VOLUME VI: NUMBER 5 (1995)

CSERIAC GATEWAY

PUBLISHED BY THE CREW SYSTEM ERGONOMICS INFORMATION ANALYSIS CENTER

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CSERIAC is a United States Department of Defense Information Analysis Center administered by the Defense Technical Information Center, Alexandria, VA, technically managed by the Armstrong Laboratory Human Engineering Division, Wright-Patterson Air Force Base, OH, and operated by the University of Dayton Research Institute, Dayton, OH.

COGNITIVE ENGINEERING

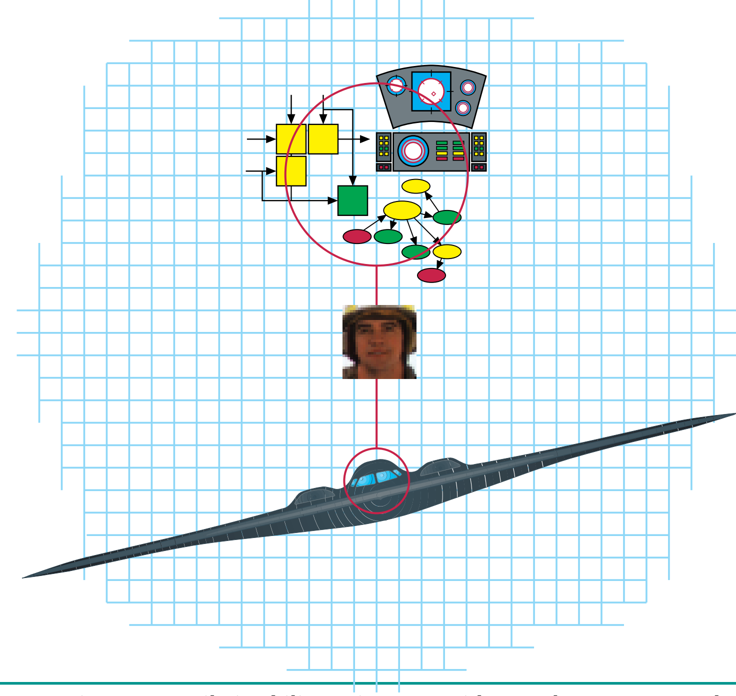

Figure 1. To improve a pilot's ability to interact with complex systems, such as the B2, cognitive engineering attempts to understand the thought processes underlying the pilot's actions. Digital illustration by David W. Radabaugh.

Cognitive Engineering: A Different Approach to Human-Machine Systems

Michael D. McNeese

Think of a real-wor lem you might have recently experienced. You might have lost your billfold, locked your keys in your car, had your luggage misplaced, or even missed your flight. Recently, I left my camera on a flight simulator at an amusement park. When I realized the problem (I didn't have my camera), I immediately tried to retrace my steps and determine just where it had been lost. Once the situation was defined well enough to predict where the camera could be found, I had to decide how to get back into the simulator and retrieve it. This immersed me in a new planning situation. Such problems may seem minor, but they present a person with a dilemma where (1) understanding and remembering the context are crucial,

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(2) plans or actions previously considered to be routine start to break down, and (3) problem solutions require innovation, risk taking, and uncertainty.

As problem solvers, we are accustomed to developing solutions relevant to our own experiences, especially in constrained settings. However, a dilemma arises when we are responsible for providing solutions to other people's problems that require us to know what they are thinking, or to be aware of the context in which they are planning or taking new actions. Unfortunately, traditional approaches to the design of human-machine systems, such as those encountered in human factors, do not often take these aspects into account.

Traditional Approaches

Human Factors Engineering

Traditional human factors engineering focuses on *human performance* and emphasizes issues such as workload, anthropometry, control-display integration, lighting, and other design considerations pertaining to human compatibility. When undertaking research to improve the human-system interface, human factors engineers and system designers typically vary a number of human-system interface elements and then measure the impact of such variations on the operator's performance. Based on the implications of their findings, they implement the system changes needed to accommodate the operator's limitations and enhance system performance. Although this tradition is very important and has its place in meeting users' needs, it often does not consider the context of work and socio-organizational factors (Bannon, 1992).

In traditional human factors practice, analysts might not always consider what a person knows, what a person experiences, or what a person needs. For example, the design of human-computer interfaces for Internet browsers may take into account keystrokes (what a person does) without addressing some of the cognitive constraints on usability (what a person knows, experiences, or needs). The result can be clumsy interfaces or design failure. As systems become more complex (e.g., nuclear power plants, intelligent highway systems), some of the limitations within traditional human factors engineering need to be examined.

Knowledge Engineering

In knowledge engineering, which is generally derived from computer science, engineers elicit knowledge from human experts and code it into a computer program's knowledge base to allow a computer system to approximate human reasoning. Such an approach to system design is *technology-driven* rather than *user-centered* because the requirements of the computer system determine the process for eliciting information and information content. Early knowledge engineering techniques were applied to limited, highly constrained domains in which knowledge was easily gleaned from the user (e.g., the development of chess programs). This process became much more difficult for real-world systems (e.g., medical diagnosis, pilot aiding). Unfortunately, knowledge engineering often produces faulty and highly constrained (often referred to as brittle) knowledge representations, and it, too, fails to consider the influences of socio-organizational and contextual factors.

A New Approach: Cognitive Engineering

Defining Features

Due to the limitations of traditional human factors engineering and knowledge engineering, there is a need for a different approach to the design of human-machine systems, one that is compatible with human cognition. Cognitive engineering is the attempt to design systems that are better adapted to the thought processes of the user (Klein, 1990) (see Fig. 1, page 1). As a *philosophy*, cognitive engineering brings expert-centered knowledge to bear on the design of a complex system. As an *approach*, cognitive engineering is primarily concerned with acquiring, exploring, and transforming knowledge throughout different stages of the design process. It should also include multidimensional descriptions of the context in which the activity occurs and the cognitive basis (e.g., plans, strategies, knowledge, decisions) for action in that context.

An Example: The Pilot's Associate

Difficulties like those you experienced in the problem you recalled at the beginning of this article are magnified immensely in complex systems. To more effectively interact with complex systems, the Wright Laboratory began work on the Pilot's Associate, an electronic "assistant" to aid pilots during a tactical mission. The Armstrong Laboratory Human Engineering Division assisted in this project by applying cognitive engineering in the development of the electronic assistant.

