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ARMY PILOT ERGONOMICS

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### I. The Problem

In the nearly four decades since the end of World War II, the US Army has considerably expanded its use of the helicopter. As an appreciation of the potential of this vehicle developed, new dimensions to the battlefield engagement evolved. The Army's ability to conduct land combat functions of mobility, intelligence, fire power, combat service support, and command, control, and communication was greatly expanded. Consequently, the missions and crew task demands of the Army helicopter are undergoing rapid and extensive change. Recently, the anti-armor role has been adopted as the primary mission for the attack and scout helicopter team, and the night and adverse weather capability has been emphasized to meet the needs of continuous operations. In addition, air-to-air combat with helicopters now appears likely. As the helicopter has acquired new missions, new tactics and performance requirements have evolved.

One of these new tactics is to fly at a very low level, often only a few feet above the surface, and close to obstacles for maximum protection from threat of radar detection. Nap-of-the-earth (NOE) flight is a most demanding flight regime requiring constant vigilance, rapid but precise control input, and adaptability to a wide variety of environmental stresses. NOE flight (usually rough, hot or cold, and noisy) requires a high degree of concentration, and produces a high workload. The pilot's sensitivity to stimuli (tactile, visual, and aural), his reaction time, his resistance to fatigue, and the efficiency of his cognitive process are influenced by this working environment. The margin for error narrows with decreasing altitude while simultaneously the probability of operator overload increases. Within this complex stress environment, the aircrew member is expected to perform precisely, innumerable tasks related to weapons systems. In addition, the pilot is expected to maintain outside vigilance for enemy aircraft, ground defense systems, targets of opportunity, navigation way point, friendly forces (both in the air and on the ground), and all of this in a visual environment reduced by haze, smoke, and clouds and, usually, at night. The reduction in external visual cues during flight at night and in adverse weather places added demands on the combat helicopter crew.

The necessity to perform these new missions in an increasingly hostile environment has resulted in many new helicopter subsystems. The number and complexity of the systems in the modern military helicopter require an enormous amount of information to be assimilated by the aircrew for proper management and control. Thus, we see the Army helicopter pilot forced to perform evermore precisely and skillfully in an environment which compromises all of his senses, diminishes his powers of concentration, overloads his cognitive ability, and reduces his physiological tolerance. The adequacy of man-machine integration has never been more tested than in the case of sophisticated weapons systems operating in the narrow flight envelope of NOE flight under combat conditions.

Consider, for example, a portion of a hypothetical mission for the US Army's projected next aircraft -- the single-piloted family of light helicopters (LHX). About 3 km from the forward line of troops, the pilot will establish communications with forward elements and initiate NOE flight. He will reconnoiter and make contact with enemy elements. He will acquire and hand-off targets to attack helicopters.

He will assist the attack helicopters in selecting firing positions and in repositioning them after firing. He will detect a threat and take appropriate countermeasures, then return to contact and continue engagement, acquiring and engaging additional targets. All of this can occur within a critical four- to five-minute interval. The pilot can be expected to supervise or control the data management and transfer system, the flight control system, the navigation and guidance equipment, the communication systems, the target acquisition and designation systems, the weapon systems, the threat identification systems, and the electronic countermeasure systems -- all while he is flying close to the ground, maneuvering around and between obstacles, possibly at night and in adverse weather while taking fire. The tasks that the pilot can be expected to perform during this brief period are indicated in Fig. 1. Of course, he will not be doing all of these things continuously, but he can be expected to do any of them at any time.

The objective of any man-machine system is to accomplish a prescribed task with satisfactory performance at acceptable workload for reasonable cost. The problem is that the human has become the limiting component of the Army airmobile system. With current developments in missions, aircraft performance and particularly cockpit information presentation techniques, it is becoming apparent that the pilot is limiting the advancement of future military helicopter systems.

The complexity of present and anticipated combat missions and the systems he is expected to operate or manage has created intolerable demands on pilots. A crew workload problem exists in today's tactical military aircraft that can contribute to mission failure and/or loss of pilot and aircraft. It is becoming evident that we have reached the point where the pilot is overloaded during critical mission phases. Training alone may no longer enable the pilot to cope with the situation. It is likely that regardless of the extent of training, we have reached the limit of the human pilot's capability.

There is increasing concern within the US Armed Forces regarding the human operator's role in the effectiveness of the man-machine system. The cockpit is an intimate part of the weapon system -- not just an adjunct to provide a place for the pilot. The capability to model and analyze complex human-machine systems has not kept pace with the technological capability to manufacture machines with very complex human interfaces. The variables which affect the operator's ability to acquire and process task-critical information are of prime importance to the design of effective controls and displays. The problem is that design engineers do not understand these variables or they tend to ignore well-known functional principles and laws of human behavior. As a result, current designs have not taken into account fundamental requirements of human sensory and cognitive characteristics and limitations. The next section addresses some examples of efforts to extend the performance envelope of systems without regard for the human limitations.

