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**REASONS FOR IMPLEMENTING  
MODELING AND SIMULATION TECHNOLOGIES  
IN SPECIALIZED UNDERGRADUATE PILOT TRAINING**

**Joseph S. Mattoon**

**HUMAN RESOURCES DIRECTORATE  
AIRCREW TRAINING RESEARCH DIVISION  
6001 S. Power Road, Bldg 558  
Mesa, AZ 85206-0904**

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This report has been reviewed and is approved for publication.

*Elizabeth L. Martin*  
ELIZABETH L. MARTIN  
Project Scientist

*Dee H. Andrews*  
DEE H. ANDREWS  
Technical Director

*Lynn A. Carroll*  
LYNN A. CARROLL, Colonel, USAF  
Chief, Aircrew Training Research Division

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13. ABSTRACT ( <i>Maximum 200 words</i> ) An investigation of Specialized Undergraduate Pilot Training (SUPT) within the U.S. Air Force's Air Education and Training Command (AETC) revealed some major challenges to effective and efficient pilot training. The implementation of modeling and simulation technologies and associated training methods were proposed as potential solutions to address these challenges. Solutions included a proficiency-tracking system that advances students as a function of individual performance; desktop simulation trainers to improve dynamic cognitive skills, high-fidelity flight simulators with stand-alone, network, and full visual field-of-view capabilities; and the installation of a flight recording system that can record training events during aircraft sorties and reproduce the events in a simulated format for subsequent debriefing and simulator training. The proposed methods and technologies are discussed in the context of theoretical principles and empirical findings of human factors, cognitive psychology, and educational technology research.			
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## PREFACE

This report provides additional support to the findings of a recent study of Specialized Undergraduate Pilot Training (SUPT) within the U. S. Air Force, Air Education and Training Command (AETC) which is documented in AL/HR-TR-1995-0157, by Andrews, D. H., Edwards, B. J., Mattoon, J. S., Thurman, R. A., Shinn, D. R., Carroll, L. A., Bowden, P., Moor, W. S., & Nelson, B. (1995), Potential modeling and simulation contributions to Air Education and Training Command flying training: Specialized Undergraduate Pilot Training.

This report presents a rationale for implementing new modeling and simulation technologies in future SUPT. The rationale is based on findings by Andrews et al. (1995) and theoretical principles and empirical findings of psychology and training research. The purpose is to identify the potential benefits of new technology in relation to current and future Air Force training needs. The work was conducted under Work Unit 1123-B2-13, Unit Level Training Research and Applications (ULTRA) group. The work unit monitor was Dr. Bernell J. Edwards.

# **REASONS FOR IMPLEMENTING MODELING AND SIMULATION TECHNOLOGIES IN SPECIALIZED UNDERGRADUATE PILOT TRAINING**

## **INTRODUCTION**

A recent study of Specialized Undergraduate Pilot Training (SUPT) within the U. S. Air Force, Air Education and Training Command (AETC), was conducted by Armstrong Laboratory's Aircrew Training Research Division (AL/HRA) to identify modeling and simulation (M&S) technologies that would address the challenges of modern pilot training (Andrews et al., 1995). The research team consulted with Air Force pilots, AETC personnel, engineers, and information management specialists during the study. This report was developed to extrapolate from and expand on the SUPT study findings, support the initiative to implement M&S training technologies, and stimulate creative planning for future training systems. Recommendations are based on theoretical principles and empirical findings of human factors, cognitive psychology, and educational technology research. For audio-visual demonstrations of the M&S technologies and concepts discussed in this report, see Mattoon & Gagel (1995).

## **CURRENT CHALLENGES TO EFFECTIVE SUPT**

The need to modernize pilot training by implementing innovative technologies is not a new or revolutionary proposal. Over 20 years ago, an extensive study concluded that undergraduate pilot training effectiveness could be improved by technological innovation (Fowell, Rawlinson, Hirsch, & Hesse, 1971), but few changes were made as a result of research recommendations (Andrews et al., 1995). The lack of technology implementation during the 1970s may be attributed to several factors:

1. Mainframe computers that supported real-time data-processing and simulation were very expensive and far less capable than minicomputers and microcomputers available today (Boyle & Edwards, 1992).
2. Early visual displays were inadequate for producing high-fidelity flight simulation (Thomas & Geltmacher, 1993).
3. Early computer-assisted instruction (CAI) did not feature the dynamic, interactive learning activities that are needed to develop complex skills (Mattoon, 1994b).
4. Initiating change within large training programs that are comprised of integrated schedules, regulations, levels of bureaucracy, and government contracts is a very costly and slow process (Mattoon, 1992; Nullmeyer, Bruce, & Rockway, 1991).

Reductions in the Air Force budget, the advanced age of training aircraft, the increasing need for pilots to operate sophisticated electronic systems, and significant advances in M&S technologies now make the task of modernizing SUPT feasible and necessary.

SUPT consists of three major training components that are separated by time, space, and methodological boundaries:

1. Academics which takes place in the classroom and CAI laboratory and teaches facts, concepts, and principles associated with aircraft systems, cockpit procedures, and aeronautical phenomena;
2. Flight simulation training which involves hands-on practice on cockpit procedures and aircraft control and takes place at a separate facility on the training base; and
3. Flying training which takes place in the training aircraft where students gain their actual flying experience.

The traditional, lecture-based approach used in SUPT academics instruction is inefficient for optimizing training time and probably less than optimal for maximizing student understanding and mastery of knowledge objectives. Also, a lack of integration among the three major training components appears to produce some training deficits. For example, the time lag between the acquisition of knowledge in the classroom and the opportunity to practice or put the knowledge to use in the simulator or aircraft may inhibit students' understanding and information retention. The physical distances between classrooms, simulator facility, and the flightline necessitates the need for separate training and instructor duty schedules and widens this time gap between training components. Also, current SUPT academics does not include the training of some key subskills that would better prepare students for simulator and flying practice. Research indicates that such gaps between academic and operational task environments (including simulated operations) can reduce knowledge and skill transfer (Gagné & Briggs, 1979; Phye & Sanders, 1992; Royer, 1986). Additionally, the current SUPT flight simulators are limited in their capability to provide effective practice on many of the required instrument procedures and flying maneuvers (Andrews, et al., 1995).

