《海外論文紹介》

Journal of the Human Engineering Society of Korea
Vol.7 No. 2, Dec. 1988

Too much, too soon: information overload

As designers strive to build more powerful hardware and software systems, the risk is that the complexity will overwhelm humans who use them

In the early 1970s, U.S. Army gunners firing Redeye ground-to-air defense missiles had a problem. Although they could usually hit the target, Redeye gunners had to identify an aircraft—friend or enemy—visually, and some types could not be engaged head-on.

An updated Redeye, the Stinger, came with Identification-Friend-or-Foe (IFF) capability. But then the gunners had another problem: spotting the target and operating the IFF had become so complex, they couldn't perform as well as before. It wasn't because the gunners were slow or untrained; the system simply outstripped the abilities of the typical operator.

Recent military experience is full of stories of fighter jets with too many control switches and tanks with hatches so small soldiers in winter gear could not climb in. Computers and information systems provide vast amounts of data and information and may compound rather than solve a problem; a warning system gives off more alarms than the human operator can take note of; a semiautomatic system forces its operator to make too many decisions in too short a time.

Such problems by no means beset only the military. Automobile companies have built cars with radios so placed that drivers have to take their eyes off the road to tune the set. Built-in trip computers that calculate such parameters as average speed and distance traveled create similar hazards. The monitoring equipment and controls in nuclear power plants, chemical plants, operating rooms, and air-traffic and spacecraft systems are among the many activities where interaction between human operators and machines may cause problems.

Man-machine interfacing, naturally, becomes critical in an emergency—and even more so when an operator is tired and under stress. Consequently, the military can recall some of the most serious—and expensive—cases of what happens when the design of a system does not take its operators enough into account.

That situation, however, may be changing. Private companies and the Government are incorporating more "human-factors" principles into systems under design. The term human factors has come to describe an interdisciplinary field that analyzes the capabilities and limitations of people relative to the machines they man. Three years ago, the U.S. Army initiated a program, Manpower and Personnel Integration (Manprint), that emphasized human factors. "The Army believed it could do a better job of meeting performance specifications with the soldier in the loop and reduce the demand for greater soldier talent and training," said Harold Booher, a special assistant to the Army's Deputy Chief of Staff for Personnel.

A prize research and development project—the Light Experimental Helicopter (LHX)—will be the first full Army project to use Manprint principles from the concept stage through prototyping. Booher believes that Manprint will give human factors a much greater role in the development of most future Army systems.

From the human outward

According to specialists in the field, most designers first address the question, "Can it work?" They may give little consideration to "Can a human operate it?"

"It's easy to forget that a successful design means making the equipment work with real live people," said Thomas Sheridan, a mechanical engineering professor at Massachusetts Institute of Technology in Cambridge. Rather than considering the operator as a part of the system throughout the entire design process, the operator is often tacked on when the design is nearly complete. Sheridan said that the designer should, early in the drafting stage, cease to define success strictly in terms of the device's mechanical or electrical operation. Although humans can learn to operate complex machines, the machines may overwhelm their human operators.

Leaving the human factors until too late may result in a whole variety of problems, which often come to light only when the prototype is built and someone tries to make it work. When the M-1 tank was prototyped, the seat gave many test drivers back and neck strain that required medical attention. And equipment maintenance may be close to impossible if designers do not consider carefully what the human maintenance team has to do. Each time the Army AHIP helicopter's electronic fuel control was removed, all the nuts and bolts fell to the ground. Such poor design can escalate equipment maintenance costs, and once the hardware is out, changing the design takes up large amounts of money and time.

Human-factors engineers argue that most such horror stories can be averted if human capabilities are considered early enough in the design. "One serious problem we face is not being called in initially, but at the end," said Sidney L. Smith, a lead scien-

Defining terms

Anthropometrics: the study of human body measurements, especially in comparison with the layout of a system.
Cognition: the act or process of knowing, including both awareness and judgment.
Human factors: the study of the capabilities and limitations of humans, relative to the systems they operate.
Manprint: the U.S. Army's acronym for its Manpower and Personnel Integration program, a management and technical project to improve the performance of soldiers and equipment by focusing on soldier performance and reliability. This will be achieved by continually integrating human-factors engineering, manpower, personnel, training, health-hazard assessments, and system-safety considerations throughout the materiel-acquisition process.

