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POTENTIAL MODELING AND SIMULATION CONTRIBUTIONS TO AIR EDUCATION AND TRAINING COMMAND FLYING TRAINING: SPECIALIZED UNDERGRADUATE PILOT TRAINING

Dee H. Andrews
Bernell J. Edwards
Joseph S. Mattoon
Richard A. Thurman
David R. Shinn, Commander, USN
Lynn A. Carroll, Colonel, USAF

HUMAN RESOURCES DIRECTORATE
AIRCREW TRAINING RESEARCH DIVISION
6001 South Power Road, Building 558
Mesa, Arizona 85206-0904

Patrick Bowden

AETC/XORR
1 F Street, Suite 2
Randolph AFB, TX 78150-4329

William C. Moor
Barbara G. Nelson

Department of Industrial and Management Systems Engineering
College of Engineering and Applied Sciences
Arizona State University
Tempe, AZ 85287-5906

ARMSTRONG LABORATORY

HUMAN RESOURCES DIRECTORATE
AIRCREW TRAINING RESEARCH DIVISION
6001 South Power Road, Building 558
Mesa, Arizona 85206-0904

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This report has been reviewed and is approved for publication.

Dee H. Andrews

DEE H. ANDREWS
Technical Director

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

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Dee H. Andrews, Bernell J.Edwards, Joseph S. Mattoon, Richard A. Thurman, David R. Shinn, Lynn A. Carroll, Patrick Bowden, William C. Moor, and Barbara G. Nelson

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Armstrong Laboratory
Human Resources Directorate
Aircrew Training Research Division
6001 S. Power Road, Bldg 558
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This report describes an investigation of the Specialized Undergraduate Pilot Training (SUPT) regarding application of advanced modeling and simulation technologies. The effort revealed training challenges within the program for which modern technologies offer training improvements and solutions. Potential solutions span the full spectrum of current activities from academics to flightline training. The study describes the methodology used in identifying and analyzing training problems as well as the process for selecting appropriate technologies. It also suggests an investment strategy for acquiring and integrating technologies within SUPT. Finally, a preliminary cost benefits model is described as a tool for assessing cost/training benefits prior to technology investment.

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PREFACE

This report describes the investigation of potential training technology modernization measures within Specialized Undergraduate Pilot Training (SUPT). The research was conducted by the Aircrew Training Research Division, Human Resources Directorate, of Armstrong Laboratory (AL/HRA) at the request of the Air Education and Training Command (AETC/XOR). Technologies recommended as training solutions are based on the opinions of modeling and simulation experts familiar with the problems and challenges of aircrew training in the Air Force. Recommended implementation methods are based on theoretically and empirically supported training principles and concepts. The intent of this report is to inform prospective users about the growing power and potential of modeling and simulation for training applications. This report also provides information about estimating potential benefits of certain modeling and simulation tools.

The work effort was accomplished as part of the aircrew training research program at AL/HRA, Williams Gateway Airport, Mesa, AZ, Colonel Lynn A. Carroll, Division Chief, and Dr. Dee H. Andrews, Technical Director. The research effort was accomplished under Work Unit 1123-B2-13, Unit Level Training Research Applications (ULTRA), Bernell J. Edwards, project scientist.

POTENTIAL MODELING AND SIMULATION CONTRIBUTIONS TO AIR EDUCATION AND TRAINING COMMAND FLYING TRAINING: SPECIALIZED UNDERGRADUATE PILOT TRAINING

INTRODUCTION

In the spring of 1994 the Air Education and Training Command (AETC/XOR) requested that the Aircrew Training Research Division of the Armstrong Laboratory (AL/HRA) conduct an evaluation of AETC's flying training programs. The purpose of the evaluation was to identify current and future training challenges/problems that might be solvable via modeling and simulation (M&S). This report describes the goals, processes, and results of the first phase of that effort which was directed toward an evaluation of Specialized Undergraduate Pilot Training (SUPT).

Modeling and simulation advances have been accelerating over the last several years so that M&S now is an integral part of many Air Force functions and activities. These advances have been made possible largely because of dramatic increases in affordable microprocessor capability. Until recently, modeling and simulating even simple processes has been too expensive to be practical, but advances in computer software now make complex M&S systems affordable and effective for Air Force training.

While modeling and simulation technologies have obviously influenced Air Force training, it is clear that much remains to be done to realize a remarkable array of potential benefits. As the Air Force looks to the 21st century, we believe that M&S will graduate from an adjunct role to a primary role in training. Indeed, M&S contributions are envisioned in all phases of aircrew ground training as well as aircraft flight training.

The ideas encapsulated in this report are not all necessarily new. An Air Force-commissioned study from 1971, summarized below, introduced a number of the training concepts that the Armstrong Laboratory investigative team expanded upon in the present review. A few of the 1971 concepts were adopted in SUPT training, but most have not become a permanent part of the program. In large measure, the delay in implementing these otherwise valuable concepts has been due to a lack of sufficiently advanced M&S tools. However, we now have necessary technology to enable implementation of many farsighted concepts for Air Force flying training.

Literature Review

A review of literature pertinent to undergraduate pilot training (UPT) is included in the present report. The review was necessary as background information for investigators. Current literature from AETC describing SUPT programs, plans, policies, and practices was the starting point for the literature review. We reviewed current SUPT course syllabi, training management documents, pilot instructor training (PIT) course documents, and SUPT instructor techniques manuals. Of special interest was the AETC Force Modernization Planning document entitled the "AETC Flying Training Mission Area Plan." This plan was examined and its implications for the present research effort are discussed below.

In addition to the above literature, we included a survey of SUPT-related training research and development in this review. We found AL/HRA's technical library to be a valuable source of data in tracing significant aspects of SUPT-related technology development. During the 1970s, AL/HRA (then the Flying Training Division of the Air Force Human Resources Laboratory) conducted a number of research efforts in support of UPT. In reviewing these research reports, we found many that were relevant to the current modeling and simulation effort. Some of these research efforts are cited below.

Several projects examined issues relative to syllabus content and training tasks (Brown, Mullen & Rust, 1975; Brown & Rust, 1975; Smith & Flexman, 1972; Weyer & Fuller, 1976, 1977). Several dealt with multimedia training methods (Baer, 1972; Baer & Beggerly, 1973, McCombs, Marco, Sprouls, Eschenbrenner, & Reid, 1973). Study of the application of cognitive methods for enhancing portions of T-37 training included work by Smith, Waters, and Edwards (1975) and Crosby (1977). A number of studies were devoted to the evaluation of various aircrew ground training devices (Wood, Hagin, O'Connor, & Myers, 1972; Woodruff & Hagin, 1973; Woodruff & Smith, 1974; Woodruff, Smith & Morris, 1972, 1974). Several reports dealt with training analysis, design and methods issues (Baum, Smith, & Goebel, 1972; Cyrus & Woodruff, 1974; Leshowitz, Parkinson, & Waag, 1974; Meyer, Laveson, Weisman, & Eddowes, 1974; Miller, Swink, & McKenzie, 1978; Tyler, McFadden, Eddowes, & Fuller, 1976).

Perhaps most relevant to current interests was research dealing with simulator training effectiveness. The primary research vehicle for these studies was a unique testbed device developed at the laboratory--the Advanced Simulator for Undergraduate Pilot Training (ASUPT). Results from projects using ASUPT played a major role in determining the application and impact of simulators in pilot training. Some of these studies included the following topics: Simulation issues and research agenda (Matheny & Gray, 1975); application of full-mission simulation in SUPT (Woodruff, Smith, Fuller, & Weyer, 1976); simulation training features (Faconti & Epps, 1975; Hughes, Hannan,, & Jones, 1979); simulator visual and motion systems studies (Cyrus, 1978; Martin & Cataneo, 1980; Martin & Waag, 1978; Nataupsky, Waag, Weyer, McFadden & McDowell, 1979; Waag, 1981).

Many of the above reports remain significant benchmarks in the literature of flight simulation. When published, they provided timely scientific evidence of the training value of simulators.

In 1971, the Aeronautical Systems Division of Air Force Systems Command published the findings of an in-depth study of the UPT program, entitled <u>Future Undergraduate Pilot Training (FUPT) System Study</u>. This was the most comprehensive study of UPT reviewed for this current research effort. It attempted to define the future role of UPT systems in the full context of Air Force pilot training. Specifically, the study sought to determine the characteristics and costs of alternative UPT systems for the 1975-1990 time period. It addressed such broad issues as training missions and requirements, facilities, bases, personnel, operational environments, and management subsystems. It also examined curricula/syllabi, training methods, training equipment and aircraft requirements.

A major portion of the FUPT study was devoted to the potential of emerging simulation technologies. A careful review of the FUPT study provided retrospective insights on training issues of that era compared to those of the present. It was possible, by referencing findings and recommendations of the FUPT report, to note some of the subsequent changes which actually occurred in the UPT program during the 1975-1990 period.

Some of these changes, clearly, were influenced by the report. Long-term outcomes reflected both accuracies and limitations within the study. For example, as forecast, the impact of simulators in UPT and elsewhere has been substantial, with advances in technology continuing to the present. Yet, in some ways, the potential of technology has been less than hoped. As previously observed, some of the ideas set forth in the report were premature to the capabilities of technologies of that time. However, another observation drawn from the study was that benefits from technology are usually proportional to the soundness of its implementation. Several technologies recommended in the study appear to have had little success, not necessarily because of inherent limitations, but more likely because of poor implementation.

The AETC Flying Training Mission Area Plan was one of the first documents reviewed for the present study. As part of Air Force Modernization Planning, it was developed with a view toward investment strategies for training systems modernization. Specifically, the purpose of the plan is to provide AETC with a vehicle to anticipate and overcome training deficiencies thereby improving training effectiveness and minimizing costs. In purpose and scope, the AETC Modernization Plan bears some similarities to the earlier FUPT study. The plan deals with a number of broader issues in defining modernization requirements. This includes needs assessments with emphasis on AETC's expanded training role in Combat Crew Training Squadrons (CCTS) environments. Other issues addressed include concept of operations (CONOPS), future missions and training tasking, assessment of current and future training requirements and deficiencies, infrastructure deficiencies, aircraft modernization, aircraft technology leveraging strategies, management system leverage technologies, and ground-based training technology leveraging strategies. These last two categories were of particular interest for purposes of the present modeling and simulation study.

The plan listed a wide variety of computer-based technologies for modernization of management programs and ground training systems. AETC will consider these as potential leveraging technologies toward modernization efforts. Technologies thus identified appear generally consistent with those considered in this report. However, the (draft) AETC planning document we examined only identified potentially useful technologies. Our inference is that analysis and application of M&S technologies were not within the scope of the document. The Modernization Plan does not address modeling and simulation technology in detail, and we hope that the analysis and results of the present study will usefully extend understanding of how modern technology can enhance SUPT programs. Mattoon (1995) completed a broad review of the psychology, education, and training literature after the present study to provide additional support to the M&S technologies proposed below.

Scope of Analysis

The Simulator Four-Star Review and the Modeling and Simulation Four-Star Review, both held in 1993, revealed the potential of M&S for achieving Air Force (AF) training objectives. The Air Force Chief of Staff recently made clear the importance and priority of modeling and simulation as keys to the future of Air Force training at all levels. The Air Force's establishment of the Modeling and Simulation Office at the Air Staff demonstrates the commitment and priority given to modeling and simulation technologies for aircrew training. AETC expects large-scale benefits from the infusion of M&S beginning in SUPT and extending to CCTS and continuation training environments.

The Draft DoD Modeling and Simulation Master Plan of 30 Sep 94 (DoD 5000.59-P) defines a model as, "A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process." A simulation is, "A method for implementing a model over time."

In aircrew training, the use of models is readily apparent. Some applications include models of natural phenomena, aerodynamic equations, force cueing, radar, and weather systems. Such models may enable users to study cause-effect relationships in order to understand processes within complex systems.

We believe that modeling and simulation capabilities will increase significantly as aircrew training tools. For example, it will be possible to accurately model student's mental makeup and learning style so that instructors can better assess their training needs and guide activities. In addition, we will be able to model many of the dynamic elements within training programs in order to automate major portions of the management process.

From a research and development (R&D) perspective, there is some risk in attempting to apply M&S technologies to existing training systems without undertaking a complete redesign of the training system. The hazard is that technology applications end up treating symptoms rather than endemic causes. The risk occurs because M&S applications may not be optimal if the goals and processes of the whole system are not understood. This point of view is well supported in the training literature as well as by many years of experience with military training systems.