Some of the current methods for measuring student pilots' performance are multiple-choice tests, students' ability to demonstrate recall of procedures for emergency situations, and performance ratings by instructor pilots who observe students' execution of cockpit procedures and flying maneuvers. These methods are limited for assessing and predicting pilot proficiency for different reasons. Multiple-choice tests measure one's ability to recognize a correct choice among several alternatives, a situation that is rarely present in real-world situations. Reciting steps of procedures shows that a student has memorized the sequence but provides little predictive information on the student's ability to perform procedures under stress, time constraints, and the influence of distracting stimuli in the cockpit.

Recognition and recall tasks alone do not adequately assess students' ability to apply newly acquired knowledge under operational conditions (Gopher, Weil, & Siegel, 1989; Phye, 1986; Royer, Cisero, & Carlo, 1993). A 4-point rating scale (unsatisfactory, fair, good, and excellent) is used to rate student performance on most flying tasks. Such ordinal measures do not clearly show the magnitude of difference between one student and another, and additional notes must be used to describe qualitative differences (e.g., type of errors made) and identify those aspects of the performance that meet or fail to meet criteria. Generally speaking, ordinal ratings appear to efficiently distinguish acceptable from unacceptable performance but are low on accuracy and validity (Glass & Hopkins, 1984). Also, as noted by Fuller, Waag, and Martin (1979), who analyzed summary score measures for aircraft maneuvers conducted during pilot training, ". . . a single score will have no diagnostic value. It will not provide information as to which parameter is producing the greatest deviation from the ideal flightpath" (p. 13). Finally, instructor pilots (IPs) report that ratings may vary as a function of training schedule instead of reflecting actual pilot ability. For example, a pilot who performs a maneuver very well on the first try may receive a "fair" rating but is likely to receive a "good" or even "excellent" rating for performing the same maneuver at the same level of proficiency on a later training sortie. This is often a judgment call by the IP that reflects the need to regulate student flow through the program rather than precisely define student performance (Capt P. Hirneise, personal communication, August 22, 1995).

Student pilots experience various degrees of "front loading" during academic training. In this report, front loading refers to problems students encounter when trying to acquire too much new information prior to the opportunity to practice and apply their knowledge under operational conditions (e.g., in the aircraft or simulator). During interviews conducted in the SUPT study (Andrews et al., 1995), IPs indicated that students almost always experience front loading when moving from the academics phase to flying training. Front loading may cause what instructor pilots call "helmet fires"--a colloquial term that refers to a temporary condition in which the student experiences extreme confusion during a training flight and is unable to remember what to do or respond appropriately to verbal instructions from the IP. This problem seems to occur during in-flight tasks that require simultaneous recall of information (e.g., steps in a procedure) and the execution of complex motor and perceptual tasks (e.g., controlling the aircraft's heading, altitude, and attitude). Helmet fires and students' general lack of skills during initial flying training in the aircraft increase instructor pilots' need for constant safety-related vigilance and readiness to take over control of the aircraft. This situation reduces the IP's ability to effectively coach the student, increases stress level, and may even adversely affect the IPs and student's attitudes toward pilot training.

### **PROPOSED M&S TECHNOLOGIES FOR SUPT**

The general purpose of implementing new M&S technologies is to increase the effectiveness and efficiency of both academics and flying training systems. Each technology is discussed in terms of its potential advantages over existing systems and its impact on training methodology. No attempt will be made to link advantages to estimated costs or level of effort associated with procurement, development, and implementation due to rapid changes in

technological capabilities, Air Force and contractual infrastructures that may not accommodate proposed changes, and the variety of potential hardware, software, and training configurations that are possible.

### **SUPT Hub Computer System and Student Proficiency Profiles**

The SUPT hub computer system would collect and process student performance data, adapt training software to meet individual student needs, and distribute software to desktop computers and flight simulators throughout the training base. The system would consist of at least one "super minicomputer," a high-capacity data storage system, and a network infrastructure that links all training sites and systems on the training base to the hub. Super minicomputers surpass the performance of older and more expensive mainframe systems. The powerful computer graphics and real-time processing capacity of super minicomputers afford many new training delivery, training management, and flight simulation capabilities (G. Boyle, personal communication, March 7, 1995).

Proficiency profiles would maintain a variety of information in a summarized format that is easy to interpret by the student and the IP:

1. Performance measures such as test scores, error patterns (% errors in each knowledge/task area), and speed and accuracy on decision-making tasks and cockpit procedures.
2. Performance summaries that identify objectives completed and general/specific abilities, strengths, and weaknesses within knowledge and skill areas.
3. Recommendations for managing training time/activities, specification of sequence of training events, and referrals to instructors for one-to-one coaching as need arises.

Proficiency profiles would also supply performance data to adapt each training activity to each individual. CAI programs and the software that drives simulation-based training will have adaptive components that would be regulated by the hub to adjust type of instructional guidance, content, performance feedback, type and level of difficulty on practice tasks, and visual and verbal cueing. These components would be adjusted by the SUPT hub prior to downloading the instructional software to the respective delivery system (i.e., desktop training station or simulator).

