

Technical Report 1092

Optimizing Simulator-Aircraft Mix for U.S. Army Initial Entry Rotary Wing Training

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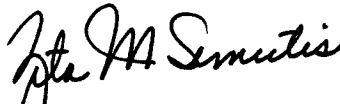
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FOREWORD

The Aircrew Performance Team of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) Rotary Wing Aviation Research Unit is located at Fort Rucker, Alabama. The ARI Aircrew Performance Team is committed to enhancing aviation training in the Army. The focus of the present report is on the optimization of simulation-augmented Initial Entry Rotary Wing (IERW) training programs. A program of research in this area was deemed necessary because little data existed for developing benchmarks as to how best to use simulation in the IERW environment.

Currently, the Army uses simulators only for instrument training in its IERW training syllabus. ARI has conducted transfer of training research which has demonstrated that simulation can be effectively employed in both the primary (non-instrument) as well as the later instrument phase of IERW training. Building on lessons learned from the completed research, ARI has proposed a program of research to determine the best "mix" of simulator and aircraft training in the Army's IERW program. The results of this program of research will provide objective data by which the rotary wing training community (i.e., private operators as well as the Army) will be able to improve the efficiency and effectiveness of IERW training. The principal research plan, based upon this report, was briefed to the Commander, Aviation Training Brigade, on 16 February 1999.


ZITA M. SIMUTIS
Technical Director

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The authors are indebted to Dale S. Weiler of CAE, Inc. for his invaluable support as a subject matter expert. Mr. Weiler was assigned the task of bringing up to date the documentation on the Army's Initial Entry Rotary Wing Program of Instruction. This he accomplished with great skill, giving the authors a better understanding of how the Army currently administers primary aviation training. This in turn provided a benchmark for the design of future transfer of training experiments, in which the authors plan to address alternative instructional strategies for this type of training.

OPTIMIZING SIMULATOR-AIRCRAFT MIX FOR U.S. ARMY INITIAL ENTRY ROTARY WING TRAINING

EXECUTIVE SUMMARY

Research Requirement:

Early fixed wing research demonstrated that simulators can be both cost- and training-effective. More recently, programmatic research on simulation-augmented aircrew training has been the exception, not the rule. This can be stated even more emphatically in the case of rotary wing (helicopter) aircrew training research. Because so little research has been conducted in this area, a systematic knowledge base does not exist. Consequently, training developers and other decision-makers have little substantive foundation for determining what such a training system (or even a simulator) should look like.

The U.S. Army presently does not employ simulation for the primary, visual (contact) phase of Initial Entry Rotary Wing (IERW) training. It does, however, provide 30 hours of training time in a UH-1 helicopter simulator without a visual display system. It is not known how much training time can be offloaded to simulation without degrading the quality of training. Research is required to determine the optimal mix (i.e., tradeoff) of aircraft for simulator training time for IERW training.

Another, related research issue to be investigated in this context is the use of criterion-based as opposed to class-based (i.e., lock-step) training. In criterion-based training, all student pilots do not train for a preset number of hours. Instead, each student trains until he or she has reached a criterion for the performance of a specific task (e.g., three consecutive successful stationary hovers). Once having met the criterion, the student moves on to the next task or set of tasks. Although previous research has shown some advantages for criterion-based training, the Army's IERW program remains class-based.

Procedure:

The present report reviewed the limited research literature on military aviation transfer of training (TOT) research, examined the current IERW Program of Instruction, and analyzed in some detail more recent IERW simulation research. On the basis of these efforts, recommendations were made for a programmatic research effort to determine ways of enhancing both the efficiency and effectiveness of IERW training.

Findings:

Review of aviation transfer of training research. The review revealed that what little research had been conducted, showed that simulation had the potential for making current ab initio training more efficient. An examination of simulator visual display research indicated that, though research has provided useful data on visual display requirements unique to helicopter simulation, these data have not been exploited by the designers. A review of Army Research Institute (ARI) TOT research showed that a combination of synthetic flight simulation

and criterion-based training had the potential of saving training time and costs in the aircraft. ARI research on the Intelligent Flight Trainer, an adaptive training aid incorporating artificial intelligence, was also promising.

Proposed research program. A research program, demonstrating the advantages of a simulation-augmented IERW training system, was proposed. The research would be programmatically focused, in that it would concentrate on the total IERW training system, and not just the low-cost simulators that are part of it. Instructional strategies would be criterion-based, not classed-based as they are now. Phase I would concentrate on the instrument phase of IERW training, in which some simulation is currently employed. It would examine the effects of varying the mix of simulator and aircraft hours beyond the current 30 simulator-20 aircraft mix. It would also compare the TOT effects of a low-cost simulator with those of the Army's current instrument trainer simulator. Phase II would concentrate on the contact (i.e. visual) phase of IERW, which currently does not employ simulation. The research would draw upon previous ARI studies that investigated the effects of pretraining in a low-cost simulator on trainee performance in the aircraft.

Utilization of Findings:

The insights gleaned from the present review and planning effort will form the basis for a research program to investigate the use of simulation in a model IERW training system. This research will provide an empirical basis for determining the configuration of such a training system for the next millennium. Results of the planned research should provide the Army with much-needed guidance in the design of training systems that are more efficient and effective than those of today.

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OPTIMIZING SIMULATOR-AIRCRAFT MIX FOR U.S. ARMY INITIAL ENTRY ROTARY WING TRAINING

Introduction

Background

Objectives of the present report. The main objectives of this report are to (a) summarize representative research that has been done, as well as ongoing research in the area of rotary wing simulation and training, (b) discuss the evolution and current status of the U.S. Army primary rotary wing training course, (c) identify limitations and problem areas in simulation-augmented primary flight training research, with an emphasis on rotary wing training systems, and (d) propose a program of research with the goal of demonstrating the feasibility and effectiveness of low-cost simulation in a primary helicopter training environment, with the goal of specifying the optimal mix of simulator and aircraft training for the Army's primary training syllabus.

Assumptions underlying simulation research. Some assumptions related to optimizing the training capabilities of simulators are: maximizing the number of task iterations per training hour, and maximizing the rate of learning progression to integrated, whole task performance. A much larger number of assumptions pertain to optimization of the cost-effectiveness and efficiency of training. Many approaches for accomplishing this objective have been proposed (e.g., trading aircraft for simulator time, reducing student training time, and maximizing instructor effectiveness in the simulator). The challenge is to control program costs without diminishing, and preferably, proving, product quality. However, with a few exceptions (e.g., Derrick, Tomczak, Nullmeyer & Burrigh, 1992), existing research addresses only a few of these assumptions in limited training contexts, most of which are outdated. As we shall see, most of the transfer of training (TOT) research concerns fixed wing rather than rotary wing flight training. What little flight training research exists has been limited in scope.

We will now briefly review some of the empirical research. The emphasis will be on helicopter-specific training and training device research. We seek to provide a general framework for conveying the rationales and training strategies that, according to the literature, should be considered in the development of a primary helicopter flight training system.

Aviation Transfer of Training Research

Evidence of training effectiveness. Taylor, Lintern & Koonce (1993) define simulator to aircraft TOT simply and concisely.

A flight simulator is effective if the skills that a pilot learns in the simulator can be performed in the aircraft; that is, if the skills transfer from the simulator to the aircraft. The effectiveness of training in a flight simulator is a function of the amount of skill that transfers. Its cost-effectiveness in a pilot-training program depends on the amount of skill that transfer to the aircraft as well as the ratio of simulator to aircraft operating costs.

In this age of increasing reliance on simulators, it is ironic that so little research has been done to optimize the effectiveness of aviation training systems. In spite of the assumption that a

simulator should "fly" like an aircraft, little research has been conducted to determine how many of them actually do (Stewart, 1994). Furthermore, little is known as to how much fidelity is required for effective training. Simulators that "fly" poorly can still be effective training devices, in some environments. For example, Grimsley (1969) has demonstrated that even low fidelity simulators can produce good TOT. Procedural and flying tasks are so interrelated, however, that it is often difficult to determine which of these contributes to the positive TOT. This makes it difficult for the researcher to determine from TOT results, how closely the flying characteristics of the simulator and aircraft should match.

Even today, simulators are frequently integrated into training systems without evaluating their training effectiveness. One possible explanation for this was proposed by Caro (1973), who observed that most personnel who design and integrate simulators are engineers, not behavioral scientists. Caro also expressed concern that much more attention has been paid to the development of the simulator itself, than to the training program which supports it. Caro (1976) stated that those who integrate and employ simulators in aviation training systems are best described as artisans. They have shown considerable skill in getting simulators, even bad ones, to perform their training missions. However, their efforts do not provide a common base of constructs that describe the functional requirements for effective simulators. This leaves training system developers without much guidance. Caro's observations of two decades ago are echoed by Salas, Bowers & Rohodenizer (1998), who state that though simulation technology has undergone incredible evolution, the evolution of training is at a virtual standstill. In short, evidence of training effectiveness is lacking for most military aviation simulation and training systems, because little research has been conducted.

Early fixed wing transfer of training research. Pioneering TOT research (e.g., Mahler & Bennett, 1950; Williams & Flexman, 1949) demonstrated that pretraining in training devices produced payoffs for later training in the aircraft. Examples of payoffs included fewer trials, fewer flight hours, fewer errors to qualify in the aircraft (Williams & Flexman, 1949), fewer serious student errors and fewer total errors in the aircraft (Mahler & Bennett, 1950). Early fixed wing studies demonstrated that simulators can be both cost and training-effective (Flexman, Roscoe, Williams, & Willeges, 1972; Williams & Flexman, 1949). Another, somewhat more recent research emphasis has been on optimizing the mix of simulation and aircraft time, and associated cost-benefits tradeoffs (e.g., Povenmire & Roscoe, 1973).

More recent fixed wing transfer of training research: an example. Edwards and Hubbard (1991) conducted a controlled experiment to evaluate the training effectiveness of the Air Intercept Trainer, a low-cost simulator for the F-16. It is also a good example of in-simulator transfer, or quasi-transfer. The experimental group practiced air intercept tasks in the Air Intercept Trainer, while the control group spent the same number of hours training in conventional academics. Next, both groups performed these tasks in the Operational Flight Trainer, a high-fidelity, full-mission simulator for the F-16. Edwards and Hubbard found that mean proficiency ratings of participants in the experimental group were significantly higher. Further, proficiency was obtained by these participants on more types of intercepts than the controls (2.7 vs 1.5); this difference was also significant. They concluded that the Air Intercept Trainer had the potential of significantly reducing training time in the simulator (whose operational costs are higher).

Early helicopter transfer of training research. Much of this early research was conducted by Paul Caro and his associates of the Human Resources Research Organization division at Fort Rucker, Alabama. The Fort Rucker division was the predecessor of the current Army Research Institute for the Behavioral and Social Sciences (ARI) Rotary Wing Aviation Research Unit at Fort Rucker. Some of the research took place at Fort Wolters, Texas, before all Army aviation primary training was transferred to Fort Rucker. Caro and Isley (1966) reported the results of an Army TOT experiment involving the Whirlymite, a lightweight, single-place helicopter tethered by an articulated arm to a ground-effects machine. Its handling characteristics were the same as those of a lightweight free-flying helicopter. Caro and Isley pretrained student pilots for 3.75 or 7.25 hours on the device, and compared their flight training performance with a non-pretrained control group. Results indicated that the two experimental groups were ready to solo significantly earlier than the control participants, though training time for subsequent evaluation flights did not differ. Differences due to checkride grades were not statistically significant, nor were differences between the 3.75 vs. the 7.25-hour experimental groups. However, Whirlymite training was found to produce a significant reduction in eliminations of students from flight training.

Valverde (1973) acknowledged that the results of some aviation TOT studies, both fixed and rotary wing, have been inconsistent, offering several possible reasons. First, criterion measures of performance (e.g., flight grades) were often subjective. Secondly, questions have been raised as to the homogeneity of subjects and the use of paper-and-pencil tests as matching criteria. Thirdly, instructor effects needed to be acknowledged. Finally, studies have differed in their basic designs, especially with regard to the ordering of blocks of simulator and aircraft training events. These are important issues that affect the comparability of studies, whether they were conducted in the 1950s or the 1990s. These studies have evaluated the training device, not the overall program. Scientific, or even systematic, evaluation of simulation-augmented training programs remains the exception, rather than the rule. Hays, Jacobs, Prince, & Salas (1992) were able to locate only seven helicopter simulation experiments. Their meta analysis revealed negligible differences between simulator plus aircraft training vs. training in the aircraft alone. Consequently, an adequate knowledge base upon which to anchor constructs for rotary wing TOT research does not exist. A review of two more recent studies, which follows, will demonstrate the advantages of a programmatic approach to training system research.

