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CSERIAC GATEWAY

PUBLISHED BY THE CREW SYSTEM ERGONOMICS INFORMATION ANALYSIS CENTER

In this issue:

CSERIAC is a United States Department of Defense information analysis center hosted by the Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio, and operated by the University of Dayton Research Institute.

Figure 1. Cockpit of an Airbus A320

Cognitive Science In The Cockpit

Donald A. Norman

Commercial Aviation Conflicting Images

Commercial aviation is a strange and wondrous place where perceived images sometimes conflict with reality. The image is of a heroic, skilled adventurer, successfully navigating a crippled aircraft through storm, fire, and unexpected adversity. Images of Lindberg flying alone over the Atlantic, or World War I fighter pilots in open cockpits with helmet, goggles, and scarf still come to mind.

The reality is that the commercial aviation pilot of today is a manager and supervisor, not a daredevil pilot. Today's flight crew must be well schooled in the rules, regulations, and procedures of modern aviation. They are not permitted to deviate from assigned boundaries, and on the whole, if they do their job properly, they will lead dull and uneventful lives. The modern flight deck is heavily automated (see Fig. 1), and multiple color computer screens show maps, instrument readings, and even procedures. The flight crew must act as a team, coordinating their actions with each other, with the Air Traffic Control System, and in accordance with company and federal policies. Pilots spend much of their time studying the vast array of regulations and procedures and being tested and observed in the classroom, in the simulator, and in actual flight. Economics and reliability dominate.

The conflict between image and reality leads to a number of problems.

Continued on page 2

Procedures, flight instruments, and regulations are still guided more by instincts, anecdotes, and reactions to individual incidents than by systematic, scientific analysis of the issues. Have a major difficulty in one flight, and the cure is to add yet another regulation or another training requirement, a "seat-of-the-pants" mentality of how to correct for errant behavior. The aviation system is ill-served by these approaches. The fact is that it is time to do a systematic, scientific analysis of the entire role of the flight crew, the procedures, the instrumentation, the communication, and to redesign the system accordingly, probably from the ground up (pun intended).

The Need for Cognitive Science in the Cockpit

I see little evidence that anyone has systematically and scientifically analyzed the role of the modern flight crew and designed the cockpit, instrumentation, and procedures around that role. Even the comfort of the flight crew is ignored. Only recently have decent places to hold coffee cups emerged, and good writing areas, working areas for the manuals and flight charts do not exist. The lighting and design of the panels seem like an afterthought, so much so that a standard item of equipment for a flight crew is a flashlight. If comfort is ignored, think how badly mental functioning must be treated.

Consider that many flight crews carry as standard equipment such advanced cognitive tools as a roll of tape, Post-it™ notes, and an empty coffee cup, to be used as reminders on the instruments and controls. The empty coffee cup is actually quite effective when placed upside down over the throttle or flap handles to remind the pilots that some special condition applies to future use of these controls.

The real problem, as I see it, is that the many procedures and requirements have grown up independently of one another. Each may actually be the result of study and thought, but the total package is contradictory. It is time to start over and consider the entire package.

The Role of Automation

Although automation is often identified as a major culprit in industrial accidents, I propose that the problems result from inappropriate application, not the commonly blamed culprit of "over-automation." According to this view, operations would be improved either with a more appropriate form of automation or by removing some existing automation. Current automatic systems have an intermediate level of intelligence that tends to maximize difficulties.

The problem is that the operations under normal operating conditions are performed appropriately, but there is inadequate feedback and interaction with the humans who must control the overall conduct of the task. When the situations exceed the capabilities of the automatic equipment, then the inadequate feedback leads to difficulties for the human controllers.

Automation is at an intermediate level of intelligence, powerful enough to take over control that used to be done by people, but not powerful enough to handle all abnormalities. Moreover, its level of intelligence is insufficient to provide the continual, appropriate feedback that occurs naturally among human operators. This is the source of the current difficulties. To solve this problem, the automation should either be made less intelligent or more so, but the current level is quite inappropriate.

This leads to a second point, namely, that in design, it is essential to examine the entire system: the equipment, the crew, the social structure, learning and training, cooperative activity, and the overall goals of the task. Analyses and remedies that look at isolated segments are apt to lead to local, isolated improvements, but they may also create new problems and difficulties at the system level.

The Case of the Loss of Engine Power

In 1985, a China Airlines 747 suffered a slow loss of power from its outer right engine. This would have caused the plane to yaw to the right, but the autopilot compensated, until it finally reached the limit of its compensatory abilities and could no longer keep the plane stable. At that point,

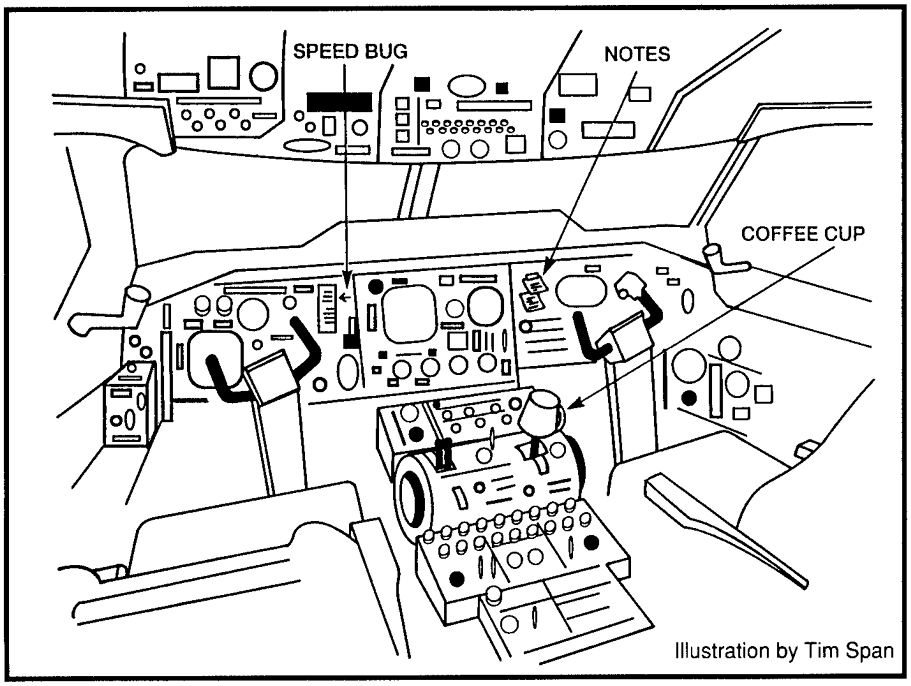


Illustration by Tim Span

Figure 2. Some cognitive aids in the cockpit

the crew did not have enough time to determine the cause of the problem and to take action: the plane rolled and went into a vertical dive of 31,500 feet before it could be recovered. The aircraft was severely damaged and recovery was much in doubt (National Transportation Safety Board, 1986; Wiener, 1988).

The Case of The Fuel Leak

In the China Airlines incident, the crew was unaware of the developing problems. In this next case study, the vigilant second officer noticed one sign of a problem, but failed to detect another. Here is a quotation from the accident report filed with the NASA Aviation Safety Reporting System (Data Report 64441, dated Feb., 1987). (These are voluntary reports, submitted by the people involved.)

