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Simulation and Aircrew Training and Performance

Wallace W. Prophet and Paul W. Caro

Presentation at the Conference on Aircrew Performance in Army Aviation, November 1973, Fort Rucker, Ala.

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

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Prefatory Note

This paper is based on a presentation given at the Conference on Aircrew Performance in Army Aviation, 27 November 1973, at Fort Rucker, Ala. The conference was sponsored by the Office of the Chief of Research and Development, Department of the Army.

Dr. Prophet is Director of HumRRO Division No. 6, Fort Rucker, Ala. Dr. Caro is a Senior Staff Scientist at Division No. 6. Research for the paper was performed for the Department of the Army under Work Unit SYNTRAIN, Modernization of Synthetic Training in Army Aviation, and related research projects.

SIMULATION AND AIRCREW TRAINING AND PERFORMANCE

Wallace W. Prophet and Paul W. Caro

INTRODUCTION

In this paper we intend to outline some major areas of use of simulation in Army aviation and to make a few comments about current research findings and state-of-the-art. This will serve as the backdrop for statements concerning certain aspects of future Army aviation research and development needs in the simulation area.

Most of us tend to think of simulation as a fairly modern innovation, but its use by the military is probably as old as warfare itself. In World War I barrels mounted on sawhorses, as illustrated in Figure 1, provided a very practical and inexpensive form of simulation.

Figure 1. World War I Simulation.

In the field of aviation, simulation put in a very early appearance. One of the earliest devices, the Sanders Teacher illustrated in Figure 2, came into use about 1910.

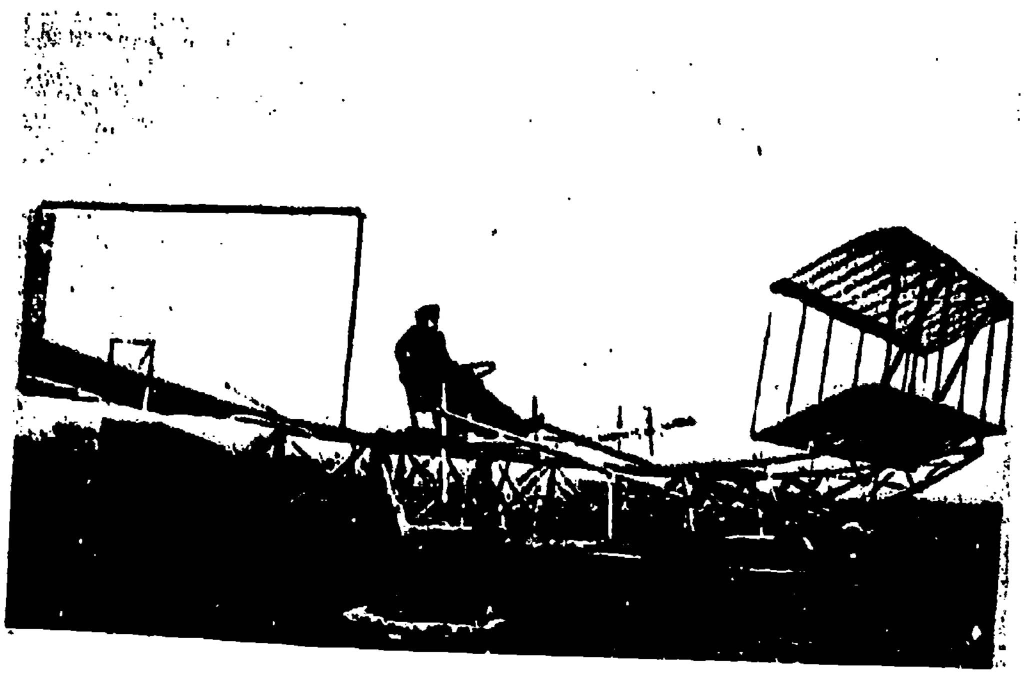

Figure 2. The Sanders Teacher Circa 1910.

Various kinds of training devices were used in Army Air Corps training in the years before organic Army aviation came into existence in 1942. However, the first really major use of devices in Army aviation training dates from the mid-1950s when the Army received a large number of 1-CA-1 instrument trainers from the U.S. Navy.