The MH-53J training system evaluation. Selix (1993) evaluated the effectiveness of a rotary wing training program, based upon an integrated suite of training devices. This study shows the advantages of a holistic, systems approach to training program development and evaluation. Selix addressed the question of simulator/aircraft mix for the U.S. Air Force MH-53J Pave Low Combat Crew Qualification Course. This investigation was driven by the high hourly operational costs of the MH-53J, an extremely complex multimission helicopter. In 1986, the MH-53H aircraft qualification course was almost entirely aircraft-based. The increasing complexity of aircraft systems imposed additional training demands when the MH-53H was replaced by the MH-53J in 1990.

This became the Air Force's longest aircraft qualification course (150 training days) at a time when flying hours were being reduced. Thus, it was decided to offload as many training hours as possible to simulators and a suite of part task trainers. Each part task trainer was

dedicated to a specific sensor/ avionics subsystem. Students were trained to proficiency in the least sophisticated training device on which a given task could be satisfactorily trained (this had been determined through task analysis). Students did not proceed to the next level in the syllabus until after having demonstrated proficiency. Once these skills were acquired on part task trainers, they were integrated through crew-level practice in the Weapon System Trainer, a high-fidelity, full-mission simulator for the MH-53J. Selix describes the 1993 course as approximately a 50:50 mix of simulation and aircraft hours, and even more simulation-intensive for the tactical and sensor phases of the course.

The Pave Low phase, in which integrated sensor operations were taught, was the most demanding. In 1990 it comprised 18 two-hour aircraft sorties. Selix states that the Weapon System Trainer's advanced capabilities allowed this phase to be restructured to 12 simulator and three aircraft sorties. In brief, the MH-53J course is a good example of how the use of simulators and PTTs can effectively save training time and costs in the aircraft. The savings in this case were quite real: 1993 hourly costs for the MH-53J were \$3100 vs. \$800-1000 for the Weapon System Trainer.

The training effectiveness of the MH-53J Pave Low training system is further underscored in a study by Rakip, Kelly, Appler & Riley (1993), who conducted a survey of experienced Pave Low crewmembers and their commanders, who were assigned to operational units. The respondents were asked to evaluate new crews assigned to their units on the basis of their knowledge, understanding, and execution of critical mission functions (e.g., operational qualifications, tactical understanding, mission planning/execution). They rated crewmembers with whom they had flown, who were trained during a time when the system was being upgraded (i.e., non-simulator group). They also rated crewmembers who were trained during a time that the Pave Low Weapon System Trainer was integral to the curriculum (i.e., simulator group).

The survey measured perceptions of proficiency and not actual performance-based proficiency. Rakip et al. found that new crewmembers trained in the simulator were rated as superior to their aircraft-only counterparts on all criteria except Night Vision Goggles abilities, for which ratings were virtually the same. Respondents commented that crewmembers trained in the simulator took 2-3 months to be brought up to operational standards vs. up to one year for the non-simulator group. Likewise, the simulator group combat qualification time was approximately 20 flight hours vs. at least 50-60 hours for the aircraft-only group. The only area where crewmembers trained only in the aircraft showed superior performance was in their ability to fly the aircraft, due to greater accumulated flight time. It should be noted, however, that most of the skills required for the MH-53J course are procedural, and that respondents thought the tradeoff was worthwhile. Rakip et al. concluded from these post hoc, quasi-experimental results that course graduates trained in the simulator exhibited better, more highly-integrated mission-related skills than did those who trained in the aircraft alone. Simulator-trained graduate crew members required less time for full mission qualification than did those who only trained in the MH-53J, when they reported to their operational units. The most important point of this study is that the simulator need not be merely a substitute for the aircraft, but a superior training alternative, for some mission tasks and elements.

ARI AH-64A Aircraft Qualification Course proof-of-concept project. Like the Pave Low project, the AH-64A project was driven by cost considerations. The AH-64A is a complex, expensive aircraft to operate, so major reductions in training costs should be possible if simulator time were substituted for time in the aircraft. In this project, conducted by Wightman and Wright (in preparation), students were required to practice and demonstrate proficiency in the simulator on maneuver tasks from the Aircraft Qualification Course Program of Instruction (POI). Students practiced these tasks in either the AH-64 Combat Mission Simulator, or ARI's Simulator Training Research Advanced Testbed for Aviation, which also simulated the AH-64A. Following these simulator sessions, students demonstrated performance of the same tasks in the AH-64A. On the basis of this demonstration, the amount of helicopter flight training required for proficiency was determined for each student pilot. The results were compared to those of classmates trained within the normal aircraft-based POI. The results demonstrated that offloading training to simulation can substantially reduce the time it takes to qualify in the aircraft. Mean total helicopter flight training time was reduced by 20 hours. The combined reduction in actual aircraft flight training time resulted in estimated (1997 cost basis) savings of \$70,000 per student. The simulation-based POI required approximately 56 hours in the simulator and 25 hours in the aircraft; the traditional POI required approximately 28 hours in the simulator and 45 in the aircraft.

The research and development efforts leading to the simulation-focused Pave Low course, and the AH-64A proof of concept research, were in response to external pressures, both economic and technological. Both of these systemic factors are also affecting the conduct of Army helicopter training. The next millennium will undoubtedly see more intensive use of simulators and part task trainers at all levels of training. This will necessitate restructuring of the training courses to increase the use of simulators and other training devices. The primary phase of Army aviation training is at present heavily aircraft-focused, employing simulation only for instrument training. Consequently, it is an excellent candidate for systematic training effectiveness research which could specify the optimal mix of simulator and aircraft training.

Improving Initial Entry Rotary Wing (IERW) Training Efficiency

Army IERW Training Program

Background. The POI is the official statement of what is to be trained. The IERW POI is developed and administered by the U.S. Army Aviation Center at Fort Rucker, Alabama. The purpose of the IERW course is to provide ab initio helicopter training for neophyte trainees. The challenge faced by the aviation training community is to train both college graduates (the Commissioned Officer Corps) and high school graduates (the Warrant Officer Corps) efficiently and effectively. Training involves not only "hands and feet" flight skills, but also Army rotary wing missions, within the budget and scope of the IERW POI. This has become more of a challenge in recent years, because of a decrease in funding, particularly for flight hours.

Historical overview of the IERW POI. The IERW POI has evolved from the 175/40 (175 hours aircraft; 40 hours simulator) POI jointly developed by ARI and the Directorates of Evaluation and Standardization and of Training and Doctrine, (presently called the Directorate of Training, Doctrine and Simulation) at Fort Rucker, AL. In Fiscal Year (FY) 77, the 175/40

program was introduced to add more simulator-based training to the POI and to introduce a second training track for Aeroscout aviators (U.S. Army Aviation Center, 1979). The 175/40 POI instituted several changes in the training regimen:

1. The number of aircraft training hours was reduced from 180 to 175 while the number of simulator (instrument) training hours was increased from 20 to 40.
2. A second training "track" was added to the course. The 180/20 course trained only plenary (i.e., fully rated) aviators in the utility mission. The 175/40 course added the Aeroscout mission (flown in the OH-58A aircraft) to the POI, thus, creating a multitacked POI.
3. An assignment algorithm was empirically developed and validated to identify students for assignment to the demanding Aeroscout Track.
4. A procedure was developed, using the Aeroscout Algorithm, to identify students for "turnaround" training in the AH-1 Cobra Aircraft Qualification Course immediately following IERW graduation.

Since the introduction of the 175/40 POI, the number of IERW training tracks has been changed to four and then back to two, while the primary training aircraft has been changed from the piston-powered TH-55 to the UH-1, and most recently, to the TH-67. However, only one of these changes to the POI was based on research. When the Multi-Track POI was first introduced, bringing additional training tracks into the IERW curriculum for the UH-60 Blackhawk and the AH-64 Apache, a requirement existed to expand the Aeroscout assignment procedure to include the additional training tracks. ARI developed an algorithm to make track assignments based on probability of success in each track. A battery of tests was developed and data collected on students' performance in the IERW course. The assignment algorithm was designed using discriminant analysis. This empirically-based assignment procedure was successful in improving the throughput of the IERW course but it was abandoned when funding for the IERW POI fell to the point where multiple mission-based training tracks were no longer viable.

Description of the current Program of Instruction. In FY 95, Army aviation revised the IERW POI. The lead agency was the Aviation Training Brigade at Fort Rucker. The redesign effort, entitled Flight School 2000, was largely motivated by a substantial cut in training funds available for the IERW course. The goal was not solely to reduce training costs. The stated program objectives were to "make flight school more efficient" and to "increase warfighting capability of graduates." ARI reviewed the existing POI to ascertain whether research data were available to guide improvements in the efficiency of *ab initio* training. Particular attention was paid to the use of simulation to lower training costs without a corresponding decrement in training quality.

The POI was changed to reflect a reduction in flight and simulator hours, resulting in the 149-hour aircraft and 30-hour simulator mix. The Common Core was designed to provide the student with basic rotary-wing operator skills and knowledge for qualification in the TH-67 aircraft. At the outset, students attend a series of classes designed to bring warrant and commissioned officers to a common starting point. Warrant officers attend the Warrant Officer Entry Level Course; commissioned officers attend the Officer Basic Course. Both courses teach

a general development curriculum and give orientation to students on their careers in aviation and the Army.

The IERW Aviator Common Core begins after completion of these classes. The group of students is divided into two sections, of which one becomes the AM (i.e., morning) and the other the PM (i.e., afternoon) section. For the remainder of the training cycle, the two groups alternate AM and PM training sessions. One group attends academics (covering topics such as fundamentals of flight, aeromedical science, and weather) in the AM session while the other attends flight line training. AM and PM groups switch activities during the midpoint of the training day. On Training Day 1, classes cover aeromedical subjects emphasizing effects of rotary wing training on the human body. Other topics concern hazardous conditions in the aviation environment, and basic flight systems of the TH-67. Students begin TH-67 cockpit procedure training on or about Training Day 7 and continue through Training Day 10. On Training Day 11, they attend the flight line for the first flight session and continue through Training Day 26. They fly 1.3 hours each day until their stage I flight exam at the 18.5 flight hour level. Students then progress to the 22-25 flight-hour level. At that time, they are allowed to perform solo-flights of 1.3 hours in duration with their "stick-buddy" (i.e., fellow student pilot) acting as copilot.

Next, student pilots advance to more complex maneuvers and also refine their skills at basic maneuvers. That training cycle continues until they reach the 58-hour level where the stage II (end of primary phase) flight evaluation is administered. If the student pilot demonstrates knowledge and proficiency in all maneuvers, he or she is phased into the next level of training: Instruments.

In Basic Instruments all instruction takes place in the UH-1H Synthetic Flight Training System (i.e., UH-1 simulator). The student pilot receives 29.2 hours of instruction in the simulator. At that point, the Basic Instruments (simulator) checkride/evaluation of .8 hours is administered. If proficiency is demonstrated in all maneuvers, the student pilot progresses to Advanced Instruments where all instruction takes place in the TH-67. The student pilot flies 18.5 hours in the aircraft, practicing all basic instrument maneuvers, after which the 1.5 hour Advanced Instruments checkride/ evaluation is administered. Upon completion of Instruments, the student pilot moves on the next phase, Combat Skills, where tasks more pertinent to the tactical mission are mastered. The Aircrew Training Manual maneuver tasks which comprise the POI (including the Combat Skills Phase) appear in Appendix A. A glossary of relevant acronyms appears in Appendix B. A listing of Army Aviation training courses for Fiscal Year 1998 can be found on the World Wide Web at: www-rucker.army.mil.

