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Evaluation of Tactical Aircrew Workload using Advanced Cockpit Simulation and its Impact on the Design of the EA-18G Aircraft

Christopher Michael Bahner
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Christopher Michael Bahner entitled "Evaluation of Tactical Aircrew Workload using Advanced Cockpit Simulation and its Impact on the Design of the EA-18G Aircraft." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Robert Richards, Major Professor

We have read this thesis and recommend its acceptance:

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Vice Provost and Dean of the Graduate School

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EVALUATION OF TACTICAL AIRCREW WORKLOAD USING ADVANCED COCKPIT SIMULATION AND ITS IMPACT ON THE DESIGN OF THE EA-18G AIRCRAFT

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

Christopher Michael Bahner
May 2006

DEDICATION

This thesis is dedicated to Michael Fischlien a man of true honor, courage and commitment, who passed away May 2005, and to my wife April, whose confidence and support has helped me persevere through this endeavor.

ACKNOWLEDGEMENTS

I wish to thank all of those who helped me write this thesis in order to complete my Master of Science degree in Aviation Systems. In particular I would like to thank Professor Bob Richards for all of his time and effort. I would like to thank Betsy Harbin and the rest of the support staff at the University of Tennessee for all their help while participating in the Aviation Systems Program.

In addition, I would like to thank the entire EA-18G Avionics Integration Team for their hard work and steadfast dedication to the project during its development.

ABSTRACT

The purpose of this paper is to document and study the evaluation performed to minimize the workload of the new EA-18G crew vehicle interface design prior to flight testing the aircraft system. The EA-18G concept was selected, from options presented in an Analysis of Alternatives (AoA) commissioned by the United States Navy, to replace the aging EA-6B Prowler. As part of this analysis the Navy expressed concern of aircrew workload increasing due to the reduction of aircrew in the cockpit, from four to two.

The Boeing Avionics Integration Team, in St. Louis, Missouri, developed the design interface for the EA-18G through a series of Design Advisory Groups (DAGs) consisting of test and fleet aircrew from the F/A-18 and EA-6B communities. As the design of the crew vehicle interface was developed it was implemented in the Network Centric Operations Center (NCOC) 3 simulator for evaluation by aircrew. Four workload assessments were performed over a one year period, evaluating multiple operator tasks, during simulated missions in various areas of the world. The crew vehicle interface design was altered following each assessment, in order to enable the aircrew to perform the next set of simulated missions with increased system functionality and lower operator workload.

The design, as implemented in NCOC 3 for the fourth assessment, was not functional enough to allow the aircrew to truly evaluate the system for a valid workload. A fifth workload assessment was added to the program following an inconclusive evaluation at the fourth workload assessment. The design was finalized and the simulator was programmed to resemble the completed paper design. In addition to the finalized design, the Human Factors Engineering team, working with the Crew Vehicle Interface team, utilized a new method of flight testing to gather metrics, which the workload assessments could then be compared to during the final evaluation. This new method of Use Cases allowed the engineering team to evaluate the design based on aircrew designed metrics for different missions and task subsets.

In the opinion of this author, although the design of the EA-18G will reduce the number of aircrew in the cockpit, the design lends itself to a more user friendly and low workload interface. While simulation will never replace the true reactions and workload

experienced by aircrew during real combat conditions, the implementation of advanced simulation techniques in this design has given the Navy insight into the crew vehicle interface performance of the EA-18G system earlier in the developmental cycle than ever before.

PREFACE

Information contained in this thesis is unclassified and was obtained from Department of Defense reports and manuals and product literature from Boeing St Louis. Any conclusions or opinions presented within this document are the opinion of the author and should not be interpreted as that of the United States Navy or the University of Tennessee Space Institute. Approved for Public Release, 265SPR-131.05.

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LIST OF ACRONYMS

A/A	Air-to-Air
A/G	Air-to-Ground
AEA	Airborne Electronic Attack
AoA	Analysis of Alternatives
ASUW	Air Surface Warfare
ATO	Air Tasking Order
BIT	Built-in-test
CAG	Carrier Air Group Commander
CAS	Close Air Support
CCS	Communication Countermeasures Set
CLC	Control Launch Computer
COMM	Communications
CTTG	Counter Targeting
CV	Carrier
CVI	Crew Vehicle Interface
CVIAR-A	Crew Vehicle Interface Analysis Report - Aircrew
DAG	Design Advisory Group
DDI	Digital Display Indicator
DEAD	Destruction of Enemy Air Defense
DRAWS	Defense Research Agency Workload Scale
DT	Developmental Test
EA	Electronic Attack
ECMO	Electronic Countermeasures Officer
EMCON	Emission Control
EMI	Electromagnetic Interference
EW	Electronic Warfare
FWD	Forward
FR/AZ	Frequency versus Azimuth
HARM	High Speed Anti Radiation Missile
HOTAS	Hands on Throttles and Stick
HUD	Heads Up Display
ICAP	Improved Capabilities
ID	Identification
INCANS	Interference Cancellation System
ISA	Instant Self Assessment of Workload
MCH	Modified Cooper-Harper Scale
MDB	Mission Data Base
MIDS	Multifunction Information Distribution System
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
NCOC	Network Centric Operations Center
OPEVAL	Operational Evaluation

OPS	Operations
OT	Operational Test
RAD	Radiate
RPE	Rate of Perceived Exertion
RTB	Return to Base
SEAD	Suppression of Enemy Air Defense
SSC	Surface Search and Control
SWAT	Subjective Workload Assessment Techniques
TCT	Time Critical Target
TDS	Tactical Display System
TOI	Time of Impact
TLX	Task Load Index
UFCD	Upfront Control Device
WLR	Work Load Rating
WSO	Weapon System Operator

Chapter 1: Introduction

Designing aviation systems in the past involved building aircraft around the general principles of aviation and physics, answering the question of “how will the aircraft fight at high rates of acceleration and airspeed” and then providing simple instrument gauges for the pilot. As aviation systems become more advanced with the new technologies available today, crew vehicle interfaces on these new systems have the potential to be overwhelming to the operator. Aircraft crew vehicle interfaces have surpassed the older gauge and dial instruments that presented information to the aircrew. In the current methods of design, engineers that have never used a system in combat are designing interfaces that war fighters will be utilizing in high stress environments on a daily basis. It has become even more important for aircrew to become involved early in the design of these new interfaces to ensure that the requirements for an acceptable workload environment are addressed in the design correctly.

The EA-18G program took the approach of evaluating the crew vehicle interface design early in the program with a variety of aircrew evaluations. Through the process of multiple aircrew advisory groups, aircrew were given the opportunity to evaluate the design recommendations not only on paper but also as coded in the Network Centric Operations Center (NCOC) 3 EA-18G simulation. These evaluations allowed aircrew to address the requirements to present the information needed to perform the Electronic Attack (EA) mission in the most appropriate and acceptable workload way for the operator.

This paper summarizes the results of the human factors evaluation of the aircrew workload with the EA-18G crew vehicle interface design. The issues addressed include the comparison of crew vehicle interfaces, accurate measurement of workload analysis and the results of the workload analysis performed using advanced simulation.

Chapter 2: Aircraft System Background

ELECTRONIC ATTACK MISSION

The EA mission consists of denying, degrading or exploiting the enemy's use of the electromagnetic spectrum. This is done by intercepting, analyzing, jamming and destroying enemy radar and communication systems. EA is accomplished with the use of the AN/ALQ-99 Tactical Jamming Pods, each with two transmitters, that vary in frequency range output. In addition, the AGM-88 High Speed Anti-Radiation Missile (HARM) is used to target and destroy enemy radar systems. When the aging E/F-111 aircraft was retired by the U.S. Air Force, the EA-6B became the primary EA platform for all NATO forces. The Navy recently upgraded the EA-6B to incorporate the new ALQ-218 receiver set on the Improved Capabilities (ICAP) III system. With this successful program, the Navy has paved the way to a more successful integration on the EA-18G.

EA-6B DESCRIPTION

The EA-6B (Figure 1) is a four-place, twin-engine, mid-winged monoplane designed for carrier based operations. Grumman Aerospace Corporation based the design of the EA-6B on the A-6 Intruder for the EA mission. The aircraft is an integrated electronic warfare system, combining long-range all weather day and night operations with advanced electronic countermeasures. The crew is comprised of a pilot and three Electronic Countermeasure Officers (ECMOs). The crew is seated side-by-side in tandem with pilot and ECMO 1 in the forward cockpit and ECMOs 2 and 3 in the aft cockpit. This side-by-side seating arrangement in the forward cockpit was designed for maximum comfort, visibility and crew coordination. A detailed description of the EA-6B can be found in the EA-6B ICAP II and ICAP III NATOPS Flight Manual (Reference 1).

EA-18G DESCRIPTION

The EA-18G design is based on the integration of the ICAP III Airborne Electronic Attack weapon system and the F/A-18F airframe systems. The F/A-18F is the two seat model of the Super Hornet and is configured with tandem cockpits (Figure 2). The rear cockpit can be configured with a stick, throttles, and rudder pedals (trainer

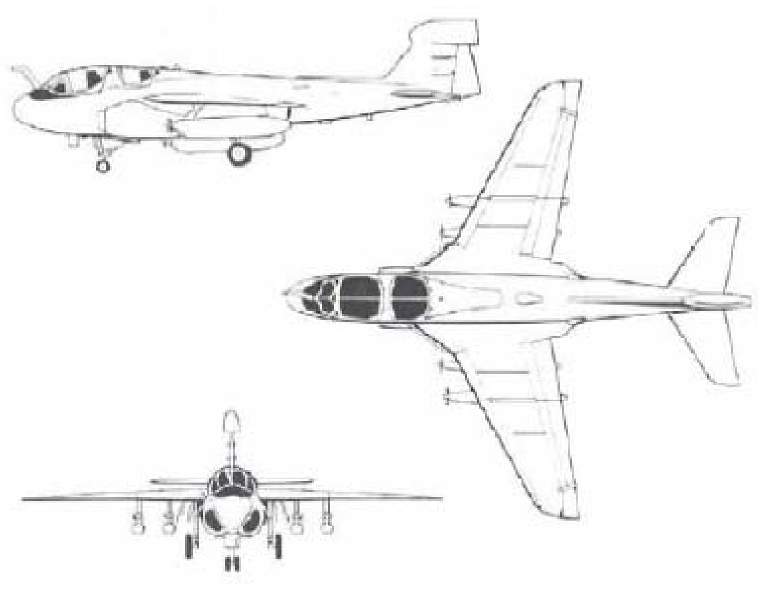

FIGURE 1: THREE VIEW OF THE EA-6B AIRCRAFT

Source: *NATOPS Flight Manual Navy Model EA-6B Block 89A/89/82 Aircraft*, NAVAIR 01-85ADC-1, dated 15 April 2004.

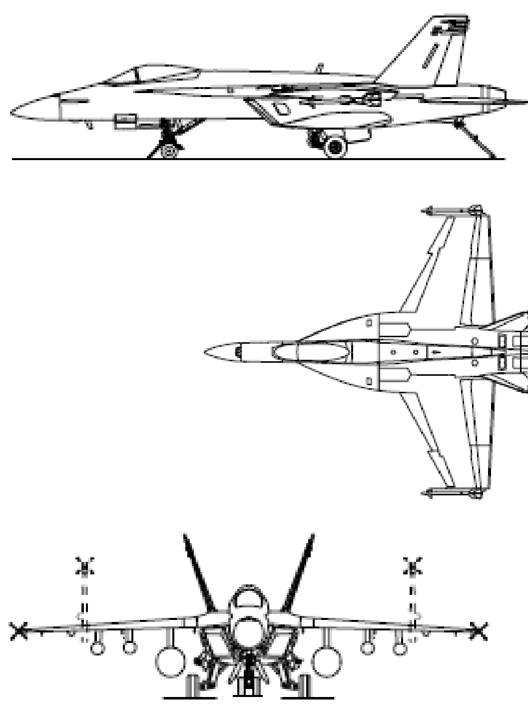

FIGURE 2: THREE VIEW OF THE F/A-18 SUPER HORNET

Source: *NATOPS Flight Manual Navy Model F/A-18E/F Aircraft*, NAVAIR A1-F18EA-NFM-000, dated 1 March 2001.

configuration); or with two hand controllers, an Up Front Control Device (UFCD) adapter, and foot-operated communication switches (missionized configuration). The rear cockpit controls and displays operate independently (decoupled) of those in the front cockpit. The F/A-18F Super Hornet is built by the Boeing McDonnell Douglas Corporation based on the F/A-18 design. The F/A-18F aircraft has an internal 20 mm gun and can carry AIM-7, AIM-9, and AIM-120 air-to-air missiles; and numerous air-to-ground weapons. With the addition of the ALQ-218 receiver pods on the wingtips, the EA-18G configuration will not support the AIM-9 missile. The placement of the Airborne Electronic Attack (AEA) suite (Figure 3) of components in the gun bay location will necessitate the removal of the 20 mm gun as well.

Current plans include retaining all air-to-ground weapon capability that the F/A-18F has on the EA-18G. The aircraft fuel load may be increased with the addition of up to five external fuel tanks. The aircraft can also be configured as an airborne tanker by carrying a centerline mounted air refueling store. A detailed description of the F/A-18F can be found in the F/A-18E/F NATOPS Flight Manual (Reference 2).

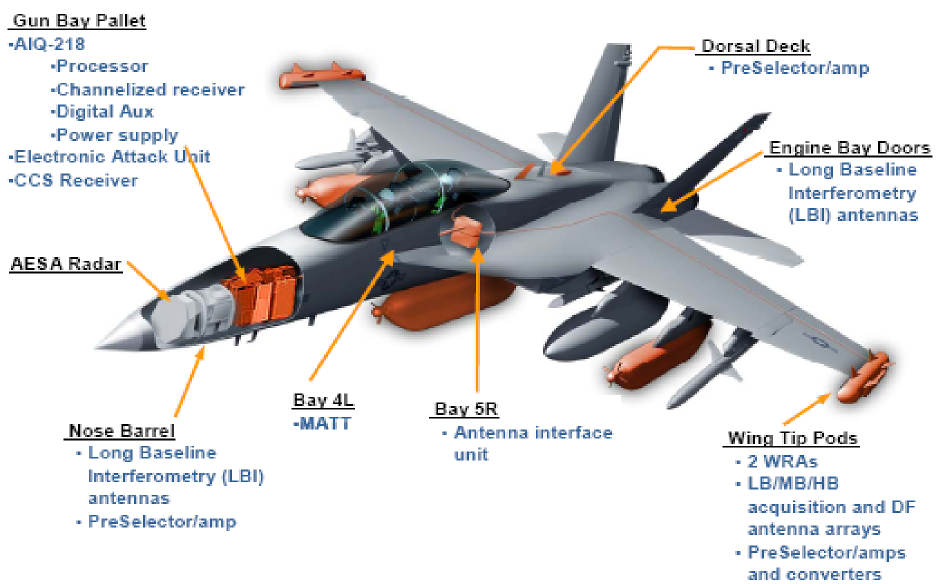

FIGURE 3: E/A-18G AIRBORNE ELECTRONIC ATTACK SUITE

Source: *Crew Vehicle Interface Draft Cyan Book DAG #4 December 2004*, Boeing Avionics Integration Team.

Chapter 3: System Comparison and Design

DISPLAYS AND CONTROLS

ICAP III has three ECMOs that divide the EA mission tasks among each position. Each station is equipped with a single Tactical Display System (TDS) (Figure 4) and a means of data entry. The Pilot and ECMO 1 are equipped with a hand controller (Figure 4), while ECMO 2 and 3 utilize a keypad and slew control (Figure 5). The slew control allows the operator to position the display cursor over any signal of interest, or other display item, and hook the signal. By hooking the signal of interest, the operator commands amplifying information to be displayed in the frequency analysis format.

The ICAP III display formats are divided into six zones of information (Figure 6). Zone 1 is designed to display amplifying information for aircraft heading and the current

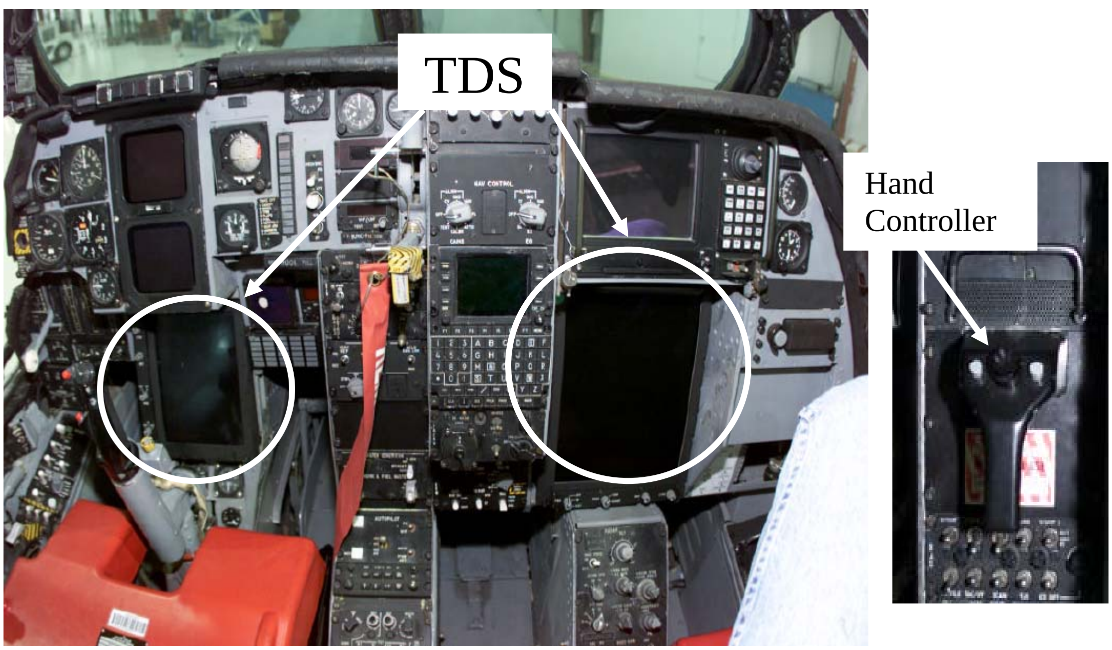

FIGURE 4: ICAP III PILOT AND ECMO CONTROLS AND DISPLAYS

Source: VX-23 ICAP III Test Team, April 2000, NAS Patuxent River.