METHOD

Implicit in AETC's request for this research was tacit agreement that a detailed needs assessment would reduce the risk of M&S applications resulting as "band-aid" solutions. The procedures described below were designed to provide AL/HRA with information necessary for training system analysis. Two questions emerged: First, "What are the major training challenges in SUPT?" and second, "What modeling and simulation technologies are available [or in development] which can help meet these challenges?" To address these questions, data gathering and analytical procedures were used in combination with consultation with subject-matter experts and "think tank" techniques.

First, we formed a team of investigators within the laboratory. This research team was composed of Air Force pilots, research psychologists, and training systems engineers. Operations researchers, educational technologists, and former military pilots were used on a consulting basis from outside the laboratory. A suitable approach to identifying training a consulting basis from outside the laboratory. A suitable approach to identifying training problems was required. It was also apparent that some types of analysis, such as task analysis, would be inappropriate. The objective was to identify both problems *and* solutions. After due consideration, we selected needs assessment procedures recommended by Kaufman (1991). In connection with the identification of needs and their meaningful solutions, we believe the methodology described in this report accomplished the intended purposes.

Three conditions must be satisfied in a successful needs assessment study. First, the appropriate form and substance of inquiry must be determined and cast into a suitable vehicle. Second, the inquiry must be addressed to the proper subject population. Third, data resulting from the inquiry must be correctly interpreted.

Questionnaire Development. Investigators developed a questionnaire with the objective of producing a valid vehicle for the inquiry. Psychologists and pilots required several revision cycles to agree on content. The questionnaire was then circulated to managers and qualified pilots for critique and comment. Reviewers included training managers at the 56th Training Squadron at Luke AFB, AZ, and AETC/XOR at Randolph AFB, TX. Using inputs from these sources, investigators again revised the questionnaire. It was then distributed to selected personnel at the 64th Operations Support Squadron (OSS) at Reese AFB, TX for validation and final revision.

A structured interview technique using questionnaire content was selected as the most efficient method for obtaining information about the SUPT program. Currently assigned SUPT instructor pilots at Reese AFB were chosen as the target population. The Reese site was used because it was the only SUPT base at the time with an active T-1 program in addition to the T-37 and T-38 programs. The choice of the instructor pilots was based on the rationale that they would be the most knowledgeable and direct source of information on the day-to-day operational training problems within SUPT. A copy of the questionnaire materials is contained in Appendix A.

Preliminary Technology Identification. Concurrently with development of the questionnaire, investigators prepared a preliminary list of candidate modeling and simulation technologies. This list was distributed to training experts at AL/HRA for review. The preliminary list was revised based on the opinions of reviewers.

Data Collection. The research team conducted instructor pilot interviews on-site at the 64th OSS in June 1994. Twenty-eight instructor pilots assigned to the squadron participated, most of whom were captains and majors (three of the interviewees were contract simulator instructors for the T-1 program). Pilots were interviewed in groups of two or three. Two interviewer teams, each comprised of a research pilot (who had prior instructor pilot experience) and two research psychologists, conducted interviews. The research pilot asked the questions and led the discussion. Conversations were primarily pilot-to-pilot which helped keep the dialog spontaneous and facilitated clear communication. Psychologists wrote the instructors' responses to questions on blank copies of the questionnaire. We made audio recordings of interviews (with the interviewees' knowledge) as a backup source of information. A senior psychologist also interviewed selected members of squadron management. These interviews were conducted apart from the instructor pilot interviews using a separate set of questions.

Problem Identification and Analysis. Following data collection, members of each research team examined the completed questionnaires and compiled response information. Psychologists first reviewed and tabulated data for each of the groups they had interviewed. They then worked jointly in categorizing and analyzing response data. Comments by pilots were organized by assigned type of aircraft (T-37, T-38 or T-1). In tabulating questionnaire data, psychologists used audio recordings as needed to clarify written responses. Pilot responses were categorized by areas of training reported as being problematic. Several categories emerged from this sorting process. We found that instructors tended to describe training problems in three basic dimensions: (a) difficulties encountered by students in attempting to learn, (b) difficulties encountered by instructors in attempting to teach students, and/or (c) factors within the training program itself which cause or contribute to problems of training.

Investigators pursued a second level of analysis which involved referencing categorized problems to the formal training program (syllabus objectives and content). We reviewed training objectives to determine specific points at which problems occur or may occur. The effects of each problem on stated training objectives were also analyzed. To validate this analysis, a panel of pilots with prior SUPT instructor experience examined the relationship of problems to syllabus content. Pilots confirmed the validity of this analysis.

A third level of analysis involved in-depth examination of causal factors. Psychologists and research pilots jointly probed a variety issues for each of the problem areas. The causal analysis provided perhaps the most useful basis for identifying potential technology solutions. A natural tendency during these discussions was the extrapolation of "fixes." However, so that the problem definition process would remain separate from the solution development process, systematic consideration of solutions was reserved until the entire problem analysis phase was concluded. Problem analysis was pursued until all team members were satisfied with the definitions, descriptions, and contributing causes for each problem area. We reviewed written descriptions to ensure documentation was accurate and sufficiently detailed to communicate the findings.

We identified six primary challenge/problems areas: position identification, VHF Omnidirectional Range/Distance Measurement Equipment (VOR/DME) fix-to-fix navigation, overhead landing pattern, formation flight, low attitude training and instructor pilot continuation training. Each of these areas is described in detail later in this report.

Identification of Technology Solutions. Using the preliminary list of M&S technologies (described above), investigators considered various technology options as solutions for each problem area. We selected the focus group technique as the process of greatest advantage for this phase of the effort. The focus group method provides an avenue toward group consensus. During group sessions, team members explored a wide range of ideas about technology. At the outset, several procedures and rules were invoked to control the discussions. A member of the team, with experience in focus group methods, organized and led the discussions.

The product of focus group efforts was a detailed set of technology descriptions matching the identified problems. Some of the solutions were found applicable to more than one problem area. In describing technologies, we also decided that visual media (videotape) would help clarify the characteristics and capabilities of some modeling and simulation concepts. Focus group discussions required approximately five working days to complete.

Two groups of experts at the laboratory were asked to evaluate the matching of problems with proposed solution technologies. Briefings were presented; first, to a panel of in-house engineers and pilots; and second, to a panel of research psychologists. Suggestions from these groups were integrated with descriptive materials to improve the completeness and accuracy of technology descriptions. The content of the briefing and support media materials was revised for final presentation

The next step was to present the results of the team's findings to the SUPT community. This was accomplished in two steps. First, four instructor pilots from the 64th OSS at Reese AFB were invited to come to AL/HRA to evaluate results of the problem-solution matching process. Pilots were given demonstrations and first-hand experience with some of the technologies. They generally were able to validate the matching of technologies with the training problems. They also identified other training needs which had not been emphasized in the June group interviews. These included the importance of the debriefing in the pilot training process and the need for the best possible media/methods to support debriefings. The instructors also indicated that low-altitude training is a challenge in SUPT and suggested several technology approaches. We added this topic to the original list of problems. The process of analyzing low-altitude training and identifying solutions followed the same analytical procedures previously described.

An additional short questionnaire was developed as a result of the inputs from the four instructors. Its purposes were: (a) to allow pilots to verify results of the analysis and description of training problems, and (b) to obtain estimates from instructor pilots as to the usefulness of the various technology solutions for problems identified.

As the second and completion step in this part of the research, members of the research team returned to the 64th OSS at Reese AFB to brief SUPT personnel on the study findings. Fourteen instructor pilots, most of whom had participated in the June interviews, were present for the briefing. Various research team members briefed various aspects of the study. Video clips were used to demonstrate proposed technologies. Using the questionnaire, instructors rated the degree of seriousness of each training problem area identified in the study posed to the SUPT program. They also rated the usefulness of each proposed technology as a training problem solution. The results of this questionnaire are presented in the Results section below (see Instructor Feedback on Analysis and Results).

RESULTS

This section describes the major findings on training problems and challenges identified by this research effort. Results are described under two major headings in this section: Description of Training Problems Areas, and Proposed Modeling and Simulation Technology Solutions.

Description of Training Problem Areas

Position Interpretation. Instructor pilots (IPs) report that position interpretation is one of the most pervasive problems in SUPT. This is a basic flying skill which enables students to interpret navigation instrumentation to know where they are at any given point in the flight. Instructor pilots indicate that this is a major training problem for the following reasons:

1. The T-37 is poorly instrumented. As a 1950's-era aircraft, its navigation aids are outmoded, and the Tactical Aid to Navigation (TACAN) and VOR/DME are no longer used outside of SUPT. The poor design of aircraft instrumentation increases the difficulty of this task for the student. It is hard for students to translate abstract data from the instruments into real-world geometry. While improved instrumentation is expected in the Joint Service Pilot Aircrew Training System (JPATS), that new aircraft will not be operational for some time. Thus, the position interpretation problem will continue for the remaining service life of the T-37. IPs also indicated that position interpretation persists as something of a problem in T-38 and T-1 training. Position interpretation is a subskill of situational awareness and, therefore, a fundamental concern in developing basic piloting skills.

2. This problem is compounded during flying because of the number of concurrent tasks which compete for the pilot's attention. Novice students, who have not yet learned to prioritize and manage multiple tasks, tend to become overloaded mentally so that awareness of correct position may be lost. However, position interpretation is a skill that must be acquired and perfected regardless of the quality of the cockpit instruments.

3. The complexity of position interpretation is also seen from the instructor's viewpoint. During interviews, IPs expressed concern that some instructors, themselves, may not have radial geometry concepts firmly set in their own minds. The concern seems to be that an instructor may execute the task correctly, but only at a procedural or mechanical level. We interpret this to mean that while some instructors may be able to perform correctly, they may be unable to teach students what they are doing, why they are doing it, or to convey concepts underlying the procedures.

VOR/DME Fix-to-Fix Navigation. Position interpretation is an enabling skill for performing fix-to-fix navigation. Like position interpretation, fix-to-fix navigation is a three-dimensional (3D) concept that is difficult to learn on the ground. Chair flying (mental practice) is often used but it is difficult to attempt mental practice without being able to visualize complex instrument readings. The ability to visualize comes only after considerable practice in the aircraft. In addition, IPs are concerned that the instrument regulation, Air Force Manual 51-37, is incomplete due to its limited textual and graphical content. Because presentations on paper are static, they do not convey the dynamic nature of the task and the environment in which fix-to-fix is performed. IPs are concerned that there are few opportunities for students to practice fix-to-fix and receive meaningful feedback. When students are finally able to hold a mental picture of the task sufficient for mental practice, they have largely learned the task in the aircraft.

During aircraft training, students easily become task-saturated and may miss verbal instructions. Students at this stage are still trying to perfect position interpretation skills and, thus, cannot practice fix-to-fix effectively without first knowing where they are. Getting off course is a common error which only compounds the problem. Time required to reach the final fix may be so long that the IP finds it difficult to revert to any initial problems. Finally, it is difficult for IPs to assess the proficiency of students' fix-to-fix attempts. The initial turn is hard to evaluate "on the fly." The number of course corrections that need to be made tend to mask the students' true proficiency.

Overhead Traffic Pattern. SUPT instructors consistently identified the T-37 overhead traffic pattern as one of the most challenging training tasks in the entire syllabus. Several reasons account for its difficulty, for both students and instructors. Because students must learn to solo quite early in the T-37 phase, they need to acquire landing skills first. This creates a "front-loaded" training demand on the student, the instructor, and the system.

Academic training plays an important part in familiarizing students with this task. However, for the student, the associated cognitive and procedural skills are difficult to acquire short of training in the aircraft. Being able to practice cognitive and procedural skills in a ground training device would improve the rate of skill transfer to the aircraft. However, a learning gap between academics and flight training is very evident for this task. Tools are also needed to permit students to develop critical procedural repertoires prior to entering the aircraft.

The full impact of this task "comes home" when the students first try to land the aircraft. Students find it difficult to execute procedures in proper order while maintaining the correct flight envelope. Events transpire quickly, the student becomes mentally overloaded, "gets behind the jet," and the instructor must intervene.

From an instructor perspective, the overhead traffic pattern is a challenging task to demonstrate and teach to students. Instructors need ground training tools which can convey essential spatial-geometric aspects of the task. Present simulators limit the instructor's ability to demonstrate model landing patterns and to show common errors and corrective actions.

Training in the aircraft challenges instructors. Aircraft resources are limited, so aircraft sorties allocated to landing training are also limited. The critical nature of the task tends to increase stress on the instructor, particularly in cases of marginal student performance.

The training challenge continues after each training flight. Instructors indicate that the debrief is potentially a very powerful training opportunity, but a lack of effective debriefing tools limits the instructor's ability to give feedback to the student. During flight, the IP attempts to collect as much information as possible, but monitoring the student and the aircraft leaves little opportunity to write notes. Instructors rely largely on mental recall for debriefings. No technology is currently available for capturing and replaying SUPT aircraft sorties. Such a capability would allow instructors to provide students with much more precise performance feedback. This, in turn, would help optimize the value of debriefings as part of the learning process.