## II. Current Solutions

As Army helicopters have been developed to keep up with their changing operational roles, additional controls and displays associated with these equipments have appeared in the cockpit. The designer's current approach to obtaining increased mission performance has been to add more and more equipment to provide the crew more information and aids (Fig. 2). In many cases, the situation has simply been a matter of finding space in the cockpit for additional dedicated displays and controls. But, obviously, this is not the solution to our problem.

Responding to the need for presenting more information in less space, the avionics "magicians" have apparently come to the rescue by providing the crew with multifunction displays and controls. The so-called "integrated cockpit" (Fig. 3) replaces many of the traditionally dedicated instruments, displays, and subsystems controls with interactive multi-purpose displays and multi-function keyboard switching.

Advanced avionics have opened up possibilities for aircraft cockpits which are radically different in terms of configuration, information presentation, and control mechanics. Due to the extensive information retrieval capabilities of multi-function displays, the pilot has access to vast amounts of information for decision making which previously was either committed to memory or based upon estimates or perceptions of systems' status. With a reduced number of instruments competing for limited cockpit panel space, the multi-purpose controls and displays can now be located within prime reach and viewing areas. In conjunction with appropriate integrated controllers, operating via data-bus concepts, the use of multi-function displays enables the cockpit environment to be considerably "tidied-up" but may not be at all appropriate from an ergonomic point-of-view.

A multitude of information can be provided to the pilot by modern cockpit displays but selection of display options can become an additional cognitive burden to the pilot. With this capability, it now becomes possible to literally saturate the pilot by the number of displays and decisions confronting him. In many instances the amount of information may already exceed the pilot's ability to observe and assimilate. Consider, for example, the F-18 cockpit (Fig. 4) -- an outstanding example of our most advanced integrated cockpit. There are over 675 acronyms that appear on any of the three Cathode-Ray-Tube (CRT) multipurpose display indicators. There are 177 different symbols and each of these can appear in any of 4 sizes. There are 73 threat, warning, caution and advisory messages, plus an additional 59 indicator lights. There are 6 auditory warning tones (no messages). There are 22 separate Head-up-Display (HUD) configurations using the same basic symbols, but in different locations. There are 40 different display formats that can appear on any of the three CRT screens. There are 8 switches on the throttle (left hand) most of which are multifunction and 7 switches on the stick grip (right hand). Will he remember all of these in a pressure situation?

With increasing demands for information to be delivered the pilot, increased consideration is being given to what kind, how much, and in what format this information should be provided. Unfortunately, the pilot is not necessarily the best source of answers. As an example, consider the results of a study, recently supported by the US Army, of a concept for a Subsystem Status Monitor that is intended to reduce pilot visual and decision-making workload during the monitoring of helicopter subsystems by automatically displaying only what the pilot needs to know; when he needs to know it. The approach was to ask a large number of helicopter pilots what instruments they frequently monitored. One of the recommendations of this study was to eliminate the rotor rpm indicator. The Subsystem Status Monitor System replaces the dedicated pointer and dial for rotor rpm with 1) a digital readout of percentage rpm, 2) an arrow indicating increasing rpm, 3) an arrow indicating decreasing rpm, 4) a precautionary light indicating the rate at which it is approaching a cautionary condition, 5) a caution warning light, 6) a warning light, and 7) an alpha-numeric indicator of the problem. Have we indeed succeeded in reducing the pilot's cognitive and monitoring workload?

The Army helicopter pilot operating NOE at night must have sufficient external reference to fly safely clear of obstacles and, therefore, night-vision aids are needed. The forward looking infrared (FLIR) system sensor is usually mounted in a turret on the nose of the helicopter with the FLIR imagery provided either on a panel-mounted or helmet-mounted display for the pilot and copilot. In the U.S. Army's Advanced Attack Helicopter, the Apache, flight symbology and weapon-control symbologies are superimposed on the FLIR imagery (Fig. 5). Two different flight control symbology formats are provided -- the symbology format for enroute flight and the symbology format for transition to hover and hover (Fig. 6). Each of these formats provides 19 symbols representing various flight control information. For the pilot using the helmet-mounted display system (Fig. 7), all of this information -- FLIR image, flight-control symbology and weapon-control symbology -- is presented on a 2.5 cm CRT covering one eye; he is expected to take care of other matters -- like the peripheral scene and the instrument panel -- with his other eye. Can he really do all this when flying a few feet off the ground, avoiding obstacles, at night while someone is firing at him?

