

The Cognitive Cockpit – State of the Art Human-System Integration

Gary S. Kollmorgen
BMH Associates, Inc.
Norfolk, VA
kollmorg@bmh.com

CDR Dylan Schmorrow, Dr. Amy Kruse
DARPA
Arlington, VA
Dylan.Schmorrow@darpa.mil,
Amy.Kruse@darpa.mil

LCDR James Patrey
NAVAIR
Patuxent River, MD
James.Patrey@navy.mil

ABSTRACT

The "One Team" theme concept will have to include a closer integration of system performance with human performance and limitations. The Cognitive Cockpit (CogPit) is an effort to look at leading edge physiological and neuro-physiological advances applied to operational environments, integrating the "best of the best", and providing a weapons platform capable of enhancing the human's capability beyond today's standard performance expectations. Leveraging technology advancements being matured under DARPA IPTO's Improving Warfighter Information Intake Under Stress (IWIIUS), the CogPit strives to be a revolutionary system that will provide relevant and timely operational data to the pilot in a manner that will allow increased cognitive processing while maintaining or increasing operational performance. The CogPit allows the warfighting system, the plane, to be aware of the pilot's cognitive loading and how best to provide additional or new information in a manner that will not disrupt overall system performance. Four industry teams have been maturing the IWIIUS technology over the past two years. Each team has been developing in a unique warfighting system environment and together they have encompassed the land, air and sea domains. The CogPit is looking at the different neurological and physiological sensor systems and related technology as well as cognitive performance enhancing technologies to integrate best of breed to further mature the state of the art. Additionally, the CogPit will be a test bed for developing tactical cockpits of the future.

ABOUT THE AUTHORS

Gary S. Kollmorgen is a program manager for BMH Associates; a Norfolk VA based simulation technology company. Mr. Kollmorgen is currently working as the BMH program manager for DARPA's IWIIUS Program. Mr. Kollmorgen is working with a team from QinetiQ, NAVAIR, and DARPA to provide a cognitive cockpit that will continue to mature and discover new human-to-computational system interfaces and interactions.

CDR Dylan Schmorrow holds a Ph.D. degree (Experimental Psychology) from Western Michigan University. He currently directs science and technology research programs in the areas of augmented cognition, virtual environments, and advanced distributed learning. These interdisciplinary programs integrate advances in cognitive, neural, behavioral and computer science to provide technologies vital to ensuring DoD military superiority.

Dr. Amy Kruse is a DARPA program manager in DARPA's Defense Sciences Office and has served as Technical Manager for the DARPA Augmented Cognition and Control of Agent Based Computing programs. Dr. Kruse holds a BS in Cell and Structural Biology and a Ph.D. in Neuroscience from the University of Illinois.

LCDR James Patrey is an Aerospace Experimental Psychologist in the Navy's Medical Service Corps. He is currently the Program Manager for 6.4 research and development programs within PMA 205 at the Naval Air Systems Command, Patuxent River, MD. LCDR Patrey is the author of over 50 technical papers and presentations and has served as science advisor to programs at ONR, DARPA, and Sandia National Laboratory. He holds a Ph.D. in Cognitive Psychology from the University of Illinois.

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BACKGROUND

Moore's law has continued to increase computational power for more than two decades. Yet the interface between computers and humans has made only incremental advances in ease of use and virtually no advances in the ability of the computer to adaptively interact with the human in real time. Combine these computational and interface issues with a revolution in cognitive neurosciences as a result of the 1990s "Decade of the Brain" and a paradigm shift in how computers interact with their human operators is feasible⁶. Given that standard human computer interfaces (HCI) have effectively made humans more productive, they have not addressed how to keep a human at his peak while operating in stressful environments by maximizing the cognitive capability of the human operator. DARPA's Improving Warfighter Information Intake Under Stress (IWIIUS), or sometimes referred to as Augmented Cognition (AugCog) program is addressing these possibilities in a pragmatic and systematic fashion. Phases 1 and 2 are complete and Phase 3 will be complete by the end of calendar year 2005.

Augmented Cognition Phase 1

Phase 1 of IWIIUS looked at the basic capability of being able to measure in real time functional states of the human operator, primarily the state of the brain.