Adaptive (proficiency-advancement) instruction that adjusts to individual student ability and learning progress has been investigated and proven successful for teaching mathematics (Ross & Rakow, 1981), science and language concepts (Johansen & Tennyson, 1983; Tennyson, 1981), cognitive strategies (Breuer & Hajovy, 1987), and complex skills (Fabiani et al., 1989; Frederiksen & White, 1989; Mané, Adams, & Donchin, 1989). The rationale for designing adaptive instructional systems is based on the fact that even students with equal potential may

not have the same aptitude for managing their training time and efforts on different training tasks (Snow, 1992). However, most research studies on adaptive instruction have involved small portions of curriculum, short training sessions, and relatively simple delivery systems. Adaptive training for SUPT would encompass a full SUPT training cycle, software that covers the entire pilot-training curriculum (syllabi), at least one large computer, portable computers, microcomputer training stations, and training simulators.

The following example illustrates some of the adaptive training functions of the proposed system. During a practice session on landings in the flight simulator, the SUPT hub would:

1. Access the individual's proficiency profile;
2. Verify training prerequisites;
3. Identify the student's level of ability;
4. Set the simulator for the proper level of instructional guidance;
5. Select the appropriate training task according to the student's choice or request for assistance;
6. Adjust flight parameters for task difficulty (e.g., wind, visibility, and competing air traffic);
7. Provide the student with a "prebrief" on the landing practice activity;
8. Monitor performance and provide real-time feedback when appropriate;
9. Upload performance data from the simulator to update the student's profile;
10. Generate a performance summary for the practice session;
11. Present the performance summary to the student in the form of a "debrief;"
12. Suggest the next activity according to the student's performance and training schedule.

A multilevel-security control system will restrict students' access to their own profiles and appropriate training activities while enabling instructors to control training resources and access all proficiency profiles. Students would have the option to purge data collected during practice activities, but data recorded during performance assessments (tests) would be automatically integrated into proficiency profiles and could only be purged by an instructor. Instructors would also be able to override other SUPT hub decisions when necessary and customize any training activity in terms of level of difficulty and instructional features.

The proficiency-advancement approach to training is generally supported by Bloom's (1984) work on mastery learning and other learning interventions. Several aspects of the proposed training approach reflect the most powerful learning interventions that Bloom and his associates have investigated--one-to-one tutorial instruction, individual reinforcement, immediate performance feedback, cues and explanations based on error patterns and other learner data, and proficiency-controlled time on each learning task. Empirical studies show that as many as 98%

of students (two standard deviations above the mean) who receive one-to-one coaching (tutoring) perform better than those who receive group instruction. Each of the other four learning interventions has been shown to be at least half this effective (one standard deviation or greater) for improving learning and skill development.

In the current pilot training program, students' advancement from beginning academics to graduation is largely a function of predesignated schedules instead of their ability to demonstrate proficiency as knowledgeable and skilled pilots (Andrews et al., 1995). This "lock-step" training process advances students from one training block to the next as a homogeneous group. Each training block covers a specified portion of the curriculum and knowledge/skill objectives. There are some options available for remedial training when a student fails to achieve objectives, but attending to individual needs is severely hampered by the group-training approach. For example, a student who masters the objectives immediately in one block cannot advance to the next block any faster than a student who barely meets requirements within the maximum allotted training hours. Also, a student with good potential, who experiences severe front loading or other difficulty in a single training block, may "wash out" of the program. Even with the proposed M&S-based improvements, some students will fail to complete pilot training due to health problems or may fail to achieve an adequate level of skill. However, the proficiency-advancement approach would help reduce the possibility of rejecting (washing out) a student who would be a successful pilot if allowed to continue training and failing to reject a student who would be better suited for a different Air Force career.

As the SUPT student masters knowledge and pilot subskills, responsibility to control training materials and activities would gradually shift from the SUPT hub to the individual student. This approach is based on research which suggests that automated instruction move from computer-controlled to a learner-controlled format as learners progress in their understanding of the subject matter and their proficiency to solve problems on their own and perform independently (Steinberg, 1989). As training progresses, student pilots would be compelled to develop independent decision-making skills, learn how to take advantage of electronic performance- and training-support tools (e.g., proficiency profiles), and learn interdependent student-team strategies for meeting training goals. Such broad-ranging skill development has been observed among students in schools as the result of implementing computers (Chernick, 1990; Newman, 1990) and cooperative learning strategies (Cohen, 1994; Riel, 1990).

Proficiency profiles could help identify an individual students' ability to use performance-support systems and organize and execute coordinated (team) training activities. Such metacognitive skill is not addressed by the current training program, even though it may be an important indicator of an Air Force pilot's long-term potential. The ability to combine and implement information technologies and human resources to accomplish goals has been referred to as "distributed intelligence" or "distributed cognition" (Pea, 1993; Perkins, 1993; Salomon, Perkins, & Globerson, 1991). In modern Air Force settings, where an integration of technology and team effort are essential to successful missions, distributed cognition skills will increasingly become a more valuable asset.

The SUPT hub would make software maintenance easier and more cost-effective because the procurement of new software or reprogramming of existing software would occur at the hub and be immediately activated throughout the training base. Aircraft scheduling and other management functions would also be more efficient by distributing information to all sites and individuals on the training base simultaneously. The linking of all student and training management data and software via a local area network (LAN) system would make it possible to provide continuous individualized training, constant monitoring of student and training system performance, and advancement of SUPT students from basic academics through advanced flying training at a rate that suits their individual achievement and ability.

### **Portable Electronic Trainer.**

The SUPT hub represents the "heart and brain" of the proposed training system, while several other technologies will function as vehicles for generating instruction, managing practice and performance assessment activities, and establishing communications among students and instructors. One of these technologies would be the Portable Electronic Trainer (PET) system. The PET would be a portable microcomputer, similar to currently available electronic message pads (Lee, 1995) but with some additional capabilities. The PET would perform some training functions, independently, from any location on the training base, but it would also "dock" with a desktop training station that would supply additional hardware (e.g., large monitor and CD ROM) for delivering CAI and simulation-based training. The PET would be used by instructor and student pilots to access proficiency profiles, conduct on-line aircraft scheduling, and provide real-time communications and data transfer among IPs and students. PETs would link to the SUPT hub and other systems via cellular modem when operated away from training stations.