The scale of the monocular FLIR image on the pilot's night vision system (PNVS) is approximately one-to-one. However, it has been shown that when objects are observed through a lens system with projection on a framed flat screen of limited dimensions, their judged size is smaller than when observed under contact conditions. There appears to be such an effect upon the perceived size of objects viewed through the PNVS that results in judgements of altitude that are too high. There is no agreement as to why this phenomenon obtains but the effect is robust. A magnification of the viewed scene of 30% is required to bring objects into proper perceived perspective and scale.

It is well-known among the visual psycho-physiologists that discrimination of a target can be masked by visual noise such as a randomly patterned flash. The masking effect is due to the luminance of the mask, the patterning of the mask itself, and temporal factors. Consider how this may apply to the detection of a target in a FLIR image over which there is superimposed a time-varying symbology. Will the discrimination of the target be masked by the time-varying pattern of symbology?

The man-machine interface for mode control for the Apache system is provided by a Control Display Unit (CDU) consisting of a CRT display, master function switches, line key, and an alpha-numeric key set that enables the copilot to view either the mission flight plan, or the navigation plot showing fly-to-point data, reference points and aircraft position along a projected course. Even in experiments when the CDU was used only by the copilot as a navigational aid, there was copilot confusion and numerous copilot input errors. These errors were the result of consistent problems with parallax and misunderstanding of key functions. Copilots depressed line keys several times in succession in trying to obtain a response or to correct an error. The problem was attributed to keyboard layout and CDU feedback cues -- or, in other words, a lack of understanding of human perception and, perhaps, of the need for stimulus-response compatibility.

The extent of the changes being made to the cockpit is so great as to drastically revise not only the skill requirements for a pilot, but his workload, his information input requirements, and the very style with which he approaches the task of flying. No longer will a simple eye movement be sufficient to bring a required piece of information into his field of view. With the new systems, he may be required to 1) decide which information he needs; 2) recall the particular cognitive and motor behaviors such as codes and switching sequences which will bring up the appropriate information; 3) perform the actual movements to acquire the information; and 4) move his eyes to the point of information presentation. Previously, only the first and last of these tasks were required. Should the demand for such added activities occur during times of peak operator workload, the impact on mission success might not be offset by the increased calculating power, speed, or accuracy afforded by the digitally based systems.

Operational controls and displays are being specified without objective consideration of the sensory and perceptual characteristics and requirements of the operator. The current approach is more likely to increase rather than decrease pilot workload because it forces the pilot to manage more systems, control more switches and buttons, and make more decisions than he did before. The use of computerized monitors and electronic display devices can increase the crew workload by requiring additional manipulation, taxing human memory and information processing capacity, or delaying response time by complicating decision-making processes. There is no evidence whatsoever to suggest that the current "integrated cockpits" will enable the human pilot to accomplish any new feats beyond today's capability because they do not address the needs of the limiting element of the system -- the human.

### III. Conflicts of Cognition and Perception

To gain full appreciation of the pilot's difficulties and capabilities in the cockpit environment, we need a comprehensive understanding of human psychomotor

capability and this necessarily embraces the entire domain of human information processing and cognition.

Flight operations involve the encoding and processing of vast amounts of information in the form of visual displays, system-status updates, and operator perception of parallel and interactive task performance. Highly involved cognitive and psychomotor processes are apparently employed in the operation of such systems. To accomplish guidance and control functions, the human pilot sets up a variety of nested, closed loops about the aircraft which, by itself, could not accomplish these tasks. His control and decision actions are functions of the desired and actual aircraft motions. Precision of multi-closed-loop control is a function of the rapidity with which the operator perceives the results of his control inputs. To be satisfactory, these closed-loop systems, although comprised of both animate and inanimate components, must, nevertheless, have the same qualities of any good closed-loop system. The pilot is the adaptive element to accomplish this end and must make up for any dynamic deficiency of the system by appropriate active adjustment of its properties. Fundamentally, the cost of this adjustment is workload and can consist of increased stress, increased concentration of operator facilities on the mission task dynamics, and decreased capability to cope with the unexpected.

The main unknown in this complex process is the way in which a pilot chooses from the myriad of stimuli presented to his sensory systems and the way in which he mentally processes the information contained in these stimuli such that he can successfully fly the aircraft. What are the sensory and perceptual variables which influence (1) acquisition of information, (2) processing of information and (3) selection of control strategy? These issues relate primarily to the cognitive and perceptual workload, and it is precisely this portion of the total workload which seems to be at or near the critical level.