In many ways, the overhead landing pattern is a cross section of the entire syllabus. It requires a composite of exacting flying skills executed in rapid sequence. Current training challenges to both instructors and students could be largely eliminated with advanced modeling and simulation techniques that could capture and replay selected flight sequences.

Formation Flight. Learning to maneuver a high performance aircraft in close proximity to another aircraft presents a training challenge unique to military pilot training. At the outset, instructors must have considerable confidence in students' piloting ability, since students have not yet attempted this level of flying. In formation flight training, students must first learn to perform takeoffs, climbs, turns, mild maneuvering, instrument approaches and landings as two-ship operations. The student must then become proficient in separating from, and rejoining, formations (break-ups and rendezvous). All formation flight maneuvers require students to expand situational awareness to include other aircraft. Essential new skills include determination of angle off, bearing line, and closure rates, all of which demand rapid, accurate spatial judgments. Students learn a large repertoire of visual cues associated with precision aircraft control. The exacting character of formation flight requires an environment in which students have ample opportunity for effective practice. Yet, except for the aircraft itself, no practice device is available for this task. Particularly for close formation, visual discrimination of surface details of the lead aircraft, used in judging distance and closure rates, are critical cues. But the present simulators lack sufficient visual fidelity to display these cues. Instructors familiarize students as much as possible using available teaching tools such as diagrams, verbal descriptions and stick models. The net result of inadequate ground training is the consumption of large amounts of jet fuel while students develop needed skills in the aircraft itself. Thus, formation flight is another area of training that would benefit dramatically from simulation modernization.

Low-Altitude Flight. Low-altitude flying is a critical task involving knowledge and skills that differ from other flying activities. Evidence shows the vast majority of low-altitude flight accidents are caused by poor task management. Experts in this flight regime have developed a task management concept to reduce its risks. The concept organizes low-altitude flight into three piloting activities or priorities as follows:

1. The first priority, obviously, is to maintain enough altitude to avoid hitting the ground. Thus, Terrain Clearance Tasks (TCTs) are those actions the pilot must take to maintain a safe margin of altitude at all times.

2. Second priority tasks are those the pilot must accomplish to complete the mission. These are called Critical Tasks (CTs). They include navigation, communication, and other requirements.

3. Finally, in third priority are Non-Critical Tasks (NCTs) that the pilot can accomplish as time permits during periods not demanding attention by TCTs and CTs.

Thus conceived, low-altitude flight becomes an activity in which the pilot continuously evaluates aircraft status and mission demands in order to allocate attention to the task of immediate priority.

Safe low-altitude flying requires:

1. Vector Control--assessing and modifying the aircraft vector, elevation, azimuth, and velocity relative to terrain;

2. Above ground level (AGL) control--assessing and modifying aircraft AGL in relation to terrain; and

3. Time Control--mentally controlling the frequency and duration of mission cross-check time relative to the existing TCT vector and AGL control requirements.

CTs and NCTs for SUPT would be simplified subsets of the components of tactical fighter low-altitude training. TCTs are similar in nature, although SUPT altitude minimums are substantially higher than those in fighter training. A proposed set of CT and NCT components in SUPT include:

1. Situation awareness--sorting and sequencing mission tasks and anticipating the near-term flight situation in order to make safe and effective aircraft-control decisions;

2. Navigation--interpreting and using spatial and navigation displays, controlling closure time and distance, adjusting heading, controlling aircraft orientation (yaw, pitch, and roll), altitude, and using ground culture and dynamic visual information; and

3. Performing command, control, and communication (C3)--radio communications between aircraft and formation aircrew members and tower.

Low-altitude flying involves the ability to recognize critical visual cues quickly and accurately under heavy task-loading conditions. The current method of training involves textbook study and classroom instruction, chair flying, and training in the aircraft. Students are under close observation of an IP during initial low-altitude flight training.

Although the primary training environment is the aircraft, in practice, low-altitude flight training sorties may be delayed, or too few in number due to adverse weather or aircraft nonavailability. These eventualities may reduce available training time and ultimately affect student flying proficiency.

The current problem in low-altitude training arises largely from simulator visual system inadequacies. As with formation flight training, safe low-altitude flight is heavily dependent upon the pilot's ability to discriminate visual features of ground objects and texture details. The Operational Flight Trainer (OFT) for the T-37, T-38, and T-1 lack visual systems with an adequate fidelity for this task. Low-altitude training simulation requires high-speed (e.g., 60 Hz update rate), high-resolution visual display of ground cues (e.g., trees, riverbeds, buildings) at different altitudes, air speeds, and angles of view. Fortunately, simulator visual systems state of the art is now capable of providing these high levels of fidelity at reasonable cost. Given the benefits of modern simulators, SUPT students would be able to develop many low-altitude flying skills prior to aircraft training. This would significantly increase flight safety and reduce the time and cost of this training.

Instructor Continuation Training. The current instructor pilot training program requires that each IP spend eight weeks at the PIT course at Randolph AFB. During this course, each IP receives training on how to instruct, both in the classroom and/or in the aircraft. Some of this training is intended to give the IP a sensitivity for instructional principles relevant to problems instructors will face with students in the training squadron. These principles as embodied in Systems Approach to Training (SAT) include:

- defining training tasks
- demonstrating flying procedures and skills
- understanding internal and external conditions of learning
- evaluating trainee progress
- diagnosing learning problems
- providing feedback at an appropriate time in an effective manner

However, due to the brief span of the PIT course, only a cursory treatment of these principles is provided. It also may be that the present PIT treatment of instructional principles is not sufficiently specific or focused for effective application by new instructors when they reach the flightline. Also, because of limited time in the course, new IPs may tend to devote more time to re-familiarization with their assigned training aircraft (T-37, T-38, or T-1) than to developing training skills and strategies. Since AETC already has a comprehensive mechanism for developing instructional programs, it is not necessary for each IP to have a deep understanding of instructional principles required for syllabus development, but they should be well grounded in basic and mid-level instructional principles and diagnostic/prescriptive techniques to deal effectively with student learning problems.

Our analysis, based on interviews with PIT personnel and instructors, revealed that IPs presently receive insufficient training on the application of instructional principles and teaching techniques. During the interviews we conducted, instructors almost always characterized student learning problems in terms of the inability to perform flying tasks rather than in terms of learning processes or instructional needs. At times, instructors seemed hard-pressed to identify specific information to give students which would help the students understand why they were having problems. In prescribing activities and exercises to aid students, instructors tended to repeat generic "fixes" such as more chair flying, better debriefings, more practice, etc., for a range of problems. The net effect of not receiving more by way of teaching skills in PIT is an IP who arrives at the SUPT squadron with a rather sparse instructional tool kit.

Also, there appears to be no formal continuation training for IPs once they reach their training squadrons. IPs seem to rely on the training methods they themselves observed as SUPT students. Squadron leaders and fellow IPs routinely share experiences and insights, but this probably does not enable IPs to train at their highest potential, nor will such sharing of training wisdom always be complete, consistent, or accurate.

For these reasons, systematic continuation training for IPs in the squadrons is needed. Time is an obstacle for such training. IPs have more than enough to do, but we believe that even two hours per month for this kind of training would increase IP effectiveness thereby increasing the efficiency of the entire SUPT program. Several M&S technologies described later in this report could be used to help deliver IP continuation training. Technology could do much to decrease the time burden by maximizing use of discretionary time. Some of this training might occur in a classroom; some might be delivered via personal computers--content of such training is critical. If it is noticeably helpful in reducing the IP's workload or solving student training problems, they will use it.

Proposed Modeling and Simulation Technology Solutions

This section continues the reporting of our research results. It describes the modeling and simulation technologies identified as the result of the analysis process reported earlier. Each section below describes the characteristics and functions of the recommended technologies, plus an indication of the training problems they will address. Estimated costs for AETC implementation of these technologies are included in the roadmaps presented later in this report.

SUPT Hub Computer System. This system will function as the "brain" of modeling and simulation training applications proposed in this report. It will contain and manage all data, models, and media-associated activities. This will extend to simulation models of the environment not contained and directly managed by individual simulators and training devices. The database will contain libraries of training scenarios and will contain all training-relevant student data. The hub will provide instructors, students, and managers great flexibility in accessing and manipulating training software and data.

One of the most difficult problems in any training program is the integration of instruction with training systems responsive to the changing needs of the student. The hub proficiency profile system will contribute much to overcoming this problem. Currently, integration of instruction with training systems is bypassed by requiring all trainees to attend the same courses and to receive about the same content and exposure to activities. Research and experience indicate that a group "lock-step" method does not optimize learning. Lock-step, in fact, may result in students who perform below their potential. The problem is compounded because IPs may lack sufficiently detailed student data to optimize guidance to individuals. Students' scores on written tests and IP ratings of flying performance currently lack the detail and sensitivity to support truly individualized programs. Moreover, training devices cannot be adjusted to deliver appropriately detailed learning opportunities unless individual abilities and progress can be monitored, accurately assessed, and applied to each training event.

One of the most salient features of the modeling and simulation tools being proposed is the capability to measure individual performance across all phases of training. This includes academic testing, performance checks using simulated aviation tasks (at several levels), and performance in the training aircraft. To collect and manage training data of this magnitude, a central database system is essential. It must contain detailed records of student performance (in the form of proficiency profiles). Data from academics tests, training devices and simulators, and aircraft sorties should be used in the profiles. As a student progresses through the program, data from each training episode will be downloaded to the hub database and analyzed to update the respective profile.

As a student enters SUPT, each individual's profile will include demographics, data from prior education and training, and other relevant aptitude and achievement data. As data are added from current training, the profile will expand to yield an increasingly complete, definitive picture of student performance. Skill areas in need of improvement will be highlighted and the student will receive appropriate feedback and individual guidance. Thus, the SUPT hub proficiency profile system will provide a dynamic, highly individualized tool to assist students toward successful completion of SUPT.

The SUPT hub will be accessed by students, instructors, and managers via portable electronic trainers (PETs), microcomputers with built-in modem capability, linked via local area networks (LANs). Each student will use a PET to access on-line training, performance-support software, and one's own proficiency profile from the classroom, personal quarters, simulation training laboratory, squadron-ready facility, or even the training aircraft. Figure 1 shows the communication links between remote sites and the SUPT hub within the training base LAN.

Visual Displays. Visual displays are extremely important to pilot training activities because of the need to integrate cognitive and perceptual skills to produce high levels of performance in dynamic flight environments. Three types of display technologies are described for implementation into academics and simulator training phases of SUPT.

Large-Screen Displays. Large-screen displays (LSDs) are electronic devices for projecting computer-generated imagery and digitized photography. A classroom instructor could use an LSD to display electronically generated word slides, graphs, charts, figures, or maps, in the same way as blackboards (whiteboards), overheads, and film projectors are now used. A unique advantage of LSDs over older media is that they support active versus passive learning. With LSDs, students can interact directly with information and see changes resulting from their inputs, an obvious advantage to the learning process. With a computer-image generator connected to the LSD, an IP could demonstrate cockpit and out-the-window visual phenomena similar to those afforded by flight simulators. This would enable a wide variety of instructional activities.

Some examples may help to illustrate potential interactive applications for SUPT topics. A terrain map or simulated terrain area could be displayed in such a way that students could "fly" in real time over the area as seen from the cockpit. They could interact with information by changing certain flight parameters, or selecting or designating(identifying) salient ground features or positions through joystick inputs. Such exercises would help familiarize students with local flight areas, restrictions, and procedures. Basic formation flying concepts could be demonstrated and enable instructors to execute control inputs using a joystick or mouse to show various viewpoints of pilots during a formation flight. Aircraft position could be changed or "flown" in real time relative to other aircraft to illustrate envelopes of safe flight, closure rates, or common errors. Another application of the LSD would be to show a full array of active cockpit instruments that the instructor manipulates during simulated flight and highlights certain instruments or sequential changes to demonstrate correct scanning patterns, cross-checks, instrument procedures, etc. Students could use the same medium to demonstrate their knowledge and to practice identification skills following instructors' demonstrations.