The PET system would feature interactive training and performance-support functions that would tie academics and flying training closer together to reduce front loading. The obvious differences between classroom lectures and flying can lead students to believe that academics is "just something you need to get through before becoming a pilot." The focus on rote learning and lack of skill training in the current SUPT academics phase encourages students to use learning strategies that are effective for passing academic tests but ineffective for applying knowledge or developing important flying subskills. The PET system would address this problem by: (a) presenting dynamic visual demonstrations that promote the development of useful mental models of flight situations; (b) providing practice via instructional simulations that replicate flight conditions and help students transform their knowledge into operational skills; and (c) setting up performance contingencies whereby students move from general knowledge and simple skills (subskills) to more specific and complex pilot tasks as a function of their demonstrated proficiency in each knowledge/skill area. In short, the PET system would function as the primary vehicle of the proficiency-advancement system at the academics phase of SUPT.

Automated instructional delivery systems for academics training would also help exploit IPs' expert knowledge and skills. Instructor pilots are currently tasked with the labor-intensive and repetitive job of delivering the same content material to each new group of students. The role of instructional vehicle hinders optimal utility of IPs' experience and expertise and makes

their job less interesting and rewarding. Individualized instruction on the PET would give the student a more responsible role in training and free the IP's time to engage in more one-to-one coaching where and when it is needed most. Also, the local area network (LAN) would link PETs to enable students with different duty assignments to connect with each other or an IP from anywhere on the training base. It is now feasible to use a system like the PET to manage various team training functions across remote locations on the training base.

The type of learning transactions students engage in during academics can significantly affect their readiness to begin flying training. Such transactions should promote the development of subskills which facilitate the process of mastering more complex skills (Frederiksen & White, 1989). Complex skills consist of integrated units of intellectual, perceptual, and motor components that are characterized by the learner's ability to perform with speed, accuracy, and smooth, effortless action (Gagné, 1962; Schneider, 1985). Scaffolding between academics and flying training could facilitate and even accelerate student pilots' acquisition of complex flying skills and could be accomplished by using M&S training tools during the academics phase of SUPT. Definitions of domain-specific and strategic knowledge by Alexander and Judy (1988) is used here to explain the scaffolding process. Declarative knowledge (knowing what) refers to facts, steps in a procedure, and descriptions of objects or systems that the student can recall and distinguish from similar items. In SUPT, this type of knowledge involves the study of navigation, aircraft systems, and aeronautical principles. Procedural knowledge is the "compilation of declarative knowledge into functional units that incorporate domain-specific strategies (knowing how)," such as knowing the proper steps and sequence for executing an instrument landing. Conditional knowledge is the ability to apply declarative knowledge while conducting a procedure under varying situations within specific domains (e.g., knowing how to adjust timing and sequence of steps for an instrument landing under different weather conditions). Subskills refer to the student's ability to demonstrate various types of conditional knowledge without performing the entire target task (e.g., flying the aircraft). Many pilot subskills are cognitive in nature and can therefore be practiced and assessed using lower-fidelity systems like desktop trainers that simulate portions of a cockpit instrument panel. After mastering subskills on such trainers, the student can more easily adapt to the complex environment of a high-fidelity flight simulator, where flying tasks simultaneously incorporate cognitive, motor, and perceptual components.

Instructional simulations can effectively teach many types of dynamic skills (Alessi, 1988; Breuer & Hajovy, 1987; Mané, Adams, & Donchin, 1989; Reigeluth & Schwartz, 1989), including pilot skills (Gray & Edwards, 1991). They facilitate students' interpretation and understanding of complex systems and help them construct useful mental models (Mayer, 1989; Mayer & Sims, 1994; Perkins & Unger, 1994). Waag (1986) indicates that lower fidelity desktop trainers can effectively teach skills that are dependent on cognitive resources rather than complex motor and perceptual abilities which must be practiced in the aircraft or a high-fidelity simulator. Munro and Towne (1992) provide a review of several instructional simulations that have proven effective for a variety of technical training applications. Unlike print-based instruction or conventional CAI, instructional simulations produce representations of dynamic systems by replicating functions, conditions, and the appearance of system components via

computer graphics. SUPT instructional simulations would replicate portions of the task (cockpit) environment to enable student pilots to develop subskills that would prepare them for more advanced flying tasks. The PET system would deliver conventional CAI to facilitate SUPT students' development of declarative and procedural knowledge. Then, students would improve their speed and accuracy by engaging instructional simulation practice that becomes increasingly challenging as a function of the individual's skill development.

The method of moving learners from initial knowledge and subskills to complex skill training has been referred to as progressive part-task training and was found to be successful for training pilot tasks (Mattoon, 1994a; Wightman & Lintern, 1985) and other similar dynamic tasks (Mané & Donchin, 1989). This approach requires that a complex criterion task (e.g., flying an aircraft) is decomposed into a number of subtasks which are practiced as a prelude to attempting the whole task (Gropper, 1983; Naylor, 1962). Frederiksen and White (1989) have suggested that automated training be designed to move from part-task to whole-task formats as a function of the learner's demonstrated proficiency on dynamic, simulation-based practice tasks. The PET system would be used as a vehicle for implementing this approach in SUPT to better prepare students for the transition from academics to flight simulator training.

