To the Graduate Council:

I am submitting herewith a thesis written by Michael Joseph Coury entitled "Automation of the EA-6B Weapon System." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Masters of Science, with a major in Aviation Systems.

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AUTOMATION OF THE EA-6B WEAPON SYSTEM

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Michael Joseph Coury

May 1996

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DEDICATION

This thesis is dedicated to my wife

Mrs. Maureen Estelle Coury

whose patience and support of my professional career

and educational development has been steadfast.

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ABSTRACT

The fourth major software release for the EA-6B electronic attack (EA) aircraft failed due to several discrepancies relating to the implementation of additional automation into the weapon system. The propensity for improved performance by the aircraft due to advertised automated capabilities was significantly offset by faults and inadequacies of the automation design as well as human factors deficiencies directly related to the automation. As a result, Air Test and Evaluation Squadron FIVE (VX-5), and its parent command, Operational Test and Evaluation Force, disapproved full fleet introduction of the software until critical deficiencies were corrected.

This research is an assessment of the EA-6B weapon system software and the principle aspects of automation with which it relates. Levels of automation and generic design characteristics were derived from non-military applications. Several Navy and Air Force studies pertaining to automation of generic electronic warfare (EW) systems were used to identify critical issues specific to military design and implementation. An analysis of the EA-6B weapon system hardware and software features, including operational test results conducted by VX-5, was used to assess the successes and failures of automation implementation.

It was concluded that automation implementation into the EA-6B weapon system was consistent with generic design characteristics of both non-military and military EW

systems. The application of the automation and the level of automation were predominantly successful. However, several critical issues relating to the accuracy and adequacy of the automation were found faulty. In addition, several human factors problems were found to be a direct result of the automation implementation. Using the non-military and military studies, recommendations on correcting each of these problems was offered for incorporation into a correction of deficiencies (COD) software release.

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LIST OF ABBREVIATIONS

Advanced Command and Control Warfare Aircraft System ...	AC2WAS
Automatic Control and Display	ACD
Artificial Intelligence	AI
Airborne Instruments Laboratory	AIL
Anti-radiation Missile	ARM
Battle Damage Assessment	BDA
Control Display Indicator	CDI
Computer Interface Unit	CIU
Computer Interface Unit Encoder	CIUE
Computer Load Panel	CLP
Central Mission Computer	CMC
Chief of Naval Operations	CNO
Corrections of Deficiencies	COD
Critical Operational Issues	COI
Carrier Air Wing	CVW

Display Computer	DC
Digital Display Console	DDC
Digital Display Group	DDG
Digital Display Indicator	DDI
Defense Electronic Countermeasures	DECM
Department of Defense	DOD
Electronic Attack	EA
Electronic Counter Countermeasures	ECCM
Electronic Countermeasures	ECM
Electronic Countermeasures Officer	ECMO
Electronic Order of Battle	EOB
Electronic Protect	EP
Electronic Surveillance	ES
Electronic Surveillance Measures	ESM
Electronic Warfare	EW
Expanded Capability	EXCAP
Functional Category	FC

Grumman Aircraft Corporation	GAC
Geographic (display)	GEO
High Speed Anti-radiation Missile	HARM
Harm Control Panel	HCP
Improved Capability	ICAP
Interface Control Unit	ICU
Intermediate Frequency	IF
Inertial Navigation System	INS
Jammer Assignment Status	JAS
Local Oscillator	LO
Naval Air Warfare Center Weapons Division	NAWC-WD
Operational Advisory Group	OAG
Onboard System	OBS
Onboard Program Loader	OPL
Office of the Chief of Naval Operations	OPNAV
Operational Test Director	OTD
Pacific Missile Test Center	PMTC

Pulse Repetition Interval	PRI
Ram Air Turbine	RAT
Rules of Engagement	ROE
Recorder Reproducer Set	RRS
Surface to Air Missile	SAM
Software Control Review Board	SCRB
Suppression of Enemy Air Defenses	SEAD
Software Support Activity	SSA
Tactics Manual	TACMAN
Tape Control Assembly	TCA
Tactical EA-6B Mission Support System	TEAMS
Tactical Jamming System	TJS
Technical Review Board	TRB
Universal Exciter	UE
United States Air Force	USAF
United States Navy	USN
Air Test and Evaluation Squadron FIVE	VX-5

CHAPTER 1

INTRODUCTION

EA-6B Issues

AIRCRAFT EMPLOYMENT

The United States Air Force (USAF) made a dramatic departure from previous electronic combat aircraft employment doctrine by announcing the retirement of the EF-111 electronic warfare (EW) aircraft during the first quarter FY-95, to be replaced by the United States Navy's (USN) EA-6B aircraft. In part, this announcement was the result of the USAF attempt to reduce costs by retiring an aging aircraft and the associated maintenance and operational expenditures [1]. It also was an acknowledgment by the USAF of the capability of the EA-6B aircraft to perform EW for its mission requirements. In the past, the USAF maintained that the EF-111's speed and profile compatibility with USAF strike aircraft was required to support the EW mission. Experience gained through joint Navy and Air Force operations of the Desert Storm conflict proved the capability of the EA-6B. Its ability to support all U.S. and multi-national/coalition forces by providing surveillance, jamming, and hardkill capability in a single platform proved not only the airframe's versatility, but also its superiority over any similarly tasked aircraft. The EA-6B earned the reputation as the "weapon of choice" in the suppression of enemy air defenses (SEAD).

SOFTWARE TEST AND DEVELOPMENT OVERVIEW

Although the aircraft's tactical mission performance is unmatched, there have been problems in some developmental aspects. Specifically, during the operational test of the EA-6B "Prowler" weapon system software SSA-4.0, from June through October 1993, several problems were identified with software programming and operation threatening aircraft weapon system performance. The automated functions developed to assist the operator in jammer management had the propensity for degradation in aircraft and operator performance. This degradation was significant enough to warrant only partial release of the software to Navy and Marine Corps "fleet" EA-6B squadrons, initiation of a corrections of deficiencies software release, and a review of software development and testing processes.

Software is operationally tested using criteria known as critical operational issues (COIs). These COIs are divided into two major categories designed to test the operational effectiveness and suitability of the software. During the operational test of this software release, significant discrepancies were discovered in both major COI categories specifically as a result of the automated jammer management functions. Although automated processes had been successfully integrated into previous software releases for the aircraft, the new attempt to automate jammer management processes was significantly more challenging. The operational effectiveness COI, Mission Enhancement, dealing specifically with the new automated functions, was assessed to

have significant deficiencies. Since the automation dealt directly with human machine interface, the software failed the operational suitability COI of Human Factors.

One of the primary reasons why the software had significant difficulty passing developmental test and ultimately only conditionally passed operational test, is that insufficient thought, preparation and time was given to the complexity of the additional automation in the software. The additional automation was a culmination of the software development process. Software is designed based on "fleet" operator input. Aircrew who deploy with an approved software release make recommendations on how to improve or correct discrepancies of the software. These recommendations are prioritized at an Operational Advisory Group (OAG) which is comprised of fleet representatives, developmental and operational test community representatives and program directors. The recommendations are discussed at a Technical Review Board (TRB) comprised strictly of the software engineers, program office representatives, and developmental and operational test representatives. The software engineers provide information on the feasibility of incorporating the recommended changes along with a predicted time frame for incorporation. Following the TRB is the Software Control Review Board (SCRB) which is attended by all members of the TRB as well as some "primary" fleet representation. SCRB members decide on the final software requirements based on the software engineers feasibility predictions and fleet requirements.

Software releases follow a "life-cycle management plan" which directs a finite time frame from the point of initial software engineering, through formal developmental and

operational testing, and finally fleet release. The developmental and testing agencies must limit software change incorporation to only those recommendations that can meet the limited time period. Fleet pressure allows little room for delay by the developmental engineers and the testing agencies since the software is frequently associated with funding limitations, hardware upgrades or greatly needed enhanced capability. Estimations on the difficulty and time requirements to implement the recommendations do not account for major delays. If little research is available on these recommendations, the engineers estimations may be insufficient. In some cases, significant delay of the software to the developmental and operational test communities can occur. Even worse, flawed software may reach developmental or operational testing resulting in significant delay or failure of the software.

SSA-4.0 jammer management automation characteristics were not critical to mission completion since manual jammer management techniques were already available and combat proven. However, automation of the jammer management would decrease operator workload allowing for improved operator efficiency and was a recommendation for incorporation into the software. The automation proved a significant software engineering feat. Automation in previous software releases had been relatively simplistic in comparison to the jammer management automation. Whereas previous automation followed simple decision and result processes, the complexity of jammer management required in-depth analysis of multiple factors used by the operator to manually manage those assets. Factors which included the unpredictability of mission requirements along

with hardware and software failures and faults required an operator to determine the optimal use of the jammer assets under these conditions based on professional tactical knowledge. The possibilities of mission changes and failures are nearly impossible to predict completely. Rules to govern all possible modifications in jammer management would have to be extensive to cover each scenario and completely automate the jammer management process. Studies done by Department of Defense (DOD) agencies conclude a system of average rule base may contain up to 400 rules [2]. The interactive effects of this type system would contain nearly 2^{400} possible interactions making a real-world problem impossible to predict. With 400 rules, it is estimated that only 2 percent of a human expert's knowledge is captured. Considering this dilemma, current technology does not lend itself to being able to replace the operator. That conclusion, however, does not exclude the possibility of assisting the operator in completing critical tasks [2]. In view of the complexity of the automation, it was determined that the automation could only partially assist the operator due to the unpredictable factors of each mission. Only generic "rules" of jammer management automation were incorporated. The problems occurred during those instances when the software design was defective or removed the operator either fully or partially from the management logic, requiring significant operator software manipulation to correct the automated jammer management problems. In these instances, the software automation became more of a liability than an asset.

OBJECTIVE

The objective of this thesis is to compare the EA-6B weapon system automation design and functionality with automated systems of both generic design and those specifically tailored to the task of EW. Using lessons learned from the design of these automated systems, conclusions about proper implementation of automation to the EA-6B weapon system can be ascertained. Specifically, the underlying reasons for the failure of the automated jammer management software can be brought to light. From these conclusions, specific recommendations can be made to correct the major failures which prevented full fleet release of the software.

SUMMARY

As the premier EW platform, providing service to joint and coalition forces, there is little room for mistakes in software engineering which could significantly impact this aircraft's performance. This is certainly true when software affects safety of flight, however it is also true with respect to mission accomplishment as was the case with SSA-4.0. Development of future electronic warfare aircraft must include lessons learned from EA-6B software development to avoid repeating the same mistakes. The Air Warfare Division of the Office of the Chief of Naval Operations (OPNAV) is expected to release a mission needs statement for a future joint EW aircraft replacing the EA-6B [3]. The proposed follow-on aircraft, labeled the Advanced Command and Control Warfare

Aircraft System (AC2WAS), is reported to be a modification of the F/A-18E/F which will seat a pilot and a single Electronic Countermeasures Officer (ECMO) rather than the three ECMOs in the EA-6B. Software engineering and human-machine interface must include automation which accounts for the increased workload for the single ECMO. As a record of the problems associated with automation implementation, this thesis should convince engineers and aircrew that the design of the future generation EW aircraft must be tempered with sound knowledge of automation, its capabilities and limitations.

CHAPTER 2

EVOLUTION AND CAPABILITY

An Assessment of EA-6B Development and Mission Requirements

EVOLUTION

Development of the EA-6B began in 1965 as a Navy-Grumman Aircraft Corporation (GAC) contract to build an airborne Electronic Attack (EA) platform [4]. The contract led to the development of the EA-6B aircraft which began initial service life in 1971 when it was deployed during the Vietnam War. The aircraft, similar in design to the A-6 Intruder bomber, was compatible in profile and performance characteristics of all fixed wing aircraft deployed to the Carrier Air Wing (CVW) at that time. That characteristic continues through present day. Its initial capabilities were directly proportional to the threats of the period. Subsequent versions of the aircraft were developed incorporating improved avionics and weapon systems capabilities to match the increased threats. These improvements have been the primary developmental changes in the aircraft with only some aerodynamic performance characteristics improvements throughout the history of the aircraft.

Although GAC was the primary developer of the EA-6B, several other major developers were also tasked to provide specific equipment to the EA-6B. Airborne Instruments Laboratory (AIL) designed the Onboard System (OBS) which incorporates much of the avionics and all of the internal weapons systems components. Raytheon/

MacDonnell-Douglas developed the tactical jammer pods which are externally loaded on the wings or centerline of the fuselage. In 1988, the High Speed Antiradiation Missile, developed by Texas Instruments was introduced for EA-6B employment as its only destructive or "hard-kill" capability. Litton Amecon developed the superheterodyne surveillance receivers. Pacific Missile Test Center (PMTC), subsequently reorganized as the Naval Air Warfare Center Weapons Division (NAWC-WD), developed the software for the central mission computer (CMC) and other associated computers. Finally, PRB Associates developed the mission planning hardware and software, known as the Tactical EA-6B Mission Support System (TEAMS) to support the EA-6B.

Continual modifications were made to the EA-6B to meet the ever increasing electronic threats to the Air Wing, Carrier Battle Group ships, and joint/coalition forces. Although airframe and performance capabilities came slowly, the system improvements have been substantial over the life-cycle of the EA-6B. The initial or STANDARD version of the EA-6B incrementally received improved weapon system components resulting in the development of the Expanded Capability (EXCAP), Improved Capability (ICAP), and the Improved Capability second version (ICAP II) which is in service today. The initial version of ICAP II was developed in 1982 and is referred to as the BLOCK-82 aircraft. The subsequent version of ICAP II, developed in 1986, is correspondingly referred to as BLOCK-86. Figure (2-1) shows the evolution of the EA-6B.

Although only minor hardware differences separated the two aircraft, specifically minimal modification to the tactical receive and processing hardware, the aircraft received different weapon system software until the release of SSA-4.0. BLOCK-82

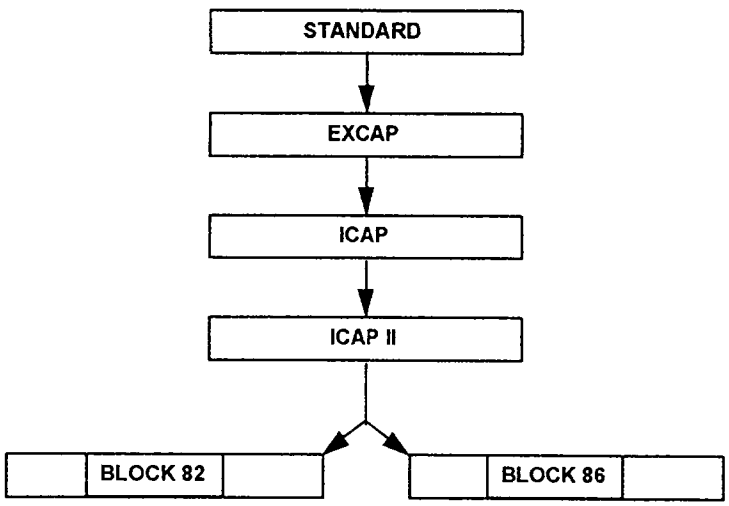


Figure (2-1)

EA-6B EVOLUTION

aircraft received software upgrades through contract with the Software Support Activity (SSA) located at NAWC-WD. Due to contract obligations, GAC was required to provide the first software release to the BLOCK-86 aircraft and a subsequent corrections of deficiencies (COD) release known as 86-2 software. The SSA developed software updates about every 18 months for the BLOCK-82 aircraft while the BLOCK-86 aircraft received only two software releases from 1986 through 1993. As such, not only had separate software releases remained in each block aircraft until development of SSA-4.0, but BLOCK-82 aircraft software performance characteristics, specifically its ability to assist the operator by reducing workload, increasing situational awareness, and therefore completing mission requirements, became significantly better than the BLOCK-86 software.

Following the 86-2 COD implementation for BLOCK-86 aircraft, GAC was released of all obligation to provide further software upgrades to the BLOCK-86 aircraft. The SSA was tasked to provide software with primary specifications to include unification of the software between BLOCK-82 and BLOCK-86 aircraft and enhance the software with automated jammer management capability. Therefore, the demand for SSA-4.0 by the fleet and EA-6B program office was significant. The unification of software between BLOCK-82 and BLOCK-86 aircraft would result in significant savings in funding required for software support. Training of all aircrew operators, regardless of block aircraft, would be standardized. As a result of the unified software, the BLOCK-86 aircraft would finally reach parity with BLOCK-82 capabilities. Finally, the jammer management automation would provide a significant software engineering advancement,

not only in reducing operator workload, but also in preparing for future advanced EW aircraft.

Each of the specific goals of SSA-4.0 held a priority. The 1990's, epitomized by a downsizing and financially restrained military, had a direct influence on the priority of each goal. Unification of software between the different block aircraft held the highest priority because the cost of software support and training requirements would be reduced. The automated jammer management function priority paled in comparison to the financial savings obtainable through a single software release for both block aircraft and the BLOCK-86 "parity of capability" agenda. As a result, the developing engineers' resources and time allotted to the automated jammer management functionality were limited.