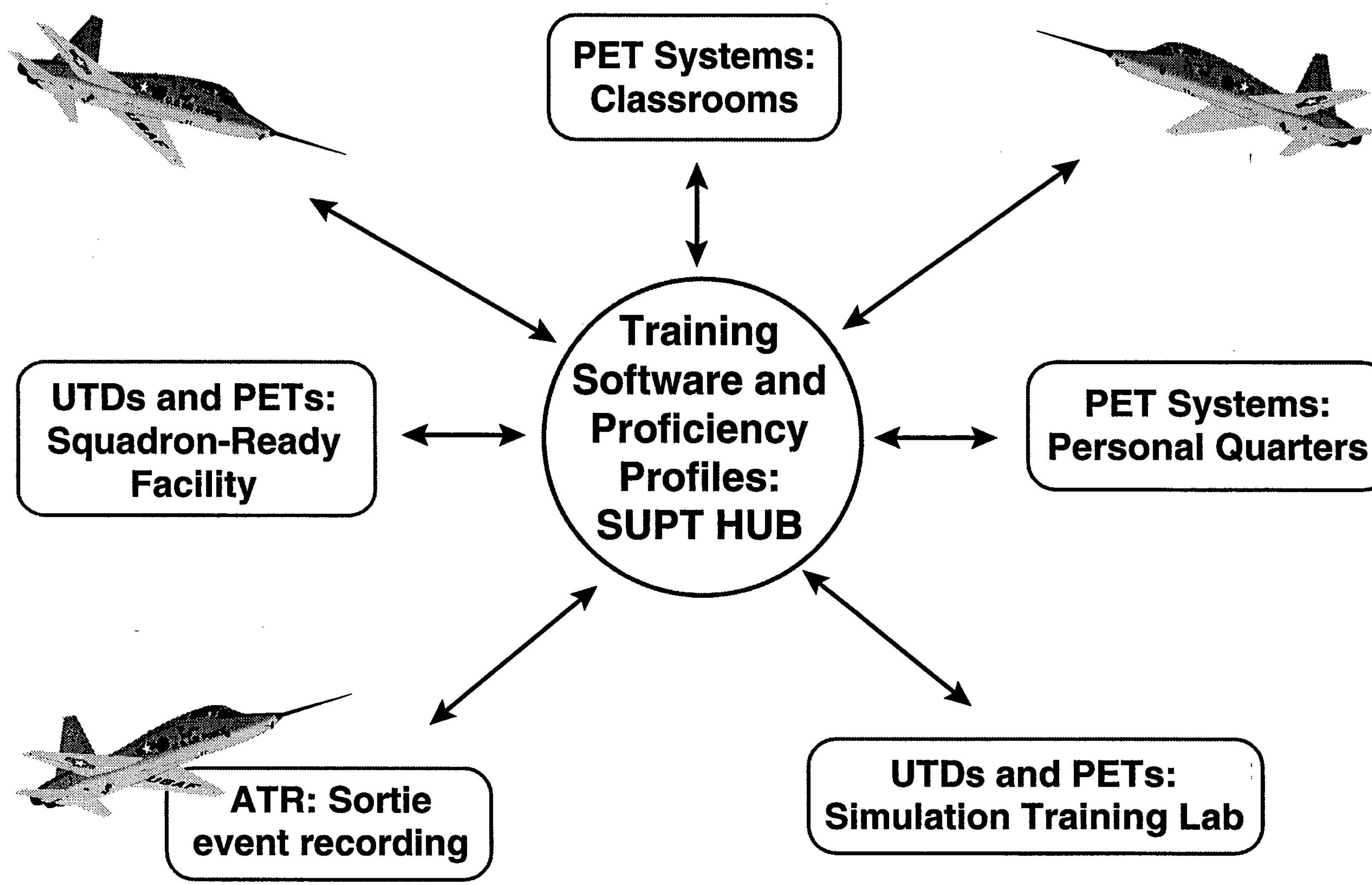

Figure 1
LAN Network Including Hub and Remote Training Sites

LSDs have gained some acceptance in the last few years in academic classrooms both in and out of the military in spite of high costs. However, recent advances and growth in this technology have reduced the cost of high quality LSDs. The Navy's T-45 training program already uses LSDs in its classrooms. Continuing advances in flat panel technology are expected to make these types of displays increasingly attractive for classrooms.

To be considered an LSD, the display must have a diagonal dimension of four feet or more. Rear-screen projection systems enable viewers to move about in front of the display without disrupting the image and may be most practical for the classroom. Image quality is normally a function of cost. For use in a typical SUPT academic environment where viewers may sit up to 50 feet from the screen, resolution and brightness should be the maximum available.

All six problems areas identified in this research effort can be improved with LSD technology. Visual displays in an academics environment are envisioned primarily as teaching tools to impart knowledge and foundation skills. Thus, the best apparent SUPT application is using LSDs to support the building of basic skills and knowledge as prerequisites to advanced flying skills.

Remote Three-Dimensional Displays. Adding depth cues to simulation displays can greatly enhance ability to perceive distance and spatial relationships. Adding a third dimension permits the student to engage in realistic aircraft control practice. Depth perception is a function of several different types of visual cues and dynamic perceptual processes. For example, the brain constantly monitors and interprets differences in image placement perceived by each eye. Several interface technologies use different approaches to simulate 3D vision within computer-generated simulations. Remote 3D displays project 3D imagery from flat display surfaces that are viewed from a distance (e.g., computer or video monitor).

Polarized Systems present separate images to the right and left eye by alternating horizontal and vertical polarizations of the image at a very fast rate. The viewer wears glasses with polarized lenses. This gives each eye a slightly different view of the scene and, hence, creates the perception of three dimensions.

Shutter Systems employ special eyeglasses with shutters to control the display of a slightly different perspective to each eye. The function of the shutters is to alternate the opaqueing (blocking) of information to each eye. The scene alternates between a slightly right offset and a slightly left offset perspective at a very fast rate which the brain perceives as a continuous 3D image.

Autostereoscopic Displays use a high-quality video raster scan color screen combined with special eyewear. To generate 3D visual imagery, the screen displays the left and right halves of the scene on alternating columns of video pixels at a rate of 30 frames per second. The left image appears in the odd columns and the right image appears on the even columns. The user, by remaining in a specified viewing position, receives independent sets of information to each eye, and thus perceives a continuous 3D image.

The visual capabilities of remote 3D displays may be useful in a variety of training phases where it is important for students to gain an understanding of 3D flight dynamics (e.g., interactions encountered among flight parameters such as altitude, closing range, attitude, yaw, pitch, role, etc.) or practice within an environment where 3D cues are essential to the task at hand.

The Display for Advanced Research and Training (DART). DART simulation technology provides out-the-window visual imagery for the flight simulation environment. It is designed to complement a variety of simulation cockpit configurations. In the present case, it is recommended for use with the unit training device (UTD) flight simulator. DART was developed to provide high quality visual display characteristics at very low cost. In tandem with image generator technology of comparable value, DART furnishes sufficient visual quality to provide useful training for aircraft such as the F-16.

One of the geometric display configurations for the DART is a dodecahedron composed of eight interlocking display channels. Barco data rear screen-mounted projectors (one per channel) for the DART exceed 1,000 lines of video resolution. Display surfaces are located about one meter from the pilot's eyepoint. Resolution to the pilot's eye is 4.75 arcminutes/pixel. Field of regard is about 300 degrees horizontally and 150 degrees vertically. A Polhemus magnetic tracker is used to track the head movement, and data are used to reduce image generator (IG) channel processing requirements. This is accomplished by dimming the appropriate projectors for unused imagery behind the pilot's head. Overall brightness (7 footLamberts) and contrast characteristics (30:1) are excellent in comparison to previous simulator display designs and overall system cost. The overall result is true "wraparound" visual imagery in full color with high visual fidelity. The Mini-DART uses fewer IG channels and display screens to accomplish almost the same capability as the full-size DART but occupies a much smaller space, has greater portability, and is more economical.

Immediate training effects anticipated from employment of the DART can improve transfer of training from simulator to aircraft. Long-term effects can be estimated based on a substantially expanded role of simulation training in SUPT.

DART technology is estimated to have excellent evolutionary potential. Video projection technology used in DART is advancing rapidly and the industry forecast is for stable long-term growth. This suggests commercial, off-the shelf hardware will be readily available for system updates during the projected life cycle of the program.

For training the overhead traffic pattern, DART would offer the first opportunity for SUPT students to visually experience the entire maneuver in real time in a flight simulator. The DART provides students with a visual environment in which they can develop recognition skills for key visual cues and integrate cues with crucial flying procedures. The information processing demands which create much of the difficulty in the landing pattern could be better managed if the trainee had sufficient practice time in a high quality simulator equipped with the DART.

Head-Mounted Displays (HMDs). Basically, an HMD is an individual headgear with close-fitting lenses. Typically, the HMD is connected to a computer that generates visual images on two small screens (one-and-a-half to two-inches diagonal) positioned in front of each eye. With the help of magnifying power, the lenses can encompass the entire normal field of human vision. Since the viewer is visually "partitioned" from the actual surrounding environment and "immersed" within the simulated scene, the effect on the viewer is one of experiencing a "virtual reality."

There are several technical approaches or variations of HMD design. Each significantly modifies the overall perceptual effects. Each involves functional components for image position-tracking, image opaqueing, and degree of binocular or monocular characteristics of the imagery as perceived by the viewer.

Position tracking allows the viewer to move their line of site and head position, while the simulated imagery changes to accommodate the shift in the viewer's perspective. For example, as one moves closer to a simulated aircraft, it becomes larger, and perspective angles change realistically. As the viewer's head turns, the available field of view shifts accordingly. HMDs can also be designed so that the computer tracks eye position and changes the simulated environment relative to the viewer's eye movements. Position trackers use mechanical, optical, or electromagnetic devices to sense changes in the viewers position and line of sight.

Opaque HMDs permit viewers to see only simulated imagery, thereby "opaqueing" or blocking out the viewer's actual visual environment. See-through HMDs, by contrast, enable the user to see the surrounding physical environment along with the simulation by superimposing simulated imagery on top of the display lens. Both methods have advantages or disadvantages based upon effects desired.

Some HMDs provide binocular depth cues (shift in perspectives perceived by the right and left eye) using similar techniques featured by remote 3D displays (described above). Binocular HMDs have advantages and limitations. Perception of depth is most pronounced within relatively short distances, up to about 30 feet. Beyond that, binocular disparity is less effective as a distance cue. For this reason, binocular HMDs would be most useful for aircrew tasks performed fairly near the pilot.

Monocular HMDs, on the other hand, can be used for simulating imagery for tasks which do not require critical depth cues. In addition, monocular HMDs require less computing power since the computer needs to create only one visual scene instead of two. In many simulator applications, lesser demand for computer capacity can significantly reduce system cost. Also, various HMD designs differ in size, weight, image resolution, image brightness and contrast, and color capability. Some low fidelity devices that are currently under development may provide visual immersion within simulated imagery with the viewer having to wear no more than a pair of lightweight visors and a lightweight tracking sensor.

HMD technology may enhance the effectiveness of training for the overhead traffic pattern. In the academic phase, HMDs could be used to accelerate the student's familiarization with visual information necessary for performing this difficult maneuver. A virtual representation of the landing environment would allow a novice to experience spatial and geometric aspects of the landing area before ever entering the aircraft. Students could study flight path envelops, ground references, and visual cues from a variety of eyepoint perspectives. Such information would be valuable in helping students develop accurate mental models of flying tasks.

The major impact of HMD technology may by in training formation flight. To maximize training benefits in the aircraft, ground training in a simulator with a state-of-the-art HMD should precede formation flight in the aircraft. Field of view and display resolution will be particularly important parameters because of the critical nature of visual cueing associated with formation flight training. A wider field of view and better resolution, than is currently featured by most HMDs, is needed to allow the pilot sufficient flexibility to view other aircraft during formation flight. The pilot must be able to resolve surface details of other aircraft during formation because these cues allow precise judgments concerning distance and closure rates. Thus, some additional improvements are still needed in HMD capabilities before they will be 100% effective for training detailed and close-up visual tasks.

Figure 2 shows an artist's conception of the UTD equipped with each of the two proposed visual display systems, the Mini-DART on the left and a lightweight visor on the right.

Upgrades in Computer-Assisted Instruction and Portable Electronic Trainers. Recent developments in microprocessors, application software, computer architecture, communications hardware and software, and multimedia technology have resulted in tools that offer great potential for improving the quality and capability of computer-aided instruction (CAI) curriculum and training activities. Periodic assessment of knowledge acquisition, performance analysis, and the delivery of appropriate remedial training can now be more easily designed into instructional software. Systems containing such features can be networked in order to (a) expand economy of scale and program flexibility, (b) enhance training synergy by permitting student interaction with subject matter, instructors, and other students in the classroom and at remote locations, and (c) allow individual students freedom and flexibility to access varieties of information and instructional programs on a 24-hour basis. Advancements in microprocessor technology have resulted in the development of powerful, lightweight, and compact systems capable of providing a wide range of training and management functions.

