, Link 11, and/or Link 16. Because this information is generated and sent mostly automatically, via the computer and software, any problem like a dropped track on Link 11 or a fighter symbol drifting away from the actual track it represents must be fixed quickly with operator inputs. The CICO would also be talking with the air warfare commander of the task group usually referred to as AW on a dedicated AW net. The CICO is also coordinating with other Airborne C2 platforms from not only the US but NATO and other countries.

When overloaded, the CICO often asks the copilot to monitor a net for him. The copilot acts as a human filter and relays only pertinent information via ICS to the CICO. The CICO may sporadically or as required listen to the AIC as a way of updating himself on how they are progressing and to coordinate critical radar coverage with the pilot or copilot. The SATCOM radio allows direct links with higher echelons of command which often increases requests and demands for information and explanation. The CICO monitors the RO's net and notes his performance for debrief after the flight.

E. ACTIONS

To highlight the tasks performed by the CICO the same example flight from the previous section will be used. This time the example is presented chronologically. Immediately upon entering the aircraft the CICO begins assessing the status of the aircraft and systems by gathering information from the Radar Operator, Air Control Officer, and his displays. The CICO also exchanges information with the pilots providing them essential information on the status of specific systems, while getting updates from them on the aircraft and flight deck. Passdown information on current situations is also received from other airborne C2 platforms including another E-2 coming off station. This information is used to update or change information briefed prior to manning up.

System setup is done all the while. Radios are tuned to pre-briefed frequencies, the radar options are selected, and personal scope preferences entered. Specific information pertinent to the current mission (such as geographic references, aircraft identities, and data link setup) is also entered and displayed. As launch approaches, the CICO focuses more on the aircraft and the pilot's incoming information. Most of the radio communications just prior to launch will be incoming and significant changes are noted. Before launching, a final ``go'' system status is required, and choices must be made in seconds that could result in cancellation of the flight.

Immediately after the wheels leave the deck the CICO begins talking to the ship and pilots. Climbing up to station the CICO assists the pilots with traffic avoidance. As the sensor picture comes to life and tracks fill the scope, all operators begin sorting out who is who by fusing information from the sensors, radios, datalinks, each other, and information from the preflight brief. With a firm grasp on the tactical and operational picture for 300 miles in all directions from his airplane, the CICO begins to coordinate his mission with other commanders in the area. These could include commanders of air, surface, sub-surface and electronic warfare. As a player in these missions the CICO must divide his attention amongst distinctly different missions. The CICO provides assistance to his controllers by fixing or adding information on their scopes. He and his controllers must be in synch for their highly efficient smart push, user pull information exchange to be effective. Along with his primary duties, he must help the RO and ACO.

All three operators are continuously noting and reporting new and unknown contacts and immediately taking action to help identify them. The CICO must also commit part of his attention to looking at the tracks as they relate to his own aircraft. In addition to looking at tracks and how they might affect the CAP and SSC aircraft controlled by his operators, he must also consider these tracks and any other's impact on the carrier, or other ships of the task force.

F. A SIMPLIFIED EXAMPLE OF CURRENT SYSTEM SHORTCOMINGS

The main displays in the E-2C's CIC present a bird's eye view, 2D perspective. A major drawback of this type of display is a lack of visual altitude cues. Because only two dimensions are used, the third dimension (altitude) is relegated to alpha-numerics and usually displayed in another region or screen when a track is selected. To demonstrate how this shortcoming adversely affects the human operator let us consider the radically simplified case of three tracks converging at one spot on the bird's eye view screen. The CICO can see this immediately without having to check text based course and speed readouts because of the speed leaders on each track. At a glance he can see from the direction the leaders are pointed that they are all headed toward the same point in the two dimensional world depicted on his screen. He can also tell from the size of the speed leaders roughly, how fast each are going and conclude that all will reach the same point at the approximately the same time. This is an example of using graphics to more efficiently convey information to the human. This same idea can be applied in still more ways with similar favorable results. We can know at a glance their motion relative to each other (in 2 dimensions). Standard Naval Tactical Data System (NTDS) symbology tells us that one is friendly, one unknown and one hostile. Is the friendly aircraft going to run into the unknown aircraft? In order to decide, the operator must determine the altitude of each. To get this third dimensional information he hooks the friendly aircraft, reads the alphanumeric readout and stores this string of numbers in short term memory. Next he hooks and reads the altitude of the unknown aircraft, and compares this with that of the altitude of the friendly aircraft. While doing this, what did the hostile aircraft do? Did an important call on a radio distract him? Has the hostile aircraft maneuvered to a threatening position on the friendly or unknown aircraft?

To complicate the scenario slightly, consider the possibility of the hostile aircraft performing an air to surface missile launch tactic against a nearby ship in the task force? What was his flight pattern, and altitude? The displays used in the E-2 CIC are not designed to display this information in an easily assimilated way. Specifically, the third dimension which is so essential to understand this situation is represented with text on a separate screen. It would be extremely difficult without any distractions at all, no less all the CICO is confronted with, to construct a mental image of the flight path in three dimensions. Any number of three dimensional techniques could do this extremely demanding task for the operator and provide him with the end result for his use at a glance. Freeing the CICO of this mentally taxing task allows him to focus more of his efforts on tactics and strategy which require human judgment. A simple analogy is trying to do long division in your head instead of on a calculator.

G. EXACT HARDWARE DETAILS

In the actions portion of this chapter the author purposefully limited references to specific keystrokes, or buttons, pushed by the commander at his station. The reason for this is to avoid addressing current limitations in hardware and software that either have or will be fixed in updated versions of the Hawkeye. The ideas proposed in this paper transcend the buttons and keys.

The decision aid in the E-2 CIC should be rethought from the ground up to minimize the cognitive load of the commander and maximize the transfer of information through the HCI. Naturalistic Decision Making (NDM) principles and three dimensional depictions are two tools that could enable this. These tools speed the commander's decision cycle or OODA Loop (see Figure 5) and free his mental capacity for decisions that require judgment and human intelligence.

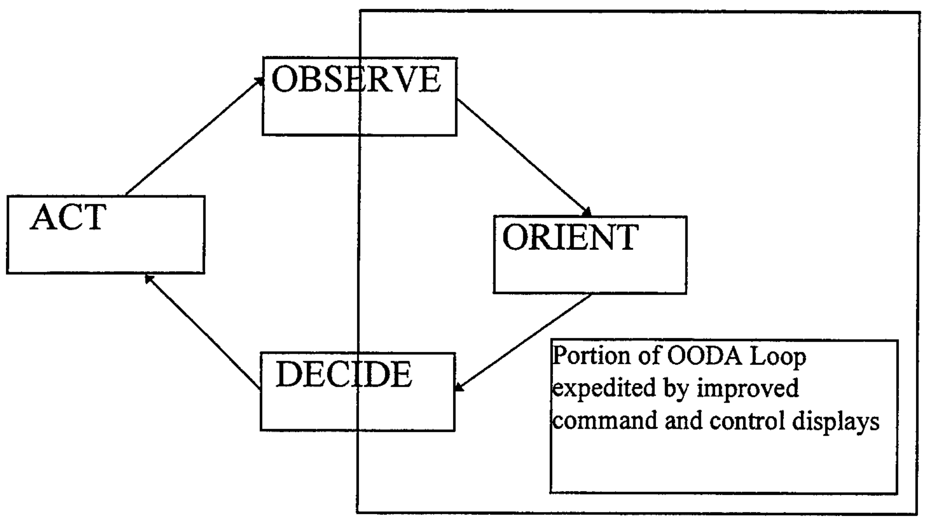


Figure 5 OODA Loop

III. TADMUS

This chapter will briefly discuss the background and theory of TADMUS. Then, TADMUS DSS-2 modules are presented along with the benefits each provides to the commander. Finally, these modules are presented from the perspective of benefits they would provide to an E-2C Hawkeye crew.

A. BACKGROUND AND THEORY

The TADMUS project was born from a recent problem and a newly recognized possible solution. The recent problem was a pair of mishaps by the US Navy involving decisions that produced horribly wrong outcomes. First, the USS Stark did not engage an aircraft that eventually shot an Exocet missile at it. The Commanding Officer and the crew in CIC did not believe the aircraft was a threat. Second, the USS Vincennes engaged what it thought was a hostile inbound aircraft when in fact the aircraft was an Iranian Airbus. The hope was to develop a decision support system that would prevent similar incidents in the future.

Researchers, analyzing the decision making processes from these incidents, recognized a deficiency in the systems designed to aid the operators in the CIC. These systems were designed with an outdated view of the human cognitive process. ``Traditional'' decision theory suggests that the commander gathered as much data as possible, developed hypotheses or options, and selects the optimal solution based on situational key performance parameters. This form of decision making is extremely time intensive and requires protracted calculations by the decision maker.

New research in decision making has produced a new hypothesis on how commanders decide on a course of action. Naturalistic Decision Making (NDM) shows that experienced decision makers use a different technique to provide solutions to problems that are time limited and entail some uncertainty. According to NDM, a person with considerable experience in a dynamic environment quickly assesses the situation, classifies it, and provides a solution based on his memory of previous similar situations, applied solutions and outcomes.

This new view of decision making and the recent tragic events with the Stark and Vincennes led researchers to design a new decision aid for the commander. The product of the TADMUS program is a decision support system (DSS) that supported the commander's (newly understood) naturalistic decision making process.

Two specific tenets of NDM used to develop DSS-2 are (1) feature matching and (2) story generation. (1) ``Feature matching involves an organization of memory, or `schemas,' and information processing where decision makers use their previous experiences to asses a situation and identify promising actions.''(Noble, 1989) (2) Story generation is ``employed when the body of evidence relevant to a decision is large, complex, and the implications of its components are interdependent.''(Hutchins, 1996)

Naturalistic decision making principles of feature matching and story generation are incorporated into DSS in many ways. A key component of NDM and especially feature matching is the commander's situational awareness (SA). Though SA is not a new term to the military commander, decision support systems specifically designed to markedly improve SA through a better understanding of his decision process are. Current and previous systems tried to convey the ``picture'' to the operator; while feature matching provided the awareness of the absolute best depiction of the situation. The ``picture'' depiction was critically important because it contained the features the commander would try to match to memory of a similar scenario to produce a decision. Previously, traditional decision making designers thought providing the most information to feed all the theories and courses of action was paramount.