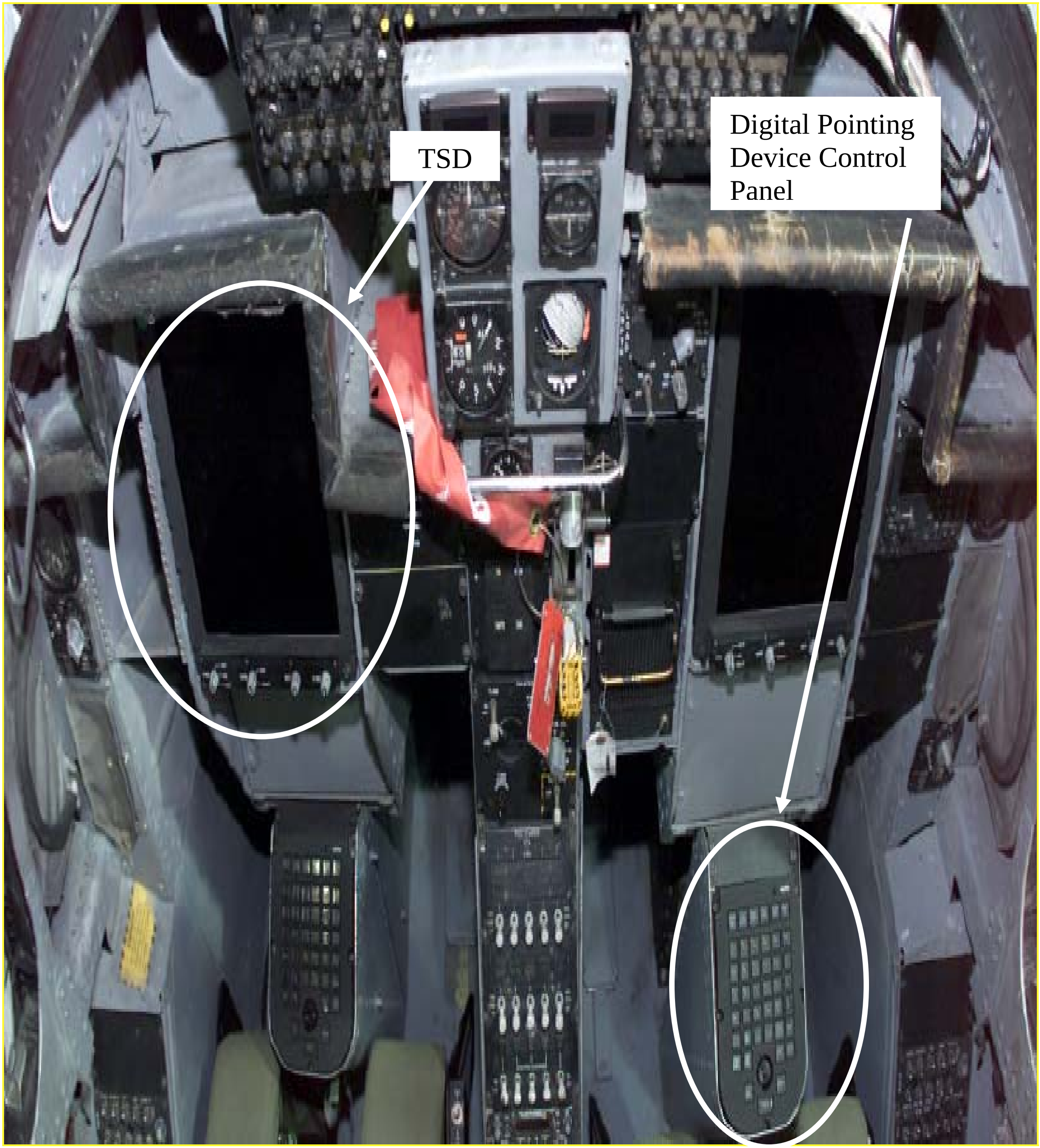

FIGURE 5: ECMO 2 AND 3 DISPLAYS AND CONTROLS

Source: VX-23 ICAP III Test Team, April 200, NAS Patuxent River.

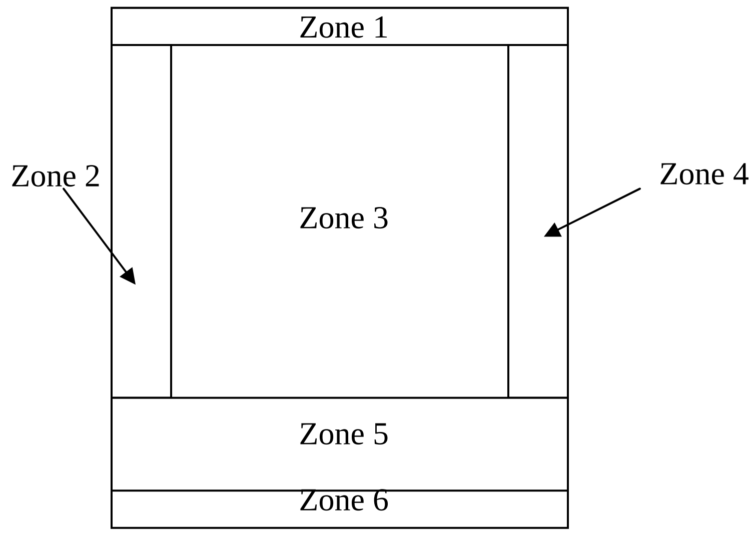

FIGURE 6: ICAP III DISPLAY ZONES

display format. Zone 2 displays frequency information on the FR/AZ format and target information on the GEO page. Zone 3 is the primary working/display area for all formats. It displays the frequency versus azimuth and geolocation information for the two primary displays. Zone 4 displays weapon information for any ALQ-99 transmitter pod and AGM-88 HARM that are loaded on the aircraft. Zone 5 displays amplifying information on any hooked items from Zones 3 and 4. Zone 6 is the software control stick.

The E/A-18G replaces the three ECMOs with one and the single TDS with four individual displays; a digital UFCD, two 5” x 5” Digital Display Indicators (DDI’s) and one 8” x 10” Digital Display (Figure 7). There are two types of display formats; dependent and independent. A format is dependent because either the Pilot or the ECMO control the same format at the same time. Because of this, there is a chevron and rocker placed in the upper right hand corner of any display that the two operators can be on at one time.

FIGURE 7: E/A-18G AFT COCKPIT

Source: *Crew Vehicle Interface Draft Cyan Book DAG #4 December 2004*, Boeing Avionics Integration Team.

If the aft cockpit has control, the display will show a rocker (an upside down chevron), if the front cockpit has control, the format will display a chevron. Figure 8 shows that both cockpits are on the same display format at the same time (the chevron and rocker form a diamond in the upper right hand corner).

Data entry in the EA-18G is divided among two methods, the use of the UFCD and the Hands on Throttles and Stick (HOTAS) missionized controllers (Figure 9). The UFCD provides the symbol and character entry method while the HOTAS provides the primary method of slew and hook control. Hooking a signal of interest in the E/A-18G also commands the frequency analysis format to be displayed, automatically on the left DDI.

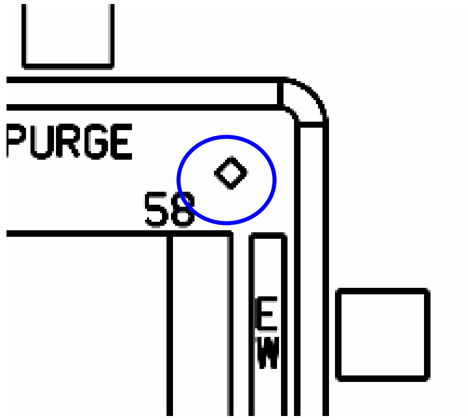

FIGURE 8: OPERATOR CONTROL SYMBOL FOR DEPENDENT DISPLAY FORMATS

Source: *Crew Vehicle Interface Draft Cyan Book DAG #4 December 2004*, Boeing Avionics Integration Team.

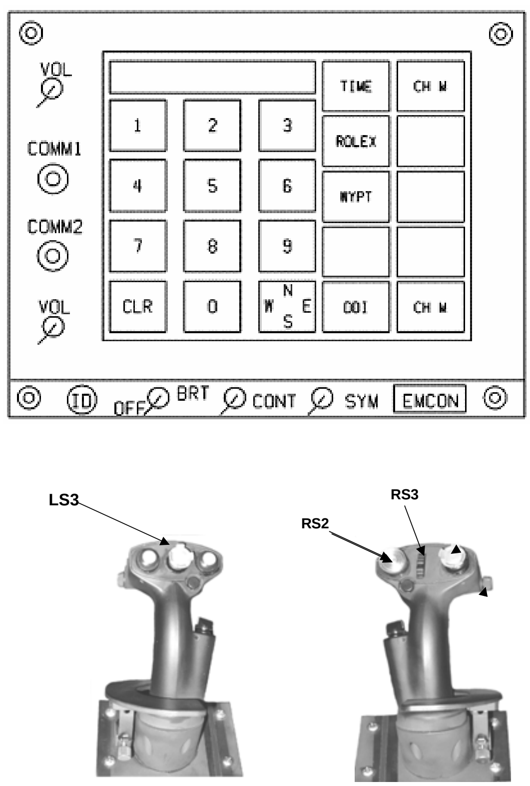

FIGURE 9: E/A-18G UFCD AND AFT COCKPIT HOTAS MISSIONIZED CONTROLLERS

Source: *Crew Vehicle Interface Draft Cyan Book DAG #4 December 2004*, Boeing Avionics Integration Team.

PRIMARY DISPLAYS

The EA mission requires two key parameters to be performed to accomplish the mission, an indication of what frequency the threat system is operating at and a general location of the threat. The ALQ-218 receiver set provides this information to the mission computer to display to the operator. A single dimension display view can not be used to display this four dimensional (frequency, three-dimensional location and time) problem to the operator, therefore two primary displays are utilized in both designs; the Frequency versus Azimuth (FR/AZ) and Geographical displays.

FREQUENCY VERSUS AZIMUTH (FR/AZ)

As the name describes, both designs utilize a single display to provide the frequency versus azimuth (Figure 10) indication of the detected threat emitters to the operator. The frequency scale is scalable to all or any portion of the detectable electromagnetic spectrum. Even if the emitter has an actual location (latitude and longitude), the azimuth of detection is still presented to provide a steering cue for the jamming requirement. This cue allows the operator to assign jamming assignments and determine that the threat emitter is covered by the ALQ-99 transmitter. The FR/AZ format is a dependent format in the E/A-18G and independent in the ICAP III design, the display setup is independent while the information for active emitters and jamming is reported on all displays.

GEOGRAPHIC LOCATION

In the ICAP III design a geographic display is presented to the operator with the threat emitter's latitude and longitude represented by a character symbol and associated error ellipse displaying the potential error in location (Figure 11). For the EA-18G design the same detected signal is correlated into a grouping with other like contacts and presented by a symbol where the group is located (Figure 11). Because there are two TSD formats in the EA-18G design (one aft and one forward), the TSD is an independent format. The geographic display provides the operator with threat warning information for the striker group as well as the aircraft position. The pilot and ECMO can both view two different displays of information on the same display format depending on the filter and declutter settings of the operator.

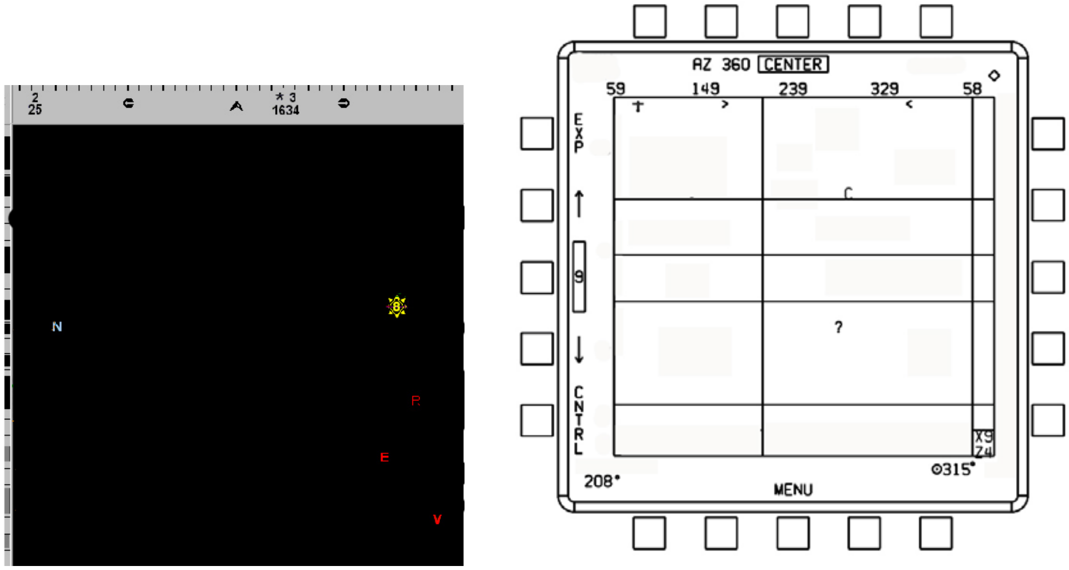

FIGURE 10: ICAP III AND E/A-18G FREQUENCY VERSUS AZIMUTH DISPLAY FORMATS

Source: ICAP III VX-23 Test Team, NAS Patuxent River and the *Crew Vehicle Interface Draft Cyan Book DAG #4 December 2004,* Boeing Avionics Integration Team.

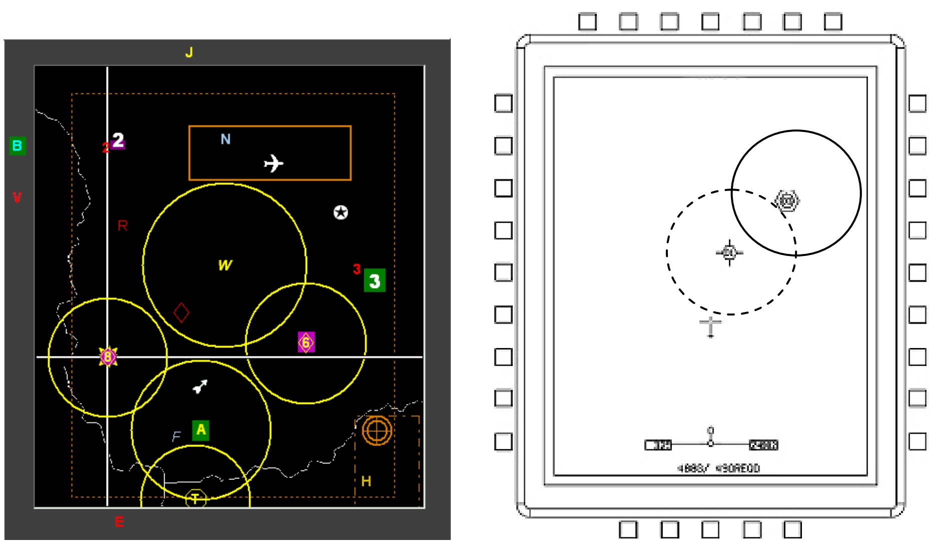

FIGURE 11: ICAP III GEO DISPLAY AND THE E/A-18G TACTICAL SITUATION DISPLAY

Source: ICAP III VX-23 Test Team, NAS Patuxent River and the *Crew Vehicle Interface Draft Cyan Book DAG #4 December 2004*, Boeing Avionics Integration Team.

SECONDARY DISPLAYS

Secondary display formats provide the operator amplifying information about the detected signals of interest, the weapon system status and jamming information. Each secondary format can be viewed while still maintaining situational awareness on the primary display of interest.

SIGNAL ANALYSIS

Upon hooking a signal of interest in either design, the operator is presented with a signal analysis format with amplifying information of that signal. ICAP III displays this information in the Zone 5 window of the TDS format (Figure 12). The E/A-18G displays this information with the EPAGE on the left DDI (Figure 13). Each format was created to display the same information to the operator in a quick intelligible manner. The EPAGE is an independent format in the E/A-18G design.

JAMMER MANAGEMENT

ICAP III uses the Zone 5 amplifying jammer information format (Figure 14) to display all amplifying information about a jamming assignment that have been made or requested. The name and type of jamming assignment, frequency, coverage and ALQ-99 station where the assignment was made are all presented on these two formats. The jammer management format (Figure 15) is a dependent format in the E/A-18G design. By monitoring the jammer management format, the aircrew control the ALQ-99 weapon system in order to deny and defeat the enemy radar systems. In ICAP II and III, jamming is assigned through the use of push button actuations on a keypad, while the EA-18G design utilizes HOTAS controls to activate jamming assignments.

STORES MANAGEMENT

The ALQ-99 transmitter pods provide the operator with information on what jamming assignment has been made and the steering of any particular transmitter. This information is displayed in the Zone 4 of the FR/AZ and GEO formats in ICAP III and on the stores management format in the E/A-18G design (Figure 16). At a quick glance the operator can determine what jammer assignments are made to each transmitter, without

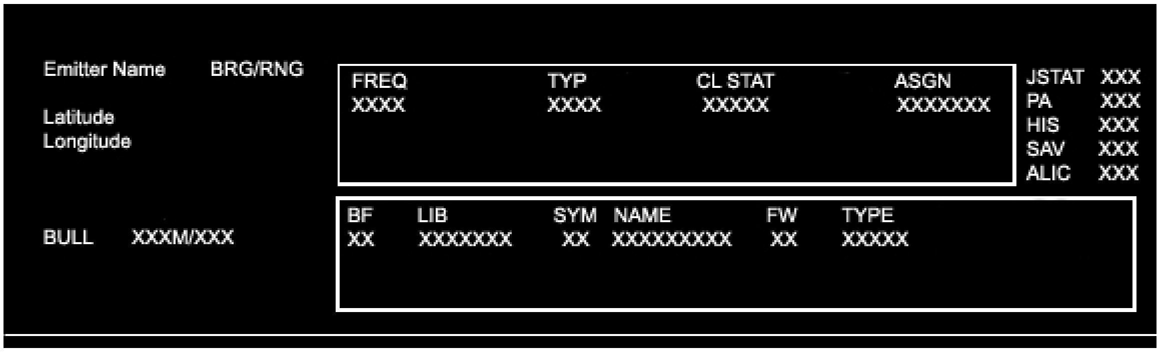

Figure 12: ICAP III ZONE 5 EMITTER AMPLYFING INFORMATION

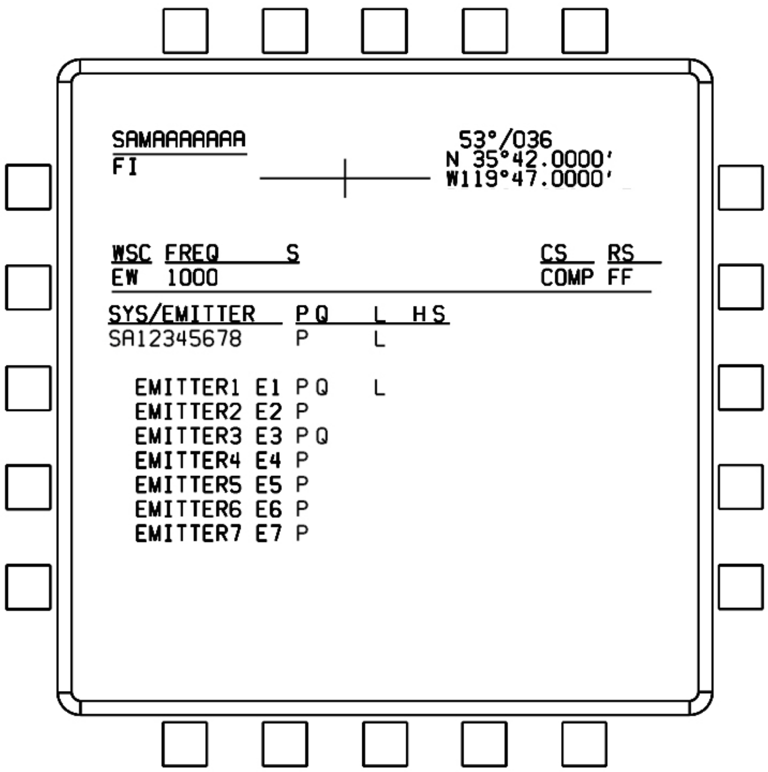

FIGURE 13: E/A-18G EPAGE

Source: ICAP III VX-23 Test Team, NAS Patuxent River and the *Crew Vehicle Interface Draft Cyan Book DAG #4 December 2004,* Boeing Avionics Integration Team.