CAPABILITY

The primary mission of the EA-6B is EW. Schleher defines EW as "the concept of exploiting the enemy's electromagnetic emissions in all parts of the electromagnetic spectrum in order to provide intelligence on the enemy's order of battle, intentions, and capabilities; and to use countermeasures to deny effective use of communications and weapons systems while protecting one's own effective use of the same spectrum"[5]. By controlling the enemy's use of the electromagnetic spectrum, one can influence his actions or deny his ability to conduct warfare using modern weapons which require the use of the electromagnetic medium in some form. In addition, EW is used as a force

multiplier. A force multiplier is any asset or program which sustains a force level by minimizing the threat to those forces resulting in fewer losses over an extended period of time. Although EW does not always entail full or complete destruction or attrition of opposing force assets, the value as a force multiplier requires the modern warfare commander to employ EW when executing any aspect of a mission.

Electronic Warfare is divided into three subsets which support either its offensive or defensive postures. They include electronic surveillance (ES), electronic attack (EA), and electronic protect (EP). EP, formerly known as Electronic Counter Countermeasures (ECCM), is the division of electronic warfare in which actions are taken to protect your own force units from the employment of electronic warfare by hostile forces. The execution of EP is usually a function of individual systems to protect themselves. EP is not a primary function of the EA-6B.

ES, formerly referred to as Electronic Surveillance Measures (ESM), is the process of intercepting, identifying, and locating electromagnetic emissions. Intelligence gathering missions are distinguished from ES which is predominately tactical in nature [5]. ES capability is comprised of the multiple sensors on a myriad of sources not always directly controlled by the theater or battle group commander but able to provide him with real time or near real time surveillance data. The timeliness of these sources and their ability to pass data to multiple consumers allows for immediate action as well as intelligence collection and analysis. Therefore, depending on the capabilities of the platform

performing the surveillance, ES may be either tactical or strategic in nature and performed as either an offensive or defensive action.

The EA-6B is capable of both radar and communication surveillance. Components of the mission critical systems process the data and display results real time to the operator or Electronic Countermeasures Officer (ECMO) for immediate use. Accuracy of detection, subject to system limitations and ambiguity between different emitters, are compensated by the ECMO. In a benign environment with exact parametrics and no modification of emission sources, the ECMO could be replaced by a fully automated system. However, the electromagnetic environment remains dynamic. System limitations and mission modifications require that the ECMO be present to decipher the myriad of information, account for system hardware or software faults and failures, and resolve ambiguities.

The offensive division of EW is known as Electronic Attack (EA) and is similar to Electronic Countermeasures (ECM) described in older documentation. EA involves any actions taken to prevent or reduce an enemy's effective use of the electromagnetic spectrum. It encompasses electronic jamming in which deliberate radiation, re-radiation, or reflection of electromagnetic energy is conducted for the specific purpose of destroying, damaging, or disrupting enemy use of the electromagnetic spectrum. EA also includes use of anti-radiation missiles (ARMs).

EA-6B aircraft are best suited towards electronic attack in the denial, degradation, or destruction of the hostile system. Once the ECMO has positively identified the system,

the ability to jam or launch an ARM against the system is a function of directing the appropriate weapon system components. The operator's interface with the jamming equipment is similar to the interface with the aircraft's ES systems as they both require human intervention in the decision process.

SUMMARY

The EA-6B has evolved in capability to meet the ever increasing threat to strike aircraft and naval assets alike. The most significant evolution has been specific to the EA-6B weapon system. Although the aircraft aerodynamic performance characteristics have changed little, it's ability to accomplish the mission of EW has improved significantly. The development of two separate block ICAP II aircraft did lead to some disparity of capability since the software was provided by different developing agencies. The objective of the SSA-4.0 weapon system software was not only to provide automated weapon system functions to improve the EA-6B EW capability, but also to alleviate the disparity of capability problems associated with the separate software development.

CHAPTER 3

HARDWARE

An Exploration of Hardware Component Design and Integration

ONBOARD SYSTEM

The EA-6B hardware components which enable it to receive and jam radar signals is known as the Tactical Jamming System (TJS). It is divided into two subsystems known as the ONBOARD system (OBS) and EXTERNAL STORES. The OBS includes all components of the TJS internal to the aircraft airframe. External stores are those systems which are mounted on any of the five external stations, 4 wing and one fuselage centerline, which are accessed as part of the TJS.

The OBS includes receivers, computers and supporting hardware, and displays which allow for the analysis of the electromagnetic environment. Currently, the only means of intercepting electromagnetic emissions for display to the operator are the aircraft's superheterodyne receivers and antennas. The superheterodyne receivers are located in the vertical stabilizer of the Prowler. The mission of the EA-6B requires the detection and discrimination of a wide variety of electromagnetic signals and therefore requires a wide spectrum of frequency coverage. To accomplish both accurate signal detection and wide coverage, a multitude of superheterodyne receivers are required. Once the electromagnetic emissions are detected, the signals are processed through internal computers.

The EA-6B requires a receiver which will have high sensitivity (high gain) and an ability for precise frequency measurement. Such a capability in a receiver describes narrow band receivers. In order to achieve acceptable gain characteristics, it is necessary to optimize the amplification circuits to work at one preset frequency [6]. Several amplifying stages usually make up this amplifier. Working together, these stages make up the intermediate frequency (IF) amplifier.

Consider an AM radio that has an IF amplifier tuned to 455 kHz. The IF amplifier will not process any signal not at its preset frequency within a given tolerance. A standard commercial AM broadcast is transmitted within a band of frequencies between 550 and 1600 kHz and the AM radio signal processed as depicted in Figure 3-1.
To detect signals (radio stations) at different frequencies in the AM band, it is necessary to convert the frequency of the received signal to the IF of 455 kHz. This process is called superheterodyning. Superheterodyning is the process by which "the receiver exploits the phenomenon that whenever two signals at two different frequencies are mixed together, the mixer regenerates the emitter signal at four frequencies"[7]. Those four frequencies are the two original frequencies which were mixed and two new frequencies which are the sum and difference of the two original frequencies. If a down converter is used, the resulting difference frequency is exploited by the superheterodyne. If the up conversion is used, either sum or difference mixing may be employed. As with most superheterodyne receivers, the receivers in the EA-6B employ the down conversion application. A mixer is then used which accepts the signals passed by the antenna, and also accepts a controlling frequency generated by a local oscillator (LO).

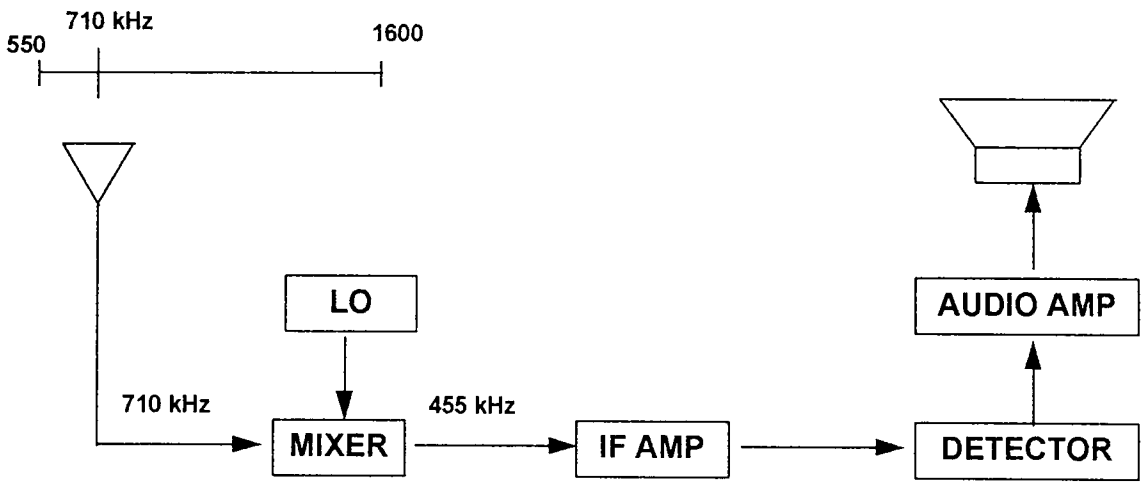


Figure (3-1)

SUPERHETERODYNE SIGNAL PROCESSING

Mathematically, this process is described by the equation:

$$IF = [f_y \pm f_l] \qquad [7]$$

IF is the output or intermediate frequency, f_y is the received frequency, and f_l is the local oscillator frequency. By tuning the LO and mixing its output with those radio station frequencies present, the AM radio can be tuned across the AM band and will detect those stations whose difference frequency from the mixer equals the IF (455 kHz in this case).

There are several advantages of superheterodyne receivers over straight receivers. The gain and the selectivity obtained from the intermediate frequency amplifier do not depend on the frequency of the signal. The intermediate frequency can be made lower than the signal frequency, resulting in a higher stage gain and a narrower response curve than is possible at the signal frequency. The intermediate frequency circuits are cheaper and take less space than the signal frequency circuits. There is less risk of undesired feedback within the intermediate frequency amplifier, and screening is easier. The total radio frequency gain is distributed over two frequencies so that overall-feedback is less dangerous.

There are also some disadvantages of the superheterodyne receiver. The receiver has a tendency towards increased receiver noise. Spurious responses may result from the increased receiver noise [8]. By using a superheterodyne receiver of the narrow band type, the EA-6B gains the qualities of high sensitivity (gain), high selectivity (frequency discrimination), and a relatively broad frequency operating range through tuning. Since the signal of interest must be present at the front end of the receiver when the local oscillator is tuned at the right frequency for detection, a problem in detecting a varying

signal, as in the case of a scanning radar, may occur. "The tuning rate of the receiver, frequency band to be tuned across receiver bandwidth, and availability of the signal at the front (a function of power, beamwidth, and scan) determine a probability of intercept or detection" [4]. Therefore, the largest disadvantage of superheterodyne receivers is an increase in time required to detect an emitter and the possibility that no detection will occur at all.

A unique design of the vertical stabilizer allows for housing of each receiver within an oblong structure at the top of the vertical stabilizer frequently referred to as the "football". The two lowest band receivers are not located in the football, but are housed along the outside and mid-section of the vertical stabilizer due to their longer length (Figure 3-2). Each of these receivers are designed to intercept a specific spectrum or "band" of electromagnetic emissions. They can be programmed to search their entire spectrum, or can be programmed for specific frequency search within their spectrum. This is controlled by the Central Mission Computer (CMC) based on an accessed library of specific emitters. If the library of emitters does not include the entire frequency spectrum of a specific receiver, the receiver will simply skip those portions of the band it is not required to search. This expedites receiver scanning in the critical frequency ranges.

Once an emission is detected, it is then processed for identification. The two units which perform the function of processing the signals are the Computer Interface Unit (CIU) and the Encoder. In BLOCK-82 aircraft, these units exist and operate separately. In BLOCK-86 aircraft, the two units are combined as a single component (CIUE).

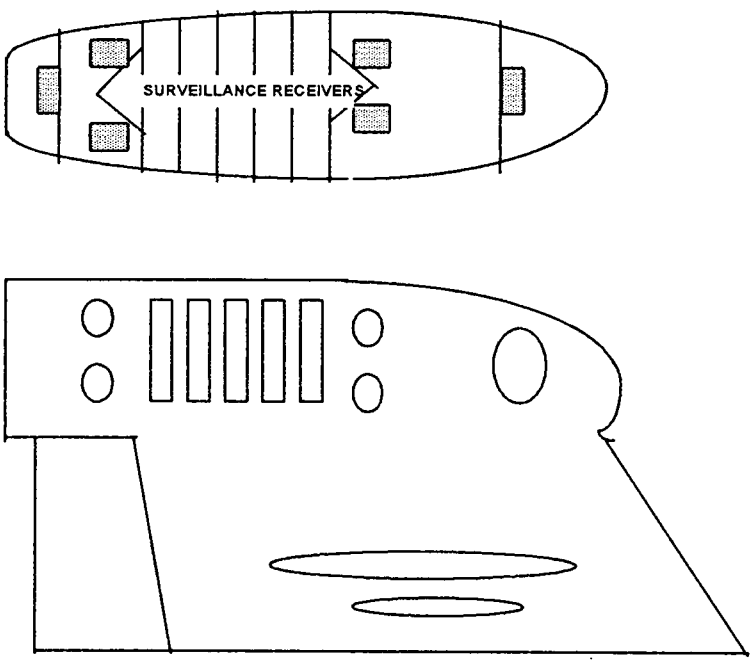


Figure (3-2)

ANTENNA/RECEIVER COMPLEMENT OF THE EA-6B

Regardless of connectivity, the end product is the same. A measurement of electromagnetic parameters are made and converted to digital format. In addition, timing functions via a clock housed in the CIU/CIUE are used for calculating and recording time of intercept and direction of arrival.

Once these functions are completed, the received pulse data is sent to the CMC. In both BLOCK-82 and BLOCK-86 aircraft, the CMC is the nucleus of information processing. Not only does it perform signal analysis by comparing intercepted electromagnetic emission pulse data to stored library data, it also performs several other mission critical functions. These include navigation, calculation and integration for locating sources of electromagnetic emissions. Navigation calculations are also integrated into the jammer management schematic by assisting in directing the jamming transmitters toward the intended target. The CMC jammer management functions are not limited to just steering functions. In addition, the CMC allows the operator to provide optimal jammer assignments using a tailored priority structure against intended emitters which are referred to as targets. The CMC assists in integrating the High Speed Anti-radiation Missile (HARM) against targets as well. Finally, the CMC interfaces directly with the operator by executing operator commands, providing alert or status information, and recording critical mission events. Operator interface with the CMC is through the Digital Display Group (DDG) which consists of a Digital Display Indicator (DDI) similar to a computer monitor and a Digital Display Console (DDC) equivalent to the keyboard. These displays and controls provide the operator with a variety of visual information.

The information includes an accounting of the current EW environment, system states, and the ability to adjust system parameters with tactical requirements.

A second computer existing in the OBS also assists the operator. This computer is known as the Display Computer (DC). It acts as a liaison between the operator and the CMC by interpreting operator commands, ensuring completeness of required information in those commands, and passing the information to the CMC. The DC controls all the displays which pass information between the CMC and the operator.

Analysis of recorded data is required for complete post flight intelligence collection assessment including any possible battle damage assessment (BDA). To perform this function, a recorder reproducer set (RRS) is integrated into the onboard system. The RRS performs two functions. It not only records critical mission data including electromagnetic intercepts, navigation history, and jammer assignments, it also functions as an onboard program loader (OPL), used to program mission libraries into the CMC and DC. The OPL is comprised of two transportable tape storage units or cassettes which can be configured to load or record mission data, a tape control assembly (TCA) which interfaces with the CMC and DC, and computer load panel (CLP) which provides the interface control for the operator.

Several peripheral controls external to actual manipulation of the receiver and jammer assets yet critical to providing information for the correct manipulation of those assets are also a part of the onboard system. They include the HARM Control Panel (HCP) which is used to pass target library data to the HARM missile and arm the missile for launch; Control Display Indicator (CDI) which provides additional HARM targeting data

and navigation data to the CMC for jammer steering management; and the Interface Control Unit (ICU) which enables control and exchange of data from the inertial navigation system via a data bus.

The link between all these hardware components is a military standard 1553 data bus. It provides the connectivity and exchange of information between the CMC, jammer pods, HCP, DC, CDI, RRS, inertial navigation system (INS), CIU/E and ICU. Two 1553 data buses exist, one primary and one secondary. Each is singularly capable of providing complete data passage between hardware components as well as allowing operator manipulation.

EXTERNAL STORES

The second component of the TJS is the external stores. They include the tactical jammer pods and HARM. Additional fuel tanks, chaff dispensing pods, and training aids may be loaded on the external wing stations and fuselage centerline. However, unlike the jammer pods and HARM stores, these components are not integrated with the TJS.

The tactical jammer pods consist of various components which allow them to be tailored toward specific frequency spectra. Their power is provided by a generator which is driven through an external ram air turbine (RAT). The generator drives the universal exciter (UE). Production of the waveform modulations is the function of the UE, so named since it is able to produce modulations for any frequency band the EA-6B is designed to jam and is therefore interchangeable between different band pods. As the aircraft reaches a specified airspeed, sufficient power is produced through the generator

to power the UE and transmit through two internally mounted transmitters. These transmitters are connected to antennas which further modulate the energy to within their designed frequency spectrum. In other words, the only components in each pod which dictate the frequency spectrum of jamming are the transmitters and antennas.

The HARM missile is the EA-6B's only offensive hard-kill air to ground missile. It was designed for suppression of enemy air defenses (SEAD) and is programmable via the CMC. The operator passes specific threat data to the HARM missile which then searches for these threats in a specified search pattern. Once a threat is detected through the missile seeker, the weapon will track and home using internal guide laws. Integration between TJS systems are described in Figure (3-3).

