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ABSTRACT

The rationale is developed that training equipment should be selected or designed to furnish what the student needs to know and to be able to do to perform successfully on the operational job. Several considerations relevant to training equipment design from the systems engineering standpoint are examined. Suggested design features based upon particular student learning needs and on student learning characteristics are presented. These include automated instructional functions, performance monitoring, malfunction insertion, variation of task difficulty, student feedback and guidance, flight demonstration, sequencing of maneuvers and mission segments, permanent recording of results, instructor aids, performance playback, audio and visual recording, plotting devices, instructor displays and controls, and trainee controlled instruction. Training equipment design features for particular categories of training objectives and for levels of training (e.g. initial training of aviators vs. trainsition training) are considered. Also discussed is the criticality of the synthetic training program with respect to the total training engineering process. (JK)

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Some Current Issues in the Design of Flight Training Devices

Wallace W. Prophet, Paul W. Caro, and Eugene R. Hall

HUMAN RESOURCES RESEARCH ORGANIZATION
300 North Washington Street • Alexandria, Virginia 22314

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16. Abstracts

This paper develops the rationale that training equipment should be selected or designed to furnish what the student needs to know and to be able to do to perform successfully on the operational job. Several considerations relevant to training equipment design from the systems engineering standpoint are examined. Suggested design features based upon particular student learning needs and on student learning characteristics are presented. Training equipment design features for particular categories of training objectives and for levels of training (e.g., initial training of aviators vs. transition training) are considered. Also discussed is the criticality of the synthetic training program with respect to the total training engineering process.

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Prefatory Note

This paper is reprinted from the Naval Training Device Center, 25th Anniversary Commemorative Technical Journal, November 1971. The research on which the paper is based was performed at the Human Resources Research Organization Division No. 6 (Aviation), Fort Rucker, Alabama. Dr. Prophet is Director of the Division; Dr. Caro is a Senior Staff Scientist and Mr. Hall is a Senior Scientist at the Division.

Some Current Issues in the Design of Flight Training Devices

Dr. WALLACE W. PROPHET
Director, Human Resources Research Organization, Fort Rucker, Alabama

Dr. PAUL W. CARO
Senior Staff Scientist, Human Resources Research Organization, Fort Rucker, Alabama

Mr. EUGENE R. HALL
Senior Scientist, Human Resources Research Organization, Fort Rucker, Alabama

The value of the system engineering approach to training program development has become fairly well recognized. Not so well recognized, however, are the implications of the approach for training equipment design. Systems engineering of training focuses on the student and emphasizes the job for which training is to be given. All decisions concerning training should be made in favor of the student. The essential question is always, "How can he best be trained to perform the job he will be required to do?"

In selecting or designing training equipment, of whatever order of complexity, careful attention should be given to what the student needs to know and be able to do to perform successfully on the operational job. Care should be taken to ensure that the equipment provides the necessary information content and/or allows for the creation of appropriate job-relevant conditions for performance practice. Too often, though, emphasis is placed solely on duplication of the operational system. The result may be an excellent simulation, but a less-than-optimal trainer. Attention should also be given to the inclusion within design of features whose sole function is to facilitate the student's acquisition of knowledge and skill, features based on the laws and principles which govern human learning and retention. These features may represent deliberate departures from the real-world or operational system model underlying the usual high-fidelity simulation. The learning and performance characteristics of the device user, the student, must be paramount if simulators or trainers are to be maximally effective learning systems.

This paper develops the rationale described and examines several considerations relevant to training equipment design from the systems engineering standpoint. Suggested design features based on particular student learning needs and on student learning characteristics are presented. Training equipment design features for particular categories of training objectives and for levels of training (e.g., initial training of aviators vs. transition training) are considered. Also discussed is the criticality of the synthetic training program with respect to the total training engineering process.

An examination of the history of development of flight training devices would reveal a number of recurrent issues concerning their design. Generally, the issues that have been raised (e.g., is motion required? is a visual display required? what are the best mathematical solutions for representing aircraft performance?) have tended to center on how best to simulate dynamic operation of an aircraft in a flight environment. In short, the major concern has been, and continues to be, fidelity.