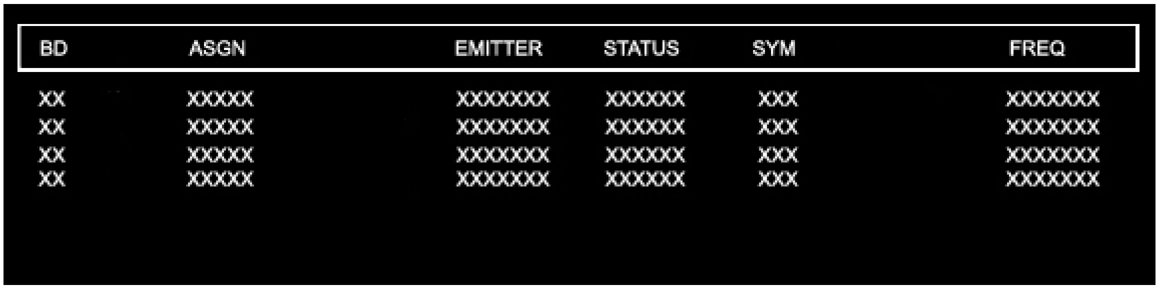

Figure 14: ICAP III ZONE 3 JAS FORMAT

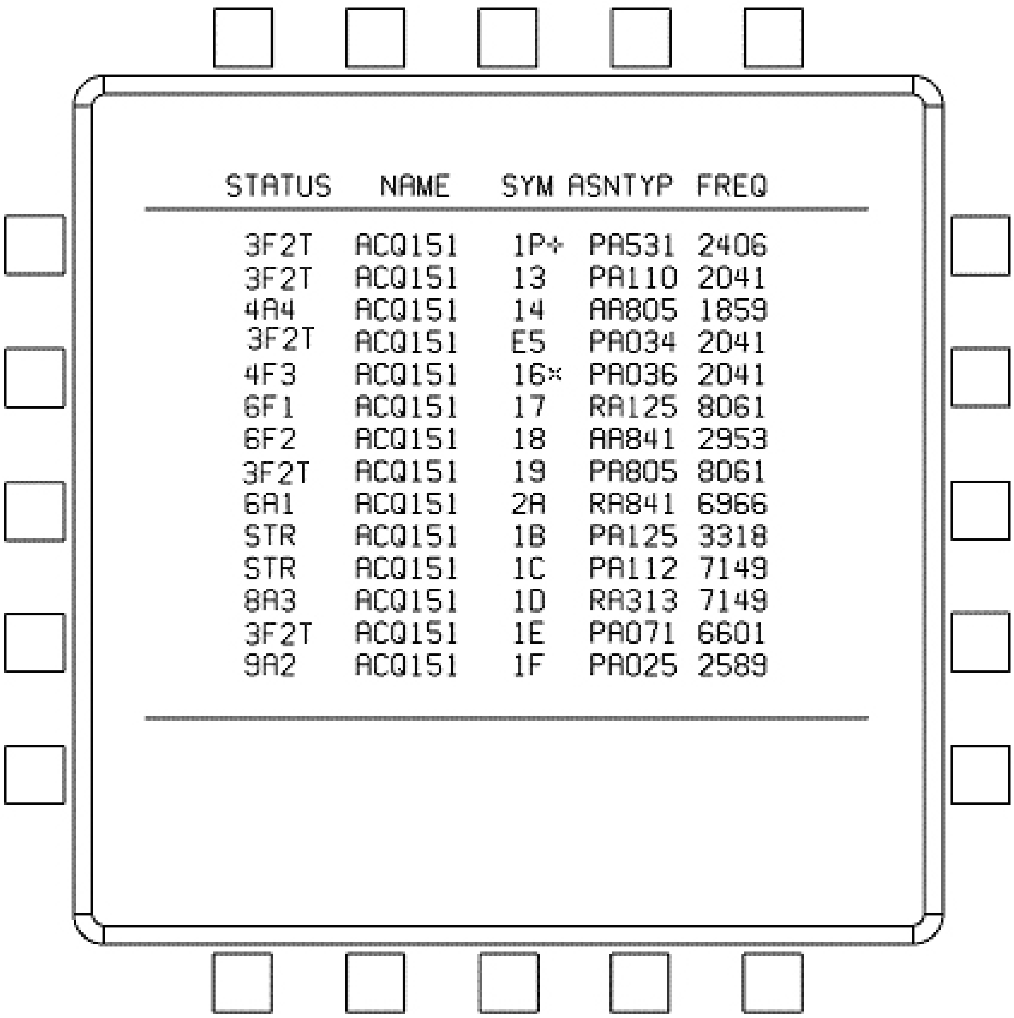

FIGURE 15: E/A-18G JAMMER MANAGEMENT FORMAT

Source: ICAP III VX-23 Test Team, NAS Patuxent River and the *Crew Vehicle Interface Draft Cyan Book DAG #4 December 2004,* Boeing Avionics Integration Team.

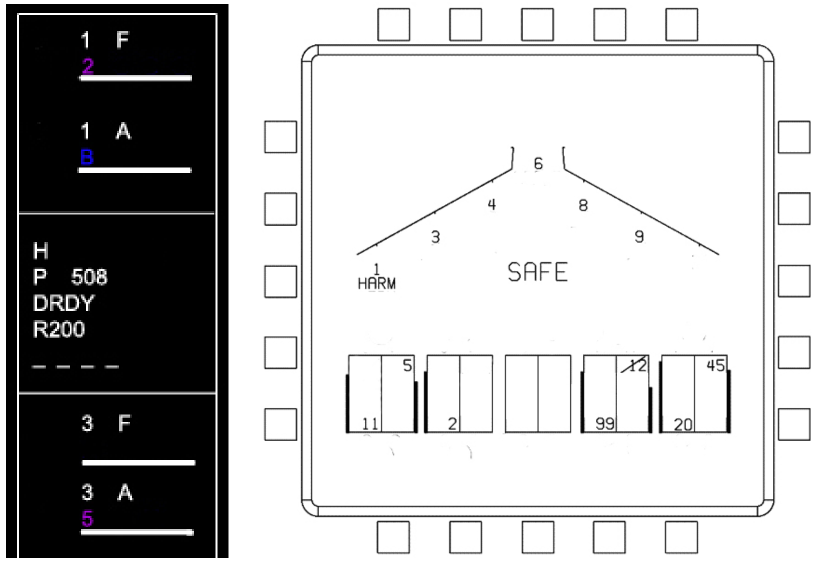

FIGURE 16: ICAP III AND E/A-18G WEAPON AND STORES MANAGEMENT FORMATS

Source: ICAP III VX-23 Test Team, NAS Patuxent River and the *Crew Vehicle Interface Draft Cyan Book DAG #4 December 2004,* Boeing Avionics Integration Team.

ever viewing the jammer management format. Steering information in ICAP III is provided by a graphical footprint on the geographic display format. In the EA-18G this steering information is provided only by the small circle symbology on the ALQ-99 stores format. The ALQ-99 information was added to the existing F/A-18F stores management format for commonality in stores management across the Super Hornet fleet. The stores management format is a dependent format in the E/A-18G design.

DESIGN COMPARISON

Where the ICAP III design presents all of this information on various areas of one or two display formats, the E/A-18G has divided the information into five different formats on different displays. Even with the slight differences in the presentation of the information, the E/A-18G formats were created to present the same information in a similar and common fashion.

This commonality between the designs aided in leveling the skill and experience levels of each operator (prior EA-6B operators). With this baseline in the design, the workload analysis became a question of whether this information was presented correctly and in a logical manner for the operator to perform the tasks required to accomplish the EA mission.

Chapter 4: Analysis of Assessment Alternatives

WORKLOAD

Workload can be defined as the measurement of the demand placed upon the operator of a system. There are two types of workload, which play a role in the tasks performed by any operator. The first is physical workload, typically associated with the manual labor portion of performing a task (i.e. HOTAS and push button actuations). The operator's skill or training generally has no impact on how well the task can be performed. The second is mental workload, a more subjective measure of workload that relies on the operator's view of how hard the task was to perform. It is very difficult to evaluate and will vary between operator and tasks. Mental workload is related to subjective states of stress, mental effort and time pressure, leading to breakdowns in task performance (Reference 3). A specific task does not denote a particular level of performance or workload alone, practice, fatigue and skill level all play a role (Reference 3). While metrics are readily available for physical workload ratings (i.e. heart rate variability and blink rate) mental workload is more difficult to determine and more subjective.

To assess the subjective mental workload of operators, the industry has turned to a multitude of techniques. These techniques fall into different categories, rating scale procedures, psychometric techniques, paired comparisons and conjoint measurement and scaling. In order to measure the workload of a system several subjective techniques are typically used; Modified Cooper-Harper Scale, Bedford Workload Scale, Rate of Perceived Exertion (RPE), NASA Task Load Index (TLX), Defense Research Agency Workload Scale (DRAWS), Instant Self Assessment of Workload (ISA), and the Subjective Workload Assessment Technique (SWAT). Rating procedures, such as Cooper-Harper Aircraft Handling and the Bedford Workload scales, use a decision tree process to allow the operator to rate the difficulty of the tasks. While rating scales can be sensitive to different levels and varieties of load, psychometrics have the advantage of being capable of providing interval information regarding task difficulty (Reference 3). By measuring workload we can ascertain more understanding and meaning from the performance of a task. Typical variables in measuring workload include task completion, time and performance quality (accuracy in performing the task) (Reference 4).

Traditionally the measurement of operator workload associated with a new system under test does not occur until the final design has been implemented in the first test aircraft. With software delivery schedules that bring new functionality to the aircraft throughout it's testing, the full design never receives a full evaluation until the very end of the test period, typically when it is too late to change factors in the design that are influencing high operator workload. Most of those items would then be addressed in the next iteration of the design and not implemented for months or even years if the individual factor was of a low priority. Multiple workload factors that combine to not allow the operator to perform a mission area are often dealt with directly. Either way, the impact to the program has typically been to accept a lower performance level in order to maintain cost and schedule. By evaluating the workload of the EA-18G system early on in the design phase, items that influenced the workload were addressed during the design phase, before ever reaching the official flight test phase. This allowed for more opportunity to achieve fixes to the design, enabling the chance to deliver better performance for the fleet upon initial acceptance of the aircraft system.

MODIFIED COOPER-HARPER SCALE (MCH)

Originally designed to measure the handling qualities of aircraft under test, the Cooper-Harper scale uses a binary decision tree to determine the workload required to fly the aircraft. The modified scale (Figure 17) was developed to evaluate workload for more generic situations in aircraft system testing. It can be used for perceptual, cognitive and communication tasks (Reference 5). The scale ranges from 10 to 1, 10 being the highest workload. Studies have been performed involving remotely piloted vehicle systems and air defense systems to evaluate operator workload (Reference 6). The MCH can distinguish between low and medium levels of central processing demands and "appears to represent a globally sensitive measure as opposed to a diagnostic measure of mental workload" (Reference 6).

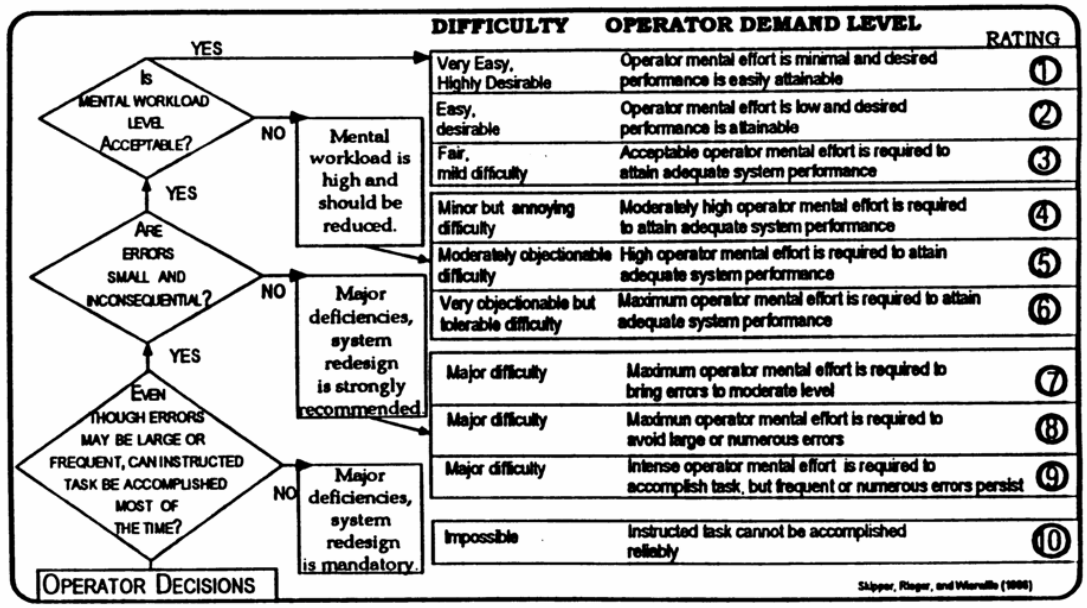

FIGURE 17: MODIFIED COOPER-HARPER RATING SCALE

BEDFORD WORKLOAD SCALE

The Bedford Workload Scale was designed to identify the operator's spare capacity while completing a task. The spare capacity is measured through the operator following a hierarchical decision tree rating scale (Figure 18), while performing the task. The scale ranges from 10 to 1 with 10 being the highest workload value. Similar to the MCH scale, the Bedford workload scale does not have a good diagnostic capability for determining why the subjective workload was high.

RATE OF PERCEIVED EXERTION (RPE)

RPE uses a scale from 6 to 20 (Figure 19) that was originally developed for assessing physical workload. The verbal ratings attempt to provide a sense of subjective evaluation to the scale. The scale evaluates the level of workload for physical activity (i.e. exercise) by multiplying the rating of perceived exertion by 10, the scale thereby roughly approximates the heart rate during exercise. Due to the physical nature of this evaluation technique, it is more suited for the more physical analysis than when attempting to assess the subjective workload of a system.

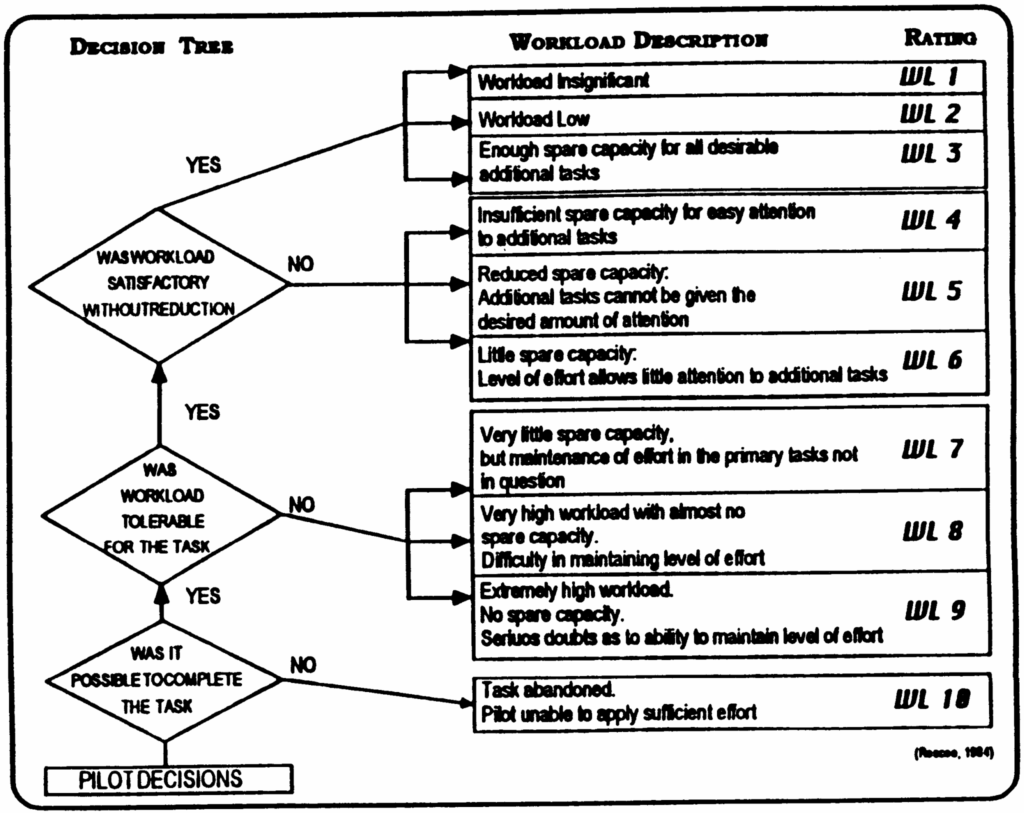

FIGURE 18 BEDFORD WORKLOAD SCALE

PERCEIVED EXERTION (PE) SCALE	
NUMERICAL RATING	**VERBAL RATING**
6	
7	very, very light
8	
9	very light
10	
11	fairly light
12	
13	somewhat hard
14	
15	hard
16	
17	very hard
18	
19	very, very hard
20	

FIGURE 19: PERCEIVED EXERTION SCALE

Source: Virginia Tech Army ROTC. http://www.armyrotc.vt.edu/PT/appg.pdf

NASA TASK LOAD INDEX (TLX)

Originally developed by NASA engineers Hart and Staveland, the rating method consists of evaluating mental demand, physical demand, temporal demand, performance, effort, and frustration level with a low to high rating. The scaling method is based on a 6 element structured subjective assessment, with an individual relative element calibration. Users typically have to be trained in how to fill out the evaluation tools, which can sometimes be difficult to interpret.

At the end of each task, the operator is asked to rate the six dimensions, based on their descriptions and what the operator felt was emphasized more in the task (Figure 20). After rating each element, the operator is asked to choose what element was emphasized more through word pair association. The word pairs and the original weightings are combined to return a workload rating for the task. The scale, while subjective, is designed to balance out the subjectivity of an operator, thereby making it easier to compare different subjective operator workloads for a similar task.

Title	Endpoints	Descriptions
Mental Demand	Low/High	How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

FIGURE 20: NASA TASK LOAD INDEX RATING SCALE DEFINITIONS (REFERENCE 7)

DEFENSE RESEARCH AGENCY WORKLOAD SCALE (DRAWS)

DRAWS is a multi-dimensional tool (similar to NASA TLX) that provides a subjective assessment from operators. Rating scales consist of input demand, central demand, output demand, and time pressure. Input demand can be defined as the "workload associated with perceiving things" (Reference 8). Central processing is the "workload associated with interpreting information and deciding on an action" (Reference 8). Output is "the workload associated with overt action; and Time, the pressure to act quickly" (Reference 8). Verbal prompts are given to the operator following each task and the operator responds with a rating (0 to 100). The workload for each task can then be compared between operators on the 0 to 100 scale. This leaves the operator's skill and experience level as the determining factor in the required level of workload for any given task evaluated.

INSTANT SELF ASSESSMENT OF WORKLOAD (ISA)

ISA is a method which allows the operator to estimate their perceived workload during real-time simulations. At regular intervals the operator is asked to evaluate how busy they are on a scale of 1 to 5 (1 is underutilized, 5 is excessively busy). The method allows different operators workload to be evaluated for the same task without a particular tool (Reference 5). This method is much more subjective in non-scripted evaluations, due to the varying priorities between operators.

SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUES (SWAT)

Originally designed to assess aircrew workload, SWAT is a multi-dimensional tool that incorporates factors of temporal load, mental effort and psychological stress. There are two stages to SWAT; first, the operator ranks the level of the three workload scales in order from the lowest to highest, through pair wise comparison (Figure 21) before the task is performed and then rates each scale during the task. While the pair wise comparison is similar to that used in the NASA TLX scale there are only three factors measured in the SWAT as compared to the six in the NASA TLX scale. It has been said that SWAT is not a very sensitive method of workload rating and therefore can be less effective in low workload task evaluations (Reference 9).

Please tick one of the two dimensions of workload that you think is more important to you.

Mental Effort Load ❐/ Time Load ❐
Time Load ❐/ Psychological Stress Load ❐
Psychological Stress Load ❐/ Mental Effort Load ❐

FIGURE 21: AN EXAMPLE OF THE PAIR-WISE COMPARISON PROCEDURE (REFERENCE 9)

Chapter 5: Method of Design and Analysis

DESIGN ITERATION

The design schedule for the EA-18G program was laid out in an iterative approach, to allow the software engineers time to design, review and finally code in the time allowed in the program, prior to delivery of the first system to flight test. Design Advisory Groups (DAGs) were formed to review the process of the design following the contract awarding of the program. At each DAG, the industry presented design ideas for display formats and interface in a power point format, to aircrew from both the EA-6B and F/A-18 communities, in order to obtain the operators perspective on the requirements for the aircraft system interface. At the completion of each DAG the aircrew met to discuss the changes they would like to see in the design and presented this list to the Program Management team for approval. The changes approved were then coded into the NCOC 3 EA-18G simulation for the next workload assessment.

The EA-18G design iteration focused on the RADAR jamming portion of EA during the first two DAGs (DAG 1 and 2) and the AGM-88 and communications jamming portion of EA during the last two DAGs (DAG 3 and 4). With this breakdown in design, changes in the design requested by the aircrew following the first two DAGs were fully funded; while allocation of funds was still plentiful. In contrast, the requests made following the last two DAGs were approximately 70-80% funded both due to cost and schedule impacts. In hind sight the program might have suffered functionality needed following the later DAGs, due to these funding issues. If these issues were addressed sooner, they could have been weighed against earlier requests as higher needs and then implemented. To alleviate this, DAG members rated the higher workload and mission impact items higher than other items. Even with this draw back in funding aircrew requests, the program sought to make the changes needed for the aircrew to perform the mission, at all costs.