> *Shortly after level off at 35,000 ft. . . . the second officer brought to my attention that he was feeding fuel to all 3 engines from the number 2 tank, but was showing a drop in the number 3 tank. I sent the second officer to the cabin to check that side from the window. While he was gone, I noticed that the wheel was cocked to the right and told the first officer who was flying the plane to take the autopilot off and check. When the autopilot was disengaged, the aircraft showed a roll tendency confirming that we actually had an out-of-balance condition. The second officer returned and said we were losing a large amount of fuel with a swirl pattern of fuel running about mid-wing to the tip, as well as a vapor pattern covering the entire portion of the wing from mid-wing to the fuselage. At this point we were about 2000 lbs. out of balance. . . .*

In this example, the second officer (the flight engineer) provided the valuable feedback that something seemed wrong with the fuel balance. The automatic pilot had quietly and efficiently compensated for the resulting weight imbalance, and had the second officer not noted the fuel discrepancy, the situation would not have been noted until much later, perhaps too late.

Suppose the automatic pilot could have signaled the crew that it was starting to compensate the balance more than was usual, or at the least, more than when the autopilot was first engaged. This would have alerted the crew to a potential problem. Technically, this information was available to the crew, because the autopilot controls the aircraft by physically moving the real instruments and controls, in this situation, by rotating the control wheel to maintain balance. This is a subtle cue, however, and it was not noted by either the pilot or the co-pilot (the first officer) until after the second officer had reported the fuel unbalance and had left the cockpit. At the time the second officer commented on the fuel gauge reading, he did not know what the problem was, but his comment alerted the crew.

The Problem Is Lack of Feedback, Not Automation

The culprit is not actually automation, but rather the lack of feedback. The informal chatter that normally accompanies an experienced, socialized crew tends to keep everyone informed of the complete state of the system, allowing for the early detection of anomalies. Were the equipment never to fail, were it capable of handling all possible situations, then the human operator would not be necessary, so the feedback and interaction would similarly not be necessary. Today, in the absence of perfect automation an appropriate design should assume the existence of error, it should continually provide feedback, it should continually interact with operators in an appropriate manner, and it should have a design appropriate for the worst of situations. What is needed is a soft, compliant technology, not a rigid, formal one.

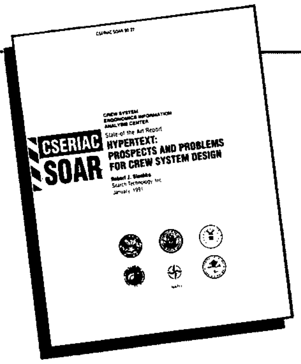
Continued on page 4

State-of-the-Art Report

HYPERTEXT

Prospects and Problems for Crew System Design

Robert J. Glushko
Search Technology



This informative report reviews the state of the art in the important new field of hypertext, an innovative concept for displaying information on computers that uses nonlinear methods for linking related information. Hypertext can significantly improve the accessibility and usability of on-line information for crew system designers and users. The report discusses:

Definitions and historical context: What hypertext is and why it has recently emerged as an important design concept.

Hypertext applications: How hypertext concepts can be applied in crew system design, including on-line presentation of handbooks, standards documents, software manuals, and maintenance aids.

Hypertext design and technology: The elements of hypertext, and software and hardware to support its implementation.

Hypertext development: Practical advice for designing hypertext capabilities into information systems.

The report is 88 pages and includes 17 figures. The cost is $75. To order, contact the CSERIAC Program Office.

Why Is an Empty Coffee Cup One of the Most Powerful Cognitive Aids in the Cockpit?

One of the most widely studied areas within cognitive science is that of human memory and attention. Although the final scientific theories have yet to be developed, there is a considerable body of well-understood phenomena and several approximate theories that can be used to good effect in design (see, for example, the tools in the classic study of Card, Moran, & Newell, 1983). Among the simple lessons are that:

- Working memory has a small capacity, perhaps 5 items;
- The most common errors from working memory result in acoustical confusions (even of visually presented information), losing items, and transposing order;
- Conscious attention can be focussed on only one task at a time, and disruptions of attention (caused by interruptions) are apt to lead to severe degradation of memory and task performance;
- People can make good use of the combination of external and internal information: good design practice, therefore, is to provide external aids to memory;
- People are not very accurate at tasks that require great precision and accuracy or precise memorization;
- People are very good at perceptual tasks, that involve finding similarities (analogies) between one situation and another;
- People are good at creative problem solving.

Unfortunately, more and more of the tasks in the cockpit force people to do just those tasks they are bad at and detract from the ability to do the things they are so good at.

How does the flight crew guard against problems? There are surprisingly few aids. Most of the aids in the cockpit are casual, informal, or invented by the crew in response to their own experiences with error (see Fig. 2). The most common (and effective) cognitive aids in the cockpit are:

- Speed bugs;
- Crew-provided devices: written notes, coffee cups, and tape;
- Checklists.

Checklists are worthy of their own section, but before I turn to them, let me briefly examine speed bugs and crew-provided devices.

Speed bugs. Speed bugs are plastic or metal tabs that can be moved over the airspeed indicator to mark critical settings. These are very valuable cognitive aids, for they transform the task performed by the pilot from memorization of critical air speeds to perceptual analysis: is the airspeed indicator above or below the bug position. Moreover, this transformation of the task is the hallmark of the well-designed artifact. The speed bug is an excellent example of a cockpit aid (see Norman, 1991).

The speed bug is an example of something that started out as an informal aid. Some pilots used to carry grease pencils or tape and make marks on the dials. Today, the speed bugs are built into the equipment and setting them is part of standard procedures. Unfortunately, instrument designers have now gotten so carried away by the device that what used to be a single, easy-to-use tool has now been transformed into as many as five or more bugs set all around the dial. As a result, what was once a memory aid has now become a memory burden. I foresee speed bug errors as pilots confuse one bug with another. And, again, because of the lack of system knowledge, newer computer-displayed airspeed indicators sometimes neglect to include speed bugs or other memory for critical airspeed settings, sending us back to the dark ages of memory overload.

Crew-provided devices. Pilots and crew recognize their own memory deficiencies, especially when subject to interruptions. As a result, they use makeshift devices in the cockpit to act as reminders or signals. In particular, they rely heavily on physical marks. You know, want to remember something, tie a knot around your finger. Want to remember to take your briefcase, prop it against the door so you stumble over it when you go out. Want to remember to turn off the Air Packs before lowering the flaps, place an empty coffee cup over the flap handle. Crude, but effective.

But why hasn't this need been recognized? Why don't we build in devices to help the crew? Instead, we force them to improvise, force them to search the cockpit for coffee cups, or tape, or pieces of paper they can wedge over the desired location.

Checklists

The existence of checklists in aerospace is admission that not all human behavior is perfect, that errors occur, and so, for safety and thoroughness, some items need to be especially "checked" to ensure that they are done properly. If checklists were only used for checks, then items would only be placed on checklists when:

- There is a reasonable likelihood of failure;
- There is high cost for an error.

However, our analyses of aviation checklists indicate that checklists serve multiple functions:

1. As Checks
2. As Triggers
3. For Crew Communication
4. To Satisfy the Legal Department

But why do we need checklists at all? Checklists are not only a sign of human fallibility, they are also a sign that the procedures or equipment design is inappropriate.

Consider a recent incident in which an aircraft took off without lowering its flaps, resulting in a major accident (National Transportation Safety Board, 1988). The "taxi" checklist wasn't done properly. But checklists are supposed to check, not act as "read-and-do" lists, so failure to do the checklist doesn't explain failure to set flaps. And besides, the plane could have taken off without flaps, except that the crew interpreted the symptoms as windshear, so they reacted inappropriately. Why did they interpret the takeoff problems as windshear, given that the symptoms were somewhat different? Well, there was a windshear alert. And (as National Transportation Safety Board member Lauber said), an experienced crew would never consider that they would have failed to set flaps (Lauber, 1989).