### **Unit Training Device**

The vehicle for transitioning student pilots from ground-based training to training in the aircraft is the flight simulator. To help student pilots develop complex flying skills and develop an accurate mental model of the flight environment, flight simulators must accurately replicate both physical and functional aspects of the aircraft and the experience of flight (Hays & Singer, 1989). The current Operational Flight Trainer (OFT) used in SUPT adequately replicates the physical components of the training aircraft and many of the instrument functions, but it does not effectively simulate visual imagery experienced during flight. Also, the OFT cannot provide students with experience on some of the most important and challenging flying tasks like landings and formation maneuvers (Andrews et al., 1995). These limitations may contribute to the student's development of an inaccurate, or at least, incomplete mental model of the flight environment. Wilson and Rutherford (1989) described mental model as “. . . a representation formed by a user of a system and/or task, based on previous experience as well as current observation, which provides most (if not all) of their subsequent system understanding and consequently dictates the level of task performance” (p. 619). Thus, limitations of the OFT may result in less than optimal flight simulator training.

The OFT was designed with the accurate replication of aircraft functions as the main objective rather than instructional design, so it lacks instructional guidance features. Andrews (1988) warns that a narrow focus on flight simulator fidelity, which excludes training functionality in flight simulator designs, may result in poor training effectiveness. The OFT's lack of an adequate visual system and training functions would be addressed by the implementation of a new flight simulator, the Unit Training Device (UTD). The UTD would consist of a full-cockpit flight simulator like the OFT, but it would also feature a wide-field-of-view, high-resolution visual display and a training guidance system that would help students

during their initial attempts to execute complex maneuvers and instrument procedures. The UTD design would probably employ hardware/software engineering that has been developed by AL/HRA in its Multitask Trainer (MTT) program and which has proven successful in fulfilling many fighter-pilot training needs.

The MTT and other types of portable simulation systems have already demonstrated that new computer technologies will continue to improve our capability to train high-performance skills within safe and economic environments (Alessi, 1988; Boyle & Edwards, 1992; Mowafy & Thurman, 1993; Thomas & Geltmacher, 1993). The UTD would surpass the OFT in several practical areas such as small size, portability, a training guidance system, independent student operation, and visual fidelity. Installing the UTD at strategic locations throughout the training base would enable SUPT students to integrate subskills acquired in lower fidelity systems (e.g., PET training station) with minimal time delay. UTDs located at the squadron-ready facilities would provide students with an opportunity to practice a training mission in the simulator immediately before an aircraft sortie or practice maneuvers that were found to be most difficult immediately after a training sortie.

The OFT requires a simulator operator, and student performance must be rated by an IP. In contrast, the UTD would be a "stand-alone training device." The student would access the SUPT hub via the PET and download the appropriate training mission setup according to prerequisite skills described in his/her proficiency profile. For example, a student would not be granted access to aerobatics practice in the UTD until meeting performance criteria on prerequisite tasks (e.g., instrument procedures, basic aircraft control, and emergency procedures). After accessing the student's proficiency profile, the hub would verify completion of prerequisite training and generate an automated "prebrief" on the training mission via the PET training station. (Prebriefs are normally conducted by instructor pilots to provide students with information on potential emergency procedures associated with the mission and current conditions that are important to pilots such as weather, wind, visibility, and availability of runways.) On completion of a training mission in the UTD, performance data would be uploaded to the student's proficiency profile, and the student would receive an automated debrief. The debrief would describe the student's performance on each maneuver or instrument task and help him/her schedule remedial training for correcting any performance deficits identified during simulator practice. As soon as flying performance objectives in the UTD were attained, authorization for scheduling a training sortie in the aircraft would be added to the student's profile by the SUPT hub.

Currently, students must learn to perform overhead traffic patterns and formation maneuvers in the aircraft due to limitations of the OFT (Andrews et al., 1995). The UTD would feature additional capabilities that would enable SUPT students to practice virtually any instrument procedure or flying maneuver prior to training in the aircraft. For example, UTDs could be networked so that two students could practice formation maneuvers. As an alternative to networked UTDs, a subsystem that generates visual and functional representation of other aircraft would enable a single student to engage in formation training practice. For example, the student could instruct the computer to generate a lead aircraft for a two-ship maneuver. The

simulated lead could fly specific patterns, while the student (wingman) attempted to execute appropriate maneuvers to stay with the lead in close formation. An improved visual system would further extend these capabilities by making it possible for the student to see all the ground culture normally viewed when landing or flying at low altitudes.

Additional M&S technology may be employed in the UTD design that would enable students to practice more independently. A voice-recognition system would accept commands from the student to initiate real-time changes in training scenarios or request instructional guidance. For example, a student could command the UTD to fly a model example of a particular aerobatic maneuver by stating "computer, demonstrate lazy eight." During initial practice on unfamiliar flying tasks, the student would receive audio (voice) performance feedback to provide guidance with minimal disruption to learning. These voice-recognition/control and instructional guidance capabilities would be some of the most important features of the Instructor/Student Associate (ISA), an expert system that would support learning at initial stages of the most challenging flying tasks (Andrews, et al., 1995). The ISA would further reduce the need for training assistance from a simulator operator or IP.

The design and development of an automated training guidance and performance-assessment system like the ISA could be accomplished by the application of modern technologies and training principles. Brecke and Miller (1991) and Waag, Raspotnik, and Leeds (1992) identified major difficulties in the task of accurately measuring combat pilot performance. Yet, the most serious roadblocks in this type of endeavor are associated with the multiple-person (e.g., pilots and aircrew), multiple-system (e.g., aircraft and ground threats) complexities present in combat engagements. In contrast, the skills associated with SUPT are less complex and better defined in quantitative terms within course syllabi. In fact, Fuller et al. (1979) demonstrated that automated performance measurement techniques worked fairly well on basic aircraft maneuvers, but at the time this research took place, the size and expense associated with such systems was prohibitive. However, Boyle and Edwards (1992) outline some recent advancements in technology that make the production and maintenance of compact, deployable, high-fidelity flight simulators affordable and would be incorporated in the design of the UTD:

- a. software portability and reusability across different systems,
- b. standards for database formats and network protocols to link multiple units for real-time team training,
- c. modular hardware/software designs to allow for evolution to keep pace with the speed of technology advancement and user requirements, and
- c. user involvement in the design and development of training systems.