The "Real Time Assessment"

A relatively simple but demanding command and control (C2) "game" was used to stimulate the human operators in a real time environment to experimentally test neurological and physiological sensor/gauges. In the Airspace Monitoring task, displayed in Figure 1, the participant plays the role of a Naval Air Warfare Commander protecting a military convoy located off the screen to the south (bottom of the display). The commander's task is to monitor the airspace and disallow any aircraft determined to be potentially harmful to penetrate south of the line of engagement (red line 2/3 the way up the screen). The task involved identifying all aircraft, warning threatening aircraft,

and shooting any threatening aircraft that would not heed the warning before they attacked own ship or the convoy.⁴ This phase was not about interacting with the computer but whether brain state information was observable and measurable in real time. Four teams ran approximately 8 subjects and nearly 30 experimental runs during a week long Technical Integration Experiment (TIE) in March of 2002.



Figure 1. Warship Commander Task (WCT)

Sensor/Gauge (TIE Report)

Using Electroencephalography (EEG) and functional Near Infra-Red (fNIR) imaging, government, academic, and industry teams built "gauges" that measured functional states of the brain. Additionally, other physiological sensors (eye tracking, Electrocardiogram (EKG), Galvanic Skin Response (GSR), etc.) were used to increase the accuracy of the state classification of the neurological based sensors. These gauges indeed showed a capability to observe brain state activity. This capability was to mature and function as the basis for Phase 2 development. Phase 1 results (see Figure 2) were documented in report developed by SPAWAR and delivered to DARPA in JAN 03.⁴ In this figure, a filled circle indicates a high level of consistency across participants in the degree of sensitivity to changes in task load for that gauge (all participants showed a similar size correlation between gauge value and Number of Tracks per Wave: standard deviation (σ) less than 0.15). In other words, the gauge was equally sensitive (or insensitive) for every

Gauge	Sensor Type	Developer	Task Load Factors			Consistency Across Participants
			Number of Tracks per Wave (6,12,18,24)	Track Difficulty (Hi/Lo)	Secondary Verbal Task (On/Off)	
fNIR						
fNIR (left)	Blood Oxygenation	DrexelU	●	○	○	●
fNIR (right)	Blood Oxygenation	DrexelU	●	○	○	●
EEG-Continuous						
Percent High Vigilance	EEG	ABM	●	◐	○	●
Probability Low Vigilance	EEG	ABM	●	○	○	●
Executive Load	EEG	QinetiQ	●	◐	○	●
EEG-ERP						
Motor Effort	ERP-IFF	EGI	◐	○	◐	●
Auditory Effort	ERP-Engage Sound	EGI	○	◐	◐	●
Loss Perception	ERN-Error Sounds	Sarnoff/Columbia	◐	○	●	●
Ocular-Frontal Source	ERP-Comms	UNewMexico	●	○	○	●
Synched Anterior-Posterior	ERP-Comms	UNewMexico	○	○	●	●
Visual Source	ERP-Comms	UNewMexico	○	○	○	●
Arousal						
Arousal Meter	Inter-Heart Beat Interval	Clemson U	○	○	○	●
Arousal	GSR	UHawaii	○	○	○	●
Arousal	GSR	AnthroTronix	○	○	○	●
Physiological						
Head-Monitor Coupling	Head Posture	UPitt/NRL	◐	○	○	○
Head Bracing	Body Posture	UPitt/NRL	◐	○	◐	●
Back Bracing	Body Posture	UPitt/NRL	○	◐	○	●
Perceptual/Motor Load	Mouse clicks	UHawaii	●	●	○	●
Cognitive Difficulty	Mouse pressure	UHawaii	●	●	○	●
Index of Cognitive Activity	Pupil dilation	SDSU	◐	○	●	○

Figure 2. Summary of Phase 1 Results

participant. A half-filled circle indicates a moderate level of consistency across participants (participants showed moderately different size correlations: $\sigma < 0.30$). An open circle indicates a low level of consistency across participants (participants showed widely different size correlations, $\sigma > .30$).⁴

IWIIUS Phase 2

Phase 2 of IWIIUS took a pragmatic approach to using the information/development in Phase 1. Four industry led teams were awarded contracts to apply the sensor/gauges developed in Phase 1 to a particular military domain as shown in Table 1.