The individual differences in men, the variety of machines and of environments in which they must operate, and the various types of missions all influence the selection of stimuli and responses. From all of the sensory stimuli available to the pilot, only those elements are used which are most relevant to the purpose of the observation. Less essential stimuli tend to be ignored. Psychologically, these cues permit perception of task demands and of performance requirements, influence motivation and govern selective attention. Physiologically, they influence the arousal level of the autonomic system. Engineering-wise, cues permit observation of actual aircraft behavior and updating of the internal model.

In order for adaptive behavior to exist, the perceived world must be predictable. Repeated encounters with the structure of the physical world produces learned experiences about the outcome of possible perceptual-motor acts. These expectancies permit us to perceive that object, event, or scene which would most likely have produced a given pattern of cues as a result of particular sensory-motor movements. These mental structures are continually added to or modified as the perceiver tests his expectations about what he will see when he moves so as to bring presently hidden or blurred parts of the scene into clear vision. Thus, perception is a process of sampling, testing, and construction derived from cues and based on knowledge, past experience, and guess-work on the part of the perceiver.

One of the important factors in helicopter NOE operations is that most of the inputs received by a pilot for his short-term memory come from outside the cockpit through his vision. These are stimuli that reflect terrain, obstacles, orientation, other aircraft, ground targets, hostile fire, and the head-up display. Conversely, most of his long-term inputs come from inside the cockpit through radar sensor, navigation, and map head-down displays. In both cases, he is required to operate flight and weapons controls at the same time and these operations must not divert his attention from the visual input. When the pilot must look at a multifunction controller while operating it, he is denied outside-world sensory inputs for that period. If heavily involved in NOE flight, the pilot cannot afford to look in at all. The problem here is that the channel capacity of the human organism as a

processor or receiver of information is limited. Two information-processing tasks can be performed simultaneously if they utilize different processing steps. Thus, for example, a person can drive a car and listen to a conversation, but cannot listen to one conversation and type another at the same time.

The human operator is frequently viewed as a single-channel device capable of attending to only one visual signal at a time. If a pilot is looking at a display, he cannot be looking outside for enemy aircraft or ground targets. Since the basic mission of the helicopter pilot is involved with the outside world, anything which competes visually with this task reduces mission effectiveness. So, while there are powerful arguments for multifunction displays and controls, there are even more powerful arguments for confining their applications to systems which are operated during periods when temporary loss of visual input from the outside world or flight displays is not crucial.

The allocation of attention is not easy to understand; it is neither entirely stimulus-determined nor entirely voluntary. For selectivity to occur, all stimuli must first be identified and then the unwanted ones discarded without their intrusion upon awareness. This implies a mechanism that acts as a gate in selecting what enters consciousness and what does not. Attention is first attracted by some characteristic of the stimulus which catches the subject's eye or ear but the far more important part of attention comes from some internal direction on the part of the subject. The limit does not seem to lie in the overall information level but rather in the number of physically separate inputs we can handle or in the number of separate sequences of interdependent items we can follow. The party phenomenon is a good example. You are at a party and someone is talking to you. You are, however, attracted by some characteristic about a person who is standing near you in a neighboring group. As you pretend to be listening to the individual who is talking to you, your eyes drift in the direction of the other person, and perhaps you even try to listen to what is being said in the next group. Even though you cannot hear anything coming from the other group, the fact that your visual attention is directed there, blocks out most of what is being said to you. If anyone were then to ask you what the person talking had said, you would remember embarrassingly little.

When we choose to look at something, we usually do so by directing the line of sight of the eyes to the target. This action positions the retinal images of the target over the foveas. The process of visually searching for specific information can change when the searcher is placed under stress, or when the task is made very difficult, or when the penalty for failure is very severe. Our eyes are never still and are always moving very rapidly. Most of these movements improve the quality of perception. But eye movements are not necessary in order to shift attention -- perceptual images can be scanned in a manner similar to the way eye movements permit scanning of the physical world. Attention can be directed to different locations within a field of view without eye movements. We can be sensitive both to the whole field and to only specific parts within each glance.

The measurement of pilot eye fixations and movements about the instrument panel has been a research area of interest for many years. The inspiration for much of this work was the belief that the cues used by the pilot in control would be given by noting the instruments his eye was examining. This has been shown to be only a partial picture because of the pilot's ability to operate very effectively on parafoveal information and, of course, on reinforcing (i.e., nonconflicting) motion and aural cues. Furthermore, there is considerable evidence that in "stare mode" circumstances, fixing the eye point of regard serves merely to stabilize the eyeball for good parafoveal viewing (e.g., of "streamers") and is unconnected with the information actually used or even perceived by the pilot. So, at the outset, we cannot say that what is being fixated necessarily corresponds to an input. A pilot does not necessarily see what he is looking at, nor does he necessarily look at what he is seeing.