Tactical mission planning begins days or even weeks before the actual mission as potential targets are identified, classified, and prioritized. Commanding officers explore information (intelligence and reconnaissance data), alternative mission scenarios, and potential losses and threats, and then outline the specific details of the mission. Once a flight is undertaken, the pilot must coordinate his or her efforts with other members of the crew (e.g., navigator and weapons officer), other pilots on the mission, and information sources in the air and on the ground (e.g., air traffic controllers). However, incidental battle damage, weapon type, threat potential, weather conditions, terrain features, force size, time of day, and equipment malfunction can all potentially create conditions that alter the original mission and tactics plan, and create new problems to be solved as the mission unfolds (Young & McNeese, 1995).

Our initial work in applying cognitive engineering to the Pilot's Associate focused on developing a knowledge base which was used to define the interface between the pilot and the Pilot's Associate (McNeese, Zaff, Peio, Snyder, Duncan, & McFarren, 1990). To limit the scope of the problem, the target acquisition elements of a tactical mission were selected for study.

First, we interviewed pilots to develop concept maps. (Concept mapping is a graphic interactive interviewing technique where a domain expert is allowed to speak uninterrupted about a topic. The expert's words are then represented as interconnected concepts on a white-board.) This way, we could create mental models of how they viewed their mission, the contexts they typically experienced during a mission, and the knowledge that precedes taking action. These maps were summarized and used to help develop later design solutions. After pilots completed maps that defined their knowledge, they were given a mission profile which contained specific targets, weapon selections, attack geometry, etc. Using this information, they initially plotted out a rough timeline of target acquisition. Within this timeline, critical decision points were defined by the pilots. For each decision point, the pilots provided a variety of information related to plans, strategies, perceptual recognition, action points, etc., in proper sequence and in the context of the real mission demands. This method allowed us to create mental simulations of these events (often refered to as *cognitive walkthroughs*). Here, the pilots acted as "experts" to derive new strategies, procedures, and requirements. The combination of the pilots' mental models and the sequential progression through a mission provided an understanding of the cognitive complexity inherent in a tactical mission.

Next, we were ready to use our knowledge base to influence the design solution. For each of the decision points that were defined and developed, a storyboard was created. Design storyboarding, used in the film industry, allows illustration of a scene's staging and outlines a story. Storyboards portray what should be heard or seen, how it should be presented, and when it should appear. Storyboards look like a comic strip as they develop a story line through graphic portrayal (see Fig. 2, which shows concepts transformed into designs using concept mapping and design storyboard techniques). The individual storyboards for each pilot were merged to form a final summary storyboard which contained specific knowledge about preflight planning, key decision nodes, communications, visual acquisition, aircraft systems, problems and solutions, and information requirements (McNeese, Zaff, Citera, Brown, & Whitaker, 1995).

This example shows one specific approach used in cognitive engineering. Since this approach was originally implemented, several improvements have been made as well. As we began to apply cognitive engineering to several new areas of flight (e.g., in-flight planning in a B-2 mission), new extensions have been made in the area of observational field studies. In addition to active participation by the pilots and other experts associated with the mission, the use of observational data modeling tools can create powerful perspectives on how a pilot operates directly within the context of flight. Through use of the MacSHAPA data analysis tool (Sanderson, Scott, Johnston, Mainzer, Watanabe, & James, 1994), a variety of sequential behaviors can now be integrated for joint investigation. Observational data, as recorded on video-tape, can then complement the previous methods to produce a rich understanding of expertise, context, and design (see Sanderson, McNeese, & Zaff, 1994).

The value of cognitive engineering is that, unlike traditional human factors engineering and knowledge engineering, it approaches the design of complex human-machine systems by trying to make sense of the mutual transactions occurring between people and their environment under a variety

Continued on page 4

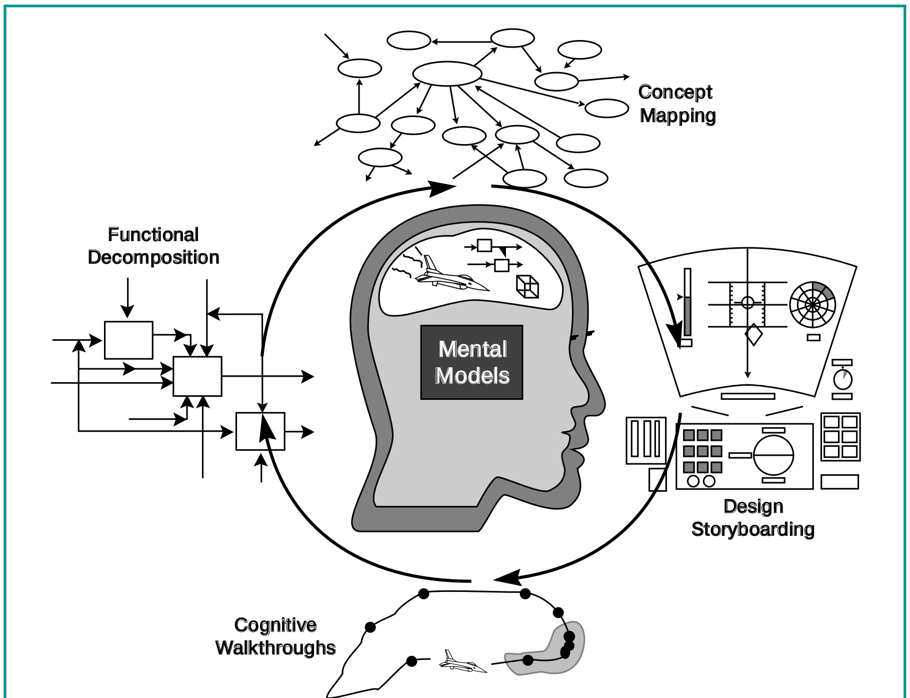

Figure 2. Cognitive engineering techniques that are often employed include concept mapping, design storyboarding, cognitive walkthroughs, and functional decomposition.

of changing conditions.