SUPPORT EQUIPMENT

Support equipment can generally be defined as equipment which is an integral part of the EA-6B ES and EA capability, but is not physically integrated with the CMC. The only support equipment which integrates with the TJS is the Tactical EA-6B Mission Support System (TEAMS) used for pre-mission planning. Defensive Electronic Countermeasures (DECM) systems are stand-alone systems not integrated with the TJS. TEAMS is the pre-mission planning and post mission analysis computer for the EA-6B. As a pre-mission planning tool, TEAMS allows the operator to assess the electronic order of battle (EOB) for specific geographic areas. The system is run in a windows menu type environment allowing the operator to access information and tools from a variety of displays. A map display is available on TEAMS for greater situational awareness of

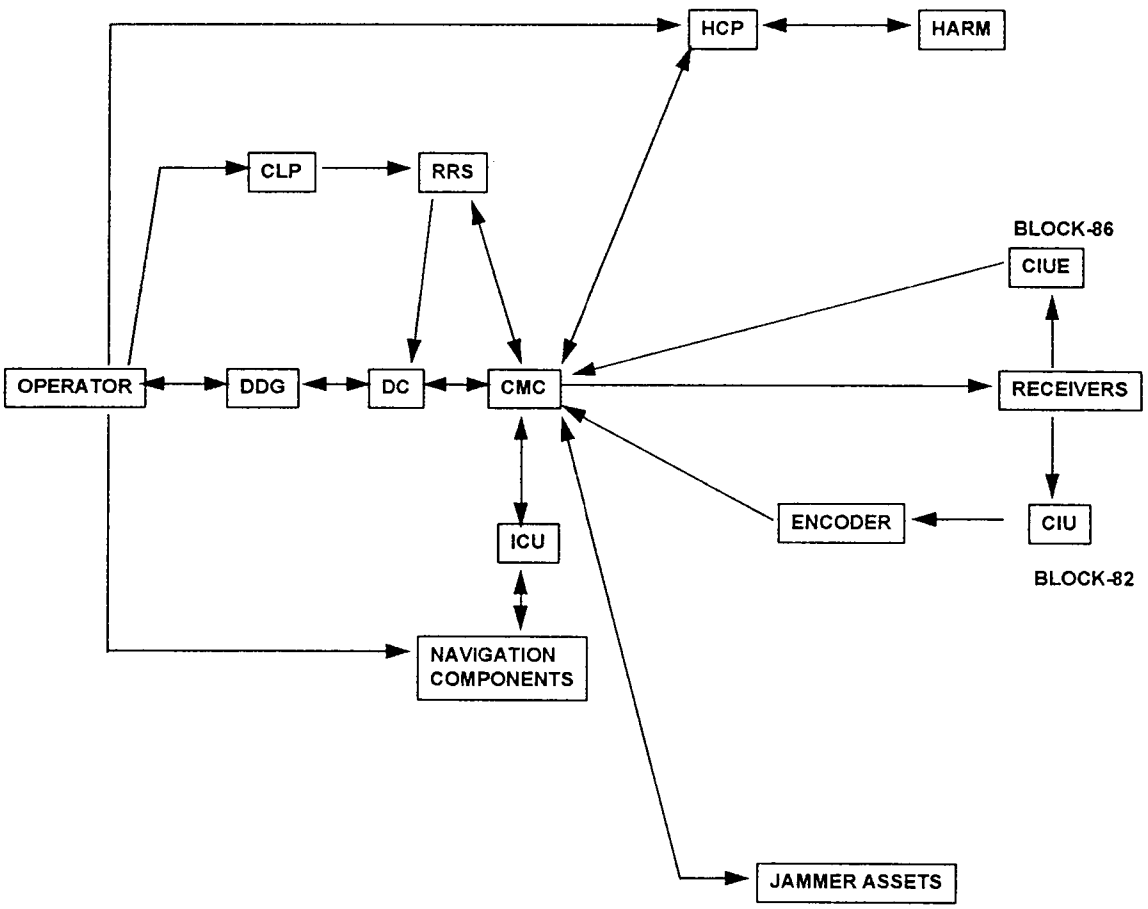


Figure (3-3)

HARDWARE INTEGRATION

potential threat system location with respect to the strike package and EA-6B flight routes. TEAMS houses the complete EOB database, of which specific libraries, as designated by the operator, are then loaded to a digital RRS cassette tape to load into the EA-6B OBS. In addition to these libraries, TEAMS holds the initialization programs for both the CMC and DC. The RRS passes specific database and map information to the CMC and DC as determined by each mission. In addition, the RRS can initialize the CMC and DC if those program loads are not already resident on each computer. During the flight, the CMC feeds information back to a recorder configured RRS for post-flight analysis on TEAMS.

SUMMARY

The EA-6B weapon system, referred to as the TJS, is a highly integrated system. It combines systems internal to the aircraft structure with weapon components which are externally mounted. In addition, there is significant human-machine interface required to adequately operate the weapon system. The complexity of the system requires a specific mission planning system (TEAMS), allowing the operator to adequately program on-board computers. The number of components within the weapon system and the high degree with which they are integrated requires a correspondingly complex software load in order to adequately operate the system and execute the EW mission.

CHAPTER 4

AUTOMATION THEORY AND APPLICATION

Theory of Automation and Artificial Intelligence Integration in Combat Aircraft

AUTOMATION CONCEPTS

Several studies have been done by Navy and Air Force developmental organizations regarding the automation of aircraft EW systems. The increased sophistication of aircraft instrumentation and weapons systems to counter the advancements in threat technology has proportionately increased the demand on aircrew to effectively operate those systems and accomplish mission objectives. Applications of automation integration for aircraft EW system are numerous and range in levels of complexity. However, it is virtually impossible to set "requirements" for the degrees of automation required generically for EW systems since the specific application is both operator and system dependent. The limitations of the operator, the complexity of the system, and total tasking (mission) requirements are what dictate the extent of automation integration. The studies show exact rules do not exist, however certain guidelines of automation implementation are available. In order to understand how automation can successfully be implemented into EW systems, one must first understand the general concepts of automated systems.

There are a plethora of studies done regarding automation and artificial intelligence (AI). There is only vague distinction between where automation ends and AI begins. AI is usually associated with machines which work autonomously. In general, AI and

automation differ by the systems capability to process natural language, apply perception to task completion, retrieve and store intelligent information, play games, receive automatic programming, incorporate computational logic, and solve complex problems [9]. However, automated systems do not necessarily exclude any one of these capabilities. They may incorporate some or all of those qualities to some degree. For the purpose of discussion, the term automation will be used with the understanding that some qualities of automation discussed may be considered AI applications.

Several plateaus exist in which automation can be incorporated into a system. In the most simplistic form, the automation only informs the operator of some relevant information, leaving all action to the operator. In its most complex form, the system collects information and takes action without informing the operator. The degrees to which the automation includes human interface is known as supervisory control. There are different stages of supervisory control [10]. These stages are based on the relationship between the operator and the computer and the degree of a task completed by each. In general, the stages can be divided into three main categories. Category one is the relationship where no assistance is given by the computer in designating options. The operator determines all the options and only accesses the computer to execute the option chosen. Category two encompasses those situations where options are provided by the computer, but no automated action is taken by the computer. The operator assesses the options proposed by the computer. If one of the options is accepted by the operator, then the computer is directed to execute the option chosen. Category three encompasses those situations where the computer provides options and takes action.

Category three is divided into additional echelons based upon the operator's ability to reject the action and the amount of information provided to the operator. In the most automated echelon, the computer takes action and only informs the operator when it determines that it is required.

Reduction of operator workload appears to be the central theme in each of the Navy and Air Force studies. "Less work through machine substitution of physical and mental labor" [11] is a primary objective of any automated system. However, the studies also conclude that the automation should be designed to assist rather than replace the aircrew regardless of the type of systems to be automated. Specifically, they exclude those levels of supervisory control where the operator becomes too far removed from the action implementation process. When implemented correctly, the automation performs tasks and analysis normally required of the operator but which does not require an operator's professional judgment. These tasks are frequently executed in a manner suited toward the methodical methods of automated systems and are the nucleus of successful mission accomplishment. Automated systems which perform this level of supervisory control are referred to as "Expert Systems" and will be the primary emphasis of discussion.

EXPERT SYSTEM DEVELOPMENT AND PERFORMANCE

Automation and subsequently, artificial intelligence, developed in phases. Initially, development of automation was approached from the purely mathematical standpoint using predicate calculus. However, using such a method was sufficient only for accomplishing simple tasks. The next research phase involved developing efficient

computer search algorithms to limit the size of the problem to manageable proportions. This was done by using "heuristics"- strategies to minimize the number of nodes that have to be searched [2]. As a comparison, consider that algorithms try all possible solutions while heuristics uses "rules of thumb" for faster resolution [12]. The current application of automation integration is known as "knowledge engineering" or the "expert systems" approach. Knowledge engineering is the compilation of rules that experts rely on when doing problem-solving in the course of their professional work. The rules are arranged in a logical sequence, called a production system, that forms a rule base. The rule base then is integrated in the expert system, and is used to solve real world problems [2].

There are both conventional rule-based expert systems employing binary logic and those which employ "fuzzy" logic. Fuzzy logic is the use of algorithms which attempt to simulate the human reasoning process when supplied with vague or ambiguous data [13]. According to the Navy and Air Force studies, the "fuzzy" logic approach to automating EW systems has not been implemented to date. Therefore, discussion will focus on binary expert systems which implement rules through a tree-like reasoning structure.

The term "expert system" evokes different images of the relationship between man and computer. In general, expert systems are designed to support a human operator in expediting problem solving beyond simple data processing [14]. Data processing is based on algorithms which resolve specific problems. In contrast, expert systems access "domains" of knowledge, applying that information to resolve a problem. The most elemental components of an expert system are knowledge (knowledge base) and

reasoning (inference component) [15]. The expert system operates by analyzing and classifying domain knowledge. When multiple domains exist, they can be consolidated and compared by the expert system. In addition, past experience is applied to the process of evaluation, and recommendations are made to the operator who interfaces with the system. In summary, the functionality of an expert system is defined by a " collection of assertions gathered into a knowledge base containing facts, assumptions, definitions and heuristics." [16]. The inference component then uses the knowledge base to respond to questions.

The capability of the expert system to access multiple knowledge domains should ease tasking on the operator. By performing in this manner, the expert system acts as a resource, a colleague, an assistant, and in some instances, a substitute [14]. Consider a knowledge domain which is used to interpret sensory data. This domain will be a large and encompassing data base overwhelming an operator who would have to retain the information mentally. An expert system applied to this domain acts as a resource, enabling the operator to correctly classify and identify the sensory data quickly without a significant research or recollection effort.

As a colleague, the expert system performs the functions of checking the operator's reasoning process, provides alternative solutions or guides him through a solution process. The example of classifying sensory data applies in this function of an expert system. After the expert system matches the sensory data to options contained in the knowledge domain, the operator must then select the best alternative. The expert system can assist by informing the operator which of the possible alternatives are "best fit". In

other words, the sensory data may have detected a system operating in a preferred operating range. If there are multiple choices, yet only one choice involves the preferred operating ranges, the expert system may prompt the operator in selecting the best fit alternative. In addition, the expert system can reduce the total possible selections by comparing the possible solutions to other domains (e.g. geo-location) applicable to the sensory data. As such, the expert system acts as an assistant or guide to the operator.

As a substitute to the operator, the expert system performs functions that the operator is not capable of completing. In order to correlate sensory information, the intercepted information must be processed into digital format. Often, the processing of sensory data includes functions which the operator is incapable of calculating. Extremely accurate timing calculations needed to assess the sensory data epitomizes a function where the expert system substitutes the operator.

The benefits of an expert system toward final completion of the mission are numerous as they increase the operators ability to resolve problems required for mission accomplishment. These problems include speed, ambiguity, simultaneous tasking, human emotions such as confusion or uncertainty, redundant mistakes, conflicting constraints, and complicated chains of reasoning [14]. Human operators are limited in capacity and prone to outside stimuli. Expert systems, when designed properly, either relieve the operator of these limitations or allow the operator to successfully work through them.

In a world of high performance aircraft and similarly advanced anti-aircraft weapons, system design to counter those systems requires accurate and real time response

capabilities. Expert systems which complete the sub-problems in short order relieve the human operator of tedious and time consuming operations. As such, the operator can counter the advanced weapon systems.

Frequently there are multiple domains of knowledge which must be accessed in order to come to an accurate conclusion. It may be difficult for an operator to independently access each of these domains and assess whether relevant information to resolve a problem is available. Expert systems do not neglect this information as an operator is prone to do. They are able to correlate all sensor data and apply it to all applicable domains to reach the best possible conclusion.

Simultaneous tasking is the nemesis of efficient operator performance. It is easy for an operator to become overloaded, often ignoring or delaying other tasking while attempting to resolve the problems of a single task. Insignificant details further exacerbate the situation. Expert systems, when designed properly, apply only relevant knowledge and are able to draw quick conclusions allowing for successful completion of simultaneous tasking.

In a hostile environment, a human operator is subject to emotions of stress, fear, and self preservation. All detract from the ability to operate efficiently. The operator is prone to miss relevant information while these emotions are in play. Expert systems are not subject to this adverse stimuli and continue to operate at maximum performance levels.

Operators are prone to mistakes. Since expert systems are a product of human operator design, they are also prone to mistakes if there is an error in the design process

or if the domains which the expert system accesses are incomplete. However, expert systems follow a specific chain of reasoning. Unlike a human operator which can make the same mistake twice following different reasoning chains, once the error in the expert system is identified, it can be corrected avoiding further mistakes.

Conflicting constraints can preclude both an operator or an expert system from resolving a problem. If only portions of information required to resolve a problem are available, and these portions are contradictory in nature, the best possible solution must be identified. Human operators may not be able to weight or prioritize the information using a defined method. If an expert system is designed correctly, it can assess the conflicting information, determine which carries the most significance, and draw conclusions accordingly in a consistent manner. "Classical, first order logic is not adequate to represent default reasoning" [17]. Expert systems are designed to go beyond simple comparisons where conclusions are only drawn from a simple "match" or "no match" criteria.

Human operators tend to be overwhelmed by long and complicated reasoning chains. When multiple domains must be accessed to draw a conclusion, it is not uncommon for successful problem resolution to require access to each of the domains multiple times. An operator may find this process overwhelming and time consuming. Conversely, expert systems can be designed to approach the problem solving process in a methodical manner that can be relied upon consistently. Expert systems are well suited toward resolving complicated reasoning chains since "expert behavior is characterized by high performance problem solving behavior in a specific domain" [18].

It can be concluded that the advantages of expert systems are dependent on the correctness of design characteristics. However, design characteristics have proved to be obstacles which detract from the usefulness of expert systems introduced into EW systems. The specific obstacles include a lack of standard architecture, no rules for the methodology used by expert systems in problem solving, and no specific guidelines for correcting and maintaining expert systems [14]. Expert systems retrieve the required information from each of the knowledge domains. However, these knowledge domains are products of humans and are therefore subject to their shortcomings. Additionally, there are no set guidelines to the establishment of the domains or how they integrate with the expert system. Each time an expert system is designed, the guidelines used are subject to the interpretation of the designer. The architecture of the system designed is based on the problems to be solved. There are no set procedures since problem solving requirements vary from system to system. In addition, the designers are limited to the equipment, languages and models that are available to them or with which they are familiar.

The final obstacle is the interface requirements between the expert system and the operator. The expert system is designed to support the operator. In order to do so, it must be able to communicate to the operator with means that are understandable. Displays and the data or language presented on those displays must conform to the operator's limited comprehension ability. Human-machine interface must be sufficient for the operator to easily extract the expert system's product. In addition, the operator

must understand the reasoning with which the expert system arrived at its solutions in order to best use the information.

Maintenance of expert systems pertains to the ability to modify or correct its operations. Testing of the expert system relies on a comparison of the results of the expert system and the results the designers of the expert system expected. This presumes that the engineer is able to emulate the expert systems process. Subtle modifications of the accessed domains through the data stream and chain of conclusions can cause large differences in the end product of the expert system. Assuming the data stream and chain of conclusions are not too long and complex, testing can be used to check the expert systems problem solving capability [14].

EXPERT SYSTEM DESIGN

An expert system design includes several major components. They are the expert knowledge engineer, a knowledge base supporting knowledge acquisition, the domains of knowledge, an inference engine for consultation, and finally the operator or end user as described in Figure (4-1) [14]. These components describe the modules which make up a simple expert system and how they interface. The knowledge engineer builds the knowledge base using personal expertise gained in that domain. The engineer also establishes and organizes the facts for the domain of knowledge, and formulate the rule base for the inference engine. The end user or operator interfaces with the inference engine by requesting problem resolution, accessing the options of the inference engine, and initiating task execution when required.