The ongoing revolution in computer technology promises reductions in cost and size of hardware systems and dramatic increases in data-storage capacity and functional capabilities. Portable systems can operate on battery power and be designed to dock with (plug into) full-size, desktop training stations. It is hard to predict specific developments in applications during the next 20 years from a SUPT perspective. However, it is likely that instructors and students would benefit from a microcomputer-based PET that would provide each individual with advanced training support and communications capabilities at any location on the training base. The PET would be small enough to fit into a flight suit pocket, yet would provide students with immediate access to their individual student profile and communication with any instructor pilot. It would support a variety of training, time-management, and scheduling functions to increase the efficiency of individual and team training activities.

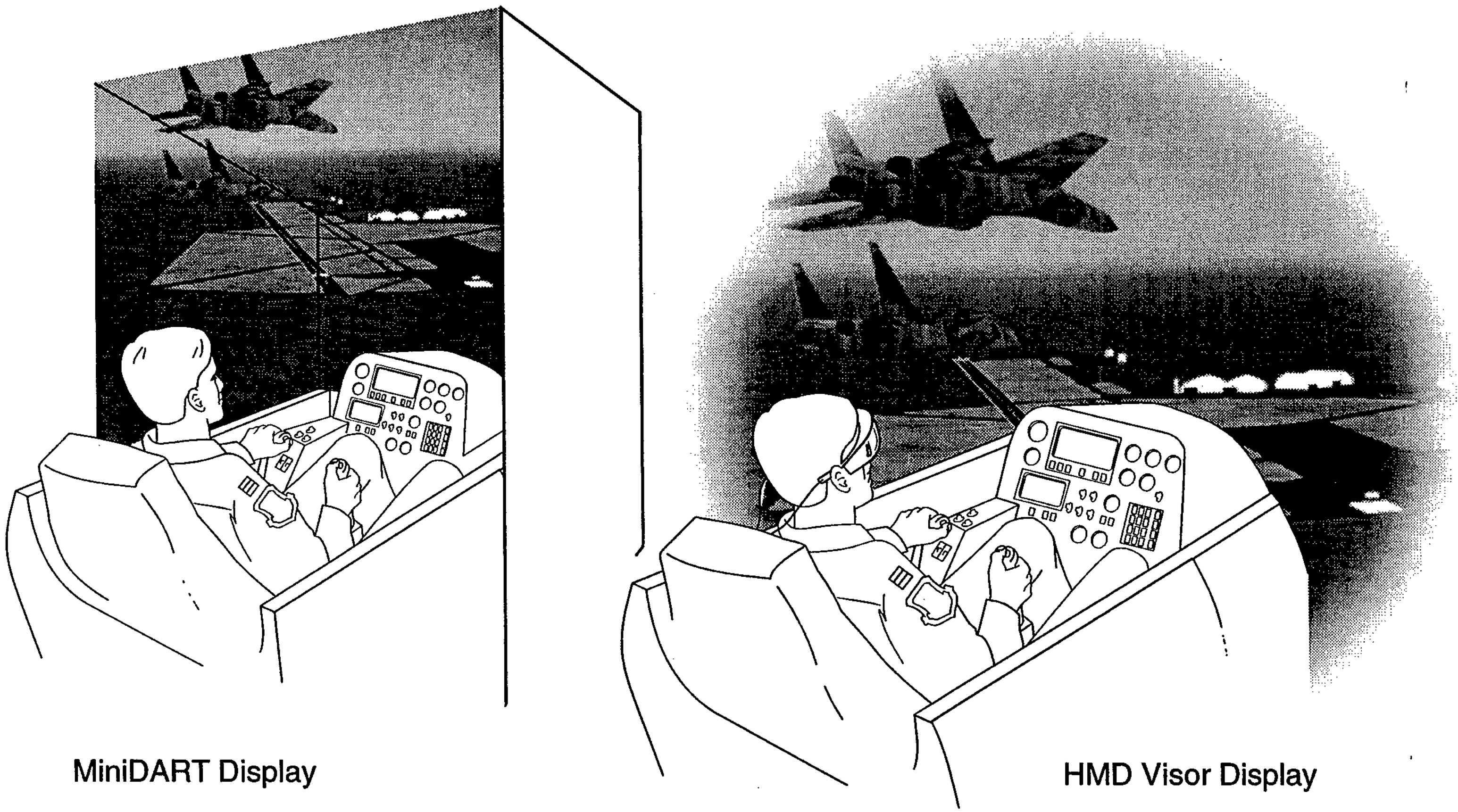

Figure 2
Types of Visual Displays

The PET would be combined with desktop systems to provide all the computer and simulation capabilities needed for academics. Desktop systems can be equipped with special interface devices to accommodate built-in, quadruple-speed, compact disc, read-only memory (CD-ROM) drives; modems for high-speed communications and data transfer; high-resolution displays for both flat-display and 3D simulations; and stereo or even 3D (localized) sound. Such systems would support a broad range of training activities, including the development of high-performance cognitive skills needed to maintain situational awareness in the cockpit while executing time-critical tasks. Such training would provide a stronger foundation of skills prior to a student's engagement in full-fidelity flight simulation training. Intermediate level work stations with some advanced microcomputer features could be installed in classrooms and even students' private quarters at a reasonable cost, while specialized displays and simulation capabilities would be reserved for the simulation training laboratory (discussed below).

The capabilities of new microcomputer systems and software would enable learners to play a more active (interactive) role in learning and advancing through training activities as opposed to traditional group lecture/demonstrations and passive media presentations in the classroom or media lab. The location of learning activities would become more flexible because of multiple training-delivery modes and options.

Linking microcomputers together via a LAN system has many practical advantages. A LAN can be configured in a variety of ways to enable students to access a full range of desktop applications as well as real-time communications and interactive training programs. Such functions would include performance-support programs like wordprocessors, spreadsheets, and databases as well as specialized pilot-training courseware. From a more expansive perspective, students could use such desktop systems to gain immediate access to military, private, and commercial communication lines to and from literally anywhere in the world (e.g., Internet and worldwide web). Instructors could transmit to and receive from students, staff, and command personnel various types of verbal and graphic communications. A microcomputer LAN can also support multiple security levels which restrict or facilitate access to designated materials or data to specific personnel (e.g., grade records). Instructors could make changes to courseware so students always receive up-to-date materials. Scheduling of events (e.g., training flights) could be input on the network so every user has immediate information updates. Special integration with other supercomputer systems can also provide desktop users with special capabilities that are not possible with stand-alone systems.

The PET and associated training software could be applied to all six problem areas identified in this research study. The basic improvements to current training would be individualized training, performance tracking, automated performance assessment, and an extension of the current academic training capabilities. An artist's conception of the PET and desktop training station is illustrated in Figure 3.

Instructional Simulations. More powerful microcomputer systems have also made it possible to combine simulation with CAI. This becomes a very important capability when dealing with learning of a dynamic (versus a static) nature. Instructional simulations can be used to teach complex skills that consist of intellectual, perceptual, and

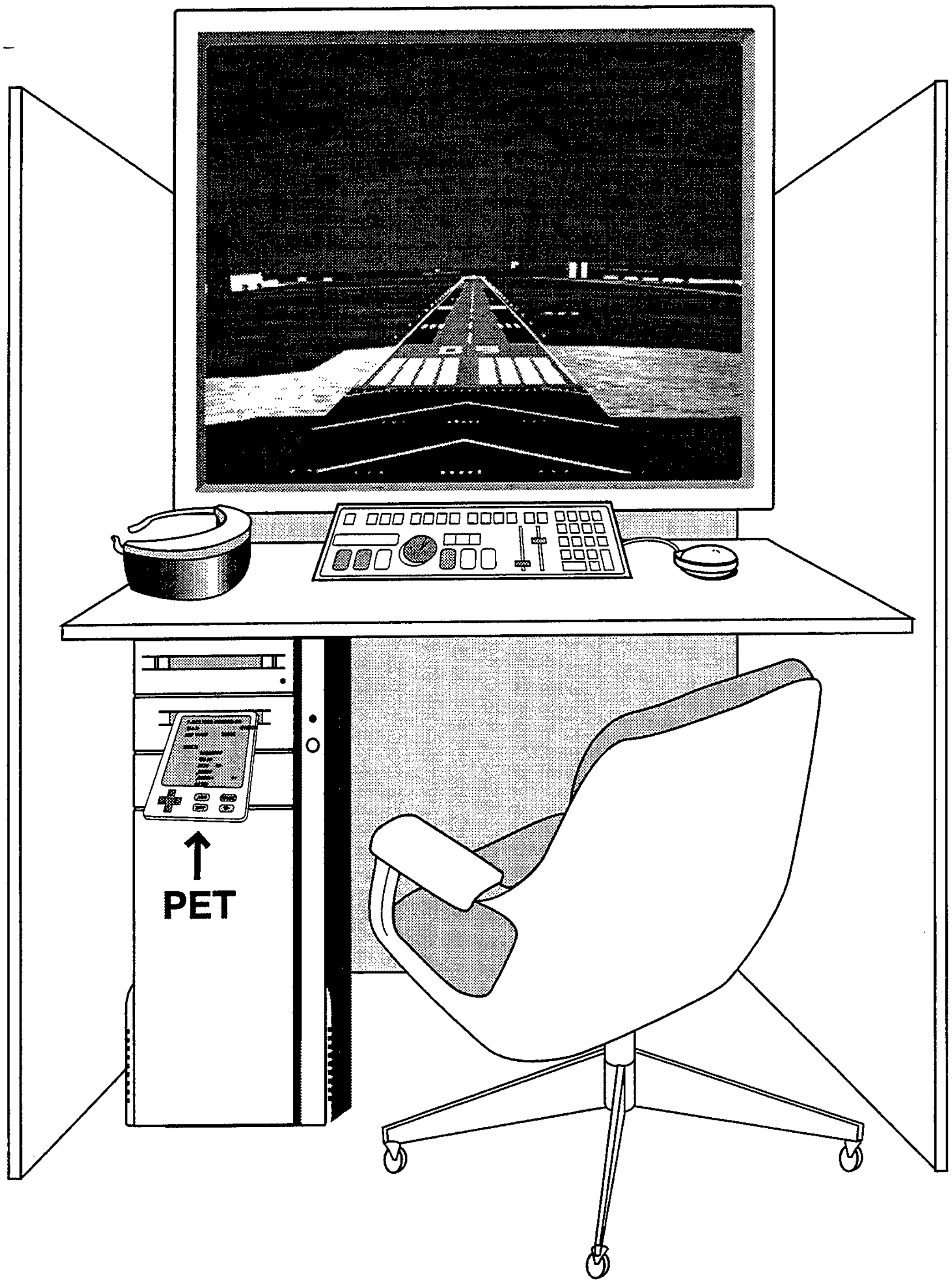

Figure 3
Artist's Conception of PET and Desktop Training Station

motor ability components. The design of instructional simulations differs from conventional CAI whereby learners typically receive sequences of text and graphic information that tests students' knowledge with various questions. Such learning sequences are essentially static and are based on the recall of facts, identification of concepts, executing recall of procedural steps, etc. In contrast, instructional simulations go a significant step further to engage learners with dynamic tasks that integrate knowledge of the task with the complex cognitive challenges associated with fast-changing environments and decision structures. For SUPT applications, instructional simulation would extend the value of desktop trainers. Efficiency in the overall program would improve because students would develop cognitive skills that readily transfer to advanced phases of simulator and flight training.

Instructional simulations replicate the dynamics of task environments using visual and sometimes audio media. Learners interact with dynamic representations of either physical or abstract environments. They can learn both abstract aerodynamic principles, which cannot be demonstrated using common instructional tools and media, or students can build skills practicing hands-on tasks that require great speed and accuracy. During the simulated tasks, the computer monitors and records student responses, provides visual or acoustic cues, performance feedback, and advice on increasing level of skill. Instructional simulations can also automatically alter task environments according to learner performance.

Complex flying tasks usually involve the execution of multiple subtasks (parts of the whole task) to accomplish a single goal. Part-task instructional simulation is one method for reducing difficulties learners have in understanding and performing these tasks. Microcomputer training is a platform for implementing part-task training for a variety of aviation tasks that are primarily dependent on intellectual skills rather than motor abilities. Part-task instructional simulation enables learners to move smoothly from a state of no knowledge of a task to a basic understanding and, eventually, to high proficiency on one or more complex task components.

The following are examples of potential SUPT instructional simulations:

1. Instrument Interpretation Training--Desktop simulation training that would provide real-time feedback to students on their ability to monitor and interpret dynamic situations with navigation instruments such as NAVAID displays.

2. Concepts of Radial Geometry Training--Simulations, animations, and video clips would be integrated into a series of exercises to teach the geometric nature of navigation. It would go beyond interpreting instrument displays by permitting students to manipulate concept models which underlie navigation problems.