While a variety of other devices have been used over the past 15 years in Army aviation training, the 1-CA-1, illustrated in Figure 3, represented the state-of-the-art in Army aviation—or, more properly, the state of our resources—until the delivery to Fort Rucker of Device 2B24, the Synthetic Flight Training System (SFTS) in late 1971.

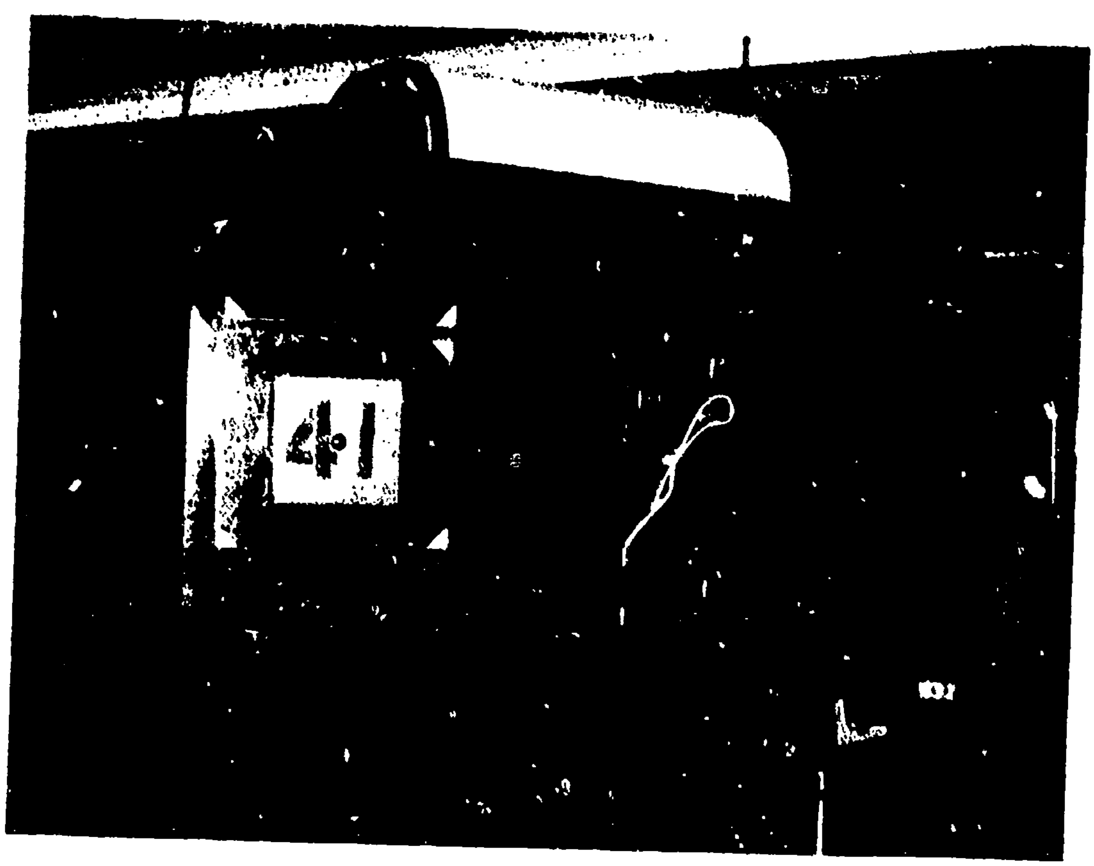

Figure 3. 1-CA-1 Trainer

The SFTS, illustrated in Figure 4, of which all of us in Army aviation are justly proud, is a four-cockpit UH-1 simulator with a five-degrees-of-freedom motion system. It is probably the most modern and effective simulation system in use in military undergraduate pilot training anywhere.