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tist with the Mitre Corp. in Bedford, Mass. But while calling in a specialist early on can help, human-factors considerations should play their part throughout the entire design of a project. Smith pointed out that it is difficult to anticipate all the human aspects when viewing a system from only one point in its development cycle.

A historical perspective

Human factors considerations first gained recognition early in World War II, drawing on research in psychology, physiology, engineering, education, and—later—computer science. Interest was especially strong within the aeronautics community, and with the arrival of supersonic-speed aircraft human-factors researchers analyzed pilot reactions to determine how humans could best handle such high-performance equipment. Later, however, military efforts in the field waned, particularly when budgets were cut after the Vietnam era.

Researchers do not pretend to have solved every man-machine interface problem. No satisfactory way, for example, has yet presented itself for dealing with glare from a monitor screen. In some cases, research has produced databases too small, or containing too many inconsistencies, to provide insight into a problem. And human-factors research has not yet done enough work on such emerging areas as computer-software interfaces.

Nevertheless, there are many problems that have been dissected. A collection of theories exist on topics such as human response time, the factors affecting response, how long it takes a person to make a decision and take action, and how the person reacts to light or noise. One classic problem is vigilance: How well, over time, does a radar operator distinguish between signal and noise?

Human-factors issues fall into several categories. There are the classic problems of anthropometrics, which have evolved into questions on how humans fit the layout of a system. Can the operator reach the controls and see the console? Most theories in this field are defined, experts say, although in some cases databases are still small or inconsistent.

New twists on problems are always arising, said Frank Stech, a human-factors engineer at Mitre Corp.'s McLean, Va., office. In one submarine, for example, a computer card rack was built into the vessel's nose, and crew members had almost to touch their toes to reach the rack, before pulling out the lowest cards. "It turned out to be physically impossible," Stech said; a human-factors specialist could have identified the problem long before. And such situations may become more intricate when a system is in motion—in a tank or aircraft for example.

While anthropometrics remains a key concern, cognitive problems—how much mental activity is required—have become an overriding question with advances in computer technology. The National Academy of Sciences in 1983 called for more research in cognitive processes, warning: "The role of people in systems is shifting to those of monitoring and directing otherwise automatic processes."

From a human-factors standpoint, automation is a mixed blessing. On the one hand, it reduces the number of tasks an operator must perform; on the other, remaining tasks or new ones may be significantly more complex, and there may be additional maintenance tasks. Reducing the number of tasks will not necessarily reduce the number of people needed to run the system. The basic question, said MIT's Sheridan, lies in which tasks and decisions should be delegated to computers and which handled by humans.

Computers raise a different, albeit related, set of questions. Besides the anthropometric issues—such as whether the operator can see all the screens—engineers must address cognitive questions—such as whether the system is providing too little, enough, or too much information.

The characteristics of the operator will also affect design. Will the operator have an engineering degree or a high school diploma? Stech said the ideal designer keeps the user in mind. Will the operator be more comfortable with a keyboard or a joystick? Will the operator take orders from the system, issue orders to it, or combine the two roles? Will the operator want to learn more advanced languages or use a few simple commands?

Finally, the designer must consider how many people will use the system, whether they will have to interact with each other, and whether the system will enable them to do so.

Some research has gone into many of these issues on the theoretical front. Other investigations have taken those theories into the field. Design of civil and military aircraft has been one of the few areas where human-factors considerations have consistently played a strong role. Sheridan observed that major aircraft manufacturers—McDonnell Douglas, Boeing, and Europe's Airbus Industrie—as well as the National Aeronautics and Space Administration, all have "competent staffs of human-engineering people who worry about visual computer displays, task loads on pilots, seating, and other issues."

In the mid-1960s, the Defense Department formally recognized a need to consider the human's position in the system. Military specification H-46855 requires contractors to include human factors, manpower, personnel, and training issues in weapons-system design, but in most designs, that has not always taken place.

Army personnel aide Booher, who was on the team that wrote H-46855, said the specification is sound, but conceded: "It hasn't had the impact that people thought it would." Booher said efforts to apply the specification have been diffuse, inadequately funded, and not vigorously enforced. "It's the difference between desiring good results by depending on something that's been written into a specification, and making sure it happens by actively participating throughout the procurement process," he said.