With the new revelations of NDM, the **importance** shifted to quickly instilling situation awareness so the commander could match it to a previous experience. Exact details were still provided and available, but the **importance** shifted from providing information to instilling SA quickly and accurately.

The researchers in the TADMUS program recognized the advantages of graphical presentation over text to speed and ease understanding. For a majority of uses, graphics ``reduce the amount of mental computation required to perform tasks and allow users to spend less time searching for needed information.'' (Larkin and Simon, 1987)

A specific example of the DSS taking advantage of graphics is the track history module of the DSS which uses templates of weapons envelopes of the ship as well as templates of potential weapons of threat tracks (Hutchins, 1996) (see Figure 6). With these templates the commander can instantly asses his own weapons against the potential hostile's. Without this module the commander would have to perform timely and mentally demanding information hunts, comparisons and calculations, while he is also busy doing other activities.

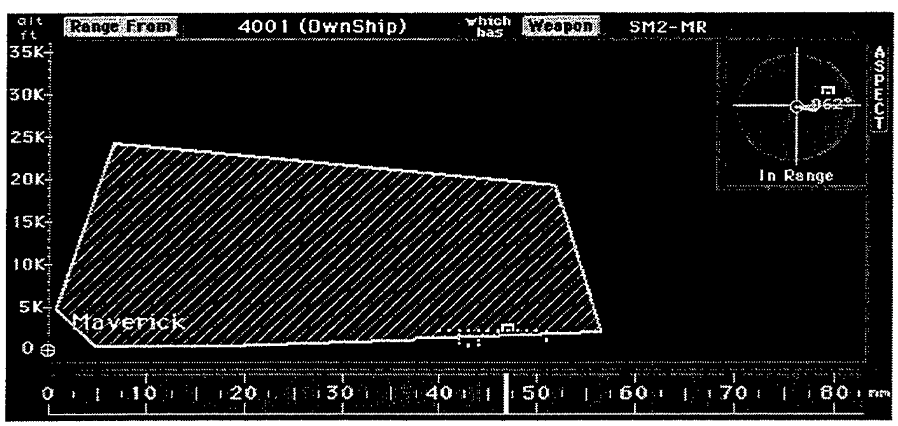


Figure 6 Track Profile module of DSS-2 (Morrison et al, in press)

B. DESCRIPTION OF TADMUS DSS VERSION 2.0 (DSS-2)

The TADMUS DSS-2's design is based on the results and feedback from DSS version 1 (DSS-1) and lessons learned from operating DSS-1. New considerations for DSS-2 were to fully integrate the geo-plot, use DSS-2 as both a primary and supplementary display vice strictly a supplementary display, touch-screen, rapid scaling, declutter tools and other technical considerations.

Cognitive task analysis provided the designers with a detailed understanding of a tactical commander's workload. The DSS was then designed to aid this specific workload. ``The prototype DSS was developed with the objectives of: (1) minimizing the mismatches between cognitive processes and the data available in the CIC to facilitate decision making; (2) mitigating the shortcomings of current CIC displays in imposing high information processing demands and exceeding the limitations of human memory; and (3) transferring the data in the current CIC from numeric to graphical representations wherever appropriate.'' (Morrison et al, in press)

Figure 7 is a representation of DSS-2. Next, the author will describe each of the components.

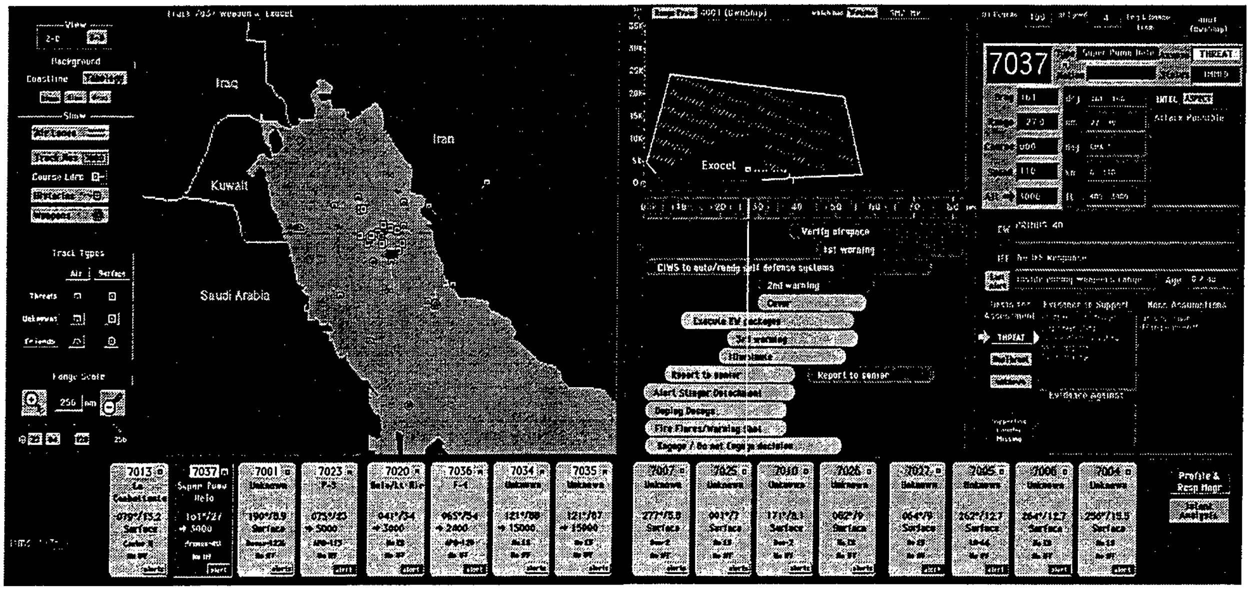


Figure 7 DSS-2 (Morrison et al, in press)

1. Geo-Plot

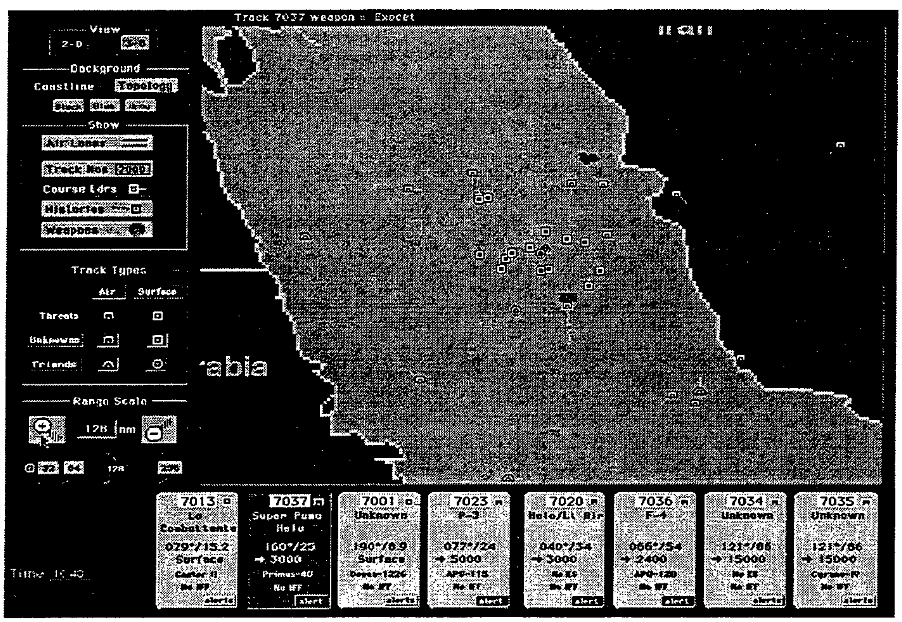


Figure 8 Geo-plot (Morrison et al, in press)

DSS-2 incorporates a geo-plot(Figure 8) which results in a smooth interface both visually and functionally. This geo-plot is similar to the current (2D) bird's eye-view used in most CIC environments. Functions which involve both a module and the geo-plot are seamless and intuitive. Also, significant new features are:

- *the use of variable coded NTDS symbology*
- *improved overlays*
- *improved scaling and declutter*
- *weapon envelopes that can be shown on units*
- *the ability to toggle the screen between symbols and track numbers (referred to as the track number toggle)*
- *the option of seeing the geo-plot in three dimensions (really 2½D - more on this in Chapter V).*

2. Multi-Character Read Out (CRO) and Access Panel

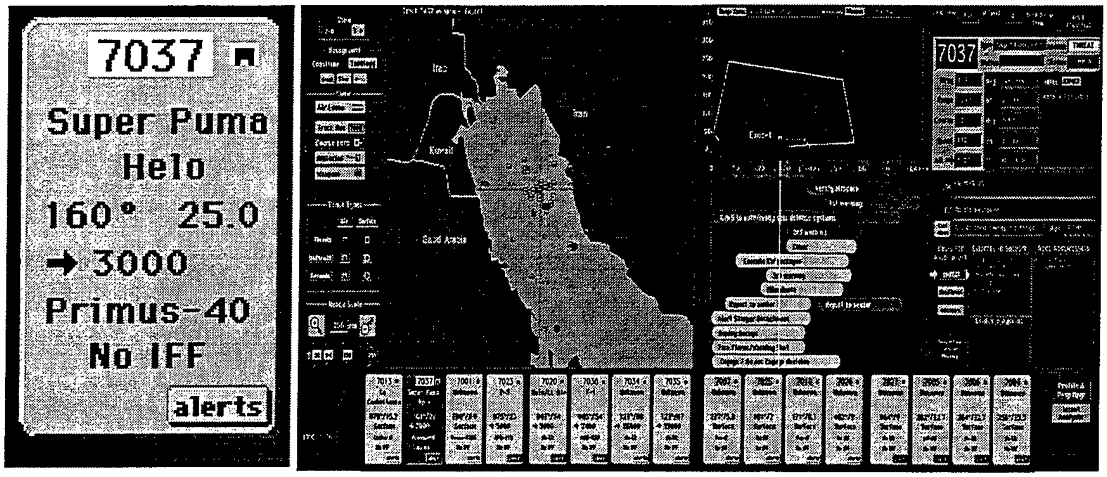


Figure 9 CRO and Multi-CRO Access Panel (Morrison et al, in press)

Along the bottom of the DSS-2 are summaries or CROs (Figure 9) of the highest priority tracks from left to right. The priority is determined by an amenable algorithm. Three significant aspects of this part of the system are: (1) As the priority of tracks change, the CROs move within the multi-CRO panel. This feature provides another cue for the user that a change in the situation might require his attention and or action; (2) The arrow gives an immediate indication of the direction of the track(inbound, outbound, ascending, descending); (3) Selecting a track in the geo-plot highlights that CRO in the multi-CRO access panel and vice versa.

