FLIGHT CREW TRAINING TECHNOLOGY--A REVIEW

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There is a technology of flight crew training. It is based upon human learning processes, and it involves the manner in which information, cues, and practice opportunities are presented to a learner. In pilot training, the term "training technology" has been closely associated with the use of simulators, generic training devices, and various classroom training aids. We must not be misled into thinking that these equipment items comprise training. In fact, they do nothing more than provide convenient means by which information can be presented, cues can be manipulated, responses can be practiced, and guidance and feedback to the student can be controlled.

This paper devotes a good bit of attention to simulators and other training equipment, but the most important message it contains is that pilot training is a process that is not dependent upon costly training equipment. Such equipment may be an important factor in making the training process easier to administer and control, but the single most important factor in efficient and cost effective training is the training process, that is, the way in which equipment and training resources are used to present information and cues, and to provide and reinforce practice.

In the good old days, pilots learned to fly in airplanes. Not a lot was known then about how skills are learned, and pilot training was largely a process of self-instruction and surviving. In the French Foreign Legion prior to World War I, for example, pilot training consisted primarily of lectures by instructors on the ground and solo practice in single seat airplanes. An instructor did not fly with a student until the student had mastered basic airplane maneuvers and had completed a solo cross-country flight. Each trainee was on his own to find the cues necessary to aircraft control and to work out and practice responses to those cues that would enable him to survive each flight. The trainee could figure out the consequences of his responses, but, without an instructor on board there wasn't much guidance to keep him from making mistakes while he learned. Under such trial-and-error learning conditions, training was expensive, particularly when measured in terms of broken bones and airplanes, and trainees killed (Footnote

1).

Not all pilot training was conducted solo, of course. In the beginning, so to speak, the Wright brothers gave dual instruction to would-be pilots who purchased their airplanes, but the brothers did little more than function as safety pilots while their trainees learned to fly through trial and error, much the same as was done in the Foreign Legion. One would hardly describe such experiences as applications of training technology.

But the beginnings of a technology of flight training were emerging. The Foreign Legionnaires discovered that a plane with little or no fabric on its wings made a pretty good ground training device. In such a device, pilots could at least learn a little about aircraft handling while taxiing fast without the danger of becoming airborne before receiving the first lecture on takeoffs and landings.

Other, more imaginative, people were also attempting to advance the technology of flight training. The device shown in Figure 1 is an early generic flight trainer. There is no surviving evidence that it was effective. Like a lot of training devices used in flight training today, it filled a block of time in a training program. Since it did that quite well, its effectiveness probably was not seriously questioned.

We sometimes think that training technology was invented by pilots. That is not true. The need to provide training even when operational equipment could not be used for that purpose has been around for a long time and in many areas of activity. For example, General Wood resorted to simulation when horses were not available to train his troops, as is shown in Figure 2. Similarly, flight training devices probably would not even have been developed if it were not for the fact that dual-control training aircraft were not available and solo flight training was inefficient and presented unacceptable risks to trainees and equipment.

One might debate whether General Wood invented a horse simulator or a generic trainer. The issue, presumably, is whether he had simulated a particular horse or a more general class of animals that might have included mules.

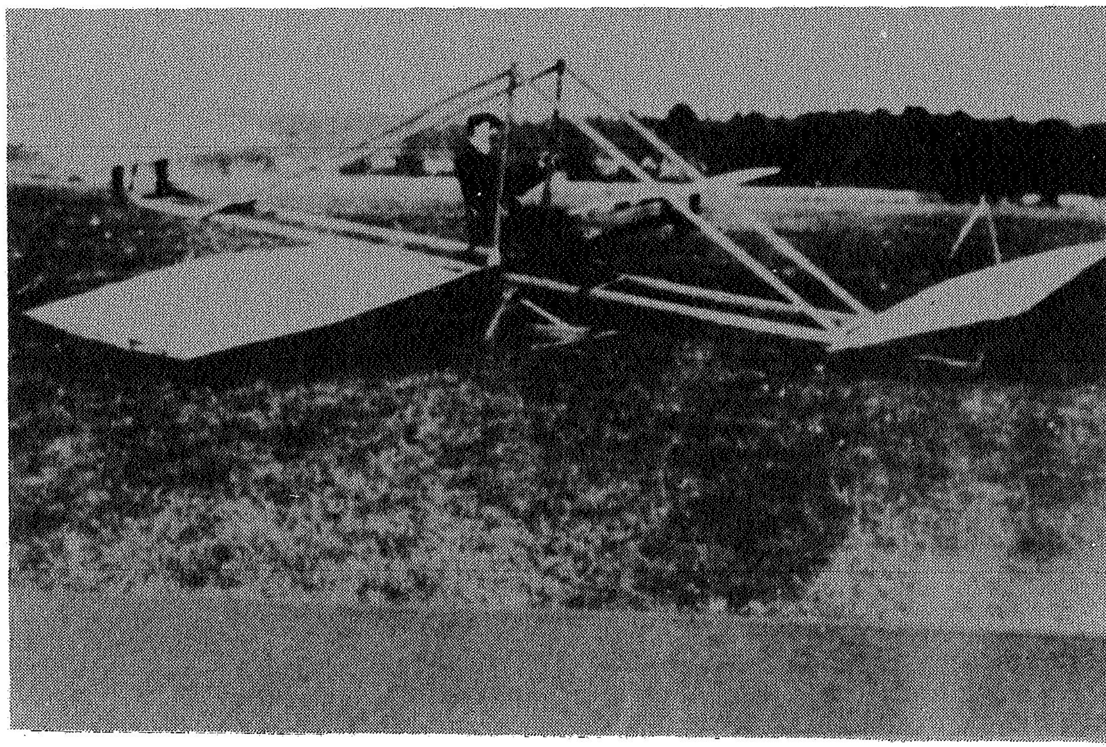

Figure 1.- An early flight training device.

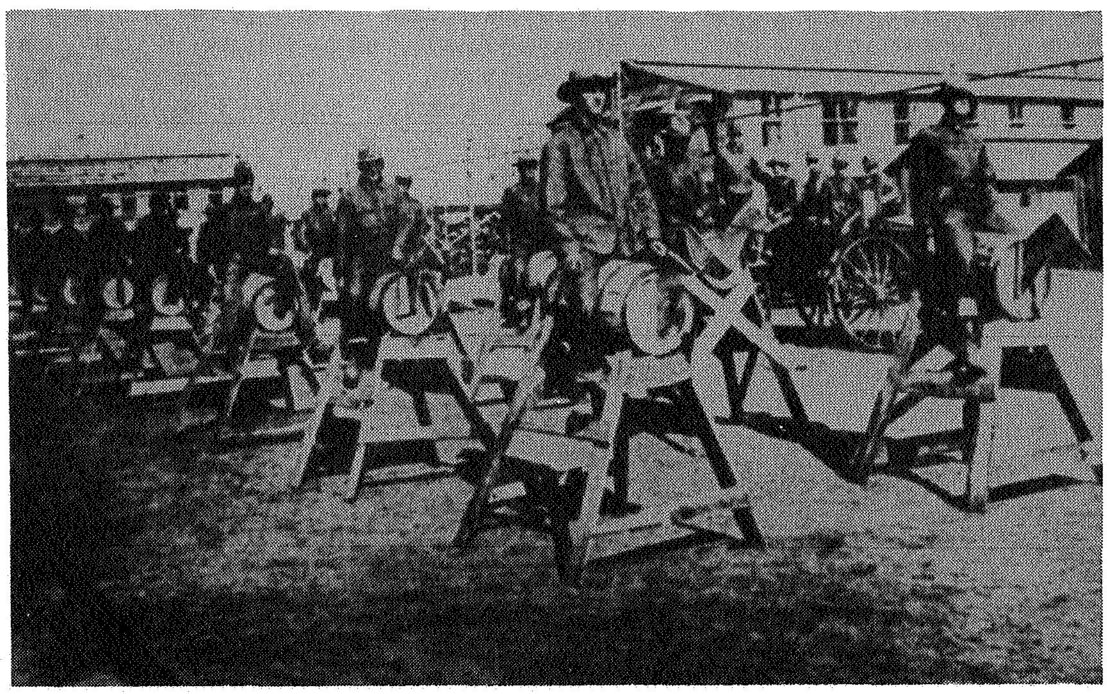

Figure 2.- General Wood's troops training on simulated horses.

His device probably should be classified as a simulator. The evidence suggests that he was attempting to make it as much like a horse as available technology and resources would permit, because he thought that realism is necessary in training.

The concept that realism is necessary to transfer of training, that is, to assure that training received in a trainer will transfer to operational equipment, underlies the design and use of training simulators even today. The concept is based upon a theory by an early psychologist, Edward L. Thorndike (1931). His theory would suggest that transfer will occur to the extent a simulator and the equipment simulated share common elements. A later theorist, Charles E. Osgood (1949), developed a "transfer surface" based upon a common elements theory. Using Osgood's transfer surface, one could map an assumed relationship between elements or features of a simulator onto the equipment simulated. Where there is one-to-one correspondence, according to Osgood, transfer of training will be positive and high. Less than one-to-one correspondence will yield decreasing transfer, to the point that none will occur.

From these theories, it was an easy step to assume that physical correspondence between a simulator and the system or equipment simulated was the key to transfer of training. Largely for this reason, the evolution of simulation became primarily a matter of technological advancement to make simulators realistic, accurate, and comprehensive representations of a particular system. Some people refer to realistic simulators as "high fidelity".