Experiments have shown that when people view a series of dials they appear to be able to take in more information than might be expected by means of peripheral vision, once they have formed a hypothesis of what is likely to happen there. It appears that they can confirm or reject such an hypothesis without direct vision of the instrument such as would be required for accurate quantitative readings so that it seems some information can be usefully extracted even from the extreme periphery of the visual field. An experienced pilot will line up the needles on the instrument dials in the green so that they are all oriented in the same direction. He knows immediately when one moves off the green even if he is not looking at it.

Explanations of the limits on our ability to handle information are most frequently concerned with the generation of responses to one or more incoming messages. On the other hand, it is now well known that stimulus-response compatibility may be a vital factor in determining the maximum rate at which information may be handled. There is considerable evidence that there can be an interaction of the information presentation scheme with decision strategy. The more complex the response, the more the interference with the reception of information. Incompatible stimulus-response relationships will produce longer reaction times than compatible ones.

As an example of stimuli-response conflicts, consider the results of an experiment designed to investigate pilot performance and workload associated with the use of three different symbology sets for the PNVs. Analysis of performance measures indicated that the major errors were primarily associated with altitude control. Though not borne out by all objective performance measures, five of the six pilots reported that they preferred the symbol for altitude placed on the left side of the display, which was the case in two of the symbology sets. This curious subjective report led to an experiment intended to investigate the effects of stimulus-response compatibility. Typically, in a helicopter the altitude, which is controlled by the collective in the left hand, is displayed to the right of the pilot's line of sight while the airspeed, controlled by the cyclic in the right hand, is displayed to the left. This arrangement suggests an incompatibility between the stimulus (display) and response (control). This was posited as the basis for the subjective reports of preference for a more compatible arrangement with the altitude presented on the left and airspeed to the right of the display. Under normal flying conditions, the effect might not have been experienced. However, under the high workload of the PNVs NOE simulation experiment, the lack of stimulus-response compatibility apparently became noticeable. A simple experiment was designed and executed to test the differences between compatible and incompatible display-response conditions in a discrete closed-loop control task with representative helicopter dynamics. The results showed a statistically significant difference of 130 msec in reaction time in favor of the stimulus-response compatible group. This result suggests that it takes 130 msec more of information processing time for the incompatible arrangement than the compatible with no other task present. In high altitude cruise flight, this is insignificant; in NOE flight the difference can be critical.

Another consideration is the existence of competition between outputs at the behavioral level, for example, when you try to pat your head while rubbing your stomach with a circular motion at the same time. There is selection of attention associated with the outputs just as there is among the inputs. In a critical flight control situation, will a pilot be able to use a four-axis, side-arm controller while simultaneously operating a multifunction key-board with his other hand?

There is also a question as to which sensing modality to use for displaying particular information. Some aspects of human capability may involve modality-specific faculties. It may be possible to enhance performance of certain tasks by arranging the information input to match effectively with these faculties.

There has been a great deal of research aimed at understanding the psychophysiological aspects of perception but very little effort has been given to

interpreting the results of this research in terms of man-machine design. However, it is essential that the characteristics of the "man" component should have a major influence on the design of the "machine" component if an effective system is to be created. The two components cannot be treated in isolation. The human factors of cognition and perception must be considered in developing improved systems of cockpit displays and controls. Displays and controls must be designed to be compatible with the basic concepts of human cognition. The amount of information that can be processed has limits that may be inherent in the nature of the process or may be due to the nature of the information itself.

#### IV. What is Needed?

A weapon system is no more effective than its human operators. The thesis that the pilot is now both pivotal to mission success and, as a consequence, acts as the ultimate constraint on mission performance is now generally accepted. This human component of the flying weapon system continues to be pushed closer to his physiological and psychological limits. This has never been more true than in the NOE flight operations at night or in adverse weather. Under the circumstances of combat NOE flight operations, the time and attention span which the pilot can give to system operation is exceptionally limited and, regardless of the logic and elegance of the control and display functions provided, he will be unable to use them unless their operation can be made in a near instinctive and natural manner with minimum distraction from the flying task. The system should be designed as an extension of the operator's sensory, muscular, and cognitive capabilities. To qualify as an effective system, the machine with its sensors and controllers must be compatible with the capabilities and limitations of the human operator. We can change the design of aircraft and aircraft components, but we cannot change basic human capabilities and limitations.

Rising personnel costs raise questions about reducing crew size. Greater and more diverse vehicle and weapon capabilities raise questions about the crew's ability to cope and employ. A common concern is the congestion on the instrument panel and the lack of space for adding new devices. New systems compete for space. Rising costs and increasing complexity of equipment raise questions about the inclusion of such equipment. In all cases, the tradeoff process must look at the effects of any decision upon mission effectiveness, and this must be done before major expenditures for prototype equipment.