3. Track Profile

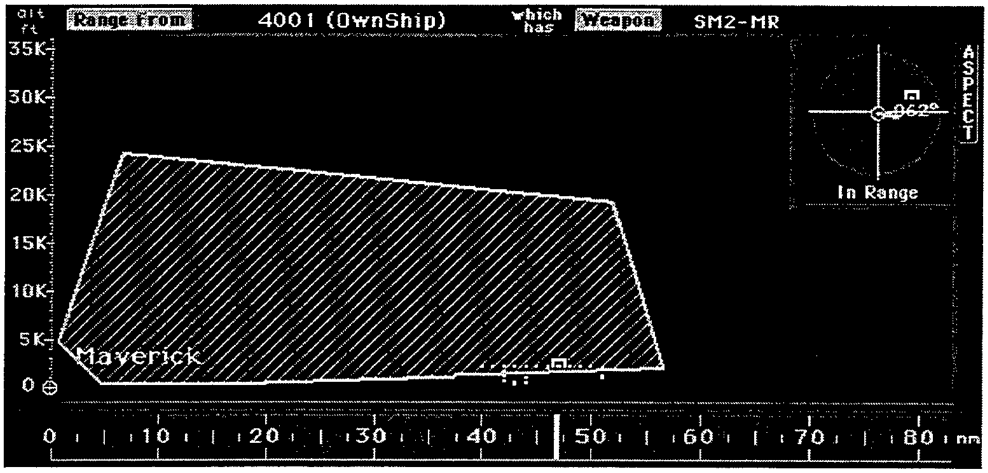


Figure 10 Track Profile (Morrison et al, in press)

The track profile module (Figure 10) allows the user to see at a glance, where the selected track is relative to the ship in range and altitude in the main screen and range and azimuth in the mini-screen inset in the upper right corner. Additionally, history dots or trailers are displayed to aid understanding of the track's flight profile and possible related weapons, actions or intentions. This panel allows the commander to evaluate the threat's potential weapon envelopes against his own ship. This threat can also be shown relative to another friendly unit and that unit's associated weapon envelopes. This feature aids deconfliction and coordination and thus improves the effectiveness of the battlegroup as a whole. This feature is obviously well suited for use by warfare coordinators and battle group commanders or any other higher level commander.

4. Response Manager

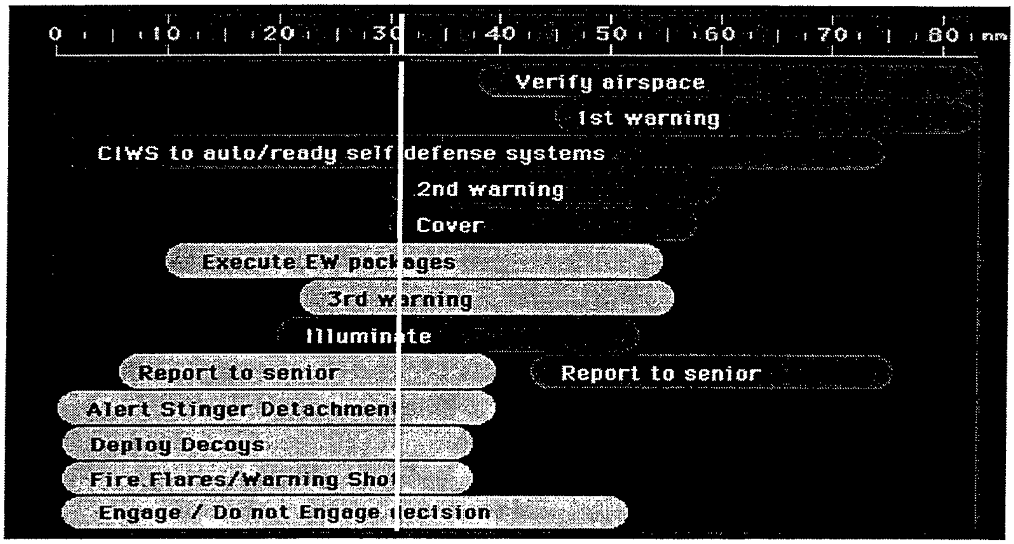


Figure 11 Response Manager (Morrison et al, in press)

The response manager (Figure 11) depicts necessary or recommended actions and responses relative to the selected track's range from own ship. This allows the commander to understand what responses he should be considering or doing and should have done as the tracks range(depicted by the white vertical line) changes. The responses and actions displayed reflect current doctrine, battle orders and/or ROE. The track's range is shown with a vertical line against a range scale across the top of the module. Responses are displayed below the ranges that they should be initiated and completed. The actions taken are a different color than those not yet taken. This module aids the commander in keeping track of what he has done, while cueing him as to what possible or recommended actions he should take.

5. Track Summary

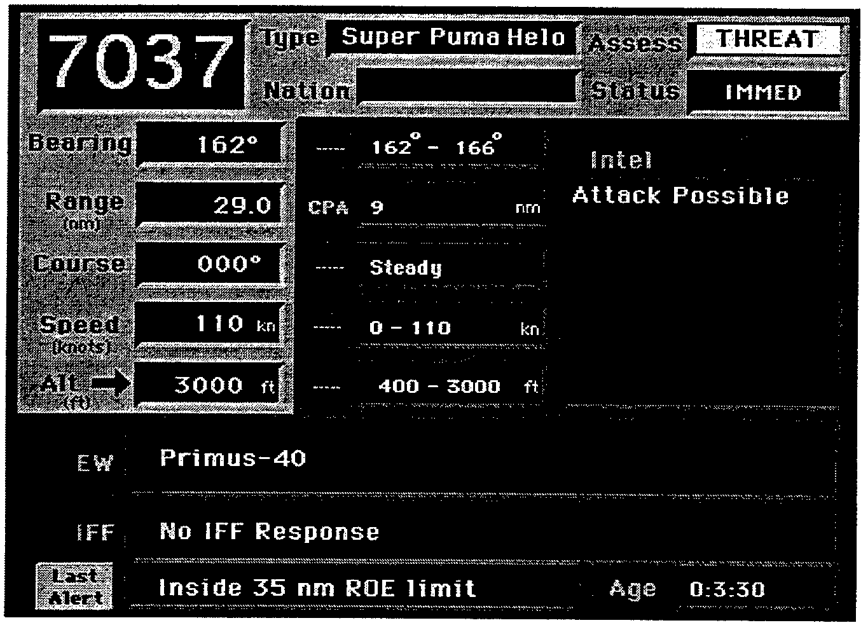


Figure 12 Track Summary (Morrison et al, in press)

The track summary module (Figure 12) provides detailed information about the selected track. It will incorporate amplifying data from various sources and summarize it all in one display window along with the standard parametric data (bearing, range, altitude, course and speed).

6. **Basis For Assessment**

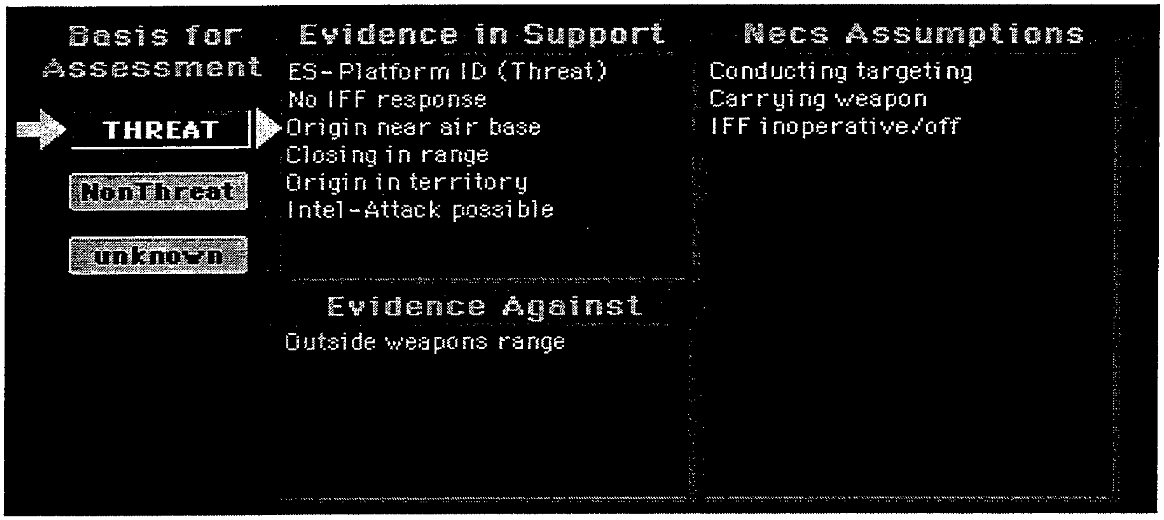


Figure 13 Basis for Assessment (Morrison et al, in press)

This module is more text intensive thus requiring more time to assimilate the information, but must be included and used whenever possible. The basis for assessment module (Figure 13) allows the commander to review the reasoning behind his assessments and classifications of tracks. The user can evaluate (1) evidence supporting his assessment; (2)evidence contradicting his assessment; (3) evidence supporting a different assessment; and (4) evidence contradicting that assessment. The module also lists the necessary assumptions needed for each assessment. This list helps the commander be aware of, understand and remember the necessary assumptions behind his assessment. This list of assumptions can also cue the decision maker to acquire information that might help him reduce or resolve any ambiguity or uncertainty and build confidence.

C. TEST RESULTS

Each of the modules in the DSS-2 was designed to specifically support the actual decision processes used by commanders. (1) Story generation is directly supported by the ``basis for assessment'', ``track summary'', and ``track profile modules''. (2) Feature matching or [Recognition-Primed Decision(RPD)] making is supported by the ``geo-plot'', ``response manager'' and ``track profile''. Other factors considered in the design of the modules are:

- bias errors(basis for assessment)
- short term memory (basis for assessment, geo-plot, response manager and track profile).