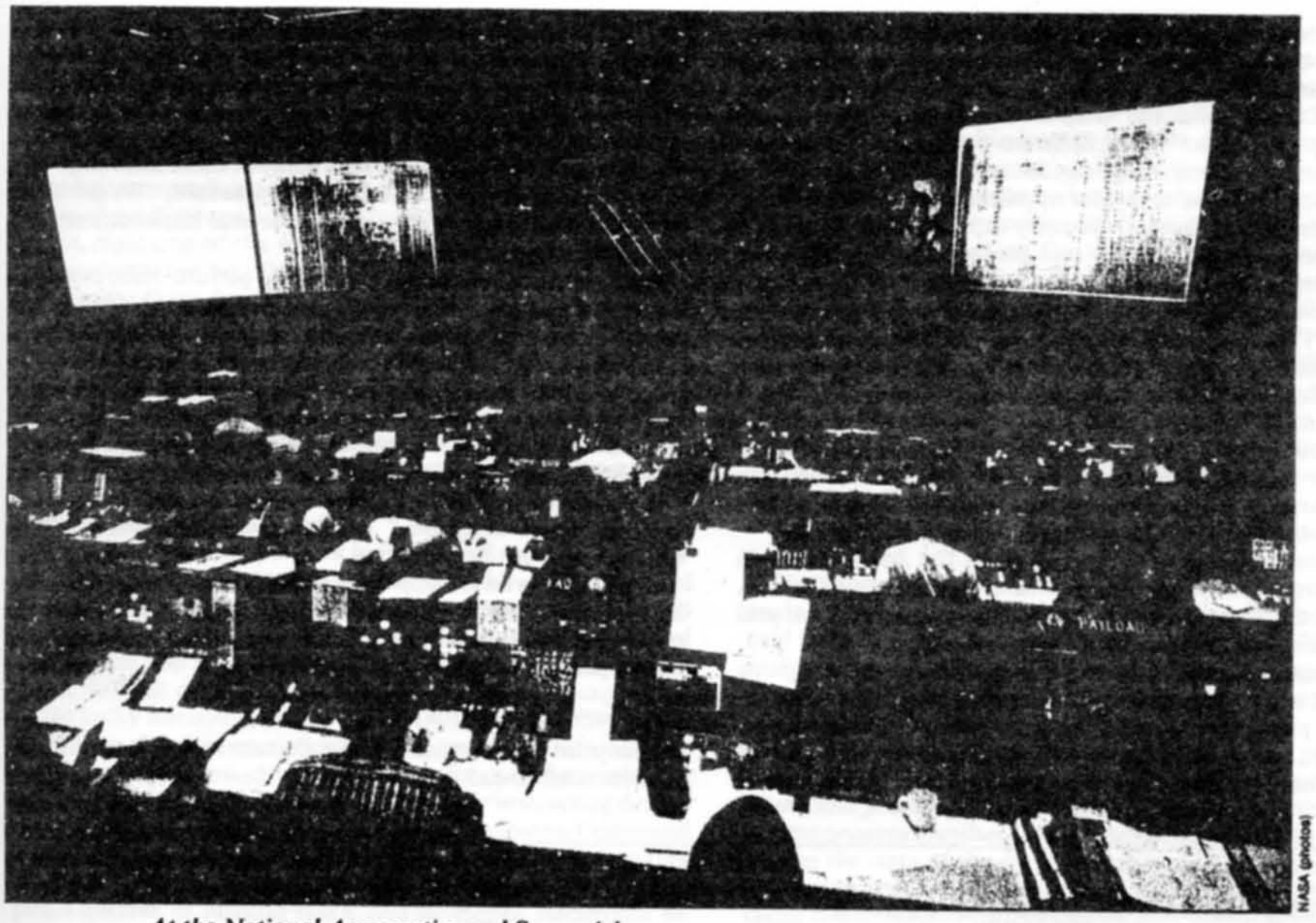
One reason human-factors issues are not fully investigated is that contractors try to save time and money on a project. Other reasons cited in a 1985 report by the U.S. Army Research Institute for the Behavioral and Social Sciences include: "a delay or absence of analysis of human factors, manpower, personnel, and training (HMPT) requirements; inadequate information on human limitations; inadequate techniques for producing manpower and personnel requirements; lack of attention to soldier performance in test and evaluation; and insuffiencient incentive for project managers, test directors, contractors, etc., to attend properly to HMPT issues in the face of competing priorities."