While we are considering dramatic changes in cockpit design as a consequence of the flexibilities afforded by electronic displays and by the new flight-control technology paced by digital microprocessors, let us not forget that these are merely the inputs and the outputs of the human controller and, as with every other element in the system, his I/O requirements must be satisfied. The proper design of the Information Display System can maximize the efficiency of transfer of information just as the Flight Control System design will affect the efficiency of control; however, neither of these necessarily reduce the cognitive or decision-making workload of the pilot. Only an artificial copilot that can take over the responsibility for certain management and control functions can reduce the requirements on the human pilot's data processing system. The piloting tasks require both cognitive and motor skills and, therefore, automatic performance of any of these requires some degree of artificial intelligence. Much information (e.g., aircraft systems status) will have to be automatically monitored and only presented to the crew as needed. Some events will require corrective action to be performed automatically; system recognition of the event and display of the required corrective action to the pilot is not sufficient.

Of course, the helicopter could be made easy to fly or even to fly itself, but such benefits are costly. Automation can significantly increase cost and complexity and adversely affect reliability and maintainability. To be cost effective, the military helicopter must make full use of its pilot and his capabilities.

However, he must not be overloaded to the extent that his mission performance is degraded or his margins for errors are decreased until there is an increased susceptibility to accidents.

Modern microprocessor technology and display systems make it entirely feasible to automate many of the cockpit functions previously performed manually. The question today is not whether a function can be automated, but whether it should be and, if so, how. While automation can greatly enhance system performance, it does not generally reduce the demands on the operator. There is serious concern about the impact of automation on aircrew performance, workload, and ultimately, safety. The requirement for ergonomics input into the design and operation of systems is in no way diminished by automation. The basic issue is to determine the appropriate distribution of duties between human aircrew and artificial intelligence to achieve the objective of the man-machine system; namely, to accomplish a prescribed task with satisfactory performance at acceptable workload for reasonable cost.

There are advantages and disadvantages of having humans in the control loops. Humans need to be motivated and tend to be poor monitors and watch-keepers. They are susceptible to sequential errors where a step is left out of a procedure and capture errors where a familiar procedure is substituted for an intended new procedure. On the other hand, humans provide flexible control and can invent new procedures and adapt old methods to new circumstances. Human visual perception is hard to replicate. Advantages of automation include increased capacity and productivity, relief from small errors, and relief from and more precise handling of routine operations. However, the question is whether the overall pilot workload is reduced or increased by automated systems intended to aid the pilot.

There are many fundamental issues which psychologists, physiologists, and engineers are sincerely trying to address. The questions that have yet to be considered are: Which duties should (must) the human perform in a given task? What control and management functions must he retain to perform these satisfactorily? What information (cues) does he really need to perform them? How are these cues weighted in arriving at his control strategy? How should (must) the information be provided (e.g., continuously or sampled; visually, audibly, or tactually).

The role of the human operator in control systems is evolving towards that of a supervisor who plans, sequences, and coordinates, and away from strictly manual control. The human is valued in these systems precisely for his abilities to process information and to provide an adaptive decision-making capability in an otherwise automated system. In future aircraft, he will monitor the input and output variables of the automatic controller (via push-buttons or continuous control devices) as a function of mission phases, environmental conditions, or as a consequence of failures. The operator's cognitive and perceptual activities will become more important than his skill at motor tasks. Under what conditions will the human acting as a monitor be a better (or worse) failure detector than the human as an active controller/operator? Is there a significant time delay when the human changes from passive monitor to active controller? What should be the form of the interaction between the operator and the automatic system?

We cannot create a symbiotic relationship between the human operator and the automated computerized system unless we understand both elements equally well. Human-machine interfaces should be as natural and consistent with the operator's personal style and decision strategy as possible. A person's efficiency in responding to his environment depends not just on the efficiency of the machine at his disposal but on how well it is matched to his processing limitations.

With the CRT, the designer can display anything the pilot needs -- if he only knew what the pilot needed. Since information may now be presented on a sampled basis rather than being continuously present, it becomes necessary to specify the ease with which certain types of information should be made available. The need for information and the most efficient way to present it therefore represents a

significant effort in human engineering, and one without a great deal of precedent in systems such as those currently being considered.

In summary, our concern is that the human controller has become the limiting element in the man-machine system required to perform our current Army helicopter missions. We have little confidence that our current concepts for advanced cockpits are compatible with the sensory and perceptual requirements of the pilot or that the displays are compatible with the controls. We are concerned that we may be increasing rather than decreasing the pilot's cognitive workload by some of the current applications of CRT's, micro-processors, integrated avionics, multi-mode SCAS, automation, etc. We are concerned that we have reached the limits of human capability for processing the kind and the amount of information we are providing. Our interest is centered on the development of the cockpit. It is essential that the characteristics of human perception be factored into the cockpit design. Our goal is to present requirements with sufficient specificity, clarity, and scope to assure the Army that the final design would be suitable for the job and satisfactory to the aircrew. Pilot workload must be the driver. Regardless of the mission requirements, it is fruitless to continue to add to the information display if the system is already overloaded.