Also, the track summary module supports short term memory by enabling the system to maximize graphic, efficient displays; while keeping fused and concise information accessible for detailed analysis.

In all the modules of DSS-2 there is an effort to reduce the amount of raw data displayed. Well-processed and presented information is used to reduce the amount of cognitive workload placed on the commander.

A detailed description of the results of tests with DSS-2 are included in (Morrison et al, in press). A summary of their results follows.

The DSS was tested using AEGIS CIC experienced TAOs and COs. The testers found that with DSS, critical contacts were reported as tracks of interest much more often than without DSS. With DSS, teams were more likely to take defensive action against imminent threats. Another benefit of DSS was a reduced verbal communication flow. Individuals had more information readily available to them and did not need to verbally acquire information as much with DSS. Additionally, there were less requests for clarification information concerning track kinematics, emitter information and the tactical picture.

D. DSS APPLICATION TO E-2C CIC

In general, the TADMUS DSS was designed in response to the specific problem of AAW aboard AEGIS ships. That limits the usefulness of DSS-2. However, the principles of NDM, specifically ``story generation'' and ``situation assessment'' would greatly benefit display designs for most command and control applications.

Specifically each panel in DSS-2, Figure 7, would provide the following advantages to the E-2C crew:

1. Geo-plot

The geo-plot is similar to the current E-2C CIC display and features. The track number toggle is an ingenious and valuable capability. The three dimensional feature could prove much more useful for the Hawkeye crew. Because so much of their focus is in the air, the ability to see that environment in 3D has the potential to ease memory and processing demands while aiding RPD. In the E-2C CIC, altitude information is more essential and assessed more often than on a ship. Incorporating the alphanumerics of altitude into another dimension in the picture can produce significant improvements in the commanders SA.

2. Multi-CRO Access Panel

The multi-CRO access panel would be equally valuable to the E-2 commander for the same reasons as the ship commander. The priority algorithm may prove more difficult to implement because of the different missions performed. A simple fix for this problem would be an individual, operator-selectable algorithm based on the mission he is performing or personal preference.

3. Track Profile

Track profile would be useful for the E-2 to evaluate threats as they relate to various surface units and could be applied with some success to air to air engagements. A limitation of the track profile panel that could be addressed with some kind of 3D view is the ability to assess more than one track's profile simultaneously. The author can imagine the commander repeatedly viewing the profiles of a number of seemingly related tracks one at a time to try to determine if they are acting in concert (demands extremely high cognitive workload).

4. Response Manager

The E-2C commander may have less use for the response manager. It might be somewhat more useful if it could display ROE or tactics for different missions on demand. Implementing this might be difficult because of the multitude of missions performed and the fact that the E-2C often must consider threats as they relate to other units as well as itself.

5. Track Summary

The track summary window is similar to a supplementary screen currently in the E-2. This module assumes an improvement in data fusion from a wide range of sources and various levels of classification. The data fusion problem is being addressed and the potential classification problem is minimized in the Hawkeye by a universally cleared crew and restricted access to those that were in the plan when it took off.

6. Basis for Assessment

The basis for assessment window is an excellent application that may prove useful for the E-2 crew depending on crew loading and mission intensity. One hope for more use of this module during high workload flights would be that the time savings realized from the other benefits of the DSS-2 could be spent using this module. The reality is that most likely other more important tasks will use that time. During a busy flight, a best case scenario involves operators glancing at the module for confirmation or a gut check.

IV. NEMESIS

A. BACKGROUND

NEMESIS (New Millennium Electronic Surveillance Interface System) is the product of Monterey Technologies' (MT) work for a future E-2C CIC HMI. They were contracted to perform a complete review of all operator tasks and loading in the CIC. Then design an HMI for the E-2C from scratch. The focus was to apply the latest technology and principles in decision aiding to make the most effective HMI for the operators, not to improve the current displays.

MT created a top down task analysis, bottom up task performance description and an analysis of task loading. They relied heavily on input and recommendations from experienced E-2C NFOs throughout the analysis, design, testing and reviews. They incorporated lessons and recommendations from a prototype model.

Monterey Technologies' goal was to produce an ``HMI that allows NFOs to focus their energy and attention on situation evaluation and decision making, rather than on tasks required to simply operate the system.'' (Sharkey et al, 1997)

Unfortunately, one significant limitation of the NEMESIS design was not fully incorporating communications (voice, data and imagery). The requirement was not in the contract and would have required considerable additional resources and time to accomplish. MT acknowledged this limitation and included many recommendations in that area. However, by not including full communications in the analysis, the interface may result in less than optimum performance of the system and its operators.

The designers of NEMESIS make a critical distinction between most HMIs in use in today's military and HMIs for use with tactical systems; many military and commercial standards for HMI development **do not** apply to tactical systems. ``Tactical systems are real-time systems in which some mixture of computer automation and human decision making must: (1) maintain an awareness (SA) of the evolving situation, (2) continuously process multiple threads of diverse information, (3) respond to selected events rapidly and accurately, (4) to meet mission objectives, (5) while minimizing risk to human life and combat materiel.'' (Sharkey et al, August 1997)

B. DESCRIPTION AND ANALYSIS

The following condensed description of NEMESIS is based on the design guides found in the final report. (Sharkey et al, August 1997)

The NEMESIS display surface is depicted in Figure 14.

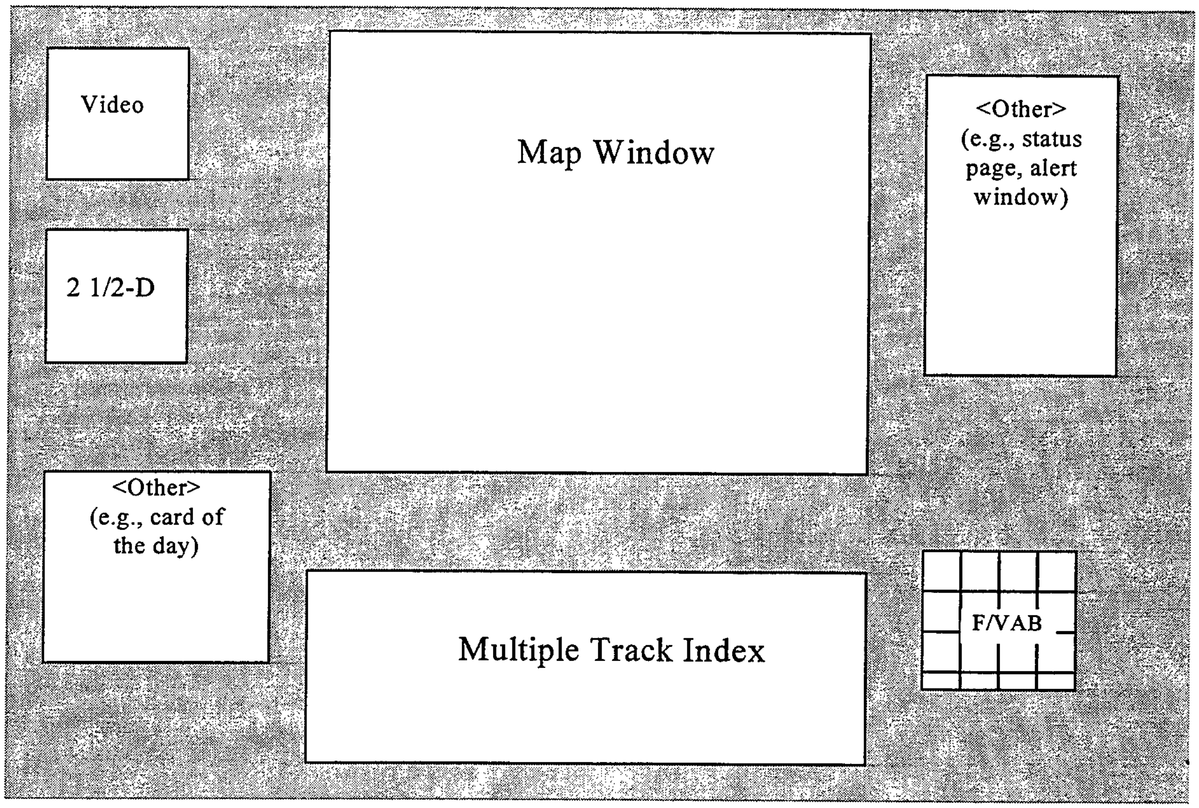


Figure 14 NEMESIS Display Surface (Sharkey et al, 1997)

``Key features of NEMESIS include(Sharkey et al, August 1997):

- A large (34 in wide by 24 in tall; 816 sq. in.), flat panel display
- A display area dedicated to PDS contacts
- A display area dedicated to contacts of interest outside the current map display

- A touch screen capability allowing use of a finger or stylus in lieu of lightpen
- Support for multiple, redundant cursor control devices (joystick, trackball, mouse)
- Plan and 2½-D map displays
- An advanced hooking algorithm
- A Multiple Track Index (MTI) allowing NFOs access to all raw and fused track data
- Natural language voice recognition & synthesis
- A system voice-reply capability
- Automated monitoring and alerting.''

The following sections describe the details of NEMESIS.

1. Variable Action Buttons (VABs) & Fixed Action Buttons (FABs)

Unlike many non-tactical HMIs pull down menus would be too time intensive to use repeatedly. For those actions performed often and in time-compressed situations experience shows FABs and VABs have proven most efficient.

FABs represent operations required in almost all scenarios. These buttons would not change and would be accessible at all times. The VABs are a set of buttons that allow the user to make a breadth and depth of selections. Figure 15 is an example of commands that might be accessed by VABs.