Requirements for Enhanced Training Effectiveness

Past research demonstrated increased training efficiencies as a result of the application of low-cost simulators and automated, adaptive trainers to the IERW POI. These findings were not adopted by Army Aviation as modifications to the training curriculum. Prior to the mid '90s, the Army aviation training community did not acknowledge a requirement for greater training efficiencies. The general rule was to retain the same number of "blade hours" in the curriculum and to resist attempts to increase reliance on simulation. A related issue is that increased use of

flight simulation in training requires that additional simulators be procured. In financially austere times, it is difficult to obtain funds for simulator development and fielding. The austerity of the current training environment is driving the need for increased efficiency and effectiveness. Thus, Army decision makers are increasingly interested in research supporting greater use of simulation and other low-cost training techniques in the IERW course.

Optimization of the IERW POI. The IERW course has continued to be successful in that a high percentage of trainees have graduated and won their wings. Still, there is little guidance regarding the minimum number of flight hours required to graduate a capable Army aviator. Similarly, additional questions have emerged, regarding whether increasing the use of simulation could lower training costs without affecting the quality of the course graduate. To address these research questions, ARI proposes an overall analysis of the IERW POI to include:

- The current training objectives.
- The measurement of trainee performance.
- The mix of aircraft and simulator (including other training devices) training.
- The integration of academic classwork and flight training.
- The costs of each training phase and each instructional method.
- The effect of instructor pilot attitudes and beliefs upon training effectiveness.
- The effects of trainees' individual differences, e.g., personality, prior flight experience, attitude toward training, specific strengths and weaknesses, learning style and disposition toward feedback, upon training effectiveness.
- The structure of the curriculum, i.e., the limitations inherent in a fixed-time POI with students remaining in flight classes, versus the feasibility of a self-paced curriculum in which students' progress based on completion of training objectives rather than on a fixed-time curriculum.

Issues to be addressed in future experiments. Based on that analysis of the current POI and the training objectives which must be met, a series of experiments will be designed to address the key questions in developing a more cost-effective mix of simulator and aircraft flying training events in the IERW POI. The focus will be on empirically determining methods of increasing training efficiency through instructional strategies such as:

- Criterion referenced (competency-based) training.
- Individually-paced instruction.
- Increased use of flight simulation.
- Increased use of artificial intelligence such as neural networks to augment training.
- Matching students' and instructors' personalities and learning styles.
- Implementing self-paced, self-evaluated computer-based academic instructional modules
- Replacing fixed flight-hour training with objective-based training with continuous evaluation to signal the instructor pilot when the student has met the training objective.
- Functional requirements/design tradeoffs for a low-cost, training effective simulator for both visual and instrument flight training.

The results of these experiments will provide the most cost-effective training milieu for the IERW POI. However, it will not necessarily provide the optimal means of implementing such a program. ARI personnel will need to cooperate closely with the Army Aviation Center, as well as the Training and Doctrine, and Simulation, Training, Research and Instrumentation Commands, to develop an approach meeting the Army's training objectives. The development and procurement of new training devices and simulators has been a costly endeavor, though emerging, PC-based technologies may moderate these costs. A cost-effectiveness model will need to be developed to determine whether up-front training development costs will be amortized within a reasonable time frame.

Measures of Training Effectiveness and their Meaning

ARI has conducted demonstration experiments, in preparation for a larger, more integrated program of IERW research. These experiments were also performed in conjunction with the development and refinement of research simulator testbed equipment. At this point, it would seem appropriate to review these research efforts, in order to acquire a perspective on the research that is planned.

In the reporting of the research that follows, and in later sections of this paper, metrics of training effectiveness will be used with which the reader may not be familiar. At the outset, the reader will be presented with a verbal description of the rationale behind each of three metrics. These are the Transfer Effectiveness Ratio (TER), Cumulative Transfer Effectiveness Ratio (CTER) and Incremental Transfer Effectiveness Ratio (ITER). Conceptually, they are quite similar. They are, however, different tools for different jobs. What tool is used depends on what we want to know about the consequences of training. Do we want to know the end effect of simulator-based training, the cumulative effects at a point on the learning curve, or do we want a "snapshot" of simulator-based training at a particular point on the curve?

Table 1 presents some notional training data, to illustrate the rationale behind these measures of transfer effectiveness. Note that although the total number of iterations saved in the aircraft increases with increased training, the efficiency of training diminishes. In this example, pretraining for ten trials in the simulator would save ten iterations in the aircraft, but to save another ten, pilots would have to train for 20 more trials, for a total of 30 iterations. These same relationships appear graphically in Figure 1.

Table 1.

Quantitative Relationship between CTER, ITER, and Number of Trials Saved in the Aircraft

Simulator Trials	10	20	30	40	50
CTER	1.0	.80	.67	.55	.46
ITER	1.0	.60	.40	.20	.10
Trials Saved in Aircraft	10	16	20	22	23

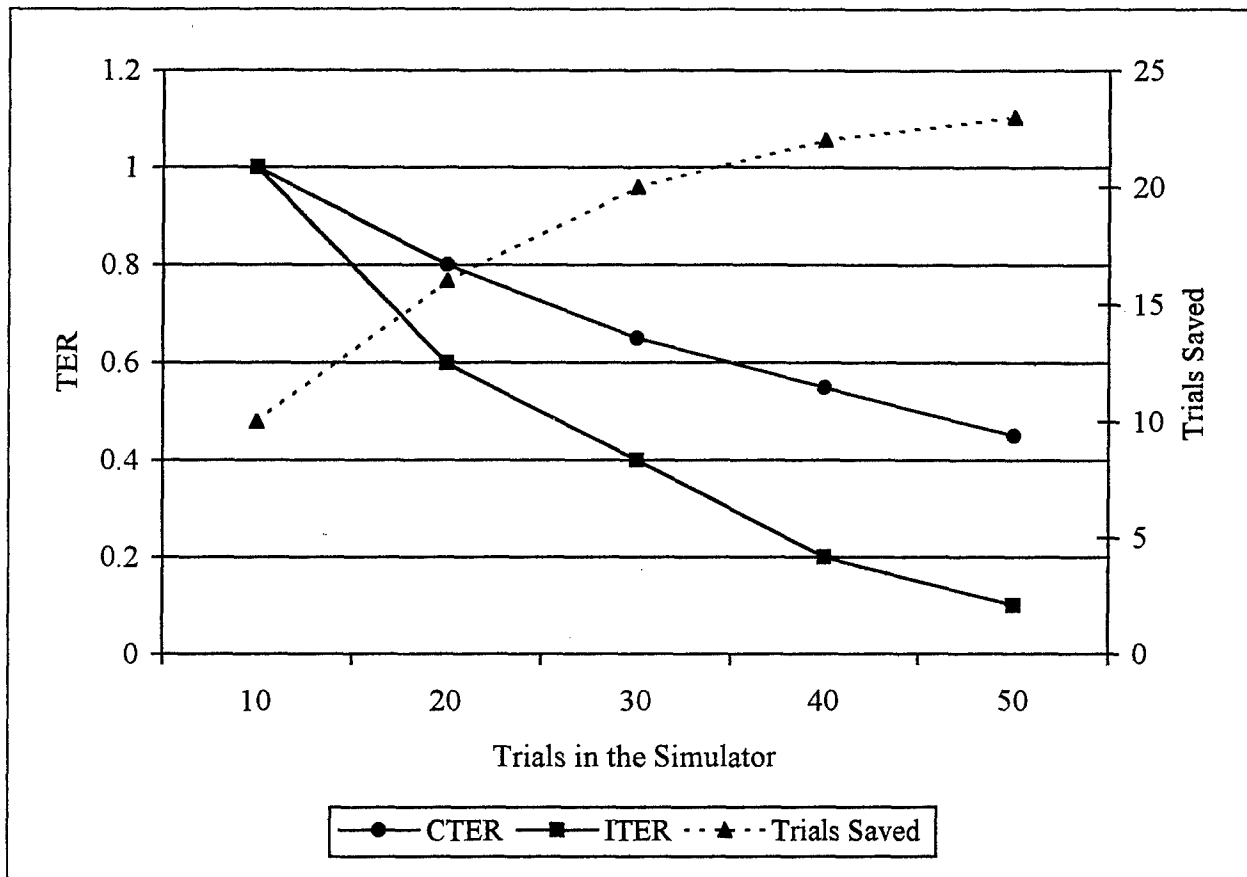


Fig 1. Effects of pretraining in the simulator on Transfer Effectiveness Ratio (TER) and number of trials (iterations) saved in the aircraft.

Again, Table 1 and Figure 1 provide strictly hypothetical data to illustrate training effectiveness metrics. The TER is a snapshot measure of the effectiveness of simulator pretraining expressed as the ratio of pretraining in the simulator to the savings achieved in the aircraft. It is calculated using the following equation (adapted from Roscoe & Williges, 1980):

$$TER = \frac{C_I - E_I}{E_{I(sim)}}$$

where C_I is the number of control group (no simulator training group) iterations to criterion in the aircraft, E_I is the number of experimental group (simulator pretraining group) iterations, and $E_{I(sim)}$ is the number of experimental group iterations in the simulator. TER is the ratio of savings in aircraft maneuver iterations to the number of iterations performed in the simulator by the experimental students (which is a training cost in that operation of the simulator and student pilot time expend economic resources). Examining the curves in Figure 1 reveals that successive sets of simulator iterations yield diminishing reductions in flight iterations.

Roscoe (1971) proposed a more dynamic measure of transfer effectiveness, the CTER:

$$CTER = \frac{(y_0 - y_i)}{x_i}$$

where x_i represents the number of iterations performed in a simulator, y_i is the number of iterations needed in the aircraft to demonstrate criterion performance after x_i simulator training, and y_0 is the number of iterations that would be required in the aircraft if no simulator were available. Each point on the CTER function represents a TER. For the first point on the CTER function, ten simulator iterations reduced iterations needed for students to demonstrate criterion-level behavior in the aircraft by ten in flight iterations for a TER of 1.0. CTER is similar conceptually to TER. TER measures the effects of simulator pretraining for a particular number of trials or iterations; CTER is concerned with the cumulative effects (see Figure 1). The main distinction is temporal. The training researcher is concerned with the CTER when he or she is interested in the effects of training along a continuum of simulator trials as illustrated in Figure 1. The CTER conveys more information than the TER in that it illustrates the actual shape of the transfer effectiveness curve, whereas the TER simply conveys the effects of training at one particular point (in the illustration, after 40 simulator trials, 22 trials are saved in the aircraft, so $TER = .55$).

By contrast to CTER, the ITER isolates the savings in expensive aircraft training as a consequence of each successive increment set of lower cost simulator training iterations (Roscoe, 1971). The ITER is defined as:

$$ITER = \frac{y_{t-k} - y_t}{x_t - x_{t-k}}$$

where:

- x is time (or iterations) on the simulator
- y is aircraft time (or iterations) to criterion
- t is the t^{th} measurement point
- k is the range incrementer such that $t-k$ gives the range over which the ITER is calculated, 10 in this example.

The ITER is expected to be a negatively decelerating function and its parameters are expected to vary widely from maneuver to maneuver (Povenmire & Roscoe, 1973). A researcher would use ITER to predict the amount of savings expected in the aircraft, if the student were to train for x more iterations (or trials) in the simulator. The fundamental questions he or she would ask are: would it be worthwhile to practice for one more trial, and when do we reach the point of diminishing returns? ITER is separately calculated for each block of maneuvers to determine the overall cost savings attributable to that additional set of simulator pretraining. As illustrated in Figure 1, increasing the number of simulator iterations from 20 to 30 (providing ten additional

simulator iterations) produces an additional savings of four iterations (or trials) in the aircraft, yielding an ITER of .4 at this point of the function.

The applications of these variables to models of simulation and training efficiency and cost-effectiveness will be discussed in more detail in a subsequent section. The purpose of presenting these metrics at this point was to help the reader to understand the rationales underlying them, and why more than one is needed.

An Optimal Mix of Aircraft and Simulation Training

The current section will take a more in-depth look at the metrics of training effectiveness previously introduced; namely, the TER, CTER, and ITER. Prior allocations of aircraft and simulation training resources to IERW training have been made by experienced training managers who have used expert judgment to structure the POI. This method will produce a successful training program, especially if the training schedules for each training phase are adjusted iteratively in response to changing demands and changes in normative performance over time. However, a judgmentally-based method will not necessarily produce the most cost effective curriculum. Mathematical models have been developed to quantify the increased training effectiveness and efficiency that results from the increased use of simulation in flight training. These models derive from the more general cost-effectiveness analysis approach. In the current application, the purpose of the model is to identify the most cost-effective allocation of aircraft and simulator training hours.