And why the failure to set the flaps? The crew was harried. They weren't sure where the taxiway was (they actually missed the assigned one). The runway direction had just been changed. And they didn't get the weather and runway conditions until the taxi itself. They actually did the proper checklist, but were interrupted by Air Traffic Control at a critical moment. Lauber argues the checklist procedure is faulty in not having a specific triggering point. We suspect he is right.

Let me give another example. Figure 3 presents the first five items in the "Before Start" checklist that a major commercial aircraft corporation provides for one of its aircraft.

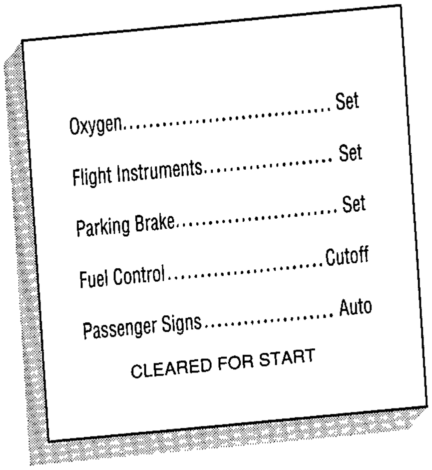
The point of this example is that these five items serve three quite different purposes. The stated aim of the checklist is to check for critical safety items at each stage of flight, but of the five items, only the middle three are relevant to safety at the "Before Start" phase of the trip. The first item, "Oxygen" will not be relevant unless there is some emergency depressurization as the plane exceeds 14,000 feet—some time away. The item "Passenger Signs" is not directly relevant to the safety of the aircraft. Moreover, passenger movement, seatbelts, and smoking behavior are all controlled by the cabin crew anyway; the signs are redundant. The item is added to the list only because of concern that procedures in different airlines might lead the crew to forget this item. This seems more dictated by legal worries than by safety. The problem is that as checklists become longer, it becomes a greater burden for the cockpit crew. Worse, as more and more items are placed on the list that do not seem to be of direct relevance, the crew is more likely to rush through it or otherwise not take it as seriously as they should (see Degani & Wiener, 1990). Again, the point is not to criticize the checklist but to indicate the widely different pressures on the design of procedures coupled with the lack of any firm guidelines.

Human Error—A Way to Avoid the Real Issues

One last point: the prevalence of blaming incidents on human error: the "blame and train" philosophy. Most aviation accidents today are caused by human error, we are told. Or are they? How much of that human error really reflects poor design, which in turn reflects the lack of scientific knowledge in the design process. Do pilots today keep their heads "in the cockpit," reprogramming the automated equipment when they should be flying the plane? Yes. Is the solution more training? No: I strongly suspect that the problem is in the design of the equipment that makes it so difficult to use. From a cognitive engineering viewpoint, the equipment is poorly designed.

Let me illustrate the point with a different example. In 1988, the Soviet Union's Phobos 1 satellite was lost on its way to Mars. Why? According to *Science* magazine, "not long after the launch, a ground controller omitted a single letter in a series of digital commands sent to the spacecraft. And by malignant bad luck, that omission caused the code to be mistranslated in such a way as to trigger the test sequence" (the test sequence was stored in ROM, but was intended to be used only during checkout of the spacecraft while on the ground; Waldrop, 1989). Phobos went into a tumble from which it never recovered.

This is a typical reaction to the problem—blame the controller for the error and "bad luck" for the result. Why bad luck—why not bad design? Wasn't the problem the design of the command language that allowed such a simple deviant event to have such serious consequences (see Norman, 1990b)?



Oxygen	Set
Flight Instruments	Set
Parking Brake	Set
Fuel Control	Cutoff
Passenger Signs	Auto

CLEARED FOR START

Figure 3. "Before Start" checklist

It is Time for a Change

Cognitive Science — Cognitive Engineering

Cognitive science is the systematic study of mental performance, from the biological basis, to behavioral analysis, and to models of cognition through mathematics, artificial intelligence, and neural networks. The applied side of this discipline is "Cognitive Engineering." Both the theoretical and applied sides of the discipline are relatively new, but much systematic knowledge does exist. Cognitive science has amassed a large body of procedures and techniques, but primarily as theoretical tools.

Human factors has not tended to concentrate upon cognition: instead, it has been more concerned with behavioristic analyses of situations and with design concerns that emphasize physical size, legibility, and controllability. The nature of cognitive problems differs somewhat from that studied within traditional human factors. This emphasis is starting to change, in part because of the influx of new methods and people from the human-computer inter-

Continued on page 6

action field. But these new approaches have had little impact upon aviation.

My major concern is that the lack of any systematic analysis of the human side of aviation has led to numerous problems including the design of instrumentation that does not accommodate the real behavior of pilots. The aerospace community still treats human error as a training or discipline problem, not as a sign of poor design and inappropriate procedures.

Aviation still maintains the myth of the heroic, individualistic pilot. As a result, things are designed by the intuitions of the chief engineers and the chief pilots. Intuition and hunch govern specification. And perhaps worst of all, the aviation community insists that its problems are so unique that lessons learned from other industries do not apply. And even within the industry, lessons from one manufacturer or airline company do not apply to another.

It is time for a change.

Donald Norman is Chair of the Department of Cognitive Science at the University of California, San Diego. His research is supported by a grant from the NASA-Ames Research Center.

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Office of Research and Technology Applications (ORTA)

Wiliam Anderson

The term "technology transfer" includes a range of formal and informal cooperation between federal laboratories and United States businesses, universities, state and local governments, and other federal agencies. The purpose of the transfers is to strengthen the nation's economy by enhancing the application of federal technology and resources to these groups. Product improvement, service efficiencies, improved manufacturing processes, and joint development to address government and private sector needs are its major goals.

The Stevenson-Wydler Technology Innovation Act was passed in 1980. It established the Office of Research and Technology Applications (ORTA) at major federal laboratories, to identify and provide information on federally developed technologies to private industry, universities, state and local governments for use in research and commercialization. ORTA serves as a technology conduit to the outside world.

The major functions of ORTA include:

- Technology application assessment for federal research and design projects to determine their commercial potential.
- Providing information on federally owned or originated products and processes which have potential private or public sector application.
- Cooperation with organizations which link laboratory resources to potential technology users.
- Providing technical assistance to state and local programs to facilitate technology transfer.

The ORTA office located at Wright-Patterson Air Force Base interfaces directly with other well-established technology transfer organizations including (see fig.):

- The Federal Laboratory Consortium (**FLC**) at the national level.
- The Ohio Technology Transfer Organization (**OTTO**) at the state level.
- The Technology Assistance Panel (**TAP**) at the local, Dayton area level.
- The Dayton Area Network (**DATN**) at the local, Dayton area level.
- The Edison Materials Technology Center (**EMTEC**).
- The Center for Artificial Intelligence Applications (**CAIA**).