What is needed is a system of information display laws similar, conceptually, to our flight control laws. A great deal of the data that are needed to establish these display laws or principles already exist in the psycho-physiological literature. However, it is of limited usefulness because the emphasis is on the research itself, the terminology is often unfamiliar to the engineer, and the implications for design are not readily accessible. Consequently, the designer often fails to recognize the relevance of the information to his problem.

In the crew systems arena, we are not going to advance capability until we know and define the behavioral, physiological and psychological capabilities and limitations of the biological element. Until the engineer understands the requirements and limitations of human cognition, he cannot design the displays and controls with assurance that the pilot can perform the prescribed task with tolerable workload. The questions of when, why, and how to apply automation can only be answered by a completely interdisciplinary approach to the overall man-machine design of combat aircraft. The solution requires the integrated efforts of control and display engineers, physiologists and psychologists who are currently working independently (Fig. 8).

\*NOTE: The lack of a reference list does not imply that all the thoughts expressed originated with the authors. Rather it reflects the desire to meet the Forum Committee's limit on number of pages. A suggested reading list on the subject will be provided by the authors on request.

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| <p><b>1. Data management and transfer</b></p> <ul style="list-style-type: none"> <li>• Monitor engine and systems displays</li> <li>• Monitor advisory panel</li> <li>• Monitor master caution/warning lights</li> <li>• Monitor performance and power</li> </ul>                         | <p><b>4. Communication</b></p> <ul style="list-style-type: none"> <li>• Select radios</li> <li>• Enter frequency</li> <li>• Operate voice security system</li> <li>• Comms. ground troops</li> <li>• Comms. scout on station</li> <li>• Comms. unit operations</li> <li>• Comms. artillery control</li> <li>• Comms. attack helicopters</li> <li>• Comms. tactical air</li> </ul>   | <p><b>6. Fire control</b></p> <ul style="list-style-type: none"> <li>• Prepare weapon systems</li> <li>• Designate targets</li> <li>• Select appropriate weapon</li> <li>• Perform target lock-on</li> <li>• Monitor target</li> <li>• Launch/fire weapon</li> <li>• Assess damage</li> </ul> |
| <p><b>2. Flight control</b></p> <ul style="list-style-type: none"> <li>• Adjust flight controls</li> <li>• Monitor flight displays</li> <li>• Avoid terrain</li> <li>• Avoid obstacles</li> </ul>   | <p><b>5. Target acquisition and identification</b></p> <ul style="list-style-type: none"> <li>• Select sensor</li> <li>• Perform pop-up</li> <li>• Perform external observation</li> <li>• Monitor sensors</li> <li>• Adjust sensor controls</li> <li>• Identify targets</li> <li>• Designate target</li> <li>• Handoff target</li> <li>• Maintain designation</li> <li>• Observe hit</li> <li>• Terminate designator</li> <li>• Assess damage</li> </ul> | <p><b>7. Threat detection</b></p> <ul style="list-style-type: none"> <li>• Perform exterior observation</li> <li>• Select sensors</li> <li>• Respond to sensors</li> </ul>  |
| <p><b>3. Navigation</b></p> <ul style="list-style-type: none"> <li>• Scan flight path</li> <li>• Identify terrain</li> <li>• Cross-check terrain against map</li> <li>• Adjust speed</li> <li>• Monitor heading</li> <li>• Operate flight computer</li> <li>• Receive nav aids</li> </ul> | <p><b>8. Countermeasures</b></p> <ul style="list-style-type: none"> <li>• Perform evasive flight maneuvers</li> <li>• Perform mask maneuver</li> <li>• Engage threats</li> <li>• Select appropriate countermeasure</li> <li>• Activate appropriate countermeasure</li> </ul>  |   |