Table 1. Industry Team Domain Assignments

Honeywell Labs	Dismounted Infantry (US Army)
Lockheed Martin ATL	Tomahawk Control Station (US Navy)
Boeing Phantom Works	UAV Operator Station (Joint/US Air Force)
Daimler Chrysler Corp.	Combat Vehicle Driver (US Marine Corps)

The Possible

Phase 2 was to determine “what was possible” using AugCog technology. Ergonomics, maintainability, sustainability, etc. were not a significant concern during this phase of development. Being able to measure what had come to be known as sensory bottlenecks (see Figure 3) and then manipulating the HCI to avoid bottleneck overload was the primary task. An assessment of the developed capability and its fieldability was conducted at the end of Phase 2 to lay the ground work for Phase 3. Four Closed Loop Integrated Prototypes (CLIPs) were developed and used for experimentation in developing the AugCog sensor/gauges and state classification algorithms and performance.

Sensory Bottlenecks

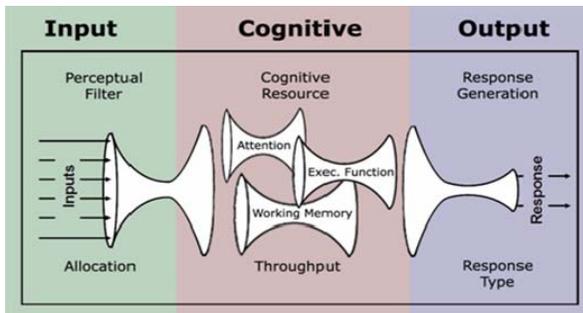


Figure 3. Illustration of Cognitive Bottlenecks

Sensory bottlenecks were hypothesized to be the basic limiting factors of maximizing human performance. There were four bottlenecks: Attention, Working Memory, Executive Function, and Sensory Input.

- Attention Human attention can be overloaded (divided beyond capability to process) and information is potentially lost, decisions not made or not made in a timely fashion.
- Sensory Input More than one data stream arriving for operator consumption but competing for a single modality channel (visual, aural, tactile)

leading to lost information and possible incorrect decision analysis execution. The HCI may be able to handle multiple data streams in one modality (multi-screen workstation) but the human limitation is generally one data stream to one modality at a time.

Executive Function Overall processing power of human can be overloaded where information is lost or decisions not made

Working Memory Working memory has specialized areas for different types of cognitive processes but those areas can be overloaded to where information is lost

Phase 2 culminated in the four teams conducting Concept Validation Experiments (CVEs) during the latter half of CY 2004. Exciting results included a 642% increase in working memory for an enhanced Tactical Tomahawk Weapons Control System operator, a 241% increase in executive function for a conceptual Joint Unmanned Air System operator, a 380% increase in attention capacity for a future dismounted infantry soldier, and a 108% increase in auditory sensor input and 72% increase in visual sensory input (an amazing increase given the primary mission is driving a vehicle and highly visual in nature) for a armored vehicle driver. A summary report was prepared and delivered to DARPA on the success of Phase 2 in addressing bottlenecks and maturing the capability to measure cognitive states/loading in near real time.⁵

IWIUS Phase 3



Figure 4. Conceptual AugCog System

Phase 3 is to mature the AugCog technology even further. Additionally, a fifth team was formed to leverage similar work being conducted by QinetiQ in the United Kingdom. This work is leading to the development of a Cognitive Cockpit which is described in detail below.

Phase 3 is also to focus on “what is feasible” when applied to the same domain areas as was laid out for Phase 2. Here the “ilities” (maintainability, survivability, etc.) are to be considered. Additionally the tasking is to become as operationally relevant as possible while still allowing for controlled experimentation. The planned result of Phase 3 is to have a capability that is transferable to a military service. Further, the four industry teams are being encouraged to cross-pollinate and leverage each others work to the maximum extent possible to mature those technologies that show the most promise.

COGPIT

The “Fifth Team” is composed of NAVAIR, BMH Associate, Inc. and QinetiQ. The opportunity is to look at another domain (Air) that was not being represented directly by the other teams and to leverage ongoing work by QinetiQ. Additionally, this team has a free hand in picking the best of breed from the other work being performed under the IWIUS program. The development of an aircraft virtual simulator or cockpit combined with the cognitive neuroscience sensors led to the obvious name of Cognitive Cockpit or CogPit.