FLC was institutionalized and funded by the Federal Technology Transfer Act of 1986. It has a charter to move technical information and expertise to industry, small business, universities, and state and local governments. This act also provides financial incentive to encourage federal scientists and engineers to patent, license, and commercialize their research. These incentives include royalty-sharing arrangements

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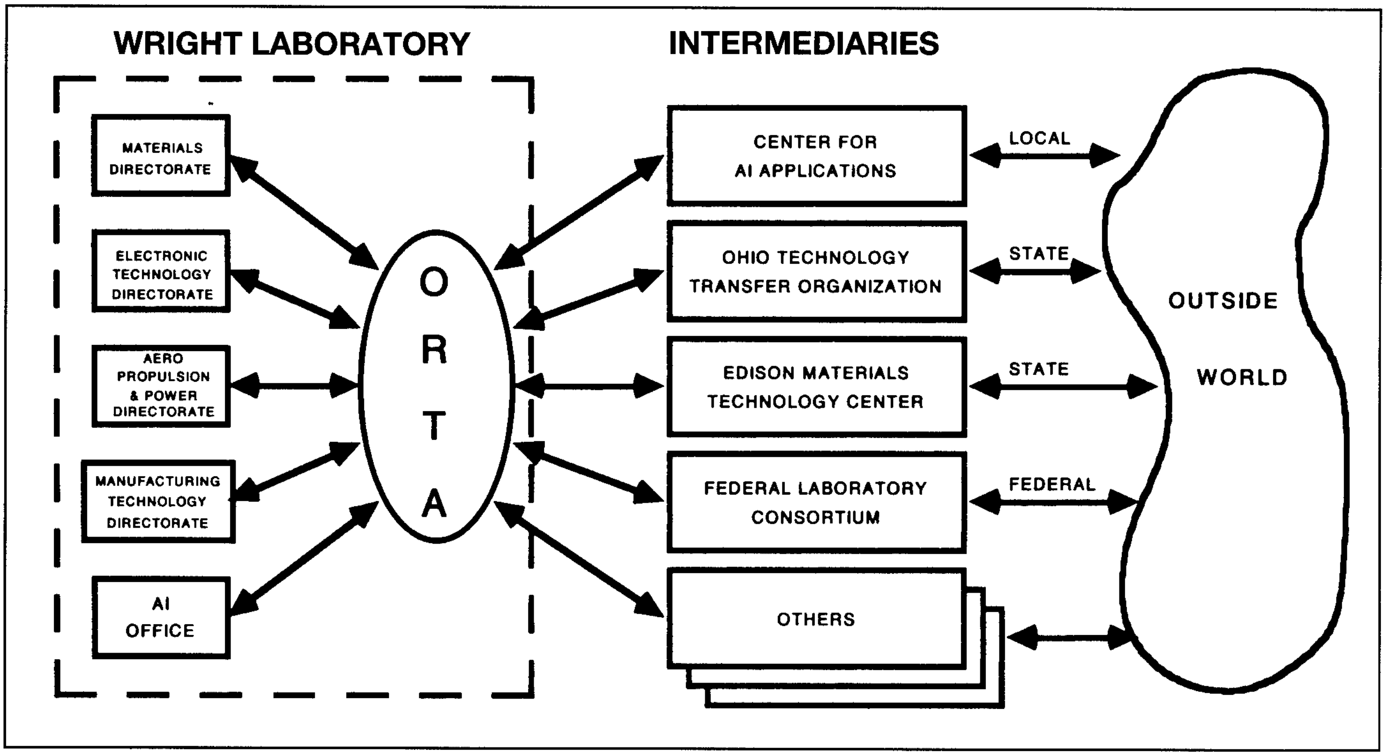


The technology transfer process

GATEWAY

and government waiver of ownership to inventions made with federal funds.

In addition, the Federal Technology Transfer Act of 1986 grants government laboratory directors authority to enter into cooperative research and development agreements (CRDAs) with for-profit corporations, assign patent rights to firms participating in CRDAs, and license technologies while returning licensing royalties. It mandates that at least 15 percent of royalties on federal patents be awarded to federal inventors.

The Technology Transfer Act of 1986 also provided the authority for involvement of ORTA with FLC.

OTTO was created in 1979 by the Ohio State Board of Regents as a network of 28 two-year colleges and universities whose agents work one-on-one with Ohio businesses. The agents are concerned with new business start-up, new product development, adoption of new technologies and productivity. Working closely with other transfer organizations, they transition valuable expertise to Ohio business.

One manufacturer of titanium blades for an aircraft engine was experiencing a high percentage of blades that deviated from the specification at the end of the manufacturing process. This manufacturer contacted the OTTO agent at a local college for help, who in turn, called ORTA at Wright-Patterson AFB. ORTA then contacted personnel in the Air Force Materials Laboratory, who discussed the production procedures with the manufacturer in detail, and helped him identify two changes in his manufacturing process. The company credited the Materials Laboratory with a 75-percent reduction in off-specification parts.

TAP was formed in 1977 to help local governments improve their relationship with the private sector, and to develop marketable products and expanded earnings of area companies. Its membership includes representatives from colleges, companies, school boards, public commissions, county, city, and township governments.

DATN, with a membership of over 100 senior management personnel from local industry, academia, and government, was created to establish a database of high-tech businesses in the Dayton area and to produce synergistic teaming of companies for business expansion. It encourages linkage between government, private industry, high-tech business, and area colleges to improve the community's leadership standing in the high tech area.

EMTEC is a non-profit cooperative of academic, industrial, governmental, and civic organizations. EMTEC helps to solve problems jointly and shares resources in research, development, transfer, and transition of new innovative materials and processing technologies. It focuses on needs identified by member organizations.

CAIA was created to accelerate the application of AI technologies already developed, to promote and expand the AI talent base and nurture its expansion into industry, academia, and government.

As one can see, there are many organizations available to transfer technology and resources to the engineers, designers, and researchers who need them. The common thread linking them is the Office of Research and Technology Applications. ORTA can be reached at (513) 255-2006 or DSN 785-2006, WL/XPT, Wright-Patterson Air Force Base, Ohio 45433.

William Anderson is a Technical Information Specialist for ORTA in the Wright Laboratory, Wright-Patterson Air Force Base, OH . ●

CALENDAR

June 10-14 **Lake Tahoe, NV**

Annual International Industrial Ergonomics and Safety Conference '91, sponsored by the International Foundation for Industrial Ergonomics and Safety Research in cooperation with the University of Louisville and Industrial Commission of Ohio, at Caesar's Tahoe Hotel. Contact W. Karwowski, Dept. of Engineering, Tampere University of Technology, Box 527, SF-33101 Tampere, Finland; +358-31-162-111, fax +358-31-162-034.

July 15-21 **Paris, France**

11th Congress of the International Ergonomics Association. Contact J. Monnier, Secretariat IEA 91, Laboratoire d'Ergonomie et Neurophysiologie du travail, 41, rue Gay-Lussac, F 75005 Paris France; fax (33) 1.47.07.59.01.

August 27-30 **Vancouver, BC, Canada**

24th Annual Conference of the Human Factors Association of Canada (HFAC/ACE) at the Coast Plaza Hotel. Theme: " Ergonomics-Managing Your Environment." Contact HFAC, 6519B Mississauga Rd., Mississauga, Ontario L5N 1A6, Canada; (416) 567-7193.

September 2-6 **San Francisco, CA**

35th Annual Meeting of the Human Factors Society, sponsored by the HFS Bay Area Chapter, at the San Francisco Marriott. Contact HFS Central Office, P.O. Box 1369 Santa Monica, CA 90406; (213) 394-1811 or (213) 394-9793; fax (213)394-2410.

Modeling Human Force Response (A Continuation)

Norm Phillips

In the last GATEWAY we discussed a simple model of the live human, created to replicate the force and moment response of the seated human to an applied spinal +Gz acceleration. The model consists of a particle having a mass equal to that of the total mass of the subject located at the center of gravity of the seated subject and supported by three viscoelastic elements. The elements are located directly beneath the mass and diagonally upward and backward from the mass to attachment locations representative of shoulder strap attachment points.