Fig. 1 - Major Task Breakdowns During Critical Portion of LHX (Scout) Mission

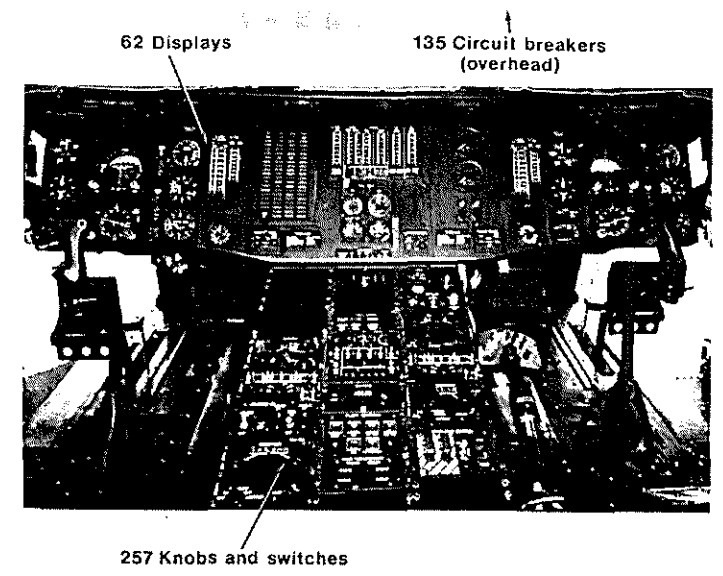


Fig. 2 - UH-60A Black Hawk Cockpit

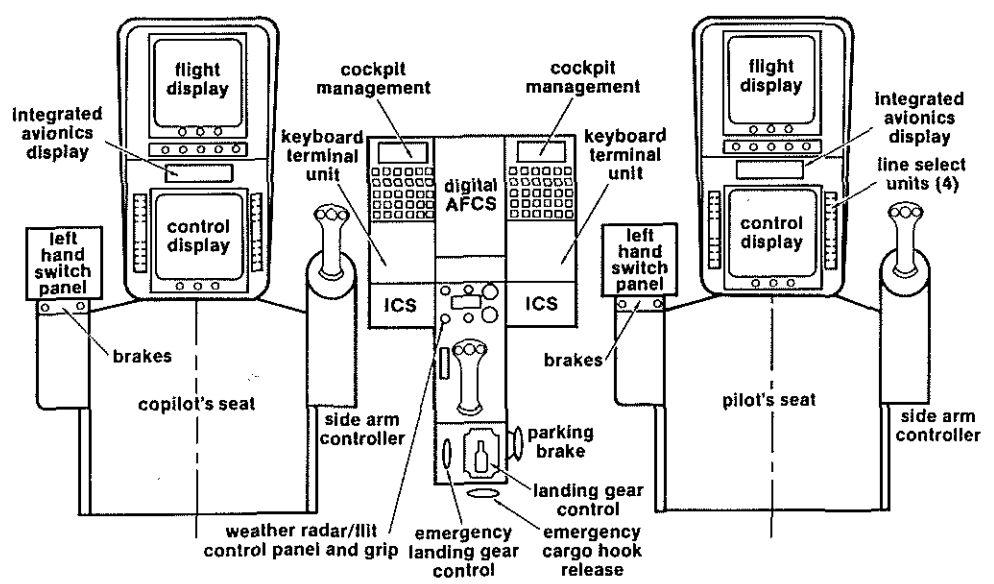


Fig. 3 - The "Integrated" Cockpit is not Necessarily the Answer

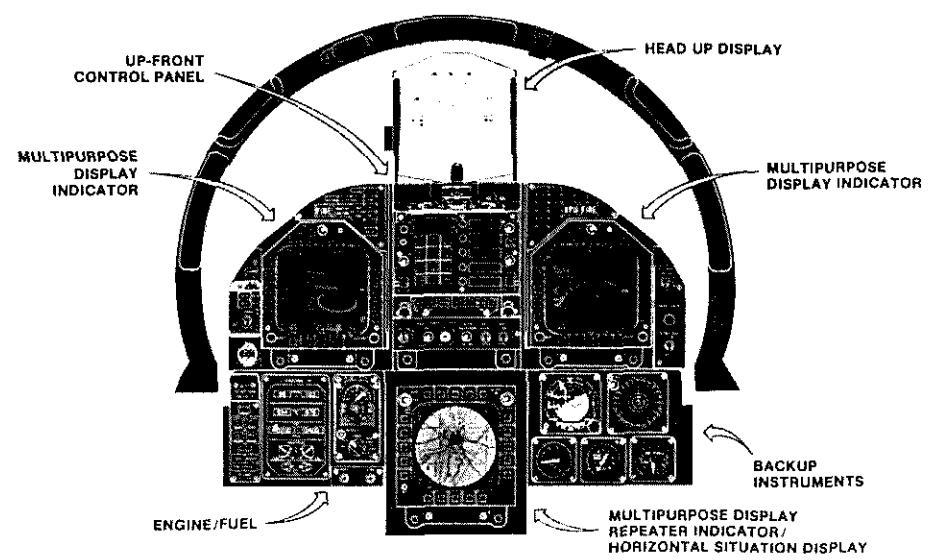


Fig. 4 - F/A-18 Hornet Cockpit