For additional information on theories, methods, and tools of cognitive engineering please refer to Card, Moran, & Newell (1983); Hollnagel & Woods (1983); Klein, Orasanu, Calderwood, & Zsambok (1993); Norman (1986); Rasmussen, Pejtersen, & Goodstein (1994); Sanderson, McNeese, & Zaff, (1994); and Woods & Roth (1988). These practitioners have applied cognitive engineering to such diverse areas as medical decision making/information systems, flight deck operations, nuclear power plants, electronic diagnostic reasoning, library retrieval systems, and designer support systems. ●

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Letter to the Editor

Sirs,

Much though one may admire Paul Fitts, the claim by Walter Summers (*CSERIAC Gateway*, Vol. VI, No. 2, 1995) that "Fifty years ago a group..founded..the entire field of human engineering" is unfortunately comparable to the notion of a World Series in sports when the only country which takes part is the United States (–Oh yes, there IS also Canada, isn't there?), or that the first nuclear reactor to feed electricity into a grid commercially was built under Rickover's management in the late 1950's (the UK actually had its first industrial nuclear accident by that time, let alone having generated electricity for several years). As Munipov, Shackel, and many others have noted, the origins of human factors, ergonomics, human engineering, call it what you will in one form or another, can actually be traced back to the last third of the 19th century, while there was recognisable work on human-machine systems begun in World War I in Europe, and continued throughout the 1920's and 30's, and indeed right through WW II. No doubt the US contibution has been bigger and brighter, and more centered on military research, but one would like to encourage an accurate sense of history in students (of any age) who may read your publication.

Yours sincerely,

Neville Moray

The History of Human Factors

1857 E. B. Jastrebowski, *An essay on ergonomy, or science of labour based on the laws of natural science*.

1897 I. Sechenov, *Physiological criteria of the length of the working day*.

1890s F. Taylor, *Principles of scientific management*.

1900s F. B. Gilbreth, *Methods time measurement*.

1915 UK Health of Munitions Workers Committee.

1918 UK Industrial Health Board (with physiologists, psychologists, doctors and engineers-lasted through 1920s and 1930s).

1920s Hawthorne Experiments.

1921 K. Tanaka, *Human Engineering* (published in Japan).

1930s Development of personnel psychology, motivation and groups dynamics in US Psychology.

1940s Tavistock Industrial Psychology, UK. UK Flying Personnel Research Committee. USA Military Human Factors Research (Paul Fitts et al.).

1949 Ergonomics Research Society, UK.

1957 Human Factors Society, USA.

1961 International Ergonomics Association.

Reply from Walter C. Summers:

Dear Dr. Moray,

Thank you for the opportunity to clarify a fine, but very important, point. It is undeniable that important work in human factors, ergonomics, or human engineering has taken place, and continues to take place, outside the US. It took place before World War II and continues to this very day. My hat is off to these many outstanding researchers. Nonetheless, I stand by my assertion that human engineering, as an organized and delineated discipline, can be traced to its beginning with Paul Fitts in the post-World War II era. The systems approach, very much at the heart of the new human engineering, was initially developed in the biological sciences and further refined by communication engineers in the 1940's. Adoption of this approach was bolstered during World War II when it was recognized that military systems were becoming too complex for humans to successfully operate. "...(D)uring World War II...the emphasis was almost entirely on selection, classification, and training, although near the end of that conflict human factors engineering (then generally referred to as 'engineering psychology') began to emerge as a distinct discipline" (Christensen, 1987). The time was right. Engineering design of equipment specifically to accommodate human performance, i.e., human engineering, was finally viewed as an imperative. And so I say "Bravo" to the countless men and women worldwide, as far back as mankind used tools, who advanced our ability to understand and deal with human-machine issues–they are the giants upon whose shoulders the field was built. However, if you ask the question "Where did the field of human engineering coalesce and under whose leadership?" my clear choice remains the Psychology Branch under Dr. Paul M. Fitts.

Sincerely,

Walter C. Summers

Christensen, J. M. (1987). The Human factors profession. In G. Salvendy (Ed.), *Handbook of human factors* (p. 5). New York: Wiley.

The COTR Speaks

Reuben L. Hann

This issue of *Gateway* begins with an introduction to the topic of "cognitive engineering." Dr. Mike McNeese, from the Human Engineering (HE) Division's Crew Station Integration Branch, discusses the emergence of cognitive engineering within the contexts of human factors engineering and knowledge engineering. In addition, he provides us with an example of how cognitive engineering can be applied in a real-world situation.

In 1995 the Armstrong Laboratory Human Engineering Division Colloquium Series began its fifth year with Dr. Grant McMillan, from the HE Division's Human Interface Technology Branch, speaking on "Brain-Actuated Control." Grant was kind enough to provide a synopsis of his presentation for us and I also had an opportunity to chat with him about his research. Edited excerpts from that conversation follow his synopsis.

Continuing the series on CSERIAC Technical Area Tasks (TATs), CSERIAC Senior Design Engineer Steve Harper has written about his project with the U.S. Air Force National Air Intelligence Center (NAIC). Steve discusses how CSERIAC can apply state-of-the-art technology through the use of tools such as the FARO Arm® to perform anthropometric analysis of various crew stations.

One of CSERIAC's ongoing tasks is to support the Department of Defense Human Factors Engineering Technical Avisory Group (DOD HFE TAG) in the operation of their semi-annual meetings. If you have never heard of this organization, you should know that it was formed 18 years ago to provide a forum for coordinating and communicating research and development at the working level among the military services and other Government agencies involved in human factors engineering activities. The most recent meeting was held 6-9 November in

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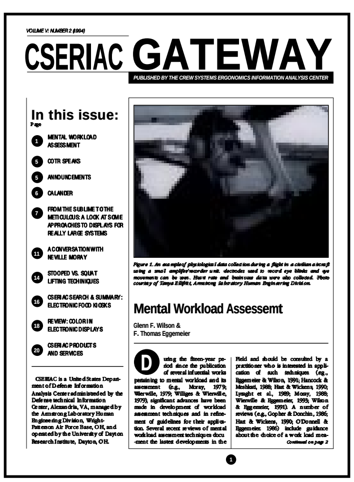
VOLUME V: NUMBER 2 (1994)

CSERIAC GATEWAY

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Figure 1. An example of physiological data collection during a flight in a civilian aircraft using a small amplifer/recorder unit. electrodes used to record eye blinks and eye movements can be seen. Heart rate and brainwave data were also collected. Photo courtesy of Tanya Ellifritt, Armstrong Laboratory Human Engineering Division.