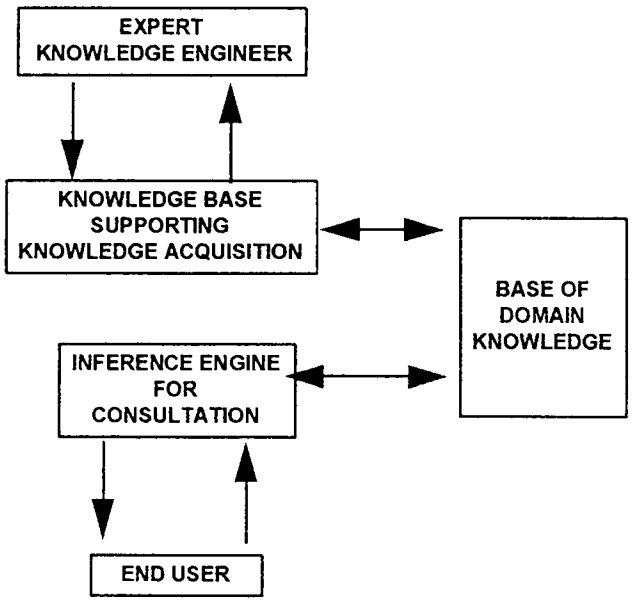


Figure (4-1)

BASIC EXPERT SYSTEM DESIGN

The manner in which an expert system operates can be either static or dynamic. A static expert system is one which is designed without any possible functionality modification by the operator. The operator understands what functions are performed by the expert system and no modification is made in that capability by the operator. In contrast, some expert systems can operate dynamically. In a dynamic system, the operator can elect to use all, some or none of the functions of the expert system. When an expert system is designed dynamically, the operator is afforded additional control over automated processes.

In conclusion, the key to a successful implementation of an expert system is ensuring proper delegation of responsibility between operator and expert system. Operators must trust and direct the expert system since aircrew members distrust automation when they are not afforded the ability to control it [2]. Incorporation of automation must be balanced between reducing workload of the operator while allowing full comprehension and executive control by the operator. A certain level of trust is afforded data processing systems which handle complex data processing tasks. However, expert systems are based on artificial intelligence technology which is relatively new technology only recently being introduced in practical application. The delegation of responsibilities to expert systems should be introduced in stages. If done correctly, the expert system can advance logically and correctly while the operator gains trust in the system through experience.

AUTOMATION IN EW SYSTEMS

As a result of the proliferation of advanced threat systems, aircrew members encounter a high-workload environment while executing mission objectives and controlling EW systems implemented in their aircraft design. In order to adequately manage this increased workload, some form of automation is required. Effective implementation of automation in EW systems requires modeling after generic expert systems.

As with any automated system user, aircrew distrust automation which operates or executes without adequate interface [19]. The most prevalent area of concern is with issues affecting safety of flight. The FAA has conducted studies on the failures of adequate interface between pilots and their highly-automated systems which have lead to "accidents or incidents" [20]. The same concerns are true for military aircraft weapon systems required for mission accomplishment. As a result of these studies, there are several requirements for successful implementation of automation in aircraft EW systems. The aircrew must maintain executive control over decision making processes. The amount of control depends upon the EW system to be automated. Automation must accommodate changes in the tactical environment, allowing the operator to adjust quickly to changing mission objectives. Finally, the automation must operate such that it does not interfere with other aircrew tasking nor interrupt system integrity [2].

Automation of ES and EA systems of combat aircraft has been applied in the past. It has been used to interpret sensory data of electromagnetic emissions and apply countermeasures either offensively or defensively. Correlating received sensory data such as frequency, pulse repetition interval (PRI), pulse width, and scan type/time to a

database relieves the operator of lengthy comparison requirements. Additionally, EA systems designed to jam these systems can be tailored to automatically provide optimal jamming with various levels of operator intervention depending on the type of EA system. When ES and EA applications are combined into a single EW system component, the two taskings can be tailored to work in conjunction with each other. In general, successfully automated EW systems have incorporated the ability to maintain an awareness of the tactical situation; monitor their own aircraft status; execute critical tasks as directed by the operator; and manage mission tasks so that they are performed efficiently [21].

The level of automation implemented in EW systems depends upon the function of the system. The task allocation between the operator and the automated system must be resolved before the automation is implemented. The amount of automation in a system must also be adjustable. When the automated functions are strictly set, a shortfall may occur since such a design is a static answer to a dynamic problem. Too much automation can result in aircrew loss in situational awareness or laziness. Too little can leave the aircrew overwhelmed in task completion. The solution is that the automation should be interactive and should always allow the aircrew to have active control over the system [2]. In other words, automation integration for EW aircraft and systems is best implemented as a dynamic expert system.

An EW expert system is defined by a hierarchy between the aircrew, the computer assistant, and the sensors and weapon systems which will be controlled. The hierarchical automation relationships are shown in Figure (4-2) [2]. The model shows the ability of

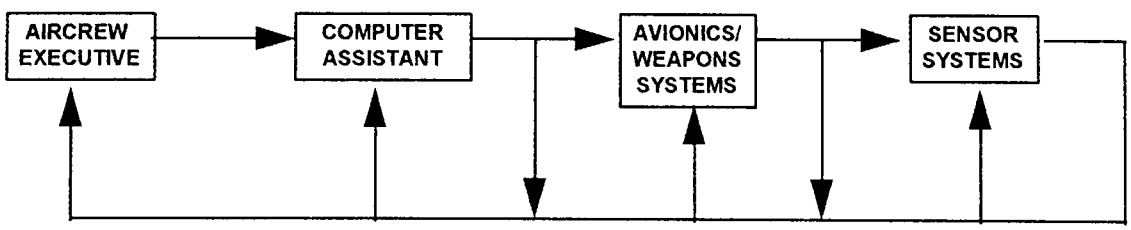


Figure (4-2)

HIERARCHICAL CONTROL MODEL

the aircrew to intervene or access avionics, weapons, and sensor systems either through computer assistance or directly when required. It also indicates the ability of the computer and accessed systems to operate automatically when required and when the software is tailored as such. Since the tactical situation is the variable which determines task allocation, this hierarchy allows for adaptive task allocation based on the executive's (aircrew) desires. Rather than having a static automation process, the allocation of tasks is adaptive or dynamic. The executive decides at any given time which functions need to be handled by the expert system and which should remain aircrew responsibility. Depending on the dynamics of the mission, aircrew may select to exclusively accomplish tasks during one portion of the mission and then opt for the expert to complete all or part of the task during other portions of the mission. For instance, all radar jamming functions of the aircraft could be automated while the operator concentrates on targeting and launching an anti-radiation missile against a radar which has been assessed as a threat to the strike group. This would allow the aircrew to be neither overtasked nor underutilized at that time, adhering to Air Force studies which concluded that aircrew are most efficient when moderately tasked [2]. Moderate tasking is dependent on aircrew expertise. Therefore, a less experienced operator may choose to automate more functions allowing focus on other important tasks. More experienced operators may feel comfortable automating fewer tasks. In general, aircrew tasking would center on decisions critical to overall mission accomplishment while the expert system assistant performs subfunctions which would otherwise overload the aircrew at any given time.

When implemented correctly, adaptive automation will effectively reduce operator workload to a manageable level without usurping the operator's decision-making prerogatives. As with a generic expert system, an EW expert system incorporating dynamic automation will have three main functioning modes. The least automated mode of a dynamic system is when it simply monitors and informs the operator of events (Category I). The next mode incorporates recommendations and implementation by the expert system as it suggests an action and executes upon aircrew confirmation (Category II). The last mode of a dynamic EW expert system is a near or fully automated mode in which actions are taken automatically when pre-specified conditions are met (Category III). Figure (4-3) illustrates adaptive automation [21].

Supervisory control is maintained by the aircrew while the computer acts as an assistant. The computer notes important events such as threat detections or system hardware and software failures and faults and brings them to the attention of the operator. Expert system automated functions as designated from the tasking database are controlled by the operator. Additionally, the mode of automation in the execution of the selected task is also controlled allowing for dynamic automated functions based on aircrew requirements and the tactical environment.

Figures (4-2) and (4-3) do not include the knowledge domains which must be accessed by the expert system. There are several domains inherent to electronic warfare systems. They include but are not limited to domains of pre-mission (intelligence) data, jammer assignment data, weapons system targeting data, and signal analysis data as depicted in Figure (4-4).

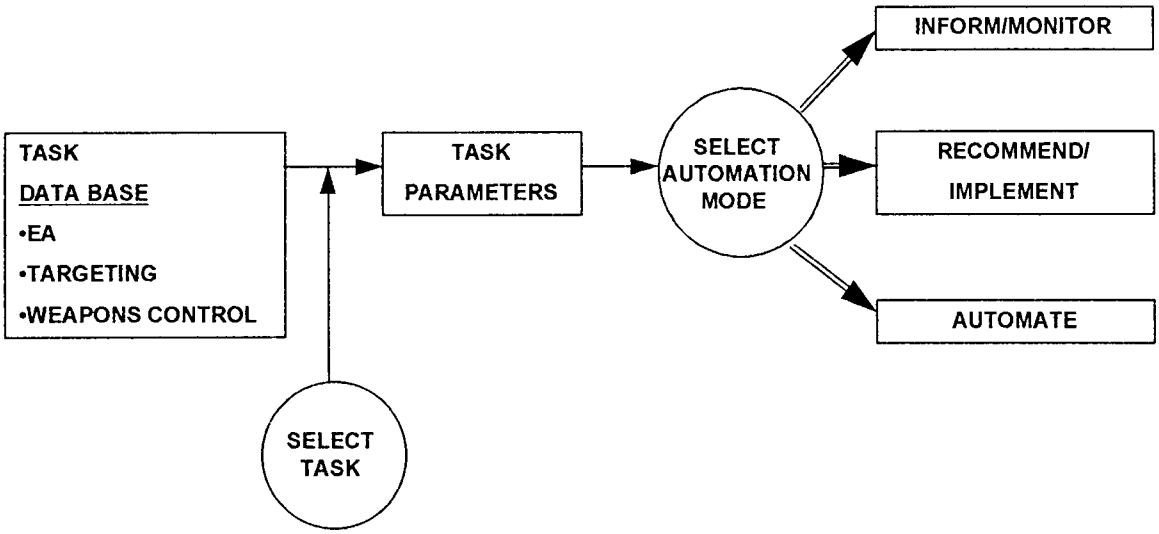


Figure (4-3)

ADAPTIVE AUTOMATION CONCEPT

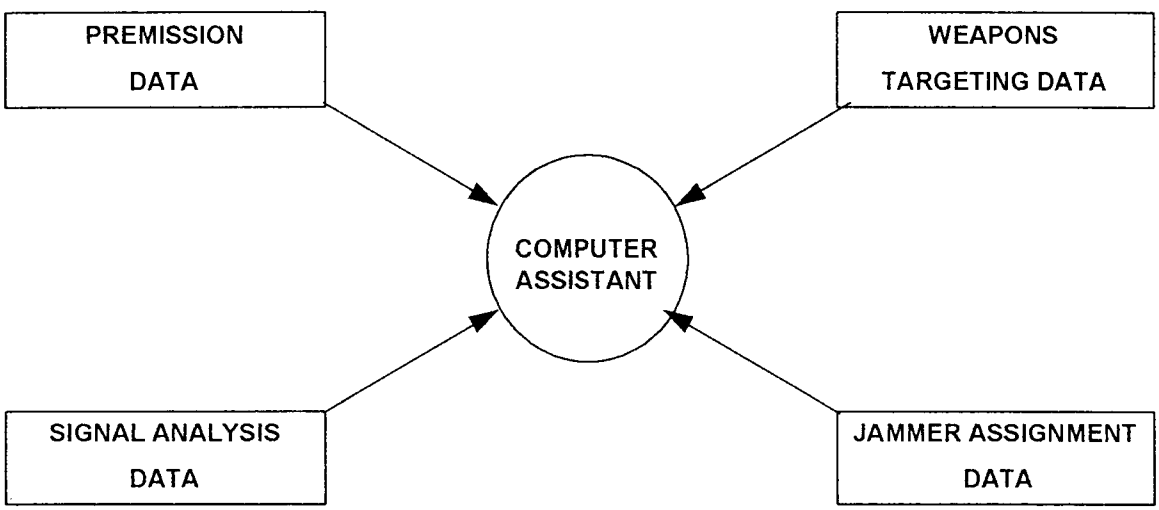


Figure (4-4)

KNOWLEDGE DOMAIN INTEGRATION

ARCHITECTURE OF ES AND EA SYSTEMS

Based on these design characteristics, the base architecture or model of an EW expert system can begin being structured. One obstacle to successful final structuring of an expert system is the complexity of the system. The intelligent algorithms necessary to coordinate the automated decisions also contribute to problems of expert system architecture. There must be multiple algorithms that not only allow the expert system to access sensory and weapon systems, but also interface with the aircrew. Often the algorithms are based on the process if [event A], then [(action) or (conclusion B)] [2]. The logic architecture can be subdivided into categories depending on the information externally derived. This can help alleviate the requirement for lengthy algorithms. In addition, the rule base expert system can respond to critical events differently. In no case can rule based systems be designed to understand the entire system, only respond to certain critical events.

ES SYSTEMS

Detection of electromagnetic emissions is one such critical event. ES systems must be able to detect the wide range of sophisticated air defense systems with which the aircraft will encounter. A complete understanding of the threat would require the reasoning capability of a human operator and is an unrealistic requirement of an expert system. However, the operator can be assisted by an expert system interfacing with aircraft and other sensors in the detection, identification and location of threat systems. If sensor data were only compared to pre-mission data, the expert system would be static in nature.

Integrating a capability to use sensor data to make a determination of the threat environment resulting in a modification of sensor search patterns makes the expert system dynamic. In order to do so, the expert system would have to incorporate the capabilities of interpretation , perceptual reasoning, anticipation, and organization of information gathering resources [22].

Interpretation of sensor data involves more than just comparison to pre-mission data. It also involves the ability of the system to account for errors in detection such as ambiguities, false alarms, and misidentifications. Ambiguity resolution is the ability of the system to understand that more than one possible interpretation of the sensor data is possible. False alarms are a result of spurious inputs to the sensor resulting in what appears to be a valid resolution. Misidentifications are incorrect resolutions of sensor data which may or may not be inconsistent with the tactical environment.

Perceptional reasoning is the human ability to develop an understanding of a given situation based on stimuli from multiple sources. Although no current system is fully capable of replacing a human in this ability, a portion of this capability can be performed by an expert ES system. A computer which can interpret sensor data based on pre-mission data, organize the sensor data to draw conclusions, and modify sensor coverage to receive additional data describes a limited perceptual reasoning capability.

Anticipation is the ability of the system to forecast future detections. In order for an expert system to anticipate the environment, it should have access to map data for the operating theater; geometric data which allows prediction of additional threat locations given the position of known related threats; temporal data which describes the sequence

of events a threat system will follow as it operates; and environmental effects which influence threat system operations. Given this information, the expert system can predict possible detections and adjust sensors accordingly.

Organization of information gathering resources is the capability of the expert system to determine which sensor is best suited to detect an anticipated threat. The suitability of a sensor would be determined by the particular guidance mode of a system. Based on a knowledge of possible sensor system capabilities, the expert system would select and operate or adjust the most appropriate sensor.

EA SYSTEM ARCHITECTURE

EA system architecture is integrated with ES system critical event reporting. An automated EA system is designed to produce or direct optimal jamming or hardkill asset against a detected threat in a short period of time. This capability is best exercised when it is available against multiple threats simultaneously. It should also be able to operate efficiently, supplying only critical knowledge to aircrew without interrupting other aircrew functions. In this manner, a properly designed EA system will increase aircraft survival in a hostile environment without interfering with mission objectives.

An expert EA system will assist aircrew with several specific tasks. Associated domains accessed by the EA system supply knowledge of particular threats on a specific mission and provide an assessment of the tactical situation. The inference engine of the EA system will include rules which provide a pre-plan and re-plan capability in the allocation of jammer and hardkill resources, adapt jammer techniques and parameters to

threats actually encountered, and monitor effectiveness of the EA response [23]. Such a system is described by Figure (4-5). In Figure (4-5), the inference engine utilizes rules which allow it to select the best EA response and determine asset allocation. The asset allocation could include any one or combination of anti-radiation missile (ARM) employment, jammer pod activation, defensive electronic countermeasures (DECM) activation, or EA expendables employment. In addition, the inference engine can access effectiveness monitoring tools to determine if the action taken was adequate or if additional EA is required. Figure (4-5) also represents an adaptable or dynamic expert system, allowing the operator to select the level of automated function of the inference engine as desired depending on the tactical situation.