Many of the promised breakthroughs in simulation technology (e.g., unprogramed visual displays), however, appear still to be "just around the corner"—a condition they were in 20 and 30 years ago. Perhaps it is time to reconsider the position that the best training device is one that most faithfully simulates operational equipment performance. Let us consider ways of maximizing the value of the devices that we are capable of producing within our current technologies while we await the hoped-for developments in fidelity.

It is the contention of the authors that training device designers should modify their primary concern with aircraft fidelity issues somewhat, and focus their attention more heavily on the trainee, the instructing function, and the learning process. It is here that the most significant gains might well be made in the contribution that synthetic training equipment can make to the training process.

This is not to say that the problems of simulation engineering technology warrant no further attention. Certainly, simulators whose primary purpose is for engineering or operational research (e.g., tactics development) or for evaluation of flight crew performance require high levels of fidelity—the higher the better. Also, we are not saying that physical fidelity should not be of concern in devices to be used for training. The need for a particular level of fidelity in a given training device is not an issue. Numerous studies have demonstrated the relationship between physical fidelity and transfer of training (e.g., see Caro[1]). However, we are suggesting that the emphasis should be on learning, and it should be noted that transfer and learning are not the same. The conditions that make for high transfer (i.e., stimulus/response equivalences), however, do not necessarily make trainee learning (i.e., his acquisition of desired skills) any easier or more efficient. If the aircraft is a poor learning environment—and for many flight related skills it is one of the poorest imaginable—then a ground-based duplicate of that environment will not necessarily be a better one in which to learn. There is evidence, for example, that skill structures change during training (Fleishman and Bartlett[2]). Thus, an exact duplication of an aircraft with fixed characteristics cannot be optimally suited for training if trainee skill structure does change over time.

Consider, if you will, that most synthetic trainers used today for military pilot training have been inappropriately designed. Ostensibly, trainers are procured to fulfill a *training* mission. In reality, they are most often nothing more than an approximation to a duplication of some sort of operational equipment, equipment which has a totally different mission than training. A visit to any large military pilot training school, and a look at the sundry, often home-made training aids and assorted devices, as well as the current user interest in learning centers, all suggest that the user has training needs which are not being met by the equipment supplied to him.

Have device designers fallen behind the user in failing to recognize his training needs and to design equipment to meet these needs? We, who may possibly be in a position to influence training equipment design or to devise ways of overcoming design limitations to meet training goals, should seriously consider altering the direction of device design. It is our contention that there is more to be gained at this point in time from applications of our present knowledge of learning and of techniques which facilitate learning than from seeking further increments in hardware fidelity. In short, we believe that device designers should design their products for *training* and not primarily for the creation of illusions. We should cease thinking so much about producing aircraft simulators (i.e., land-locked aircraft) and begin thinking more about producing the most effective and efficient learning environments.

A number of steps have already been taken in this direction. Several characteristics of existing aircraft simulators and training devices can be identified that make them better suited for training than the aircraft they simulate. For example, simulators have a "freeze" capability which allows interruption of all simulated aircraft action during training activities; the simulated aircraft can be rapidly repositioned, thus decreasing the amount of relatively unproductive time required to perform approach maneuvers; and certain emergencies can be introduced and corrective procedures can be practiced in simulators more safely than in actual aircraft.

Characteristics such as these are important. Several of them provide sufficient economic justification for the acquisition and use of simulators by airlines, industry, military establishments, and educational organizations. Others are there solely to aid in the training process, and it is these features in which we are primarily interested.

The usual simulator design goal is to duplicate, within state-of-the-art limitations, a particular aircraft. But, the freeze and reposition capabilities do not contribute to this goal. They are features for which no counterparts exist in the aircraft, and they illustrate ways that the training value of a device can be enhanced through the inclusion of features which are there for training reasons rather than solely for engineering reasons.

The process of specifying those training features that should be included in simulator design is difficult to describe. Whatever the process may be, its output (i.e., design features) must be suitable for the development of relevant skills. The product need not faithfully reproduce in all respects the aircraft for which training is intended, although certain aircraft-specific stimuli must be included. Design features should be based upon those learning principles related to skill and knowledge acquisition. For example, we know that factors such as augmented feedback, reinforcement, and behavior shaping are important in skill acquisition. A simulator based upon design considerations such as these might be less like an aircraft than like a multimedia learning laboratory built around modern training concepts such as adaptive training, self-confrontation, and modeling. The overriding objective of training simulator design, however, should be to produce a learning environment in which relevant and aircraft-specific skills can be learned in the most efficient manner.