In 1929, Edwin A. Link introduced the forerunner of modern flight training simulators (Figure 3). The influence of the then-current theories concerning realism and training effectiveness are evident in its design. Although the Link trainer was used primarily to teach instrument flight, the device was made to look like an airplane, complete with wings and tail. Even when Link later added a hood to his device's design to make it a more realistic instrument trainer, the wings and tail were retained. This basic device, complete with wings and tail, was widely used in military flight training programs during World War II (Footnote 2).

Following World War II, training technology evolved to the point that the need for some of the realism that

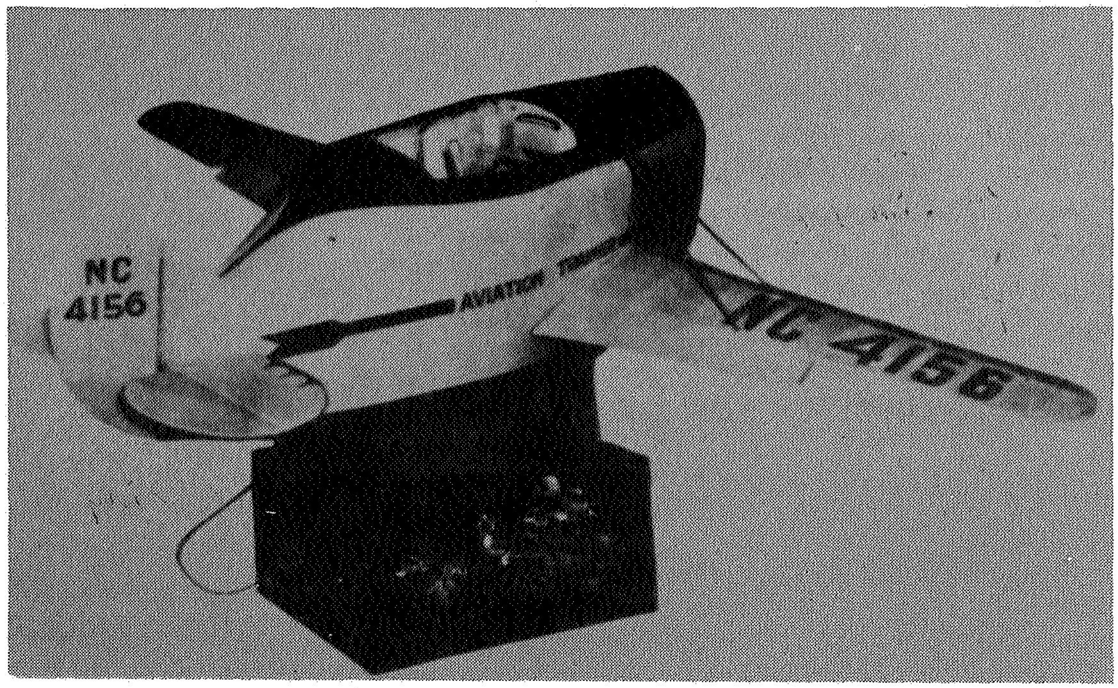

Figure 3.- 1929 flight trainer by Edwin A. Link.

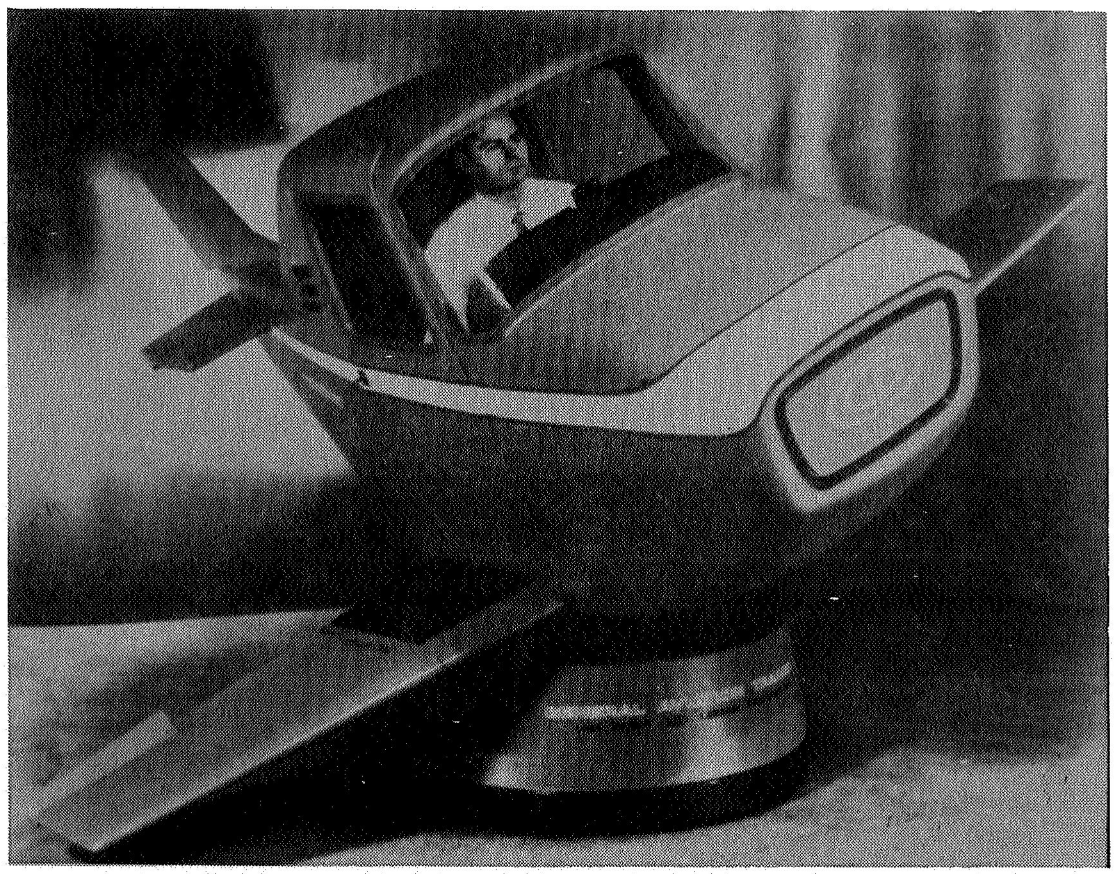

Figure 4.- Link GAT-1 trainer.

characterized flight training simulators was being questioned. The relevance of some simulator features to the training objectives, such as the relevance of external structures of the airplane to instrument training, was not obvious, so such features were omitted. However, the realism inside the cockpit or in the simulated flight characteristics was not being questioned. The only limitations there were the state of engineering art.

Even then, it was not possible to simulate a particular aircraft with high realism. The Link trainer of the early post-war era was an instrument trainer that simulated the instrument environment. It responded to pilot input with many of the characteristics of airplanes, but it did not simulate with any accuracy a specific aircraft. It was a generic trainer rather than a simulator.

In the 1950s, training devices were viewed as increasingly important due to the rapidly increasing complexity of aircraft and the corresponding increase in the complexity and cost of pilot training. It was reasoned that more realistic training devices would produce increased transfer of training. Consequently, attempts were made to develop devices whose features corresponded precisely to features of specific aircraft.

Thus, the modern flight simulator was born, at least conceptually. Because of engineering limitations at the time, these simulators were more realistic in cockpit appearance and switch functions than in flight characteristics. Extra-cockpit visual displays began to appear at about the same time, so the training to be conducted in the new simulators was not limited necessarily to instrument flight. Motion simulation was not new, of course, having been included in the design of the very earliest flight training devices (e.g., see Figure 1).

As we came to recognize the potential of simulators, the transfer of simulator training to the operational equipment was more and more the critical issue in using these devices. Accordingly, pilot training technology became increasingly dependent upon Thorndike's common elements, a theory which suggested an objective basis for designing transfer into simulators. Aircraft-specific simulators began to replace generic training devices. There were some who resisted the trend, however, primarily because simulators were becoming increasingly costly, and several companies developed relatively low-cost generic flight trainers. For example, Ed Link's company updated one of its earlier product designs, complete with wings and tail (Figure 4), but generic trainers had relatively little appeal to pilots who had begun to expect high realism in simulators. Nevertheless, some of these devices were used effectively in a few pilot training programs. One, for example, a generic trainer for twin-engine airplanes, was demonstrated to be effective when used in a highly structured training program with specially trained instructors. In fact, even though it had no visual display, training in it was shown to reduce by about half the time required for subsequent transition training involving visual flight maneuvers and landings (Caro, Isley, and Jolley, 1973). The acceptance of generic training devices by the flight training community increased when their cockpits were configured like specific aircraft, thus presumably increasing the number of common elements they shared with the aircraft simulated.

Probably no one was more convinced that Thorndike's common elements theory was the real basis for the effectiveness of simulator training than were the people in the Federal Aviation Administration. If a simulator did not look, feel, smell, and bounce around like the aircraft simulated, the FAA apparently reasoned, its transfer of training value had to be low. Consequently, realism became the major factor in the design of simulators for the airlines, and airline design practices were soon reflected in military simulators as well. Even with respect to motion, realism was the goal, limited only by the rates of movement and physical displacement that could be provided within manageable spaces. Similarly, as soon as visual technology permitted realistic appearing airport scenes to be simulated, FAA rules were made to permit more training to be conducted in simulators that had high realism in visual scenes.