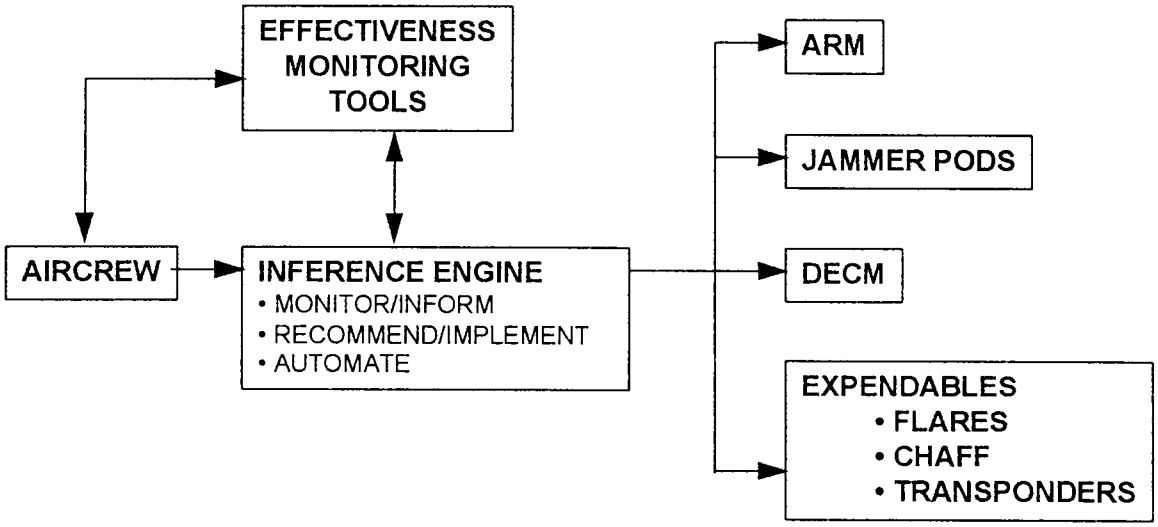


Figure (4-5)

EA EXPERT SYSTEM

ES AND EA SYSTEM INTEGRATION

Figure (4-5) does not include integration of sensory data. Rules are developed as part of the inference engine design for sensor data display and integration with the operator or weapon system. The method in which sensor information is processed by the inference engine follows a specific logic chain as depicted in Figure (4-6) [2].

This figure depicts the relationship between received sensor data to functions of an Inference Engine. In this example, data enters into the inference engine from sensors (external or on-board). Certain rule-based functions trigger three types of software logic depending on the significance of the critical event and compares the result to the operated selected mode of automation. They are Emergency, Executive, and Control/Display logic.

Emergency logic involves engineering design for automated response. If the operator has selected the automated task completion mode, then the emergent event will result in automated execution by the expert system. Emergency logic correlating to a fully automated response may be allowed by the aircrew in those instances where rules of engagement (ROE) are relaxed or reaction time required is more stringent than the aircrew are capable of executing. The initiation of defensive electronic countermeasures (DECM) in the presence of a surface to air missile (SAM) threat is an example of emergency logic. The aircrew allow themselves to be removed from emergency logic actions.

Executive logic involves received sensor data which does not pose an immediate threat to the aircraft but may require an adjustment of the weapons systems. The operator may

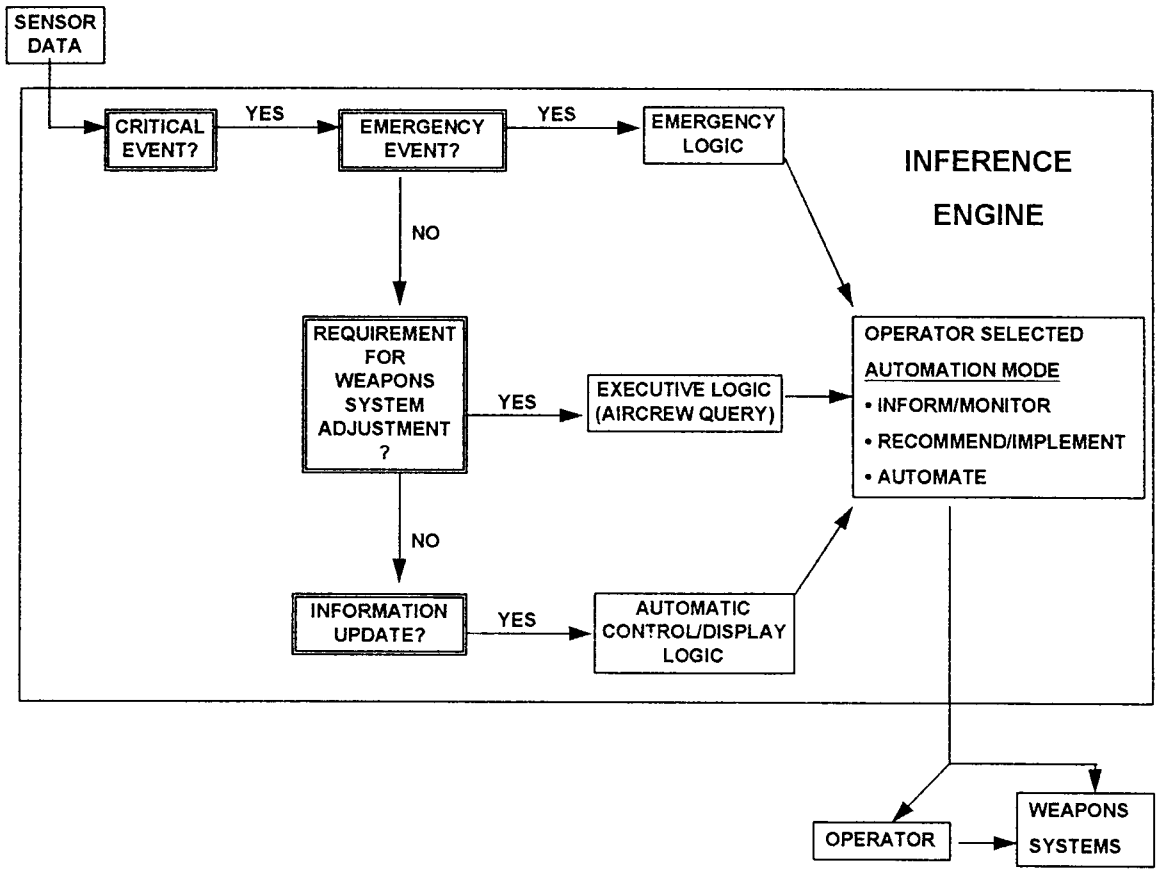


Figure (4-6)

INFERENCE ENGINE LOGIC CONCEPT

elect to fully automate the weapons system adjustment or intervene at some stage. If the "recommend/implement" tasking mode is selected in conjunction with executive logic, the expert system makes suggestions to the aircrew who may either accept or reject the recommendations. In a dynamic expert system, executive logic can be associated with any of the three automation modes.

Automatic control and display (ACD) logic is reserved for sensor derived information which does not require any action. This logic is associated with information management for the aircrew. Unlike emergent or executive logic, ACD logic would only be associated with the "inform/monitor" task mode. Friendly or non-hostile sensor detections would be presented to the operator through the ACD logic. If multiple displays are available, the expert system can select the best display to relay the information to the operator.

HUMAN FACTORS ISSUES

An additional issue regarding automated systems is their capability to interface with the human operator. Human-machine interface must be such that a common language or other understandable communication is used as the interface tool. The interface must allow the automation to adequately reduce operator workload rather than becoming a liability in task accomplishment due to inadequate, complicated, confusing, or misleading interface tools. Some of the major human-machine interface issues regarding EW

automated systems include automation allocation, control, flexibility, and display interface.

Automation allocation, control and flexibility have been described previously in the context of a dynamic expert system design. In the context of human-machine interface, EW system design must allow the operator to modify automated processes or override them when required. If the operator is unable to do so, studies have shown that the aircrew become passive and the information derived by the aircrew decreases. In addition, decreased involvement with the decision making processes frequently leads to delays or lack of response to system failures [24].

Display interface are the methods in which the automated system provides information to the aircrew. Critical display interface issues include interpretation of sensory data, threat recognition and task tracking. The displays must present visual or audio cueing to the aircrew of information gained via sensory data. If the information is not adequately displayed to the operator or is difficult to access, then aircrew will frequently not comprehend the full information available, lose situational awareness, and will make decisions based on partial information. As multiple sensor data is available simultaneously, the data must be categorized in some format. This will allow the operator to quickly recognize possible threats while disregarding non-pertinent sensory data. Finally, the displays must show the operator the tasks which are actively being completed, allowing the operator to maintain control over automated actions and make modifications as necessary.

SUMMARY

In summary, the proliferation of new avionics and EW weapon systems has dictated that the design of the inherent automation be such that it is a dynamic system, accounting for the capabilities of the aircrew. The levels of automation should be adjustable at any given time based on aircrew preference and the tactical situation. The aircrew should act as the executor over the automated system and in no case forfeit control of sensory or weapons systems functions. Finally, the interface between the expert system and the operator must be adequate for information transfer, easy task execution, and not interfere with other operator tasking.

CHAPTER 5

SSA-4.0 SYSTEM SOFTWARE LOGIC

An Exploration of EA-6B Software Design

DESIGN CONCEPT

The EA-6B incorporates automated characteristics as an inherent part of its tactical jamming system (TJS) and supporting software design. Based on the level of automation involved in EA-6B TJS functions and the relationship between the TJS and the aircrew, the EA-6B automation can be categorized as an Expert system. The automated processes of software are focused on signal processing, HARM targeting, and jammer management functions. Of the four expert system functions (resource, colleague, assistant, and substitute), the EA-6B expert system performs all in one capacity or another. In addition, the operator can modify the levels of the automated processes describing an adaptive or dynamic expert system.

The building blocks of the EA-6B expert system mirror those of the basic expert system as described in Chapter 4. It includes the domains of knowledge, inference engine, knowledge base and the engineers and users of the system. The control hierarchy is exemplary of the standard EW expert system hierarchy in which the aircrew are the executives, the central mission computer acts as an assistant, and both share control of the avionics, weapons systems, and sensor systems. In addition, the adaptive automated

concept and specific domains with which a standard EW expert system is defined are also similar to the EA-6B system.

The specific knowledge domains which the operator requires to execute the EA-6B mission are typical of what is required to execute EW. The six domains include signal analysis, tactics, pre-mission intelligence, jammer assignment, HARM targeting data, and jammer/receiver management as shown in Figure (5-1). Signal analysis is the comparison of intercepted electromagnetic emissions to radars which match those emissions. Tactics are the rules which govern the optimal employment of the EA-6B. Pre-mission intelligence includes any pertinent information needed to conduct the mission such as strike group route, electronic order of battle (EOB) and the activity of hostile forces. Jammer assignment is the data which directs the required jamming technique and frequency coverage to counter a specific threat. HARM targeting data is the specific parameter base used by the HARM to target specific threats. Finally, jammer/receiver management is the allocation of the aircraft's jammer pods and superheterodyne receivers to best detect and counter the threat.

If the operator had to access these domains without computer assistance, the process of analyzing the electromagnetic environment, determining its activity and threat posture, and finally countering those threats with correctly programmed jammer assets or HARM, would be extremely tenuous and time consuming. However, the CMC alleviates that problem by acting as a resource, colleague, assistant, and in some cases, substitute to the operator through automated processes.

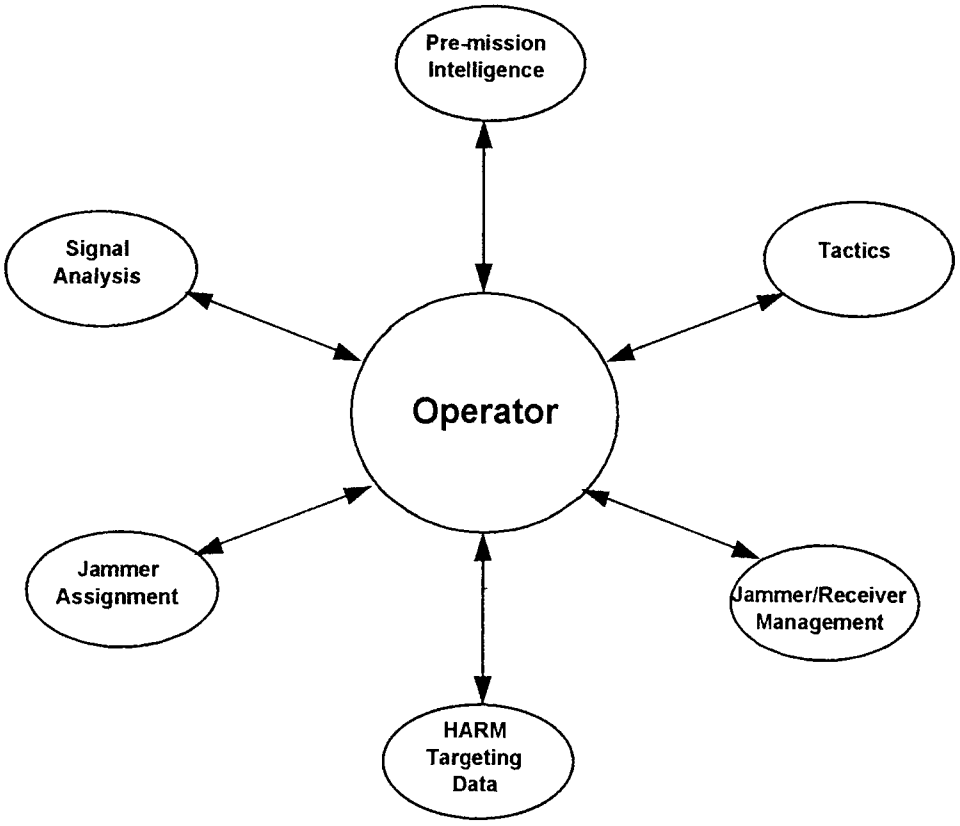


Figure (5-1)

EA-6B KNOWLEDGE DOMAINS

The functions of the CMC are described in Figure (5-2). The pre-mission intelligence database accessed by the CMC allows for display of threat data including geographic location. In addition, the CMC compares sensor data to pre-mission data acting as an assistant to the operator in determining activation status of possible threats. Signal analysis provides the database of electromagnetic parameters used to identify specific emitters from sensor data. The CMC substitutes the operator in interpreting receiver data, processing it into digital format, and calculating specific emitter parameters. As multiple matches are possible for a single sensor intercept, the CMC acts as a colleague in identifying the best resolution from multiple matches.

The CMC acts only as a resource for jamming assignments. Specific jamming techniques and frequency coverage needed to counter specific threats are provided by the CMC upon operator request. Jamming assignments are based upon mathematical analysis or operational testing and are generally not subject to interpretation or modification by the aircrew. Similarly, HARM targeting data are the specific emitter parameters which the HARM will search. The database is a compilation of mathematical analysis and operational HARM testing. Since multiple targets can be sent to the HARM simultaneously, the HARM targeting data also includes a specific pattern for the HARM to search for the targets. The operator selects the required targeting data based on current threat data from sensors or pre-mission intelligence.