Mental Workload Assessemt

Glenn F. Wilson & F. Thomas Eggemeier

During the fifteen-year period since the publication of several infuential works pertaining to mental workload and its assessment (e.g., Moray, 1979; Wierwille, 1979; Williges & Wierwille, 1979), significant advances have been made in development of workload assessment techniques and in refinement of guidelines for their application. Several recent reviews of mental workload assesment techniques docu-ment the lastest developments in the Field and should be consulted by a practitioner who is interested in application of such techniques (e.g., Eggemeier & Wilson, 1991; Hancock & Meshkati, 1988; Hart & Wickens, 1990; Lysaght et al., 1989; Moray, 1988; Wierwille & Eggemeier, 1993; Wilson & Eggemeier, 1991). A number of reviews (e.g., Gopher & Donchin, 1986; Hart & Wickens, 1990; O'Donnell & Eggemeier. 1986) include guidance about the choice of a work load mea-

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CSERIAC Gateway (Vol. V No. 2, 1994)

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Calendar

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29th Annual Human Factors in Transportation Workshop in conjunction with the 75th Annual Meeting of the Transportation Research Board. Contact Richard F. Pain at (202) 334-2964, fax (202) 334-2003. Email: rpain@nas.edu Or write Transportation Research Board, 2101 Constitution Ave, NW, Washington, DC 20418.

January 8-10, 1996
Orlando, FL, USA
Using Ergonomic Fundamentals to Analyze and Design Jobs, Work Methods, and Workstations Workshop offered by the College of Engineering, University of Wisconsin. Contact Engineering Registration, The Wisconsin Center, 702 Langdon Street, Madison, WI 53706. (800) 442-4214 or (608) 265-3448, fax (800) 462-0876 or (608) 262-1299.

January 10-12, 1996
Orlando, FL, USA
Advanced Ergonomics Application Workshop offered by the College of Engineering, University of Wisconsin. Contact Engineering Registration, The Wisconsin Center, 702 Langdon Street, Madison, WI 53706. (800) 442-4214 or (608) 265-3448, fax (800) 462-0876 or (608) 262-1299.

February 11-16, 1996
Fremantle, Western Australia
2nd International Conference on Fatigue and Transportation: Education, Engineering, and Enforcement Solutions. Contact Laurence R. Hartley, Dept. of Psychology, Murdoch University, Western Australia 6150. +61 9 360 2398, fax +61 9 310 9611. Email: hartley@socs.murdoch.edu.au

March 12-15, 1996
Ann Arbor, MI, USA
Industrial Hygiene Comprehensive Review. Contact Patricia J. Cottrell, University of Michigan Center for Occupational Health and Safety Engineering, 1205 Beal, 174 IOE Building, Ann Arbor, MI 48109-2117. (313) 936-0148, fax (313) 764-3451.

March 29-31, 1996
Dayton, OH, USA
15th Southern Biomedical Engineering Conference. Hosted by the University of Dayton, Wright State University, and Armstrong Laboratory. Co-sponsored by IEEE/Engineering in Medicine & Biology Society and the Whitaker Foundation. Contact Dr. Praphulla K. Bajpai, Conference Chair, Department of Biology, University of Dayton, 300 College Park, Dayton, OH 45469-2320. (513) 229-2135, fax (513) 229-2021. Email: pbajpai@delta.cs.wright.edu

April 10-12, 1996
Leicester, United Kingdom
1996 Annual Conference of the Ergonomics Society to be held at the University of Leicester. Contact the Conference Manager, The Ergonomics Society, Devonshire House, Devonshire Square, Loughborough, Leicestershire LE11 3DW, UK. Telephone and fax +44 509 234904.

April 14-18, 1996
Vancouver, British Columbia, Canada
CHI 96. Conference on Human Factors in Computing Systems. Contact Deborah Compere, CHI 96 Conference Administrator, Conference and Logistics Consultants, 703 Giddings Ave., Suite U-3, Annapolis, MD 21401. (410) 263-5382, fax (410) 267-0332. Email: chi96-office@sigchi.acm.org

April 22-24, 1996
Madison, WI, USA
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May 12-15, 1996
Palo Alto, CA, USA
ErgoCon '96. Silicon Valley Ergonomics Conference & Exposition. Contact Abbas Moallem, ErgoCon '96 Conference Chair, Silicon Valley Ergonomics Institute, San Jose State University, One Washington Square, San Jose, CA 95192-0180. (408) 924-4132, fax (408) 924-4153. Email: amoallem@isc.sjsu.edu. World Wide Web: http://www-engr.sjsu.edu/ergocon96/

May 12-17, 1996
San Diego, CA, USA
SID '96. Society for Information Display International Symposium, Seminar, and Exhibition. Contact Terence J. Nelson, SID '96 Conference Chair, Bellcore, 445 South Street, M/S 2L241, Morristown, NJ 07962. (201) 829-4865, fax (201) 829-5885. Email: tnelson@faline.bellcore.com

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Monterey, California. The DOD HFE TAG has a new World Wide Web Home Page maintained by our sister organization, MATRIS (Manpower and Training Research Information System). You can learn more about the HFE TAG by pointing your Web browser to the following URL address:
http://dticam.dtic.dla.mil/www/hftag/hftag.html

We are considering publishing an article about the HFE TAG in a future edition of *Gateway*. In the meantime, check out their Home Page.

Reuben "Lew" Hann, Ph.D., is the Contracting Officer's Technical Representative (COTR) who serves as the Government Manager for the CSERIAC Program.

Armstrong Laboratory Human Engineering Division Colloquium Series

Brain-Actuated Control: Thinking Ahead to "Firefox"

Grant McMillan

Editor's note: Following is a synopsis of a presentation by Dr. Grant McMillan, Armstrong Laboratory Human Engineering Division, as the first speaker in the 1995 Armstrong Laboratory Human Engineering Division Colloquium Series: Human-Technology Integration. This synopsis was prepared by Dr. McMillan. JAL

In the 1982 film "Firefox," Clint Eastwood piloted a stolen Russian fighter with thought-controlled weapons. His challenge was to "think Russian" when engaging this system. The human imagination has long been intrigued by the notion that the brain might achieve direct control over objects and events in the physical world. Only recently has this idea received serious scientific and engineering attention. This colloquium presentation provided an overview of electroencephalographic (EEG)-based control and its potential role in future military and civilian systems. Two approaches characterize most of the current work in this area:

- Computer-based recognition of the EEG patterns normally associated with specific movements, utterances, or mental states, and the use of these patterns as control signals.