Although human-factors research provides engineers with tools to build systems better tailored for human operators, most people use simple, familiar tools, said Stech. "It's amazing how many more tools we have than we use," he said, "but if the new tools were applied, they would make a difference."

Finally, experts point to what they describe as a cultural clash between human-factors researchers—typically with backgrounds in pyschology—and design engineers. "Human-factors specialists haven't learned enough about systems engineers," said Sheridan, adding, however, that the specialists will talk engineering language more readily when engineers know more about human factors.

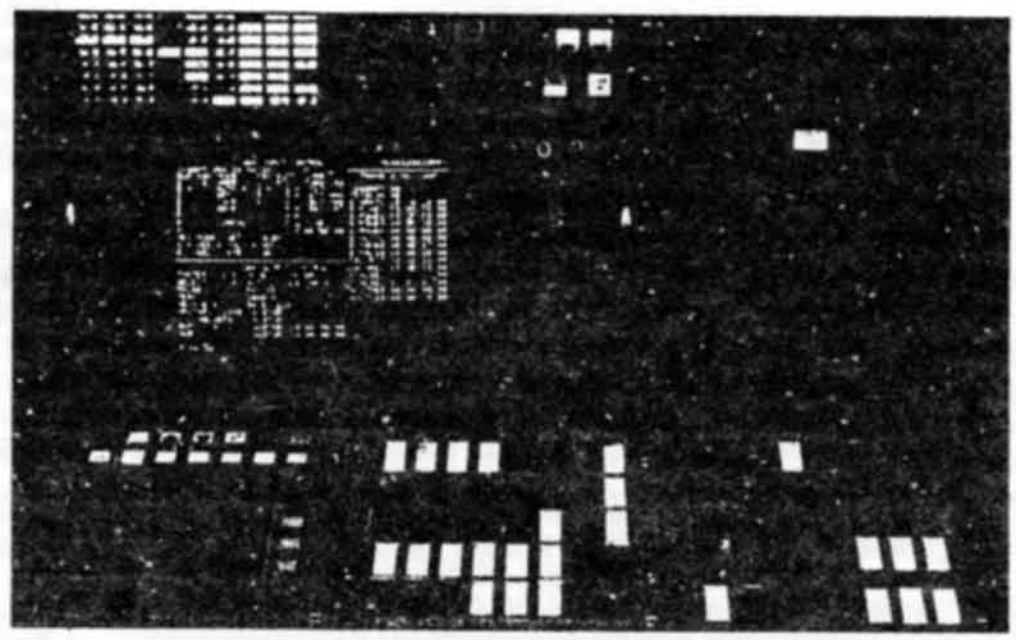
Up to now, said Booher, human-factors evaluations have too often been afterthoughts. "A system is designed with hardware and software to meet a military need, a prototype is built, and then they try to make the human operator fit the device," he said—but at that point, it is costly to alter the design.

Over the past few years, the military and the U.S. Congress have grown weary with financing projects that turned out to be difficult to operate, or that required more manpower than was available. Last year, Congress passed legislation (Section 1208 of Fiscal Year 1987's Defense Authorization Act) that requires the Pentagon to report to Congress on the projected manpower needs of new weapons before the purchase is approved by Congress. The Navy has developed a method called Hardman (for Hardware vs. Manpower) for assessing designs to see how many people will be required to operate and maintain a new weapon system. Air Force representatives say that they have been using human factors principles for many years. "The pilot is as



NASA (photos)

At the National Aeronautics and Space Administration's mission control room in Houston, Texas, systems operators are confronted with a barrage of information—from the large screens on the back wall as well as from screens on their desks. Designing such a system requires careful thought on how the human operator will fit in. Will a system's physical layout [right] be easy to operate? Will the operator be able to see all signals and warnings? And increasingly important—will the software make sense? Too often, say human-factors specialists, software makes sense to the engineer, but not to the operator who has to use it.



much a part of the airplane as the engine," said Mike Wallace, a public affairs specialist at Wright Patterson Air Force Base in Ohio. "It's just impossible to design a fighter plane without considering the human," he said.