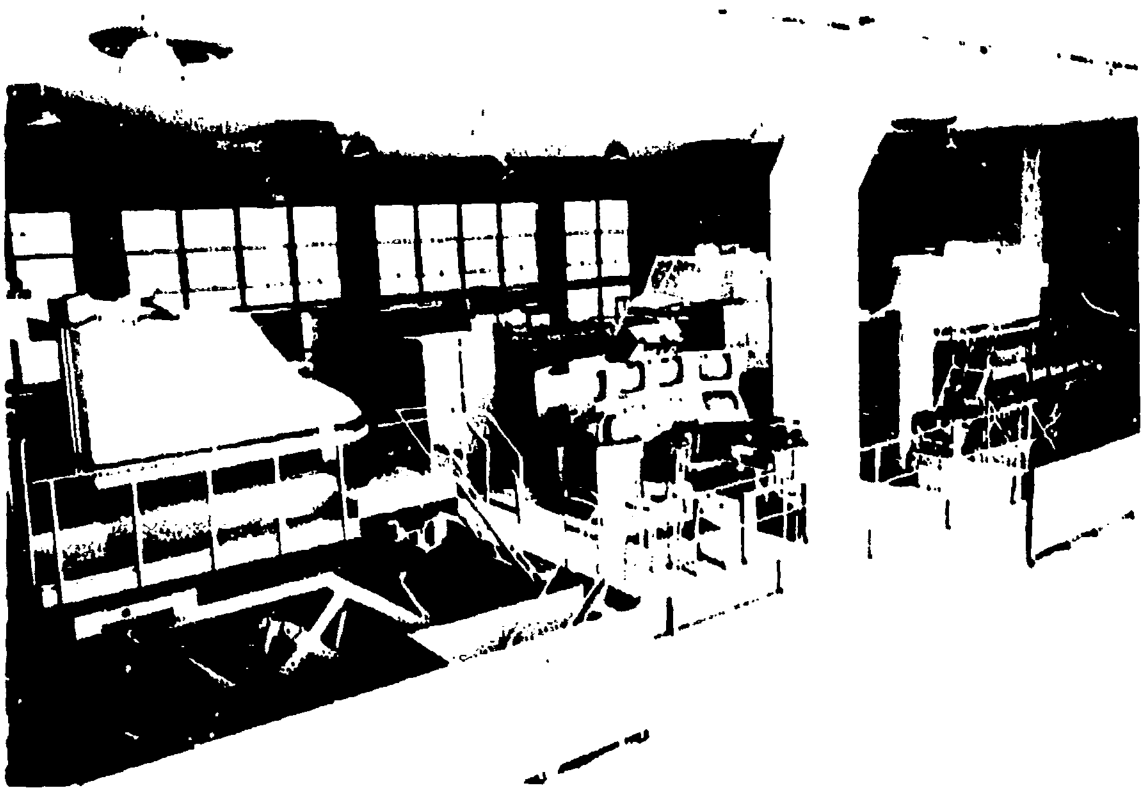

Figure 4. The Synthetic Flight Training System (SFTS).

In this short span, both mobility and simulation have gone from "horses to Hueys." However, we would like to raise a couple of questions on simulation: (a) Where are we now? (b) And where do we go from here?

USES OF SIMULATION

Let us examine where we are in Army aviation with reference to simulation in terms of four areas of application: (a) equipment development, (b) crew performance studies, (c) concept development, and (d) training.

Equipment Development

Although we tend to associate simulation with training, equipment development probably represents the most widespread and consistent application of simulation in aviation. While we do not have data on this subject, it is likely that more resources have been devoted to this application of simulation than to all others. To confirm this, one has only to look at the elaborate and expensive simulation facilities which have been established to generate and test data on aircraft design, control dynamics, avionics and instrumentation, and general engineering questions. Examples of such facilities—and one

might even include wind tunnels in this category—can be found at all of the leading aircraft and engine design plants and at government facilities such as those maintained by the National Aeronautics and Space Administration (NASA).

The Army is beginning to develop a capability in this type simulation at NASA, Ames, Fort Monmouth, and the Human Engineering Laboratories. It has occasionally made use of the facilities of the other services, NASA, and industry for such applications. The lack of adequate rotary-wing engineering simulation facilities may, at least in part, account for our rather poor track record in developing appropriate instrumentation and cockpit designs for the helicopter.