The capability of the model to replicate measured data was established by computing the vertical force and pitching moment response due to a measured input acceleration and by comparing that with the measured response. Although not emphasized in the previous article, determining the correct measured values from the many data channels of information was not trivial. The measurements result from the efforts of many investigators and facility planners who contributed to several test planning documents. Consequently, it is not surprising that opportunity for misunderstandings occurred. Mentioned in the previous article was the fact that data were measured in five different coordinate systems. This sometimes occurs because one expects "the obvious" to be understood by all. A downward gravitational acceleration may be negative, for example, but it is typically plotted as positive.

With this understanding of the nature of the data, additional research was conducted into the response of a live seated human, subjected to a fore-and-aft acceleration commonly described as a -Gx acceleration.

Many models, available for many years, predict the fore-and-aft force response of the human. Many were developed during the period when the Department of Transportation was formed and when models were necessary for the study of frontal crashes of automobiles. However, these representations tend to be multi-segment models not validated with total force response measurements collected during the testing of live subjects. The fore-and-aft models of today may suffer from the same deficiency.

During studies conducted for the U.S. Air Force's Crew Escape Technologies Program (CREST), data were available for the analysis of fore-and-aft human response. Limited studies indicated that a single-degree-of-freedom model might adequately satisfy the need for a predictive tool. That bit of encouragement was sufficient to initiate research designed to find the best single mass representation and further, to determine whether one model might adequately represent both the spinal and fore-and-aft response of the live seated human subject to either +Gz and/or -Gx translational accelerations.

Following is the methodology used in evolving the models desired. The approach is similar to that discussed in the previous article and some of it may appear repetitious. However, the discussion will be complete in deference to those not having seen the previous article.

The type of data required was found by using the Biodynamics Data Bank at the Armstrong Laboratory (AL; formerly the Harry G. Armstrong Aerospace Medical Research Laboratory, AAMRL). Data collected using live subjects accelerated in the -Gx direction were available from tests conducted under the test plan title of Crew Escape Technologies Restraint Harness Evaluation (CREST RHE). These data were supplemented by a contractor-supplied report on the specifics of the test configuration and data acquisition system. The documents and the data bank entries indicate that 19 subjects were exposed to peak -Gx accelerations of 8 and 10 G for a total of 116 tests, and that the tests were for four types of restraint systems and for acceleration levels that would permit comparison with +Gz tests using similar restraints and subjects.

It was also determined that 52 channels of data were available for analysis and included sled, seat pan, chest, head, thorax, and lumbar accelerations. These measurements were supplemented with shoulder strap loads, lap belt loads, and seat pan loads. High-speed photographic data were recorded and used later. The information indicated that there were no head, shoulder, or seat back forces measured and this was of concern, since it was desired to produce a model validated by measurements which would reflect the total force response of the subject.

Based on the specified criteria, one test was selected from the data bank for rigorous analysis. The subject weighed 167 pounds and had been subjected to a triangular 10 G peak acceleration of 150 milliseconds duration. He had been supported by a standard PCU-15/P harness within a test seat having a seat back tilted at 30 degrees and seat pan tilted upward at 26 degrees. He had been seated with fists resting on thighs and with feet placed upon a teflon surface to prohibit any pre-loading of the system by leg bracing. See Figure 1.

Continued on page 10

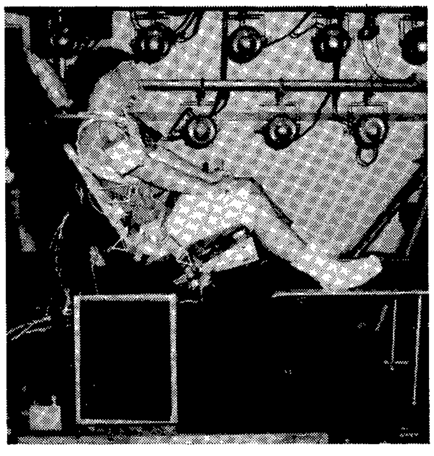


Figure 1. Example of test seat with human subject

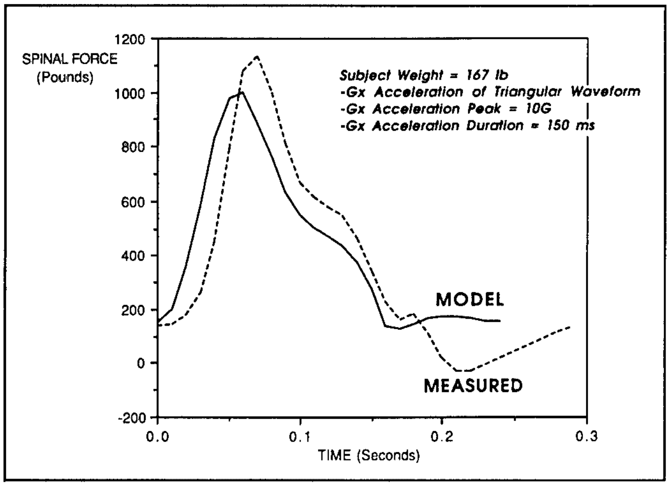


Figure 2. Computed model spinal force response compared with measured spinal force

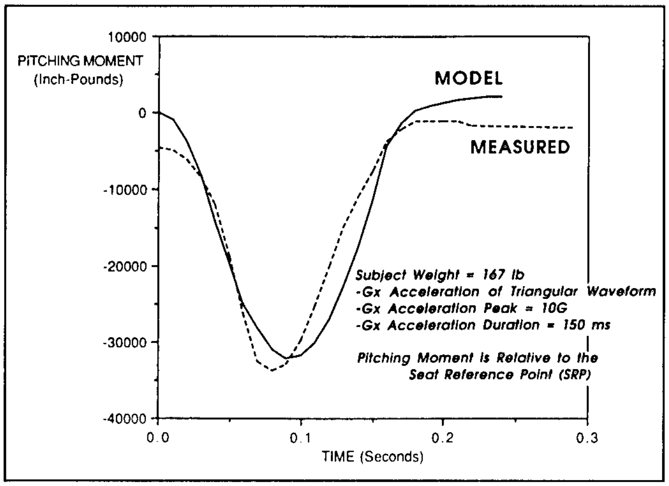


Figure 3. Computed model pitching moment response compared with measured resultant pitching moment

Examination of the data indicated that forces and accelerations were measured in different coordinate systems and that corrections had to be made to generate data in, and orthogonal to, a spinal coordinate system. Once the particulars of the measurement system and the data calibration were understood, the test results were used as input to a digital routine prepared to transform the collected forces into the resultant force and couple acting on the seat. The initial results indicated that a force and moment imbalance existed during the pre-impact phase but not at the post-impact phase of the test. The photographic data indicated that during pre-test the subject was in contact with the uninstrumented seat back. The imbalances measured indicated that a force at shoulder height would explain the difference. Photographic data also indicated that during acceleration the torso separates quickly from the seat back and the feet separate from the floor. Therefore the assumption of no force contribution at the seat back was valid. The measurements taken during the response of the subject were indicative of the total force response desired.

The single-degree-of-freedom model described earlier was used to find the viscoelastic properties of the supporting elements and to establish the attachment locations which would best replicate the measured response. It was desirable to maintain the mass of the model at the correct center of gravity location and to maintain its magnitude at full body mass. The study then varied viscoelastic properties and "shoulder" attachment points. The best fit attained in attempting to satisfy those restrictions is depicted in Figures 2 and 3. The curves are for a model having the same dimensions as the previously reported 9 Hz vertical response model, except for a needed increase in the height of the mass. The mass must be 6 inches higher, 15 inches above the seat reference point (SRP).