Jammer/Receiver management is the most recent domain to be dynamically automated by allowing control by the CMC. The management allows for an automated receiver

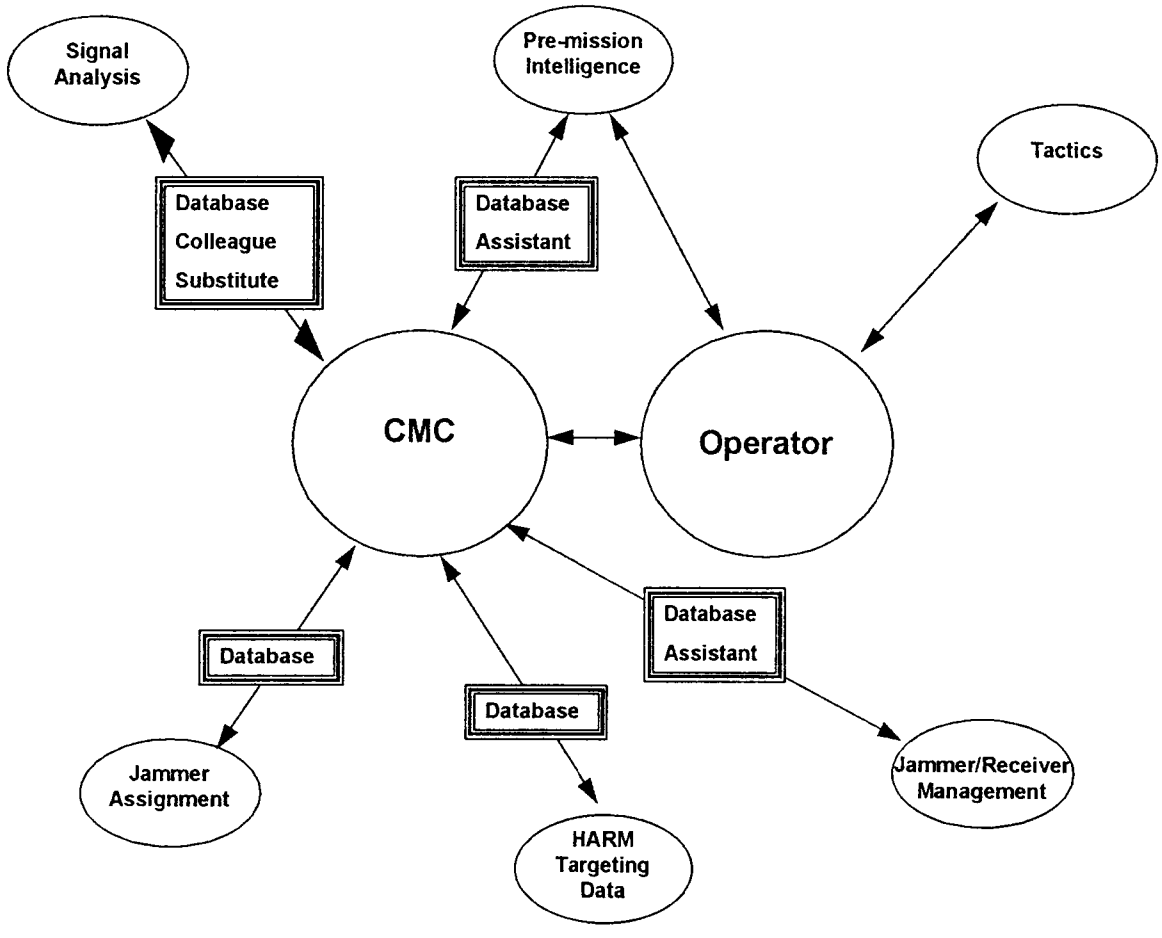


Figure (5-2)

CMC KNOWLEDGE DOMAIN ACCESS

scanning schedule. The CMC automatically sets the frequencies to be scanned by the superheterodyne receivers to improve probability of detecting critical emitters. Jammer management automates jammer asset (pod) allocation with jammer assignments through a rule based priority structure for the possible threats encountered. In the jammer management role, the CMC acts as an assistant to the operator, directing jammer assignment data to specific jammer transmitters. In addition, the CMC tracks transmitter steering where applicable ensuring coverage of the threat continues as the aircraft proceeds on track. Unlike some EW systems, the CMC does not automatically jam based on detection, but relies on an operator command, either manually implemented or executed through an operator initiated rule based priority logic, to provide optimal jamming methods to counter those specific threats. The CMC further assists the operator by correlating jammer coverage to pre-mission intelligence.

EA-6B software automated processes in previous software releases involved the domains of signal analysis, jammer assignment, and pre-mission intelligence. With the advent of SSA-4.0, the additional automation was centered on assisting the operator in quickly adjusting surveillance and jamming priorities in the Jammer/Receiver management domain. In previous software releases, these functions were completed strictly through manual means. The new automation would require significant software enhancement to include algorithms which could execute these tasks automatically when required. As such, the inference engine rule base became significantly more complex in order to adequately complete these tasks.

INFERENCE ENGINE LOGIC

The inference engine in the EA-6B is the CMC. It accesses all domains of knowledge, interacts with all TJS weapons systems and avionics, houses the rule base for controlling sensor and weapons systems, and interacts with the operator through a display computer. Unlike the generic EW inference engine, the CMC in the EA-6B does not include fully automated task execution. The only task modes available are the "recommend/implement" and "inform/monitor" modes. The primary reason for this limitation is that there exist no functions of the EA-6B TJS which are used for self defense. Defensive electronic countermeasures (DECM) equipment is the only onboard equipment for self defense and it is not integrated with the TJS. All functions of the EA-6B TJS are for offensive EA missions. Similarly, there is no emergency logic associated with the CMC. Processing of received sensor data is limited to executive and ACD logic.

The two rule base functions of the CMC are those which control sensor data and those which control weapons systems. The sensor control rule base is much simpler than the weapons control rule base. There is no emergent logic or fully automated tasking associating sensors to weapons systems. The operator determines the significance of all sensor data and makes modifications accordingly. SSA-4.0 does incorporate an improved method of adjusting sensors to detect critical emitters. In previous software releases, the operator activated or deactivated emitter libraries one at a time, modifying the receiver scanning schedule with each activation or deactivation. SSA-4.0 allows for simultaneous activation and deactivation of multiple emitter libraries through automatic

programming, decreasing the time required to optimize the receiver scanning schedule. The activation and deactivation is through an operator command to the inference engine which houses a specific mission rule-base for these actions. However, it is important to realize that no attempt was made to add an advanced "perceptional reasoning" capability to the EA-6B ES system. Recall that perceptional reasoning is generically defined as the capability to "respond to changes occurring during a problem solving session" [25]. Although the inference engine can compare detected emitters to pre-mission intelligence, provide possible matches (including cueing to which are most probable), correlate to known geo-located targets, and communicate its results to the operator, it cannot perform beyond that capability. Further conclusion drawing (e.g. If radar A is radiating, then radar B is probably radiating as well.) and modification of sensor coverage (e.g. Receiver number 2 scanning frequency needs to be expanded to search for radar B.) is a conclusion by the operator only. Expert systems incorporate the capabilities of reason, knowledge acquisition, elucidation, memory and language interface [26]. The EA-6B expert systems resolution of sensory detections exhibits each capability to some degree. However, reasoning is limited only to identification and association based on the signal analysis and pre-mission intelligence domains.

Prior to SSA-4.0, the weapons system control logic was as simplistic as the sensor control logic. Based on pre-mission or sensor data, the operator manually controlled the weapons systems (jammer pods and HARM missiles) only accessing the CMC to execute the desired task as in a Category I automated system. However, along with an automated

sensor (receiver) logic, an automated jammer management function, designed to decrease the time required for assignment and allocation of jammer pods (Category II), was introduced with SSA-4.0. Again, there is minimal perceptional reasoning capability by the CMC with regards to jammer management. The CMC informs the operator what targets are or are not being jammed (depending on the selected DDI display). However, modification of jammer "strategy" is a function of the ECMO modifying the rule-base of the inference engine (e.g. not Category III). The CMC, acting as a colleague, attempts to assign jammer assets according the ECMO's new strategy.

The SSA-4.0 receiver and jammer management functions are a result of the incorporation of a "phase mission concept". Phase missions is the concept that each EA-6B mission can be divided into phases due to changes in EA and ES priorities from one portion of the mission to the next. The software engineers provided phased mission planning on TEAMS and execution of the phased mission in the EA-6B. In the past, such changes in EA and ES priorities required significant software manipulation by the operator. With the incorporation of phase missions, a previously labor intensive operation was accomplished easily through simple software manipulation of a single program load to the CMC when sufficiently planned on TEAMS. While airborne, the operator manually changes from one mission phase to the next via a simple software procedure between the operator and CMC. Operators may enter any phase at any time or return to a previous mission phase. Once the mission phase change occurs, the CMC makes appropriate ES and EA modifications according to the phase mission program.

Several software indications confirm the change of phase. Although phased missions are created on TEAMS as part of preflight planning, the phase mission plan was designed for modification in-flight by the ECMO. In essence, phase missions define the rule-base for receiver and jammer management, are tailored by the ECMO during pre-mission planning, and loaded into the aircraft for execution by the inference engine (CMC).

Of the EA functions executed by the EA-6B, only jammer management is affected by phase mission software. HARM functions are not affected. Jammer management is the process of allocating the ALQ-99 jammer pods against the required target radars in the most efficient manner possible. In the EA-6B community, all electromagnetic equipment which can be jammed are considered "targets". This includes emitters such as communication nodes, land based, or platform (aircraft, ship, submarine) based radars. During a specific mission, only a specific set of targets need to be jammed at any given time. It is also true that within a specific mission, the jamming requirements may shift as the mission progresses. Jammer management is the process of prioritizing targets for different missions or within a mission and allocating the jammer assets accordingly.

The automation logic which assists the operator in jammer management must include a priority structure for all targets and an understanding of jammer assets available in order to adequately allocate them according to the jamming strategy. However, this is not the only requirement. The management process must allow for system faults (hardware) and failures (software), changes in mission requirements, and operator selected deviation

from the original jammer management plan based on professional tactical knowledge. For these reasons, the software has been tailored in order to address these issues.

The priority is based on the hierarchy of emitters which comprise a single target. During any given mission, multiple targets will be established. From the standpoint of electronic warfare, targets are prioritized based on the threat they pose to the strike group. Target priorities can be established in TEAMS or in the aircraft. Targets created have a priority assigned by operator which is then passed on to the CMC and can be modified at any time.

Targets are further divided into subcategories to provide a priority scheme of emitters to be jammed within a target and in association with other targets. Not all emitters of a given target need to be jammed at any given time. For this reason, targets are divided into major subsystems based on the purpose or function of the emitters associated with a specific target. For instance, a ship may have different radars which have the same function of providing early warning of approaching aircraft or ships. Although the radars themselves are different, their function category (FC) would be the same. Other radars may be used to guide missile systems against a potential hostile aircraft. These would fall into yet another function category. The actual FC types used by the EA-6B jammer management system are not important to the discussion of automation. Suffice it to say that the types of function categories are standardized for all targets. The pre-mission planning computer, TEAMS, already associates specific radars into functional categories. The TEAMS software has been tailored such that the operator can modify the FC of a

specific radar if so desired during pre-mission planning but not inflight. Finally, once the hierarchy of functional categories has been established by the operator, it applies to all targets within a phase. Each target has the same FC priority structure. When a modification to FC priority is made by the operator for the active phase, it applies to all targets which have been phase activated.

Functional categories are not the final or smallest building block of the prioritization system. They are further broken down into the specific emitters, each containing its own singular priority. This final building block is used by the CMC to establish a jammer assignment and set the frequency which will be jammed by a specific transmitter. Consider that a single target is composed of several different functional categories. Each of the categories has a priority based on the operator's designation. If two emitters fall under the same FC for that target, they hold the same priority. The system needs a way to break the tie for the specific emitters contained in each FC. The dilemma is resolved through software logic which prioritizes each emitter from all other emitters. A default prioritization is resident on the pre-mission planning computer TEAMS. The operator can only make modification to this prioritization structure during pre-mission planning and not in the aircraft. For that reason, it is incumbent upon the operator to specify this final priority structure during pre-mission planning.

To summarize, there are two prioritization criteria which are determined during pre-mission planning and cannot be changed in the aircraft. They are the FC that a specific emitter is associated and the specific emitter priority in relation to other emitters. If the

target or FC with which the emitter is associated changes priority, then its priority will accordingly change. However, if no change in target or FC priority occurs, there is no way to modify the priority of two emitters which are associated to the same target and fall into the same FC. Figure (5-3) shows the structure scheme for jammer management. Note how at the emitter level, the priority decision ends. Within the figures target, FC type A has first priority, FC type B has second priority, and FC type C has last priority. Keeping in mind that emitter priorities are set during pre-mission planning and that only one of each type of FC exists in this example, the only comparison of emitter priority is within a FC and not between functional categories. In other words, since each FC in this example has a different priority, the emitters are only "competing" for priority within the FC. In this example, FC type A and B have multiple emitters. As a result of pre-mission planning, the CMC will attempt to jam Emitter A-1 first, then Emitter A-2, and so on.

In contrast, Figure (5-4) shows what happens when a more complex situation occurs with multiple targets, each containing FCs of equal priority. In this example, both target tracks have one FC of equal priority (type A). Target 1 has three emitters in FC type A. Target 2 has one emitter in FC type A. According to the priority logic algorithm, the inference engine will check each target for emitters which fall in FC type A first. It will make this search in target priority order, starting with Target 1 in this example. Once it has completed the search for FC type A in all targets, it will then search for FC type B (the second priority FC type). This process continues until no more FC types are available. In Figure (5-4), Emitter 2-A-1 is lower in priority than Emitters 1-A-1, 1-A-2

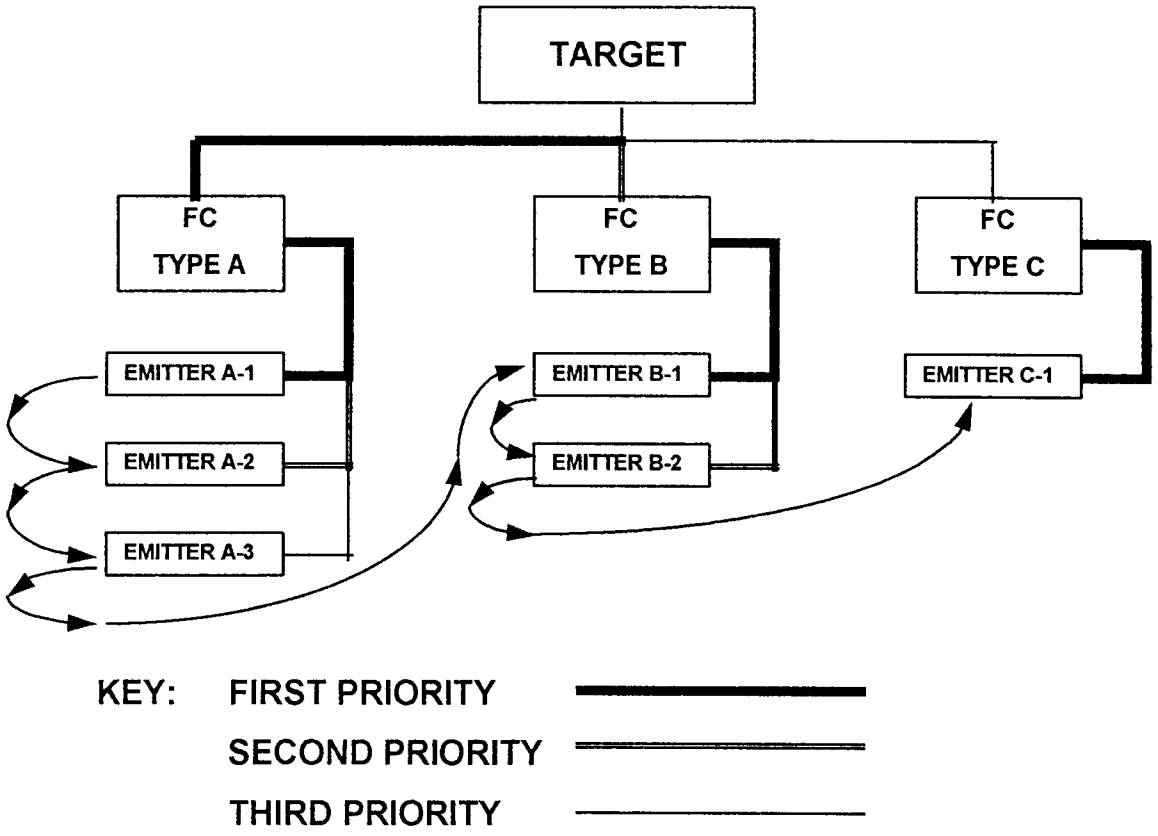


Figure (5-3)

PRIORITY STRUCTURE WITHIN A TARGET TRACK

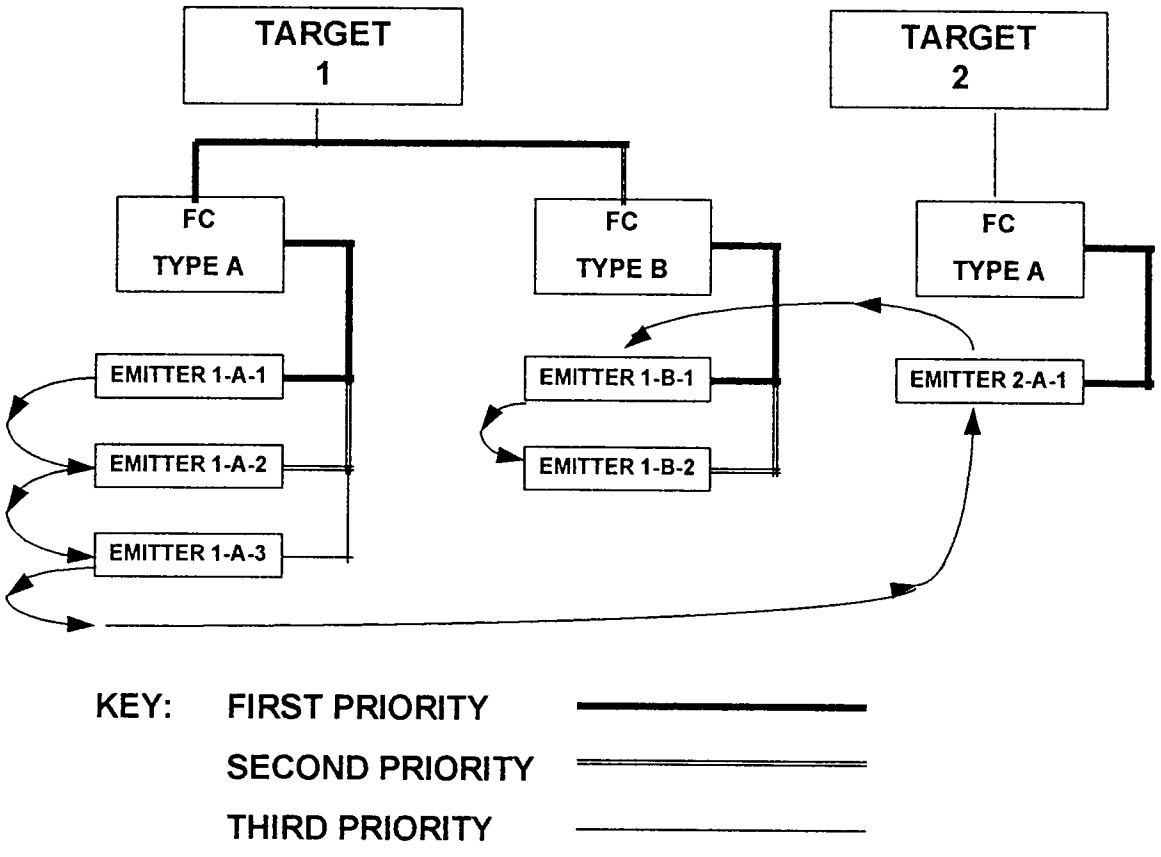


Figure (5-4)

PRIORITY STRUCTURE WITH MULTIPLE TARGET TRACKS

and 1-A-3 since they are attached to Target 1. Emitter 2-A-1 does have priority over Emitters 1-B-1 and 1-B-2 as they are associated with a lower priority FC.