But is all that realism and cost really necessary to effective pilot training? The answer to that question is both yes and no. Yes, realism is necessary if we choose to rely upon it instead of training technology, and if our training programs resemble those of the French Foreign Legion in World War I; that is, if our simulator training consists of turning a pilot loose to figure out, more or less on his own, how to fly, or even if we give him an instructor who teaches in the simulator just as he would in the aircraft. However, if we are willing to use simulators in ways that are not dependent upon their physical correspondence to aircraft, the answer is no, realism is not necessary for much of the training pilots must receive.

Studies involving simulators of intentionally low realism have demonstrated that effective training can be conducted in low-realism devices (Grimsley, 1969). In fact, at least for some tasks, training in low-realism simulators has enabled pilots to perform as well in aircraft as could other pilots trained in high-realism simulators, or even in the aircraft themselves (Prophet & Boyd, 1970). In these studies, the low-realism simulators had training value equal to that of very high-realism simulators.

More will be said in this paper about low-realism simulators. First, it is necessary to define a few terms that will help one understand why low-realism simulators can have such high training value.

Pilots depend upon cues to assess the status and conditions of their aircraft, to initiate actions, to guide their performance, and to signal when an action should be altered or ended. An important concept in flight training technology, then, is the concept of cue and the distinction which exists betweena cue and a stimulus. Stimuli are the bases for cues, but a stimulus is not a cue by itself. The term "stimulus" refers only to a physical object or event than can activate a sense organ. The illumination of a light on an instrument panel is a stimulus that is sensed by the eye. Movement of a control wheel provides pressure that is sensed by nerves in a pilot's hand and arm. The training task is to learn the meaning of such stimuli, to derive pertinent information from them, so that the proper response can be made.

As these meanings are learned, stimuli become cues. In other words, a cue is a stimulus that has acquired meaning. A panel caution light, for example, conveys information that is understood by the pilot. The goal of pilot training is to learn the informational content--the cueing value--of task-relevant stimuli so that precise actions can be taken. This role of cues, as opposed to stimuli, has a major implication for simulator design and use. The implication is that cue information available in a particular simulator, rather than stimulus realism per se, should be the criterion for deciding what skills are to be taught in that simulator.

Skilled pilot performance is dependent upon making appropriate responses to cues. Therefore, the two most important training technology considerations are how one learns to interpret cues, and how one selects the correct responses to be made to those cues. Interpreting cues and selecting appropriate responses involves a process called discrimination. Discrimination is the recognition that a given stimulus or response has a meaning different from that of another stimulus or response. Although two lights on the panel may be physically identical and have the same stimulating effect upon the pilot's eyes, he must discriminate between these lights and make a unique response to each when it illuminates.

The simplicity of this definition of discrimination should not suggest that discriminations are simple processes, or that they can be easily learned. The more complex the skill, the larger the number of moment-to-moment discriminations that must be made. Also, as task complexity increases, discriminations may depend upon very subtle differences in entire patterns of numerous stimuli. The discriminations that must be learned when practicing landings in a new aircraft or during cockpit resource management training, could be quite numerous and complex. For tasks that involve execution of relatively fixed procedures, the discriminations might be less numerous and complex. The principal difference between a novice and an expert when performing complex tasks is that the expert has learned to discriminate subtle stimulus differences that a novice cannot. He can also translate the subtle meanings of such stimuli into equally subtle control movements or other responses.

Another term that is important to an understanding of training technology is generalization. Generalization refers to the use of previously learned skills in situations that are different from the situations in which they were learned. For example, engine run-up procedures learned in a low-realism cockpit mock-up can be generalized to, that is, performed in, a high-realism simulator or in an actual airplane. They can be performed even though the two may differ considerably with respect to actual stimuli, because the meanings of cues present in the mock-up are similar to the meanings of corresponding cues present in the aircraft.

In fact, all cues learned in simulators can be generalized to, that is, subsequently utilized in, aircraft to the extent that the cues have the same meaning in both the simulator and the aircraft. The physical stimuli can vary. Instruments can be of different sizes or configurations; visual displays can resemble geometric patterns more than real-world scenery or can use symbols to represent objects; platform motion systems can be restricted to accelerations of brief duration and movements of small distances. After all, even the most sophisticated simulator provides at best a low-realism representation of many of the real-world capabilities of the aircraft simulated. Therefore, the training given in the simulator must concentrate upon cues and responses that can generalize to the aircraft and its mission. To the extent that appropriate cues and responses cannot be represented in a particular simulator due to technology or cost limitations, the skills associated with them must be learned in the classroom, in other devices, or in the aircraft itself.

About twenty years ago, the Army bought a very high realism procedures trainer for a new twin turbine powered aircraft (Figure 5) and asked us to assess its transfer of training value. We agreed to do so, but in addition, we used our knowledge of the training technology concepts reviewed above to construct a low-realism mock-up of the cockpit of the same aircraft (Figure 6) so that its training effectiveness could be compared with that of the considerably more expensive Army device.

The mock-up was made of plywood, dowel rods, and photographs. The material cost about $30, and it was constructed by unskilled labor. Physically, it was very unlike the aircraft it simulated. However, by careful design, it contained stimuli that could serve as cues to the procedural tasks that could be performed in the high-fidelity trainer the Army had developed. the responses to cues that were required in the aircraft could be practiced in the device.

The training program used with the mock-up differed slightly from that used with the more expensive Army trainer. The mock-up program emphasized the discriminations that were to be learned and the meaning, or cue value, of the physical features of the mock-up. It also called the trainee's attention to the generalizations that would be required in order for him to perform correctly in the aircraft after being trained in the mock-up.

The trainees were Army pilots who were qualified to receive transition training for the new airplane. None of these pilots had previous experience flying turbine powered aircraft. Three equally experienced groups of pilots were used during the evaluation of the training effectiveness of the two devices. One group was trained entirely in the Army-developed trainer, one group in the mock-up, and one in the aircraft itself. In addition, of course, each group received ground school instruction relevant to the tasks they were being trained to perform.

Following their training in the device or in the mock-up, each group was given a performance test in the aircraft, and its performance was compared with group trained only in the aircraft. The results are summarized in Figure 7 (Prophet & Boyd, 1970). The groups trained in the trainer and in the mock-up made just about the same number of errors during each training trial. On their first attempt to perform the procedures in the aircraft, which occurred after five training trials in the respective devices, their performance was about equal to the performance of the group

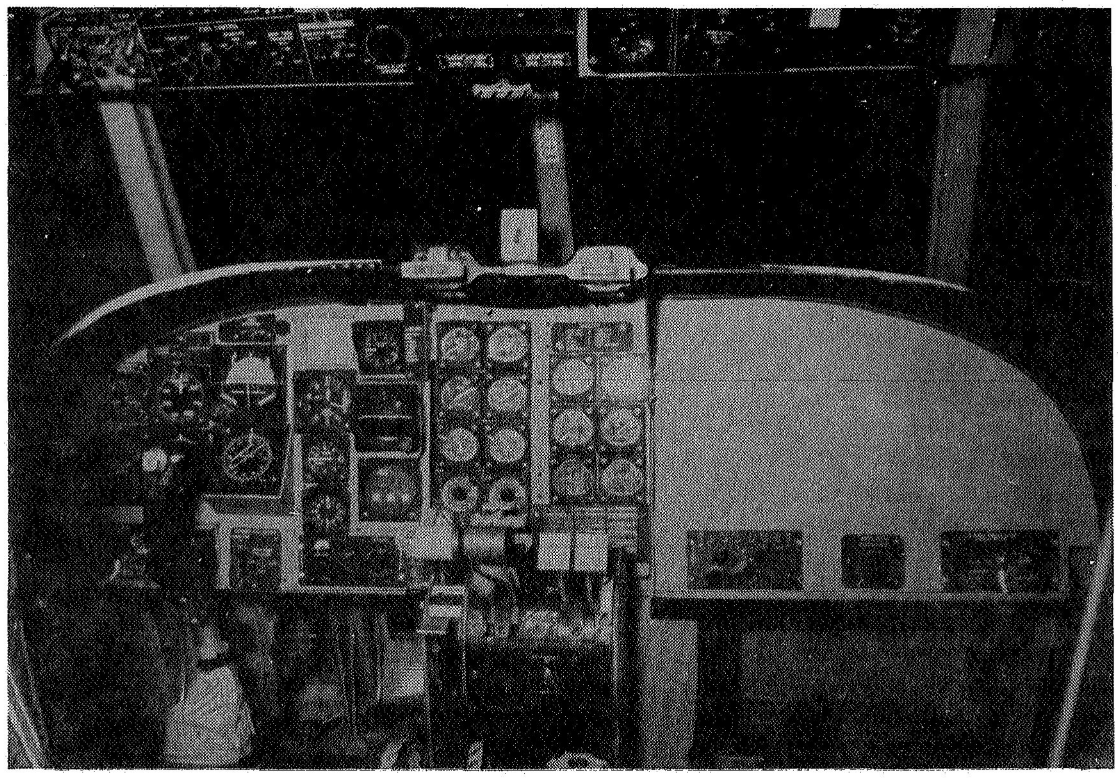

Figure 5.- Cockpit procedures trainer for U.S. Army OV-1 aircraft.