CURRENT TRENDS IN DESIGN FOR TRAINING

A survey (Caro and Prophet[3]) revealed a number of training-relevant features in their designs. These features fall into three broad categories: (1) automation of instructional functions; (2) aids to the instructor; and (3) trainee-controlled instruction. In the following section several design features which are related to the learning and instructional processes are discussed.

Automated Instructional Functions

Several recently developed training devices have attempted to improve the instructional process by assigning to the computer certain of the functions which have traditionally been performed by the instructor. For discussion of some of the specific considerations the reader is referred to Caro[4] and Faconti, Mortimer, and Simpson[5]. Some of the functions that can be automated, however, go beyond traditional instructor functions into new aids to the instructional process. Certain of these instructional design features have become feasible only because of the digital computer's great capabilities for data handling. They are examples of training device design features that are based on facilitation of the learning process. Descriptions of selected features and techniques involving computer-aided automation of instructional functions follow.

Performance Monitoring

One important function of the simulator instructor is the monitoring of trainee performance. This is necessary so that the instructor can provide appropriate feedback to the trainee and determine trainee proficiency. Many older training devices have repeater instruments for this purpose. Usually they are located at a remote instructing position, and the instructor obtains the necessary trainee-monitoring information from them. These instruments are basically the same as those designed for installation in actual aircraft where size and weight considerations were paramount. They were not optimized for displaying information needed by the instructor in a training application for use in ground-based trainers. Here is a very simple example where a training-oriented design concept would likely produce a different and more efficient item of equipment.

Training device instructor station display configuration is one design area which received early attention from personnel concerned primarily with training effectiveness. The instrument trainer of three decades ago reflected some concern for training in the design of instructor stations. The ground track plotter was developed during this period solely to monitor the track of the simulated aircraft. Some of the newer simulators incorporate other techniques for monitoring performance and show evidence of getting away from the duplicate instrument approach which still characterizes too many flight training devices.

Monitoring of aircraft tasks which are primarily procedural in nature often requires a great deal of the instructor's attention because of the necessity to keep track of time and sequence dependencies as well as task performance accuracies. Procedural tasks are relatively simple to monitor automatically. A number of training devices have greatly simplified the instructor's job in this area by presenting summary displays of procedural task performance.

The most difficult aspect of performance monitoring—whether in the aircraft or in a training device—has always been in connection with flight control tasks (i.e., the psychomotor skill area). Automatic or computer controlled monitoring of psychomotor task performance has been the subject of extensive recent investigation (e.g., Connelly, Schuler and Knoop[6]). Several approaches to automatic performance monitoring in the aircraft simulation situation are available. Each of these can determine trainee deviation from a desired model. Performances which are monitored automatically typically relate to total system output, such as deviation from preselected airspeed and altitude, rather than to direct trainee input such as control stick movement. The more sophisticated flight training device incorporating digital computers could monitor almost any system output or trainee input parameters that might be desired. Whatever the particular parameter to be monitored, however, it should be selected on the basis of task information developed through systems engineering studies, rather than on the basis of ease of measurement or some other non-training dependent consideration.

Malfunction Insertion

This functioning consists of using the digital computer to control the selection and insertion of simulated systems malfunctions during a training exercise. The trainee must respond by executing the appropriate emergency procedure sequence. Malfunction insertion in older devices is performed manually, commonly by having an instructor activate switches to introduce a system failure.

Variation of Task Difficulty

The capability to vary task difficulty automatically in response to trainee performance has commonly been called adaptive training. Application of this technique to flight training devices has attracted a good deal of interest recently. The general adaptive formulations of Kelley and Wargo[7] have attracted the most attention, although other approaches have been considered (e.g., Hudson[8]). Whatever the approach, adaptive training involves a deliberate departure from realism in aircraft simulation. It is an approach that has been found, in at least one flight trainer application, to contribute to training efficiency (Ellis, Lowes, Matheny, and Norman[9]). A discussion of considerations relevant to use of adaptive training techniques in training equipment design may be found in Caro[10]

Student Feedback and Guidance

In any training situation, one of the most demanding and critical activities of the instructor is that of providing feedback to students. Computers, which are integral to most modern simulations, can be used to analyze data rapidly and automatically provide the trainee with cues via feedback devices, supplemented possibly by summaries from the instructor. Automatic student feedback and guidance can relieve instructors of considerable feedback responsibility. Both aural and visual feedback devices are possible. Several are discussed elsewhere in this paper. In some applications, alerting or prompting cues may be automatically provided to the student if his performance approaches some specified tolerance limit. These cues may deliberately be quite different in form and frequency from those found in the real aircraft, if indeed they exist there at all.