Determination of the most cost-effective training schedule requires that the tradeoff between the lower cost of simulator-based training, especially automated simulator-based training, be balanced against the greater number of training hours required to meet the same proficiency criterion. The assumption that the overall TER for a training simulator will be less than 1.00 is supported by numerous empirical research efforts. Accepting this assumption, the most time-efficient way to train students to criterion is 100% aircraft training while the most cost-efficient POI will involve mostly simulator-based training. There are exceptions, however; optimized training programs may yield greater TERs (see Diehl & Ryan, 1977).

The reader should recall that CTER is a ratio of savings that results from simulator pretraining to the "cost" of that pretraining in the simulator. It is the same concept as the TER, except that Roscoe views CTER as a cumulative function relating the savings in aircraft training to stepwise increases in simulator training costs. The TER values were based on training students to the same performance criterion in the simulator and the aircraft, and comparing them with an aircraft-only control group. Instead of looking at the cumulative or incremental effect of varying amount of simulator pretraining, the TER approach pre-established the criterion for acceptable performance and viewed only the effect of simulator pretraining to that level of proficiency. Diehl and Ryan (1977) found that, with a properly designed training syllabus, simulation-based training programs yielded a median CTER of 1.00 vs. .43 for those programs without a simulator syllabus. These findings lend cogency to the argument advanced by training researchers (Nullmeyer & Rockway, 1984; Salas, Bowers & Rhodenizer, 1998) that effective training depends as much (or more) on the training program as on the simulator.

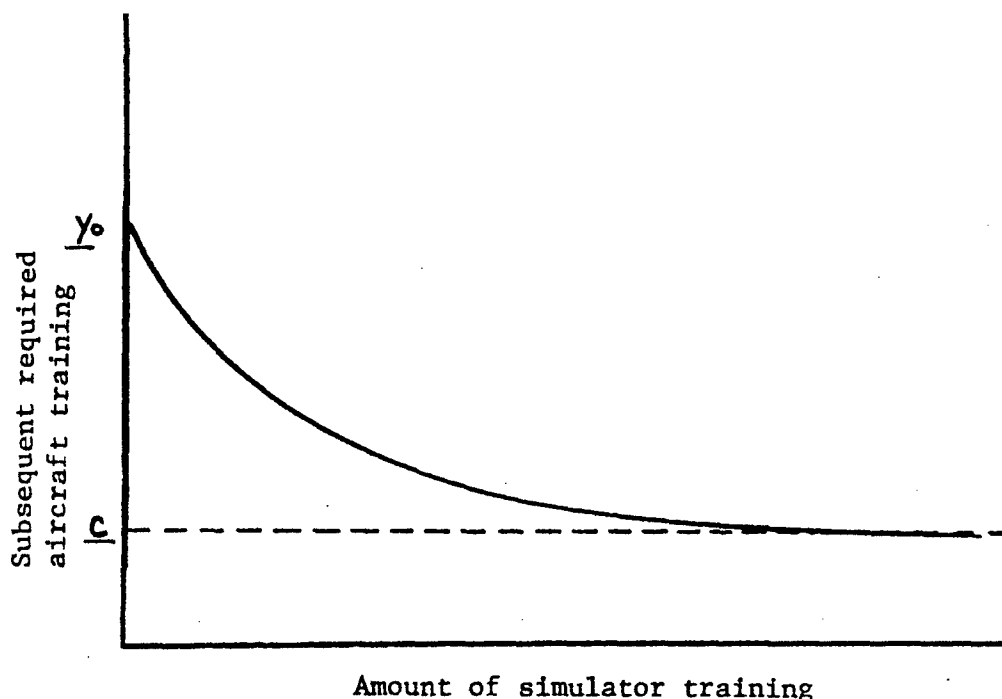


Fig. 2. Hypothetical relationship between the amount of simulator pretraining (x) and subsequent required aircraft training (y) (Adapted from Bickley, 1980).

As Roscoe points out, the CTER is not constant across varying amounts of simulator training but will decrease as the value of \underline{x}_i increases. Thus, the empirically determined value for CTER will only be valid for a small range of values in the region close to a given \underline{x}_i . As one can see in Figure 2, there is a point where continued training in the simulator will not increase training savings in the aircraft. Bickley (1980) recognized this limitation and noted that, while the a measure of the training effectiveness of all the \underline{x}_i values could be calculated by regressing CTER on various experimentally-determined values of \underline{x} , a simpler and more direct approach is to regress \underline{y} on \underline{x} . That is, a prediction model can be developed that will relate the relatively low-cost units of training in the simulator (\underline{x}) to the relatively high-cost units of training in the aircraft (\underline{y}) as required to meet the training objective. When $\underline{x} = 0$ (no simulator pre-training), \underline{y} will be equal to the CTER's \underline{y}_0 . As \underline{x} increases, \underline{y} is expected to decrease but not at a constant rate. That is, it has been empirically demonstrated that increasing amounts of simulator training result in decreasing training effectiveness in that the amount of aircraft training time (or iterations) saved is less as simulator pre-training increases. Since current simulators are not perfect replicas of the aircraft, there will always be some amount of aircraft training required to meet the training criterion, regardless of how much simulator pre-training is used. Bickley (1980) termed this amount of aircraft training \underline{c} .

Figure 2 presents the hypothetical relationship between \underline{x} , \underline{y} , and \underline{c} , depicted as a curvilinear function. As simulator pretraining increases, the aircraft training required to meet the criterion decreases, thus, $\underline{y}_0 - \underline{c}$ represents the potential savings in aircraft costs that will be realized as the result of simulator pre-training. Bickley made the assumption that, as \underline{x} increases,

the rate at which y decreases is a constant proportion of $y - c$. Bickley (1980) went on to apply this model to a reanalysis of the fixed wing simulator training effectiveness data reported above (Povenmire & Roscoe, 1973). The model showed that 44.3 hours were required for the average student to reach the criterion with zero simulator pre-training and that 37.6 aircraft hours are required to meet the criterion even if more than ten hours of simulator training were provided.

These two cost-analysis tools, the CTER and ITER, were presented by Povenmire and Roscoe (1973) for students working toward their Private Pilot Ratings in a Piper Cherokee fixed-wing aircraft. In their analysis, the simulator cost of operation of the (GAT-1) simulator was .73 times the cost of the aircraft. Their research found that the simulator was cost effective until approximately the fourth training hour at which point the ITER fell below 0.73. In IERW training, the cost of simulator operation is a much smaller proportion of the aircraft cost... more like \$75.00 vs. \$400.00 per hour so the ITER could drop to a value below 0.20 and still result in cost-effective simulator-based training.

Training Management

One means of improving training effectiveness and efficiency is through managing trainees individually rather than as members of a flight class. A computer implemented Training Management System could be developed using artificial intelligence to optimize training efficiency. By incorporating individually managed training schedules, each trainee can progress through the curriculum at his or her optimum rate. There are costs associated with flexible scheduling, such as assigning aircraft, training devices and instructors. These costs, however, should be modest when using computer based databases. The goal behind the Training Management System is to provide the instruction required for each student pilot to meet training objectives at the least cost. One requirement underlying its implementation is to develop measures to determine when the student pilot has met the criterion for each flight training objective. This suggests the value of criterion-referenced training using objective performance metrics which are sensitive enough to determine when the objective has been met. This performance evaluation could be accomplished automatically in the simulator but would probably have to be judged against published benchmark criteria by the instructor pilot, for training evaluation in the aircraft. If the student pilot's daily performances were entered into the system, then each student pilot's current training status would be known. The system could then schedule students, instructor pilots, and aircraft efficiently. Similarly, academic objectives could be scheduled and managed based on individual student pilot requirements. Students could attend classroom presentations together but could be scheduled by the Training Management System for remedial tutoring when daily performance evaluations indicated that they had not mastered the academic assignments.

The general instructional philosophy behind the managed training concept would be to train academic and procedural skills to criterion before the student pilot would begin flight training dependent on these skills. Procedural and basic flight skills training would be conducted in the part task trainer or simulator first, then validated in the aircraft. For those skills for which the student pilot demonstrated proficiency in flight, no further aircraft training would be required. For those skills in which the student pilot was not fully proficient, additional training would be prescribed by the Training Management System, based upon empirical results with

previous students. It would select the training alternative that had historically demonstrated the greatest probability of successful remediation.

Trainee Performance Measurement

Measurement challenges. An empirically-based program to improve the effectiveness and efficiency of aviator training is contingent upon reliable and valid performance measurement. Conventional measures of student performance during training are: course pass/fail, setbacks in the course, academic grades, flight training grades, checkride grades, instructor pilot "putup" grades (the checkride grade the student pilot is expected to receive on an end-of-phase checkride), and class standing. Training system and trainee proficiency measures which are possible but are not currently in use in the IERW course consist of: flight hours to criterion (in a criterion-referenced course, not a lockstep course); maneuver iterations to criterion; objective aircraft performance measures such as flight data recordings; similar objective data gathered during "flight" in a simulator; peer and student pilot self-progress ratings. Whatever measures are selected, they must be demonstrated to be reliable, valid, and sufficiently sensitive to identify relatively small changes in the efficiency of training. Such marginal increases in training efficiency may represent substantial dollar savings when multiplied across thousands of trainees.

The potential of criterion-based, empirically-derived performance measures was championed in a study by Nullmeyer and Rockway (1984), in which the researchers evaluated the effectiveness of the C-130 Weapon System Trainer, a full-mission simulator with a visual display system. Although the researchers found the Weapon System Trainer superior overall to an earlier, non-visual instrument simulator, they were nevertheless forced to conclude that it was "employed in a less than optimal manner." Its potential as a training device was unknown. Their recommendations were directed not at changes in its design, but in the training program supporting it. Among these recommendations were the abandonment of a highly-structured training regimen, and the adoption of a proficiency-based training program in which students would demonstrate proficiency in the simulator for selected tasks. Along with requiring proficiency, training would be tailored to the needs of the individual student. The student pilot would not be required to train in the simulator for a preset number of hours, but to demonstrate proficiency on the training syllabus in the simulator, and, once having done so, to proceed to flight line to demonstrate what had been learned.

Flight grades as predictors. There is even some question as to whether the performance of the student pilot during formal school training is the best criterion for the evaluation of the POI. The ultimate criterion for IERW training is not to produce course graduates, it is to produce aviators capable of safely and effectively executing Army missions in the field. The question can be asked whether the best performers during IERW training are also the best subsequent aviators after being assigned to aviation units in the field. Research by Bale, Rickus & Ambler (1973) which followed Naval aviators after graduation, showed that flight training grades did not effectively predict later operational performance. The conclusion reached by Bale et al. (1973) was that training grades do not assess all of the mission-oriented aviator skills and abilities that determine success in the field. In the current effort, it is proposed that IERW training developments be referenced against criteria in the "schoolhouse" (IERW) and in the

field. However, it must be realized that the latter performance measures will be more costly to obtain, both in dollar costs and time costs, since they will involve mission-related tasks such as gunnery, troop insertions, lift operations, and coordination of battle plans with other units. Given the high costs of IERW training, it is likely that field performance measures will be cost-effective.

A research project should be performed to investigate these two classes of performance measures to determine whether training for success in the schoolhouse is commensurate with training for success in the field. Specifically, if any measures of student pilot performance are negatively related to subsequent mission-performance in the field, they need to be identified and studied further to identify the underlying behavioral differences between schoolhouse criteria and field criteria. This research will necessarily be longitudinal and time-consuming.

Using initial entry grades as performance measures is problematic for several reasons. In the case of the Army IERW course, the daily training grade is a letter (A, B, C, or U) while the putup and checkride score are numerical, based on a 100 point scale. The modal daily grade is a B. If an A or a "downgrade" (C, or U) is given, the instructor pilot is required to explain the grade with a write-up on the grade slip. Thus, the grade of B is parsimonious with regard to the instructor pilot's time. Past research efforts have shown that there is too little variance in the distribution of daily training grades (the "swarm of Bs") to make them effective as either criterion measures or as predictors of later performance.