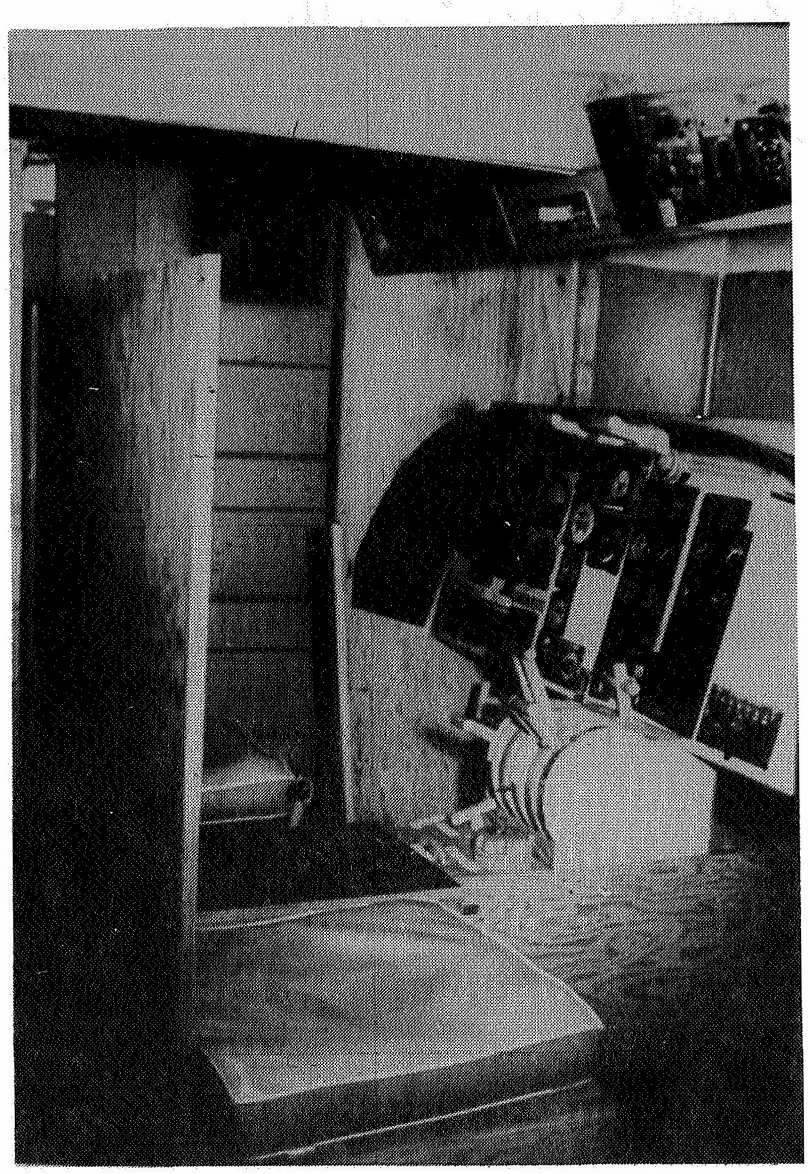

Figure 6.- Low-cost cockpit mock-up for OV-1 aircraft.

who had received all five of its training trials in the aircraft. Thus, the transfer of training value of these two simulators was essentially equal in spite of their wide discrepancy in physical realism. Further, the training received in either device was essentially as good as the training that could be provided in the aircraft.

Please note that both of the devices used in this study were simulators, not generic trainers. That is, they were designed to simulate precisely the cues and responses appropriate to a specific aircraft. Generic trainers should not be expected to result in the very high levels of transfer shown here, since the discriminations appropriate to a specific aircraft cannot be learned easily in generic trainers. The value of a generic trainer is more or less proportional to the extent of its similarity to the aircraft to which part-training performance is intended to generalize. The greater the dissimilarity, the more difficult it becomes to train the discriminations that will be required in the part-training aircraft.

Another example of a low-realism simulator is shown in Figure 8, although it is somewhat more realistic than the mock-up just discussed. This one cost about $4,300, including material and labor (Footnote 3). This simulator is a procedures trainer for the King Air airplane. None of the instruments or controls in this device are real. They are either photographs, molded plastic, or plywood, painted to resemble components of the airplane. Unlike the mock-up shown in Figure 6, the panel lights function on this device, a few in response to movement of specific controls, as they would in the aircraft. When the wiring got too complicated for the carpenters who built this simulator, switches were provided so an instructor could turn lights on and off, as appropriate, to trainee control movements and system conditions. Except for these lights, the simulator had absolutely no dynamic features.

But it had a feature that made it unlike any other airplane simulator. All of the instruments had pointers or other indicators that could be positioned manually by the trainee. When, for example, during engine start procedures, the trainee advanced the condition lever to the high idle position, he would also reach over to the N_1 indicator and set the pointer to 70%. Since the pointer would rise automatically to 70% in the aircraft in response to movement of the condition lever, the trainee's action in the

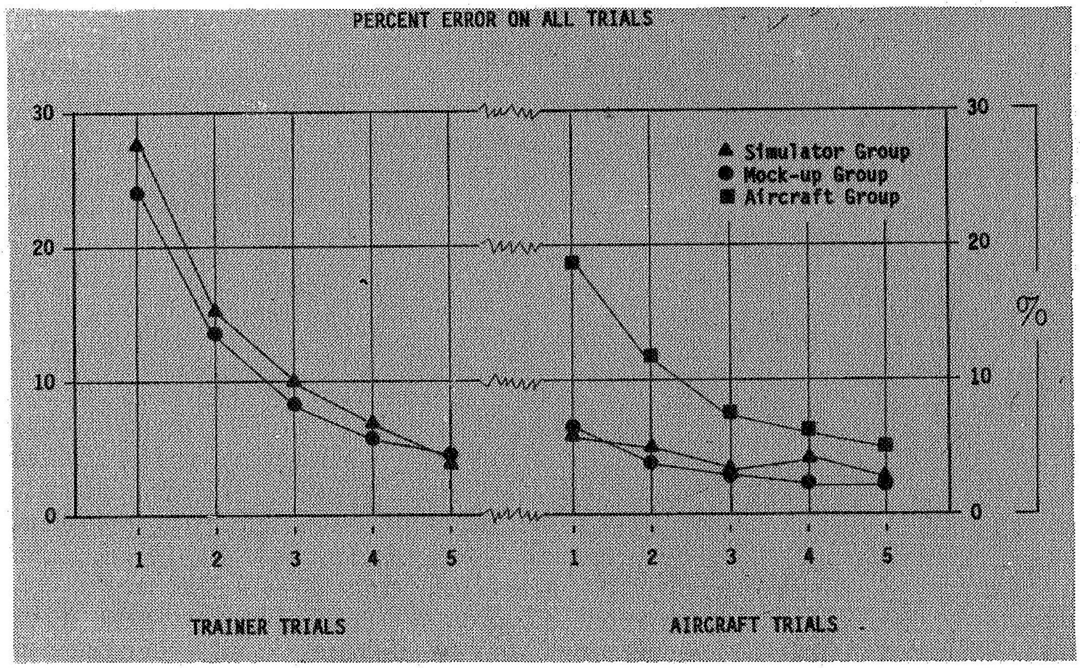

Figure 7.- Comparison of performance of pilots trained in a cockpit procedures trainer, in a cockpit mock-up, and in the aircraft simulated.

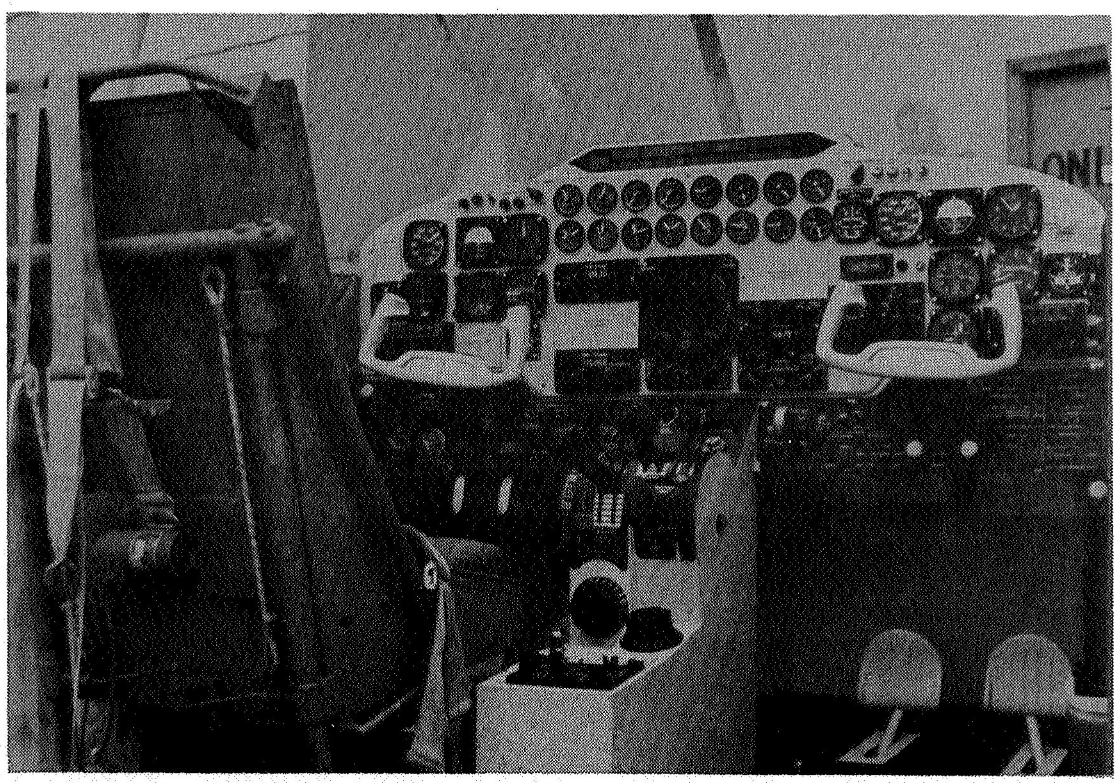

Figure 8.- Low-cost procedures trainer for the King Air.

simulator involved an intermediate step that was not necessary in the aircraft--the step of manually setting the pointer. However, the intermediate step enabled the trainee to practice the task to be performed in the aircraft, and also enabled the instructor to verify that the trainee did know precisely the value he should attain through movement of the condition lever.