WORKLOAD ASSESSMENT

As a baseline to the effort that would follow contract awarding to design a system, that two aircrew could perform the EW mission instead of four, Boeing developed and collected two separate workload surveys. The first was developed to baseline the perceived workload of ICAP II aircrew for the SOJ support mission. Boeing, working with the program office and the EA-6B wing at Naval Air Station (NAS) Whidbey Island, administered the survey to 18 fleet Pilots and 21 fleet ECMOs. The second was designed to baseline the perceived workload of the ICAP III aircrew for the SOJ support mission. Two Pilots and four ECMOs from VX-23, who had the most experience with ICAP III, were given the survey. The ICAP III survey was not as statistically representative due to the ICAP III system still being very new and not yet deployed to the fleet.

The EA-18G program had originally planned three workload assessments at various stages throughout the design. The first assessment was at DAG 2 following contract awarding to Boeing and Northrop Grumman. The DAG 2 assessment was based upon a new design that had been scoped back from pre-SDD designs, due to actual design implementation in DAG 1. The industries scoped the interface back in scale from pre-SDD, due to the amount of funding awarded with the contract (the crew vehicle interface that was presented pre-contract, as the design, was not what was presented post contract). The second and third assessments followed DAGs 3 and 4 after more of the design iterations had a chance to be coded and implemented into the NCOC 3 EA-18G simulator.

Due to the number of changes required following the DAG 2 and 3 reviews, to have the design meet the requirements, there quickly became a backlog in the coding process for the simulation. These changes were a combination of items not in the design (aircrew inputs) and items that had been misinterpreted in the design and the coding process. By in large, the second group composed the majority of changes to the simulation. As a result, the workload assessment simulation following the DAG 4 review comprised of too many errors in the simulation and did not allow the aircrew to properly and fairly evaluate the workload during the mission profiles presented. Another workload assessment was added to the schedule following the incorporation of the correction of the errors noted during the DAG 4 assessment, along with the final design implementation. At the time of completion of this thesis, the final design assessment had not occurred.

RATING SCALE

To evaluate the workload during these assessments, the human factors team for the program (comprised of NAVAIR and Boeing human factors engineers) utilized a combination of the NASA Task Load Index (TLX) rating and a Modified Bedford Cooper-Harper Rating Scale. The NASA TLX rating was determined to "be more sensitive to changes in workload" (Reference 4) while providing a highly reliable rating for tasks performed by the operator. The NASA TLX was thought to provide direction in pinpointing opportunities for implementing design changes and automation requirements of the EA-18G. The modified Bedford Cooper-Harper Scale was applied to each questionnaire to bound and describe what constituted a workload rating level (Figure 22). Each assessment was setup so that the aircrew performing in the simulator had no prior knowledge of the real scenario or specific workload tasks involved. The aircrew teams were provided a mission briefing a day before their individual simulation to allow for any pre-simulator planning required. The scenarios used for workload assessments following DAG 2 and DAG 3 were the same, using similar tasks and systems, while incorporating the improved design features and functionality at each new assessment. In order to assess the impact of pre-knowledge of the scenario for the aircrew in the last assessment in DAG 4, the scenario was altered and split into two sections. In each workload assessment the aircrew were given a specific mission to perform; such as stand off jamming, close air support, or escort strike, and abort criteria for each mission; such as a specific emitter being detected or a popup air threat. Each scenario covered a different mission area of EW that the simulator could perform with the given design at that time period. As each workload assessment was completed, the design functionality increased resulting in more of the systems being incorporated for the operator to manage in the mission scenario.

In general the aircrew did not waste valuable response time writing down their observations or frustrations during the assessment. A digital recording of all audio and display video of operator actions for each crew station was recorded for post-simulator

Satisfactory without Improvement	(No Deficiencies)	Excellent	No Compensations	1	Low tasking, safe, can accept additional tasks without impacting existing tasks.
		Good		2	Minimal tasking, safe, can accept additional tasks without impacting existing tasks.
		Fair	Minimal Compensation	3	Light tasking, safe, can accept additional taskings with minimum impact to existing taskings.
Adequate performance attainable with tolerable workload	Deficiencies Warrant Improvement	Minor but annoying deficiencies	Moderate compensation	4	Moderate / Comfortable tasking, safe, can accept additional tasking and complete all tasks with reduced revisit time.
		Moderate objectionable deficiencies	Considerable compensation	5	Moderate / pressured tasking, safety slightly impacted, additional tasks will impact / degrade existing tasks.
		Very objectionable but tolerable deficiencies	Extensive compensation	6	High tasking, safety impacted, things beginning to drop out of scan, additional tasking will significantly degrade new and existing tasks.
Adequate performance not attainable with tolerable workload	Deficiencies Require Improvement	Major Deficiencies	Adequate performance no attainable with maximum tolerable compensation	7	High tasking, safety secondary consideration, additional tasking will override or replaced some existing tasks.
			Considerable compensation	8	Very high tasking, safety not factored into tasks completion, additional tasks cannot be accepted without major degradation to all existing tasks.
			Intense compensation	9	Saturation tasking, safety not considered, scan breaking down, additional tasking will impact mission accomplishment/
Not Usable	Mandatory Improvement		Intense compensation	10	Total saturation tasking, scan and task sharing breakdown, fixation on task at hand, survival instincts take over.

Figure 22: MODIFIED BEDFORD COOPER HARPER RATING SCALE

Source: Pre-SDD Phase 2 Final Program Management Review – HFE Workload Assessment, Seavers and Perkins, Boeing Avionics Integration Team, St Louis MO play back. While the aircrew performed their mission, the human factors team recorded comments and actions of the aircrew throughout the simulation. The mission time line for each scenario involved triggers for workload tasks that the human factors team wanted to see performed. They consisted of both pre-briefed tasks that went as expected and involved novel or unexpected failures. During the post-simulator debrief the crew was provided a NASA TLX questionnaire (see Appendix C for a sample question) and asked to fill it out. The aircrew would first describe their performance criteria for the given task and then circle words on the NASA TLX pair-wise comparison table that they felt influenced the workload the most. Definitions of each pair-wise word were provided on the same sheet for reference. Then the aircrew were asked to rate the magnitude of each workload factor using the Modified Bedford Cooper-Harper scale for each TLX. If there were any ratings greater than 3 provided in the aircrew comments, they were asked to elaborate on what may have been the cause of such a rating.

In order to jolt the memory of actions performed and frustrations observed during the simulation, the crew was provided the capability to view the digital playback recording; with audio and video synchronized to each other. Groups were not allowed to interact with each other until after the assessment for that mission task level was completed, hoping to not sway comments from any one group. In addition, the workload levels for one team were not known by another until briefed months later. As the crew filled out their individual questionnaire, they also noted any discrepancies in the simulation that were not as designed and that may have impacted the workload assessment. These design inconsistencies were taken into account by the human factors team during their analysis.

During the process of filling out the questionnaires, the aircrew were asked to base their answers on whether they had accomplished their task acceptably or not. Because the aircrew where not aware of the actual task being assessed prior to seeing the questionnaire, there was some subjective interpretation of what was good enough for a given task. After the DAG 3 workload assessment it became clear that the tasks being performed were complex and more subject to interpretation. A workload level for a task does not provide useful information if you can not determine if the task was actually accomplished and within a prescribed metric. Because of this, a set of metrics were taken from the Use Cases being developed by the aircrew for flight testing. The human factors team grouped several Use Cases together, in a logical mission order, and determined which ones the NCOC 3 simulator could record during an assessment. This provided the capability to compare each operator's metric accomplishment to each other. For example, if the task was to perform an AGM-88 HARM missile shot on a newly active emitter, the time it took to complete that task and whether the shot was taken or not are the important factors. If the first operator, who took 15 seconds to perform the task, rated the task a 6 on the NASA TLX scale and another operator called it a 3, and took 25 seconds, the human factors team could better analyze whether the second operator's rating was lower because they took more time to complete the task or because they had more experience with the design. If both operators took reasonably the same amount of time, then the difference was most likely based on the experience level of the operators. To help alleviate this factor, a wide source of aircrew were utilized in the assessments.

COMPILING OF QUESTIONAIRE VALUES

After the aircrew provided their comments and ratings on the questionnaires, the human factors team compiled the rating numbers and applied the appropriate weighting factors for each aircrew and TLX (Figure 23). The raw rating was taken directly from the Modified Bedford Cooper-Harper rating scale values used to rate what influenced each TLX. The weight factor for each scale title was calculated from the pair-wise words circled and a total value was found by summing each individual values. Those scale titles that returned higher weighting values were circled more often in the comparison. Once both of these values were calculated, they were multiplied together to return an adjusted rating. The adjusted ratings were then summed and divided by the total weighting value to return the specific aircrew workload for the given TLX. That data from all the worksheets were compiled and plotted in graphical format for reporting purposes.

AIRCREW SELECTION AND PAIRING

Aircrew selection for the workload assessments was crucial to obtain a large sample source of operators. Aircrew from VX Developmental Test (DT) squadrons, VX

Scale Title	Weight	Raw Rating	Adjusted Rating (WtxRaw)
Mental Demand	4	4	16.00
Physical Demand	0	1	0.00
Temporal Demand	4	6	24.00
Effort	2	3	6.00
Performance	4	5	20.00
Frustration	1	5	5.00
Total	15	Range 1-10	
TLX 3-level 1	**ECMO 1**	composite	4.73

Figure 23: EXAMPLE OF COMPILED DATA FROM AIRCREW WORKSHEET

Operational Test (OT) squadrons, fleet replacement squadrons, fleet weapon schools, F/A-18 Pilots, F/A-18 Weapon System Operator's (WSO), EA-6B Pilot's and EA-6B ECMOs were all chosen to compile this sample set (Table 1). Those aircrew from DT squadrons had the most experience with testing new system designs and had a baseline working level knowledge of how the workload assessment process should work. The remainder of the sample set had only the knowledge gained from the design presentations in the DAGs and the training provided the day or two prior to each assessment. This limited knowledge was a concern to program leadership and training took a high priority prior to each assessment. Prior to each assessment there were two days of simulator training provided, to allow the aircrew time to assimilate the new design changes and help rule out training as a factor influencing the workload assessment. The Pilot and ECMO combination of each crew was organized by an experienced DT aircrew that was designated by the program office. Each crew was grouped together based on prior flight experience and time in type model. Crews that could be composed of operators from the same squadron were utilized first, to help negate any aircrew coordination factors that might impact the workload levels.

Another issue for the workload assessments was in maintaining the same operators for each assessment. Due to the turn over in military assignments for aircrew and the lengthy time between the first DAG 2 assessment and the DAG 4 assessment, a

Table 1: AIRCREW PARTICIPATION AND EXPERIENCE

Aircrew	Aircraft Experience	Hours	Squadron	Workload Participation
Pilot 1	EA-6B F/A-18A-F	1000 200	NSAWC	DAG 2, 3
Pilot 1a	EA-6B F/A-18A-F	1350 100	VX-23	DAG 3
Pilot 2	EA-6B F/A-18A-F	975 50	VAQ-129	DAG 2
Pilot 2a	EA-6B F/A-18A-F	1430 60	VX-23	DAG 3, 4
Pilot 3	EA-6B F/A-18A-F	1560 150	VX-9	DAG 2
Pilot 3a	EA-6B F/A-18A-F	1300 140	VX-9	DAG 3, 4
Pilot 4	F/A-18A-F	1500	VX-31	DAG 2
Pilot 4a	EA-6B	2050	VX-31	DAG 3
Pilot 5	EA-6B F/A-18A-F	1800 200	VX-31	DAG 2, 3, 4
Pilot	F/A-18A-F	1300	VX-23	DAG 4
ECMO 1	EA-6B F/A-18A-F	No Data	NSAWC	DAG 2
ECMO 1a	EA-6B F/A-18A-F	930 260	VFA-122	DAG 3, 4
ECMO 2	EA-6B F/A-18A-F	2200 400	CVWP	DAG 2
ECMO 2a	EA-6B F/A-18A-F	900 100	VX-23	DAG 3, 4
ECMO 3	EA-6B F/A-18A-F	1100 75	VX-9	DAG 2, 3, 4
ECMO 4	F/A-18A-F	1500	VX-31	DAG 2
ECMO 4a	EA-6B F/A-18A-F	800 2	EAWS	DAG 3
ECMO 5	EA-6B F/A-18A-F	2300 50	VX-30	DAG 2
ECMO 5a	EA-6B F/A-18A-F	800 15	VX-30	DAG 3, 4
ECMO 6	EA-6B F/A-18A-F	No Data	VX-31	DAG 4

large number of operators left and were replaced. In order to maintain some data that could be compared throughout the four assessments the team tried to maintain a small number of crews that had participated in all the DAGs. TABLE 1 shows as list of aircrew that participated in the workload assessments and their flight time in type model. A mix of fleet experienced F/A-18 and EA-6B aircrew was requested for each workload but not always achieved. Anyone with more than 500 hours in type is assumed to be fleet experienced.

TASK MANAGEMENT

Iani and Wickens (Reference 10) describe several factors that affect aircrew task management in aviation. These are described as task complexity, cognitive or attentional tunneling, task importance, and physical salient (Reference 10). As the workload assessments continued throughout the design process, the task complexity in the simulator increased. New functionality was added and higher level tasks could be evaluated by the human factors team. Each workload assessment was performed during a two day period. The first day the crew would be asked to perform the mission at one task complexity level and the next day the same scenario with different, higher level tasks, would be performed. The first day's assessment would be fairly simple in order to provide a baseline for the new design functionality. The final CVE 1 is planned to be a four hour extended mission during one day, with increasing task workloads.

By not briefing the aircrew on all of the tasks to be evaluated during the mission, the human factors team attempted to reduce the cognitive tunneling that can occur during the performance of a task. Iani and Wickens describe cognitive tunneling as "the compellingness, and not necessarily the complexity, of the task at hand may decrease the awareness that other tasks need to be performed in general, and decrease our ability to notice cues signaling the need to switch to another task" (Reference 10). Aircrew, who had experience in EW, were left to their own decision process to prioritize what tasks needed to be performed (task importance), rather than try to meet the objectives of the workload assessment. This allowed the human factors team to separate any undue induced pressure of task completion from the assessment.

To simulate as real of an experience as possible during the workload assessments, the human factors team used prior aircrew on the Boeing simulator team, to provide scripted radio calls during the event. This, plus the added benefit of a dome simulator that could project a realistic simulation of flight, and a scripted scenario aided in producing controlled physical salient. During certain assessments, a negative salient was introduced when the simulator system crashed. The crew would be through half of the mission and because of the design of the scripted mission it would have to be restarted. This occasionally introduced a certain amount of bias due to the aircrew knowing what to expect during the second run at the scenario. Any trigger that had been unexpected previously was adapted to and was overcome more easily. Recommendations were made to script future scenarios in a way that they could be restarted at any point if the simulator crashed.

SCENARIO TASK DEFINITION

The human factors team developed a set of critical mission tasks for evaluation (Appendix E) through out the design phase. The scenario for each workload assessment was then defined as the series of these tasks and events that were required to complete that specific mission. The mission scenarios were derived by EW subject matter experts and approved by the program manager. Pre-SDD paper surveys of the ICAP III and II systems were based on the standoff support mission. DAG 2 and 3 focused on the Stand-off Jamming mission and the system capability to manage detected threats. DAG 4 focused on the Modified Escort and Close Air Support scenarios. These mission areas were derived from the standard areas that EA-6B aircrew train in the fleet to help alleviate and issues of the aircrew not having experience in a particular mission area.

As part of each of these different mission scenarios, a set of NASA TLX tasks were comprised for a specific time interval during the mission. The operator was required to key into the additional tasks in this set while still performing the base tasks required for completion of the mission. Tables B1 through B6 show these individual tasks for each workload assessment. The workload assessments were run at multiple levels of difficulty. The first assessment of a crew for the particular mission was at an induced lower level of workload and then raised for the next level. Therefore the higher level number represents the attempt to induce a higher workload. The human factors team increased the level of workload by inducing faults and failures into the system that the operator had to work around to perform the task set. They also applied external environmental cues to the operator to create a perceived urgency while performing a specific task. These injected faults and cues also provided the team with the ability to evaluate whether the cue was sufficient to notify the operator when a issue of importance was present.

USE CASE METRICS

Use Cases have been present for a number of years in the software development field. The EA-18G program set out to develop Use Cases as a means to better combine the efforts of the developmental and operational test squadrons during flight test. Tactical Use Case's were written to provide a more mission relatable method of testing to developmental test planning and execution, while still addressing the specifications required for the aircraft system. While developing the set of Use Cases the flight test team will utilize in later test, a set of metrics were developed for each Use Case to provide data and relevance to the test. In the development of these metrics it became obvious, as it had in the workload evaluation, that workload estimates of actions performed by the operator without an end result of how to determine the action was completed successfully, would leave open questions of whether the workload rating was valid or not.

Each Use Case was developed to be a set of actions that an operator would have to perform for a task, given a specific vignette, in a mission area. Vignettes were defined as a set of specific operational conditions sufficient and necessary to support an appropriate level of analysis or assessment and, typically, a segment of a mission phase. The mission areas that the vignettes consisted of were taken from the common set of areas to which the EA-6B aircrew train and fight. The particular actions were written in a general form that did not specifically lay out how to perform the task just that the task had to be performed (Figure C1). An example of this, is do not tell the operator to press push button 5 to activate the audio capability of the receiver set, instead it was stated "Evaluate Scan Rate and Scan Type using AUDIO function as required". This allowed for a better evaluation of the functionality and less of the software logic used to perform the function.

While some metrics (Figure C2) put in place for the Use Case's came directly from the specifications provided for the program, a large portion of the specific tasks were not covered. The Use Case team developed additional metrics based on input from fleet experienced aircrew who knew the specific mission areas. These metrics, while not binding to the contractor, enabled the test team to use a mission relatable set of metrics for testing. Because the Use Case team was developing the Use Cases in parallel with the workload assessments, the Use Cases were not utilized until the final workload assessment, slated for September 2005.

The human factors team chose sets of the Tactical Use Cases that would relate to the full length mission during the final workload assessment and grouped them together to create a timeline of tasks. They determined how to utilize the functionality of the NCOC 3 simulation hardware and observation tools to capture the various metrics. Some metrics were determined to be flight test only, while others could be captured using various different methods, while some only with the use of the NASA TLX scale.

Chapter 6: Results

ICAP II SURVEY RESULTS

The workload assessment survey for the ICAP II system returned results showing that the highest workload was for the ECMO performing front seat tasks (Figure 24). When this result is taken in context of what tasks the front seat ECMO performs, situational awareness becomes the largest impact to workload. With no front seat display to provide the ECMO 1 information on what is going on in the mission at any on time. They have to rely on feedback from the backseat. Temporal and performance were the two largest influences to the aircrew tasks assessed in the survey.

The pilot's workload increased for the descent to HARM launch because of the mental and temporal demand increase in flying the aircraft to the designated launch point. The recovery TLX also increased due to the physical and performance increase of landing a jet aircraft on the pitching deck of a carrier. The survey provided results as best recalled by the operators involved with no simulation of events. Because of this, there is some bias to be accounted for from the memory of the operator. The tolerance could be as much as ± 1.0 difference in the resultant workload rating. Overall, the workload survey did provide a baseline workload for the program that was within 1.0 of the minor compensation level.