Basic Qualities. Army IERW training uses the concept of Basic Qualities to reference the individual student pilot's underlying knowledge, skills, and abilities that are judged by the instructor pilot to predicate the assignment of an upgrade or downgrade. Each student pilot is evaluated on each of the six Basic Qualities during each training flight. Those that are postulated to underlie IERW training performance during Primary Phase are:

- Flight Safety
- Attitude
- Knowledge of Procedures
- Co-Ordination (sic)
 - Planning and Judgment
 - Division of Attention

These are hypothetical constructs that are postulated to explain an student performance during training. They are not empirically derived from trainee performance using a quantitative procedure, but instead reflect traditional beliefs in Army aviation. Previous analyses of the distribution of Basic Qualities grades has not shown them to be effective as criterion measures or as predictors of future training performance (Dohme, 1979). They are worthy of further analysis, however, in that empirically derived Basic Qualities may provide a basis for the knowledge, skills, and abilities that contribute to IERW training performance. Other researchers have identified additional weaknesses in the use of IERW training grades as criterion measures.

Pilot Performance Description Record (PPDR). Researchers have long been cognizant of the deficiencies mentioned above. This has led to attempts to objectify and standardize the

performance evaluation process. Greer, Smith & Hatfield (1962), pretested the PPDR, a performance rating system consisting of scales referenced to the Aircrew Training Manual standards for basic flight maneuvers. The rationale behind the PPDR was to minimize the subjectivity and variability between instructor pilots that the investigators had found to be inherent in the use of conventional flight grades and Basic Qualities. Results of the pretesting were promising. The use of the PPDR showed evidence of improved reliability when compared to grades, and that it was demonstrated to be a good tool for diagnosing specific sources of an student pilot's flight deficiencies. Furthermore, check pilots highly familiar with the PPDR showed higher reliability in their scoring of students than did those not so familiar. The PPDR was used operationally at Fort Wolters, Texas, for five years. Despite its demonstrated superiority to conventional flight grades, its use was discontinued when all IERW training was consolidated at Fort Rucker.

Basic Flight Instruction Tutoring System. Koonce, Moore & Benton (1995), describe the Basic Flight Instruction Tutoring System as a PC-based system that has both a tutorial and performance measurement function. It is criterion-referenced in that it requires the student to meet a pre-set standard for one maneuver before proceeding to the next one. It is tutorial, teaching the student how to perform a given maneuver, then demonstrating the maneuver, measuring performance while the student performs it, and presenting feedback when the student exceeds certain pre-set parameters. The feedback (e.g., airspeed low) instructs the student pilot how to get back into the specified performance envelope while performing the maneuver. After completion of the maneuver, the student pilot is told whether or not performance was satisfactory. The student pilot must perform all maneuvers in a particular lesson module to standard before being allowed to move on to the next, more advanced, module. The system captures error scores for each variable comprising a particular maneuver. In this sense it is a performance measurement system.

Koonce et al. demonstrated the effectiveness of the Basic Flight Instruction Tutoring System by pretraining ten entering students in an FAA Part 141 training school on it, and comparing their performance on the same maneuvers in the final checkride in a Cessna 152. Seventeen control students progressed through the course unassisted. Performance of the pretrained students was superior to that of the controls on a number of dimensions, notably flight hours to solo ($p < .001$). Instructor pilots noted also that pretrained students required fewer attempts to land the airplane, and seemed to impact the ground more softly than the controls. The investigators concluded that the Basic Flight Instruction Tutoring System is a criterion-based training system that minimizes the cost of instruction, and has also demonstrated TOT to the aircraft. It was developed under a Small Business Innovative Research grant, and has been adopted and operationally employed by a commercial flight training academy. It could possibly alleviate problems inherent in the subjectivity of evaluating performance in the simulator.

The Semi-Automated Flight Evaluation System was derived from the Basic Flight Instruction Tutoring System (Benton, Corriveau & Koonce, 1993). It is PC-based on-board performance evaluation and tutoring system that is intended to be easily installable and removable. This system should be of great interest to researchers such as the current authors. Performance measurement systems have been tested in simulators, but there are no operational, on-board systems in aircraft. Since the system is configured from commercial, off-the-shelf

components, it should be a cost-effective alternative to more expensive hardware, namely, digital flight recorders. Devising a common set of performance measurement parameters for both simulator and aircraft, and demonstrating their reliability and validity, would be a significant milestone in the development of aviation training technology.

Tradeoffs and Recommendations

Several authors have demonstrated the utility of designing a flight training curriculum for optimal cost-effectiveness using mathematical models to calculate the most economical mix of aircraft and simulation time (Derrick, Tomczak, Nullmeyer & Burrigh, 1992). This approach is recommended for the IERW POI. Westra and Lintern (1995) recommend the application of an exponential decay model to determine the ITER for the optimal use of simulation. This type of mathematical model requires that the amount of aircraft training (to criterion) for each maneuver be known, and that the operational costs of the aircraft and the simulator be calculated. In the case of an experimental training simulator, the operational costs are unknown and must be estimated. Similarly, the operational cost of the training aircraft is dependent upon the assumptions that go into the cost model. For example, does the model include:

- Cost of the instructor pilot?
- Cost of operating the stage (training) field?
- Cost of providing emergency medical and fire personnel?
- Cost of providing aviation weather services?
- Cost of bussing students to the stage field where the aircraft is located?

Calculation of the cost of training to criterion in the aircraft with no simulator pretraining is difficult to determine in the case of the IERW course since the current lockstep curriculum does not allow relating training costs to proficiency. The curriculum is fixed for each training day and so the cumulative training time to criterion for a given maneuver is not known. ARI has surmounted this problem in the past by counting maneuver iterations to criterion (three successive maneuvers within published standards). While this criterion measurement is arbitrary, it is, at least, repeatable and provides for an empirical estimate of training costs. Cost-effectiveness data will need to be estimated based on research results and then refined based on the accumulation of daily training data to precisely determine the most cost-effective mix of simulator and aircraft for each specific training maneuver.

The sections to follow review prior ARI research on increasing the cost-effectiveness of flight training. We propose new research leading to a validated IERW POI that will meet increasingly demanding training objectives while reducing training costs. A research master plan is proposed for FY 98, supporting empirical research to be conducted in FY 99. The goal of the research is development of an empirically-based IERW curriculum by FY 2000.

Army Research Institute Ab Initio Training Effectiveness Research

Background

As we have learned, research has addressed the training effectiveness of entry level flight training programs. Most of this research was conducted over twenty years ago; simulators have evolved dramatically since that time. Most of it concerned fixed wing ab initio students and may not apply to rotary wing training. This section reviews ARI research for experimental rotary wing training programs. We will attempt to draw conclusions regarding the contributions of prior research to the development of a more efficient IERW POI. In addition, benchmarks established by prior research will serve as heuristic devices for the research program under design. We will also examine what is known and what remains to be determined in the design of an optimally cost-effective IERW training POI.

In the late 1980s, ARI began to answer the questions posed by the Army Aviation Center regarding simulation as a "training efficiency multiplier" by developing a low-cost simulator specifically designed to support IERW training. Since the newly developed simulator had unknown training capabilities, it was necessary to determine whether training in the UH-1 Training Research Simulator provided any TOT to the UH-1 aircraft before it was evaluated as a substitute for the aircraft. The TOT paradigm was chosen as the best metric to evaluate the effectiveness of the simulator since it provided a separate estimate of training effectiveness for each maneuver and could serve to estimate the cost-effectiveness of simulator-based training.

Overview

Four TOT experiments were performed, using the Training Research Simulator. These experiments were embedded in the IERW course structure, and in all of them IERW students served as participants. In the four experiments that follow, eight Primary Phase maneuvers were selected for evaluation: takeoff to hover; hover taxi; hovering turns; hovering autorotation; normal takeoff; traffic pattern; normal approach; and landing from hover. There were specific variations among these experiments; hence, they are reported separately. In overview, Experiment 1 was a process evaluation of the simulator, to investigate TOT to the UH-1 aircraft. Participants were student pilots who had completed Primary Phase training in the TH-55 aircraft. Experiments 2 and 3 were conventional TOT experiments, employing neophyte trainees. Experiment 4 was a substitution experiment in which seven hours of UH-1 aircraft time was replaced with nine hours of simulator time. Weather conditions on the flight line reduced the number of aircraft flight hours from the originally planned nine to seven.

Experiment 1

Introduction. The UH-1 Training Research Simulator was evaluated by selecting a random sample of ten flight students who had already completed the Primary Phase of IERW training in the TH-55 helicopter. All students had soloed the aircraft and had demonstrated proficiency in a variety of emergency procedures as well as in the common rotary wing flight maneuvers. It was hypothesized that all these student pilots, who had an average 46 hours flight training, would demonstrate positive TOT from the simulator to the UH-1 since they had already

demonstrated basic helicopter piloting skills. Students who had also graduated from TH-55 Primary Phase of IERW served as controls. They went directly to the UH-1 aircraft without any intervening training. The hypothesis was that the simulator-trained students would meet the criteria for soloing the UH-1, as written in the Contact (UH-1) Phase POI, in fewer maneuver iterations than would the control group.

Method. Instructor pilots were all qualified to teach Primary Phase and were given two students each for 1.0 hours of training per day in the simulator to the same standards they would use on the flight line. The control group students were selectively matched to the experimental students on factors known to influence performance in the IERW course: Flight Aptitude Selection Test scores, Primary Phase flight grades, rank, and age. The matched pair flew as stick buddies in the UH-1 with the same instructor, to reduce variance in the experimental design. To ensure a fair and unbiased evaluation, instructor pilots were not informed which of the paired students had been pretrained in the simulator.

Findings. There were three possible outcomes for each of the eight maneuvers: the simulator could demonstrate: (1) positive TOT; (2) no TOT; or (3) negative TOT. The actual results of the experiment provided all three outcomes depending upon the particular maneuver. Given the primitive nature of the visual imagery from the low-cost image generators used at that time, this result was not surprising. Overall, the evaluation showed an average TER of .22.

TER values from Experiments 1 through 4 are presented in Table 2. The data show that six of the eight maneuvers demonstrated a moderate positive TOT, one (normal approach) was essentially zero, and one (normal takeoff) demonstrated a negative TOT. The average TER across all eight maneuvers was .22.

Table 2

Transfer Effectiveness Ratios for Transfer of Training Experiments

Experiment	Aircrew Training Manual Maneuver Tasks							
	T/O to Hover	Hover Taxi	Hover Turns	Hover Auto.	Normal T/O	Pattern	Approach	Land from Hover
1	.21	.41	.24	.31	-.13	.42	.07	.24
2	.15	1.0	-.03	-.35	.54	.38	.48	.67
3	.25	.73	.70	.48	.43	.68	.31	.40
4	.32	-.06	.61	.21	.00	.09	.24	.49
Combined	.23	.52	.38	.16	.21	.39	.28	.45

Table 3

Iterations Transfer Ratios for Transfer of Training Experiments

Experiment	Aircrew Training Manual Maneuver Tasks							
	T/O to Hover	Hover Taxi	Hover Turns	Hover Auto.	Normal T/O	Pattern	Approach	Land from Hover
1	4.8	2.5	4.2	3.2	n/a	2.4	14.3	4.2
2	6.7	1.0	n/a	n/a	1.9	2.6	2.1	1.5
3	4.0	1.4	1.4	2.1	2.3	1.5	3.2	2.5
4	3.1	n/a	1.6	4.8	n/a	11.1	4.2	2.0
Combined	4.7	1.6	2.4	3.4	2.1	4.4	6.0	2.6

The same data are presented in another form in Table 3. Iterations Transfer Ratio (ITR) values are the reciprocals of the TERs. They provide the number of simulator iterations required to save one iteration in the aircraft. Thus, ITRs serve as a practical index of the amount of TOT expected in an applied training scenario.

The performance metric entailed iterations to criterion rather than the more customary flight hours to criterion. This was because the exact number of hours each student pilot required to meet each published training objective was unknown. The IERW POI follows a fixed-hour curriculum in which every student pilot gets the same training regimen. If the POI calls for 0.5 hours of hover training on a given training day, each student pilot gets that amount of training. Therefore, it is impossible to review the students' logbooks and determine how many hours were required to meet the training standard for a given maneuver.

Experiment 1 demonstrated that the low-cost simulator produced positive TOT to the aircraft in students already familiar with the basic Primary Phase IERW flight maneuvers. Based on these results, ARI decided to upgrade the image generators and to make improvements to the aerodynamic simulation model before conducting additional TOT research.