During subsequent performance of the engine start procedures in the aircraft, the intermediate steps learned in the simulator rapidly disappeared, because they were no longer needed. During the first trial in the aircraft, the trainee would move the condition lever to the high idle position, reach over and touch the N_1 instrument, and verify that the instrument read 70%. During the second trial, he only pointed to the N_1 instrument. By the third trial, all of the intermediate steps had dropped out, and his performance was totally appropriate to the aircraft.

The intermediate steps that were performed in the simulator are known technically as mediators. That is, they come between, or mediate, the link between stimuli, cues, and responses. But a mediator is not necessarily an overt act such as physically positioning a pointer. <u>A mediator can be a word, phrase, or thought that helps a trainee connect a cue with a response or associate meaning with a particular stimulus, as in a verbal or other response that substitutes in training for a nonverbal action that must be taken subsequent to that training.</u> In brief, it is an <u>understanding of cues</u> and <u>responses</u>, and how they are to occur.

Another King Air simulator is shown in Figure 9. It is 4/10 scale and is printed on a single sheet of paperboard, ready to be cut out and assembled as shown. Transitioning pilots with no prior turbine experience, with the aid only of the aircraft flight manual, have been able to learn all the procedures associated with operation of the King Air using this simulator (Caro, Jolley, Isley, and Wright, 1972). In doing so, they have made extensive use of verbal mediation to discriminate stimuli, to establish cue meanings, to practice operation of the aircraft's controls, and to anticipate the generalizations that would occur during subsequent performance in more realistic simulators or in the aircraft itself. Through mediation, demonstratable transfer of training can be obtained by mental rehearsal of discriminations to be learned, of controls to be activated, and of switches to be repositioned. In fact, in a carefully structured and administered training program, such training can be just as effective and efficient as actually performing the procedures involved.

We are currently employing a higher technology version of the paper simulator concept which consists of an image on a computer display. With computer simulation, images are generated electronically and displayed on a video terminal, as is illustrated by the photograph of a computer-generated image in Figure 10, instead of printed on paperboard. The graphic appearances of the aircraft cockpit panels simulated is similar in both instances, although display size limits the computer simulation to a portion of the cockpit in order to present cues in sufficient detail to permit necessary discriminations to be made. In the example shown in Figure 10, only the fuel system controls and relevant display panels are included in the simulation. Thus, it is a fuel system simulator rather than a more complete aircraft simulator.

Using a computer, it is easier to represent the dynamics of the system being simulated than is the case with a paper simulator or some other low-realism approaches. Mediation is still required, however. The responses to be learned or practiced on such a simulator can be mediated through a keyboard, a light pen, or a touch-sensitive screen. In the simulation shown in Figure 10, for example, touching simulated panel switches results in their being repositioned with resulting simulation of fuel system dynamics, just as would occur in the aircraft were the actual switches similarly repositioned.

The simulation depicted in Figure 10 was generated through a computer program using the computer's graphic display capability. Current technology also permits the same kinds of simulation employing other image sources, including television. Simulations that use interactive videodiscs operated under computer control and in conjunction with touch-sensitive panels permit more realistic looking aircraft controls and displays to be used, as illustrated in Figure 11. By employing the mediating response of touching the proper portion of the image of the panel of a display generated from either computer or videodisc sources, a simulated switch may be repositioned (assuming use of a touch-sensitive screen).For example, the image of the lamp check switch in Figure 11 was used to simulate performance of the lamp check task, producing the display shown in Figure 12. (The location of the activated switch has been highlighted in this example to call the reader's attention to it.)

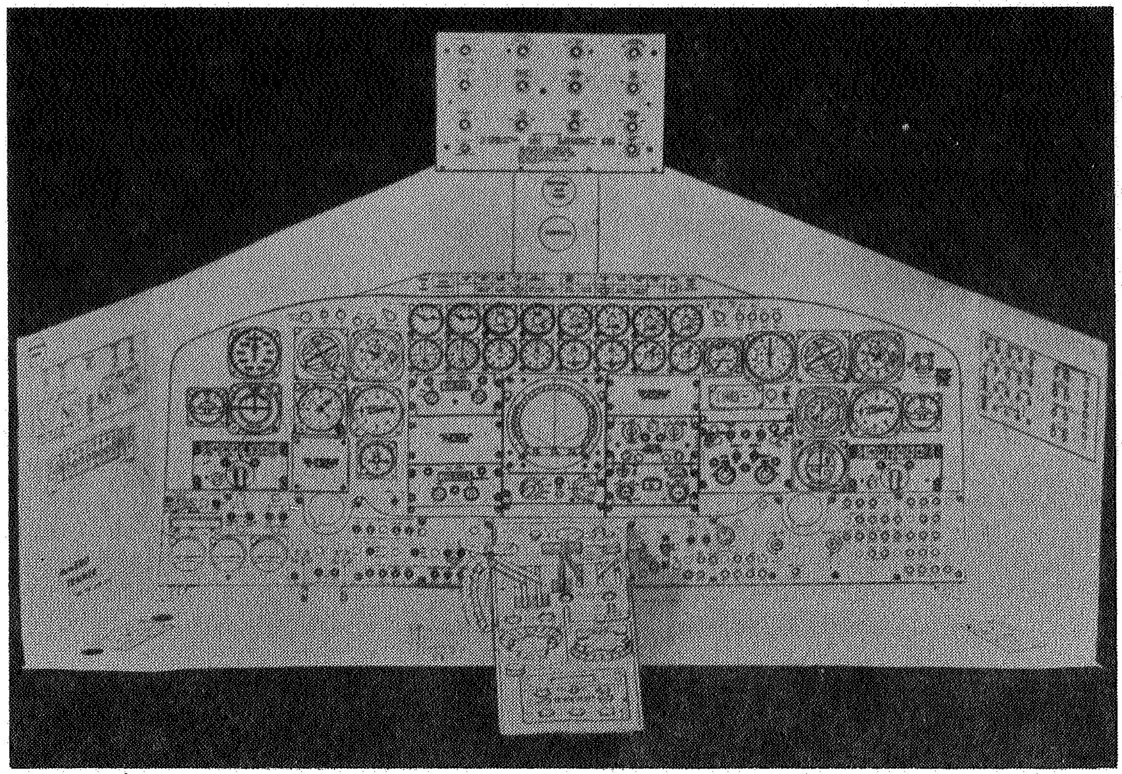

Figure 9.- Paperboard procedures trainer for the King Air.

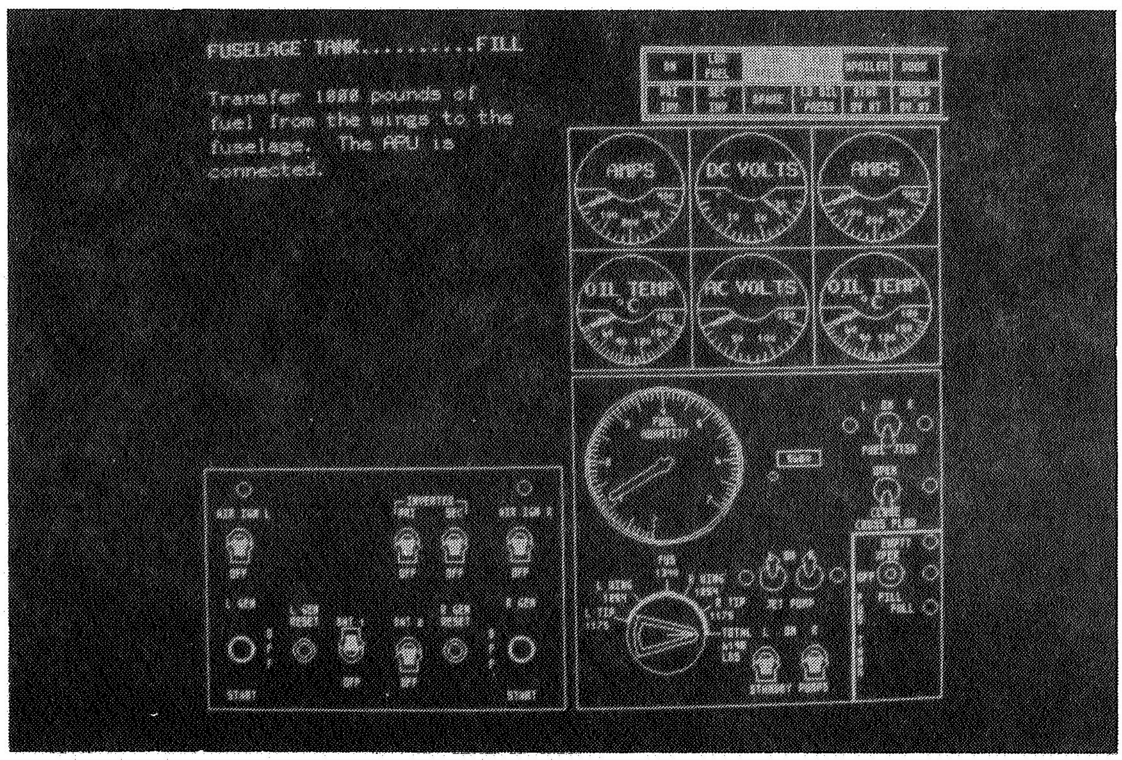

Figure 10.- Computer simulation of an aircraft fuel system.