Background

QinetiQ, a United Kingdom company, has built and been experimenting with a cognitive cockpit (see Figure 5) that has all of the CLIP capabilities shown by the other four industry teams. DARPA and NAVAIR saw the potential in having this capability in the US for further experimentation and maturing of the science and technology behind the CogPit. The basic modular structure of the QinetiQ CogPit would be used for the basis of the NAVAIR CogPit. Two significant changes would be made initially. First the proprietary simulation would be replaced with a GOTS/COTS solution to reduce cost and to allow greater flexibility in integrating the virtual cockpit into US exercises/events. Secondly, the current QinetiQ sensor/gauge system was on an unsupportable hardware platform and had individual training issues that were considered overly complex given the other sensor/gauge systems available via the four industry teams – it was replaced.



Figure 5. QinetiQ's Cognitive Cockpit

Components

The CogPit block architecture is shown in Figure 7. The main components are the Cognitive State Assessor (CSA), The Tasking Interface Manager (TIM), the Generic Decision Support System (GDSS), and the Simulation System (or the Virtual Simulator).

Each component operates as a module and uses a simple web server interface to pass data between modules. The CSA monitors the pilot's cognitive state and passes state information to the TIM. The GDSS recommends plans based on the state of the aircraft and the aircraft's situational awareness (sensor information). The TIM tracks goals and pilot's state, knows possible plans of execution, and then determines how to adaptively interface with the pilot and/or execute intelligent automation. Finally the simulation environment is an HLA based virtual “future” glass cockpit operating in a Joint Semi-Automated Forces (JSAF) synthetic environment.

Cognitive State Assessor (CSA)

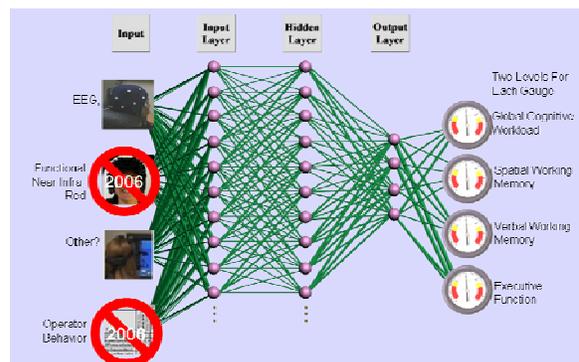


Figure 6. NuWAM Artificial Neural Net

For initial testing NAVAIR has chosen to experiment with the Air Force Research Lab's New Workload Assessment Monitor (NuWAM). NuWAM (See Figure 6) is a fourth generation on-line psycho-physiological data collection, reduction, analysis, and Operator

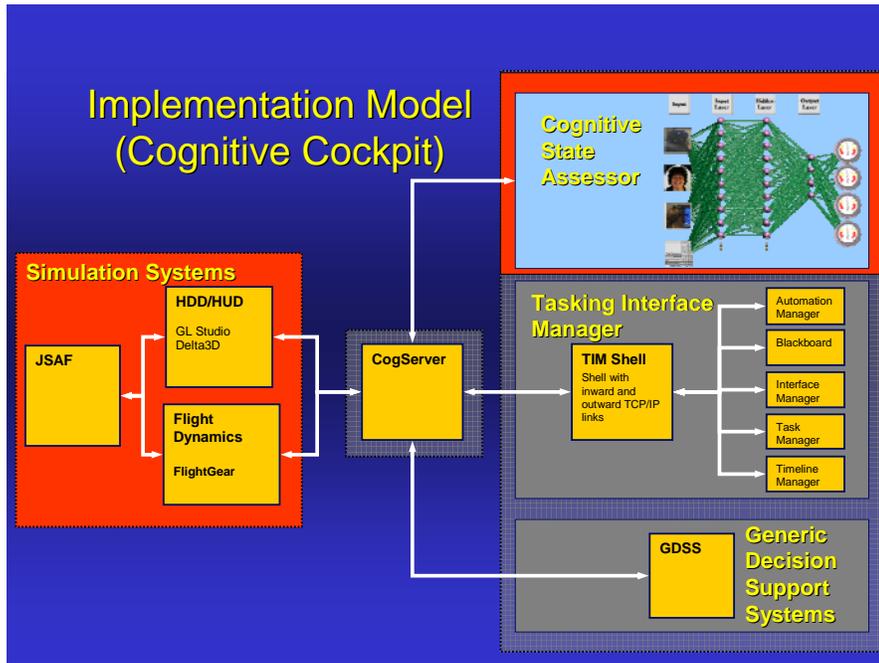


Figure 7. CogPit Architecture

Functional State (OFS) assessment system.⁸ The output of the NuWAM system is a classification of the operator's state and is sent to the TIM to aid in determining mitigation strategies to control the level of workload or stress.