- Training a human operator to produce specific EEG patterns and the use of these patterns as control signals. Figure 1 depicts the basic components of this type of system.

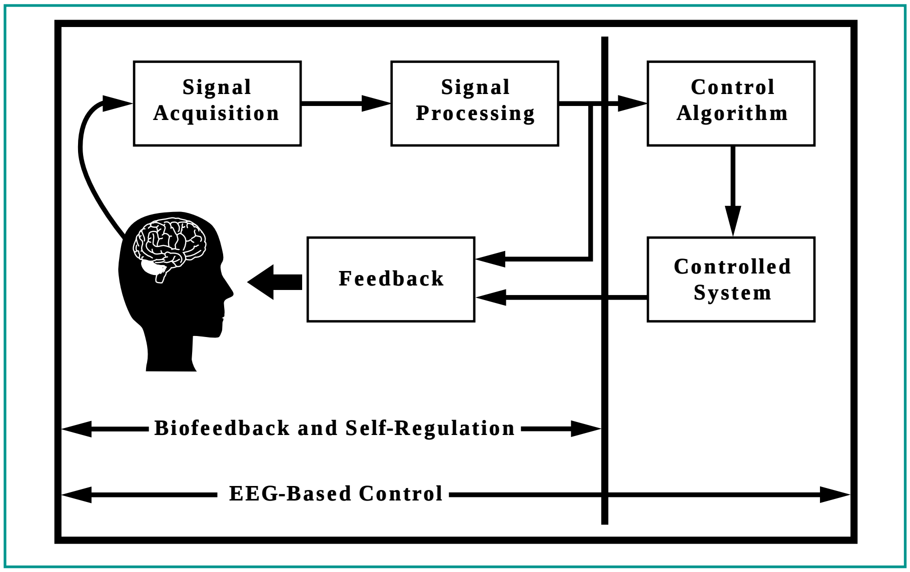

Figure 1. Basic elements of an EEG-based control system.

Pfurtscheller and his colleagues at the Graz University of Technology in Austria are pursuing the first approach. Neural networks are used to recognize the alpha- and gamma-band EEG patterns that precede finger, toe, and tongue movements. Their system has achieved 89 percent accuracy, for example, in predicting right versus left hand button presses. Pfurtscheller's work is most like the popular notion of thought-based control. When fully developed, it may represent the most natural form of a direct brain interface. However, no current system is capable of true thought or intent recognition.

More complex control applications have been demonstrated with the second approach, despite the fact that it requires a training investment on the part of the user. Wolpaw and his colleagues at the Wadsworth Center for Laboratories and Research in New York have developed an EEG-based system for controlling the position of a cursor on a computer monitor. Their method is based on self-regulation of the amplitude of a sensori-motor rhythm known as "mu." At the Armstrong Laboratory, Dr. McMillan and his colleagues have demonstrated a system based on self-regulation of the visual cortical response to a flickering light incorporated into the user's task display. By learning to regulate the amplitude of their steady-state visual evoked response, users have controlled the roll-axis motion of a simple flight simulator (see Fig. 2), a neuromuscular stimulator designed to exercise paralyzed limbs, and other computer-based tasks. In both laboratories, EEG-based control has been observed after as little as five hours of training. In addition, learning to control EEG patterns does not require any unique skills or individual characteristics. The learning process appears to mimic the development of conventional motor skills.

EEG-based control systems can be implemented with commercially available biological signal amplifiers and inexpensive personal computer systems. Size and cost are not limiting factors in their application. Although direct brain interfaces may not be optimal for primary aircraft control, they can provide an alternative means to control multifunction displays, weapons, radar, and communications systems. Perhaps it is no coincidence that thought control performed this function in "Firefox." There may be a high payoff for incorporating EEG-based control in the head-mounted display systems being developed for certain applications. For example, head-mounted displays are being designed to provide on-line technical information to maintenance technicians. They are also being considered for space operations. Since maintenance operations often take place in high-noise environments, voice control may be difficult or impossible. An EEG-based control system would allow technicians to interact with the information display while keeping their hands dedicated to the maintenance task.

Similar applications are possible in civilian aviation and industrial environments. In addition, EEG-based applications could provide significant assistance to persons with physical disabilities. The rapid progress made over the past five years suggests that direct brain interfaces will play a role in many future home, entertainment, transportation, and military systems, as well.

Recommended Reading

Calhoun, G. L., McMillan, G. R., Morton, P. E., Middendorf, M. S., Schnurer, J. H., Ingle, D. F., Glaser, R. M., & Figoni, S. F. (1995). Functional electrical stimulator control with a direct brain interface. *Proceedings of the RESNA 18th Annual Conference*, 696-698.

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Pfurtscheller, G., Flotzinger, D., & Neuper, C. (1994). Differentiation between finger, toe and tongue movement in man based on 40 Hz EEG. *Electroencephalography and Clinical Neurophysiology*, *90*, 456-460.

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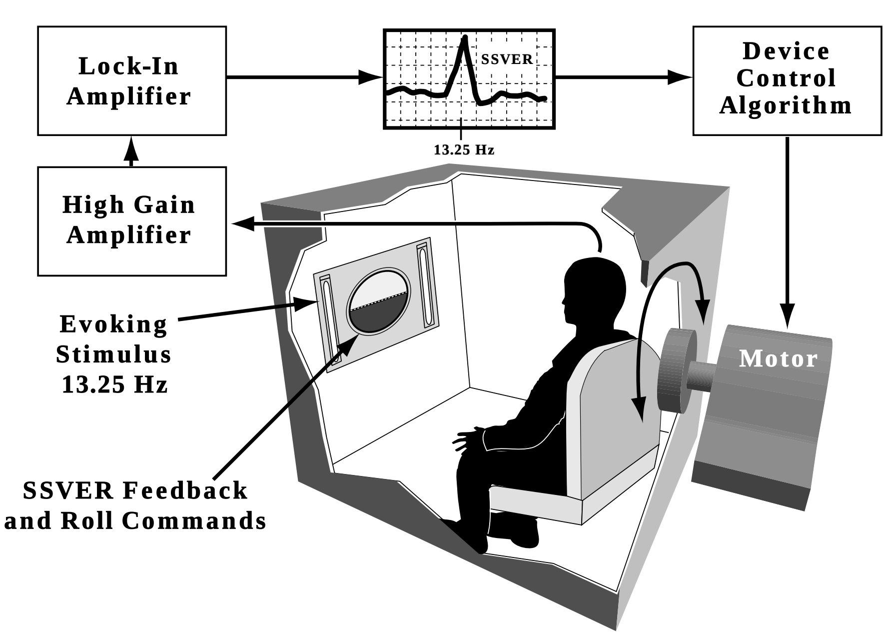

Figure 2. EEG-based control of the roll position of a flight simulator.