Other papers address the topic of human factors aspects of equipment design more directly, but, it should be acknowledged that most equipment design studies must take account of the interaction of man and machine and, hence, they must be concerned with aircrew performance. Most man-machine problems can best be studied in a simulation environment where data describing aircrew and equipment performance can be obtained reliably and objectively under controlled conditions, and where experimental parameters can be manipulated systematically.

Crew Performance Studies

The use of simulation to study crew performance is virtually non-existent for Army aviation, although the other services and NASA have made fairly widespread use of simulation in such studies. The effects of workload, task, and environmental stress on aircrew performance are of greater concern as Army aircraft grow more complex and the environment in which they operate becomes more varied and more severe.

Relatively little systematic attention has been paid to the allocation of crew duties in Army aviation. Many studies of fatigue effects and effects of drugs and physiological factors on aircrew performance could best be conducted in the simulator environment. Although the Army Aeromedical Research Laboratory is acquiring a small simulation facility for their studies, this area of simulator application in Army aviation is rather primitive. However, it will be of increasing concern to us in the future.

Concept Development

The evaluation of new concepts of doctrine, employment, and tactics has always been difficult for the military, particularly in aviation. The Army's growing mobility, increased acquisition and operating costs of its aviation systems, and declining amounts of available terrain and airspace have resulted in an acute problem. The application of simulation to the development and evaluation of new aviation concepts has not been recognized, or at least realized, to any significant extent by the Army, but this is a promising area for the future.

One reason for the lack of simulation applications in this area is the necessity for high simulation fidelity in many concept development studies, and the Army's general lack of high fidelity simulation equipment suitable for such studies. As the fidelity of Army aviation simulation equipment improves, particularly with respect to the simulation of the visual environment, there will be much greater use of simulation in concept development.

There is a renewed interest in nap-of-the-earth (NOE) flight. Although we have recognized the requirement for NOE operations for 10-15 years now, Vietnam shifted our attention. As a consequence, we find that NOE tactics and doctrine are still evolving. Nap-of-the-earth maneuvering and weapons employment tactics are difficult to develop in the real world because of constraints imposed by safety requirements and because it is an exceedingly difficult operating task. Future simulators may permit us to approach this area much more systematically and effectively.

There is one further aspect of the tactics development area in which simulation could be applied. The Air Force is in the process of procuring an air-to-air combat simulator for such applications. We can conjecture about the likelihood of helicopter air-to-air engagements in the future, but an appropriate simulator would allow us to investigate the feasibility of such employment concepts and to develop effective tactics if such employment is feasible. The likelihood of helicopter-tank engagements, however, is not a matter of conjecture. The development of maximally effective tactics (and counter-tactics) could be vastly aided by a helicopter-tank simulator facility.

Training

The application of simulation technology to aircrew training is second only to that of equipment design in terms of resources involved, although it is a poor second. The experimental evidence is overwhelming that simulation, *when used in conjunction with a properly developed and administered training program*, can greatly reduce training costs, can conserve limited resources, and can result in significant increases in aircrew proficiency. In fact, in certain areas it can lead to proficiency levels probably unattainable in any other practical way.

Reduced Training Costs. A recently published study by the General Accounting Office (GAO) addressed the question of savings that could be realized in Air Force and Navy aircrew training through greater use of simulation, and those projected savings are impressive. Equally impressive are the aircrew training cost reductions of several commercial air lines which have replaced most of their in-flight training with training through simulation.

The GAO report makes no mention of the savings possible through simulation in Army aircrew training, although GAO personnel did investigate the Army's use of simulation as a part of the study leading to their recent report. In all probability, the Army's lack of mention is due to the fact that the Army *is* developing an effective capability to train aircrew through substantial use of simulation and is in the process of *implementing* that capability. At the present time, the Army is generally recognized as being at the forefront among Department of Defense agencies in the use of simulation to reduce training costs.

The Army's use of the Device 2B24 (SFTS) has, in one instance, yielded a savings of about $4,500 per student (a 25% reduction) in aircraft utilization during undergraduate pilot training. Now additional Device 2B24s are being procured in order to implement the previously developed program. We and the Army have further training technology research underway at Fort Rucker which could lead to even greater savings using this same device in undergraduate training. Comparable savings are also possible in other Army training and proficiency programs for which the 2B24 is a suitable training vehicle.