The training improvements afforded by the PET system and UTD would enable SUPT students to develop a higher level of skill at earlier stages in the SUPT training cycle. The assumption that this change would lead to more productive training in the aircraft is supported by

research on automaticity (Logan, 1985). Automaticity refers to one's ability to perform one task while attending to other tasks, such as controlling an aircraft while attending to an IP's instructions. People develop automaticity for performing complex tasks only after spending a substantial amount of time and effort mastering subskills (e.g., navigation, instrument procedures, and basic aircraft control) and integrating these subskills during practice on the whole task (e.g., flying entire training missions in the flight simulator). Higher levels of automaticity developed on ground-based training devices would give the SUPT student greater confidence and competence during initial training in the aircraft, reduce the frequency that the IP must take over the controls to maintain safety, and better exploit the potential of one-on-one coaching between student and IP during training sorties.

### **Specialized Visual and Acoustic Displays**

Pilots depend on visual perceptual and sometimes acoustic cues for many flying tasks. Repeated exposure to visual information during actual or simulated flight enables pilots to develop effective mental models that help them make rapid decisions and solve in-flight problems. Mental models appear to be frequently based on mental imagery (Paivio & Linde, 1982; Rouse & Morris, 1986) and generated and retained via visual stimuli (Paivio, 1979). Generally speaking, visual information used for instructional purposes has proven to facilitate learners' understanding and development of complex concepts and dynamic systems far beyond that which can be accomplished with only verbal descriptions (Glenberg & Langston, 1992; Mayer, 1989; Perkins & Unger, 1994; White, 1993). The need for facilitating mental model development will be addressed in the proposed SUPT system by specialized state-of-the-art displays. In the academics phase, specialized displays represent the key change factor in moving from noninteractive, static, print-based instruction to interactive, dynamic, electronic, experience-intensive learning environments. In the SUPT simulator training phase, high-fidelity displays will broaden the scope and increase the effectiveness of skill development in flight-simulation environments.

Although PETs and UTDs would support individual training, some group instruction in the classroom will be necessary to preclude repetitive one-to-one tutoring on some aeronautical concepts and flying maneuvers. The implementation of large displays in classrooms would provide greater efficiency for such group instruction. Large rear-projection displays with stereo or "surround sound" acoustics are available but not currently employed in SUPT classrooms. Rear-screen projection systems can produce large (2 m or larger) medium- to high-resolution color images at costs that are practical for permanent training installations. Some new systems even simulate three-dimensional surfaces via special projection systems and concave display screens. Rear-screen projection enables viewers to move about anywhere in front of the display without disrupting the image. A hand-held remote device, about the same size as a standard television control, would be used by instructors to switch between output devices to integrate video with computer animation. These display technologies would enable instructors to incorporate dynamic demonstrations in classroom activities without the time delays and disruptions in student attention that can occur when switching among separate media systems.

A multiple rear-screen projection system called the Display for Advanced Research and Training (DART) was developed at AL/HRA and is a likely candidate for the SUPT UTD visual system. The DART consists of several CRT projectors that are linked to a multichannel visual image generator which synchronizes their output to produce one large complete scene. The design is similar to that of a video wall except that screens wrap around the simulator cockpit to simulate the view available to pilots during flight. A head-tracking system monitors the pilot's line of sight and conveys this information to the computer that drives the image generator. The head-position data is used to switch off projector channels (and the corresponding imagery) that are outside of the pilot's current view to reduce the number of active channels required for producing an acceptable field of view. This "channel-intensive" strategy minimizes the required number of visual channels to reduce overall cost of the system. Compared to other simulator visual systems, DART's commercially available components cut development costs by at least 75% (Thomas & Geltmacher, 1993). The Mini-DART system, also developed at AL/HRA, employs the same technology but further reduces the size and cost by using fewer screens, projectors, and image channels. Compared to the DART, the Mini-DART is smaller, less expensive, and portable, so it will be the more likely choice for future SUPT applications.

During certain maneuvers, pilots use fine visual details to estimate distance and closure rates. For example, they focus on particular parts of their "wingman's" aircraft to maintain precise positions during formation flights, and when flying at low altitudes, pilots use textures and density associated with ground terrain (Toldy & Miller, 1985). The current OFTs can produce neither visual detail nor a large field of view, so effective practice on formation maneuvers and low altitude flight is not possible. However, planned improvements in image resolution of the Mini-DART would enable student pilots to use flight simulator practice to hone their skills on these and other visual-intensive maneuvers like the overhead traffic pattern.

An older prototype flight simulator proved that simulator training could be effective for developing formation flying skills using video technology (Reid & Cyrus, 1974), but this technique is expensive and too limited to specific training tasks to be practical for SUPT. However, the mini-DART system, combined with modern computer graphics engines and a high-fidelity UTD cockpit would be flexible enough to enable student pilots to practice virtually any flying maneuvers. This capability, combined with reduced costs associated with off-the-shelf display components and increased portability of lightweight hardware, makes the DART a good choice for future SUPT flight simulation training.