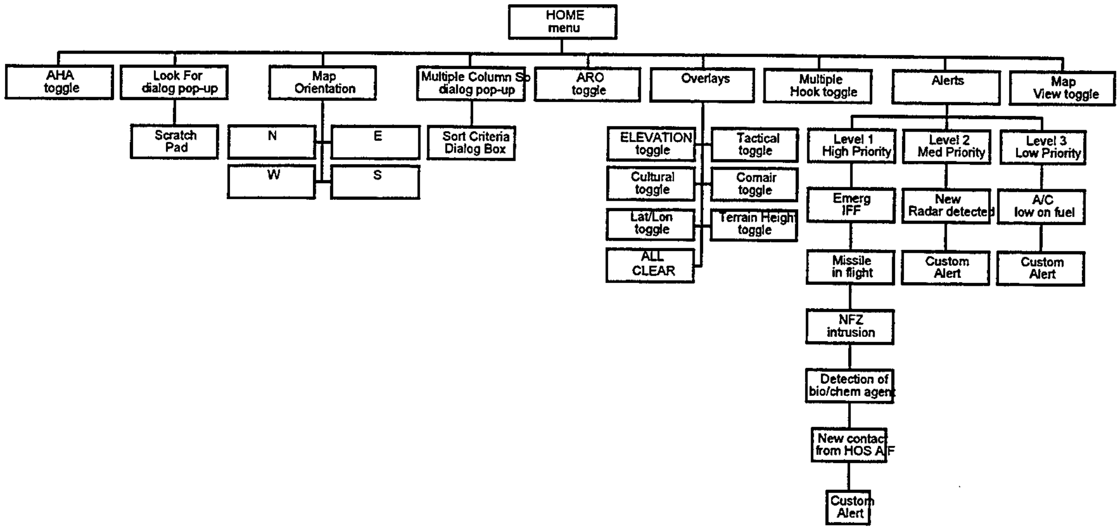


Figure 15 Example of Commands Accessed by VABs (Sharkey et al, 1997)

Figure 16 is an example VAB layout that changes map orientation. Selecting the Map Orientation VAB the user would then see the VABs change to North, South East or West. The other spaces would be blank. Selecting the VAB for South would then change the orientation of his map display. VABs and FABs must be iteratively designed with the users to be most effective.

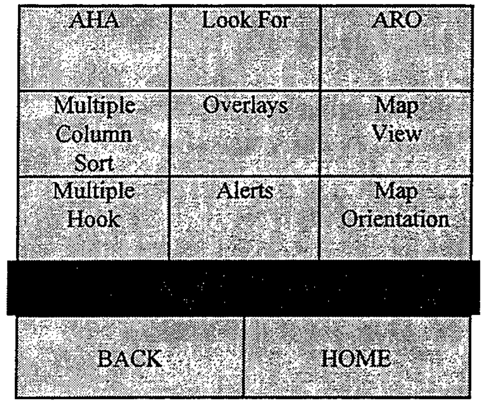


Figure 16 VAB Layout (Sharkey et al, 1997)

2. Map Display Window

The map display is the primary focus of the commander. This picture gives him the majority of his situational awareness. Functions and other windows are used to fill in information or resolve questions.

Dr. Glenn Osga's (Osga G. and Keating, R., 1994) research has provided information on optimum gray coloring of land and sea. NEMESIS utilizes his findings as the default, but allows qualified users to choose other colorings. NEMESIS uses contrasting pixels to represent the shoreline with the land appearing raised relative to the sea.

Prelook is a function that provides a melding of the information in the MTI with those on the map window. This function will display a select number of pertinent fields from the MTI whenever a track is selected for prelook.

The Association Read Out is a dramatic improvement of a current capability of the E-2C. This read out (Figure 17) displays intercept information specific to designated intercepting tracks (usually aircraft intercepting another unit including tanking).

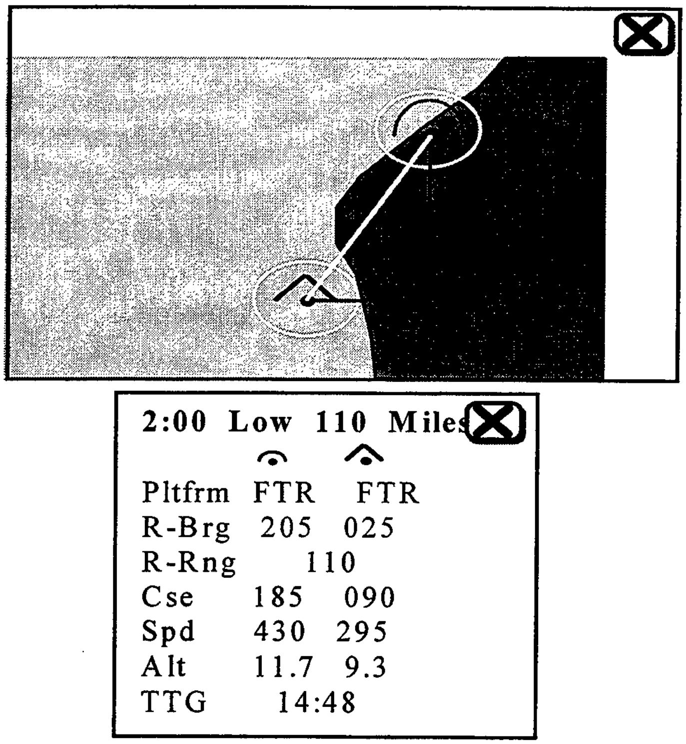


Figure 17 ARO w/ Intercept Page (Sharkey et al, 1997)

A declutter feature is included for congested areas of the screen. Current displays in the E-2C CIC only allow the user to select a smaller scale to better see a cluttered group. The major drawback of the current method is that when you change the scale of the display you lose the larger picture. (The windows style of child windows is an obvious and easy COTS solution.) The zoomed window also includes an abbreviated version of the MTI for those tracks in the declutter window.

3. Multiple Track Index

Figure 18 is a generic example of the standard MTI. Like TADMUS, NEMESIS fully integrates the MTI with the map. Selections and functions done in one window are reflected in the other and vice versa. It is immediately obvious that the MTI contains more information than the DSS multi-CRO display. Whether this is better is debatable.

The CRO's allow a quicker summary of information without overloading the user with text. The altitude arrow represents a key piece of knowledge not readily attained from the MTI. The priority algorithm of the multi-CRO display would help alert the user of changes in status and reduce his cognitive load.

However, the MTI is specifically designed for the E-2 and the CRO was designed to function for an AEGIS in AAW mode. The multitude of missions and scenarios the E-2 is involved in would make the processed knowledge displayed in the CROs and priority algorithms difficult to implement if not impossible. The next best thing to do, which NEMESIS does, is to present the information in a familiar form (spreadsheet) and allow rapid processing via sorts and other functions. The MTI will be more time intensive and require more cognitive effort, but software to handle CROs for the E-2 would represent a step beyond today's technology.

One item the author noticed that might be difficult to implement is the possibility for a field in the MTI to be any length. In the interest of simplicity, brevity and uniformity the author's opinion would be to limit the fields. The value of knowledge gained from scrolling or looking at lengthy fields will most likely not out weigh the value of other tasks missed or delayed. This is a compromise between the CRO and lengthy spreadsheet fields.

Smbl	Type	ID	Pltfm ID	GeoPoints	Hdg	Spd	Alt	Brg	Rng	C/S
	Surface	FRN	Carrier	36 35N 124 15W	180	12	0.0			Eagle
	Surface	FRN	FFG	36 30N 124 10W	180	12	0.0			G1L
	Surface	FRN	DDG	36 30N 124 20W	180	12	0.0			5FI
	Surface	FRN	DDG	36 40N 124 10W	180	12	0.0			S4R
	Air	FRN	KC-10	36 00N 123 00W	ORBIT	280	27.0			Texaco 21
	Surface	FRN	FFG	36 40N 124 20W	180	12	0.0			63P
	Air	FRN	E-2C	37 28N 123 50W	ORBIT	190	25.0			
	Air	FRN	EC-135	37 10N 124 20W	ORBIT					Baron 52
	Air	FRN	E-8C	36 12N 123 40W	ORBIT					Bishop 56
	Surface	FRN	LHD	36 33N 123 09W	020	12	0.0			7BE
	Surface	FRN	LPD	36 31N 123 11W	020	12	0.0			U2Q
	(Air)	FRN	RDVZ Point	36 15N 123 00W						
	Surface	HOS	PTBoat	36 47N 121 58W	270	50	0.0			
	Surface	HOS	SS (Sub)	36 55N 122 29W	250	8	0.0			
	(Surface)	HOS	Capital Arfld	36 56N 121 47W						
	Surface	FRN	LPD	36 35N 123 11W	020	12	0.0			Y8H

Figure 18 Standard MTI (Sharkey et al, 1997)

Figure 18 is not an efficient organization of the MTI. The type and ID columns would be handy for sorting, but they are redundant and inefficient for quick use. The two columns are combined more efficiently in the symbol column. This redundancy is not of great concern since mission or personal sorts would probably move them anyway. For example, the author would move the Type, GeoPoints and ID columns out to the right. GeoPoints would not likely be needed since future data links will make almost all tracks available to the other units in the force. Now the headings start to resemble the entries found in a CRO. The author would sort them left to right, symbol, C/S (callsign), heading, speed, altitude and platform ID. The pertinent information would be readily available while less used information would continue out to the right.

The author would also rather extend the width of the window than scroll sideways in the window. This would reduce the need for the complicated function of freezing columns. Freezing a column keeps it visible while others slide out of the window as the user scrolls to the left or right.

Another helpful feature of the MTI is the fused column. This is a way of showing sensors (radar, IFF, passive, Electro-optical, satellite, visual) and units that are reporting information on a track. The column provides a concise report of what sensors onboard the E-2 and other units that are reporting information. If the user needs amplifying information, he can select the more detailed descriptions of platforms and sensors reported (Figure 19). This may allow him to perform conflict resolution or consider alternatives.