3. "What If" Training--Instructional simulations would allow a student to manipulate graphic representations of aircraft, navigation instruments, and navigation aids (NAVAIDS) to discover strategies for interpreting and understanding the instruments. For example, changing the position of a graphic representation of the aircraft would update settings on relevant navigation instruments respectively. Such real-time animated training

scenarios would accelerate the students' grasp of many types of complex phenomena and tasks.

4. Fix-To-Fix Instructional Simulation--Instead of attempting to visualize dynamic situations by chair flying, students would be able to set various factors such as wind, airspeed, and turning radius on visually simulated instruments and flight map and observe results in real time. The simulation would include such factors as radio communications with the tower during maneuvers.

Instructional simulations could be applied to all six problem areas with special emphasis on dynamic, cognitive skills that can be trained without the use of a full-fidelity flight simulator.

Simulation Training Laboratory--The simulation training laboratory is proposed, in this report, as an additional component to the SUPT syllabus. The creation of this learning environment is possible through a combination of technologies which we describe in this report. Functionally, the training laboratory would bridge what amounts to a training gap in the syllabus between academics and simulator/aircraft training phases. Presently, the student inculcates knowledge from lectures, printed material, and CAI (academics), then attempts to apply that knowledge to develop flying skills in the simulator and aircraft. Most students encounter some degree of difficulty with this transition. An environment for developing basic hands-on piloting skills is needed, and new technology can provide it at reasonable cost. Research also shows that student pilots benefit from, indeed prefer, opportunities to experiment, discover, and practice without instructors. Also, the synergism of two or more students learning jointly can improve motivation, learning, and retention, and also engender a favorable climate for team training and crew cooperation.

The specific objective of the simulation training laboratory would be to produce highly transferable skills for subsequent simulator and aircraft training. The training laboratory would provide entry-level simulation experiences well beyond what can be produced using conventional CAI. It would also obviate the need to resort to chair flying (abstract mental rehearsal). The simulation training lab would provide a vehicle for exploiting some low-cost simulation technologies to better integrate academics with simulator/aircraft training activities.

The simulation training lab would feature microcomputer-based, part-task training systems and PET training stations (described above). A selective-fidelity approach would be used in the design of part-task trainers to match the respective training task. For example, a trainer for practicing basic aircraft control skills would feature only stick-and-throttle controls with force-feedback (control loaded) response, ADI (attitude indicator), VVI (vertical velocity indicator), HSI (horizontal situation indicator), and ALT (altimeter). A navigation procedures trainer would consist of a microcomputer-based system that simulates navigation instruments and controls on a touchscreen and provides a large display for digitized maps and flight planning information. The cockpit would interface with the SUPT hub computer system to download various preprogrammed, computer-generated scenarios depending upon the student's choices, current training status, and level of achievement on cockpit procedures training as indicated by his/her proficiency profile.

The training laboratory would be available to students during all phases of the training cycle, and the hours of operation would permit maximum accommodation of student schedules. Figure 4 shows an artist's conception of two selective part-task trainers, one for practicing basic aircraft control skills on the left and the other for practicing navigation procedures on the right.

Unit Training Device (UTD)--Aircraft time allocated to each SUPT student is limited. Advanced flight simulation technology could substantially address this challenge by producing more capable student pilots on entering flying training phases. The assumption is that students could perfect many skills prior to training in the aircraft given sufficiently capable simulators.

The UTD will replicate the functional capabilities of the JPATS/-T-38. Currently, the Air Force is procuring UTDs for F-16 training and is planning to procure UTDs for the T-38 training aircraft. The UTD approach uses engineering and software design methods developed by the Aircrew Training Research Division of Armstrong Laboratory in its Multitask Trainer (MTT) program.

All instrumentation, flight controls, and panels will be accurately positioned. All aircraft systems will be functional. Simulation fidelity will be sufficient to perform all required syllabus events associated with the JPATS and T-38 training missions. A motion platform for the UTD is not required.

Since the greatest expense in the development of any flight simulator is the simulation software, existing T-38 OFT software should be converted to operate with microcomputers selected for the UTD. This use of existing government software can greatly reduce the development time and costs. Aircraft Line-Replacement Units (LRUs) should be simulated in software instead of using the actual aircraft LRUs for high fidelity simulation. UTD computer simulation software must be bit level-compatible with the T-38 OFT simulation software.

The UTD will use commercial, off-the-shelf, simulator components instead of actual aircraft instrumentation and controls. This, combined with use of microcomputers, will greatly reduce the cost and overall size of the UTD. It will also preclude the need for special simulator facilities to house the device. The UTD will have on-board air conditioning for operation in normal office environments using standard, 110 volt, 20 amp electrical power.

The UTD will be self-contained, excluding the instructor-operator station (IOS), image generator and the visual display system. The simulation computers, cockpit interfaces, power supplies, control loading for the flight control stick, and air conditioner, can be housed within the UTD cabinet. The UTD will be easily operated and can provide the flexibility to meet the training needs of the JPATS and T-38 pilots. Students will be able to operate the UTD independently or with an instructor depending upon the training requirements. The UTD will be easily transportable by truck or aircraft and will have wheels to facilitate movement. The average set-up time for the device, from crate to operation, will be approximately one hour. The footprint of the UTD will be less than 10 feet x 10 feet. UTD software will easily integrate with commercially available visual or digital radar landmass systems, image generators, and various types of visual displays.

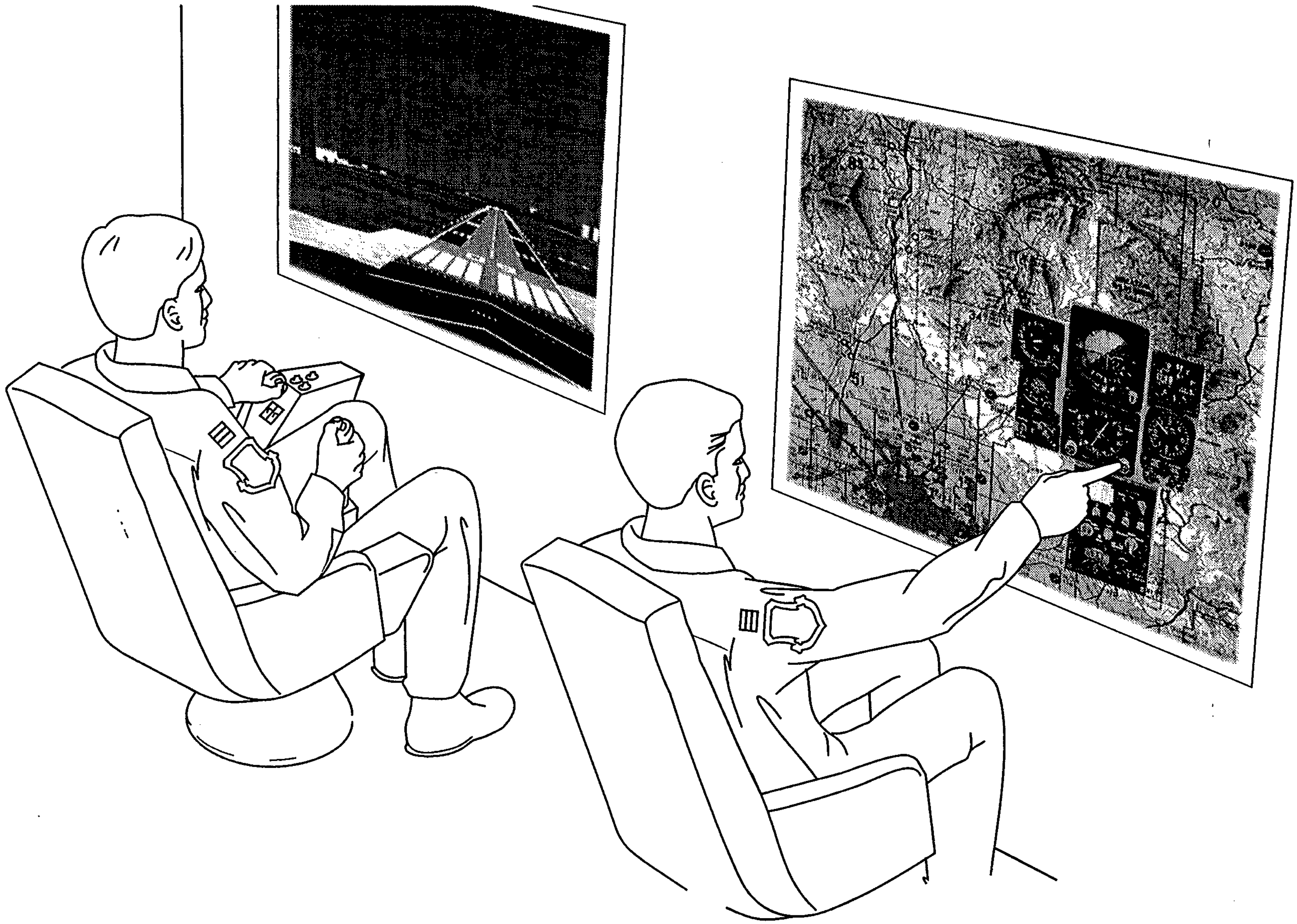

Figure 4

Artist's Conception of Selective Part-Task Trainers
for Aircraft Control and Navigation Procedures Practice

The UTD will be employed at advanced stages of pilot training, prior to and integrated within, flying training in the aircraft.

Simulation Networking Technologies--As an R&D agency with considerable experience in distributed interactive simulation (DIS), AL/HRA is in a favorable position to recommend and/or design multiship network simulations for SUPT training applications. The technical risk of developing and implementing such systems is relatively low because SUPT technical requirements are now well within the current DIS capability.

Two- or four-ship combinations of simulator cockpits housed in the same training squadron (T-37 or T-38 for first-phase applications) would employ LAN technologies in combination with low-cost simulation technologies previously developed and demonstrated in MTT R&D by AL/HRA. Multiship simulation would provide the SUPT program with the capabilities of having (at a minimum) two pilots (such as instructor trainee in separate aircraft, or lead/wingman) fly a full range of two-ship missions or maneuvers as specified by the training syllabus. Each simulator would provide highly realistic representations of the flight environment including other aircraft in the scenario. High fidelity simulation models of aerodynamics, engine, radio, and all associated avionics functions and subsystems would be provided. The networked simulators would be equipped with either DART or HMD technology. Flight environments modeled in a computer-generated visual database would include local areas, practice ranges, and other required geographic areas.

Networking Applications and Benefits. Simulation networking for SUPT would be superior to existing technology simply because these capabilities are now unavailable in the program. Immediate benefits would come in formation flight training where the advantages of interaction between pilots in separate simulated aircraft would become obvious. Such an addition to the program can be expected to produce substantial gains in student pilot performance due to the transfer of superior ground training to aircraft formation flight sorties.

Specific types of training supportable through use of multiship simulator networking are as follows:

1. Formation Flight--Skill development for between-aircraft closure rates and control techniques, aspect angle, heading crossing angle, and co-altitude rejoins.

2. Overhead Traffic Pattern--One aircraft in overhead pattern, multiple aircraft in pattern, emergency aircraft recovery, and confused tower scenarios.

3. Multiship Mission Rehearsal--Exposure and rehearsal of complete missions prior to actual aircraft sortie.

Enhancement of formation flight training for all aircraft would be feasible, but cost effectiveness determinations will require additional data collection beyond the scope of this study. Optimal phasing of technology acquisition would be based upon whether simulator networking would be more beneficial if introduced first in the T-37 or in the T-38. As multiship networking costs recede, all aircraft training would logically benefit from networked simulator capabilities. By extension, the linking of SUPT training squadrons at various bases could be considered. Such capabilities obviously transcend current SUPT training requirements. However, this may be due to the fact that DIS technology has not been available until recently.

Networked simulators afford the AETC community the means to explore new horizons in advancing the training for USAF pilots. DIS might be particularly beneficial in SUPT depending upon the degree to which multiship training is expanded. For example, it appears quite certain that such capabilities would increase SUPT trainee proficiencies for introductory basic fighter maneuvering (BFM). Beyond that, multiship training could be expanded to encompass considerably advanced levels of sophistication of training to better prepare SUPT students for selected CCTS assignments.

Portable Electronic Trainer (PET) in the Cockpit. Ever since flight instructors began training students, they have faced the challenge of recording information on the student's inflight performance that is useful for the debrief. IPs have traditionally used notebook-style checklists and rating forms on a "kneeboard"--a small notebook that is strapped around the pilot's leg during the flight. Kneeboards have drawbacks as training aids because (a) there is little space for written information; (b) the IP must look down to write and may miss important student behavior; (c) notes must be manually transferred to some type of filing or storage system for use beyond the immediate debrief; and (d) using kneeboards during night sorties is awkward.