Head-mounted displays (HMDs) consist of some form of head-mounted gear (e.g., helmet or visor arrangement) that projects a visual image to each eye to produce stereoscopic (3D) visual perception of simulated imagery. A variety of volumetric cues such as perspective, stereopsis, occlusion, and motion parallax can be incorporated in simulations delivered on the HMD (Ellis, Kaiser, & Granwald, 1993). HMD imagery is displayed by either miniature CRTs or liquid crystal displays (LCDs) and transported to the eyes by either dual-channel mirror systems or through fiber-optic cables. The HMD completely surrounds and "immerses" the viewer within the imagery and produces a convincing illusion of being transported to and immersed within a simulated (artificial) space (Grunwald, 1993). The combination of this experience and the

apparatus that produces it is referred to as virtual reality (VR) (Helsel & Roth, 1991; Rheingold, 1991; Thurman & Mattoon, 1994). The user can move about within VR and observe static and dynamic objects and entities in a similar manner that one would explore a physical environment. Low-cost VR systems are now being developed that have much education and training potential (Mattoon, 1994c). For example, a VR debriefing system that was developed at AL/HRA enables pilots to visually travel through a virtual airspace, change viewpoints at will, and observe a previously recorded combat maneuver called the stern conversion (Mowafy & Thurman, 1993). After completing the maneuver via two networked simulators, one pilot acts as the aggressor while the other attempts to evade being overtaken, the pilots can download the recorded maneuver to a VR system and visually assess their strategies using an HMD interface.

Different training problems reveal tradeoffs in display capabilities for HMDs and displays that are viewed from a greater distance (e.g., DART). The lack of well-developed 3D mental models sometimes causes student pilots to misjudge closure rates between aircraft and make inaccurate estimates of appropriate flight paths for complex maneuvers (Capt. P. Hirneise, personal communication, April 25, 1995). Pilots' mental models must carry some 3D components, because aircraft operate within the dynamic conditions and factors of volumetric space (Mowafy & Thurman, 1993). This seems to suggest that HMDs are superior to the DART and other image-projection systems that are not capable of completely immersing the user within a 3D space. Also, large display screens take up far more space and are less portable than HMDs. Yet, HMDs currently lack the visual resolution and wide field of view of the DART. Objects viewed through HMDs appear grainy because of limits in number of pixels and other design factors, so HMD imagery is currently limited to simple geometric shapes with coarse textures. Also, the field of view of even the best HMDs is only about 80° horizontal by 40° vertical compared to approximately 220° horizontal by 120° vertical range of normal human vision. Finally, there are some problems with HMDs that can contribute to visual disorientation that may affect pilots' performance in virtual environments and their ability to transfer HMD-based skills to operational flight environments (Grunwald, 1993; Roscoe, 1993). However, it is expected that many of these limitations will soon be overcome and may make the HMD the visual display of choice for flight simulation (Mr. M. Thomas, personal communication, December 14, 1994). The HMD is proposed for two potential SUPT training functions: (a) a high-resolution HMD as an alternative to the DART for a UTD visual system and (b) a low-cost, medium-fidelity HMD for PET training stations to expand their instructional simulation capabilities.

Virtual environments perceived via HMD interface may also help student pilots understand concepts and phenomena that cannot be directly experienced in physical environments. In VR, size, scale, mobility, and even physical laws can be manipulated to provide learners with greater observational abilities and foster understanding of complex relationships. For example, a jet fuel system is an extremely complex system that is difficult to fully understand when described by simple diagrams and mathematical notation. However, a functioning fuel system model, visually represented in dynamic 3D computer graphics, could be quite revealing when viewed from within via an HMD. This approach would enable a student pilot to visually "shrink down" to the size of a small particle, move about within the model, and

observe the system under various conditions that are present during flight (Col L. Carroll, personal communication, November 10, 1994). This type of application could be implemented on PET training stations because a medium-resolution display is usually sufficient for such exploratory learning. There are many avenues yet to be investigated in the use of HMDs for training and education, and the rate of improvement of image quality, field of view, and other functional capabilities can be expected to climb rapidly in this decade (Boman, & Piantanida, 1993).

Acoustic displays, although less important than visual systems, can provide additional sensory information to facilitate learning and performance under high task-load conditions (Sorkin, Wightman, & Kistler, 1989; Wenzel, 1991). Three-dimensional acoustic systems are now available for simulation training. Three-dimensional acoustics (i.e., localized sound) is a fairly new advancement in sound-based interface that enables the listener to estimate the direction and position of sound sources within a virtual environment via standard stereo headphones (Wenzel, 1991). Interactive 3D sound can be combined with 3D visual displays and generated in real-time simulations to provide learners with multisensory information about complex systems and phenomena.

Three-dimensional acoustics can be integrated with flight simulation to add perceptual information (e.g., radar warning signals, acceleration of jet engine, wind and weather noises, and specialized auditory tracking cues). For example, a virtual ground-control interface system is currently under investigation at AL/HRA that enables Airborne Warning and Control System (AWACS) operators to maintain surveillance over a vast expanse of airspace that is covered by powerful radar systems. Further research at AL/HRA will investigate the use of 3D audio cues to keep down visual clutter and help the operator keep track of many simulated aircraft in complex scenarios.

Localized sound appears to be one of the most appropriate methods for preventing visual overload within VRs and may effectively replace visual cues when a user's eyes must be focused elsewhere (Begault, 1993; Begault & Wenzel, 1992). For example, 3D acoustic cues that designate up, down, left, and right relative to the body midline could be used to help SUPT student pilots overcome spatial disorientation during complex aerobatics in the aircraft or the flight simulator (Dr. D. Andrews, personal communication, September 14, 1994). These training and performance-support methods have not yet been tested, but research on augmenting several types of flying tasks via 3D acoustics has just begun and will probably show greater potential in the near future (McKinley, Erickson, & D'Angelo, 1994).

### **Aeronautical Training Recorder**

Structured interviews with IPs indicated that their most challenging task is conducting effective and safe flying sorties (Andrews et al., 1995). Currently, SUPT IPs must continuously be ready to take over the controls when a student errs in a manner that places the aircraft, people or property on the ground, or other aircraft in danger. Besides safety considerations, instructor pilots' attention is occupied by many tasks during sorties: (a) visual cross-checking instruments; (b) assessing the student's behavior and ability to control the aircraft; and (c) memorizing or

writing down information about the student's performance. Instructors are not currently equipped with recording devices, so they must rely heavily on memory to debrief the student after each flight. IPs indicate that debriefing is one of the most important training interventions in SUPT, but they also report that the mental workload of the cockpit and flying with different students makes it almost impossible to recall enough information to maximize the potential benefits of debriefing.