The evidence is clear—significant flight time savings can be effected through simulation. There is considerable question, though, as to what to do with such savings. Until recently, the Federal Code requirement for a minimum of 200 flight hours in undergraduate pilot training made this question somewhat academic. The recent change in the 200-hour requirement makes the question pertinent. However, it also brings into sharp focus the need for an adequate detailed specification of the skills and knowledges required of the Army aviator to fly operational missions under nap-of-the-earth conditions in mid-intensity conflict. It is our position that an adequate assessment of the extent to which current training meets future operational requirements will indicate that we need to use every resource at our command, especially simulation, in the achievement of future training objectives.

The Army's employment of simulation in aircrew training is not limited to the 2B24. There are other devices in use, and new ones are on the way. A contract was

awarded in the summer of 1973 for high fidelity simulators for the CH-47 helicopter, and contract negotiations are underway for procurement of simulators for the Army's AH-1G Cobra helicopter and its weapons systems. Because of the relatively high cost of operating these two aircraft and the training cost reductions which can be achieved using simulation, even greater savings than those resulting from use of Device 2B24 will be realized when these additional simulators are delivered to the Army Aviation School.

How is it possible to effect such cost reductions? Basically, the answer is substitution. In situations ranging from very low to very high fidelity simulation, our research has found that an hour of training in a simulator costs approximately one-sixth as much as an hour in the training aircraft. These savings are attributed not only to differences in operating costs—POL in the case of aircraft and electrical power in the case of simulators—but to the total cost of equipment deprivation, facilities construction, personnel, maintenance, contractor fees, and all other identifiable training costs. In addition, it should be kept in mind that an hour of simulator training produces more training per unit of time and, consequently, faster learning than does an hour of aircraft training. In fact, we have found with both the high-fidelity 2B24 and lesser-fidelity devices that we were able to save about 1 1/4 hours of flight time for each hour of simulator time, *when the simulator is used in a well-conceived instrument training program*. The transfer ratio is about 1.25 to 1.

Conservation of Resources. Sometimes the direct dollar cost of training is not the most important consideration when the impact of simulation is considered. Fuel is in short supply and reduced fuel consumption made possible through simulation can be more important than dollars saved. The ecological benefits are also obvious.

This point can be illustrated with a specific example using data generated during our suitability testing of the 2B24. One of these four-cockpit devices provides 8,000 hours of training each 250-day training year when used eight hours per day, or approximately 15,000 hours per year when used for 15-hour training days as is currently being done at Fort Rucker. Thus, using the 1.25 to 1 transfer ratio mentioned, the 15,000 2B24 hours can replace 18,750 aircraft hours per year. Since the UH-1 consumes about 100 gallons of fuel per hour, one Device 2B24 can reduce the fuel requirement of the Aviation School for this training by approximately 1.9 million gallons of jet fuel per year. In considering these savings, it should be kept in mind that the UH-1 is not known for its high rate of fuel consumption. Comparable use of devices being procured for the CH-47 and the Cobra will lead to even greater economy of fuel resources.

Increased Aircrew Proficiency. One sometimes hears that the only proper place to learn to fly is in the aircraft. While there are few who see *no* value in simulation, there are those who resist substitution of simulation training for in-flight training on the assumption that in-flight training is essential for skill development. While we strongly support the use of simulators, we too feel that in-flight training is necessary to flight skill development and that it will continue to be so. At this point in the development of the simulation arts, it is doubtful that in-flight training can be eliminated in meeting most Army aircrew training requirements. But, there have been numerous demonstrations that some training given in flight can be accomplished effectively in simulators, and it appears equally likely, that some very important training can be conducted only, or at least best, through simulation.

Two examples will illustrate this point. There are emergency procedures associated with the operation of most sophisticated aircraft that require a pilot to be highly skilled in their execution if he and his aircraft are to survive. Yet, practice of some of those skills involves risks too great to take in an actual in-flight situation. High-side governor failure in the UH-1 aircraft is such an emergency situation. While the risks associated with practice of the skills required to deal with this situation are too great to take with typical students in the aircraft itself, the simulation of that situation in the

2B24 has provided the needed training in an effective no-risk manner. In fact, the 2B24 allows excellent training in about 100 emergency situations.