Source	ID	%	Mode	Alt	Freq	Spd	Active	Passive	IFF	Visual ID
E-2C	MIG-21	85	2	34.3			lat/long/alt/speed	PRF/freq		
JSTARS	SU-27	87				464	lat/long/alt/speed		XXX	
EA-6B	MIG-21	93			341		lat/long/alt/speed	PRF/freq		@ time cod

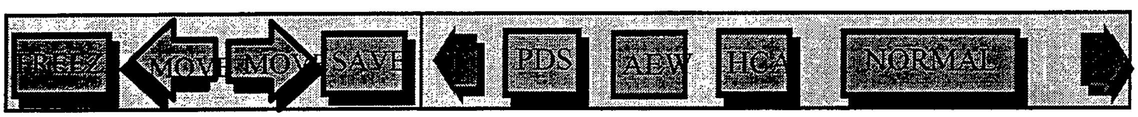
Figure 19 Detailed Fused Data Report (Sharkey et al, 1997)

Figure 20 represents the MTI in an unsorted state. The solution to the multi-mission status of the E-2 is addressed in the MTI by mission select buttons that allow the user to sort the fields in a way optimized for specific missions (PDS, AEW, HCA) or by personal preference. The following figures depict a mission sort selection.

symbol	Type	ID	Platform ID	GeoPoints	FRQ	Activity	Heading	Speed	PRF
	Air	FRN	AC-130	33 55N 118 25W		Gunship	360	160	
	Air	FRN	AC-130	33 55N 118 25W		Gunship	360	160	
	Air	FRN	C-130	33 55N 118 25W		Rescue	360	160	
	Air	FRN	P-3C	38 00N 125 00W		Patrol	180	240	
	Air	FRN	KC-135	38 00N 124 30W		Tank	180	320	
	Air	FRN	EC-135	38 00N 124 00W		EW	180	360	
	Air	FRN	E-8C	38 00N 123 50W		EW	180	350	
	Air	FRN	KC-10	33 55N 118 25W		Tank	300	340	

Figure 20 Unsorted MTI (Sharkey et al, 1997)

Figure 21 represents the MTI after selecting a mission sort for AEW. The rows remain the same while the columns are moved to facilitate the AEW mission. This ability to tailor the MTI makes the enormous amount of information manageable and thus more useful to the user.



symb	GeoPoints	C/S	Platform ID	Hdg	Speed	Alt	DLTN	Rng	Brg	Bingo
	33 55N 118 25W	Falcon 01	AC-130	360			3021			
	33 55N 118 25W	Falcon 02	AC-130	360			3421			
	33 55N 118 25W	Sparrow 101	C-130	360			3542			
	38 00N 125 00W		P-3C	180			3642			
	38 00N 124 30W		KC-135	180			3045			
	38 00N 124 00W	Baron 52	EC-135	180			3043			
	38 00N 123 50W	Bishop 56	E-8C	180			3022			
	33 55N 118 25W	Texaco 21	KC-10	300			3125			

Figure 21 MTI Sorted for AEW (Sharkey et al, 1997)

The inclusion of callsigns in the MTI is an obvious improvement. This inclusion assumes and implies the ability to automatically incorporate Air Tasking Orders (ATO), Air Control Orders (ACO) and other such information. Today, the ability to gather and process information from these orders is all done manually and requires significant preflight planning and cognitive effort before and during the flight.

Previously, the only link between the IFF and track number and the ATO callsign has been a manually entered label for the callsign on the display when time permits. By including this information in the MTI data the user's burden when referencing callsigns is dramatically reduced.

4. Look For Window

A search feature not currently available but required is the ability to search all contacts for those meeting specific requirements. This is essentially a query performed on the MTI that could be done via a window or verbally. An example ``Look for'' window depicting a search for hostile air tracks within 100 miles of the carrier is depicted in Figure 22.

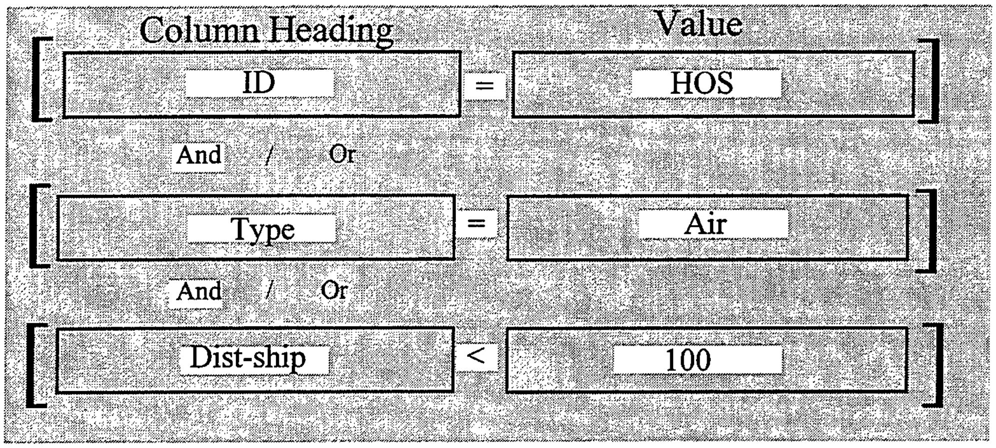


Figure 22 ''Look for'' Window with Hostile Air Within 100 Miles of Carrier Entered (Sharkey et al, 1997)

``The following are examples of information that the `Look For' algorithm can find(Sharkey et al, August 1997):

- Contacts that disappear (e.g., they are shot down, or have landed)
- Contacts not visible; but still exist in system
- A contact in the system, but off the display, viewable at a larger scale.
- A contact in the system, but not found by the NFO (possibly due to the symbol being minimized).

- Other example searches are:
  - Find track number 1234
  - Find GP-162 (specific C/S)
  - Find Texaco (pilot's call sign)
  - Find Fighters, Interceptors (A/C types)

•Find `Low on Fuel' (A/C within certain status categories).''

5. Voice Control Window

Voice control of the system in the E-2C CIC is proposed for NEMESIS. One of the major causes of errors in the CIC is a large queue of tasks that builds up as the operator struggles to prioritize and then perform the most important tasks. NEMESIS helps to reduce this queue by accepting voice commands. Initial analysis shows that less of the operator's time will be spent manipulating the system and more time can be devoted to tactics and operational decisions.

With the current system the operator must dedicate cognitive effort to constantly prioritizing and re-prioritizing waiting tasks while he completes them as fast as his hands can move. Voice activation allows him to perform tasks simultaneously and thus reduce the amount of waiting tasks. This shortened list of queued tasks requires less prioritizing and thus less cognitive effort. The effects are synergistic. Less cognitive load required for prioritizing a queue allows him to perform the tasks faster and better.

The author sees great potential for this feature but would like to consider some difficulties in implementation. The first is ambient noise in the aircraft which affects the clarity of inputs. Noise cancellation and filters can solve this until ambient noise is reduced in the current air frame or in the follow-on aircraft currently designated the Common Support Aircraft (CSA).

The second difficulty, as noted by the designers, is the slow advance of natural language (continuous voice recognition) technology. If this proves to be problematic, hot (discrete) word systems could be used as a fallback. Both of these methods concern the author because of the increased amount of communication required by the operators within the aircraft; while communications with sources outside the aircraft remain constant. Verbal commands to NEMESIS must compete with normal voice communications already required to perform the E-2C mission. Commands to the computer would potentially interfere with the other NFOs' understanding of the voice communications.

NEMESIS addresses some of the auditory traffic problems by proposing cues, and alternate outputs for messages in the queue such as text on the screen. The effect of a backed up queue and difficult algorithms or procedures to ensure proper priorities are assigned concerns the author.

6. 2½D Tactical Aid Window

MT took a big step with NEMESIS, by providing a 2½D or perspective view as an option. (A 2½D view is actually one of many types of 3D displays. Chapter V describes some of these, including 2½D.) Because NEMESIS is designed for the E-2C, the designers realized the importance of altitude in the situational picture. They understood the negative effects on performance of the operators by a third and crucial dimension being stored in alpha-numerics usually off the main display map. They knew that operators were constantly trying to develop a mental picture and associate altitudes with their two dimensional displays. They understood the potential benefits of representing all three dimensions in one intuitive display. In discussions with some of the designers, the author encountered some who did not believe there would be improved performance with the 2½D display. To their credit, MT included the capability as a response to user requests, inputs and feedback.

This 2½D view of NEMESIS is much more robust than the side view of TADMUS DSS. TADMUS' design was specifically aimed at an Aegis ship in AAW. NEMESIS was designed to meet the wide range of missions and air focus of the E-2C.

NEMESIS uses a side 2½D view with selectable looking directions (north, south, east and west). It also uses a sliding scale for height of eye selection. The default height of eye is 25,000 feet which is a typical height for an E-2C station. The default look direction is to the North. Figure 23 depicts a default 2½D view window.

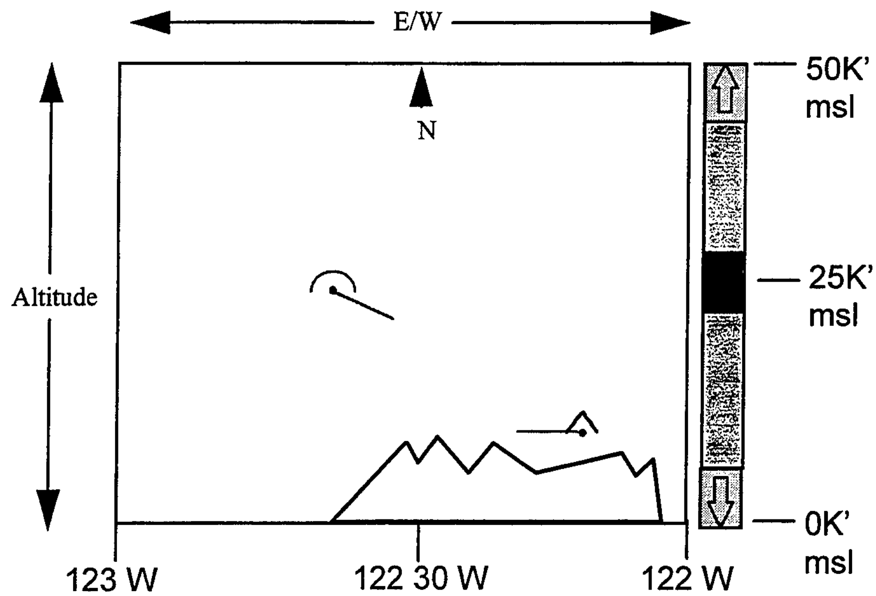


Figure 23 2½D View (Sharkey et al, 1997)

The user can create 2½D windows for any portion of the main map display. This 2½D window can be selected by specifying a geographic region in the main map window, or by selecting tracks (usually intercepting aircraft) and designating them for the 2½D display. The 2½D display then automatically changes scales as necessary to keep the selected tracks in view.