The primary components of the NuWAM system are EEG/ECG/EOG sensors, a filtering system, and a feed-forward back-propagation Artificial Neural Net (ANN) classifier. The filtering system has been required in all tested operational environments to remove undesired characteristics in the real time data stream. These characteristics include spurious or repetitive (involuntary) movements such as eye blinks and large head movements. The system is trained by observing the outputs from the ANN and comparing to ground truth knowledge of pilot workload (level and type). This allows weightings of the outputs from the ANN to achieve a gauge that effectively measures pilot cognitive state.

NuWAM construction is modular in nature to allow for easy integration of additional sensors, filtering techniques, and/or state classifiers. The system is ideal for the experimentation environment of the CogPit, yet lends itself to being productized as a fieldable system is developed.

Generic Decision Support System (GDSS)

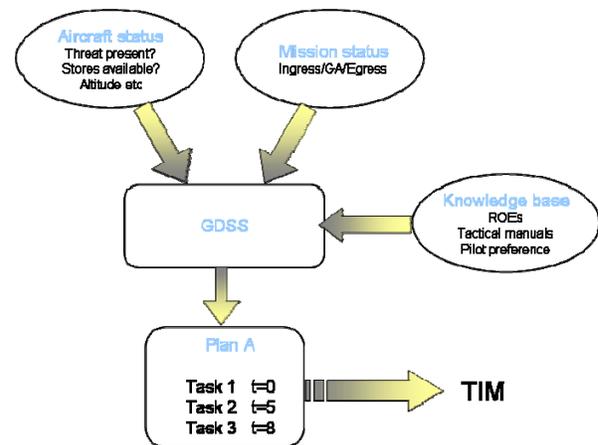


Figure 8. GDSS Architecture

As shown in Figure 8, the GDSS develops plans based on three primary inputs. First, the GDSS knows the aircraft state such as sensor information, stores information, altitude, speed, heading, etc. Secondly, the GDSS has knowledge of the mission phase (takeoff, enroute, ingress, egress, etc.) the aircraft is currently conducting. Thirdly, the GDSS has access to a knowledge base of rules of engagement, tactics, techniques, and procedures (TTPs), and pilot preferences. The combined knowledge of these components allows the GDSS to formulate plans that are subdivided into subordinate tasks. The best plan given the current aircraft state and mission phase is presented to the TIM for situational awareness and time management tracking.

Tasking Interface Manager (TIM)

The TIM is the critical component to actually aiding the pilot in mission accomplishment and efficiency. Its primary purpose is to reduce pilot workload/stress when his state indicates he is overloaded or increase workload if pilot state is going too low (lack of attention, drowsy). It does this by presenting the right “decision making” information at the right time in a manner that is consumable and understandable by the pilot. Consumable and understandable means the information is presented in a manner that won’t conflict with a cognitive channel that is already being used. For an example, if a surface to air missile has been fired at the aircraft, the TIM understands that the pilot is busy visually trying to find the missile or avoid terrain in a counter maneuver, and the next action should be to deploy flares as a countermeasure – the TIM would not flash a sign on the glass cockpit to employ flares; most likely the pilot would miss it. Instead the TIM would create an audible signal saying “Deploy Flares”.

The TIM has the capability to interact with the pilot on several levels (warning, warning and then automation, automation, etc.). Because of the variability between pilots and the different missions that a single pilot may conduct, a system was devised to allow the pilot to negotiate with the TIM on how the TIM and pilot will interact. This system was developed by QinetiQ and was named the Pilot Authorization and Control of Tasks (PACT) Framework. It is depicted in Figure 9.

	PACT LEVEL	Pilot Authority	Computer Autonomy
Assisted modes	AUTOMATIC	5	Interrupt
	DIRECT SUPPORT	4	Revoke
	IN SUPPORT	3	Authorize
	ADVISORY	2	Full
	AT CALL	1	Full
	COMMANDED	0	Full
			Full
			Action (unless revoked)
			Action (if authorized)
			Advisory
			Advisory (if requested)
			None

Source: Taylor et al. (2000)

Figure 9. PACT Framework

The TIM takes inputs from the CSA and the GDSS and algorithmically determines how best to aid the pilot taking into consideration the settings of the PACT. The pilot then receives information through different modality channels (haptic, visual, audio, etc.) or through automation and feedback.