All of these drawbacks could be corrected by modernizing the kneeboard concept. The PET could conceivably be equipped with a special set of functions that would enable instructors and student pilots to enter relevant flight data via a simplified keyboard or touchscreen interface with minimal distraction during flight. A high resolution screen (about 5 inches x 5 inches) would display a simple menu that could be illuminated during night flights. Performance notations and ratings could be made with a few keystrokes or screen touches. The resulting PET data would interface directly with the Aeronautical Training Recorder (ATR, described below) to integrate performance ratings and notes with respective flight events. All such data could be immediately downloaded to the SUPT hub computer after the flight to update the student's proficiency profile and to use for debriefing. Whether the device is used on the knee or attached to a panel in the cockpit, it would be easily attached and removed and designed to comply with flight safety regulations.

The PET could also be used by IPs during flight simulator training for the same performance-monitoring purposes. Increasing the quality and quantity of useful performance data available to IPs during debrief was emphasized as a main concern of instructor pilots. IPs must work with a number of students, and they are currently unable to remember and/or write down enough information to optimize student guidance during flight training. This application of the PET would extend its usefulness to all phases of training from academics to flight training in the aircraft. PETs would help keep students on track by keeping them informed on their flying progress and would reduce IP's workload by facilitating student profile monitoring and inflight performance assessment tasks.

<u>Aeronautical Training Recorder (ATR)</u>. The ATR would capture a continuous sequence of real-time, dynamic flight data from the aircraft during training sorties. Aircraft data would be integrated with local terrain database models for purposes of re-creating actual training flights via simulation. This capability should vastly improve debriefing capabilities.

The ATR would consist of three major components: (a) an aircraft-mounted (on-board) microcomputer with high-capacity data storage; (b) an on-board Global Positioning System (GPS) linked to the ATR computer; and (c) a ground-based computer system that would combine aircraft flight data (instrumentation and GPS) with a local terrain database. The on-board computer would sample instruments, cockpit acoustics, and radio communications at about 60 Hz to reproduce the flight in a high-fidelity simulation format. The recording process could be manually engaged and disengaged at any time during the flight by the instructor using the PET as the inflight ATR interface.

A removable data packet would permit easy transfer of flight data to ground-based systems. The ground-based image generator would reproduce any recorded portion of the flight from a variety of viewpoints (tower view, inside-cockpit view, off-the-wing view, stern view, etc.). The ATR would remove the IP's challenge for remembering dynamic details about each training sortie to effectively debrief the student. A similar technology is currently used in the Air Combat Maneuvering Instrumentation (ACMI) program. However, the SUPT version would use modernized technology at a much reduced cost.

The GPS would triangulate time/position data of the aircraft (at a suitable level of accuracy) by continuously interrogating navigation satellites and synchronizing the aircraft position data (longitude, latitude, and altitude) with the instrumentation data. The GPS system would require some aircraft modifications to accommodate receiving/transmitting antennae.

The ground-based computer system would translate the inflight ATR data to a format which would enable the flight to be simulated and replayed in a high-fidelity format on the UTD or in a medium-fidelity format on classroom training stations.

The ATR would be employed at advanced stages of pilot training when the student pilot begins flying sorties in the aircraft. The ATR simulations would be used to debrief student pilots in a passive (view only) format so their performance could be reviewed and discussed with the IP. ATR-captured training sorties could also be employed to enable students to re-experience a sortie. By downloading ATR data to the UTD, a student could re-fly exactly the same maneuvers in the UTD that were found to be most difficult in the aircraft.

Figure 5 shows an artist's conception of the way in which the ATR system would closely integrate in-flight training with ground-based training and practice activities.

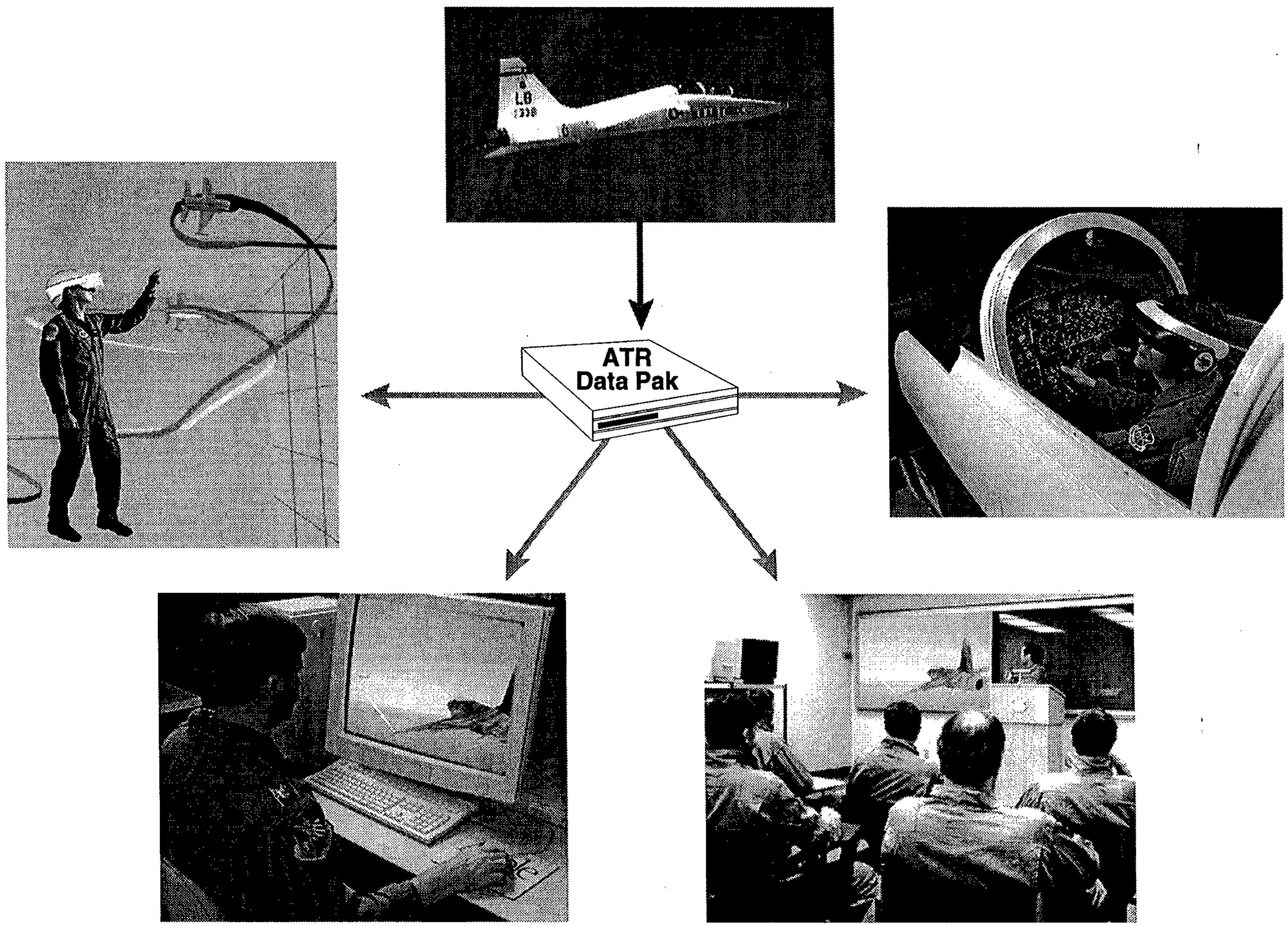

Figure 5

Artist's Conception of Integration of Inflight and Ground-based Training via the ATR

Instructor/Student Associate--Expert systems technology has potential for SUPT applications. It may be possible to develop an Instructor/Student Associate (ISA) to aid students as they learn to fly in the UTD or even in the training aircraft. Prompting logic within the system would be based upon instructional principles and a comparison between the student's performance and established performance criteria. However, the instructor would be able to override the ISA as needed.

In a fully automated mode, the ISA would provide aural cues or advice on how to correct the error when a student pilot meets or exceeds allowable parameters during a maneuver. In a manual mode, the IP or student could query the ISA for advice on a particular maneuver that has just been completed or is about to be attempted. The ISA would be a voice-activated system to provide minimal distraction and would use student proficiency profiles to adjust advice based on individual ability and level of skill.

The ISA would require extensive development effort. Substantial analysis and modeling of training scenarios would be required to identify and define a suitable universe of instructional problems. Problem solutions with corresponding instructional prescriptions would also require identification, test, and validation. Training and psychology literature provides some general foundations for the instructional associate, but the extent to which an automated expert can be designed to recognize and deal with ongoing complex flight tasks remains to be determined. While such a system could potentially address many pilot training challenges, the technical risks inherent in such an endeavor would be substantial.

A proof-of-concept videotape was developed as a supplement to this report (Mattoon & Gagel, 1995) and demonstrates how each technology may enhance training capabilities and increase flexibility in SUPT environments.

Instructor Pilot Feedback on Study Analysis and Results

Following the investigation team's analysis of findings, there was interest in determining the level of agreement among instructor pilots regarding the team's findings about challenges/problems found in SUPT as well as technical solutions as proposed. After the team had fully briefed the instructors on the findings, a questionnaire was presented to a number of the IPs who participated in the original interviews.

For each of the six training problem areas identified, the IPs were asked to indicate the "degree of seriousness" of each problem. They were also asked to indicate the degree to which they thought the proposed technology solutions would help overcome each of the problems identified.

Specific instructions contained in the questionnaire for rating the seriousness of problem areas were as follows:

"Please rate each of the six problem areas below in terms of its degree of seriousness in affecting SUPT trainee performance and ability to successfully complete training. (0 = unsure, 1 = not serious, 2 = somewhat serious, 3 = very serious)"

Mean ratings by problem area:

Position interpretation	2.8
T-37 overhead traffic landing pattern	2.6
Formation and fluid maneuvering	2.6
Fix-to-fix navigation	2.3
IP continuation training	2.2
Low altitude flying	2.0

Instructions on rating the probable effectiveness of the modeling/simulation solutions were recorded. (Terms used in the questionnaire varied slightly from those mentioned above, but the content of technology descriptions was essentially the same):

"Please rate each of the modeling/simulation solutions in terms how effective/useful you think it would be for solving SUPT problems experienced by students and IPs. (0 = unsure of usefulness, 1 = not useful, 2 = useful, 3 = very useful)"

Mean ratings by technology solution:

Aeronautical Training Recorder	3.0
Video media	2.8
Instructional simulation	2.8
DART	2.8
Large classroom monitor(s)	2.6
3-D Displays	2.6
Unit Training Device	2.6
Improvements in CAI	2.4
Simulator Networking	2.1
Electronic Kneepad (previously referred to as PET)	2.0

These results generally indicate that instructor pilots concurred with the challenges and technology-based solutions identified by the laboratory investigators. IPs rated all of the identified training problem areas as "serious" to "very serious" in SUPT. All of the proposed technology solutions were rated as "useful" to "very useful" for application to these training challenges.

SUPT INVESTMENT STRATEGY ROADMAPS

The roadmaps in this section show the time frames and estimated costs associated with developing and procuring the necessary quantities of M&S technologies described in this report for implementation in SUPT. The program time frame extends through the year 2020. The assumption is that procurement of any of these M&S systems could not begin before 1998 due to funding programming regulations. Armstrong Laboratory has R&D planned to support many of these efforts. Laboratory work is shown where it is planned. As with any planning document, various considerations may warrant AETC procuring something less than the full slate of M&S technologies recommended. AETC already has some funding programmed in anticipation of some of the technologies shown in the roadmaps. Therefore, not all of the funds required to procure roadmap technologies would need to be new program money. It is also possible that technologies unknown at present may emerge in the next 10 or 15 years that could obviate selection of some technologies recommended in this report.

The investment roadmaps are based on evaluations of current M&S technologies of highest merit for intended purposes. While cost estimates have been included, they should be considered in view of the character and rapid growth of these technologies. Estimates combine current knowledge of trends and long-term forecasts for technologies. Breakthroughs, although not predictable, must be taken into account as possibilities due to the nature of this sector of industry. For these and other reasons, we have been interested in developing a cost-benefit model that eventually would reside at AETC Headquarters. Such a tool would help AETC model hypothetical applications of specific technologies to better estimate training benefits potential. A preliminary model toward this objective is contained in Appendix B.

An underlying assumption in recommending these technologies is that technology and sound methodology are co-dependent. Therefore, technology investment must involve substantial methodological effort including training analysis, design, and technology transition. These elements will be needed to ensure effective integration of modeling and simulation within existing programs.

Roadmaps are organized by technology development areas, so each major roadmap may involve R&D for several of the technologies described above which may be applied to multiple areas of SUPT training. Each roadmap is organized as follows:

1. Title of technology effort and fiscal year ribbon shown at the top;

2. Title or type of subtechnologies shown in boldface atop grouped time ribbons;

3. AL/HRA lead-in technology development shown in shaded ribbons;

4. Specific milestones shown on charts as numbered triangles (annotation of triangles shown in left margin; and

5. Cost (in $M) indicate estimated dollars for development, and operation and maintenance (O&M) phases for each technology.