Instructor pilots currently use a "kneeboard" during aircraft sorties--a small notebook of forms and note pages that is strapped to the pilot's leg and used to rate student performance, access flight regulations, and write notes. Writing in longhand or even using a concise coding on the kneeboard requires the removal of the instructor's visual attention from the flight situation, and at least one hand (usually two) is occupied during note-taking tasks. This can become a potentially hazardous situation when considering how little flying skills student pilots currently possess at early stages of training in the aircraft. Also, performance data in a physical (rather than electronic) form must be entered into student records via a computer terminal, so it involves additional time and effort, and increases the likelihood of data entry errors. These problems could be addressed by an automated flight recording system.

The Aeronautical Training Recorder (ATR) would extend the application of M&S training capabilities within flying training and address the problems associated with rating and recording student performance during aircraft sorties. The ATR would enable IPs to record actual training sorties, reproduce them in a simulated format, and use the simulations to focus one-to-one coaching and individual performance improvement activities. The ATR would consist of several hardware/software components that are described by Andrews et al. (1995). It would record aircraft position, movement, speed, altitude, and several other types of dynamic data during a training sortie, so specific maneuvers or instrument procedures performed by the student could be "played back" on ground-based simulation systems.

A global positioning system (GPS), one component of the ATR, would triangulate positional coordinates by interrogating satellites in geosynchronous orbit (Capt R. Reasor, personal communication, March 23, 1995). This would make it possible to combine ATR data with a visual database of the local flying area (e.g., ground culture such as roads, bridges, and buildings) and show the entire sortie in the visual context in which it was flown. A removable data pack would enable the IP to easily transport flight data from the aircraft to ground-based systems where the simulation could be generated. During the flight, the ATR would accept voice commands to control various flight-recording functions: start/stop, purge specified events from the data pack, place electronic markers at specified points on recorded events, and organize voice notes around particular events. This capability would enable the IP to mark and prioritize portions of the simulation that show events which need to be discussed and visually analyzed by the IP and student during the subsequent debrief.

The ATR system would improve efficiency of training sorties by reducing instructors' physical and mental workload in the cockpit during training sorties and by increasing their ability to record and organize student flying performance. The voice-controlled interface would

improve flight safety by enabling instructors to rate and record student performance without having to look away from the action or move their hands from the aircraft controls. During ground-based training activities, the IP could demonstrate common performance problems via event markers and demonstrate them on classroom, PET, or UTD display systems. ATR simulations would enable IPs and students to review actual flight maneuvers from viewpoints inside or outside the aircraft (e.g., tower, plan view, or view from tail or wing). Additionally, by initializing the UTD with the ATR data, any flight procedure or maneuver could be reproduced by the simulator, and the student could observe or practice particular tasks immediately after the aircraft sortie.

Students do not always fly with the same IP, and this can make the task of performance assessment even more difficult. The SUPT student performance records available to IPs do not reveal precise details about a student's strengths or weaknesses in the aircraft, so a substantial amount of flying time (and fuel) can be expended during an instructor's initial attempt to assess an unfamiliar student's flying ability. The ATR would help IPs prepare to instruct unfamiliar students by including more robust performance summaries within students' proficiency profiles and by enabling them to replay specific portions of previous flight events.

Students have difficulty keeping track of their own performance and specific skills throughout the training cycle. Although the proficiency profiles will guide students' efforts on academic knowledge and their practice in the UTD, the aircraft represents the final proving ground for graduation from pilot training, so students are most concerned about their flying performance. A detailed flying performance report based on IP ratings and ATR data would be updated in the student's proficiency profile after each sortie. This information would guide students in their efforts to prepare for future training sorties. Combined with the previously described simulation and visual display capabilities, the ATR would ensure safer and more productive training sorties.

## CONCLUSIONS

All of the methods and systems described in this report are within the current technological capability of the Air Force given the appropriate R&D time and effort. The proposed systems could be developed, implemented, and set into operation following a detailed examination of SUPT syllabi and training management operations. In fact, AL/HRA is now conducting R&D on prototype microcomputer-based training stations for the classroom and prototype flight simulators that are equipped with many of the capabilities described in this report. However, a complete implementation of all M&S technologies in SUPT will depend on the restructuring of extant policies, systems, regulations, and processes with an acute respect for the attitudes, beliefs, and expectations of decision makers and pilot training personnel at all levels. Lessons learned in large-scale program development and technology transition indicate that such multilateral changes in established organizations require cooperative participation, planning, and delivery of action by all supporting bodies within and outside of the target program. For example, the present SUPT program is not structured for the development of individualized training materials nor would it easily accommodate variable rates of flying

training and graduation for each student. Predesignated scheduling of courses, simulator training, and aircraft usage has been the primary method of coordination for many years. Key Air Force operations and government contractor efforts revolve around this system, so initiating development of individualized training would require substantial revisions in the SUPT infrastructure as well as day-to-day operations, management, and maintenance.

The M&S technologies proposed for SUPT would affect the manner in which training is managed and delivered, the type of interactions that take place among students and instructors, and the way that students advance from initial enrollment to graduation. Teaching and learning would become more experience-intensive and active in the sense that instructors would spend more time on one-to-one coaching as opposed to teaching and briefing groups, and students would spend more time engaged in dynamic, interactive practice as opposed to memorizing textbook material and cockpit procedures. It is expected that the long-range benefits of these changes will outweigh the short-range costs of development in terms of improvement in student pilots' knowledge and skills, more effective use of instructor pilots' time and expertise, more robust assessments of individual student ability and potential, safer and more effective flying training, and greater efficiency per training cycle.

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