Virtual Simulator

The Virtual Simulator is made up of several components riding a High Level Architecture (HLA) network protocol. The simulation environment is the

Navy Training Baseline version of Joint Semi-Automated Forces (JSAF). This is a synthetic environment and computer generated force application. The aerodynamics model flying in this environment is an open source application called FlightGear (see www.flightgear.org). It is an open source, multi-platform cooperative flight simulator. For a head up display (HUD) the simulator uses Delta3D for visual terrain (outside world) and GL Studio™ for the actual HUD aircraft information display. Delta3D (see delta3d.org) is an open source game engine with visualization capabilities being developed by the US Military. For the Head Down Display (HDD), or cockpit controls, weapon systems, and sensors, a combination of GL Studio™ and Delta3D is being used.

COGPIT NEAR TERM DEVELOPMENT

The second half of CY05 will see the CogPit undergoing some basic testing and experimentation. Initial desires are to test/improve the CSA capabilities of the CogPit using techniques being developed by the other industry teams and fine tuning through experimentation. High on the list is development of a fNIR sensor/gauge capability that is showing great promise in work being conducted by the Boeing Team.

Development will include additional mitigation strategies within the TIM and creating a more interactive PACT control system. Further enhancement of the GDSS and its knowledge is also on the plate for development. An SBIR is also underway to look at basic HCI improvements. Phase 1 of the SBIR looked at improvements in information flow at a command and control (C2) center, namely a Tactical Flag Command Center (TFCC). Several HCI issues were observed and mitigated to improve information flow to the operators and staff decision makers allowing for quicker and more accurate decision making. It is postulated that the typical cockpit design has had little effective change, short of analog to digital, since early aircraft design. Further, given the changing state of warfare, sensors, networking, and information availability, the pilot will have an ever increasing amount of information at his fingertips – much of which will be of little use and could actually be detrimental (confusing, clutter) to prompt decision making. Leveraging the work from the Phase 1 SBIR, capabilities such as filtering, prioritizing of threats, 3D display techniques can all have a role in improving the pilot’s ability to conduct warfare. The Phase 2 SBIR will look attempt to provide an improved HCI which

can then be further improved by overlaying AugCog technology.

COGPIT AREAS OF EXPLORATION

As stated above, HCI improvements through a Phase 2 SBIR as well as leveraging from the other four IWIIUS teams and through continuing literature study will help to make the CogPit a more capable fighting platform. Several mitigation strategies to lessen the workload or aid the pilot have already been discovered by QinetiQ and the other teams. What is not yet clear is if these mitigations (triggered by cognitive sensor/gauges) are best used continuously (not triggered) or if there is an operational cost to having them “on” all the time. Future experiments with the CogPit will hope to make a distinction and show the improvement but also any cost of employing different mitigation strategies.

Sensor/Gauges have continued to improve and mature since Phase 1 of this DARPA project. It is assumed that this will continue both in CogPit experimentation and in work done by the four industry teams. Additionally, in July 05, Augmented Cognition International will have its inaugural meeting. It will bring together international government, industry, and academia developers and researchers furthering this groundbreaking field of study. Through this medium, additional exposure to techniques and capabilities will allow additional enhancement of the CogPit.

The system being developed is “closed loop”. This implies that the system will need to have stability mechanisms in place to avoid destructive feedback within the system. Concern and studies have already commenced on how to control mitigation strategies. Early development has shown great success in determining when to “turn on” or aid the operator based on cognitive state and current mission context. What is not so clear is when and how to “turn off” the mitigation without causing a yo-yo effect. The CogPit will be looking at this area to determine how best to employ mitigation techniques.

The GDSS is currently simplistic in capability. In order to apply CogPit capabilities to an actual operational environment (even a current, fielded virtual simulator), much work will have to be done in expanding the knowledge base and capability of the GDSS. This is a fairly straight forward Knowledge Acquisition/Knowledge Engineering task that will take place as more missions are added and tested in the CogPit.