Jammer assets are divided into specific frequency spectra. Each jammer pod will only accept jammer assignments which fall within its frequency range. As such, the CMC will attempt to make these assignments in priority order based on asset availability. If a high priority assignment cannot be assigned due to jammer asset unavailability or failure (such as CMC failure to communicate with a specific asset), the CMC will continue to assign based on priority order. For this reason, it is conceivable that a lower priority emitter will be jammed while higher priority emitters are not due to unavailability of the required band transmitter.

The operator may decide while airborne that several emitters assigned to the same FC of the same target track require modification of priority which was established during pre-mission planning. Since these emitter priorities cannot be modified in the aircraft, the operator must have a means of manipulating the jammer assignments made by the CMC based on the pre-mission priority. SSA-4.0 includes functionality for the operator to clear higher priority assignments. However, the functionality can only be initiated once the assignment is already made and does not transcend phases. If in Figure 5-3, the operator clears Emitter A-1 to allow jamming of Emitter A-2, this instruction would not transcend into the next phase. If the target track is still a phase active target track, the operator would have to repeat the instruction. In any case, jamming is initially initiated against a target where it is not desired and delayed against the desired target.

The next step is to establish a means of automatically activating the required targets for jamming in each stage of a mission. This process is the essence of phased missions. The process of telling the CMC to execute a change in surveillance and jamming requirements is known as "phase activation". For instance, suppose 10 targets are established for a given mission with their target number the same as their priority with target number 1 having top priority during the first portion of a mission and target 10 having the least priority. For this example, assume that the operator has assessed that targets 7, 8, 9, and 10 are not critical to the first phase of a mission and only become critical in the second phase. For that reason, the operator only activates targets 1 through 6 for the first phase. The receivers will therefore not search for emitters associated with targets 7 through 10 during this first phase. Correspondingly, the CMC will not direct any jamming towards these targets. The benefit is two-fold. First, the operator is not provided information during a specific phase of the mission which is superfluous to its execution, such as the detection of emitters radiating at non-critical targets. Second, no attempt is made at allocating jammer assets against those targets when it is not required.

As a final note on jammer management, the SSA-4.0 software still allows manual allocation of jammer assets as was available in previous software releases. The operator selects the appropriate jammer assignment from the jammer assignment domain and directs the CMC to initiate jamming from a specific transmitter. This is completed one assignment at a time or one target at a time. It allows for deliberate action by the operator which is much slower than the automated process. Since manual assignments

are made in the order requested, priority logic is normally not a function of the inference engine with two exceptions. If manual assignments are made in conjunction with automated assignments, the manual assignments take top priority. If the auto-reallocate logic is initiated with manual assignments, these assignments are subject to emitter priority logic and may be reprioritized with other manual assignments resulting in inadvertent re-assignment and reallocation of jammer assets.

INFERENCE ENGINE LOGIC EXECUTION

When manually initiated by the operator the change in mission phase results in activation of emitter libraries and assignment of the jammer assets based on priority order. By activating and deactivating emitter libraries, the CMC is actually reconfiguring the receiver scan schedule. In addition, old jammer assignments no longer applicable in the new phase or of a lower priority order such that they can no longer be maintained are cleared from the jammer assets and the new, higher priority assignments are made. The CMC must make availability and compatibility checks for all assignments requested. Manual jammer assignments transcend phases and must be manually cleared if no longer required in the new phase. For each manual jammer assignment made, the CMC must re-evaluate availability and compatibility for the new phase assignments in comparison to the higher priority manual assignments. There is no means of establishing a manual assignment lower in priority than some or all of the phase activated assignments.

Changes in jammer management priority can occur not just upon transition into a new phase but also within an active phase. Jammer assignment priority change when the

operator modifies target or FC priorities. However, no action is taken by the CMC until the operator initiates a specific software command after all changes have been made. This allows the operator to make multiple modifications without the CMC attempting to re-assign or re-allocate jammer assets after each individual modification. Once all changes are made, the reallocate logic is initiated by pressing a single button on the DDC known as the AUTO-PA button.

The priority structure is only one of several factors addressed in the assignment of jammer assets. Steering the jammer transmitter toward the intended victim radars is also controlled by the CMC. Assignments which continue to be eligible along with new assignments must meet geometry restrictions of the jammer assets. Some jamming assets are omni-directional, cover a 360 degree arc around the aircraft, and are not restricted by transmitter steering limitations. Other jamming assets are directional based on the transmitter beamwidth limitation. The CMC calculates the jammer antenna direction based on the bearing to the selected target from the aircraft. If two jammer assignments of different targets (i.e. different geographic locations) are made to a single transmitter, the CMC tracks the bearing to each assignment. The transmitter antenna need not be steered directly at each target in order to maintain sufficient jamming coverage. However, the targets must remain within the jammer beamwidth limitation. As the aircraft continues to proceed on track or as new assignments are added to the transmitter, the jammer antenna steering adjusts, accepting those assignments which fall within the beamwidth limitation. Multiple assignments on a single transmitter which once met the beamwidth limitation criteria may eventually exceed the limit due to aircraft movement

in relationship to the targets. This circumstance is known as a "Walk-Out". If more than one transmitter of the same band are available, the CMC will move assignments accordingly when directed by the operator in order to continue to meet the geometric limits. In any case, if insufficient jammer assets are available, the CMC will alert the operator that a jammer beamwidth limitation has occurred. Initiation of the "re-allocation" logic directs the CMC to move or clear the lower priority assignments of that transmitter.

In contrast to the "Walk-Out" scenario, aircraft movement may allow for two previously geometrically incompatible assignments to become compatible on the same transmitter. This is known as a "Walk-In". When a "Walk-In" occurs, the operator may initiate the re-allocation logic directing the CMC to make the lower priority assignment which was previously unmade. Unlike the "Walk-Out" condition, SSA-4.0 does not alert the operator to "Walk-In" conditions. The CMC only monitors steering compatibility continuously on an assigned transmitter and not between assigned and unassigned jammer assignment requests. Initiating the reallocation logic during a "Walk-In" will result in re-allocation of the jammer assets as the CMC will then check all possible options at that time. Therefore, it is incumbent of the operator to monitor possible "Walk-In" situations.

During a given mission, different target tracks may have the same radar. When the target tracks are located along bearings such that a single transmitter can jam both within its jammer beamwidth limitation, it is not required that two separate assignments be made. The assignments are known as "Duplicates". The higher priority assignment is

called the "Parent" assignment and the lower priority the "Child" assignment. If both assignments existed on different transmitters, the operator initiation of the re-allocate logic directs the CMC to clear the "Child" assignment when within transmitter beamwidth limitation and adjust transmitter steering accordingly. Since this is a "Walk-In" situation, no alert is given to the operator. If the duplicate condition exists upon initiation of a new phase, the CMC will simply not make the "Child" assignment. The whole concept of duplicate logic allows for a lower priority assignment to be made in lieu of extraneous higher priority assignments, maximizing the use of the jammer assets.

Jammer assignment automation does not include the ability to make modifications based on hardware failure. Multiple failures can occur including the inability of the CMC to communicate with the pod, transmitter steering failures, power loss or fluctuation, and specific transmitter failures. Although the CMC recognizes these failures and provides alerts to the operator, the allocation logic is not sophisticated enough for it to make appropriate modifications. For example, the CMC will assign a high priority assignment to a failing or failed transmitter. The operator must manually move the assignment to a good transmitter. In order to accomplish this, the operator must remove a lower priority assignment (if one is occupying the good transmitter) and move the higher priority assignment to that transmitter. If the auto-reallocate logic is initiated without any further action, the CMC will make assignments to the bad transmitter. For that reason, the operator has the ability to disable specific transmitters, removing them from possible CMC allocation.

MAN-MACHINE INTERFACE

Through the man/machine interface, the ECMO manages the system, controls the sensors, focuses information processing and implements action. He monitors the system's capabilities, compensates for failures by shifting to alternate modes, and communicates with the CMC. The primary TJS operator interface is the digital display group (DDG) which, as previously stated, is comprised of the digital display indicator (DDI), digital display control (DDC), and display computer (DC). The DDI is a computer driven video presentation whose information content is selected by the operator through the DDC. The DDC is a keyboard control through which the operator directs the tactical program. Data entry and operator controls are input with the DDC push-buttons entries and a cursor slew control similar in functionality to a computer tracking ball. The DDI/DDC combination may be described as "interactive". The DDI immediately displays each operator input to the system via the DDC. Movements of the DDC cursor control immediately slews the cursor on the DDI. The DDI displays other inputs to the system, (i.e., signal intercepts, navigation information, jammer status, and other information) in real time. In addition to the DDG, the operators have multiple hardware switch controls and alert lights to initiate operations and backup computer functions.

The DDI shows a map display known as the geographic or GEO display. For situational awareness, the GEO display provides a map reference of targets for a given operating area. It also shows the current position of the aircraft and strike group providing greater aircrew situational awareness

There are software prompts for the operator when a phase transition should occur. These prompts are based on time which the operator either sets during TEAMS planning or modifies via the mission plan display while airborne. Two clocks are available for use by the operator to prompt the change. When the selected time is met, the time displayed on the DDI flashes and a "CHANGE PHASE" alert appears.

Several displays are available to the operator to inform him of jammer assignment status. A dedicated DDI display, called the jammer assignment status (JAS) display shows the operator at a glance whether all, some, or none of the jammer assignments associated with a target track have been made. This display is only available for the active phase. In other words, future phases cannot be checked on the JAS display until they become active. A map display and a frequency vs. direction display also provide indications of only current jamming status.

SUMMARY

In summary, the EA-6B TJS mirrors the basic EW expert systems. It includes all components of the expert system and includes a rule based inference engine which assist the operator in task accomplishment. The relationship between the operator and the inference engine are such that the operator can modify the degrees of task automation which typifies a dynamic expert system. The adaptability of the expert system is not the same for all tasks it can accomplish. The more dynamic automated functions require a larger rule base within the inference engine than the simpler, less dynamic functions. Jammer assignment, HARM targeting, and receiver scanning schedule are relatively

simple functions. The automated jammer management functions are very dynamic and complex requiring a much larger rule base.

CHAPTER 6

SSA-4.0 SYSTEM SOFTWARE OPERATIONAL TEST CASE STUDY

An Analysis of Operational Test Results Specific to Automation

PROJECT OPERATIONS

The operational test of SSA-4.0 was the third Software Qualification Test and Evaluation for the EA-6B system software. Air Test and Evaluation Squadron FIVE (VX-5) conducted the test and reported the results to the Commander, Test and Evaluation Force for review and official reporting to the Chief of Naval Operations (CNO). The purpose of the evaluation was to determine the operational effectiveness and operational suitability of the SSA-4.0 system software upgrade, loaded in the EA-6B ICAP II Block 82 and Block 86 aircraft, and its readiness for fleet introduction.

Flight tests were conducted at the Naval Air Weapons Station, China Lake, CA, from 24 June to 15 October 1993. The testing period was divided into three phases. Side-by-side comparison was made between similar block aircraft with previous and new software releases installed and between different block aircraft with SSA-4.0 system software installed in both. . The first two phases were used to compare each block aircraft's capability in comparison to the previous software release. The final phase was used to compare SSA-4.0 software performance between block aircraft.

A total of 51 flights encompassing 113.2 hours on several Navy and Air Force electronic combat ranges were flown. Test data were obtained from several surveillance

(ES) and jamming (EA) profiles. Flight operations were conducted by VX-5 aircrew and aircrew from fleet EA-6B squadrons.

TESTS AND RESULTS

Multiple tests were run on the software. Of those tests, three either directly or indirectly dealt with the newly automated jammer management and receiver scanning capability. The three tests were phase mission integration, jammer management, and human factors.

The phase mission integration test objective was to resolve if the SSA-4.0 system software upgrade installed in the EA-6B ICAP II Block 82 and Block 86 system supported phased missions integration including mission phase plan management, mission phase change capability, enhance automatic preemptive assignment or APA, jam prioritization/reallocation logic, and quick receiver scan (automated re-directing of aircraft receivers). Multiple flights were flown using scenarios derived from the EA-6B tactics manual (TACMAN), exposing SSA-4.0 system software upgrade to varying multiple emitters in operational jamming and non-jamming environments. Each mission was flown following a phase mission plan of multiple phases as planned on TEAMS Workstation. Aircrew monitored the proper loading of the mission support program and access of all components of the mission plan file. To reflect mission deviations, which typically occur in operational EA-6B missions, mission changes were implemented on defined test flights to assess the capability of SSA-4.0 to adapt to these changes. The changes included real time mission time changes, FC jam priority changes, target jam

priority changes, strike group and own-ship track changes, threat emitter activation changes, and phase transition time changes. Test aircrew made modifications to the mission phase plan using available displays.

Throughout the test, the aircrew evaluated and reported any anomaly or deficiency with the SSA-4.0 phased mission integration system functions and modes. The aircrew completed data sheets in-flight and upon mission completion. Data products required for this test included TEAMS Workstation system pre-mission data; RRS recordings and TEAMS Workstation systems postflight emitter data, navigation data, jammer data copied to 9-track magnetic tape; and aircrew observations recorded on kneeboard cards. Data analysis was qualitative rather than quantitative in nature. Information from TEAMS Workstation pre-mission and postflight data, aircrew kneeboard cards, and OTD log entries were qualitatively analyzed to assess the functionality of phase mission integration for the EA-6B. Information from RRS recordings was downloaded to TEAMS and analyzed to verify proper phase changes based on mission/system clock time, proper prioritization and reallocation of jammer assets upon transition into a phase, and proper activation of emitter libraries (quick receiver scan) upon transition into a phase.

A proper phase change occurred when the OBS prompts a phase change with software indications and the change is accepted by the ECMO; and, at which time, jammer assignments and receiver scanning schedule are adjusted according to inference engine (CMC) logic. The jammer allocation and receiver scanning schedule should mirror the data presented on a TEAMS Workstation priority list completed during pre-mission

planning. TEAMS was also used to verify that the assignments were made and allocated in priority order. In some instances, not all candidate assignments for the new phase were made based on a lack of transmitters or compatibility with higher priority assignments already made. Proper activation of emitter libraries occurred when the ECMO accepted a phase change, the candidate libraries for that phase were activated, and the receivers' scanning schedule was adjusted appropriately. The system phase change, including jammer asset utilization and library activation, was recorded on the RRS. In addition, kneeboard cards and OTD log entries were analyzed with the above data to assess the operator's ability to manipulate the phase mission plan using mission/system time changes, jammer reallocation and prioritization logic, and quick receiver scan to adapt to changing threat scenarios; and ability to maintain situational awareness of threats and threat coverage during phase changes.

Specific results of the phase mission test showed most functions worked according to design and were acceptable with the exception of one area. The SSA-4.0 system software upgrade demonstrated adequate implementation of phase mission integration with the exception of automated jammer assignment establishment and allocation upon transition into a mission phase. Incorrect establishment and allocation occurred upon transition into a phase degrading the predictability and accuracy of jammer assignments. No major anomalies were observed regarding the ability of the ECMO to make changes to the phase mission plan. The ECMO was able to adequately construct a phase mission on TEAMS Workstation and adjust that mission in the aircraft. Changes to the phase mission plan which allowed for adaptability of the automation such as real time mission

time changes, FC jam priority changes, target jam priority changes, strike group and own-ship track changes, threat emitter activation changes, and phase transition time changes using system clocks worked well. No major anomalies were observed with ability of the CMC to correctly prompt the ECMO, through software displays, that a phase change should occur. Software prompt occurred either through system or mission time as selected by the ECMO. No major anomalies were observed with the fidelity and parametrics of jammer assignments made upon transition into a phase. No major deficiencies were observed regarding quick receiver scan capability during a phase transition. Emitter libraries were correctly activated in each phase and the receiver scanning schedule adjusted accordingly.