The panel shown in Figures 11 and 12 was drawn on a graphics computer designed for that purpose. It is not a photograph, video image, or example of board art, although either of those approaches could have been used to generate a picture of a panel or display of interest. We have found that the computer-generated graphics approach to the creation of panel images such as shown here has significant development time and cost advantages for some simulation applications.

Stand-alone procedures and other part-task training devices are becoming much less common in pilot training. Simulations consisting of less costly and equally effective computer and interactive video disc display units are taking their place. With proper attention to the design of simulations employing these new technologies, and to the mediational process to be used with them, pilot training will be increasingly cost effective in the future.

That is not to say that flight simulators are things of the past. In fact, although not essential, they are becoming increasingly important in pilot training, and for at least two reasons: first, the state of the simulator engineering art is sufficient to produce devices in which complete and very realistic flight training for line operations can be conducted; and second, such training can be conducted much more efficiently and under better control in simulators than is possible in aircraft. Although an increasing portion of pilot training in the future will be conducted using computers and video display units, the need will remain to provide whole-task training, that is, training that will integrate the various procedural, psychomotor, and cognitive skills learned using part-task simulations into the total skill requirements of the line pilot. That integration training will have to take place in a vehicle in which the whole task can be performed. That vehicle must be either the line aircraft itself or a very good whole-task simulation of it. Increasingly, whole task simulators are becoming the preferred device for such training.

Realism in visual simulation has not yet been addressed, but the same training considerations apply. The present state of the art in outside-the- cockpit visual simulation is based upon computer-generated imagery. Simulated visual scenes are becoming increasingly realistic, in large part because FAA requirements for Phase II and III simulators are based upon the common elements understanding of training effectiveness. Full daylight scenes that will meet those requirements are expensive. However, very good training can be obtained using less expensive night scenes

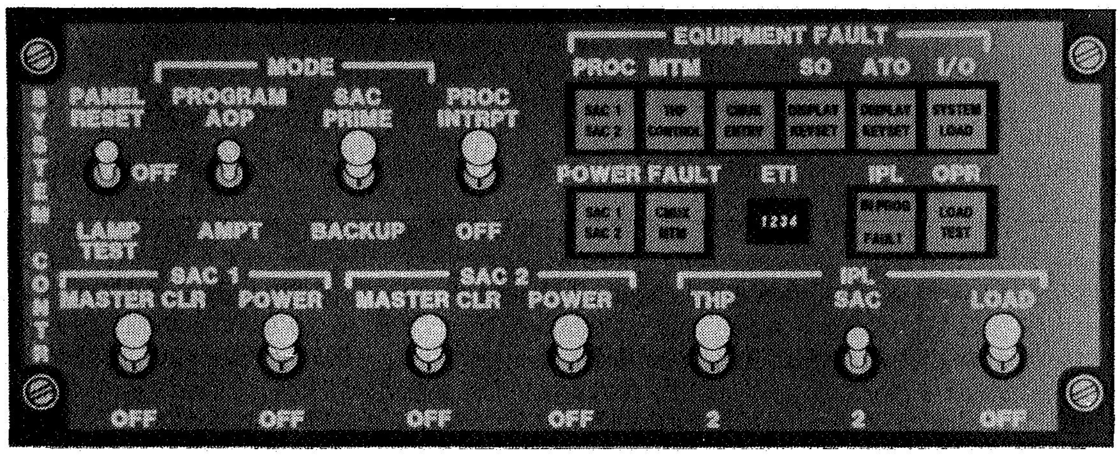

Figure 11.- An aircraft control panel created by computer generated graphics for display via videodisc.

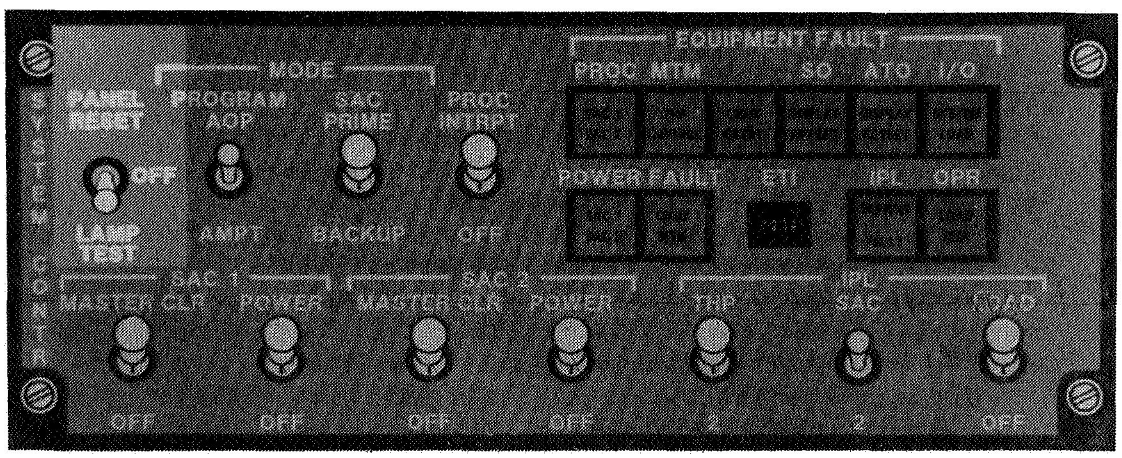

Figure 12.- Panel depicted in figure 11 with lamp text switch activated (original in full color).

such as that in Figure 13. The important cues to which a pilot must respond in practicing take-offs and landings can be presented in scenes such as in Figure 13.

Airports consist of man-made geometric patterns and points. Simulation of these patterns and points provides sufficient cues to permit practice of take-off, circling, and landing tasks. In fact, effective training of visual maneuvers has been demonstrated using even much simpler displays. Over 30 years ago, for example, researchers at the University of Illinois demonstrated that a runway pattern drawn on a blackboard, and tilted manually as a trainee simulated flying traffic patterns and landings, as is illustrated in Figure 14, provided transferable training (Flexman, Matheny, and Brown, 1950). Verbal mediation played an important role in that visual simulation.

By now, you should have gotten a message. The attention paid in pilot training programs to training process considerations makes a big difference in the cost and complexity of the training equipment needed. Realism is nice to have, even necessary for some training, but it adds cost to an already costly enterprise. A major part of the training required by pilots can be conducted using relatively low-realism, low-cost simulators. If you are results oriented and willing to attend in detail to how training is structured and administered, you can have effective training at affordable cost.

So far this paper has addressed simulators and how they are designed and used. Another aspect of cost effective pilot training, of course, is the content of that training. A characteristic of most pilot training is that its content is more comprehensive than is needed in some areas, while somewhat thin in others. There is a tendency to go overboard in developing pilot training programs, particularly where systems knowledge is concerned, because of the very real dangers of providing too little training,

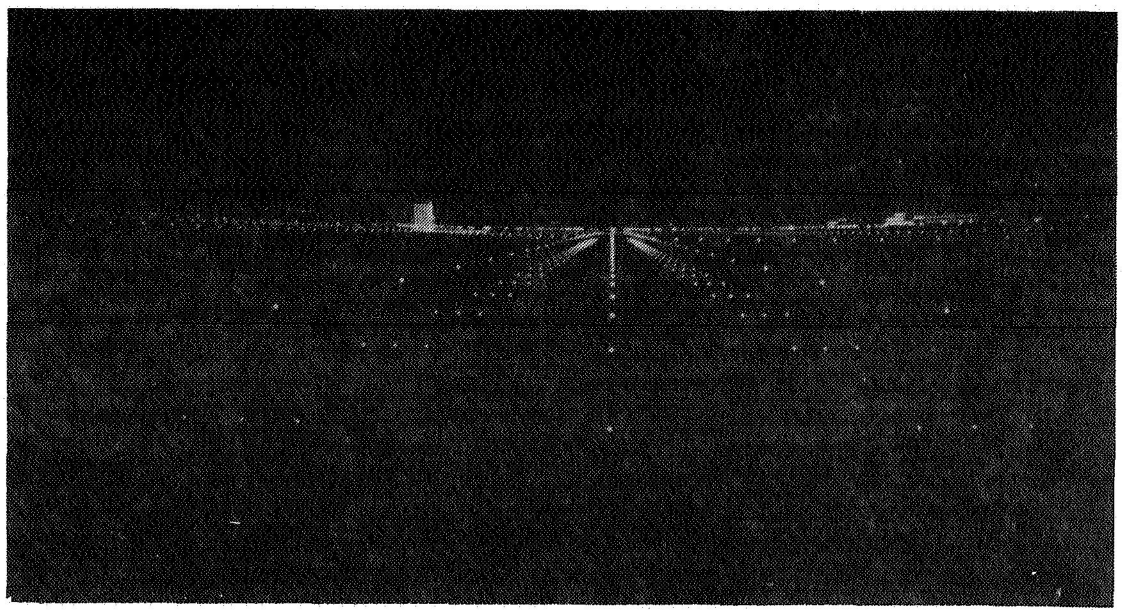

Figure 13.- Night visual scene containing cues important to takeoff and landing practices.