An area QinetiQ is investigating in their version of the CogPit and is of interest here is the idea of a feed forward capability. This is the idea of projecting forward what the pilot’s next course of action should be in order for the CogPit system to forecast the best plan of action and to monitor that the pilot is performing crucial tasking. This helps complete the human-computer symbiosis. Effectively the computer will start behaving more like an intelligent co-pilot and less like a fast database of information storage and retrieval. Additionally this capability can lead to a more stable interaction between the pilot and computer because periods of inactivity or lower stress will be predictable and mitigations can then be turned off with no detrimental effects.

Other Application Possibilities

There appear to be a multitude of other applications for this technology. One that has already sparked interest and may be continued through NAVAIR experimentation is the ability to use this capability for training purposes. Imagine being able to have cognitive state data archived for experienced pilots and then use that data to compare against novice pilots to see where they are being “over tasked” in their training regime and applying tailored training to improve overall performance.

AugCog technology has a potential benefit of providing validation to HCI design. By observing cognitive loading at different times during a mission, HCI designers can learn how best to adapt display of information to minimize cognitive loading. Once an optimum design has been achieved, AugCog technology can then be employed to enhance the pilot’s performance even more.

Application of this technology can be applied to many consumer applications. Operators of vehicles can have their performance enhanced to reduce stress and traffic accidents and fatalities. Operators of factory robots, nuclear power plants, or any plant that requires observation of many processes can have their performance enhanced thereby reducing the number of operators and/or increasing plant safety.

SUMMARY

The Cognitive Cockpit provides a basis for a new beginning in human computer symbiosis. Using maturing cognitive science as well as HCI technology the CogPit provides a platform for experimentation leading to novel cockpit design considerations. While still relatively in its infancy, AugCog technology is

showing significant performance enhancement in several sample military domain applications (e.g., USMC Armored Vehicle, USA Future Force Warrior, USN Tomahawk Control, and USAF/USN UAV). The technologies are continually maturing and have a seemingly bright future. Microsoft®, The National Science Foundation, and other organizations are continuing to fund research in Augmented Cognition. Augmented Cognition International (www.augmentedcognition.org) has been organized to help nurture the advancement and maturity of this technology field. This paper has shown one area where experimentation hopes to lead to a better military pilot. Hopefully it has also shown or inspired thoughts of other application areas and opportunities. The NAVAIR, BMH, QinetiQ team are continuing to advance the science and application in this novel field of study and experimentation. The human has never been this closely coupled with the computer systems supporting him.

REFERENCES

- ¹Dickson, Blair T., Closed Loop Systems - Stability and Predictability, International Conference on Augmented Cognition, *Proceedings of the Human Computer Interaction International Conference*, 2005
- ²Dickson, Blair T., The Cognitive Cockpit - a Test-bed for Augmented Cognition, International Conference on Augmented Cognition, *Proceedings of the Human Computer Interaction International Conference*, 2005
- ³Diethel, Tom, The Future of Augmentation Managers, International Conference on Augmented Cognition, *Proceedings of the Human Computer Interaction International Conference*, 2005
- ⁴Morrison, Jeffrey G., Editor, DARPA Augmented Cognition Technological Integration Experiment, *Space and Warfare System Command*, San Diego, 2003
- ⁵Morrison, Jeffrey G., Editor, DARPA Improving Warfighter Information Intake Under Stress – Program Phase II – Final Report, *Defense Advanced Research Projects Agency*, 2004
- ⁶Raley, Colby, Schmorow, Dylan D., et. al., Augmented Cognition Overview: Improving Information Intake Under Stress, *Proceedings for the Human Factors and Ergonomics Society*, 2004
- ⁷Schmorow, Dylan D., Kruse, Amy A., Improving Human Performance Through Advanced Cognitive System Technology, *Proceedings of the Interservice/Industry Training, Simulation & Education Conference*, 2002
- ⁸Schmorow, Dylan D., Stanney, Kay M., et. al., Augmented Cognition in Human-System Interaction, *Handbook of Human Factors and Ergonomics*, Chapter 53, 2005
- ⁹Wilson, Glenn F., Russell Chris A., et. al., NuWAM: The Development of a Modular, Real-Time Augmented Cognition System, International Conference on Augmented Cognition, *Proceedings of the Human Computer Interaction International Conference*, 2005
- ¹⁰Strausser, Jody A, Juhnke, Joseph, Technical Analysis of Knowledge Flow in Command and Control Centers, *SBIR Final Technical Report*, 2005