Request for Topics For State-of-the-Art Reports (SOARS)

CSERIAC makes every effort to be sensitive to the needs of its users. Therefore, we are asking you to suggest possible topics for future SOARS that would be of value to the Human Factors/Ergonomics community. Previous SOARs have included *Hypertext: Prospects and Problems for Crew System Design* by Robert J. Glushko, and *Three Dimensional Displays: Perception, Implication, Applications* by Christopher D. Wickens, Steven Todd, & Karen Seidler. Your input would be greatly appreciated.

Send your suggestions and other replies to:

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Armstrong Laboratory Human Engineering Division Colloquium Series

A Conversation with Grant McMillan

Reuben L. Hann

Editor's note: Following is an edited transcript of a conversation with Dr. Grant McMillan, Armstrong Laboratory Human Engineering Division. He spoke on "Brain Actuated Control: Thinking Ahead to 'Firefox'" as the first speaker of the 1995 Armstrong Laboratory Human Engineering Division Colloquium Series: Human-Technology Integration. The interviewer was Dr. Lew Hann, CSERIAC COTR. JAL

CSERIAC: In your opening remarks you talked about the movie "Firefox." It featured a Russian fighter plane which used thought-controlled weapons. This, of course, was fiction, but with the research you and others have been involved in, it looks as though we are getting closer to real systems with this ability.

Dr. McMillan: We're not there yet, but there has been tremendous progress in the area of EEG-based control in the past five years. If you think about "Firefox" you will recall that the pilot did not operate the flight controls with thought; he was doing discrete tasks, like selecting the type of weapon to be used and giving the command to fire it. These types of tasks are the most suitable for EEG-based control and are, in fact, the kinds of applications we are looking at in our laboratory.

The one thing they did in "Firefox" which I believe an Air Force pilot would not accept was the use of thought to fire the weapon. I think our pilots would prefer to give that command with a more conventional manual trigger system. But the process of selecting the weapon, arming it, or changing a radio frequency or radar setting, those kinds of discrete tasks, can be accomplished with EEG-based control.

CSERIAC: You pointed out that brain control of external events is not really that new.

Dr. McMillan: That's right. The heritage of EEG-based control comes out of biofeedback, which is teaching people to develop the control of certain biological signals or events in their body. There has been a long history of research showing that people can, for example, change their blood pressure or skin temperature. The key factor is making the relevant biological signal observable to them, letting them actually see or hear it. Similarly, in training EEG control, that's a key element; you have to give them some sort of display of their EEG signals. In this way, they can, with repeated attempts, gradually get control of the desired brain activity. This is where some of the demystification of brain control is taking place: We are letting people observe their EEG activity, and when they can observe it, they can control it.

CSERIAC: Once they have learned to control the activity, do they still need to have feedback, or can you wean them from dependency on it?

Dr. McMillan: That's an open question. We are actually looking at that in an experiment right now, where we are training one group with very clear biofeedback, and another group where they are not seeing the EEG response directly. When this group raises the EEG response above a set threshold, they see the screen cycling through the weapons selection menu and the cycling process stops if they go below the threshold.

What we do know, from some other work going on, is that if the task response to EEG changes, such as cursor motion, is very timely, it appears that that feedback is sufficient. If the task response is delayed several seconds beyond the EEG change, then it appears that direct biofeedback is necessary.

CSERIAC: Have you noticed population differences regarding how quickly a person learns to control the EEG?

Dr. McMillan: In formal experiments and less structured settings we have trained about 20 or 30 persons, to use EEG-based control. We have never encountered a person who absolutely could not learn to control the EEG to some extent. Usually, within an hour of training they will start to develop some control. They may not be sure exactly how they did it, but they see that they can produce a change. Then over the next four or five hours that control typically becomes fairly reliable.

Clearly there are individual differences. Some people learn it

> **"We have never encountered a person who absolutely could not learn to control the EEG to some extent."**

more rapidly than others, but we don't have any strong demographic characteristics that we can point to. It appears that people who have good attentional control, who can focus well, who have confidence that they can do it, seem to learn more rapidly than others. But this is not based on any scientific sampling. The other thing we and others have noticed is that learning EEG control is very much like learning other complex motor skills; it does not appear to be a unique kind of learning. That is, early in the process, people will try different strategies. They will try to think about different things; they'll try relaxation or tensing, and other such techniques. As they get better at it, they seem less able to verbalize what is working for them. This is true of other kinds of skills. As you learn to hit a golf ball or strike a tennis ball cleanly, you initially think through each step of the action, but eventually it becomes automatic and you don't think about it at all.

CSERIAC: Let's discuss potential applications for a moment. We have been talking so far about military applications, but I assume there are other areas where this evolving technology might be used.