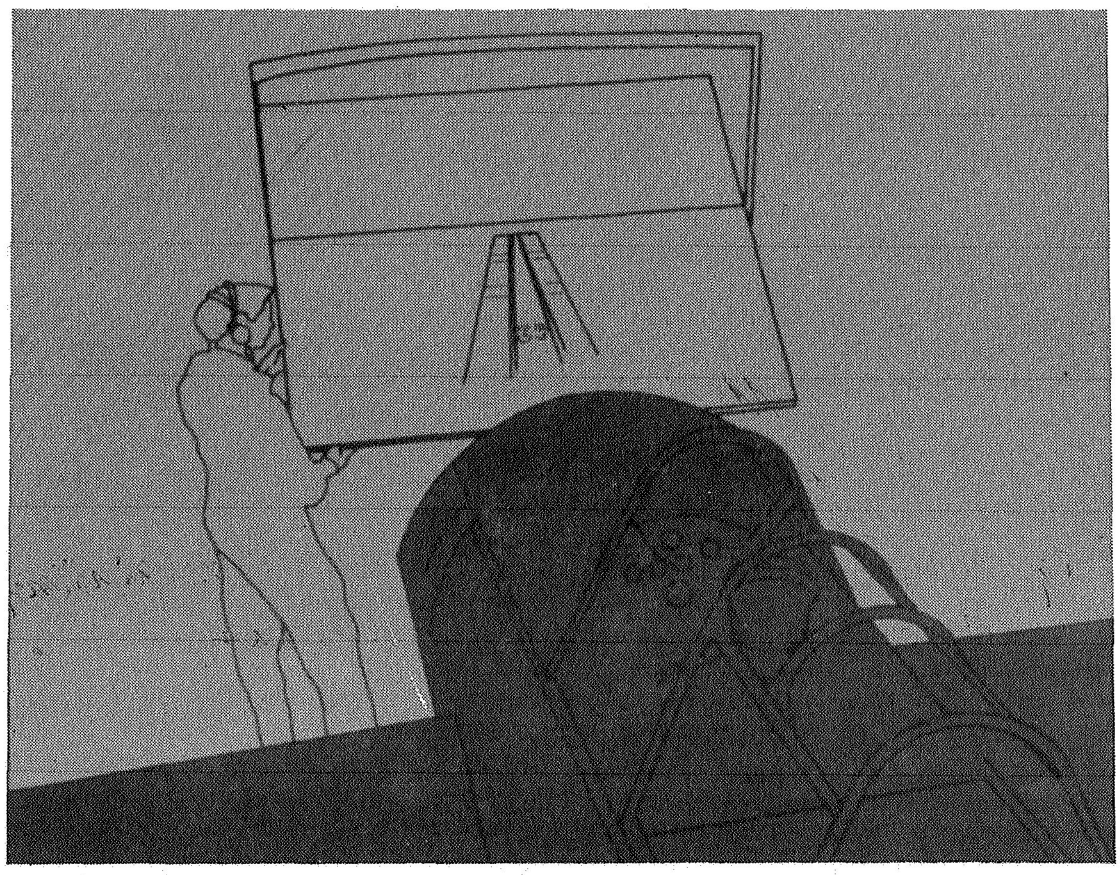

Figure 14.- Visual flight training at the University of Illinois using a run pattern drawn on a blackboard.

and sending pilots to the line who are not adequately trained to deal with any conceivable situation or equipment failure that may arise. In spite of such a tendency, however, important training content can easily be missed. The problem is to assure that each and every pilot has the knowledge about the aircraft he flies, and its many and often complex systems, to enable him to respond appropriately to unexpected equipment failures, environmental factors, traffic conditions, or events involving other crew members or passengers.

Those who are familiar with the Kemmeny Commission report on the accident at Three Mile Island will recall that the Commission was highly critical of the operators of that nuclear power plant because the content of the training provided control room operators was imprecise and was not based upon detailed and systematic analysis of the operators' tasks (Anon., 1979). Available training program development technology had not been employed, the Commission noted. The same criticism probably could be made of a large portion of the flight training conducted throughout the world. Its course content often is based upon tradition and upon the judgments and experiences of a few pilots who happen to be in positions to establish that content. Audit trails between training program content and the training requirements these programs presumably address seldom exist, probably in many instances because the training requirements have been vaguely defined, and the training therefore cannot address those requirements with any precision. Such programs characteristically rely upon stand-up lectures, delivered by instructors who are more or less free to select the course content they judge to be appropriate to the vaguely defined requirements. Additionally, these instructors' expertise is generally limited to the information presented. They usually lack a working knowledge of training technology and of how to make efficient use of the training resources available to them.

Operators who have training programs that have been imprecisely defined and therefore cannot demonstrate the relevance and adequacy of their course content with respect to known training requirements, have two major problems. One is legal, the other is technical. With respect to the legal problem, these operators would be hard pressed to build a defense against a charge that their training is inappropriate, should they ever be required to do so. Since procedures do exist whereby the necessary precision in training program content definition can be obtained, as the Kemmeny Commission noted, it will be difficult to defend the adequacy of a training program that is not derived through those procedures.

The technical problem is possibly even more important than the legal one. Unless a training program is precisely defined, it cannot be packaged for efficient delivery to pilots, it cannot economically be made available to small groups or to individual pilots when needed, and its content cannot be easily controlled or standardized from one administration to another. The advantages that can be obtained by controlling training through computer managed and administered instruction, advantages that are decreasingly costly because of recent developments in computer and videodisc technology, cannot be realized in imprecisely defined training programs. Further, without clear definition of the training requirements, the adequacy of pilot knowledge and performance at the end of training cannot be measured objectively. Regardless of the good intentions of the instructors and check pilots involved in the training and checking process, it is likely that the evaluations of pilot knowledge and performance will be more a function of the individuals conducting the assessment rather than a function of the performance of the pilots assessed, a situation that has been demonstrated to be the case in training programs where the validity and reliability of nonobjective flight grading systems have been studied (Caro, 1968).

Many training organizations, including several major airlines, have adopted systematic and carefully controlled training program development procedures to deal with the problem of precise training content definition. These procedures help assure that the scope and content of the training pilots receive is sufficient to their needs. Since every hour of training costs money, these procedures also help control training by eliminating training content that is not needed.

The procedures that are employed are varied and have been given a variety of names--Instructional Systems Development, Systems Approach to Training, Specific Behavioral Objectives, to name a few. The things such procedures have in common are detailed and systematic analysis of the tasks for which training is to be provided, and equally detailed and systematic definition of the knowledge and skills necessary to the performance of those tasks. Given the output of these procedures, it is possible to select training resources, prepare instructional lessons, train instructors, and produce pilots with the skills required to perform the jobs given them. Without such procedures to follow, the risks of omitting critical course content or of including unnecessary material in the training programs is much greater.

Just how good are these program definition and development procedures? Frankly, they are very good, but only in the hands of people who are trained specifically to use them. In such hands, they can produce good training, training that is lean and efficient, with content that is both necessary and sufficient to the performance requirements. In the hands of people whose only expertise is in the subject matter to be trained, however, these procedures are of little help.

United Airlines is an example of a company that has done a very good job of assembling a staff capable of employing these procedures for training program development, and the training programs they have produced over the past decade are generally recognized as excellent. Their programs are lean--there is no fat or nice-to-know information in them. In fact, they are so lean that questions were raised by a number of pilots concerning whether too much had been cut out of the training in order to reduce training costs.

Several years ago, we undertook a study for United to see whether enough information had been included in their pilot training programs. We surveyed about 6,000 United pilots and conducted detailed interviews with about 200 of them. Not a single instance was found in which a United pilot had been unable to perform adequately due to an omission of technical information during training. Clearly, United's program development procedures were working well. United is not unique, however. Many other examples could be given of the success of formal program development procedures in pilot and other training.

Time does not permit a comprehensive review of all aspects of training technology. The intent in this paper is to increase your level of awareness that there is a technology to be applied in training pilots. That technology involves careful attention to the definition of the content of training and to the processes through which it is conducted. Training technology is not a technology of equipment, although there are devices and delivery mechanisms that can contribute to the efficient and controlled conduct of training. When you consider buying equipment, whether it is a simulator, a computer, a videodisc, or whatever, remember that equipment does not solve training problems. In fact, you should not even consider buying training equipment until you know how it will be used, how much, by whom, and precisely for what purpose.

If your situation is such that you elect to purchase training for yourself or your pilots, rather than invest in developing your own, the considerations described in this paper should be addressed to the supplier of that training. How did he establish the training content? How is his training program administered and controlled so that you may be assured each pilot receives the standardized training you are purchasing? How does he measure the knowledge and performance of the pilots being trained to assure that they have acquired the skills required?