The fore-and-aft natural frequency of the model is 3.83 Hz with a damping ratio of 1.20. These are in a coordinate perpendicular to the spinal axis and in the fore-and-aft plane. The vertical response model of the previous article could be compared with another in the literature. A similar comparison for this fore-and-aft representation cannot be made. The figure of the spinal force comparison indicates a phase lag between measured and computed. This could have been easily rectified by the incorporation of a "slack" in the harness, but this was not included. Similarly, a nonlinear stiffness could have improved the match. This was also not included. One purpose of the analysis was to find the simplest linear-elements model possible and incorporate additional complexity only when absolutely necessary.

The fore-and-aft model has a characteristic similar to that of the vertical +Gz model of the previous article. Both have the property of changing their natural frequency toward that of the injury representation during the response. Just as the nonlinear response of the +Gz model tends to create a different natural frequency, one that is softer, the -Gx model tends to create one that is stiffer. Current injury predictors such as the Dynamic Response Index, and its three-dimensional extension, the injury ellipsoid, would indicate that those changes are in agreement with the differences between the force and injury prediction models.

The frequency characteristics of this model in the spinal direction are an undamped natural frequency of 8.27 Hz and a damping ratio of 1.29. From the previous article, the model found to replicate vertical +Gz spinal response was one with an undamped natural frequency of 9.14 Hz and with a damping ratio of 0.48. This suggested that the fore-and-aft model might provide acceptable predicted response to vertical +Gz accelerations. This was investigated, and the plots for the fore-and-aft model response calculated using the vertical accelerations of the

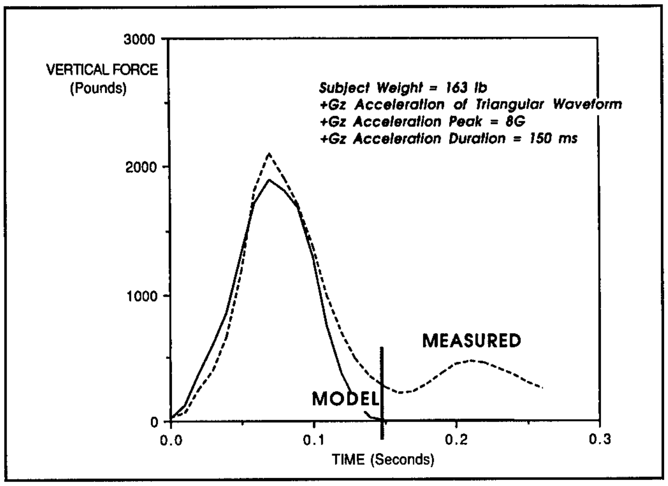


Figure 4. Computed vertical force response of -Gx model using +Gz acceleration compared with measured vertical force

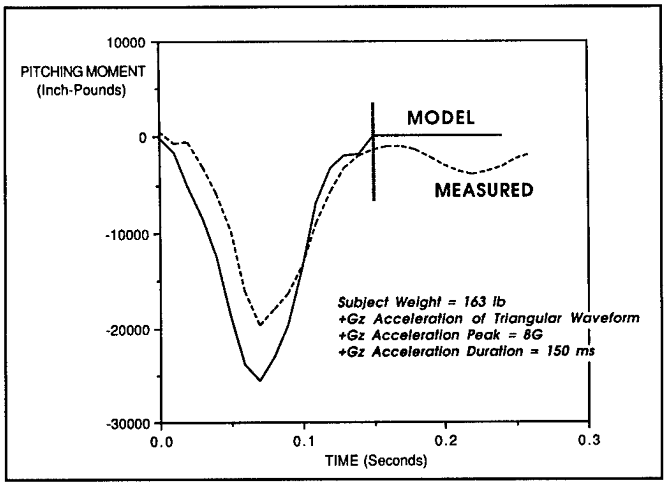


Figure 5. Computed pitching moment response of -Gx model using +Gz acceleration compared with measured pitching moment

previous paper are presented in Figures 4 and 5. The model used for computing the response was found from -Gx data of a triangular waveform acceleration. The spinal axis was 30 degrees aft of the vertical. The response is calculated for a vertical acceleration of approximately the same waveform directed along the spinal axis.

The figures indicate that the calculated spinal force and the pitching moment are similar to the measured values. The spinal force comparison is better than that of the pitching moment, as would be expected, since the spinal natural frequencies of both models are similar and the fore-and-aft natural frequencies differ by a factor of nearly two. The vertical line shown on each figure indicates the time when the particle would intersect the plane of the seat back. If the models presented are to be used in calculating the motion or trajectory of a vehicle supporting the aircrew member, practical limits on the motion of the particle will probably have to be established.

During the process of evolving an acceptable model, it is always possible to find a better representation for the specific test data being examined. Theoretically, for a linear system, it would be possible to find a transfer function with characteristics that would produce the measured output for the measured input. However, for practical applications it is desirable to have a time-domain transfer function, the model, which has properties physically similar to the realworld system. This has been a paramount concern in determining these model characteristics. The particle mass is the mass of the aircrew member. The location of the mass is indicative of that of the aircrew member. The location of the diagonal members is indicative of the shoulder height and width of the aircrew member.

The research reported indicates that there may be a "best" model for replicating the spinal force and pitching moment of the seated live human subjected to a -Gx translational acceleration and held by a standard restraint harness. The model has not been verified by the study of many test results over a range of subject sizes and acceleration waveforms, and there are no other similar models in the literature for comparative examination. The model is simple, as was the +Gz model reported earlier, and has spinal characteristics which are quite similar. This suggests that with additional time and effort and the examination of more tests, it may be possible to find one model capable of providing the predictive capability desired for a coplanar acceleration environment. This could be the frontal crash of an automobile, the ejection of an escape system, or the crash impact of a helicopter. The data are there, awaiting the next investigator.

Norm Phillips is an Associate Professor of Civil Engineering at the University of Dayton, Dayton, OH. ●

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. We are also looking for sponsors of future SOARs. CSERIAC is a contractually convenient, cost-effective means to produce rapid, authoritative reports.

Send your suggestions and other replies to Dr. Lawrence Howell, Associate Director, CSERIAC Program Office. Det 1, AL/HE/CSERIAC Wright-Patterson AFB., Ohio 45433-6573.

Group Support Technology in the Air Force

Captain Kennon Moen, USAF

Software Catches the Team Spirit was the title of an article in the June 8, 1987 issue of *Fortune* magazine. In it the writer described a new way of computing:

> *Software that will enable people to collaborate across barriers of space and time is one of today's hottest frontiers of computer research. Like an electric sinew that binds teams together, the new "groupware" aims to place the computer squarely in the middle of communications among managers, technicians, and anyone else who interacts in groups, revolutionizing the way they work.*

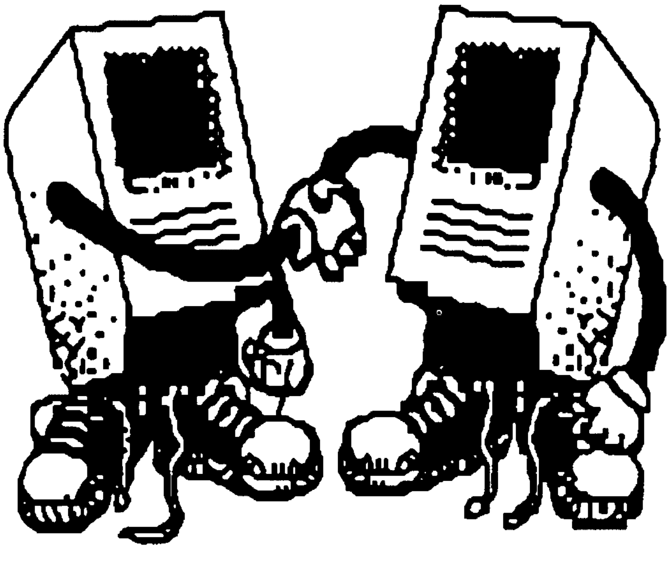
Computer support for people working in collaborative groups is an exciting and growing area of research and technology, holding much promise for government applications. Universities, software developers, and commercial research laboratories around the world are discovering new information about group interaction and computer support tools to help improve the productivity of meetings and the quality of group decisions. The tools resulting from this work are intended to provide support and structure to people and their work together. Tools also exist as research vehicles to explore the impact of technology on group processes and the role of computer technologies in enhancing socially organized work.