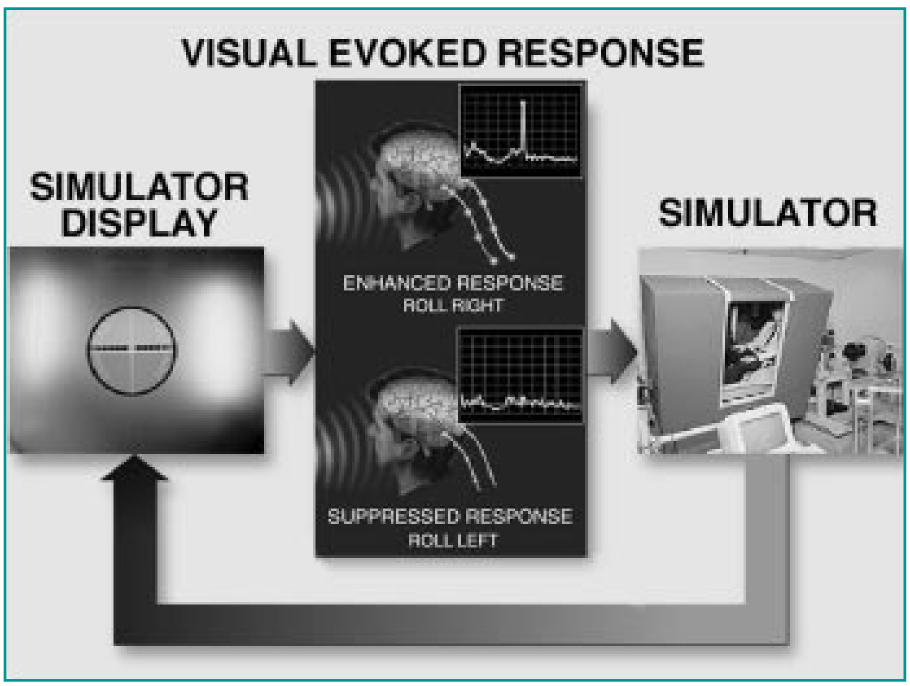
Dr. McMillan: Absolutely. I think the nearest-term application is as an alternative control technology for people with disabilities. We and other researchers have already demonstrated the ability to select icons or menus or move a cursor around on a computer display. Although it takes some training investment and the learning process would involve some errors, this could be very acceptable to someone who has major constraints on the ways they can interact with their environment, such as a quadriplegic.

There are some other industrial applications, such as the use of head-mounted displays by maintenance technicians. Their hands are occupied, so an alternative method for controlling the information on the display

Continued on page 13

Scenes from the Armstrong Laboratory Human Engineering Division Colloquium Series:

Dr. Grant McMillan, Armstrong Laboratory, discusses EEG-based control with some guests following his lecture. Photo by Larry Burgess, University of Dayton.



This vu-graph used by Dr. McMillan shows how flight simulator roll-axis motion can be controlled using the steady-state visual evoked response. Enhanced responses to the modulated light located on each side of the task display produce motion to the right, while suppressed responses produce motion to the left. A series of roll angle commands are presented on the task display to test operator performance.

CSERIAC Technical Area Tasks

National Air Intelligence Center: Human Factors Analysis of Crew Stations

Steve Harper

CSERIAC's ability to respond to a customer's needs through a Technical Area Task has been demonstrated in previous issues of *Gateway* (Vol. VI, Nos. 1, 3, & 4) and this article represents the fourth in that series.

Since its inception in 1988, CSERIAC has been involved in solving cockpit design problems. This expertise was sought out by the Human Systems Technology Branch of the National Air Intelligence Center (NAIC) to identify key methods and software tools for conducting quantitative assessments of crew stations.

To facilitate meeting NAIC's objectives, CSERIAC conducted an extensive search of literature and Internet resources on the topics of task analysis, workload, human modeling and simulation, and related subtopics. Analysis of these search results was documented in a Review & Analysis, one of CSERIAC's technical inquiry services (see *Gateway*, Vol. V, No. 3 for details on a Review & Analysis). This document is being used to identify candidate tools that appear to be capable of providing the quantitative analyses required by NAIC.

CSERIAC is currently receiving demonstration copies of human performance assessment software for evaluation. The evaluation of these workload analysis and human modeling and simulation tools will be bounded by NAIC's unique requirements. Their mission is to attempt to derive the human factors attributes and their operational implications from a system about which only physical attributes may be known. This challenge is a classic example of applying human factors principles in reverse. Instead of using human factors methods throughout a design process in an effort to improve human-system performance, the tools of the human factors analyst are applied to an operational sytem to derive an appreciation of its performance capabilities and limitations.

Geometry data collection methods are also being explored. CSERIAC, through its affiliation with Armstrong Laboratory, is exploring the use of a coordinate measurement machine (CMM) for collecting cockpit geometry data and generating a representative computer-aided design (CAD) model. The CMM being used is the FARO Arm® developed by FARO Technologies, Inc. in Lake Mary, Florida (see Figs. 1 & 2). This is an integrated system consisting of a sophisticated data collection arm (the model owned by Armstrong Lab is accurate to 0.0012 in.) and a portable laptop computer which contains the AUTOCAD® CAD software and the AnthroCam™ modeling software. CSERIAC recently created a CAD model of the cockpit of a U-2 aircraft to demonstrate the feasi-