It is the author's firm belief that three dimensional displays will follow the same path as color's incorporation in displays. The price and complexity of color coupled with numerous tests and studies that showed no significant improvement in performance kept it out of displays for a long time. As the cost of color displays decreased and users demands increased, color was incorporated. Only recently is color widely accepted as a performance enhancer in C2 systems.

Color and 3D are intuitive and real world to the user. Like color enhancements only a few years ago, there are many studies available that do not show improved performance with 3D displays. The user believes that with time and refinement 3D displays will produce an improvement in performance in airborne C2 systems. In fact, for some specific tasks there are studies that show improved performance with 3D displays (more on this in Chapter V).

7. Track Alerts

Track alerts significantly aid the user in maintaining the most up-to-date SA. These cues help the commander notice changes in the picture more often and sooner, much like the changing priority algorithm of the multi-CRO display panel of DSS-2. This reduction in the commander's cognitive load frees his mental resources for more critical decisions.

An example of reducing the cognitive load of the commander is having the computer perform a simple function of watching an airfield for departing aircraft. The constant vigilance required by a human to notice a track becoming airborne from a specific field is difficult to maintain for a four to five hour mission, especially since other tasks and distractions are never ending during that time. By using the alerts, the commander's focus can shift to other tasks while the computer continues to monitor the subject airfield. If a track is formed for an aircraft taking off from the airfield of interest, the computer alerts the commander. Other significant ``examples of alerts available in NEMESIS are (Sharkey et al, August 1997):

- Contacts presumed to be commercial exiting commercial corridors.
- Contacts exhibiting characteristics indicating hostile intent (e.g., jinking, sensors associated with weapons, coming within 60 NM of the carrier and having a heading within 20 degrees of the ship).
- Contacts entering designated regions (e.g., going north of a designated latitude).
- Aircraft approaching Bingo fuel state.
- Detection of new, unevaluated contact.
- Single contact splitting into multiple contacts.
- Geo/Pol boundaries.
- Intel/Elint based.
- Wing and/or CVBG SOP
- A/C under E-2C control entering radar envelope.''

8. Communications

The designers felt that NEMESIS should contain communications processing integrated into the rest of NEMESIS even though the contract did not include a communications processing requirement. One feature proposed is the ability for the computer to answer simple requests from other units. An example of a simple and routine request might be a call for ``pigeons'' which is a request from another aircraft for the range and bearing of ``Mom''(the carrier). The designers of NEMESIS suggest that with digitized communications and voice recognition the computer could handle this simple request while allowing the commander to focus on more complicated or urgent tasks. Realizing the user's reluctance to let a computer answer requests automatically, MT provides two modes. (1) Management by consent would require the user to approve the reply before it went out, or (2) management by negation would let the computer answer, unless the user overrides the reply. This implementation reduces user work load by allowing the computer to perform a more mundane task. Unfortunately, wide acceptance in the fleet may be difficult to achieve.

Another proposal is that since all communications will likely be digitized they could also be queued. However, the author does not feel confident that a queue of communications with a necessary algorithm to determine priority for presentation to the commander would provide significant improvement in overall performance. The author is concerned about time-lateness of communications in the queue.

The storage and saving of communications as a reference would however provide valuable assistance. The queue would be good for repeating missed calls or showing a message as text if necessary.

The author feels that the users would be better served with 3D sound that would allow them to improve current abilities to listen to multiple radios at the same time. A skilled commander in the E-2C has the ability to listen to multiple radios at the same time.

The designers propose that the users could view the queue to change the order of waiting communications if necessary. This proposal seems to have the potential to increase load on the user. Where the user used to manage the radios by simple listening, the proposal would entail not only listening, but having to systematically inspect queues and repeatedly reconsider priorities.

More proposals involve those features similar to the Navy's proposed Automatic Digital Network System (ADNS) involving designating the recipients of communications via any number of means and letting the computer figure out how to transmit the message to those intended recipients.

Likewise, the system could identify the platform in the display map or MTI that is generating an incoming communication.

Another result of this type of communications control is the ability to have ``smart'' volume control for users in the E-2C. Users would be able to specify volume based on almost any factor (examples include fighters, AW, other squadron aircraft, other AEW aircraft). The computer would sort communications and set volumes dynamically.

Aside from the queues these features have some obvious potential benefits, but only time will tell if voice recognition and computer controlled communication paths become a reality.

9. Replay

The replay feature may be useful for training, debriefs and to uncover missed events or lost tracks. One nice feature included in replay is a personal time marker. In addition to recorded time, the user can simply verbally mark a point in the flight for future reference. Later in the flight or on deck, he can refer to his personal time marker for further analysis of the mission.

10. 3D Sound

Spatially separated communications improve the performance of listeners. 3D sound can be presented to the user in many ways. An important description of each is included from Sharkey et al, 1997, Design Guide 16. ``The frame of reference refers to the coordinate system used to define the location from which voice communications originate. There are three (3) candidate systems:

A **head-referenced** system will localize sounds relative to the current position of the NFO's head. For example, a sound might always be presented forward and to the left of the NFO's head regardless of the direction the NFO was looking at that instant. With a head-referenced system a sound will appear to move relative to the aircraft as the NFO's head turns or rolls. A head referenced system does not require tracking the position of the NFO's head. Furthermore, a head-referenced presentation technique does not require knowledge of the aircraft's position or orientation relative to the platform sending the voice message.

An **aircraft-referenced** system presents sounds so that they always appear to be originating from the same location relative to the aircraft and its equipment regardless of motion of the NFO's head. A sound that appears to originate from forward on the port side of the aircraft when the NFO is looking straight ahead, for example, will not seem to move as the NFO's head turns or rolls with an aircraft-referenced system. An aircraft-referenced system requires that the position of the NFO's head be tracked and taken into account when presenting sounds directionally. An aircraft referenced system does not require taking the position or orientation of the E-2C relative to the calling platform into account.

A **world-referenced** presentation technique would result in sound appearing to originate from consistent geographical positions. For example, if the platform sending a voice message to the E-2C was due south, then the voice would appear to come from the south. This techniques requires that the NFO's head position and the position and orientation of the aircraft relative to the communicating platform be known and used to generate the sound. Unlike the other two referencing systems, world-referencing may result in voice communications from different platforms being perceived as coming from the same direction. (For example, when two platforms are at different distances from the E-2C, but both are to the south.'' (Sharkey et al, 1997)

NEMESIS proposes at least four sources for sound directions. These minimum four directions are depicted in Figure 24. These directions are forward right and left and rear right and left.

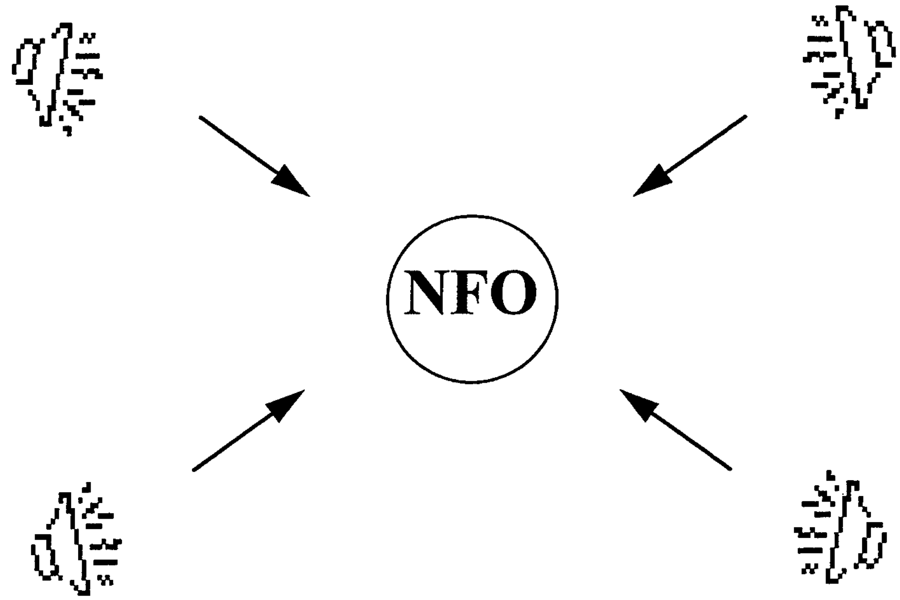


Figure 24 Minimum of Four Directions (Sharkey et al, 1997)

11. Report Generation

NEMESIS automates report generation. Almost any type of report can be generated quickly if not automatically with little or no inputs required from the users. Vast improvements in maintenance could be realized by automated BIT reports being sent back to the squadron maintenance department aboard the carrier in real-time. Currently, faults are reported back to the maintenance department via voice as the mission loading permits or via extensive and timely post flight debriefs. Post flight debriefs can be of limited value due to an inability to reproduce the fault on deck for the technician to see. This assumes improved connectivity with the carrier and new more capable computers in the squadron maintenance department.

12. Window Passing

NEMESIS includes the ability to send and receive windows from others. This concept was first proposed in early nineties. The object oriented architecture and communications infrastructure needed for window passing are now being implemented under the programs Athena and CEC respectively (Dick B., 1998). This ability allows operators to hand off tasks to another operator in the CIC or even on another platform. This feature enables dynamic task loading, while minimizing user setup and the time required to acquire SA in a new situation. With this method, the accepting user receives a preprocessed fully setup window. Manual and cognitive load is dramatically reduced. NEMESIS envisions this ability to transfer windows to any unit in the force, thus allowing dynamic loading across the entire force and maximize performance by avoiding overload on any one unit or individual.

C. SUGGESTIONS

NEMESIS was designed from the start for the E-2C from task analyses and input from E-2C users. Because of the excellent job done designing the HMI, the author can offer only limited concerns:

- Track balls or mice prove inefficient in large display spaces.
- Ergonomics of a touch-screen application on such a large surface for a five hour mission (or longer if the platform adds a refueling capability).
- It may be difficult to strike a balance between mission specific setup and personal setup.
- Research, such as that done by Dr. Glen Osga (Osga G, 1995), suggests FABs are more efficient than VABs. Groupings, color-coding and symbols help along with great human ability with spatial memory.

V. 3 D DISPLAYS

In previous chapters the author discussed different types of three dimensional displays. This chapter provides definitions and analysis of some 3D displays.