Flight Demonstration

Flight demonstration is a teaching technique used in all pilot training programs. Several methods have been devised for programing a flight simulator to fly or demonstrate maneuvers under autopilot control while a prerecorded narrative highlights important or difficult performances. One objective of such a procedure is to assure presentation to all trainees of a standardized demonstration of each maneuver to be learned.

Sequencing of Maneuvers and Mission Segments

One of the principal benefits of the programed instruction approach has been the highlighting of the importance of the sequencing of instructional content and the development of bridging behaviors in skill development. Once the particular sequence that will produce optimum learning has been established for a specific set of tasks, it is possible, under computer control, to lead the trainee automatically from one training task to another in this predetermined sequence. Branching sequences are also possible.

Permanent Recording of Results

The rapid data storage and processing capability of computers associated with many modern training devices makes it possible to record trainee performance information for later analysis or for display of data summaries for use during subsequent training activities. Putting this function under computer control not only relieves the instructor of the distracting requirement to take notes "on-line" for subsequent debriefing or grading purposes, it also vastly extends the types and amounts of performance data that can be examined. Such data can be recorded in a form appropriate for direct input into computer analyses.

Instructor Aids

Three training device design features intended primarily to enhance instructor effectiveness have already been mentioned—the freeze and reposition capabilities and the ground track plotter. Applications of several modern technologies have made available a number of other tools that can be used to aid the instructor in his task of providing feedback and guidance to the trainee. These aids can also let him make much more effective use of his time. Several of these are discussed below.

Performance Playback

To enable the instructor to confront the trainee with his errors, trainee performance (i.e., the performance of the simulated aircraft) may be recorded in real time for instant replay to the student. During playback of such recorded performance, the trainee may observe his own performance, errors and all. As with the original simulation, the playback may be "frozen" for detailed inspection. Additionally, it may be reviewed any number of times and even played back in non-real time for more detailed study by the instructor and the trainee of the performance which occurred. This provides an opportunity for performance review and corrective guidance from the instructor that cannot be provided in a real aircraft.

Audio and Video Recording

Another means of confronting trainees with their own performance is provided through audio and video recording techniques. Self-confrontation through such recordings has been used in other training settings (e.g., language laboratories, professional sports, leadership development) and has been found to be useful in effecting behavior change.

Plotting Devices

In debriefing students, instructors have learned to make good use of the information contained in ground track plots. Other time plots of performance, such as airspeed and altitude, could also be used to advantage in the instructional process. When such plots are presented on CRT displays, rather than more "old-fashioned" plotting boards, the information they contain can be manipulated in various ways for rapid analysis of student problems. Location of plots, whether on CRTs or other media, in positions where they can be observed by trainees during or immediately following training (as opposed to having them located in some area remote from the trainee station) enables an instructor to provide feedback in a much more rapid and effective manner. While the point has not been previously discussed in this paper, the temporal contiguity of feedback to the performance of concern is extremely important as a factor affecting learning. Certainly, the temporal aspect of feedback is one of the most frequently and widely studied learning variables.

Instructor Displays and Controls

In older flight simulators, and in some instances even in current ones, instructor stations involve panels 25 to 50 feet in length consisting of plotting boards, pushbuttons, toggle switches, instruments, and various other displays and controls. Such designs require considerable physical movement of a team of instructors in order to control the training for one aircraft crew. The use of CRTs with special- and general-purpose keyboards and light pens in instructor station design has allowed great reductions in the size requirements of instructor stations. More importantly, it has given instructors much more positive control over training and has permitted better organization of their tasks. Being able to concentrate in a much smaller area, particularly the area represented by a CRT and its associated keyboard, enables the instructor to be alerted much more efficiently to parameters of training and trainee performance to which he should attend. The particular information which needs to be displayed to the instructor via CRT, or which the instructor needs to insert into the training problem through the keyboard and light pen, is a matter to be determined through systems analysis, not only of the training requirements, but of the instructional task as well.