If he does not have very good answers to each of these questions, or is unwilling to share the information with you, don't take a chance. Seek another source, develop your own training, or join forces with other operators to develop training capabilities that will meet your mutual needs.

FOOTNOTES

1. A first-hand account of flight training in the French Foreign Legion, Aviation Section, in 1917, was provided by Charles J. Biddle in letters written to family and friends during his own pilot training. These letters are contained in his book Fighting airman: The way of the eagle. New York: Doubleday, 1968.

2. There were practical advantages of the airplane-like appearance of the Link trainer. In a communication to the writer, Professor Ralph E. Flexman commented: "I remember in my early 'Link training', a single instructor would watch up to four trainees simply by noticing what they were doing via the motion system -- like stalling, spinning, turning, rough movements, etc. -- the wings and tail gave an interpretable perspective for him, and the student knew it, so he tried harder, knowing he couldn't cheat."

3. The costs cited in this paper do not take inflation into account, so the devices pictured in Figures 6 and 8 would probably cost several times as much to build today. The costs are cited only to indicate an order of magnitude of cost for low realism simulators that can be used to provide effective training.

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DISCUSSION

DR. LAUBER: Thank you, Paul. I think that that was a very stimulating presentation that tied together effectively basic concepts in learning and learning theory and practical considerations when it comes to flight crew training.

We'd like to spend some time now entertaining questions or discussion from the audience. Who would like to have the first crack at commenting on Paul's presentation or questions?

MR. COLLIE: I'm Dick Collie with the Regional Airline Association.

Paul, you seemed to skip completely over the motion aspect of simulation. I know we could probably talk about this for the next year, but I would just like your comments on that.

DR. CARO: Motion is probably the most misused and least understood aspect of simulation. Most motion simulators provide with considerable fidelity motion that responds to control input by the pilot. If the pilot moves the wheel, the motion system responds accordingly. But little attention has been paid to providing cues that help the pilot learn to fly or to respond to things that might be going wrong with his aircraft, such as the disturbances that occur when a system fails. In fact, we don't even have good data on cues to provide in motion systems that will enable the pilot to detect motion even that could warn him that something has gone wrong.

We should distinguish between maneuver motion and disturbance motion. Maneuver motion is associated with maneuvering the aircraft and inputs from pilot-initiated changes in heading, altitude, or attitude. Maneuver motion is not of very much value in training because it cannot tell the pilot something he doesn't already know. Thus, it doesn't have much cue value. Disturbances arise from turbulence or from failure of some aircraft component or equipment. Disturbance motion, when it tells the pilot, for example, that an engine has failed, can have critical cue value and therefore can be important in training.

Motion is important in simulation. However, the question is not really whether motion is needed. The question that should be asked is, what motion is needed? Simulation researchers should attend to that question.

DR. LAUBER: Other questions?

MR. SMITH: Ed Smith, Air Kentucky Airlines.

I was wondering how important is it -- you've talked of visual cues even to the point of the man putting the 70% on the N1, this kind of thing. How important are auditory cues? Has that even entered in? Do you have any kind of a sound system to simulate what's going on? Is that important, have you found that out?

DR. CARO: Questions about sound simulation are similar to questions about motion simulation. The question is not whether sound is needed. The appropriate question should be what sounds are needed. What are the sounds that give the information, the cues, to the pilot that he needs to do something, to stop doing something, or to do something differently? If there are engine sounds that alert him to a particular condition that he has to learn to discriminate, then a training device that reproduces those sounds is a good place for him to learn those discriminations.

MR. CROWE: Guy Crowe, Mid Pacific Air.

Paul, you referenced United's concept of training. I think Pan Am does the same type thing. As opposed to our historical method of teaching introductory pilots in the aircraft, we teach basic systems and what goes on under the surfaces down in the bilges, etc., to some degree. It appears that United and Pan Am and some others have eliminated this and reference pilots' training, their needs to fulfill their mission, as strictly to what takes place in their cockpit environment.

I believe you stated in your survey this was a very acceptable training. So you indicate there is relatively little need if proper attention is paid to cockpit duties to not teach systems?

DR. CARO: That's not quite what I meant to say. The detailed analysis effort that is a necessary part of building a training program should identify the systems information that is necessary to effective pilot performance in the aircraft. When the analysis is competently performed, as was the case at United, for example, it usually is found that much less systems information is required than most pilots traditionally have assumed. Learning to perform correctly in the aircraft involves learning specific discriminations and responses, but some system information is also necessary.

When a carefully and appropriately structured analysis is performed by trained educational technologists and expert pilots working as a team, we usually find that much of the information presented in pilot training is not necessary.

Some of that information, it turns out, is not even relevant to the things that pilots do on the line. The question you raised, Guy, is exactly the question that got us into the study for United Airlines. Had too much information about the aircraft systems been eliminated? Based on the feedback we got from the interviews with pilots, necessary information had not been left out. Although some of the pilots we interviewed wanted more systems information in training, they could not point to an instance in which lack of information had interfered with their performance on the line.

DR. LAUBER: Yes. Ed Fell.

Mr. Fell: Paul, my question would be, with regard to the past few years the Agency has encouraged the concept of line-oriented flight training and indeed in the advanced simulation regulation has required that concept to be introduced into the training environment. Your views on line-oriented flight training, number one, had me interested in knowing your views with regard to cockpit specific simulators to be a part of that training; in other words, advanced simulators with regard to line-oriented flight training.

DR. CARO: The line-oriented flight training I've seen I thought was very good. I don't want to endorse all LOFT, because it can be done well or badly. But to conduct training in an operational context is a sound approach. It is an approach that the military has found quite useful in a variety of training situations, not just in aviation. But the content of that training, whether or not it is conducted in a functional or line oriented manner, needs to be defined through a very careful and systematic analysis process.

In terms of whether LOFT should be conducted in an aircraft specific cockpit, I guess that depends on the content of the instruction or the LOFT objectives. LOFT training can be conducted in a generic trainer or even in someone else's aircraft cockpit. The trainer used doesn't have to be precisely configured as your aircraft unless you are trying to teach responses unique to your aircraft. I don't think there is an absolute answer to the question.

MR. FISCHER: Dr. Caro, I'm Bob Fischer from Summit Airlines. Your point that training devices, simulators or whatever, that how they are used is probably more important than the hardware itself, is well taken.

The effectiveness of the training, and the end result of it must be a composite mix of the experience of the individual going into the training, i.e. the level of the hardware available to him and the complexity of the equipment he is being trained on. How do you go about actually measuring the effectiveness of the training, since it is a variable? Maybe conducting recurrent training in one case, initial training in another case?

Do you have -- are you satisfied with the kind of criteria that you can use to evaluate the effectiveness of that training in addition to the pilot responses, or is there some other way we are not aware of? There is a question in there somewhere.

DR. CARO: There is a whole discussion in there. If you are going to do a competent job of evaluating performance in any field of endeavor, you've got to know what it is you are evaluating. You've got to have a clear description of that performance. Pilot training on the line is difficult to evaluate because it involves such a wide range of skills and responses to such a wide range of cue situations.

Pilots must be evaluated against very specific job related criteria that have been derived through systematic analysis and definition of the training requirements. In fact, the very same analysis proven to be necessary to development of a training program will yield precise criteria against which to evaluate pilot performance. The performance to be evaluated, obviously, is the performance to be evaluated. When a pilot's performance is evaluated on the line, it is really the effectiveness of his training that is being evaluated. Pilots don't fail, but sometimes their training does.

DR. LAUBER: I'm going to cut in at this point. Thank you again, Paul.

I don't mean to cut off discussion, however we do have to stick to some sort of schedule here. What I would encourage you to do -- I have a couple of questions myself that I want to address to Paul, and I know there are others of you who also have the same -- please make a note of them. This afternoon or tomorrow, depending on how the schedule is running, I would like to have an opportunity to come back to these things, because I think they are important issues. And at the very least we can always feed the questions to the working group dealing with the topic that Paul was concerned with. Please note these things and we will attempt to get back to them, but we do have to attempt to maintain some semblance of schedule.

(A recess was taken.)

DR. LAUBER: We'll go ahead and get started. The next presentation follows very nicely the talk that you just heard by Paul Caro. One of the areas that specifically interested me when I started working with the Commuter and Regional Operators, was the vast difference in resources that are available to the typical commuter and regional operator as opposed to the United Airlines of the world.

In fact, one of the questions that I want to address to Paul Caro at some time has to do with the whole ISD approach to flight crew training and training program development and how that can be accomplished by operators whose resources manpower-wise and otherwise are severely limited. I think that one of the very useful things we can accomplish at this workshop is to come up with some practical recommendations as to how those kind of things can be accomplished.

One of the issues clearly is the question of low cost training aids and devices. Paul spent some time talking about some of those and how those are tied to basic learning of theoretical concepts.

Al Lee is about to make a presentation that continues that discussion and explores some specific systems that have been developed and also looks at the question of technology and the impact of technology and the implications of the incorporation of new technology for training in the future.

Al is a research scientist here at the Ames Research Center. He has been here since January of this year. He is a relative newcomer to our group. Prior to that, he was at the University of Dayton Research Institute where he did Air Force sponsored work on air crew performance and training, human information processing and similar kinds of things.

Al has a PhD in experimental psychology from the University of California. He lists his areas of special interest: artificial intelligence, human operator models, human information processing, pattern recognition and man-machine integration. Al is a member of The Human Factor Society.