A. TERMS AND DEFINITIONS

Some basic ideas and terminology for three-dimensional displays are provided here. Physiological cues are properties of the optical apparatus. Kinetic cues involve the relative movements of objects and observers. Pictorial cues are the scene attributes that convey the impression of depth. Of these cues Dember and Warm state ``In order to achieve an awareness of depth, it is clear that we use a wide variety of cues, no one of which is itself *three dimensional*'' (Dember & Warm 1979).

Descriptions of three types of 3D displays follow:

1. 3D **Perspective** Display (often referred to as **2½D**) - offers a more natural view or representation of the airspace. This method presents distance along the line of sight, similar to human visual systems. A variety of pictorial cues are used to give the impression of 3D.

2. 3D **Stereoscopic** Display (**3D Stereo**) - uses a computer-generated, fixed focus view to the plane of the screen with stereo glasses.

3. 3D **Volumetric** Display (**3DVD**) - is an evolving technology that uses more salient 3D depth cues like motion parallax, binocular disparity-stereopsis, physiological cues and pictorial to present a 360 degree scene.

B. ADVANTAGES AND DISADVANTAGES OF DIFFERENT TYPES OF 3D DISPLAYS

The problem associated with most current three dimensional displays is the viewpoint of the user. The data can be presented with any viewpoint. The problem is which viewpoint to use for each viewer for a given scenario. If designers allow the user to change the viewpoint dynamically, the user can lose his bearings or get confused as to which direction he is looking. If designers freeze each viewer's direction of look, then the commander may not be able to clearly comprehend certain scenarios that could be quickly understood from a different viewpoint.

``The compellingness of the sense of depth in a display is a roughly additive function of the number of depth cues that are incorporated into it and certain cues are more salient than others.'' (Stokes et al, 1990) This need for a maximum number of cues in a dynamic battlespace depiction will push the limits of technology and expense. Complicated algorithms may be required to present the information with as many cues as possible depending on a number of variables.

Each of the 3D display options has unique advantages and disadvantages: (T. Sharkey, personal communication, April 03, 1998)

1. 2½D

Advantages

- no need for goggles or glasses
- unambiguous presentation of altitude and geo-position without changing viewing position
- smaller footprint than volumetric
- does not require a 3D hooking device.

Disadvantages

- introduces clutter that could make a congested battlespace depiction difficult to decipher.
- altitude and geo-position not presented concurrently
- some user information required to get both.

2. 3D Stereo

Advantages

- presence information

- feeling that the operator is not missing anything.

Disadvantages

- does not improve performance on a dynamic task in a rich visual environment over that of a similar display without stereopsis.
- Also, the ability to see stereoscopic depth on a CRT must be learned.
- need a dichoptic presentation
- ambiguity between geo-position and altitude resolved by moving the user
- glasses or goggles probably required
- inherent conflict between depth cues
- some people are stereo blind.

3. 3DVD

Advantages

- no need for goggles or glasses
- show geographic and altitude simultaneously.

Disadvantages

- is still in its infancy. The problems it has been applied to have been simple, and more work is required before a fast paced operation could use it.

- The questionable value added by current versions does not justify the large footprint of the system, especially for airborne commanders.
- difficult to determine altitude from some positions
- level of resolution is not good enough yet.

C. A ROTATABLE WORLD AND TWO STUDIES OF PERFORMANCE ACROSS DISPLAYS

A technology referenced and requested by users canvassed by Monterey Technologies was the ability to ``roll the world'' as they had seen in Tactical Aircrew Combat Training System (TACTS) debriefing room. These debriefing rooms are located at various fleet training locations and provide extensive re-creation of flights for debriefing purposes. The selling point of the TACTS range debriefing room is the ability to roll the bird's eye (perpendicular to the earth's surface) viewing angle ninety degrees until you are looking parallel to the earth's surface. This allows the viewers to see the situation in relation to altitude without having to look at another screen or window. As the scene is rolled the viewers maintain SA and gain still more understanding and knowledge of the picture. This instantly added understanding could be in the form of an enemy's tactics, terrain masking, etc.

The designers of NEMESIS considered many different types of 2D and 3D displays. They decided that the perspective display was best suited for the E-2C. The author agrees, but with the acknowledgment that rapid advances in technology may enable the other methods to be refined or improved to the point that their disadvantages are reduced while maintaining their advantages over perspective.

In fact, a recent study by Dr. Jim Broyles (Broyles, in press) of SPAWARS comparing different types of 3D displays across a selected set of air traffic control tasks scored perspective the lowest of all the types of 3D displays tested. In this study 2½D (perspective) displays scored poorly compared to the other types of 3D(volumetric, stereo) and even 2D displays. The author has provided multiple reasons why in a tactical command and control aircraft 2D displays are insufficient. In section B of this chapter the author presented other considerations involving the implementation of 3D displays in the E-2C CIC that strongly supported the perspective implementation. Next the author will explain why the results of Broyles' experiment do map directly to the needs of the crew in the E-2C or other command and control platforms.

The results of the Broyles study are limited to simple air traffic control tasks performed one at a time. These tasks include speed judgments, heading judgments, altitude judgments, aircraft vectoring and deconfliction decisions. These task represent a small portion of only one function performed by the E-2C crew. Additionally, the tasks in the experiment were not done simultaneously. When one takes into consideration the multitude of simultaneous tasks and decisions performed by E-2C commanders, the poor performance of the perspective display in these few tasks does not weigh heavily for command and control platforms. This fact coupled with the limitations of stereo and volumetric displays, the perspective display becomes a compelling choice. The designers of NEMESIS reached the same conclusion.

Another study more closely matched to tasks of the E-2C CIC crew was reported in Human Factors. ``Operator Performance as a Function of Type of Display: Conventional versus Perspective'' by Bemis, Leeds and Winer (Bemis et al, 1988) compared detection of air threats, selection of nearest interceptor and time required to choose the interceptor for a standard 2D NTDS display and a perspective display. The results of the study showed significant reductions in errors of detection and interceptor selection as well as response time when using the perspective (2½D) display.

One other possible option could be a function similar to that of the TACTS range, the ability to rotate the view from perpendicular to parallel to the earth's surface. This solution would require the user to constantly manipulate his screen from one view to another. Although it happens in the same window, it is an intermediate step between multiple two dimensional displays (that require more processing by the commander to understand) and a three dimensional picture (with lower cognitive load).

There is no doubt for any tactical flyer that the TACTS range's ``world rotate'' feature adds immense rapid understanding of the 3D tactical situation. This feature of TACTS is enabled by real-time transmission of kinematic data by the participating aircraft. Improved technology in the form of advanced sensors and communications has enabled our forces to gather a similar quantity and quality of information on almost any track concerning the force. This detailed information allows us to present a accurate depiction of the situation in a form that enhances the commander's understanding of the 3D environment just as the TACTS range did.

VI. CONCLUSIONS

Joint Pub 6-0 states ``..information should be relevant, essential, timely and **in a form that warriors can quickly understand and can use to act.**'' (Joint Pub 6-0, 1995)

In that aim, the best way to depict a three dimensional environment is with some form of three dimensional decision aid. Displays have slowly progressed away from textual presentations and towards more quickly and easily assimilated graphic displays. Unfortunately, many current command and control decision support systems still rely on text or multiple two dimensional windows to provide all three dimensions of the real world to the commander.

In the past, these less than optimal implementations were unavoidable due to technological limitations. These technological limitations have been overcome for some types of 3D displays. Because commanders in airborne command and control platforms require a detailed understanding of a three dimensional environment, they should adopt some type of 3D display quickly. Perspective displays are not perfect for absolutely every situation the commander will face; but the added rapid understanding of the action, tactics and intentions of friendly and enemy forces demand its inclusion.

LIST OF REFERENCES

The American Heritage Dictionary Second College Edition. 1982 ed.

Bemis, S. V., Leeds, J. L. and Winer, E. A. ``Operator Performance as a function of Type of Display: Conventional versus Perspective.'' Human Factors 30(2) (1988): 163-169.

Broyles, J. and Orden, K. V., `` Three-Dimensional Visualization of Tactical Data'' San Diego, CA: NRAD in press.

Hennessy, R. T., Hutchins, C. W., and Cicinelli, J. G. Color Requirements for the E-2C Enhanced Main Display Unit (EMDU). Washington, D.C.: Naval Air Systems Command. 13 Dec. 1990.

Hutchins, S. G. ``Principles for Intelligent Decision Aiding'' San Diego, CA: NRAD. Aug. 1996: pp. 5.

United States. Department of Defense. Doctrine for Command, Control, Communications, and Computer (C4) Systems Support to Joint Operations. Joint Publication 6-0. Washington: GPO, 1995.

Larkin, J. H. and Simon, H. A. ``Why a Diagram is (Sometimes) Worth 10,000 Words.'' Cognitive Science 11 (1987): 65-99.

Morrison, J. G., Kelly, R. T. & Moore, R. A. and Hutchins, S. G. ''Tactical Decision Making Under Stress (TADMUS) Decision Support System.'' San Diego, CA: NRAD. in press.

Noble, D. ``Application of Theory of Cognition to Situation Assessment.'' Vienna, VA: Engineering Research Associates. 1989.

Osga, G., and Keating R. ``Usability Study f Variable Coding Methods for Tactical Information Display Visual Filtering.'' Technical Document 2628 Mar. 1984.

Osga, G. ``Combat Information Center Human Computer Interface Design Studies.'' Technical Document 2822 Jun. 1995.

Sharkey, T. J., Olsen, E. C. B., Chamberlain, R. M., Dick, R. A., Hazard, T. R., and Hennessy, R. H. The New Millennium Electronic Surveillance Interface Suite: NEMESIS Final Report (for Naval Air Systems Command [E-2C]) Monterey Technologies, Inc.: Los Gatos, California. 8 Aug. 1997.

Shrestha, L. B., Prince, C., Baker, D. P., and Salas, E. ``Understanding Situational Awareness: Concepts, Methods and Training.'' Human/Technology Interaction in Complex Systems, vol. 7, W. B. Rouse(Ed.). JAI Press. San Francisco. 1995.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center.............2
   John J. Kingman Rd., STE 0944
   Ft. Belvoir, VA 22060-6218

2. Dudley Knox Library...............................2
   Naval Postgraduate School
   Dyer Rd.
   Monterey, CA 93943