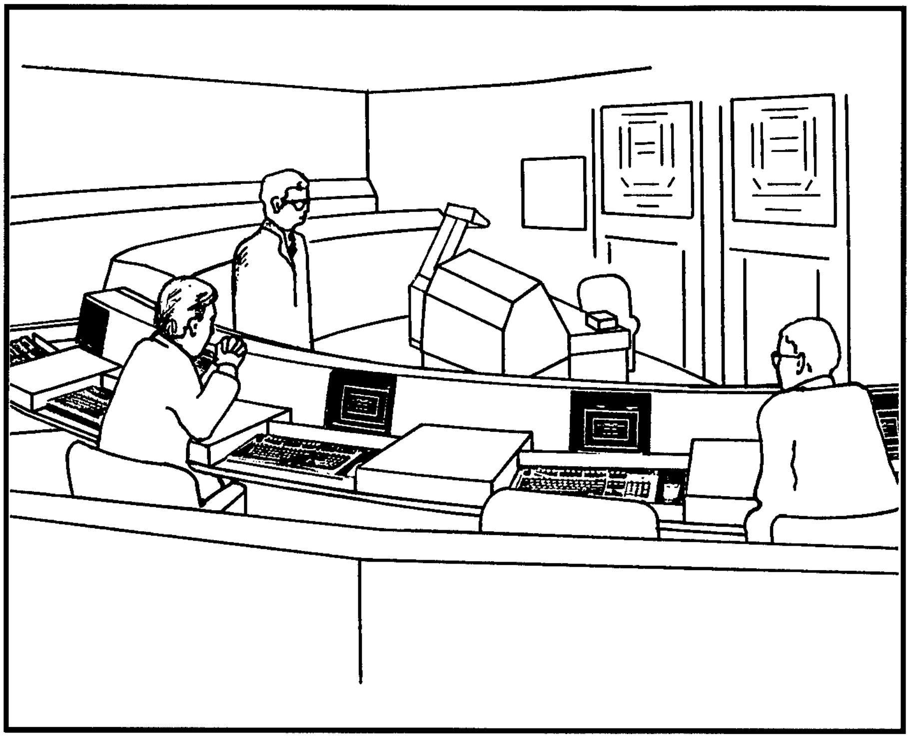
Regardless of purpose, a goal of the research is to magnify the benefits of groups of people working together to achieve organized objectives and minimize the effects of biases and other barriers that hinder people when they try to work together. Software vendors have begun to introduce "groupware" (a generic term often used for what we describe as group support technology - GST) to the commercial world. The focus of groupware has been on the needs of business teams: strategic planners, product concept developers, and business-problem-solving teams, for example. Among the benefits of groupware are shorter meeting times, more productive meetings, increased participant satisfaction, reduced project completion time, larger solution sets from which to develop possible solutions, opportunities for innovative problem solutions, increased buy-in by participants to the problem solution, and increased awareness of decision making rationale.

Our purpose at the Logistics Research Division of the Armstrong Laboratory is to draw parallels and find comparable groups of individuals within the Air Force that can benefit from the incorporation of these support tools in their group processes. We believe that very close parallels can be drawn between certain business and Air Force teams and that they can receive immediate benefit from the introduction of group support tools such as groupware.

At the same time, we are looking for new applications of these group problem-solving tools. We are looking at the design of complex modern weapon systems as a group problem-solving effort on the part of the multi-discipline design teams found in the integrated product development (IPD) environment today. We want to develop and demonstrate prototype GST tools for use by the multi-disciplined design team members. We envision tools that promote those benefits demonstrated within business teams.

IPD is a design approach in which all the upstream and downstream design constraints are brought into the design process as early as possible by representatives from the various functional areas. These multi-discipline design teams are required for complex modern weapon systems. For example, various experts evaluate the developing design with regard to reliability and maintainability, while others assess the design's ease of manufacture and assembly. Each of the IPD team members, representing all disciplines important in the life cycle of a product, brings a unique point of view and piece of the overall design problem puzzle. To maximize the benefits of using IPD, the team members must





Meetings can be transformed into computerized brain-storming sessions by providing powerful workstations for each participant

be provided a point of view into the design database that matches their specialized perspective. They must also be provided with intelligent interfaces that translate their design ideas into terms meaningful to the team members of other specialties and the mechanisms borrowed from GST to share those ideas. These technology enhancements will foster the exchange of knowledge and evolving product information required by successful implementations of IPD and total quality management (TQM).

For more information about group support technology contact Captain Kennon Moen at the Logistics Research Division, Armstrong Laboratory, Wright-Patterson AFB, Ohio (formerly the Logistics and Human Factors Division of the Air Force Human Resources Laboratory), DSN 785-6718 or commercial (513) 255-6718.

Capt. Moen is a Research Scientist with the Logistics Research Division of the Armstrong Laboratory, Wright-Patterson Air Force Base, OH. ●

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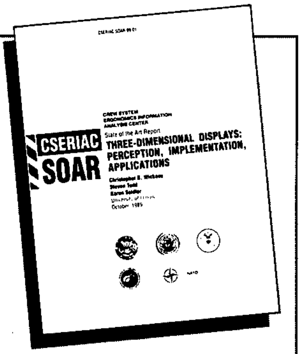
For information about CSERIAC, contact Dr. Larry Howell at (513) 255-4842. Send resumes to: Robert Artman, University of Dayton Research Institute, Personnel, Kettering Laboratory—Room 503, Dayton, OH 45469-0105.

State-of-the-Art Report

THREE-DIMENSIONAL DISPLAYS

Perception, Implementation, Applications

Christopher D. Wickens, Steven Todd, and Karen Seidler
University of Illinois



CSERIAC
SOAR
THREE-DIMENSIONAL DISPLAYS: PERCEPTION, IMPLEMENTATION, APPLICATIONS

The perceptual basis of three-dimensional (3D) representation, recent advances in 3D display implementation, and current 3D design applications are examined in this authoritative review of the state of the art in 3D display technology.

The report catalogues the basic perceptual cues that can be built into a display to convey a sense of "natural" 3D viewing or depth. It describes how the various cues interact and how cues can be combined appropriately to create the strongest sense of depth.

Techniques for implementing perspective and stereoscopic displays are described in detail. The report identifies some potential costs and risks associated with 3D display technology, including the potential for perceptual ambiguity. Ways of constructing 3D displays to reduce ambiguities are suggested.

The efficacy of 3D vs. 2D representation is compared for various display contexts, and the most useful 3D applications environments are noted.

The report reviews 3D display technology applications in several major areas: flight deck displays, air traffic control, meteorology, teleoperation and robotics, computer-aided design, and graphic data analysis and imaging.

Senior author of the report, Dr. Christopher Wickens, is head of the Aviation Research Laboratory, University of Illinois.

The report is 126 pages and includes 22 figures. Cost is $75. To order, contact the CSERIAC Program Office.