Experiment 2

Additional research evaluations were completed, following the TOT paradigm outlined above. A random sample of ten students with no prior flight experience was selected. The non-selected student pilots in the same flight class served as controls. The experimental participants' training schedule was altered to provide for two weeks simulator-based training prior to beginning in-aircraft training on the flight line. The students were trained on the same eight target maneuvers. Training was conducted in the UH-1TRS by qualified Primary Phase instructor pilots to the published maneuver criteria. An average of 8.7 training hours was required per student to meet the criteria (contrasted with 6.3 hours per student pilot for the students in Experiment 1 who had prior training). The TERs for experiment 2 are presented in the second row in Table 2. The related ITRs are presented in Table 3.

The results from Experiment 2 revealed an average TER of .36 with two maneuvers (takeoff to hover and hovering turns) displaying essentially zero TOT and one (hovering

autorotation) displaying moderate negative TOT. It was not known if the improvement in average TER in Experiment 2 was the result of improvements to the UH-1TRS or the result of using neophytes as research subjects. With neophytes, the degree of improvement in flight skills would be expected to be large for the early training hours compared to the trainees from Experiment 1 who had already completed the Primary Phase of IERW training.

Experiment 3

Further improvements were made to the UH-1 Training Research Simulator. The image generators were upgraded to improve the quality of the out-the-windows imagery. The frame update rate was increased from 30 to 50 Hz, and greater level of detail management and texturing capabilities were added. A visual database was developed to model the Fort Rucker, AL training Area of Operations. The same experimental procedure was followed as that used in Experiment 2.

TER values for Experiment 3 are presented the third row in Table 2 and the derived ITRs in row three of Table 3. In this experiment, a positive TOT was observed for all eight training maneuvers. The overall average TER for Experiment 3 was 0.45. The average ITR for these maneuvers was 2.32:1 which suggests that, under these conditions, two and one third maneuvers in the low-cost simulator will save one maneuver on the flight line. Given the differential in hourly costs of operating the aircraft and the simulator, approximately \$700 vs. \$75 respectively, the simulator was considered to be an effective trainer.

Experiment 4

Background. At the request of the Commanding General at Fort Rucker, ARI performed a fourth experiment to evaluate whether the low-cost simulator could substitute for aircraft flight training. Since the results of Experiments 2 and 3 suggested that the average student pilot meets the POI training criterion for all eight target maneuvers in approximately nine flight hours, Experiment 4 (The Substitution Experiment) replaced nine hours of "blade time" with nine hours of simulator time. The simulator was configured the same as it was for Experiment 2.

Dependent measures. The dependent measures of interest in Experiment 4 were not TERs. They were instead measures of student pilot progress in training. It had already been demonstrated that the Training Research Simulator produced positive TOT to the aircraft. The issue in Experiment 4 was whether training in it could substitute for aircraft training on an hour-for-hour basis. The simplest measure of equivalency is whether any students in either the experiment or control group were eliminated from or set back to an earlier phase of training. There were no setbacks or eliminations in Primary Phase for either group. When flight training grades were compared at the end of Primary Phase, the control group had higher training grades than the experimental group; the difference was not statistically significant.

Findings. TERs and ITRs were calculated for the ten experimental students. These are presented in Tables 2 and 3. A positive TOT was achieved on six of the eight target maneuvers; there was essentially no transfer on normal takeoff, and a slightly negative transfer on the hover taxi maneuver. The average TER for Experiment 4 was .23. Overall, the substitution experiment was considered a success because of the following:

1. No experimental group students were set back or eliminated.
2. There was no significant difference in Primary Phase grades.
3. Net savings in training cost were approximately \$36,000 for ten trainees.
4. Overall positive TOT was demonstrated.

Summary and Conclusions: Experiments 1-4

The four TOT experiments used random samples of 40 Army students as they progressed through IERW flight training. The remaining students in the same classes served as control participants. Conclusions should be generalizable to current and future Army trainees. The last row in Table 3 displays average ITR values for the four combined experiments. While each individual experiment evidenced considerable variability across the eight target maneuvers, the combined results show that, overall, the simulator produced positive TOT on all maneuvers. Variability across maneuvers and experiments was probably attributable to changes in simulator configuration, differences in instructor pilot experience, skill level, and attitude toward simulation, and to differences in student pilot abilities.

In summary, a low-cost training simulator like the Training Research Simulator has considerable potential for training IERW students in the basic flight skills at greatly reduced costs. The simulator was dismantled when the Army changed the Primary Phase training helicopter from the UH-1 to the TH-67.

The technology of the Training Research Simulator is dated. A training simulator like it can be constructed at relatively low cost using PC technology. At this writing, a high-end PC with a visual image accelerator card can produce high quality imagery for out-the-window scenes at a fraction of the cost of the image generators employed in these experiments. ARI is experimenting with this technology to stay abreast of developments that support the future generation of low-cost trainers. A TOT experiment employing a contemporary low-cost, PC-based simulator follows.

TH-67 Skills Trainer Transfer of Training Experiment

Introduction

The TH-67 Skills Trainer (Frasca International, Inc., May 1995) is the low-cost simulator used in the present experiment. Its cockpit is modeled after that of the TH-67 helicopter, with dual flight controls, flight instruments, and system indicators. The avionics can be used to train instrument flight rules (IFR) operations. A variety of environmental conditions, including wind speed and direction, turbulence, visibility, cloud ceiling, and day/dusk/night illumination can be simulated. Various engine, electrical, hydraulic and mechanical failures can also be simulated. The simulator provides helicopter sound cues, including engine, transmission, main rotor, and wind noise, plus warning tones. The out-the-window view is projected onto a screen in front of the cockpit. The visual field, as configured for this experiment, was 33° horizontal by 25° vertical. All locations in the visual database (e.g., airfield, helipad, taxi lanes) are accurately modeled and internally consistent in terms of latitude, longitude, and magnetic compass orientation.

Method

Overview. A subset of the flight tasks was selected from the IERW POI. The maneuver tasks were: takeoff/landing to a hover, hovering flight, hovering turns, normal takeoff, normal approach, traffic pattern flight, and hovering autorotation. Instructor pilots trained these tasks to a criterion of three consecutive successful iterations in the simulator. Then instructor pilots trained the same tasks to criterion for the same students in the aircraft. In short, a modified TOT design with two groups (simulator/non-simulator) was used. Participants were students from primary phase IERW classes. They were matched on Flight Aptitude Selection Test scores. One member of each matched pair was assigned randomly to the simulator group, the other to the control group. The simulator group trained to criterion in the flight simulator, then transferred to the flight line for training to criterion in the TH-67 helicopter. The control group received no simulator training prior to being transferred to the flight line for training to criterion in the TH-67. Performance measurement and data collection took place at the flight line during Phase II primary flight training.

Evaluation. Because of technical difficulties in collecting data in the aircraft, the actual number of iterations to criterion were not measured in the aircraft. Instead, the number of hours required for the student pilot to attain proficiency at critical milestones comprised the principle dependent variable.

Simulator phase. Training took place at the ARI. Each of the six simulator group participants received one 45-minute simulator training session per day for the first ten training days. This is 7.5 hours total of simulator training time. Each was instructed individually by his or her assigned instructor pilot. Each instructor pilot trained his two student pilots in consecutive sessions. Simulator sessions were partially counterbalanced across training days so that no instructor pilot or student pilot consistently got the late time slots. During training days 1 through 10 members of the control group were occupied with traditional preflight academic activities. This was a necessary part of the TOT paradigm.

Flightline phase. Six contract evaluators were selected to serve as training monitors and data collectors during the flightline phase of the experiment on training days 12 through 17: three evaluated members of the simulator (experimental) group; the other three evaluated members of the control group. Contract evaluators monitored training during each flight period. They recorded the amount of time spent demonstrating and practicing each specified flight task, and the number of demonstration and practice trials for each flight task. The criterion for any particular task is defined as performing it to standards three consecutive times.

Results

Pre-solo phase. The two major dependent variables were the overall grade the student pilot received on his or her checkride, and the total flight hours to complete a satisfactory checkride. Table 4 presents the means and standard deviations (SDs) for these two measures of performance.

Table 4

Time to Flight Evaluation Checkride and End of Pre-Solo Phase Flight Grade

Measure	Mean	SD
Experimental group		
Time	17.50	.50
Grade	87.50	3.73
Control group		
Time	19.22	2.86
Grade	82.50	6.98

Close examination of Table 4 reveals the difference in variability on these two criteria between the experimental and control groups. For both, there was much more variation in performance in the latter group. For this reason, a non-parametric test, the Mann-Whitney U Test, was used. The Experimental-Control comparison for final grade was not statistically significant ($p < .20$). The comparison for time to complete successful checkride was significant ($p < .04$), and is presented in Table 5.

Table 5

Mann-Whitney U/ Wilcoxon Rank Sum Test Comparing Time to Complete Successful Checkride for the Experimental (Simulator) and Control (Non-Simulator) Groups

Group	Mean Rank	Sum of Ranks	<u>z</u>	<u>p</u>
Experimental	4.33	26.00	-2.10	.04
Control	8.67	52.00		

These results imply that pretraining in the low-cost simulator saved training time in the aircraft. It seems, then, that time to the criterion (i.e., successful completion of an evaluation checkride) was a sensitive measure of training effectiveness. The data also suggest that pretraining in the simulator reduced performance variability in the experimental group. Flight grades did not appear to be a highly sensitive index of the effects of simulator training. Nonetheless, the experimental group did outperform the control group on one maneuver task, hovering flight ($U = 5.00$, $Z = -2.38$, $p < .02$). No other differences were significant.

Unsupervised solo phase. The two groups were followed up, and total flight hours at the completion of the unsupervised solo were collected for both groups of students. As before, data were analyzed via a Mann-Whitney U-test. The results of the analysis, significant at $p < .007$, are presented below in Table 6. The means and standard deviations for the two groups are presented in Table 7.

Table 6

Mann-Whitney U/ Wilcoxon Rank Sum Test Comparing Time to Complete Unsupervised Solo for the Experimental (Simulator) and Control (Non-Simulator) Groups

Group	Mean Rank	Sum of Ranks	z	p
Experimental	3.67	22.00	-2.72	.007
Control	9.33	56.00		

Table 7

Time to Completion of Unsupervised Solo Flight, for Experimental and Control Groups.

Group	N	Mean hours	SD
Experimental	6	28.70	1.716
Control	6	36.40	4.469

Mean total hours at the end of the unsupervised solo were significantly fewer for the experimental group. The SD was also substantially lower, which necessitated the use of the non-parametric test. The lower variability could be indicative of more uniformity in performance among those students pretrained in the simulator. Interestingly, there was no variation in the number of hours to supervised solo for the experimental group; all were ready by 22 total flight hours. However this was not the case for the control group ($M = 23.98$ hours; $SD = 3.31$).

Experimental group participants trained to criterion in the simulator. Time to criterion did not correlate significantly with total time to completion of the unsupervised solo ($r_s = -.46$). However, the Spearman correlation between total simulator grade and the same criterion variable was significant ($r_s = -.81$, $p < .05$). The small sample size makes interpretations of these correlations difficult.

Future Research Directions

Students used the Skills Trainer as an adjunct to the traditional IERW training syllabus; nothing else was changed. In future experiments, the use of simulation will be evaluated as an integral part of the total IERW training system. For example, some of the issues that ARI plans to investigate are the use of simulation to integrate and enhance those skills already learned in the aircraft, and the degree to which practice in the simulator can substitute for practice in the aircraft. Likewise, breakthroughs in PC technology have made possible new self-monitoring, adaptive training devices. ARI is currently exploring one development, based upon artificial intelligence technology.

Automated, Adaptive, Simulator-Based Training

Overview

The experiments outlined above demonstrated that low-cost simulation can be an effective tool in ab initio training. This finding led the ARI research staff to propose further inroads by capitalizing upon the ever-increasing power of low-cost PCs. Specifically, we were interested in the possibility that PCs and intelligent software applications could be used to train neophytes in lieu of the traditional requirement for an instructor pilot in the cockpit. Since a simulator cannot "crash" and hurt the trainee, there is no requirement for an instructor pilot to serve as a "safety pilot." As the authors know from experience, learning to hover, the most basic helicopter flight skill, involves much frustration. During the earliest hours of hover training, the student continues to overcontrol the aircraft, lose control, and relinquish the controls to the instructor who then brings the helicopter from its dangerous attitude back into control. The frustration, danger, and inefficiency of early hover training served as a heuristic stimulus that led to the concept of an automated, adaptive, computer-managed hover trainer.