Major anomalies were demonstrated through the incorporation of jam prioritization/reallocation logic upon transition into a phase. Upon transition into a phase, the CMC should clear assignments no longer valid in the new phase and initiate all new assignments to the maximum extent possible in priority order. The CMC did not correctly initiate and display priority jammer assignments upon transition into a phase. The CMC made lower priority assignments in lieu of higher priority assignments upon transition into a phase (not a miscalculation of priority). The CMC lists an anomalous status of jammer assignments upon transition into a phase. This refers to the jammer status display page. The CMC initiated jammer assignments upon transition into a phase when none should be assigned.

The second test evaluated the jammer management improvements. This test had similar problems as those encountered with phase mission integration. However, this test

was specifically confined to problems which occurred within a phase and not upon transition into a new phase.

The phase jammer management improvements objective was to resolve if the SSA-4.0 system software supported jammer management improvements. In other words, was the functionality of automated jammer assignment and allocation of jammer assets operating according to the expert system design engineers expectations? Tests centered on the ability of the inference engine (CMC) to execute jammer management functions according to aircrew desires.

Like the phase mission test, the jammer management test was analyzed qualitatively. Since previous system software upgrades did not incorporate automated jammer management functions, this test analysis was an evaluation of automated jammer management functions on their own, in conjunction with manual jammer assignments, and in comparison to strictly using manual jammer management techniques. Information from TEAMS Workstation postflight data and aircrew kneeboard cards was qualitatively analyzed to assess the jammer management function of SSA-4.0 system software. Information from the RRS recordings and kneeboard cards was analyzed to verify proper reallocation of jammer assignments within a phase using the TEAMS Workstation jammer summary, proper prioritization of jammer assignments within a phase using the CMC rule base structure, and proper transmitter utilization. Proper prioritization and reallocation of jammer assets was determined by computing the jammer priority of each assignment from the inference engine rule base structure which was also available on the TEAMS Workstation priority list completed during pre-mission planning, and verifying

that the assignments were made and allocated in priority order. Changes in priority and subsequent reallocation of jammer assignments occurred during phase changes and when target track priorities were changed within a phase, FC priorities were changed within a phase, or the operator made his own manual assignments which assume top priority over phase initiated assignments. Proper transmitter use was determined by the assessing whether the jammer assignments residing on each transmitter and the assignments not assigned to a transmitter were properly combined or not combined based on assignment compatibilities.

Specific results of the phase mission test showed anomalies regarding the predictability and accuracy of phase activated jammer assignments which preclude use of the automated jammer management improvements as intended. These anomalies occurred when the auto-reallocate logic was initiated within a phase. Additionally, the capability to perform manual jammer management functions as used in previous software releases was limited due to encroachment of automated functions upon previous jammer management methods.

The CMC failed to establish jammer assignments in the priority order determined by the operator and failed to correctly allocate those assignments to available jammer assets. Jammer assignments made via manual jammer management methods were susceptible to automated reallocation even though they are not intentionally incorporated into the prioritization scheme. Two conclusions were reached regarding these two failures. First, the prioritization and allocation logic of the inference engine was faulty resulting in incorrect allocation of jammer assets. Second, inference engine software "loops"

inadvertently associated manual assignments with the priority logic intended only for automatic assignments.

The aircrew determined required jammer assets based on the established targets and instituted jammer game plans (i.e., predicted utilization of jammer assets) by phase based on a TEAMS Workstation jammer summary listing. The jammer summary listed the jammer assignments which would be attempted in priority order by phase using a simulation of the inference engine (CMC) logic. The aircrew determined jammer asset requirements using the jammer summary listing. Since only a finite number of jammer assets can be carried by the aircraft, the aircrew's jammer asset selection occasionally resulted in only a portion of available jammer assignments being made during a phase.

No degradation in the ability to assign and reallocate manually assigned jammer assignments was noted when all portions of the automated jammer management logic was avoided. However, several major anomalies were observed regarding proper prioritization and reallocation of jammer assignments within a phase. The anomalies occurred on the majority of mission flights and could be duplicated multiple times within a flight. Specifics of each anomaly cannot be discussed. However, anomalies were frequently caused when the ECMO modified prioritization of targets or FC, geometry changes between aircraft and targets required reallocation due to walk-ins, walk-outs, and duplicates, and the CMC incorrectly assessed compatibility of jammer assignments.

The final test which failed as a result of the added automated characteristics of the software was the Human Factors test. Specifically, the human factors test failed due to inadequate human-machine interface. When automated characteristics were executed,

the operator was either not sufficiently informed or required significant and time-consuming software manipulation to correct inadvertent or insufficient jamming coverage.

The human factors test was a comparison between each block aircraft's previous system software release and SSA-4.0. The objective was to resolve whether a degradation or improvement in human factors features occurred due to the installation of SSA-4.0. Since previous software versions did not incorporate automated jammer management and receiver scanning features, the human factors test was a comparison of the aircrew's ability to complete the mission using either manual or automated methods. When automated methods were used, additional human factors test regarding the adaptability of those automated functions was assessed.

This test was conducted continuously throughout all flight operations. Aircrew debriefed all observations recorded on Data Sheets. In addition, the OTD interviewed aircrew and maintenance personnel and recorded the results in the OTD Journal to evaluate human factors in several areas. They included design factors related to accessibility and utility of SSA-4.0 system software upgrade to the Navy/Marine user, human/machine interface compatibility to accomplish the mission, and control and display design standardization within and among other aircraft systems.

Like the two previous tests, the suitability test of Human Factors was analyzed qualitatively. The OTD Journal, data sheets, and questionnaire responses were qualitatively evaluated to assess human factors suitability. The impact of any human factors deficiencies identified during testing on overall mission accomplishment was

evaluated. Specific results of the phase mission test showed anomalies in the human/machine interface to adequately support additional functionality (i.e., phase mission integration and automated jammer management integration) of the SSA-4.0 weapon system software. Inaccurate and contradictory jammer status displays involving the automated jammer management logic led to operator confusion. When the CMC prioritized and allocated assignments, the reason for doing so, and in some cases, the fact that it had done so were not apparent by the jammer status displays. Lengthy evaluation and complicated manipulation of software was required by the aircrew to adjust jammer management problems. This led to loss of situational awareness and inattention to other duties.

SUMMARY

The overall conclusion from the failure of the three tests was that the newly automated characteristics were not adequately supporting mission accomplishment. The propensity for unpredictable and inaccurate jammer management, described by incorrect assignment and allocation of the jammer assets, compounded by inaccurate, contradictory and misleading jammer status displays resulted in a significant delay in capability. Operator situational awareness and attention to other duties declined during analysis and correction of jammer management. Due to high integration of the automated jammer management module within the software, the anomalous jammer assignment and allocation results occurred when any portion of the automated jammer management module is accessed. Encroachment of the automated jammer management functions

corrupted some of the manual jammer management techniques. The combination of automated and manual jammer management techniques also resulted in anomalous assignment of jammer assets. As a result, the software was only partially released for fleet introduction, and a requirement for a correction of deficiencies release was mandated.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Summary of Findings and Recommended Improvements to Automation of the EA-6B Weapon System

ASSESSMENT OF TEST RESULTS

There were several reasons why the SSA-4.0 software failed to adequately implement the automated characteristics. They can be confined to the rule base of the inference engine (CMC) which was both faulty and inadequate to handle dynamic jammer asset allocation. Additionally, the inference engine interfered with manual jammer management techniques which were supposed to be independent of the automation logic within the inference engine. Finally, the inference engine failed to adequately communicate with the operator, sometimes presenting misleading displays. Recalling from Chapter 4, there were several requirements for successful implementation of any aircraft EW system. They included the criteria that aircrew maintain executive control over decision making processes, the automation must accommodate changes in the tactical environment allowing the operator to adjust quickly to changing mission objectives, and the automation must operate such that it does not interfere with aircrew tasking nor interrupt system integrity. Of these criteria, SSA-4.0 had serious flaws in its

capability to adjust quickly to changing mission objectives and perform such that it did not interfere with aircrew tasking nor interrupt system integrity.

The operator can only direct the jammer pods through the CMC. In the manual mode, the CMC is used to access the domain of jammer assignment data. Allocation is directed by the operator based only on the order the assets are assigned. The CMC, using navigation information, steers the jammer assets as required based on aircraft movement. No priority logic was supposed to be incorporated. The CMC functions were simply to monitor and inform.

With the incorporation of priority logic and automated jammer management, the CMC directed allocation during phase transitions and upon modification of target or FC priority within a phase (i.e. according to the loaded and modified rule base). According to test results, four major problems occurred. First, the rule base was faulty, allowing for inaccurate allocation of jammer assets. Second, the rule base was inadequate or insufficient to handle the new tasking. Dynamics of a mission caused by changing priorities and aircraft movement were not adequately compensated by the automated jammer management rule base. Third, the rule base encroached upon the operator's ability to manually allocate the jammer assets. Finally, the rule base did not provide sufficient human-machine interface. The displays did not adequately show jammer status. The operator had to perform intricate, complicated and time consuming software manipulation to modify or correct problems of the automated jammer management logic.

RECOMMENDATIONS

There are several recommendations which can improve these automation problems, some of which were incorporated into the corrections of deficiency release (SSA-4.1). First, the rule base must be scrubbed to eliminate faults in jammer asset allocation. As with all automated systems, aircrew distrust them until they prove to work correctly. Such was the case with SSA-4.0. The aircrew resorted exclusively to manual jammer management techniques once they realized the automated jammer management could not be trusted. In order to correct the faults, software engineers should follow the reasoning sequence of the inference engine. One of the advantages of a rule based expert system is that the errors in design can be traced through duplication of errors and corrected. Software engineers should start with the problems discovered during operational test and then extrapolate to find further problems. Using aircrew who will use the software operationally, missions should be planned which require maximum use of all automated features as a final test that no anomalies exist. Once these corrections are made and incorporated into the follow-on software release, aircrew members should continue to provide feedback to the software engineers.

Second, the operator should be brought more into the loop of automated jammer management processes. It was evident by the testing results that the inference engine jammer management logic was insufficient to account for mission changes, dynamic aircraft movement, and hardware or software failures. The automation logic could be expanded to try and account for these areas, but that would be contrary to expert system optimal design. Recall that expert systems are best designed when they relieve the

operator of tedious and time consuming operations but do not attempt to replace the tactical or professional knowledge of the aircrew. Rule based systems simply cannot be designed to replicate this level of knowledge. Additionally, any attempt to do so would lead to reduced aircrew performance.

The answer then is to bring the operator (aircrew) more into the jammer management loop. Changes in FC or target priority proved too generic. General tactical guidelines dictate that the same FC priority will be required at most targets within a phase. However, this is not always true and to impose the same hierarchy to all targets in a phase is too restrictive. The operator should be able to set FC priority individually for each target.

In addition, the final priority for jamming emitters associated with a given target or between targets may transcend FC or target priority at any given time based on the dynamics of the mission. The operator is going to realize such a situation, but with the current software design is unable to easily adjust priorities (if at all) to quickly get the required asset allocation. The only way this can be achieved is if the operator can change individual priority at the emitter level while in the aircraft. Recall that all possible emitter assignments with their associated priority and status are listed on the jammer status page of the DDI. A modification to the software empowering the aircrew to change priorities on this page regardless of target or FC priority would give the operator a quick means to make specific adjustments without complicated software manipulation. When mission requirements change or hardware or software problems occur, no time is lost in jammer allocation adjustment and aircrew can continue executing other duties.

Such a modification would be an improvement to the dynamic or adaptable characteristics of the expert system.

Finally, the human-machine interface must be improved for the aircrew to recognize possible problems and direct modification quickly. There are several changes which can drastically improve aircrew performance. First, it was mentioned that a TEAMS jammer priority prediction was used during the flight to ensure assignments were made in priority order. However, the prediction simply lists applicable emitter assignments in priority order for that phase. It does not take into account aircraft position in relation to the targets, nor does it take into account a specific jammer pod load. The aircrew should be able to "fly" the mission on the TEAMS workstation with a constructive pod load. Executing the program at high speed, TEAMS would pause at those instances where a re-allocation is required within a phase (Walk-In, Walk-Out, Duplicate) and upon transition into a new phase. This capability would give the aircrew a much better idea of how the mission will progress and in determining optimal jammer pod load.

Aircrew should also be able to view the jammer status page for any phase while in the aircraft. This would give the aircrew advanced notification of upcoming jammer asset allocation. Current aircraft position could be used or the aircrew could enter the expected aircraft position at phase change to ensure aircraft to target geometry was accurate in the jammer allocation equation. If hardware or software failures are affecting jammer allocation, these factors would also be added to the jammer allocation resolution. These improvements would eliminate delays in optimal jamming which could occur during a phase transition.

As previously mentioned, the jammer status page should become dynamic rather that static. The operator should be able to re-prioritize, clear, or activate assignments from that single page without trying to achieve the desired result by modifying target or FC priority, phase activation status, or incorporating manual assignments. Each of these actions may adversely affect other correctly existing assignments. This single interface will reduce operator workload, prevent unwanted re-allocation of jammer assets, and allow aircrew to continue with other duties.

Finally, alerts should be improved which incorporate "Walk-In" and "Duplicate" occurrences. The software is designed not to take action until the operator directs it. This situation only works when the operator is correctly informed of changes in a timely manner. "Walk-In" and "Duplicate" alerts similar to "Walk-Out" and "Phase Change" alerts would inform the aircrew that a change in jammer asset allocation is required. Using the jammer status display, the operator could assess the required changes. The operator could then use the automated reallocation logic to make the adjustment, or use the jammer status page to clear or re-prioritize assignments accordingly.

SUMMARY

In summary, the EA-6B TJS is a developing expert system. Its design and operation mirror EW expert systems which require significant operator interface due to the complexity and dynamic nature of the mission and the aircraft. Automation introduced with the SSA-4.0 software attempted to assist the operator by relieving him of time consuming tasks. However, it proved not only to be flawed, but insufficient for the

complex task of jammer management. Exacerbated by user-hostile man-machine interface, the software became almost a liability to proper mission accomplishment. Navy and Air Force studies on EW expert systems promote returning the operator into the loop rather than trying to further complicate the inference engine rule base. Automated features can be used as designed or overruled when required. This will result in an efficient and adaptable expert system with a balance of task allocation for the operator.

Due to direction by the Office of the Secretary of Defense (OSD), the EA-6B is assuming the joint mission of airborne offensive electronic warfare for all Department of Defense [27]. Software development for the EA-6B has provided much enhancement in aircrew and system performance through automated functions. However, SSA-4.0 proved that automated characteristics can adversely affect aircraft and aircrew performance when improperly or inadequately designed. As the only tactical EW aircraft for Joint and Coalition forces, engineers and aircrew alike must ensure the optimal performance of the EA-6B through sound automation implementation.

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VITA

Michael Joseph Coury was born in Quakertown, Pennsylvania on June 25, 1962. He attended elementary schools in the Southern Lehigh School District and graduated from Southern Lehigh High School in June, 1980. Following a Congressional nomination, he received an appointment to the United States Naval Academy in July, 1981. In May, 1985 he received a commission in the United States Navy as an Ensign assigned to flight training along with a Bachelor of Science degree.

Completing initial flight training in 1986, Ensign Coury received his "wings" as a Naval Flight Officer and was assigned to training in the EA-6B "Prowler" electronic attack aircraft. In February, 1988, now LTJG Coury received designation as an Electronic Countermeasures Officer (ECMO) in the EA-6B. In October, 1988, he was promoted to full Lieutenant while assigned to Tactical Electronic Warfare Squadron 141 (VAQ-141) nicknamed the "Shadowhawks". During his tour with VAQ-141, LT Coury made two six month deployments, the second of which he engaged in aerial combat during Operation Desert Storm from the Persian Gulf. LT Coury was awarded two Air Medals and a Navy Commendation Medal with combat distinguishing device for strikes flown over Iraq.

Following his tour at VAQ-141, LT Coury was assigned to the "Vampires" of Air Test and Evaluation Squadron FIVE (VX-5) as an Operational Test Director (OTD) for

EA-6B software and High Speed Anti-radiation Missile (HARM) upgrades. While assigned to VX-5, LT Coury entered the University of Tennessee Space Institute, Tullahoma in May, 1991. Following his tour at VX-5, where he completed two operational tests of EA-6B software, LT Coury was assigned to Commander, Cruiser Destroyer Group One (CCDG-1) as the staff Assistant Command and Control Warfare Officer (AC2WO) and Electronic Warfare Officer (EWO). In May 1994, he was promoted to Lieutenant Commander and completed a six month deployment to the Persian Gulf in support of Operation Southern Watch. While still assigned to CCDG-1, LCDR Coury deployed to Aviano, Italy flying the EA-6B in support of Operations Deny Flight and Decisive Edge over Bosnia-Herzegovina. LCDR Coury received his Master of Science degree in Aviation Systems in May 1996.