For some training situations, hand-held remote control devices are being used by instructors as an aid in training. These devices, typically consisting of several general-purpose keys and a digital readout, permit the instructor to communicate with a remote instructor station while physically occupying a position beside the trainee—a position that may be determined to be necessary in the conduct of certain training activities.

Trainee Controlled Instruction

The requirement that a flight training device bear some physical resemblance to the vehicle it simulates has been recognized earlier in this paper. That requirement notwithstanding, the design of the trainee's compartment should be based upon fulfilling training requirements rather than solely upon the physical characteristics of the vehicle simulated. It is quite possible, and perhaps desirable, that flight simulators designed for training might resemble multimedia learning laboratories more than the aircraft itself. Such an environment allows use of a variety of modern training concepts such as programed instruction, adaptive training, self-confrontation, functional context training, peer instruction, and performance modeling. In essence, such devices might be termed "flyable" learning centers. Obviously, the features and concepts used must not interfere with certain critical aircraft control tasks. However, a simulator designed for training would probably provide the trainee with a number of controls totally unrelated to operational flying tasks. Such controls might, for example, permit the trainee to initiate prerecorded demonstrations and exercises to freeze the simulation, to reposition himself, and to perform similar functions as directed by the training to be conducted. Displays not found in the aircraft itself might also be required to advise the instructor of certain administrative considerations, such as the condition of the motion system or that a prerecorded demonstration has been terminated and the trainee should again assume control of the simulator. If the performance monitoring functions have been automated to the extent that trainee performance can be scored against some external preprogramed performance criteria, evaluative information concerning his performance on prescribed exercises might also be displayed in the cockpit.

IMPLICATIONS

Design Considerations

What, then, are some of the principal implications for training device design implicit in this direction of development. The first is that training device design questions must be examined in a much broader frame of reference than has frequently been the case in the past. We believe that optimal efficiency and economy in training operations will come through the design of *training systems* in which all elements of the system are structured and organized in such a way as to enhance the student's acquisition and subsequent retention of the knowledges and skills that he must acquire. The central concern in design should be questions such as: what does the student need to learn? how does he learn? what is the best way to organize and present information to him? what is the best way to teach complex skills?: and similar learner-oriented factors. The main point is that design should focus on the learner. This student-centered approach is the principal characteristic of the overall training system design process that has been designated as systems engineering of training. Thus, we are really talking about applying the systems engineering approach to training device design. It is in this sense that we contend that the frame of reference for evaluating device design alternatives and issues must be a much broader one; one based on the design of the whole training system. Systems engineering of training provides this mechanism and techniques for guiding these judgments.

Systems Engineering

Application of the systems engineering process to training system design is a still-emerging technology (Smith[11]). However, the systems approach to training requires that one first carefully define the specific skills and knowledges required for effective job performance. Only after this is done can training content relevant to training goal achievement be developed and organized. Procedures, including media selection and design, must then be developed for both the training and testing of students. The overall goal is to develop a structured set of experiences that will produce, in a cost-effective manner, graduates who can perform a given set of operations to defined standards on a specified job or mission.

Integration of Device Design with Training System Design

Within the area of aviator training, we usually find three distinct instructional components that are dedicated to the training process: an academic component, a synthetic training component, and a flight training component. Systems engineering concepts and principles may be applied independently to any one of these components, and indeed they should be applied, if we are to achieve efficiently the instructional goals established for each. But it is in this process of initially establishing goals for each training component that the *training system designer* makes his first contribution to training device design. Each component has a specific role that it can play best in producing the final product—a pilot. Thus, rather than allowing the three components to exist as separately constituted parts of a whole, their establishment and existence should be founded on what each can best contribute to the total training process. Such supportive integration of training components to achieve the overall training objectives of a program sounds rather obvious, simple, and commonsensible. However, those familiar with aviation training know that this state has been all too seldom achieved. The reason is that training component design often proceeds down quite independent, and often antithetical, pathways, with only lip service paid to observance of training system design conceptions.

Often, it is determined from trade-off studies that synthetic training devices would be beneficial to an overall pilot training process. When this occurs, specific training objectives should be identified for achievement within the synthetic training component of the training system. The design of the device then should be based on the specific nature of the training to be conducted through its use. This consideration at least partially answers fidelity questions since it defines the training functional capabilities that should be included in the device. However, the training system designer and the device designer must then *jointly* return their focus to the student. It is at this point that they should consider features to facilitate the process of training and student learning within the device. This might involve specifying a number of design features similar to those we have already described. Creative design, though, will not stop with these. It will constantly seek new means of implementing the laws and principles of learning and the technology of training in specific devices.