Simulation helps

Although the Army's Manprint concept was initiated three years ago, its effects have been really felt only within the past 12 months. The Manprint regulation (AR602-2) came out in April and focuses (according to the official description) on "influencing material systems design and associated support requirement so that developmental, nondevelopmental, and product-improved systems can be operated and maintained in the most cost-effective and safest manner." Said Booher: "We're trying to create a basic philosophy here of building from the soldier outward."

The Manprint program includes a number of human-factors guidelines, although it ranges well beyond traditional human factors. While evaluations of human performance are a key part, Manprint also demands that contractors and Government look at how effectively manpower is used.

Booher pointed out that knowing the characteristics of the soldier is critical to building a system that truly fits the soldier. "You run into immense problems when you try to design for an 'average' person," he said. The Army is pushing for designs flexible enough to be used by a wide range of people, and is pursuing better descriptions of soldiers' physical and educational characteristics.

Any substantial change in the soldier population—as would occur in the event of a draft—could result in many mismatches between users and equipment. Research is also going forward on the characteristics of members of Reserve and National Guard units, as well as the active Army.

Booher has mapped out a four-part strategy for applying Manprint in the Army. First come policy and procedural changes: apart

from the Manprint order, all Army materiel-acquisition documents are being amended to emphasize more strongly the incorporation of human factors into designs.

Second, said Booher, the Army is running an "education and marketing campaign." Three different courses have been conducted over the last year: a one-day course for generals and senior executives; a one-week course for middle managers; and a three-week course for those who will carry out the day-to-day work throughout the Army. Booher said that some 500 people have participated in the program.

"We have the support of top management on Manprint," said Booher. "I've seen our generals supporting these recommendations, willing to delay a procurement rather than not have an important item of support equipment or a training simulator delivered on time."

The third part of Booher's plan covers the role Manprint will play in the actual acquisition process, and the fourth point is to increase Army research in human factors, especially in providing new ways to integrate information on human performance.

Such research is mainly done through the Army's Human Engineering Laboratory (HEL) at Aberdeen Proving Ground, Md., and the Army Research Institute for the Behavioral and Social Sciences in Alexandria, Va.

The research institute focuses on manpower issues—recruiting intelligent soldiers, basic research on training, and devising techniques to predict manpower needs early in the acquisition process. HEL, on the other hand, has performed more traditional kinds of investigation into human-factors engineering.

Richard Koffinke, a team leader for HEL's combat-vehicle systems, said most of his group's work is applied research. One topic under investigation is what information is useful to a platoon leader. HEL researchers first observe how platoon leaders run missions with a typical information base. Next, "We tell them where the 'friendlies' are and how many of them there are," and observe behavior, said Koffinke. Finally, he said, "We give them information about everything within several kilometers and see what they do with it."

Anthropometrics also comes into the picture. HEL evaluates different size displays and touch panels—"They shouldn't be too small if you're in a tank with gloves on," said Koffinke.

His team is also developing workload predictions for ground-combat vehicle crews, hoping eventually to find ways to reduce crew size. Just as their performance objectives differ, tanks have very different work requirements from those of aircraft, Koffinke said. Reaction time for a fighter pilot is a useful measure of performance, but in a tank, "Our objective is to move in a concealed way toward an objective," Koffinke said. "You can't always measure that in terms of time."

While Manprint is likely to result in higher "front-end costs," Booher said, identifying problems and changing the design on paper can cut expenses in the later development phases, as well as in operation and support.

LHX—human factors at work

Manprint is more than a paper document, however. The Army's most advanced and high-priced research project, the Light

Writing software with the user in mind

Even for computer literates, software can sometimes be a challenge. But human-factors specialists argue that it shouldn't be—if the software designer keeps the human user in mind.

To combat this problem, the Air Force Electronic Systems Division contracted human-factors guru Sidney L. Smith, lead scientist at the consulting firm Mitre Corp., in Bedford, Mass., and Jane N. Mosier, a member of the technical staff, to develop guidelines for user-interface software.