ICAP III SURVEY RESULTS

The ICAP III survey was given to DT and TO aircrew prior to the programs operational evaluation. During this time the design implementation was riddled with system performance issues. This was listed as a causal factor in the higher workload ratings for the survey (Figure 25). In particular, the Geolocation issues, the program was suffering at the time, making reactive jamming difficult to manage, causing the TLX rating to be very high. The aircrew rated temporal and frustration as the two highest influences to completing the reactive jamming task successfully. Because both the ICAP II and III designs utilize four aircrew to perform the EW mission, the difference in

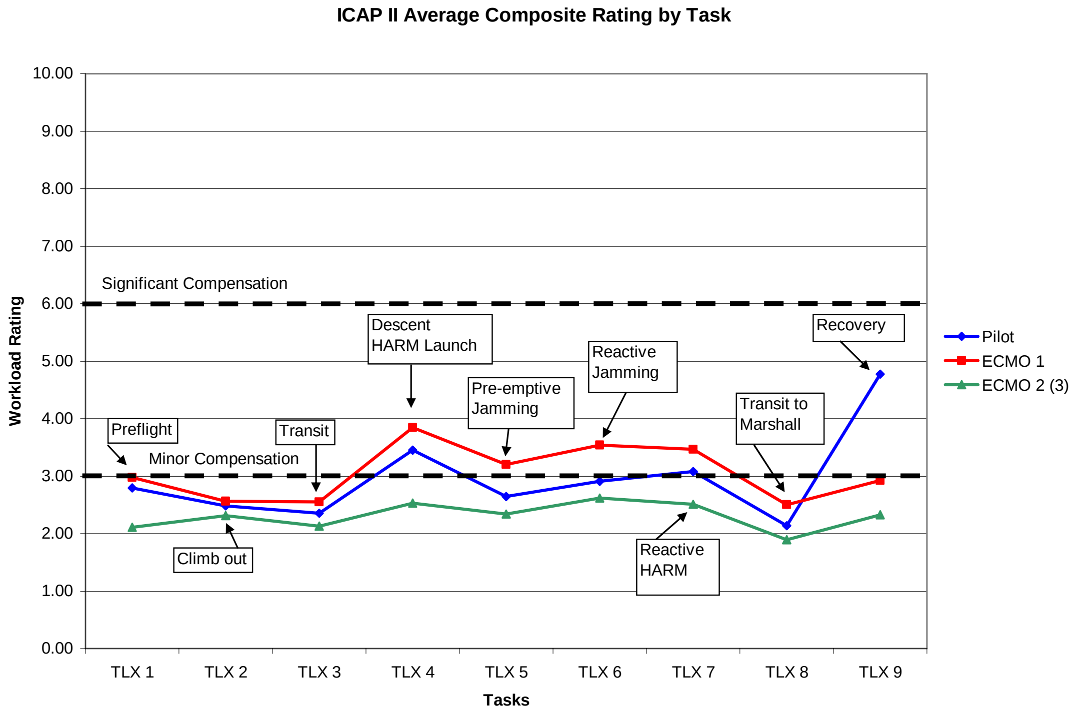

Figure 24: ICAP II WORKLOAD SURVEY RESULTS

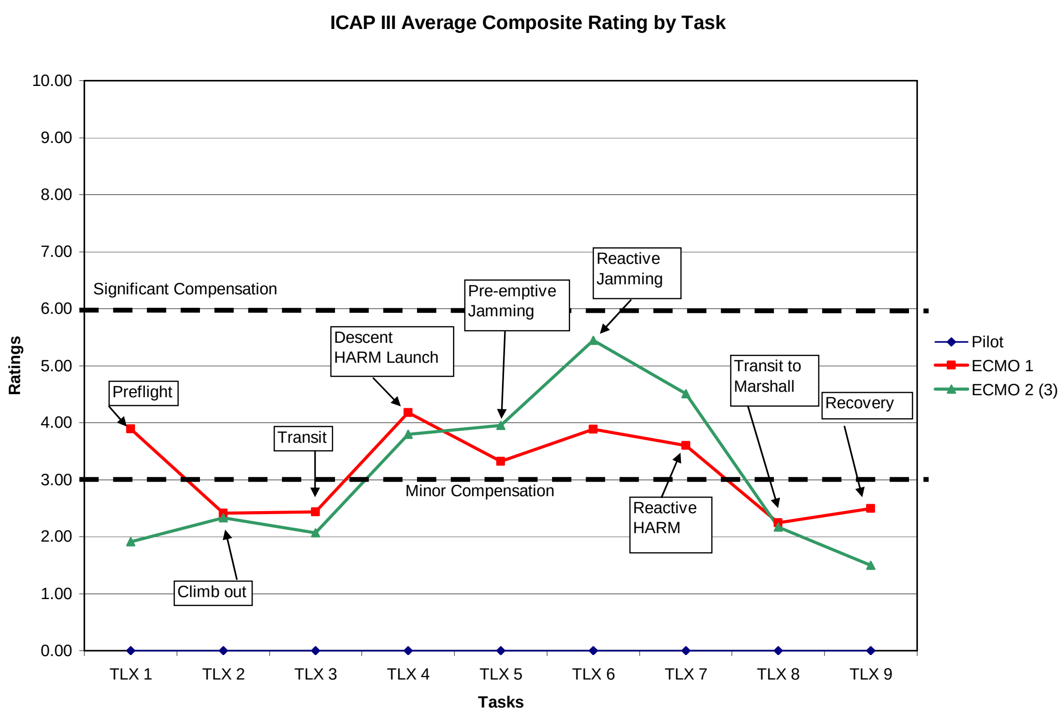

Figure 25: ICAP III WORKLOAD SURVEY RESULTS

workload rating can be attributed to operator training in workload evaluations. Fleet operators, those questioned in the ICAP II survey, are accustomed to compensate for difficult tasks and therefore do not see tasks as being difficult, they are used to dealing with the issue of poorly designed systems. DT and TO test aircrew are trained to evaluate while ignoring compensation. If the task is difficult they will rate it as such and suggest changes to lower the workload. Aside from the issues of reactive jamming, the other TLX ratings were still within only a 1.0 difference in the workload rating. The ICAP III survey provided a baseline workload rating for the EA-18G design in which to be compared.

DAG 2 LEVEL 1

The DAG 2 workload assessment was the first look at the workload for the DAG 1 design iteration in NCOC 3. The design was fairly simple involving some signal analysis and jamming tasks. The level 1 assessment (Figure 26) concentrated on the jamming tasks with minor system failures. The result was an overall workload assessment of 4.0 or less. Some improvements were noted in the design that would reduce the workload rating for all the areas of concern, but especially status monitoring and jamming. Each crew of operators were told to divide the tasks among themselves for the given mission. During the level 1 assessment, the pilots shared in the jamming tasks by trying to jam from the front display set. This was determined to be not as easy to perform as from the backseat because it caused the pilot to be more heads down than normal to fly the aircraft. As a result, the pilot and ECMO workload rating for the jamming tasks ended up being about the same. Overall, the jamming tasks were a slightly higher workload rating than the baseline ICAP II survey presented.

DAG 2 LEVEL 2

During the level 2 assessment (Figure 27), the scenario was designed to include and evaluate the impact of failures on the design. Because of the issues the pilots had during the level 1 assessment they ended up shedding some of the jamming tasks to the ECMO. This, combined with the design issues of noticing and then dealing with the

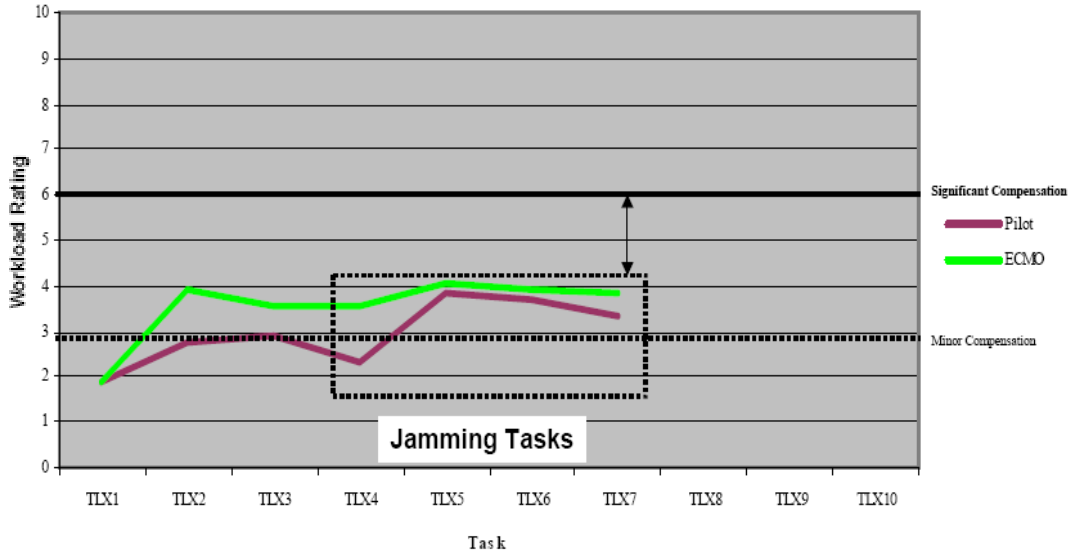

FIGURE 26: DAG 2 AVERAGE LEVEL 1 TLX

Source: EA-18G Human Engineering Crew Vehicle Interface Analysis Report – Aircrew (CVIAR-A), Revision D, 22 June 2005

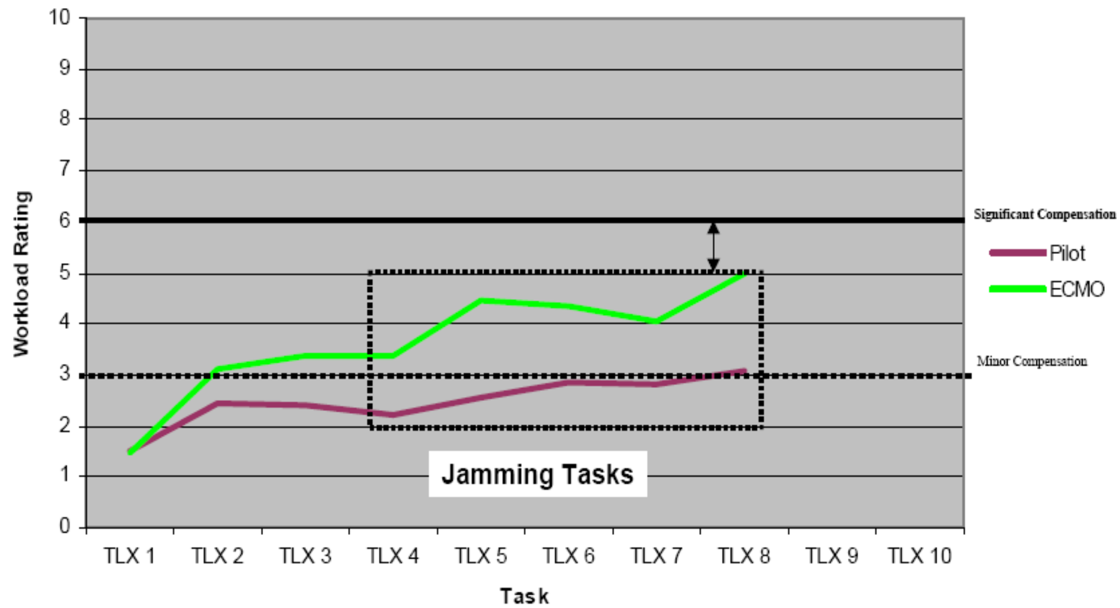

FIGURE 27: DAG 2 AVERAGE LEVEL 2 TLX

Source: EA-18G Human Engineering Crew Vehicle Interface Analysis Report – Aircrew (CVIAR-A), Revision D, 22 June 2005 induced system failures, increased the workload rating for the ECMO. At the same time, the pilot workload rating decreased due to the shed tasks to the ECMO. The overall margin of the highest workload rating to the level of significant compensation was decreased. Mental, temporal and performance ratings influenced the overall workload ratings more than any other from the level 1 assessment to the level 2 assessment.

DAG 3 LEVEL 1

The DAG 3 scenario was focused around the SOJ mission. Due to the time between the DAG 2 and 3 events a small turnover in aircrew performing the workload assessments occurred. Because of this, there were aircrew that had never seen the design before arriving to the assessment so a short training period prior to the workload assessment was provided for all aircrew involved. Aircrews were asked to divide up the tasks needed to perform the mission, so that no one individual was performing the entire mission. This division of labor in aircrew task management can be seen in the pre-emptive HARM shot and jamming tasks. The pilot's workload for the pre-emptive HARM shot was higher than the ECMO due to having to maneuver the aircraft on a time line, in order to make the shot. The jamming tasks were higher for the ECMO than the pilot, as well as the reactive HARM shot; as a result of the ECMO utilizing the HARM reactive launch procedure on the aft seat HOTAS.

Level 1 (Figure 28) did not include failures and the situational air picture was well presented to the operators at all times. Even with the added functionality of HARM and some CCS added for this assessment, the overall highest workload rating was not any higher than the DAG 2 level 1 results.

DAG 3 LEVEL 2

Level 2 (Figure 29) injected failures into the scenario with the intent of increasing the workload. The end result of the assessment showed a decrease in workload overall. The division of task sharing can still be seen in the results, including the pilots taking more of a role in the reactive HARM. Most crews gave all or most HARM tasks to the pilot while the ECMO took all responsibility for jamming. The decrease in workload rating overall appeared to be a result of training. By this workload assessment, the crews

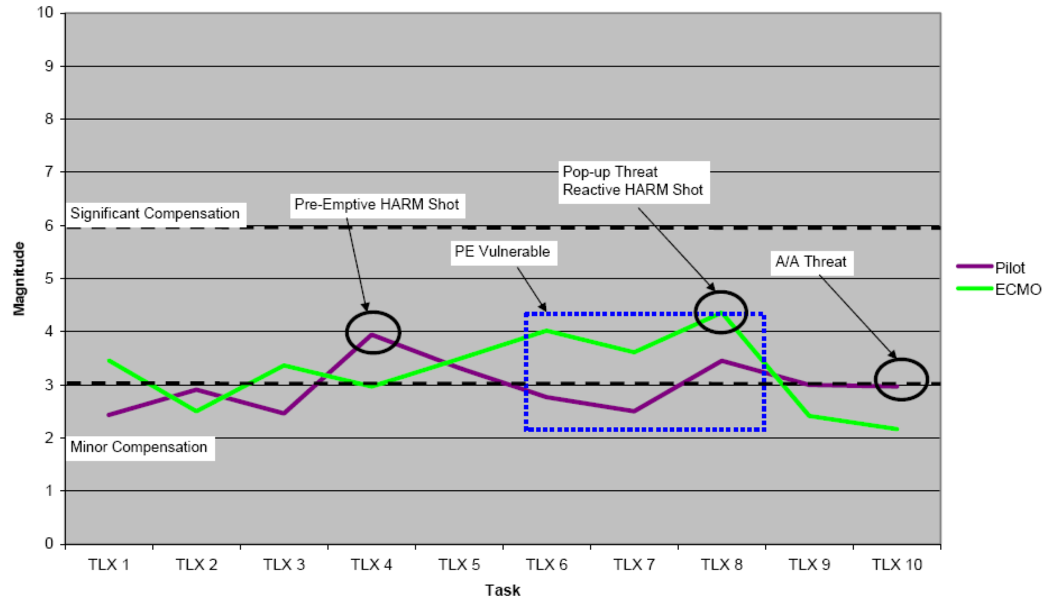

Figure 28: DAG 3 AVERAGE LEVEL 1 TLX

Source: EA-18G Human Engineering Crew Vehicle Interface Analysis Report – Aircrew (CVIAR-A), Revision D, 22 June 2005

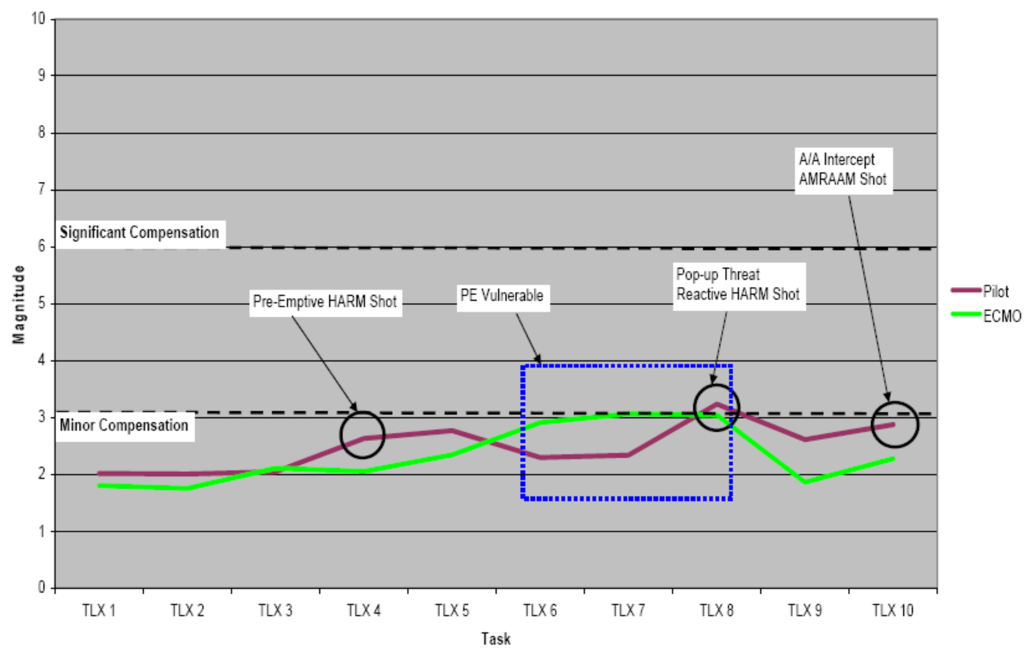

Figure 29: DAG 3 AVERAGE LEVEL 2 TLX

Source: EA-18G Human Engineering Crew Vehicle Interface Analysis Report – Aircrew (CVIAR-A), Revision D, 22 June 2005 had been provided four hours of training and the two hour workload assessment level 1. The fear was that as the operators became more familiar with both the design and the scenario tasks that the workload rating decreased. As a result, more training was provided to the crews prior to the DAG 4 workload assessment. A different scenario was utilized for the level 2 vice level 1 assessment to help reduce the impacts of prior knowledge of the scenario influencing the workload rating.

DAG 4 LEVEL 1 AND 2

By DAG 4, the human factors team had made several changes in the process of workload assessment. The first was to use two different scenarios for the two levels of assessment (Figure 30 and Figure 31). This helped to reduce the familiarity with the scenario and any impact to the workload assessment. The second was to provide more training to the aircrew. More training was implemented to reduce the impacts of the operator not being familiar with the design on the workload rating. The design was to be in the final IOC configuration by this workload assessment; however a number of display formats and functionality had not been implemented in NCOC 3. Because of this, the workload assessment was ruled inconclusive by the program office.

However, the assessment did provide suggestions for the design to help the workload ratings decrease in the long run. It also gave a glimpse at the workload rating for a different mission area, the modified escort jamming support and the Close Air Support (CAS) jamming missions. CAS jamming is renowned as being the most difficult mission area the EA-6B aircrews have to perform with the current ICAP systems. It also showed that frustration and performance were the highest factors that influenced the overall workload, which was assessed as being a result of the incomplete simulator implementation of the design that did not allow the aircrew to fulfill the mission. The level 2 numbers showed the expected slight increase in workload rating due to the added failures introduced into the scenario.