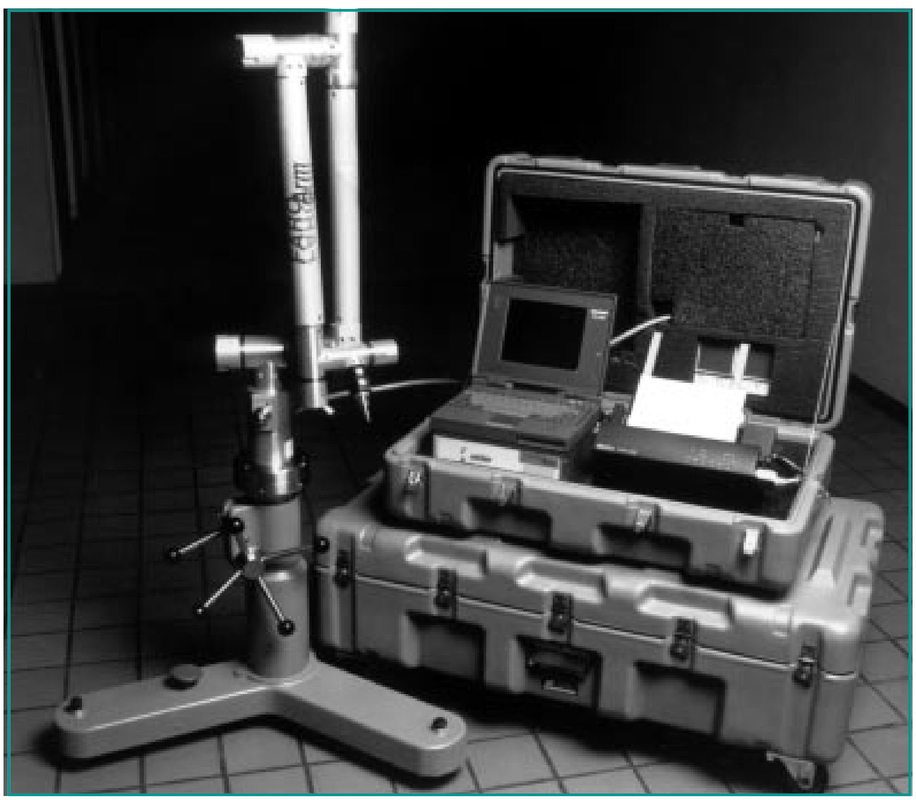


Figure 1. The FARO Arm® developed by FARO Technologies, Inc., Lake Mary, FL. Photo courtesy of FARO, Inc.

bility of using the FAROArm® to model aircraft cockpits. The ability to quickly create a CAD model of a work station is a critical element in conducting human performance analysis. The results of the U-2 demonstration project will be useful in determining the ability of the FAROArm® to meet NAIC's human factors analysis requirements.

This task was initiated as a subscription account by NAIC, allowing CSERIAC to work closely with the customer to identify those areas needing attention to ensure a successful approach to their unique human factors analysis activities. Analyzing the human factors attributes of a system about which only physical attributes are known is the challenge faced by NAIC's human factors analysts. CSERIAC is assisting the NAIC analysts in solving this unique human factors problem by extensively researching literature and Internet sources, documenting and integrating the results, and providing the expertise to evaluate candidate solutions. ●

Steve Harper is a Senior Design Engineer with CSERIAC.

Mailing Address

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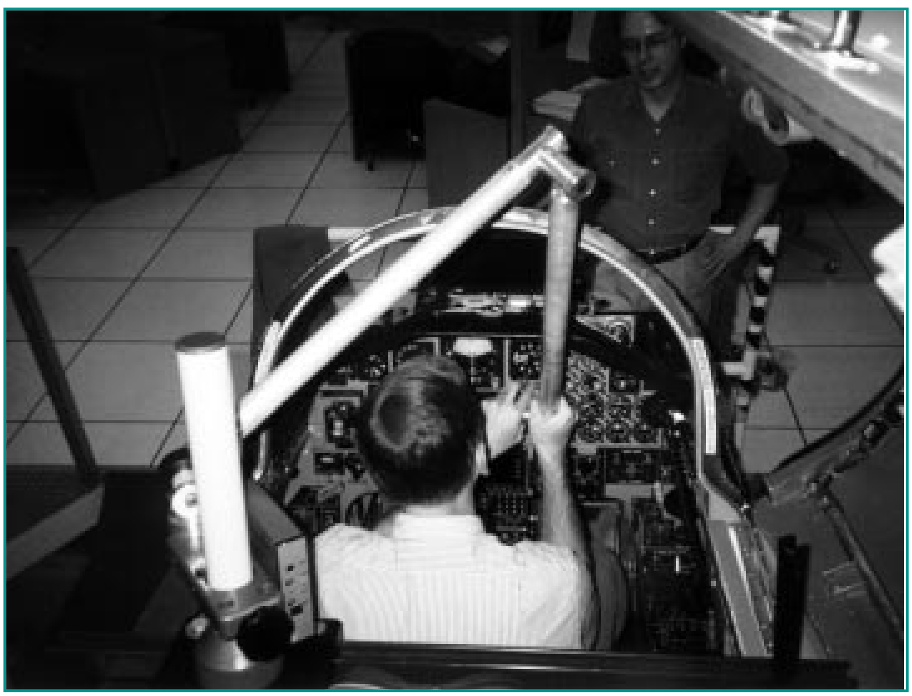

Figure 2. The FARO Arm® being used to assess the human factors attributes of a T-38 cockpit.

Continued from page 11

is needed. Voice-recognition is one candidate, but what about working in a high-noise environment? Audio-based techniques are not very effective there; the EEG-based control might be the answer in such situations. Similarly, head-mounted displays being considered for surgeons in the hospital operating room might benefit from EEG-based control. Although high ambient noise is not a problem in this setting, there is a very important continuous verbal communication between surgeon and operating assistants. Verbal commands for control of a display might disrupt this critical ongoing spoken interaction. Using EEG-controlled displays could provide a non-interfering solution for such situations.

CSERIAC: Are there any other comments you would like to make?

Dr. McMillan: Yes. I believe we tend to focus on alternative control technologies solely as a substitute for conventional controls. A much more powerful approach would be to integrate these technologies, so that the user has a variety of techniques for interacting with systems. The idea is to let the operator choose EEG, voice, gesture or manual inputs in any combination, as appropriate. Even more exciting is the possibility that as intent-recognition approaches become more powerful, these inputs may be used not only as controls but as a means to monitor the user's cognitive state and determine that he or she wants to take some specific action, needs information, or is overloaded in a task. Here the system would passively observe the users and attempt to serve as an intelligent assistant in their work. In this scenario, alternative control technology provides the tools for a more natural dialogue between the system and the user. Although we are a long way from this goal, I believe that this is where these technologies will provide the highest payoff. ●

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■ BRAIN-ACTUATED CONTROL: THINKING AHEAD TO "FIREFOX"
■ A CONVERSATION WITH GRANT McMILLAN
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CSERIAC's objective is to acquire, analyze, and disseminate timely information on crew system ergonomics (CSE). The domain of CSE includes scientific and technical knowledge and data concerning human characteristics, abilities, limitations, physiological needs, performance, body dimensions, biomechanical dynamics, strength, and tolerances. It also encompasses engineering and design data concerning equipment intended to be used, operated, or controlled by crew members.

CSERIAC's principal products and services include:

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CSERIAC Gateway is published and distributed free of charge by the Crew System Ergonomics Information Analysis Center (CSERIAC). *Editor:* Jeffrey A. Landis; *Copy Editor:* R. Anita Cochran; *Technical Reviewers:* Dr. Ron Schopper & Dr. Janet E. Lincoln *Editorial Assistant:* Joel M. Michael; *llustrator & Layout Artist:* Ronald T. Acklin.