All told, Smith and Mosier compiled 944 guidelines, broken down into six functional areas: data entry, data display, sequence control, user guidance, data transmission, and data protection. The authors emphasize that the guidelines are tools—rather than requirements or standards—for developing software.

Excerpted below are the first—and by far the most general—points in each of the six sections of Smith and Mosier's handbook, *Guidelines for Designing User Interface Software*. The authors present examples and comments on each guideline; a few are included here.

1.0.1 Data Entered Only Once: Ensure that a user need enter any particular data only once, and that the computer can access those data if needed thereafter for the same task or for different tasks.

Comment: In effect, this recommendation urges integrated and flexible software design so that different programs can access previously entered data as needed. Requiring re-entry of data would impose duplicative effort on users and increase the possibility of entry errors.

2.0.1 Necessary Data Displayed: Ensure that whatever data a user needs for any transaction will be available for a display.

Example: As a minor example, header information should be retained or generated anew when a user is paging/scrolling data tables.

3.0.1 Flexible Sequence Control: Provide flexible means of sequence control so that users can accomplish necessary transactions involving data entry, display, and transmission, or can obtain guidance as needed in connection with any transaction.

Example: In scanning a multipage display the user should be able to go forward or back at will. If user interface design permits only forward steps, so that the user must cycle through an entire display series to reach a previous page, that design is deficient.

4.0.1 Standard Procedures: Design standard procedures for accomplishing similar, logically related transactions.

Comment: Standard procedures will facilitate user learning and efficient system operation.

5.0.1 Functional Integration: Ensure that data transmission functions are integrated with other information handling functions within a system.

Comment: A user should be able to transmit data using the same computer system (and procedures) used for general entry, editing, display, and other processing of data.

6.0.1 Automatic Security Measures: Whenever possible provide automated measures to protect data security, relying on computer capabilities rather than on more fallible human procedures.

Comment: For protection against unauthorized users, who may be intruders in a system, the need for automated security measures is clear. For legitimate users, the need for data protection is to minimize data loss resulting from potentially destructive equipment failures and user errors. Even careful, conscientious users will sometimes make mistakes, and user interface logic should be designed to help mitigate the consequences of those mistakes.

Experimental Helicopter (LHX), is also the model for incorporating human-factors engineering, said Booher, and likely to be one of the first clear case studies of the effect of human factors on a major military system from concept through prototyping.

Army plans originally called for a single-seat craft; after many simulation tests, officials decided that while one operator may be able to accomplish most LHX missions, there is some uncertainty about how one operator would handle air-to-air engagements, night nap-of-the-earth missions, and target acquisition. Consequently, the Army has decided to build a two-seat prototype that can be flown by a single pilot.

Human factors also contribute to evaluations of other tradeoffs, such as crashworthiness and safety against weight. One criterion for the LHX is speed, but the faster and lighter the craft is, the more vulnerable it is in a crash. In the past, that kind of question was usually decided in favor of performance, and the operator was assumed to be able to adapt. Human-factors considerations are now weighting questions in favor of the pilot, say military sources.

There has been progress, too, in the area of maintenance. Servicing the LHX engine will take only a fistful of tools instead of a whole box of them. Competing contractors demonstrated recently that engine maintenance could be done by personnel of slighter size and strength—for example, women soldiers—and under difficult circumstances—for example, by personnel clad in the bulky mission-oriented protective posture (MOPP) gear worn near chemical or nuclear contamination.

Within the cockpit, designers have to focus on apportioning work between pilot and computer. Darrell Harrison, acting deputy LHX program manager at the Army's Aviation System Command (ASC) facility in St. Louis, Mo., said five companies were taking part in an LHX predesign effort. All simulated an LHX cockpit and a number of mission tasks, and developed electronics requirements from the simulations. Using mission simulators and Army pilots, they then looked at how the pilots handled the tasks.

"They took the missions and broke down everything that has to be done by the individual. They then looked for work overload, and how much time each task took, and evaluated what needed to be automated," said Harrison.

Navigation is one task that must be automated if one person is to fly an LHX. With most helicopters, pilot or copilot must track the craft's flight on a paper map. LHX will use the DOD Global Positioning System to find its position automatically, and will present the information to the pilot on an electronic map. All the pilot need do is input the position before take-off. Moreover, instead of facing rows of gauges, the pilot will have two or three CRT monitors displaying only cautions and warnings, or specifically requested information. Harrison said the designs were not yet at the point where the maximum number of warnings had been determined.