A second example of increased aircrew proficiency through simulation involves the practice of tactical maneuvers. Training for such maneuvers, especially in the nap-of-the-earth flight environment, involves substantial risk, and it may be extremely difficult to attain desired proficiency levels through in-flight training only. One possible such tactical flight area that may be of future concern is air-to-air combat. Realistic training in the tactics involved in such combat could be obtained in two ways. The desirable way is through simulation. The other way is through on-the-job practice in combat itself--but that is likely to be too late for all but the most rapid learners.

Safety. Safety considerations associated with training through simulation have already been mentioned. Practice of high-risk or emergency maneuvers in simulators where the risk can be eliminated has obvious benefits. But apart from that specific consideration, reducing the amount of flying involved in the development of a particular aircrew skill level reduces accident exposure and has safety implications. For example, considering the traffic density and the in-cockpit attention requirement of instrument training, conduct of training in the simulator reduces the exposure considerably.

During the period of FY 68 through 73, the Army Aviation School experienced 137 UH-1 accidents that cost 44 lives and 18.6 million dollars. Since this experience is based on several million hours of flying, the rate is low. How much it might have been reduced through extensive use of simulation, we do not know. We do know, however, that each four-cockpit 2B24 unit could potentially have reduced the in-flight exposure by 18,750 hours per year.

CURRENT STATUS SUMMARY

To sum up the present state of simulation in Army aviation, we are in relatively good shape in the training area, but in the applications of simulation to equipment design, problems of crew performance, and the development and evaluation of concepts and tactics we have barely made a beginning. Even in the training area we should temper our remarks somewhat, for we have no present capability for simulation of the visual world and for tactics training. Our lack of visual simulation capability means that virtually all of our nap-of-the-earth training must be conducted in the aircraft with the attendant risk. Procurements currently underway may alleviate these problems, although demonstration of the effectiveness of these new devices and their visual systems for such training must await their delivery and test.

We have come a long way during the past decade or so. At the beginning of the 1960s one scarcely dared say the word "simulator" in Army aviation circles. Army aviation is now at the forefront in the use of simulation. This represents a most desirable change. Let us note, though, that in no instance of the development of a new aircraft or weapons system in the current inventory has the idea of simulation been viewed as a natural, concurrent, and necessary aspect of that development. When it has been considered at all in such development, it has been, at best, an adjunct or supporting idea, one that falls by the wayside at the first pinch of the budget. We do not believe that the Army can permit itself to follow this course in the future. The simulator is as necessary to the training and tactical deployment of a new aircraft as are the first birds off the assembly line, or the last ones, or as is the spare parts package.

FUTURE REQUIREMENTS

We have reviewed briefly where we are in the flight simulation area. Now we would like to turn to future simulation research needs.

Performance Measurement

This topic is discussed first because it is general in nature and underlies all of the others to some extent. In the simulator we can measure many things—too many, perhaps. The problems for the future are what to measure, how to process and utilize the information or data, and what does it really mean with reference to real world flying? It is all too easy for behavioral researchers (and engineers) to get carried away with generating numbers and other data. However, flying is not some sort of mathematical exercise, though much of it can be described mathematically. It is, first and foremost, goal-oriented behavior, the accomplishment of mission. We need research on this aspect of measurement as well as on measurement of the mechanical and procedural aspects of flying. The pilot must make exceedingly complex decisions in the tactical situation. How does one measure such behavior? There are some enormous challenges to the behavioral scientist in this area in both the simulated and real-world contexts. An adequate metric is a necessary underpinning for an effective simulation research and utilization program.

Simulator Applications

The Army should pursue an active program of research concerning new and better applications of simulation in Army aviation. We have already mentioned a number of possible application areas, but here are a few specific applications that we feel deserve priority consideration.

Equipment Development. To pursue this area adequately an engineering simulation facility would be required. Study should be initiated to determine requirements for such a facility. The facility might well be used in certain of the other application areas that follow.