Chief Scientist Report Special:
Technical Inquiry Report on Situation Awareness

Michael D. Gravelle

Editor's Note: In place of the usual Chief Scientist Report, we are printing a Special Report by Mike Gravelle, who as a Technical Analyst assists the Chief Scientist.

In the development of appropriate experimental methodologies, sometimes a metric used in a particular domain can be effectively applied to another similar, or perhaps dissimilar, domain. For example, the Cooper-Harper Aircraft Handling Characteristics Scale was originally designed to evaluate aircraft handling characteristics (e.g. display adequacy or vehicle stability). However, the scale gradually became a popular measure of pilot workload. In fact, a modified version of the Cooper-Harper Scale was eventually developed to better address the global aspects of operator workload assessment.

Recently, a Government research psychologist asked CSERIAC to investigate such a cross-discipline issue, specifically, the advantages and disadvantages associated with applying situation awareness metrics to the assessment of command, control, and communication (C3) environments.

His analysis of the current theoretical and empirical knowledge base supporting C3 system development and evaluation revealed ambiguity. The need was identified to explore alternative research methodologies to assess the complexities of C3 environments. Situation awareness (SA), which has been primarily directed at the pilot and the cockpit surroundings, was identified as a possible concept for addressing these issues.

In response to his review and analysis request, we undertook a number of activities. First, we searched the DTIC, NASA, PsycINFO, and Energy Science & Technology databases for bibliographic information and potential subject-matter experts in SA and C3 systems. We then collected and provided him with over 25 documents which were directly relevant to the inquiry. At the same time, we also contacted several subject-matter experts for detailed information and explanations of SA metrics.

Based on our analysis, it was determined that two problems exist with the present concepts of SA, specifically (1) lack of a common, consistent definition, and (2) lack of an accepted technique for evaluating SA in competing design concepts.

The need for a precise definition of SA is critical, to identify the parameters of SA required for accurate measurement. Without an accepted definition, solid experimental methodologies and metrics for SA are difficult to develop. Several definitions were provided as examples of the tremendous diversity and equivocality present in the literature. Generally speaking, SA describes an operator's internal representation or mental model of the immediate surroundings and a certain zone of interest.

Next, we comprehensively reviewed and analyzed many SA metrics in terms of their methodological advantages and disadvantages. Examples of the SA metrics summarized include Situation Awareness Global Assessment Technique (SAGAT), 3- and 10-dimensional Situation Awareness Rating Technique (SART), post-mission recall, and performance-based techniques.

But the question remains: Can the primarily air combat-related SA metrics be used in C3 environments? Most of the research into SA has centered on a single pilot, the cockpit, and a certain zone of interest. Can SA definitions and metrics be applied to C3 environments, where team members must be *situationally aware* of the other team members, the command center, and a zone of interest?

Based on an article in a recent edition of the *Human Factors Society Bulletin* (Vol. 33, No. 12, pp. 1-4), Cannon-Bowers, Salas, and Converse suggested that mental models (which are fundamental to successful SA) are useful tools for understanding the coordination and interaction that exist between team members in C3 environments. If this is true, then perhaps good SA will allow team members to predict their behavior accurately and to anticipate information requirements without overt communication.

Obviously, a need exists to develop new metrics or to modify existing metrics of SA, to facilitate and improve the design of modern C3 systems. In the development of these SA metrics, it is clear that emphasis must be placed on the awareness of other team members, in addition to the operator's physical environment and particular zone of interest. Additionally, the current SA metrics need to be standardized to encompass a variety of operational domains.

Michael D. Gravelle is a Technical Analyst for CSERIAC. ●

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Models For Human System Design

Grant R. McMillan

There's little doubt that human-machine systems are becoming more complex. Associated with this complexity are increased cost, greater technical risk, and more difficult test and evaluation. If the design team could predict human performance and workload with proposed system configurations early in the development process, a significant portion of this difficulty would be eliminated. Today, scientists worldwide are developing tools to accomplish this goal. Included in this emerging toolbox are mathematical models of human performance. Admittedly, many models are abstract entities intended only for theoretical use. Nevertheless, numerous models can be used, at this moment, to address system design issues.

In 1982 the Defense Research Group of NATO established a working group to focus international attention on the use of models in the design of military systems. Research Study Group 9 was chartered with the following purpose:

> *Given the potential that such models have for contributing to the analysis, design, and evaluation of man-machine systems, there is an obvious need to foster their development and use. An RSG therefore is needed to pull together the available knowledge and stimulate information exchange and cooperative research.*

Research Study Group (RSG) 9 included members from the United States, Canada, Great Britain, France, Germany, and the Netherlands.

In May of 1988, RSG-9 sponsored a Technology Demonstration Symposium to share their findings and to provide potential users with an overview of available models. To ensure the widest dissemination of the results, RSG-9 published a text *Applications of Human Performance Models to System Design* (1989, Plenum Press). The book represents the most comprehensive evaluation of human performance models produced to date. International authorities detail specific model applications, currently available modeling tools, and related software. The volume is organized around six modeling areas of concern to system designers. In all cases the emphasis is on models which permit computer-based simulation of humans functioning in systems:

Section 1 - **Task Allocation and Workload Analysis** focuses on techniques for estimating human workload when various tasks are assigned to the person or machine.

Section 2 - **Models of Individual Tasks** discusses models which represent the performance of a single operator performing a single task. This is perhaps the oldest area of human performance modeling and includes many truly mathematical techniques.

Section 3 - **Models of Multi-Task Situations** primarily addresses individual operators performing multiple tasks. The techniques discussed here typically do not represent the mechanisms of human performance, but simulate instead the time, accuracy, and workload results using task network modeling tools such as SAINT (Systems Analysis of Integrated Networks of Tasks).

Section 4 - **Crew Performance Models,** which represent multiple operators performing multiple tasks, show this trend even more strongly. These models tend to be important tools for decision makers who are addressing issues of crew size and the effects of operational stressors such as fatigue and overload.

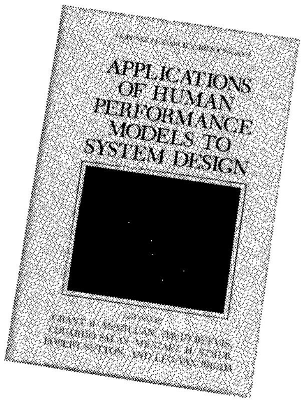
Section 5 - **Workspace Design - Anthropometrical and Biomechanical Approaches** reviews models that address human performance at a rather basic level. They predict an operator's ability to fit into workspaces, to see and reach controls and displays, and to perform materials-handling tasks without hazard.

Section 6 - **Models of Training and Skill Retention** represents techniques to aid in the design and use of training systems. The grain of analysis is relatively fine for models which predict learning curves or the acquisition and retention of specific skills. Other techniques provide a high-level analysis of the expected benefit from specific training devices or features.

The book closes with a frank discussion of the limitations of currently available models, when applied to real-world problems. Also enumerated are features which model developers should consider when developing tools for the designer.

The book has 568 pages, numerous illustrations, as well as extensive indexing and overview material to assist the reader. CSERIAC is distributing this volume through special arrangements with the publisher, Plenum Press. It is available for $ 60. Dr. McMillan served as senior editor of the book.

Grant McMillan is an Engineering Research Psychologist in the Human Engineering Division of the Armstrong Laboratory, Wright-Patterson Air Force Base, OH. ●



APPLICATIONS
OF HUMAN
PERFORMANCE
MODELS TO
SYSTEM DESIGN

Applications of Human Performance Models to System Design(McMillan et al., 1989)

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