AVERAGE WORKLOAD FOR JAMMING

When the data reported for those tasks that required jamming is compared, the results showed a positive trend of decreasing workload ratings (Figure 32) over the four

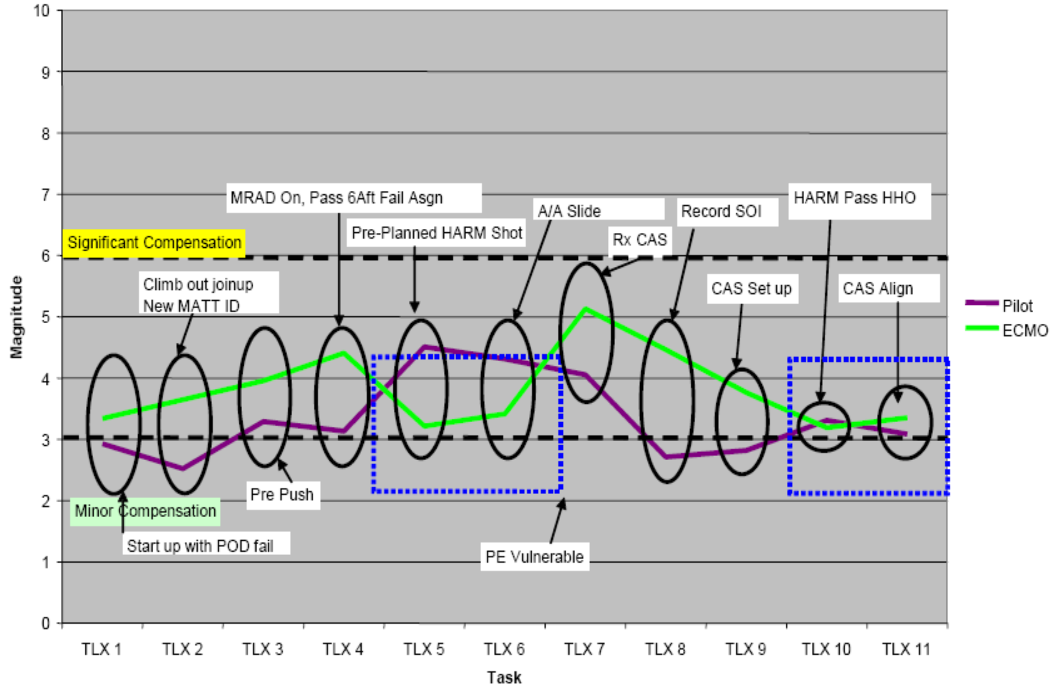

Figure 30: DAG 4 AVERAGE LEVEL 1 TLX

Source: EA-18G Human Engineering Crew Vehicle Interface Analysis Report – Aircrew (CVIAR-A), Revision D, 22 June 2005

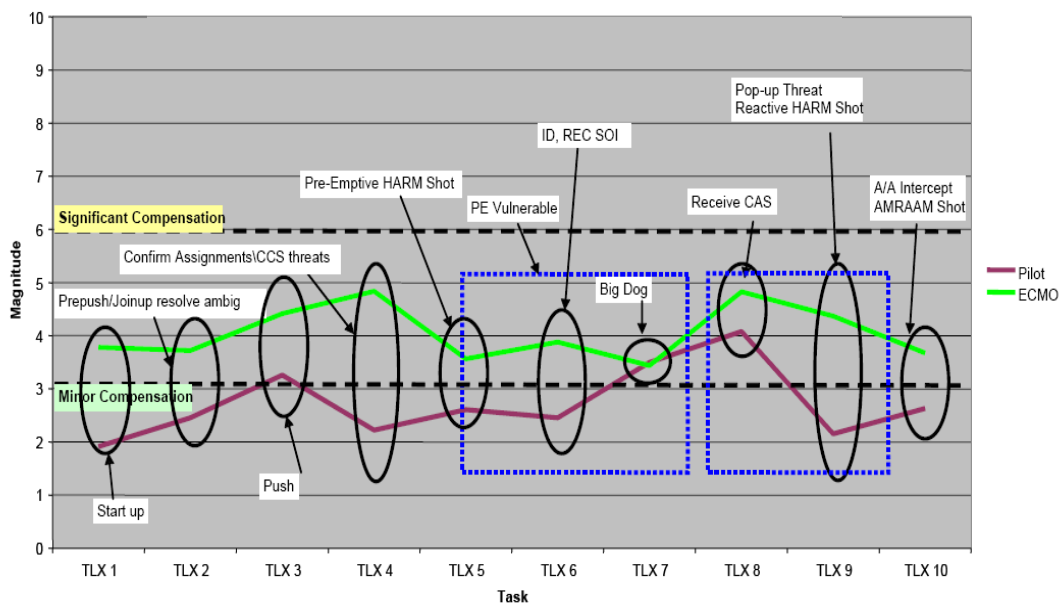

Figure 31: DAG 4 AVERAGE LEVEL 2 TLX

Source: EA-18G Human Engineering Crew Vehicle Interface Analysis Report – Aircrew (CVIAR-A), Revision D, 22 June 2005

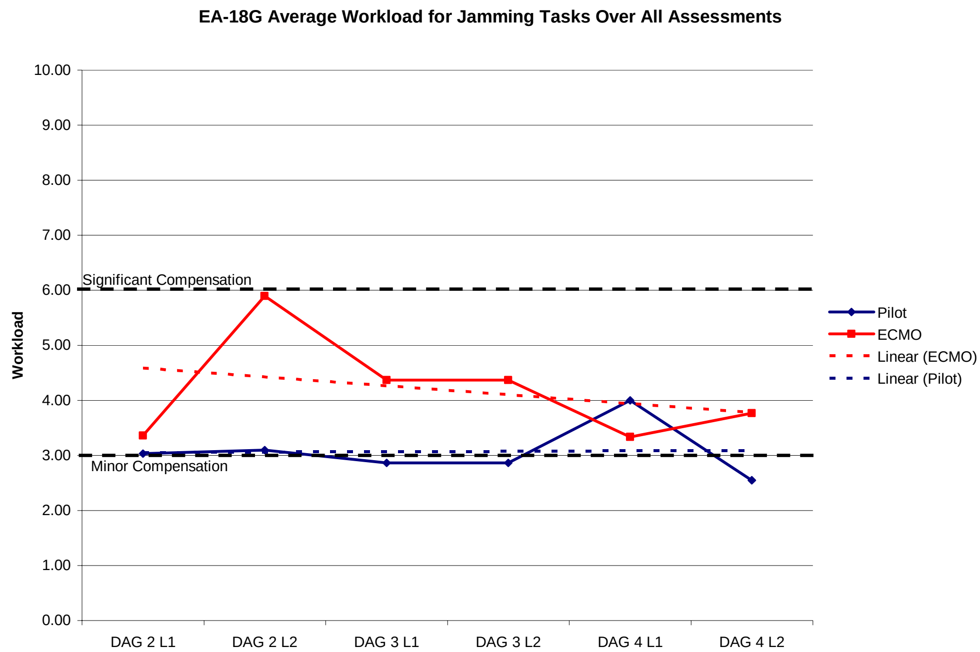

Figure 32: AVERAGE WORKLOAD RATINGS FOR JAMMING TASKS

DAG evaluations. The overall workload rating to perform a mission has decreased over time; however the workload rating still exceeds the goal of minor compensation level. Even though the specific tasks for each scenario were not always the same, the comparison of the overall mission workload demonstrated the benefits of improvements made from each previous DAG in helping to reduce the overall workload. Figure 32 illustrates a fairly flat pilot workload rating throughout the three DAGs. This helps to demonstrate the successful characteristics of the pilot vehicle interface of the F/A-18 design. The ECMO workload started higher than anticipated and then decreased significantly with the implementation of design changes that effected workload.

ANALYSIS OF ECMO WORKLOAD

Figure 33 and **Figure 34** illustrate the composite workload for the ECMO in the EA-18G design for the three assessments, at both difficulty levels. The level 1 results show that the workload for the DAG 2 design was higher than the minor compensation level desired. As the DAG 3 design was assessed, it incorporated suggested changes to the DAG 2 design that were implemented to lower the operator workload. The DAG 3

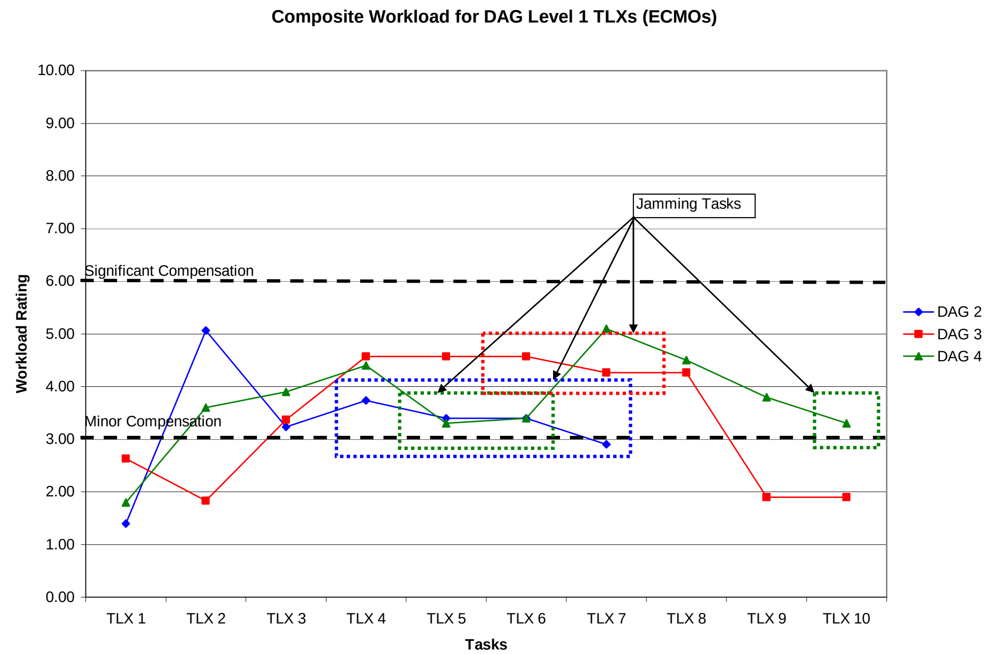

Figure 33: WORKLOAD RATINGS FOR ECMO LEVEL 1 ASSESSMENTS

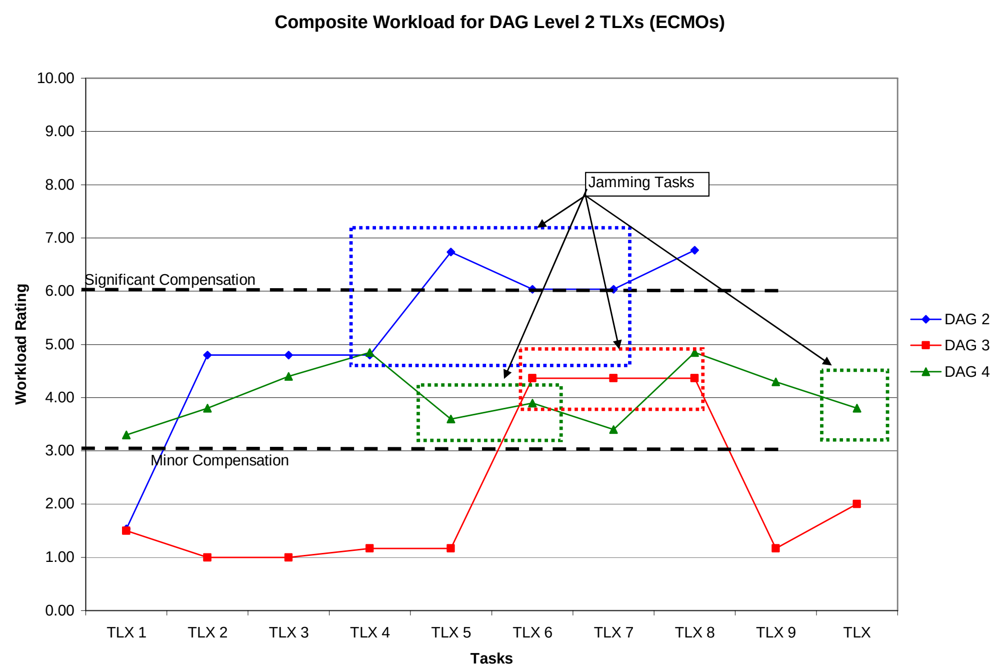

Figure 34: WORKLOAD RATINGS FOR ECMO LEVEL 2 ASSESSMENTS

level 1 results for workload were unfortunately higher as a result of the newly added, and never seen, design functionality. Even with the inconclusive results obtained during DAG 4, the average workload for the DAG 4 design was lower than that of the DAG 3 design. This is an indication that the design change recommendations made during the DAG 3 assessment helped to reduce the workload for the new design additions.

The level 2 results indicate a similar trend. The design change recommendations that were made following DAG 2, significantly reduced the workload required to perform the similar tasks in the DAG 3 assessment. Unlike the level 1 results, the level 2 results do show a negative trend with increasing workload ratings with the DAG 4 results. It was determined that this increase in workload rating was a direct result of the operator being influenced by the simulation issues that were present in the DAG 4 implementation. There was an increase in both the mental and frustration levels required to perform the tasks successfully and to attend to the failures induced in the simulation.

ANALYSIS OF PILOT WORKLOAD

Figure 35 and Figure 36 illustrate the composite workload for the pilot in the EA-18G design for the three assessments, at both difficulty levels. The level 1 workload values were higher than the level 2 values reported. It was determined that as a result of the pilot taking on more responsibility for the more unfamiliar complex tasks, their workload ratings increased. The pilots in the EA-6B community, while knowing the mission, do not perform the more complex tasks of electronic surveillance or jamming. Because of this, when the pilots took on the new unfamiliar tasks, there was a learning curve that took place at each assessment. By the time the level 2 assessment occurred, the pilots were familiar enough with the new task that the workload results reflected the actual design implementation.

The DAG 4 results for the pilots were no higher than those of the DAG 3 results. Even with the inconclusive assessment due to simulator issues, a positive trend can be assumed with the pilot results. Design inputs and changes implemented to help reduce the workload throughout the design iteration did help maintain the workload at or near the

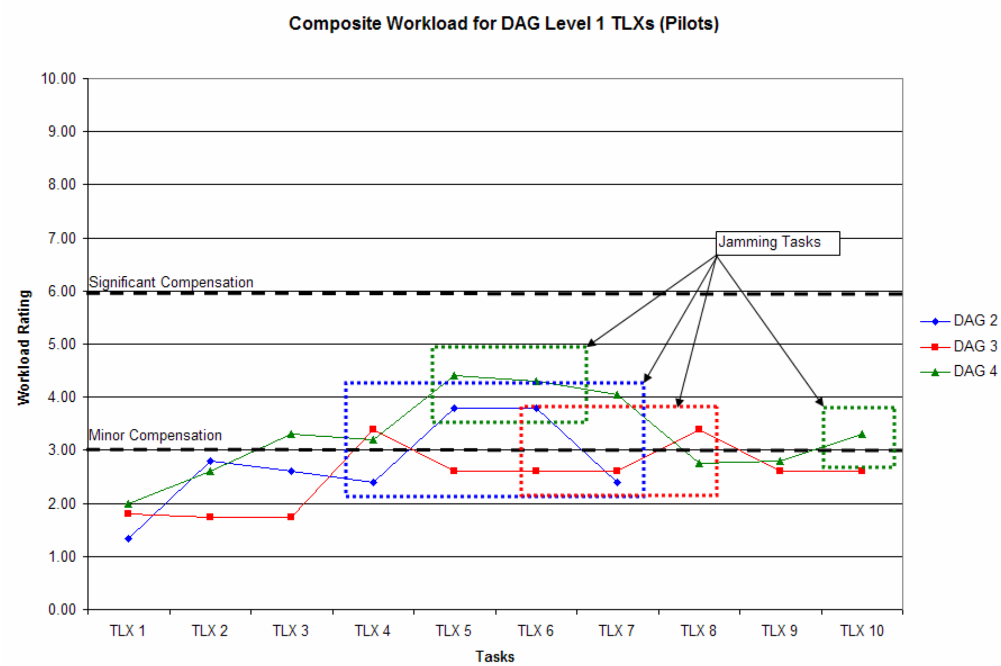

Figure 35: WORKLOAD RATINGS FOR PILOT LEVEL 1 ASSESSMENTS

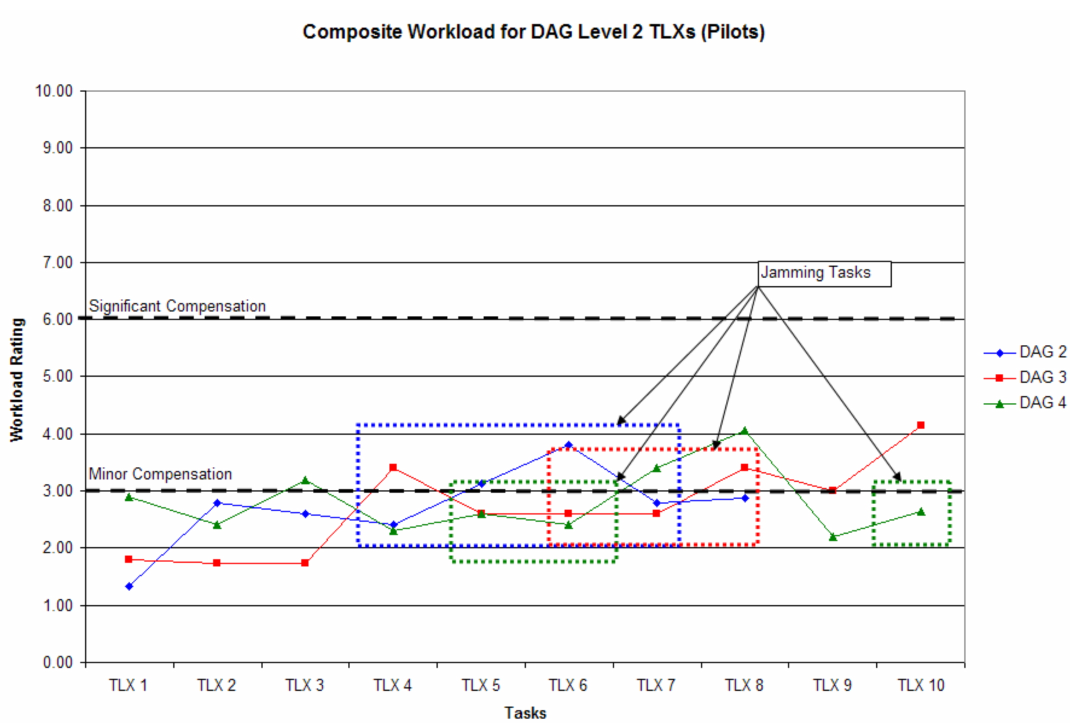

Figure 36: WORKLOAD RATINGS FOR PILOT LEVEL 2 ASSESSMENTS

previous assessment, even though new design functionality and increased task loading was occurring at each assessment. The pilot workload ratings for all tasks at the level 2 difficulty, while not below, are very close to the desired minor compensation required for system workload.

COMMON TASKS

When the human factors team developed the scenarios for the workload assessments they designed the scenarios around similar tasks for the various missions. This was an attempt to allow a comparison of results throughout the multiple assessments. Figure 37 illustrates the common tasks that were assessed with the composite workload values for all pilots and ECMOs for each task during the three DAG assessments. The higher values for the receive CAS message task were determined to be a result of the many simulator issues during DAG 4. The other tasks, while not all below the minor compensation level desired, were all below the significant compensation required. The pilot workload rating tends to be lower than the minor compensation required and can be a result of the integration of the pilot into a mission unlike they have been in the past with the EA-6B. The tasks the ECMOs performed were more of the complex EW tasks than those the pilot performed. The comparisons of these same tasks with the results for similar tasks from the ICAP II and III surveys (Figure 38) demonstrate a positive trend in not only equaling but also reducing the workload required to perform the task. The ICAP II and III surveys were not all inclusive and there were tasks that were never evaluated. For those tasks that were evaluated in the survey, the results from the DAG assessments demonstrate that the workload required for the EA-18G design was lower than that of the EA-6B.