Concept Studies. This area has already been discussed. Areas of particular concern would be open-loop, two-sided simulation of air-to-air and air-to-ground combat. Visual system technology would be critical.

Tactics Training. The need in this area is rather self-evident. Cost, ecology, and, most of all, attainment of required proficiency levels of prime concern. Here again, visual technology is critical.

Nap-of-the-Earth Training. This area will become of increasingly critical concern as the Army moves actively toward increasing its tactical capabilities in the nap-of-the-earth flight regime. Maintenance of the sharp edge of proficiency required to fly NOE with the required effectiveness and safety can be aided through effective simulation, assuming the necessary visual technology.

Decision Making. As aviation system complexity increases, as weapons lethality increases, as displays become more symbolic, as time, workload, and environmental stresses increase, as command and control problems increase, man's role as an information-processor and decision-maker becomes paramount. Much research in both simulation and non-simulation settings is required for adequate understanding of these information processing and decision making processes. Concurrently, work will be needed on how to simulate these situations for purposes of concept development, equipment development, crew performance studies, and training.

Airborne Weapons Simulation. We feel that in-flight training of a substantial nature will continue to be required if the Army is to achieve desired levels of mission performance. Without arguing the question of the necessity for live firing in helicopter weapons employment training, there is little doubt that present live-fire training lacks much in the way of whole-task realism. There are certain safety precautions that make it inevitable that live-fire training will be unrealistic. The Army is also concerned about the adverse ecological effects of live firing. A simulated airborne weapon that the trainee could fire in-flight while engaging real targets—houses, tanks, troops, bridges, and so

forth—would allow full execution of NOE tactics in the real world. The critical factor would be that the system provide, in real time to the pilot, the feedback necessary for learning and skill development. Of course, such simulated weapons can be used in two-sided engagements as well.

Remotely Piloted Vehicles (RPV). Remotely piloted vehicles will become operational during the future. These vehicles may consist of conventional subsonic jet drones, helicopters, and small radio-controlled propeller-driven aircraft. A wide variety of missions may be accomplished through the use of RPVs, and it may be possible for one controller to control the flight of several vehicles. Through proper application of simulators and appropriate training programs, personnel may be trained to control the flight and sensors of one or more RPVs, and accomplish a variety of simulated missions. This application of simulation should receive Army attention.

Simulation Hardware

The various technologies underlying simulation equipment have made phenomenal strides over the past decade. The advances in digital computer technology, in particular, have been instrumental in opening many new applications of simulation. We will not comment extensively on future requirements in the hardware area. While the requirements may be viewed as primarily engineering in nature, it is obvious that better motion systems, faster and bigger capacity computers, and similar developments are of concern to the behavioral scientist and that there are associated behavioral research problems in these areas.

The simulation hardware or technology area of greatest concern for future research and applications is that of visual simulation systems. While we speak of hardware here, there are obviously associated software problems. From what we have said about future applications needs, it can be seen that there must be considerable advancement in visual systems technology if these applications are to be made.

In spite of the great amount of research that has been done in this area, we still know relatively little about the visual cue structure that is necessary and sufficient to fly the helicopter operationally. It is likely, too, that the visual cue structure used by the student in learning to fly is different from that used by the skilled pilot. Knowledge of such distinctions is important to what should be simulated in the visual world for a given application.

There are many important visual research questions, such as display resolution, color requirements, field of view requirements, dynamic range requirements, weapons effects simulation, display of dynamic targets, computer image generation techniques, symbolic or stylized computer imagery vs. real-world pictures, that will occupy the psychologists, engineers, and mathematicians in years to come.

Existing visual systems, while adequate for many applications, are generally quite inadequate for most Army requirements. The Army's requirements are nap-of-the-earth, operation in confined areas, operation over and around obstacles in very close proximity to them and the ground, and so forth. In short, it is a 3-D visual world that will be a tough one to simulate. There are a number of excellent visual research programs in the other services and NASA, but they are not treating those problems that are unique and critical to the Army's needs. Visual simulation is Army aviation's most critical future simulation hardware requirement area.