Designers have also learned that the pilot's CRT menus should be simple and limited to a couple of pages. Other interfaces are likely to include a limited voice-recognition control system that can handle between 20 and 200 spoken commands, and a helmet-mounted display conveying pictorial and digital information—all the information needed to fly the helicopter. These systems and their characteristics are driven by the pilot workload, said Darrel Caldwell, an aeroengineer in ASC's technical management division.

The LHX flight control system, unlike those on current helicopters, will have a multi-axis controller that the pilot can work with one hand. "Helicopters are inherently unstable platforms," said Harrison. The type of control system going into the LHX, he said, is designed to help reduce the pilot's workload.

Assuming Pentagon approval, a proposal evaluation on the LHX is to take place this fall, followed by prototype construction beginning next January. One major category in the evaluation will be Manprint—notably including human factors.

"Manprint does get man into the loop," said Harrison. "We've had proposals that didn't consider the human-factors aspects." And even when some human-factors engineering was worked into previous projects, "I've never seen human factors brought in so early," he said. Caldwell concurred. "Other programs have had a minimum of flight simulation," he said. "This is the first time the Army has had a big interest in flight simulation to measure the interface with the cockpit design."

The design systems have already endured extensive monitoring on both anthropometric and cognitive levels—did the pilot have a problem reaching for the switch? Workload has been measured in tasks per second, errors made, magnitude of errors, and so on—Did the craft crash? Did the pilot die? In reviews, pilots are asked to grade the systems.

The Army and the contractors both built simulation facilities to test the LHX human-factors aspects. At Langley, Md., NASA built the Army's simulator. Evaluations are done in a tactical environment with stress, simulating the full communications workload, said Caldwell. "The pilots have said they think they're in the field," he added.

"These simulations could make the difference between getting a contract and not," said Harrison.

Harrison, Caldwell, and Michael Richey, an electronics engineer also with the ASC's technical management division, all said they are firmly sold on incorporating human factors early in the design. Richey added that he expects development costs to be reduced if mistakes are found on paper, rather than in the hardware.

"You can identify the most critical or the risky components you want to prototype—some you know, but many you don't know, and you don't know what's going to happen when you put all components together," said Mitre's Stech. But where a design pushes the state of the art, there are too many choices of what to prototype and too many potential interactions, he said. At those times, human factors can provide useful insights.

To probe further

A variety of applications and theory on human factors is covered in the bimonthly journal published by the Human Factors Society, Box 1369, Santa Monica, Calif. 90406.

Since 1980, the National Research Council has sponsored a Committee on Human Factors, which has produced several reports, notably, *Research Needs for Human Factors,* published in 1983.

In 1981, the U.S. Comptroller General presented a report to Congress entitled, "Effectiveness of U.S. forces can be increased through improved weapon system design." The report argued strongly for increased research in human factors. Copies are available from the U.S. General Accounting Office, Document Handling and Information Services Facility, P.O. Box 6015, Gaithersburg, Md. 20760; telephone 202-275-6241.

Manprint policies are outlined in Army Regulation 602-2, "Manpower and Personnel Integration (Manprint) in Materiel Acquisition Process," published April 17. It can be obtained through the Manprint Policy Office (DAPE-ZAM), Washington, D.C. 20310; telephone 202-695-9213. The Army also distributes a monthly *Manprint* bulletin, available through the same office.

Wiley-Interscience Publications recently produced a two-volume encyclopedia of human-factors principles, entitled *Handbook of Perception and Human Performance*, edited by Kenneth R. Boff, Lloyd Kaufman, and James P. Thomas (New York, 1986).

Sidney L. Smith and Jane N. Mosier compiled *Guidelines for Designing User Interface Software.* A collection of more than 940 pointers, it is available from Sidney Smith, Mitre Corp., Burlington Rd., Bedford, Mass. 01730.

An article, "Military waste: the human factor," by Colleen Cordes, appeared in the American Psychological Association's monthly newletter, *Monitor* (July 1985), and details many accounts of needless spending in military projects that disregarded human factors. ◆

Special thanks to Samuel G. Charlton.