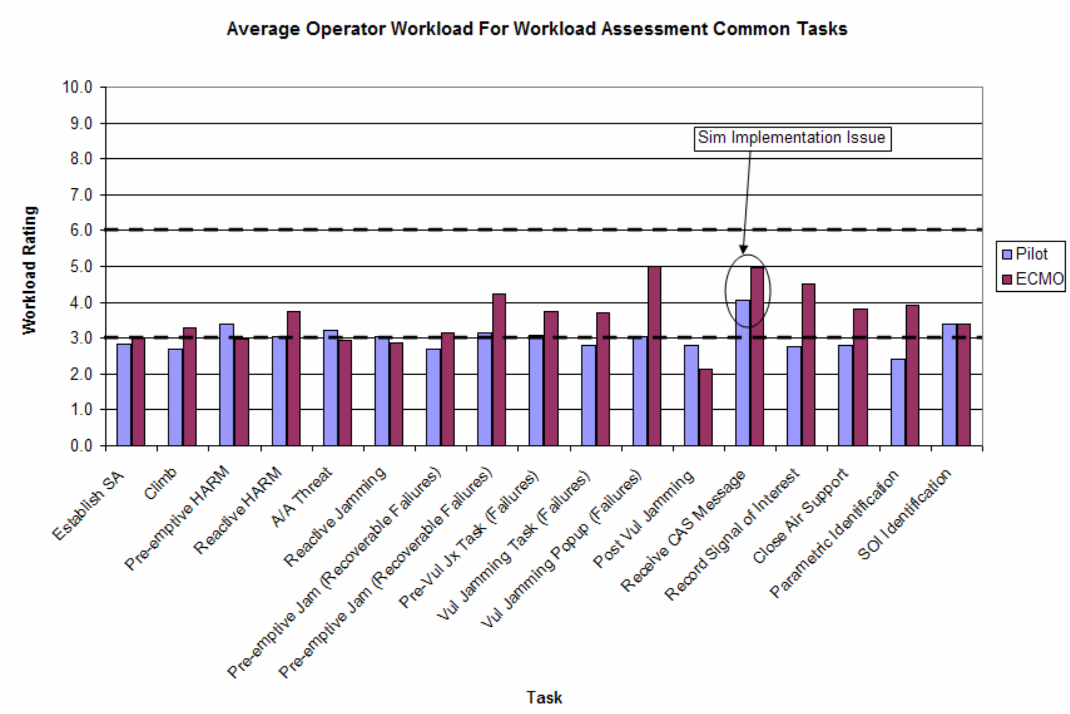

Figure 37: COMPOSITE WORKLOAD FOR COMMON TASKS

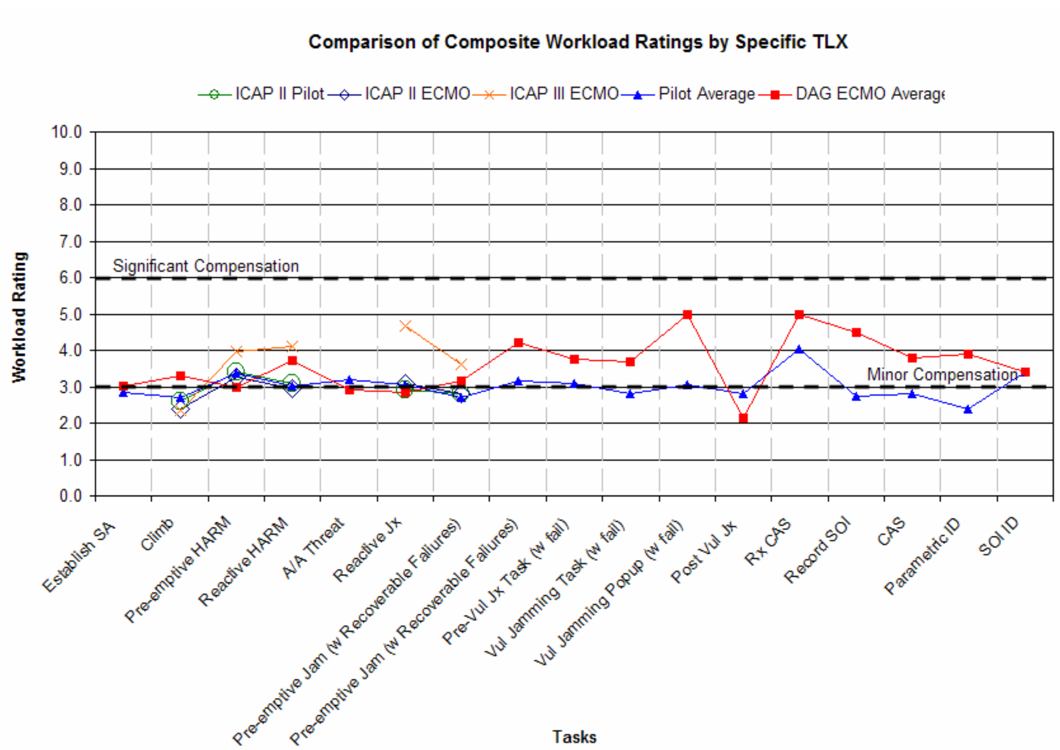

Figure 38: COMPARISON OF COMPOSITE WORKLOAD RATINGS BY SPECIFIC TLX

Chapter 7: Conclusions and Recommendations

CONCLUSIONS

The implementation of the advanced cockpit simulation in the early stages of the EA-18G design provided a multitude of benefits to the program. It allowed the human factors team to identify the higher risk areas of workload in the design much earlier and provided focus for the workload assessments to answer the question of whether the two aircrew system can perform the mission. With this knowledge, the design was able to continually be corrected to ensure the workload levels did not increase, or if they did, that methods were introduced to reduce the workload during the next assessment. Even though the final successful workload assessment has not been completed, the design of the EA-18G system is at a much lower workload level than when it started and should provide the operators a very efficient means of completing the Electronic Warfare mission.

Crew coordination issues were discovered early on through the use of the NCOC 3 simulation. With the help of the workload assessments, the analysis of the results has allowed program management to realize the necessity of pilot integration into the Electronic Warfare mission. The typical training track for pilots in the EA-6B community trains the pilots in EW, but does it at a lesser quantity and quality than that of the ECMO, due to the limited interaction the pilot actually has with the weapon system in the ICAP II and III. With the design and implementation of the EA-18G, it has been proven that the pilot is going to be just as important as the ECMO in completing the EA mission. This has had impacts on the training process and timeline of a pilot for this new platform and community.

The advanced simulation helped recognize those areas overlooked from implementation and integration of the ICAP III system into the EA-18G and the areas where the implementation of the new design features had been incorrect. If the program had relied on paper-only planning to provide sufficient coverage of the design, it is quite possible that the engineering interpretation of the requests and needs of the operators would have led to failure to produce a viable system for the end user. The use of the simulation helped to discover software coding issues very early in the design. It also allowed for training to be provided to the new industry partner, Boeing, in the world of Electronic Warfare. Without this training, the industry team misconceptions of how the systems should perform would have propagated into the test and evaluation of the system, potentially leading to disputes between the program management of all concerned.

The advanced simulation provided a means to train the new members on the government team as well. The balancing of multiple major programs concurrently (the ICAP III test program completing while the EA-18G program began) made it difficult to bring all of the flight test team on board for the early design of the system. A select few led the way and helped interpret the requirements for the industry, while the remainder of the team came onboard later. With the advanced simulation already laid out in NCOC 3, training the new engineering support personnel on what to expect from the design when it reaches flight test, became easier than just simply relying on their interpretation of the written word. This was extremely important for those who had not been a part of the ICAP III test team.

After convening multiple DAGs to refine the simulation to provide the correct presentation of the government's expectations, the simulation provided a baseline for the lab testing of software for the aircraft. The software coders were able to begin programming the real mission computer software while relying on the NCOC 3 simulation as a tool in helping to define their interpretation of the design. While the simulation will never completely capture the true characterization of the systems, it did provide a valid picture of the integration that was required to occur for all the systems to work together successfully.

The advanced simulation of the design has allowed the test community another asset in the development of testing procedures and ideas, such as Use Cases. Use Cases allowed the human factors team to "identify mission areas that were significant with respect to aircrew workload levels" (Reference 10) and develop new means to identify ways of reducing the workload in those areas. It provided a means to validate the newly implemented Use Case process for flight test and provide a means for engineers to validate their requirements and procedures for ground and flight testing. As each new test procedure is developed, the simulation of the design in NCOC 3 can be used to validate the procedure without waiting for an actual aircraft. This will help to ensure that the procedures are sound and take less time away for verification of those procedures, during the already short flight test program.

The ability to view the limitations and characteristics of the crew vehicle interface early on in the design, coupled with the existing knowledge of the characteristics of those systems already on the ICAP III and F/A-18F aircraft, allowed the program to develop a baseline for tactics that are not typically started until much later in the program. In other programs, the development of tactics occurs after an extensive and lengthy Operational Evaluation (OPEVAL) period. With the capability to start this process earlier, with the help of the advanced simulation, the program hopes to simply verify the developed tactics during a shorter OPEVAL period. This will allow the program to take less time and money away from crucial flight test on the integration of the systems.

While the simulation of the design provided these benefits, it did not provide a look at the true characterization of the system to be tested and has potentially skewed the mental picture that the program members have of the systems expected performance; the largest area of misperception resulting from the display of threats on the TSD. In the simulation, the threat environment is just that, a simulation. The picture that is displayed to the operator does not contain any flaws or imperfections that are anticipated with the actual system performance and integration of an EW weapon system into an aircraft. Some of the testers and engineers on the program have no concept of this perception, leading to the potential of the design not being fully capable or robust enough to handle the true characterization of the system. A certain amount of this is to be expected, considering simulation of the real world electromagnetic spectrum is a very difficult, if not impossible, task to accomplish.

RECOMMENDATIONS

Based on the results seen from using the NCOC 3 simulation to identify and reduce the aircrew workload on the EA-18G design, the author recommends that further development of the design be performed with the use of the same simulation efforts. The NCOC 3 simulation can continue to be used to support the development of tactics and training, at much less cost than operating flight test aircraft. Future NAVAIR system integration programs should view advanced simulation techniques as a successful means of integrating software design requirements with operator expectations.

The author recommends continuing to involve operators in the early design iterations of new systems and software. Early and iterative involvement of operator input into the design of aviation systems can provide valuable information to the engineering team for the design. The process of DAGs and simulation events for operator evaluations can help not only train the engineering team in the mission and the requirements, but also help to realize any potential design implementation issues. Design iterations performed on power point are subject to individual interpretation, while simulation of the actual software presents the true characterization of the design.

Using simulation for early human factors evaluations for new design integration can help reduce the amount of higher priced flight test required. While it will never completely eliminate the need for flight testing the interface in the real world environment, especially when interacting with the electromagnetic spectrum, it can provide a much earlier look at the flaws and issues created by higher workload tasks within in the system.

A process of selecting the correct aircrew to evaluate the human factors implications (workload) of a new design is crucial. The military spends millions of dollars training aircrew in a particular specialty that should be utilized to the fullest potential. While all Test Pilot School graduates are taught to be as diverse in evaluating designs as possible, nothing can take the place of experience. The selection of future aircrew to perform simulation evaluations should be placed around a diverse approach. The compliment of evaluators should be comprised of test oriented personnel with a specialty in the field of use for the new system (i.e., distinguish between EW and air-to-air warfare) and personnel that have the tactical experience required in the system area, who may not have any test experience.

Integration of new and potentially combined rating scales that pertain more directly to the needs of the program can add focus and concentrate the efforts of the evaluators. The overall cookbook process that has been laid out in methods such as Cooper-Harper and the Bedford scales can act as the road map to follow, while changing the particulars to fit the requirements of the programs efforts. Test teams should never assume that one rating scale fits all needs for evaluation.

It is recommended by the author that these methods continue to be used to help lower the risks to future programs. The lessons learned during the simulation efforts to evaluate the task workload in the EA-18G design should be passed onto other NAVAIR programs to aid in risk reduction for all programs.

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Appendices

Appendix A: FIGURES

MENTAL DEMAND	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

FIGURE A-1 NASA TLX RATING SCALE DEFINITIONS
REFERENCE: TLX-USER MANUAL

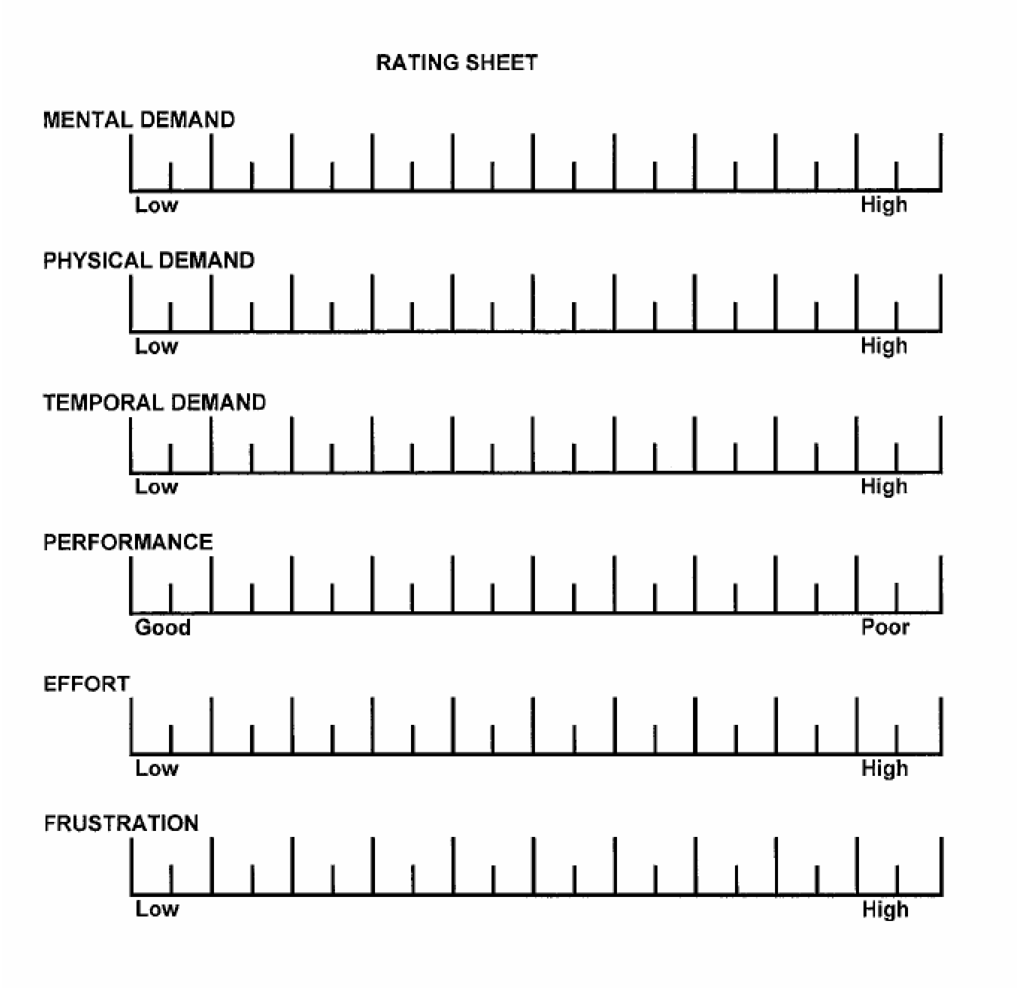


FIGURE A-2 NASA TLX RATING SCALES
REFERENCE: TLX-USER MANUAL

Appendix B: DAG TASK LOAD INDEX

TABLE B-1: DAG 2 STANDOFF JAMMING WORKLOAD ASSESSMENT TASKS (REFERENCE 10)

Workload Assessment	Task Level	TLX	Task Set	Introduced Failures	Operator Task
DAG 2	1	1	System start-up, Initialization, BIT	None	System Startup
		2	Establish Situational Awareness (task that would typically be performed during Take-off, Departure, Climb-out,) System Monitor, COMM,	None	Take-off/Climb out
		3	Pre-Push, Join-up, Climb, Ingress, System Monitor, Pre Vulnerable JAMMING Task	None	Pod Power up
		4	Pre-Vulnerable, Pre-Emptive JAMMING	None	Pre-planned Jamming
		5	Pre-Vulnerable, Pre-Emptive JAMMING	None	Pre-planned Jamming
		6	Pre- Vulnerable, JAMMING Task	None	Jamming
		7	PE Vulnerable, JAMMING Task	None	Jamming
		8	PE Vulnerable, JAMMING Task, Pop-up Threat, Abort	None	Pop-up Threat

TABLE B-2: DAG 2 STANDOFF JAMMING WORKLOAD ASSESSMENT TASKS AND FAILURES (REFERENCE 10)

Workload Assessment	Task Level	TLX	Task Set	Introduced Failures	Operator Task
DAG 2	2	1	System start-up, Initialization, BIT	None	System Startup
		2	Establish Situational Awareness (task that would typically be performed during Take-off, Departure, Climb-out,) System Monitor, COMM,	EMI, MIDS Degradation, No Failures	Take-off/Climb out
		3	Pre-Push, Join-up, Climb, Ingress, System Monitor, Pre Vulnerable JAMMING Task	COMM, EMI, MIDS Degradation, Air to Air, BIT No Failures	Pod Power up
		4	Pre-Vulnerable, Pre-Emptive JAMMING	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Recoverable Failure	Pre-planned Jamming
		5	Pre-Vulnerable, Pre-Emptive JAMMING	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Recoverable Failure	Pre-planned Jamming
		6	Pre- Vulnerable, JAMMING Task	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Failures	Jamming
		7	PE Vulnerable, JAMMING Task	COMM, EMI, MIDS Degradation, Air-to-Air, Video Record, System Monitor, with Failures	Jamming
		8	PE Vulnerable, JAMMING Task, Pop-up Threat, Abort	COMM, EMI, MIDS Degradation, Air-to-Air, Video Record, System Monitor, with Failures	Pop-up Threat

TABLE B-3: DAG 3 LEVEL 1STANDOFF JAMMING WORKLOAD ASSESSMENT TASKS (REFERENCE 10)

Workload Assessment	Task Level	TLX	Task Set	Introduced Failures	Operator Task
DAG 3	Level 1	1	System start-up, Initialization, BIT	No Failures	Start-up
		2	Establish Situational Awareness, System monitor	COMM, EMI, MIDS Degradation, with failures	Take-off, Departure, Climb-out
		3	Pre-push, Join-up, Climb, ingress, System Monitor, Pre-Vulnerable Jamming Task Set-up	COMM, EMI, MIDS Degradation, Air to Air, BIT No Failures	Join-up with Strike Package
		4	Pre-vulnerable, Pre-emptive HARM, Pre-Emptive Jamming	COMM, EMI, MIDS degradation, Air-to-Air, System Monitor, with jamming source failures.	Pre-Emptive HARM
		5	Pre-Vulnerable, Pre-Emptive JAMMING, Reactive JAMMING	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with No Failures	Pre-emptive Jamming
		6	PE Vulnerable, JAMMING Task	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Source Failure	Reactive Jamming
		7	PE Vulnerable, JAMMING Task	COMM, EMI, MIDS Degradation, Air-to-Air, Video Record, System Monitor, No Failures	Jamming
		8	PE Vulnerable, JAMMING Task, Reactive HARM	COMM, EMI, MIDS Degradation, Air-to-Air, Video Record, System Monitor, No Failures	Pop-up Threat Reactive HARM Shot
		9	Post-Vulnerable, JAMMING Task	COMM, EMI, MIDS Degradation, Air-to-Air, Video Record, System Monitor, with No Failures	Post vulnerable
		10	Post-Vulnerable, JAMMING Task, A/A	COMM, EMI, MIDS Degradation, Airto-Air, Video Record, System Monitor, Source Failure	Air-to-Air Threat

TABLE B-4: DAG 3 LEVEL 2 STANDOFF JAMMING WORKLOAD ASSESSMENT TASKS (REFERENCE 10)

Workload Assessment	Task Level	TLX	Task Set	Introduced Failures	Operator Task
DAG 3	Level 2	1	System start-up, Initialization, BIT, MDB Reload	No Failures	Start-up
		2	Establish Situational Awareness System Monitor	COMM, EMI, MIDS Degradation, with No Failures	Take-off, Departure, Climb-out
		3	Pre-Push, Join-up, Climb, Ingress, System Monitor, Pre Vulnerable JAMMING Task Set-up	COMM, EMI, MIDS Degradation, Air to Air, BIT with Power Failure. (Rolex 5)	Join-up with Strike Package
		4	Pre-Vulnerable, Pre-Emptive HARM, Pre-Emptive JAMMING	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Source Failure	Pre-Emptive HARM
		5	Pre-Vulnerable, Pre-Emptive JAMMING, Reactive JAMMING	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Source Failure	Pre-emptive Jamming
		6	PE Vulnerable, JAMMING Task	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Source Failure	Jamming
		7	PE Vulnerable, JAMMING Task	COMM, EMI, MIDS Degradation, Air-to-Air, Video Record, System Monitor, with Source Failure	Jamming
		8	PE Vulnerable, JAMMING Task, Pop-up Threat, Reactive HARM	COMM, EMI, MIDS Degradation, Air-to-Air, Video Record, System Monitor, with No Failures	Pop-up Threat Reactive HARM Shot
		9	Post-Vulnerable, JAMMING Task	COMM, EMI, MIDS Degradation, Air-to-Air, Video Record, System Monitor, with Power Failure	Post vulnerable
		10	Post-Vulnerable, JAMMING Task	COMM, Air-to-Air Engagement, Video Record, System Monitor, with Source Failure	Air-to-Air Threat