Simulation Models

Much needs to be done in refining or developing the mathematical models required in simulation. The preceding discussion of visual requirements and computer image generation highlights the need for math models of the real world. We will not dwell on

this area, but mention should be made of the need for better math models of helicopter responses while operating at low altitudes in ground effect. As the visual technologies necessary to NOE simulation are developed, we will become more concerned about faithful modeling of helicopter response characteristics in the ground flight effect regime.

Instructor Station Design

Prior to the advent of the SFTS, this topic received little attention in Army aviation flight training devices (or in others, for that matter). The custom was, and unfortunately still is, for the instructor to be seated outside the cockpit with a bank of repeater instruments. The design philosophy was to duplicate the device cockpit which, in turn, duplicated the aircraft cockpit. We will acknowledge that aircraft cockpits are very poorly designed as learning environments; but why do we persist in perpetuating their deficiencies in the simulator?

Research is needed on how to optimize the instructor's contribution to the efficiency of the student's learning. If an optimized role is developed for the instructor, then we need to develop a station design that is optimal for his job. How can we aid the instructor? What kinds of information and displays does he need, not to fly an aircraft, but to control training and to facilitate student learning? These are truly significant questions, because, in spite of the ease with which we can become dazzled by the physical, electro-mechanical gadgetry of the simulator, we must keep our eye on the enhancement of student or pilot performance. The simulator system, including the instructor station, must always be designed with this as the central concern.

Automation

There are significant issues to be settled with reference to automation of training and performance measurement. The SFTS has capabilities in this area, but we know relatively little about how best to utilize those capabilities or what changes are needed. In this sense, it is still a system in development. There is little question that significant portions of complex perceptual-motor skills training can be automated. However, we do not know, from an overall systems cost-effectiveness point of view, just what should be automated or how.

Training Program Design

We in HumRRO have devoted a great deal of effort to this area. It is our contention that the manner in which a device is used is probably as significant a factor—or, perhaps, more significant— than the characteristics of the device in terms of actual training benefits realized through simulation. We believe the Army is in front in this area, but there are many aspects of how best to use simulators that we do not know.

In particular, the design of simulator training programs for new devices and new applications will be of extreme importance in the meeting of more and more stringent operational pilot performance requirements and in meeting them under increasingly severe fiscal, manpower, and physical resource restrictions. The enhancement of student learning is the central point; it is the training program that integrates the student, the simulator, the instructor, and the other training resources into an effective system for achieving desired performance goals. Our philosophy has been that the design and use of simulators should be based on a sound technology of training.

Simulator Management

It is not enough that we have the necessary simulation and training technologies to make simulation programs really effective. We need to establish programs and procedures

for management of simulators. The range of management concern varies from ensuring that simulator development is an integral part of aircraft system development to development and implementation of effective simulator usage programs. Of course, we are not really talking about a research requirement area here, but a process of education as to what simulators can and cannot do. The flight simulator is neither an aircraft (and should not be used and managed as such) nor a somewhat incidental, adjunctive piece of training equipment. Rather, it is a principal medium for aviation training, one that can be used on extended schedules independently of the elements. Just as it has taken time to develop and realize the great potential of airmobility, so it will take time to realize the tremendous potential that simulation represents for the Army. The better the job that can be done in educating Army managers concerning the potential of simulation, the sooner that potential will be realized.

SUGGESTIONS

We would like to underscore the need for development, on an integrated basis, of a broad program of simulation research for Army aviation. The program should have two major thrusts—one engineering, the other behavioral—but the underlying concern must always be enhancing aircrew performance. The program will cost money, but it is a program that will pay its own way. The other services have invested heavily in their simulation research facilities. For example, and this makes us envious, the Air Force has just taken delivery on its ASUPT, or Advanced Simulation for Undergraduate Pilot Training, research simulator at Williams Air Force Base in Phoenix. This simulator, which cost over $20,000,000, is not intended for training, but for research on simulator training and simulator design.

We are not suggesting that the Army needs such a facility as ASUPT, but it does need some facilities and an integrated simulation research program. The Army has profited much from simulation research done elsewhere, but there are significant simulation research problems that are unique to the Army and on which no one else is working. We have touched on some of these problems in the hope that putting them in proper perspective may assist in developing the necessary impetus.