Cost Effectiveness

This broadened context for developing device design makes the training devic or simulator simply another competitor in the methods and media race. Design decisions must be justified on cost-effectiveness bases within the total training system context. Thus, the decisions are not primarily *whether* effective training can be conducted in a device or simulator—it is established that most flight training objectives can, at least theoretically, be accomplished in a simulator—but whether it can *best* be accomplished in the device. So, it is in this total training system context that tradeoffs and training function allocations must be made. As a result of such "competitive" training system design, we might, for example, see a greater stress on part-task trainers or lower-fidelity devices. In any event, the metric for such cost-effectiveness evaluations must be the trainee, the facilitation of his learning, and his ability to perform in the operational mission environment. With reference to the latter, it should be noted that the systems approach to training considers training only as a means to the end of job performance. Thus, the training system designer (and the device designer) must be concerned with long-term retention, operational-situation stress, recurrent training, and a host of other factors related to job performance in addition to those factors associated with the initial training program and its more proximal goals. As previously stated, it is our contention that concentration on design for training is the best means to achieve optimization of the training system in supporting the ultimate operational system.

Design Teamwork

The final implication of the position developed here relates to the composition of the design team and interactions of its members. As the reader has (hopefully) gathered, the authors contend that effective device design must be behaviorally oriented; i.e., toward the characteristics of the learner. It follows, then, that training specialists (whether they are training "engineers," psychologists, or whatever is not of concern: it is necessary merely that they have in-depth understanding of the human learning process) must play an active rcle in device design. They must challenge the device engineer to develop new means of implementing features to facilitate learning and the instructional process. Further, and perhaps most importantly, it is suggested that there must be full, free, and frequent communication and exchange of views between the training system designer and the device designer. Though they typically represent different organizations or agencies, they must truly form a team. To do less is to risk development of a non-integrated, overly expensive, and perhaps ineffective training system. User representation in design is the key, and we must never lose sight of the ultimate user, the student.

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Dr. WALLACE W. PROPHET
Director, HumRRO Division No. 6 (Aviation), Fort Rucker, Alabama

Dr. Prophet joined the HumRRO Aviation Division in 1958. His major areas of research are flight proficiency measurement, contact/instrument flight training methods, and flight simulation. Dr. Prophet holds the Ph.D. in experimental psychology and occupied an academic position prior to joining HumRRO. He is a Fellow of the American Psychological Association and of the American Association for the Advancement of Science. He holds memberships in the Division of Military Psychology of APA, the Association of Aviation Psychologists, and the Army Aviation Association of America. Dr. Prophet is a member of the Alabama Board of Examiners in Psychology and holds an airplane pilot rating.

Dr. PAUL W. CARO
Senior Staff Scientist, HumRRO Division No. 6 (Aviation), Fort Rucker, Alabama

During 11 years' employment with HumRRO's Aviation Division at Fort Rucker, the Army's Aviation Center, Dr. Caro has engaged in and/or directed aerial observation, flight training quality control, and training device design and utilization research for the Army and Coast Guard. He has authored numerous publications related to training device design, evaluation and utilization, and aviation training technology. Formerly employed as an industrial training psychologist, he holds a Ph.D. in industrial psychology and psychometrics from the University of Tennessee. He is a member of the Industrial, Educational, and Military Psychology Divisions of the American Psychological Association, the Association of Aviation Psychologists, the American Helicopter Society, and Sigma Xi. He has both airplane and helicopter pilot ratings.

Mr. EUGENE R. HALL
Senior Scientist, HumRRO Division No. 6 (Aviation), Fort Rucker, Alabama

Mr. Hall joined the HumRRO Aviation Division in early 1969. His major areas of effort are in flight training device design and utilization practice and in systems engineering of training. Previously, he was employed in the simulation industry with responsibility for human factors and training design of synthetic flight training equipment. He has conducted field studies of USAF flight simulator utilization practices and performed research on technical training methods. He holds an M.A. degree from Michigan State University and is a member of Sigma Xi. He is licensed as a Psychologist by the Commonwealth of Virginia.