The Automated Hover Trainer

Background. The Automated Hover Trainer (Dohme, 1995) was developed to evaluate the idea that students would learn to hover more quickly and with less frustration if they didn't have to experience the instructor pilot snatching away the controls to save the aircraft. From a human factors perspective, students should learn more rapidly and with less negative affect if they could continue to have control of the machine with varying degrees of help provided by an augmented set of flight controls that would synthesize an easy-to-fly helicopter. It was designed jointly by ARI personnel and engineers from the University of Alabama Departments of Aerospace and Electrical Engineering to test that idea. The UH-1 Training Research Simulator was used as the training vehicle. Modifications were made to add the computer artificial intelligence to the control loop. In addition, synthesized voice feedback was provided to students to provide verbal feedback regarding their errors and to provide guidance toward improving their hovering flight skills.

Rationale. The premise behind the development of the Automated Hover Trainer was to synthesize a training simulator that would continuously review student pilot performance against the IERW POI training objectives and adaptively augment control inputs such that the demand characteristics of the device would accommodate the trainee's ability to successfully hover. The Optimal Control Model (Kleinman, Baron, & Levinson, 1970) was applied to the trainer to create an adaptive trainer providing "inner-loop stability augmentation" to the man-in-the-loop simulation. The mathematical model periodically compares ongoing trainee performance with performance norms established by an expert pilot flying textbook maneuvers. As the student pilot's performance approaches the norm, the computer augmentation reduces the level of control augmentation until the student pilot is able to fly the maneuver with the unaugmented helicopter aerodynamic model.

Automated Hover Trainer Quasi-Transfer Experiments

Approach. The same approach was used that was successful with the TOT experiments, i.e., a random sample of IERW students served as research subjects and the experiment was embedded in the IERW course. A preliminary evaluation of the Automated Hover Trainer was accomplished using what Taylor, Lintern & Koonce (1993) termed a quasi-transfer experiment. Students were trained to the IERW POI standards in the Automated Hover Trainer. Transfer was evaluated by an instructor pilot using the device itself as the criterion vehicle. Students trained to IERW standards on the five basic hovering maneuvers: stationary hover, hover taxi, hovering turn, land from hover, and takeoff to hover. Criterion performance was defined as two successive minutes at autohelp level zero (no control augmentation).

The initial evaluation, using the quasi-transfer research design, was undertaken as an initial feasibility study of the Automated Hover Trainer concept. As such, it was not deemed necessary to include a control group.

Results. In-simulator checkrides were administered by a Standardization Instructor Pilot who was not privy to the training data from the research subjects (e.g. how much time or how many iterations were required by each student pilot to meet the criterion). Students were graded as though they were being evaluated for authorization to perform their first solo flight, a checkride that was administered at approximately the 14 hour level in the aircraft. At the time of the checkride, participants had spent an average of 3.1 hours each over four days in the Automated Hover Trainer (total training time was limited by the schedule imposed upon the research subjects by their Army assignments). The data from the quasi-transfer experiment are presented in Table 8, showing the percent of trainees passing each maneuver during the time-limited training and the percent passing the checkride.

Table 8

Percent of Students Meeting Criterion for Maneuver Training and Passing Subsequent Checkride

Percent Passing	Aircrew Training Manual Maneuver Tasks				
	Hover	Hover Taxi	Hover Turns	T/O to Hover	Land to Hover
Training Program	96	100	96	87	96
Checkride	100	100	100	96	96

Transfer of Training from the Automated Hover Trainer to the Aircraft

Approach. Although the quasi-transfer experiment demonstrated the Automated Hover Trainer to be an effective training device, it remained to be seen whether training would transfer to the aircraft. Two TOT experiments were conducted using a random sample of Army student pilots. The experiments followed the same procedure and are combined for this review. It was necessary to replicate the experimental design since only ten participants per day could be trained in the device during the time the students were available.

The twenty officer students, drawn at random from their respective flight classes, learned the five basic hovering maneuvers in the Automated Hover Trainer. When they went to the flight line, their progress was assessed using a research evaluation form. Each time hovering flight was trained, the UH-1 instructor pilot recorded the training on the form on his/her kneeboard. There were four possible outcomes to each maneuver iteration:

- DEMO: instructor pilot demonstrates the maneuver.
- ASSIST: student pilot attempts maneuver, instructor pilot takes controls to assist.
- ATTEMPT: student pilot completes maneuver without help but does not meet IERW POI standards.
- STANDARD: student pilot completes maneuver within standards.

Successful completion of training for each maneuver was operationally defined as three successive maneuver iterations in the STANDARD category. The dependent measure was the total number of iterations of each maneuver to meet the criterion.

Transfer of training was evaluated by comparing the hover training performance of the experimental group with classmates who served as a control group. The criterion was the same as that used in the simulator (three successive STANDARD grades). The hypothesis under evaluation was that the experimental students would meet the criterion for the target maneuvers in the aircraft with significantly fewer maneuver iterations than would the control students.

Results. The results of the experiment are presented in Table 9, which compares the iterations to criterion for the two groups by maneuver. In each case, the experimental students met the criterion in significantly fewer iterations than did the control group. The experimental group met the training criterion in the aircraft with an average of 15.2 iterations per maneuver and a total of 75.9 iterations across the maneuvers. The control group required an average of 18.9 iterations per maneuver with a total of 94.7 iterations across the maneuvers. This difference reflects a savings of 19.9% of the control group's maneuver iterations on the flight line.

Table 9

Mean Maneuver Iterations to Criterion for Experimental (n = 16) and Control (n = 33) Groups

Groups	Aircrew Training Manual Maneuver Tasks				
	Hover	Hover Taxi	Hover Turns	T/O to Hover	Land from Hover
Experimental	14.3	14.1	17.6	15.3	14.6
Control	18.3	19.0	21.8	18.2	17.3
χ^2 (df=1; p<)	10.4 (.01)	14.9 (.001)	9.5 (.01)	5.2 (.05)	4.7 (.05)

Conclusions based on Automated Hover Trainer Findings

This research demonstrates that the automated, adaptive simulator-based training concept has merit. Beyond that conclusion, it shows that the Automated Hover Trainer was an effective training device capable of producing positive TOT in the IERW curriculum. In these experiments, the IERW POI was not changed from the usual class-based approach except for the addition of the automated hover training before flight line training. Since the curriculum was not developed to optimize the effect of this specialized training, the experimental results are considered to be a conservative estimate of its potential.

Implications of ARI IERW Experimental Findings

The series of experiments described above were conducted to evaluate the feasibility and practicality of training IERW students in ab initio helicopter piloting skills using low-cost simulation and computer-automated training. Since the research was conducted using random samples of Army IERW trainees as research participants with training embedded into the IERW POI at Fort Rucker, the results are considered to be directly generalizable to that training program. Although the course structure has changed somewhat since this research was completed, the following conclusions are considered to be supported by this research:

1. Low-cost simulation is effective in training neophyte students in the basic flight control skills underlying helicopter pilotage.
2. Training in low-cost visual simulators can substitute for in-aircraft training with no significant loss in trainee performance. However, it may be necessary to provide more maneuver iterations in the simulator than in the aircraft to meet the same standards. The combined research data from Experiments 1-4 suggest that approximately 2 ³/₄ iterations in the low-cost simulator are required to replace one iteration on the flight line.
3. Training in a low-cost simulator can show positive TOT to the aircraft, provided that the visual out-the-window scene and the aerodynamic flight model offer the trainee at least moderate fidelity.
4. An automated, adaptive, simulator-based trainer can provide significant benefit to the training of hovering flight skills at very low cost.
5. Improvements in the quality of the out-the-window visual scene such as more polygons displayed, textured surfaces, and faster scene update rates resulted in greater TOT.

Based on these conclusions, we recommend that the Army conduct further experiments to evaluate the most effective application of low-cost simulation and automated, adaptive, simulator-based training to the IERW POI. At the present time, ARI is developing a low-cost training simulator based on the Automated Hover Trainer. The Intelligent Flight Trainer will go beyond automated, adaptive hover training to include other IERW Primary Phase maneuvers. It uses a low-cost simulation of the TH-67 and is being developed to provide automated, adaptive training of traffic pattern flight as well as in the basic hovering maneuvers.

General Conclusions and Recommendations for Future Research

Programmatic Issues

The research discussed above promises to improve the efficiency of IERW training by augmenting training on the flight line with lower cost training using simulation. This is a mechanism to lower training costs and it should be empirically evaluated and implemented. Other cost-savings training amplifiers should be considered in addition to simulation. These are pertinent to broader programmatic issues.

The current IERW POI uses the concept of the flight training class. All students are assigned to a class with each class following a fixed POI providing multiple modes of instruction such as the classroom, procedures training devices, simulation, and flight training, all on a fixed schedule. Experience shows that students do not all learn the material and meet the training objectives at the same rate. In the current POI, these differential learning rates are handled by mechanisms such as the setback in which a student is reassigned to another class at an earlier stage of training so as to repeat a portion of the curriculum. There are advantages of structuring the IERW course into classes. For example, students are encouraged to develop an esprit de corps by wearing a specific color of cap to identify their flight class. Likewise, students have classmates at the same stage of training with whom they can work cooperatively to master the material.

There are also disadvantages to the flight class-based (lockstep) POI. A student who is learning rapidly and is ahead of the fixed curriculum is nonetheless required to stay with the curriculum. The authors know of numerous students who have already met the training objectives of a given training phase and yet continue to fly in order to meet the flight time requirement to complete that training phase. Students and instructor pilots sometimes refer to this training as "boring holes in the sky." While additional flight time has positive consequences such as improving the students' confidence and honing overall flight skills, it is expensive. In short, the class-based curriculum is optimized to benefit the slowest learners. A critical test would be a direct comparison of the current time-driven system with the proficiency-based, objective-driven system.

Research Possibilities

Class-based vs. criterion-based training. First, we suggest that research be conducted to evaluate self-paced, criterion-referenced training (i.e., practice until a performance criterion is met) in IERW. An experiment could reveal whether students who train to meet POI training objectives (such as passing an academic test or passing an in-flight checkride on the target maneuvers) meet the criteria in fewer total training hours and/or at less training expense than under the fixed-curriculum flight class system. The same training resources could be retained, e.g., classroom instruction, procedures training device instruction, in-simulator instruction, and in-flight instruction. However, students could be administered self-paced academic and hands-on-performance exams (such as aircraft systems mastery). With increased use of visual flight simulation, the focus of "blade hour" flight training could be on evaluation. The aircraft could be used to "fine tune" training already begun in the simulator until the student pilot displayed

mastery on a specified training objective. This method would obviate the need for a conventional in-aircraft checkride. For quality control purposes, students could be randomly selected and administered a formal checkride by an Army Standardization instructor pilot to validate the training POI. In the next section, we will set forth in detail an example of such an experiment. This experiment will actually be two studies in one; the first will address questions regarding the functional requirements for IERW simulators, while the second will manipulate several combinations of simulator vs. aircraft hours.

Exploring simulation technology and simulator/aircraft mix. Thus far we have reviewed past ARI research efforts, and discussed the advantages of a proficiency-based, simulation augmented, IERW training program, along with optimizing the mix of aircraft/simulator training time. We would like to present an example of an experiment that would be employed to investigate the optimal simulator/aircraft mix, for the Instrument Phase of IERW.

The rationale for initiating the IERW research program with the Instrument Phase is based upon two factual situations. First, simulation is currently employed in the Instrument Phase, though to a limited extent. Secondly, advances in simulation technology have provided more cost-effective, PC-based alternatives to the current UH-1-based simulators currently in use. The TH-67 Skills Trainer was developed from a Bell 206 instrument trainer and has much commonality with the TH-67s now in service. Research can be initiated with minimal disruption in the training syllabus, as simulation is currently a part of the POI. Consequently, the first research effort will examine different approaches to employing simulation for IERW instrument training.

Current allocation of IERW Instrument Phase hours. The reader should recall that the duration of the Instrument Phase is 50 hours over a 40-day training period. Basic Instruments (Stage I) consists of 30 hours training in the simulator, including the .8 hour checkride administered in the simulator. Advanced Instruments (Stage II) consists of 18.50 hours in the aircraft, and a 1.5-hour end of phase checkride.