TABLE B-5: DAG 4 LEVEL 1 STANDOFF JAMMING WORKLOAD ASSESSMENT TASKS (REFERENCE 10)

Workload Assessment	Task Level	TLX	Task Set	Introduced Failures	Operator Task
DAG 4	Level 1	1	On Deck, system start-up, Initialization, BIT,	POD Load Fail	Start-up, with POD failure
		2	Establish Situational Awareness, System Monitor, MATT, Resolve Ambiguities	COMM, EMI, MIDS Degradation	Climb-out New MATT ID
		3	Pre-Push, Join-up, Climb, Ingress, System Monitor, Pre Vulnerable JAMMING Task	COMM, EMI, MIDS Degradation, Air to Air, BIT No Failures	Pre-Push
		4	Pre-Vulnerable, Pre-Emptive JAMMING	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, Coordinate Jamming Assignments due to Aft Source Failure	Pre-Emptive Jamming Failed Jamming Source
		5	Pre-Vulnerable, JAMMING	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, Pre-Planned HARM with Failures	Pre-emptive HARM shot
		6	PE Vulnerable, JAMMING Task	COMM, EMI, MIDS Degradation, Air-to-Air Threat (Avoidance), System Monitor, with Source Failure	Air-to-Air Slide
		7	Pre-Vul, Receipt of CAS	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Failures	Receive CAS message
		8	Pre-Vul	COMM, EMI, MIDS Degradation, Air-to-Air, CCS SOI Record, System Monitor, HARM Fail, with Failures	Record SOI
		9	Pre-Vul, Confirm JAMMING Assignments (including CCS)	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Failures	CAS Setup
		10	Pre-Vul, JAMMING Task, A/A	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, HARM Fail pass HARM package to wingman, Source Failure	HARM Pass HHO
		11	PE Vulnerable, JAMMING Task	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, Source Failure	CAS Alignment

TABLE B-6: DAG 4 LEVEL 2 STANDOFF JAMMING WORKLOAD ASSESSMENT TASKS (REFERENCE 10)

Workload Assessment	Task Level	TLX	Task Set	Introduced Failures	Operator Task
DAG 4	Level 2	1	System start-up, Initialization, BIT, MDB Reload	No Failures	Start-up
		2	Establish Situational Awareness, System Initialization and Monitor, Ambiguity resolution	No Failures	Pre-push, Join up resolve ambiguity
		3	Pre-Push, Join-up, Climb-out, Ingress, System Monitor, Verify Jamming Assignments, Resolve ambiguities	COMM, EMI, MIDS Degradation, Air to Air, BIT with Antenna Failure	Push
		4	Pre-Vulnerable, Confirm Assignments (including CCS) Jamming	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Antenna Failure	Confirm assignments, CCS threats
		5	PE-Vulnerable, Jamming, Pre-Planned HARM	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Antenna and Source Failure	Pre-emptive HARM shot
		6	PE Vulnerable, Jamming Task, ID and Record SOI	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Antenna and Source Failure	ID, Record SOI
		7	PE Vulnerable, Jamming Task, ID Abort Threat	COMM, EMI, MIDS Degradation, Air-to-Air, Video Record, System Monitor, with Antenna and Source Failure	Big Dog
		8	Pre-Vulnerable, Receive CAS and Load route, Receive HARM package	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Antenna and Source Failures	Receive CAS
		9	PE Vulnerable, HARM, Jamming Task	COMM, EMI, MIDS Degradation, Air-to-Air, System Monitor, with Source Failure	Pop-up threat, Reactive HARM shot
		10	A/A Leaker ID	COMM, Engage Air-to-Air, System Monitor, with Antenna and Source Failures	A/A Intercept, AMRAAM shot

Appendix C: WORKLOAD ASSESSMENT EXAMPLE QUESTION

The following questionnaire is an example taken from the workload assessments performed (Reference 10).

2. Establish Situational Awareness (task that would typically be performed during Take-off, Departure, Climb-out,) System Initialization and Monitor, Ambiguity resolution, COMM, EMI, MIDS Degradation, with No Failures.

Describe your performance criteria for this task.

Circle one of each of the paired workload factors.

Frustration	or	Mental Demand
Physical Demand	or	Performance
Effort	or	Physical Demand
Temporal Demand	or	Frustration
Performance	or	Frustration
Physical Demand	or	Frustration
Temporal Demand	or	Effort
Physical Demand	or	Temporal Demand
Effort	or	Performance
Temporal Demand	or	Mental Demand
Performance	or	Mental Demand
Mental Demand	or	Physical Demand
Performance	or	Temporal Demand
Frustration	or	Effort
Mental Demand	or	Effort

MENTAL DEMAND	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

2. Establish Situational Awareness (task that would typically be performed during Take-off, Departure, Climb-out,) System Initialization and Monitor, Ambiguity resolution, COMM, EMI, MIDS Degradation, with No Failures.

On the scale of 1 through 10, rate (mark) the magnitude of each workload factor. Use the modified Bedford Cooper-Harper rating scale (below) and the example definitions (left) to form your response.

1 Low tasking, safe, can accept additional tasks without impacting existing tasks.

2 Minimal tasking, safe, can accept additional tasks without impacting existing tasks.

3 Light tasking, safe, can accept additional taskings with minimum impact to existing taskings.

4 Moderate / Comfortable tasking, safe, can accept additional tasking and complete all tasks with reduced revisit time.

5 Moderate / pressured tasking, safety slightly impacted, additional tasks will impact /degrade existing tasks.

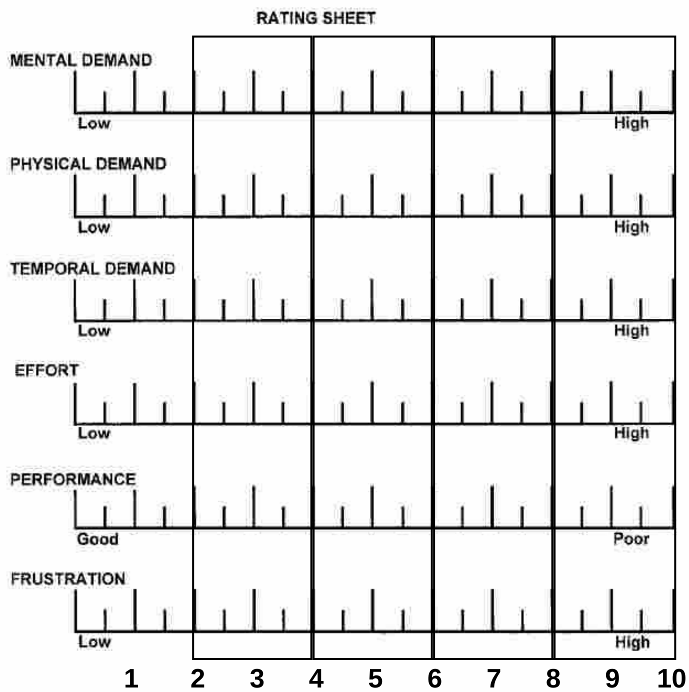
6 High tasking, safety impacted, things beginning to drop out of scan, additional tasking will significantly degrade new and existing tasks.

7 High tasking, safety secondary consideration, additional tasking will override or replaced some existing tasks.

8 Very high tasking, safety not factored into tasks completion, additional tasks cannot be accepted without major degradation to all existing tasks.

9 Saturation tasking, safety not considered, scan breaking down, additional tasking will impact mission accomplishment.

10 Total saturation tasking, scan and task sharing breakdown, fixation on task at hand, survival instincts take over.



Satisfactory without improvement	(No Deficiencies)	Excellent	No compensation	**1**
		Good		**2**
		Fair	Minimal compensation	**3**
Adequate performance attainable with tolerable workload	Deficiencies **Warrant Improvement**	Minor but annoying deficiencies	Moderate compensation	**4**
		Moderately objectionable deficiencies	Considerable compensation	**5**
		Very objectionable but tolerable deficiencies	Extensive compensation	**6**
Adequate performance *not* attainable with tolerable workload	Deficiencies **Require Improvement**	Major Deficiencies	Adequate performance not attainable with maximum tolerable compensation	**7**
			Considerable compensation	**8**
			Intense compensation	**9**
Not Usable	**Mandatory Improvement**		Intense compensation	**10**

2. Establish Situational Awareness (task that would typically be performed during Take-off, Departure, Climb-out,) System Initialization and Monitor, Ambiguity resolution, COMM, EMI, MIDS Degradation, with No Failures.

Ratings Summary

	Weighted Rating		
Scale	Weight	Raw	Adjusted Rating
Mental			
Physical			
Temporal			
Effort			
Performance			
Frustration			
			Sum of Adjusted
			Weighted

If any of your ratings were "4" or greater, please describe the cause.
Consider:

- Design/Mechanization
- Scenario
- Training/Proficiency
- Simulator Anomalies

Appendix D: USE CASE EXAMPLE

EA-18G Use Case: Pre-emptive HARM Employment

Ref # 172

Review Status: 2

Purpose: To launch a HARM based on a pre-planned target.

Trigger: Weapons Employment Timeline

End Trigger: HARM impact with target.

Mission(s)

SEAD: ASUW - Blue Water (CTTG) | SEAD: ASUW - Littoral (SSC) | SEAD: TCT

SEAD: Lethal | SEAD: Non-Lethal

Vignette(s)

On Station

Tactical Situation

Loadout Direct Support ***Formation / Profile:*** None Specified ***Altitude:*** Non-Specified

Station 11	Station 10	Station 9	Station 8	Station 7	Station 6	Station 5	Station 4	Station 3	Station 2	Station 1
ALQ-218	HARM	Hi Band	Tank	AIM-120C	Hi/Lo Band	AIM-120C	Tank	Hi Band	HARM	ALQ-218

1 Tasked to fire HARM on timeline to protect the strikers.

2 Strikers timeline has started and the signal of interest may or may not be active (active preferred).

Actions Required

	Actor	*System*	*Action*
1	G-Crew	HARM (CLC)	Verify pre-briefed mission (1-6) data.
2	G-Crew	ALQ-218	Detect signal of interest (if available).
3	G-Crew	HARM (CLC)	Receive ALQ-218 emitter information. Refine HARM data via Hook an Handoff. (if desired)
4	G-Crew	CVI (FWD/AFT)	On E-Page HARM weapon assignment appropriate site system or emitter (if desired).
5	G-Crew	HARM (CLC)	Refine HARM data to ensure target in MIZ (if desired/able)
6	G-Crew	CVI (FWD/AFT)	Monitor the timeline so that the HARM impacts on time.
7	G-Crew	CVI (FWD/AFT)	Be able to flex HARM TOI based on striker fade or rolex (this is an additional step phase rolex).
8	Pilot	CVI (FWD)	Position aircraft. Select Master Arm on. Verify A/G ready.
9	G-Crew	CVI (FWD/AFT)	Verify weapons release symbology. (HUD, Stores display, TSD, etc.)
10	G-Crew	CVI (FWD/AFT)	Determine when to pickle to ensure the correct TOI (real world time or elapsed time)
11	G-Crew	ARC-210	Call Magnum. (INCANS - active jamming).
12	G-Crew	ARC-210	Convey to the Strike lead when the HARM protection vul ends.

Review status: 0=No input, 1=Initial Input, 2=Group Reviewed, 3=Complete, 5=Canceled

EA-18G Use Case: Pre-emptive HARM Employment

Ref # 172

Review Status: 2

13 G-Crew	ALQ-218	Monitor signal of interest to determine signal deactivation at HARM TOI (+ or - 10%) (if available).

Metrics

XX = Classified requirement, see appropriate requirements reference.
[Bracketed Statements] = aircrew-in-the-loop performance estimates established by the Use Case working group. They are not requirements but should provide a reasonable performance goal/measurement for an average aircrew.

1 Passing the HARM CLC an ALQ-218 emitter trackfile should take less than XX time and require less than a [WLR <4].

2 Designating a preplanned HARM target and firing a missile on time line should require a [WLR<5].

3 Designating a HARM PB with pre-planned emitter data inflight should require a [WLR<5].

4 Monitoring of the HARM TOI in elapsed or Zulu time should require a [WLR<2].

5 Monitoring the ALQ-218 for the signal of interest activation should require a [WLR<4].

6 Release HARM with correct parameters and location. [PPTOI +- 10 seconds].

Test Environment Notes

1 CLC and HARM training station.

Requirements

	ORD	TEMP	SPEC	FRD
HARM	4.a.1.g	Table 1-1	1) Vol IV: 3.8.9 2) Vol IV: 3.8.12	6.1
Digital Data Link				9.0
Displays	4.a.1.b	Table 1-1	3.7.4	1.0
Mission Planning	5.d.2	4.C.1.h	3.7.5.1	15.0
Training	5.e.3			
ALQ-218 Integration			3.7.1.11.2.1	2.0

COIs addressed

1 Effectiveness Issue - Electronic Warfare

2 Effectiveness Issue - Mission Planning and Analysis

3 Effectiveness Issue - SEAD

4 Effectiveness Issue - SEAD - Air to Ground Sensor Performance

5 Effectiveness Issue - SEAD - Air to Ground Weapons

6 Effectiveness Issue - Tactics

7 Suitability Issue - Human Factors

8 Suitability Issue - Documentation

9 Suitability Issue - Reliability - SEAD

01 Suitability Issue - Training

Notes: Any loadout with HARM.

Review status: 0=No input, 1=Initial Input, 2=Group Reviewed, 3=Complete, 5=Canceled

Appendix E: CRITICAL MISSION TASKS

The following information was obtained from the EA-18G Human Engineering Crew Vehicle Interface Report, reference 10.

Mission Analysis/Decomposition
(EA-18G Critical Task Identification)

Mission Tasking
1. Review Air tasking Order (ATO) - Created by CAOC and intelligence
2. Review Air Plan---CV Airwing Operations generated document
3. Review Flight schedule - Squadron generated document using information from the Air Plan
4. Strike lead generates Strike (mission) plan
5. Element leads generate individual sub-mission plans

Mission Planning
6. Aircrew coordinate with intelligence to develop a mission plan using the following considerations:*
a. Required weapons based on theater threat
b. Site, System, and Emitter mission planned MDB
c. Coordinated SEAD and Strike group routes, timing, positioning
d. Develop waypoints, safe areas, and geographical restrictions
7. Element leads integrate mission plans into overall Strike plan
8. CAG approves entire strike plan. Strike lead responsible for understanding all individual elements

Mission Briefings
9. All aircrew, intelligence, and CV Operations personnel attend mass strike brief
10. SEAD, DEAD, and EA aircrew attend SEAD element brief.
11. Individual crews brief their mission roles

Pre-Flight/Before Engine Start
12. Aircrew review aircraft maintenance log
13. Aircrew check out tapes / data cards / classified material
14. Aircrew don flight gear
15. Aircrew “walk” to aircraft 45 minutes prior to launch.
16. Aircrew receive pass down from previous pilot and plane captain
17. Aircrew man crewstations.
18. Aircrew load encrypted radio (assume EA-6B)
19. Aircrew “zeroize” encrypted radio. Ground crew re-keys radio. (assume EA-6B)
20. Aircrew close cockpit canopies
21. Aircrew receive flight deck, air boss, and strike instructions

Engine Start
22. Start engines 30 minutes prior to launch

Before Taxi
23. Aircrew ensure MDBs load, computers are BITed and “up”
24. Aircrew check aircraft engines and controls
25. Aircrew power up and op-check AEA systems*
26. Aircrew initiate a POD identification and ensure communication with the AEA system*
27. Aircrew check in with element lead; Aircrew check in with strike lead

Before Taxi/Before Takeoff
28. Taxi to directed catapult
29. Take off

After Take Off
30. Climb to required altitude.
31. Check out through Strike and Red Crown
32. Make necessary “burn out” jamming assignments and “burn” transmitters out in order to check status*
33. Turn on Master RAD*

Air Refueling
34. Turn off Master RAD*
35. Fly to tanker (if required)
36. Rendezvous on tanker
37. Refuel to top off tanks

Prior to Rendezvous Pt/Combat Checks
38. Depart Tanker
39. Rendezvous with strike group, check in as fragged
40. Optimize AEA jamming assignments*
a. Ensure accuracy, steering, priority, Protected Entity*
41. Conduct EMCON procedures as briefed
42. Minimize radio activity
43. Execute mission plan, phase transitions, and jammer gameplan*
44. Verify Stores (weapons programs)*

Push
45. Push on time
46. Listen for appropriate Code words / monitor proper MIDS NPG
47. Master RAD on per strike brief/mission plan*
48. Broadcast appropriate code words at appropriate times*
49. Evaluate/manage incoming emitters* **
50. Resolve Ambiguous emitter activity **
51. Be alert for pop-up threats* **
52. Monitor timeline*

53. Monitor and fix transmitter power problems*
54. Constantly evaluate go/no-go criteria*
55. Monitor transmitter steering and power output*
56. Fly mission planned course*
57. Listen for appropriate Code words*
58. Employ Weapons* **
a. Air to Ground
b. Air to Air

Post Combat Checks
59. Master RAD off*
60. Go through RTB (Return To Base) waypoints
61. Return to tanker as fragged
62. Pods on standby*
63. Have wingman conduct battle damage checks on aircraft
64. Pre landing checks (items included but not limited to: pod power to “off”, all unnecessary boxes off, etc.)*
65. Go through carrier group check points
66. Check in with Red Crown and Strike

Marshall
67. Marshall overhead at appropriate altitude during the day, or assigned marshall location at night.

Before Landing
68. In marshall, adjust gross weight if necessary (dump fuel), hook down
69. Pass maintenance codes to maintenance
70. Conduct landing checks (e.g. landing gear down, hook down, harness locked, etc. These checks can be found in current E/F books.)
71. Land
72. OK 3 wire arrested landing

After Landing
73. Come to stop and follow flight deck handler directions.
74. Once chocked and chained secure engines or begin hot refuel.
75. Exit aircraft and conduct post-flight inspection of aircraft

Post Flight/Debriefing
76. Pass down important information to relief aircrew
a. Debrief time sensitive Intel information
77. Crew goes to maintenance*
a. Debrief time sensitive maintenance information
78. Get out of flight gear
79. Debrief Operations*
a. Inform Ops of time sensitive info

b. Inform Ops of flight time and mission/training accomplishments
80. Return tapes/data cards to the ready room
81. Attend Element Debrief
Attend Strike debrief
82. Attend Crew debrief

* EA-18G Human Engineering Essential Mission Tasks = Tasks that if not properly completed within specified criteria
could result in degraded mission effectiveness.

** EA-18G Human Engineering Mission Critical Tasks (typically involve HOTAS) = Tasks that if not properly completed
within specified criteria result in mission failure.

Note: Time and accuracy criteria for EA-18G Human Engineering Mission Essential and Human Engineering Mission
Critical tasks are documented in the individual EA-18G Use Cases.

Vita

Christopher Bahner was born on March 13, 1974 in Baltimore, Maryland. He graduated from Westminster High School in 1992 and was accepted into the Aeronautical Engineering program at Rensselaer Polytechnic Institute, Troy, New York. It was from there that he earned a degree in Aeronautical Engineering and enlisted into the United States Naval Officer Candidate School program in the spring of 1996. After graduation from OCS in February 1997, Chris went on to naval flight training and was designated a Naval Flight Officer in August 1998. From there he went to the EA-6B Fleet Replacement Squadron at NAS Whidbey Island, Washington and was assigned to Electronic Attack Squadron (VAQ) 135. During this time he completed a deployment to Incirlik Air Force Base, Turkey in support of Operation Northern Watch and a Western Pacific Cruise on the USS Carl Vinson, in support of Operation Enduring Freedom. While flying combat missions over Iraq and Afghanistan Chris earned three Strike Flight Air Medals and the Navy Commendation Medal with Combat V. Following his first tour he was selected to the United States Naval Test Pilot School at NAS Patuxent River, Maryland and graduated in the December of 2003 as an Engineering Test Flight Officer.

He is currently assigned to Air Test and Evaluation Squadron 23 as the lead Developmental Tester on the EA-18G and ICAP USQ-113 Communication Countermeasures Connectivity Suite Programs.