Limitations of current training program. One limitation is in the technology and configuration of the UH-1 simulators. They represent an aircraft that has been phased out of the primary IERW Common Core training syllabus. Another limitation concerns the many differences between the UH-1 and the TH-67. One would expect some degree of negative TOT between two cockpits with very different layouts. This may be the reason why there is no simulation-based training at Stage II of the Instrument Phase. Before the most recent revision to the POI, simulator hours were divided between both stages (12.8 hours, Stage I, and 17.2 hours, Stage II). Furthermore, the current simulators use complex, older technology. They are more expensive to operate and maintain than the present generation of PC-based training devices. Although they have a five degree of freedom motion platform, they do not have out-the-window visuals. This obviously limits their use to instrument training alone, and precludes training in tasks involving transition to visual reference landing (e.g., after breaking out under a low cloud ceiling). Whatever advantages are lent to TOT by motion cueing have not been demonstrated empirically.

Proposed research approaches. The research that is proposed here will have two basic dimensions. This is dictated by the obvious fact that, before determining the optimal training mix, one must determine the optimality of the training device itself. Phase I will compare the Skills Trainer and UH-1 simulator as alternative training devices, while Phase II will be concerned with the substitution of Skills Trainer for aircraft hours.

Phase I will seek to answer the question of how similar (different) are these two devices in terms of training effectiveness. Some configurational differences will have to be confounded. The Skills Trainer has no motion system but has out-the-window visuals; the UH-1 simulator has motion but no visuals. Comparisons can be made within each simulator, however; the Frasca Trainer can be employed as an instrument trainer with or without visuals, the UH-1 simulator with or without motion. This experiment will establish the similarities and differences between the two training devices, and give the researcher and training developer insight into the functional requirements for an effective primary flight trainer for IERW. For both phases, a task analysis will determine what specific flight maneuvers can be realistically and safely trained in the simulator. Table 10 presents a notional four-group quasi-experimental design for determining the effects of the alternative configurations on student pilot performance. It would be a quasi-experiment because, as was previously stated, motion and visual display configurations are confounded with simulator type. One important question this study would answer is whether the TH-67 Skills Trainer is a viable low-cost alternative to the UH-1 simulator.

Table 10

Quasi-Experimental Design for Investigating the Functional Requirements of an IERW Training Simulator.

Experimental Groups	Simulator	Perform to Criterion	Evaluation
1. "Motion On"	UH-1	Instrument tasks	Instruments Checkride
2. "Motion Off"	UH-1	Instrument tasks	Instruments Checkride
3. "Visuals On"	Skills Trainer	Instrument tasks	Instruments Checkride
4. "Visuals Off"	Skills Trainer	Instrument tasks	Instruments Checkride

In the above design, four independent groups of students would perform identical Basic Instruments tasks in either the UH-1 simulator or the TH-67 Skills Trainer. The dependent measures would entail ratings of Basic Instrument Phase checkride performance, time to proficiency in the instrument tasks, and performance in the aircraft during the Advanced Instruments phase, which would include the final checkride. The design of the study and the measurement of performance would reflect a proficiency-driven rather than a traditional time-driven training program.

Phase II will explore the optimal mix, and will employ the Skills Trainer at ARI as part of a model training system test bed. The primary manipulation will be in the number of simulator hours. This will necessitate the use of three simulator groups, with the baseline, or "status quo" group, adhering to the current hourly requirements as set forth in the POI. In addition to the status quo group, three other groups will be employed in order to provide four complete data.

points for different amounts of simulator hours. The proposed experimental design for Phase II of the research appears in Table 11, below. This experiment would be a four-group design, comparing the offloading of aircraft hours to the simulator from the current 30 to the maximum of 50 hours.

Table 11

Experimental Design for Investigating Optimal Mix of Simulator vs. Aircraft Hours

Experimental Groups	Simulator Hours	Aircraft Hours	Evaluation
1. Baseline (Status Quo)	30	20	Checkrides; Time to Proficiency
2. Alternative One	40	10	Checkrides; Time to Proficiency
3. Alternative Two	45	5	Checkrides; Time to Proficiency
4. Alternative Three	50	0	Checkrides; Time to Proficiency

Performance measures. Training outcomes would be assessed using the same performance measures previously discussed (e.g. checkride performance, iterations to criterion, time to training milestones, flight grades, setbacks). The same dependent measures can be used for both phases of the proposed research.

Expected results and payoffs. For Phase I, it would be reasonable to expect that students trained in the Frasca device would show more rapid acquisition (i.e. earlier proficiency) of basic instrument skills than those trained in the UH-1-based simulator. Performance during the end of Phase I checkride should be superior for students trained in the Skills Trainer. Students trained in the Skills Trainer should also reach critical training milestones earlier than those trained in the UH-1 simulator. Further, it would seem reasonable to expect that transfer from the Skills Trainer to the aircraft would be facilitated by similarity of crew stations and flight controls, as well as the presence of a visual display system. Because of a paucity of data, it is difficult to specify in advance the transfer properties of the UH-1 simulator with and without the motion system operative.

Phase II will closely parallel the methodology employed by Povenmire and Roscoe (1973). The three levels of simulator training will help specify the relationship between hours of pretraining and performance in the in-simulator and in-aircraft checkrides. This will give researchers some information as to whether there is a point of diminishing returns similar to that found by Povenmire and Roscoe, in which students' performance in the aircraft diminishes with increasing time in the simulator. This could specify a point of optimality, beyond which it is not advisable to offload more hours to the simulator.

Contact IERW Training Research

After completion of the Instrument Phase IERW research, the authors plan to address the same simulator/aircraft mix questions in the context of contact primary flight training. Recall that a quasi-experiment was previously conducted on a small sample of students and controls, with promising results. The third phase of the research program will be to conduct a similar

experiment, using the Skills Trainer, or alternative TH-67 simulators with better visual display systems. Phase III will incorporate the following refinements: (1) The amount of pretraining in the TH-67 Skills Trainer will be varied from an eight hour baseline to 16 to 24 hours; (2) display field-of-view (FOV) will be varied; (3) training in the simulator will not be conducted on a non-interference basis (simulation training will not be in addition to the total hours prescribed in the syllabus, but will be integral to it). The main variables investigated, then, will be the number of hours students train in the simulator, and the complexity of the simulator, in terms of FOV of the visual display system.

Implications of Proposed Research

Enhancing IERW training effectiveness. The authors have attempted to demonstrate the current status of the need for simulation-augmented IERW training, and its potential advantages, especially with regard to savings in training effectiveness and efficiency. We have also presented evidence to underscore the urgency of the need; it is difficult to find definitive data that could provide the guidance needed to develop and validate an effective simulation-based IERW training system. However, existing research appears promising, in that advantages of simulation for rotary-wing primary flight training were demonstrated. Unfortunately, these studies were conducted at different times with different simulator configurations, making generalizability difficult. Comparisons between different configurations were all made after the fact. Nonetheless, they do demonstrate that further research, with large enough sample size and adequate pre-experimental planning, could provide Army aviation with an empirical database regarding the functional requirements of an IERW simulator and how it can be integrated into a training program to improve training quality and save flight hours and costs.

Technology transfer possibilities. If it can be shown that a low-cost IERW training device will save training costs and possibly enhance the effectiveness of training, would civilian helicopter training operators be interested? According to an unpublished market survey conducted in 1993 by Zacharias and Dohme, the private sector helicopter training community has a high level of interest in enhancing the efficiency and effectiveness of its own primary training programs. Zacharias and Dohme performed a target market analysis to determine whether the civilian training community perceived any market potential for a low-cost helicopter flight trainer. They visited six California-based operators, ranging in size from an annual throughput of 6 to 300 students.

They found that attitudes toward the use of simulation were positive; all believed that a cost-effective trainer would positively impact student throughput. All agreed that a trainer costing the same as the aircraft, with half the operational costs, would be justified. At that time, a training device at the price of an R-22 primary training helicopter was not feasible. As a result of the market survey, they concluded that the civilian helicopter training community would cooperate in the test and evaluation of such a device. One reason to expect a high level of interest is the fact that operational and maintenance costs for a light training helicopter are greater than those for a light training fixed wing aircraft. A modern, PC-based trainer like the Frasca Trainer should therefore not only increase student throughput, but reduce overhead costs as well.

As part of the technology transfer demonstration, the Skills Trainer could be beta tested at a civilian rotary-wing training site. This would take place subsequent to the IERW demonstration research at Fort Rucker. The research proposed here can be followed up by just such a test. The bottom line for any commercial operator is cost savings, and if simulation-augmented primary helicopter training can save training costs, and possibly improve training outcomes, for the Army, it can undoubtedly do the same for the commercial operator.

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APPENDIX A

IERW COMMON CORE OUTLINE

PRIMARY PHASE

Basic Contact: Stage I		
Hover	Take Off to a Hover	Land from a Hover
Hovering Turns	Fly Straight/Level	Climbs
Descents	Turns	Accel/Decel
VMC Take Off	Traffic Patterns	VMC Approach
Hovering Auto	Standard Auto	SEF/Altitude
SEF/Hover	Low Level Auto	Shallow App-R/O Landing
Go-Around	Emergency Procedures	Eval I
Advanced Contact: Stage II		
Max Performance T/O	VMC App (shallow)	Simulated Anti-torque Malf
VMC App (steep)	Slope Operations	Simulated Hydraulic Malf
Student Solo	Standard Auto w/Turn	Low Level Auto
Emergency Procedures	Eval II	

INSTRUMENT PHASE

Basic Instruments: Stage I		
Straight/Level	Standard Rate Turns	Compass Turns
Timed Turns	Climbing Turns	Descending Turns
Steep Turns	Accel/Decel	SEF/Altitude
Climbs/Descents	Emergency Procedures	Unusual Attitude Recovery
Trim Control	Eval I	
Advanced Instruments: Stage II		
Instrument Take Off	Radio Navigation	Instrument Approach:
Radio Communication	Lost Communication	ADF, PAR, ILS, LOC,
Missed Approach	Holding: NDB, VOR, LOC	Emergency Procedures
Eval II		

COMBAT SKILLS PHASE

Basic Combat Skills: Stage I		
SEF/In Gnd Effect	Slope Operations	Simulated Anti-Torque Malf
VMC Approach	Hovering Auto	Standard Auto with Turn
SEF/Altitude	SEF/Hover	Shallow App-R/O Landing
Low Level Auto	Go-Around	Simulated Hydraulic Malf Standard
Auto	Traffic Patterns	Low Level/Low Airspeed Auto
Wire Obstacles	NOE Decel	Refueling Operations
Emergency Procedures	Eval I	
Advanced Combat Skills: Stage II		
Zone Reconnaissance	Terrain Flight	NAV:Pilotage/Dead Reckoning
Area Reconnaissance	Terrain Flight T/O	Negotiate Wire Obstacle
Route Reconnaissance	Terrain Approach	Call/Adjust Indirect Fire
Security Mission	Tactical Report	Recon LZ, PZ, Hold Area
Emergency Procedures	Hover/OGE	Select Combat Position
Evasive Maneuvers	Mask/Unmask	Target Handover to Atk Hel
Eval II		

APPENDIX B

ABBREVIATIONS AND ACRONYMS

Accel/Decel	Acceleration/Deceleration
ADF	Automatic Direction Finder
App	Approach
Atk	Attack
Auto	Autorotation
CTER	Cumulative Transfer Effectiveness Ratio
Eval	Evaluation
Gnd	Ground
Hel	Helicopter
IERW	Initial Entry Rotary Wing
ILS	Instrument Landing System
ITER	Incremental Transfer Effectiveness Ratio
Lnd	Landing
LOC	Localizer Radio Course
LZ	Landing Zone
Malf	Malfunction
NAV	Navigation
NDB	Nondirectional Radio Beacon
NOE	Nap-of-the-Earth
OGE	Out of Ground Effect
PAR	Precision Approach Radar
POI	Program of Instruction
PPDR	Pilot Performance Description Record
PZ	Pick-up Zone
Recon	Reconnaissance
SEF	Simulated Engine Failure
TER	Transfer Effectiveness Ratio
T/O	Take Off
TOT	Transfer of Training
VMC	Visual Meteorological Conditions
VHF	Very High Frequency
VOR	VHF Omnidirectional Receiver