Figure 6, SUPT Training Technology Investment Strategy, presents an integrated picture of recommended technology investments for SUPT. The development and application of these technologies is intended to provide highly capable ground training technology for all SUPT bases. Introductory information on each major technology appears immediately below, and detailed descriptions of each major area are contained in each of the subsequent roadmaps (Figures 7-10) and their accompanying explanations.

Advanced Simulation Technologies. Simulator training will have high transfer value because of the superior fidelity and currency with training aircraft and flight environments. These simulation devices will enable students to fully rehearse training sorties prior to entering the aircraft. It is reasonable to expect that pilots will achieve current proficiency standards sooner than at present through efficiencies engendered by these technologies. It is also possible that higher student proficiency levels can evolve. Simulators will be affordable in all training squadrons and therefore available to students when needed, precluding scheduling delays and generally enhancing program efficiency.

Database Modeling. Conceptually, the training database is intended as the functional center of all modeling and simulation resources in SUPT. Instructors, students, and training managers will use this central, or hub, database to access and manage ground training resources and student training records.

SUPT Simulation Training Laboratory. The training laboratory, as conceptualized here, represents a new training component within SUPT. It is intended to aid students make the transition from knowledge of procedures to usable flying skills. The laboratory is intended to provide an environment for the development of basic hands-on stick and throttle (HOTAS) skills.

Electronic Classroom. The objective of this program will be to modernize the academic learning environment through the integration of state-of-the-art instructional technology. The infusion of new technologies at this level of training is intended to provide instructors with more efficient tools, to accelerate student knowledge acquisition, and to improve the transfer of academics to subsequent training phases.

Figure 7, Advanced Simulation Technologies. This roadmap describes the integration of technologies to provide advanced flight simulators for SUPT. Ongoing laboratory R&D, identified in the shaded boxes, will provide the technology base for each of these programs. The Unit Training Device (UTD) will provide high fidelity cockpits (2 each, for 20 SUPT squadrons). Terrain models and databases for modeling environments of up to six training bases are included. DART/HMD R&D will provide the technology base for the visual system to be combined with the UTD. This program is shown in two technology phases, one for the DART and one for the follow-on helmet-mounted display technology. Thus, the DART wraparound cockpit display screen eventually will be replaced with helmet displays as a means to keep abreast of the latest display technology. The fourth component is an advanced Instruction Support System (ISS) for use by simulator instructors or by individual students in the UTD cockpit. R&D is currently ongoing at the laboratory to underpin this program.

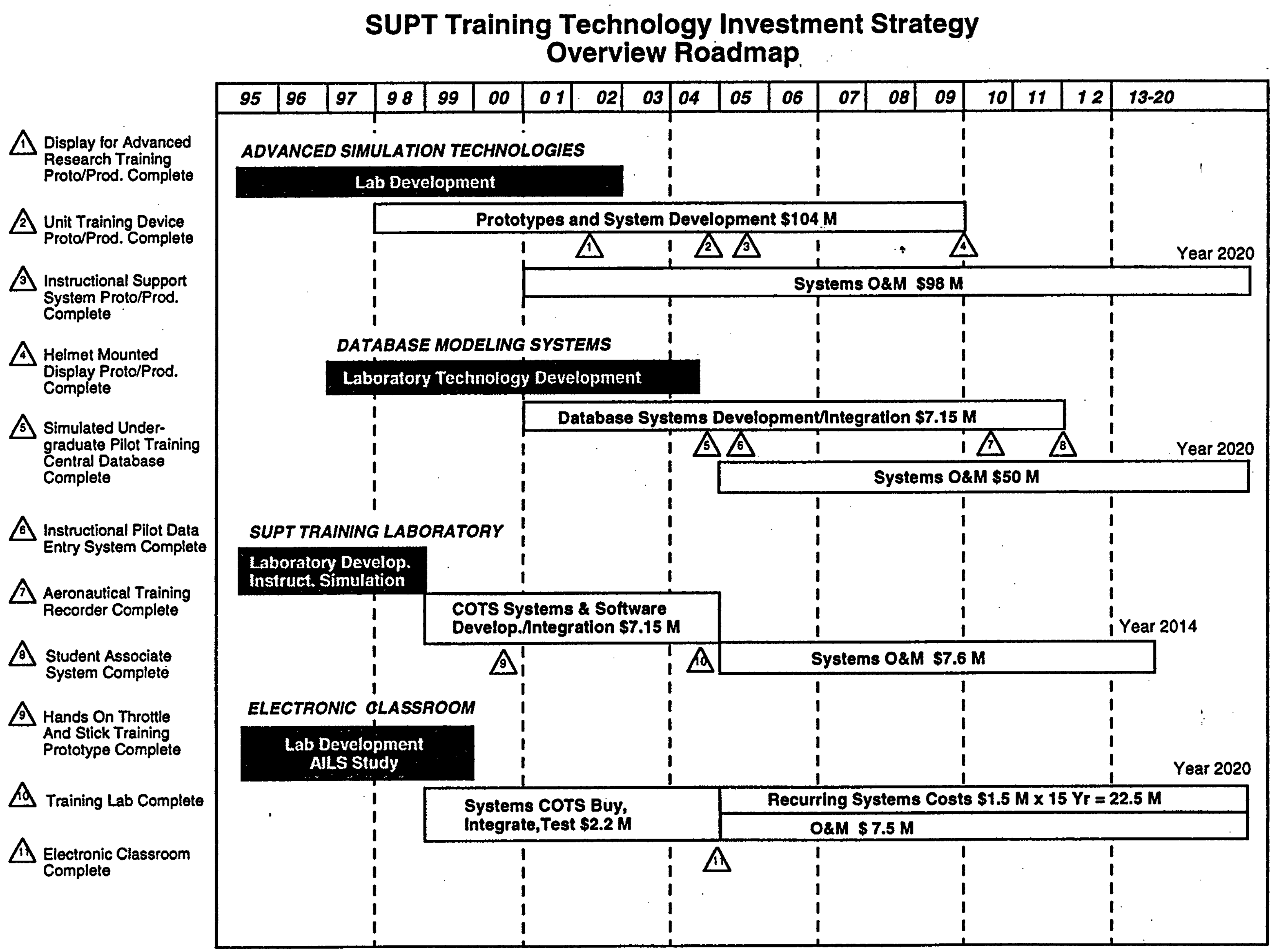

Figure 6

SUPT Training Technology Investment Strategy
Overview Roadmap

Advanced Simulation Technologies

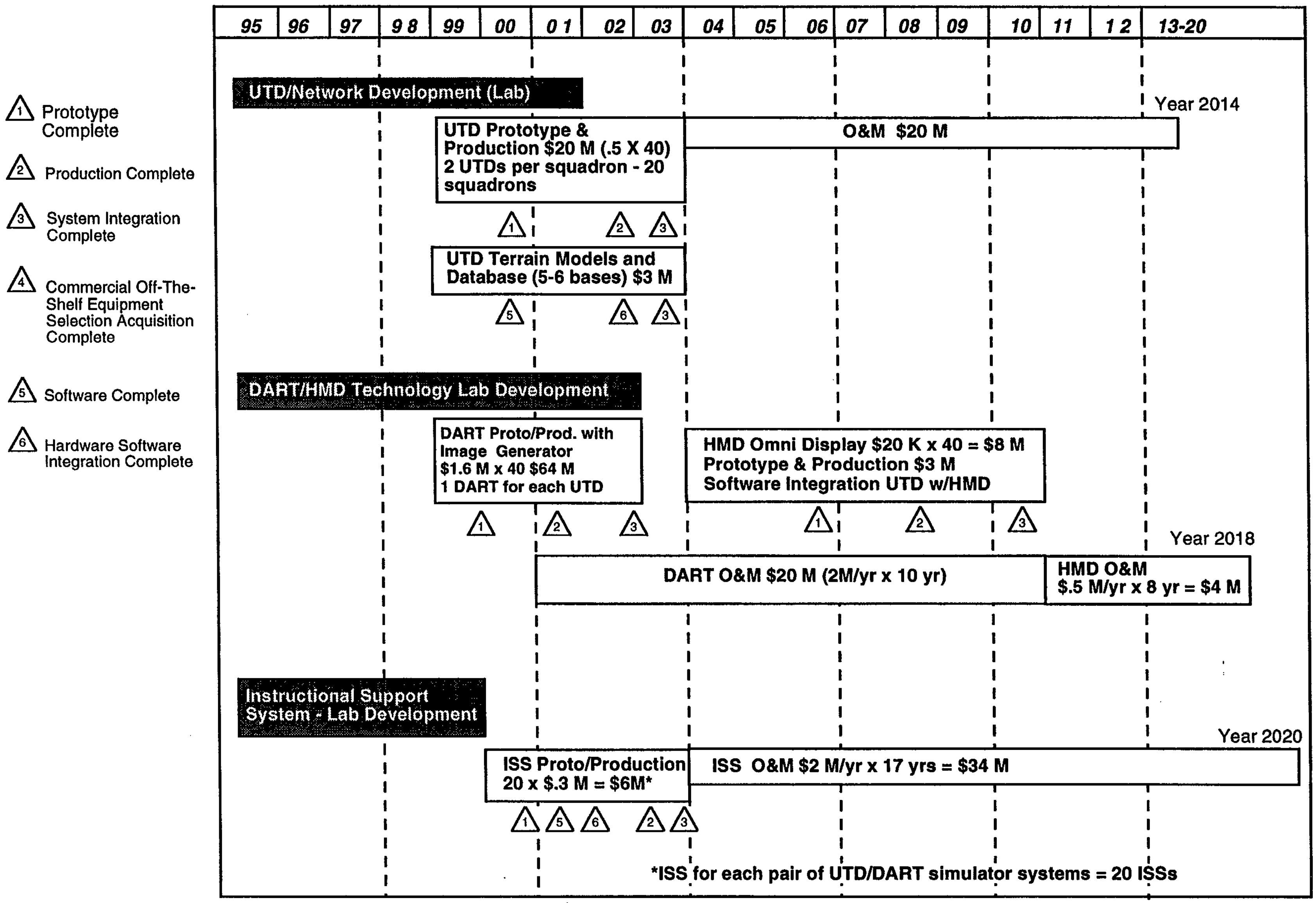

Figure 7
Advanced Simulation Technologies

The basic component of simulation training is the UTD, a high fidelity cockpit simulator. Trainer cockpits will be functionally equivalent and will remain current with the training aircraft during their life cycle. Aircraft aerodynamics, engines, subsystems, avionics, and aircxraft control characteristics will all be accurately modeled in UTD software. This portion of modernization envisions eventual integration of UTD/DART systems as networks of simulators within SUPT squadrons.

Because of the substantial lead-in development already accomplished by AL/HRA (through FY2001), the time and cost of UDT prototyping for SUPT purposes will be minimal with system completion projected for FY2003. UTD cockpit prototyping and production, and UTD terrain modeling are shown as separate timelines with their associated milestones. UTD software will contain terrain models and training databases for local areas and ranges for each squadron location. Databases developed for UTDs will be subsequently integrated with the SUPT hub database in each squadron as required. Prototyping and production phases are projected for completion by FY2002. The DART effort will include installation on UTDs and is phased to coincide with the UTD program. The DART will complement UTD cockpits with high fidelity visual environments. DART development will include an advanced image generator to furnish a visual environment with sufficient quality to support full mission rehearsal for all syllabus events. As this technology is upgraded, enhancements will transition to SUPT during the development period shown, through FY2002. The roadmap shows an approximate three-year hiatus in visual technology for UTDs occurring between DART and HMD technology. The gap reflects a maturation period for the omnidisplay technology. The omnidisplay will provide very high resolution, wide field of view, and other display characteristics superior to the DART, but in an HMD format. O&M periods for UTD, DART, and HMD are projected to coincide with integration of operating ysstems and will extend through FY2020.

This technology will be incorporated in UTDs as the successor to what is now called the instructor/operator station, or IOS. It will be based upon current R&D which will extend through FY99. The ISS will be capable of more sophisticated and direct intervention in the training process, making the student less dependent upon instructors during simulator training activities. Instructional capabilities will include advanced computer graphics, auditory cueing and feedback, and direct tutorial dialog with the student. The ISS will interface directly with the SUPT hub database. The prototyping and production phase is projected for completion by FY2003 with milestone events as depicted.

Figure 8, Database Modeling and Development, presents the timeline and cost estimates for this technology. In the SUPT application, the central or hub database will be accessible via personal computers (or portable electronic trainers [PETs]), electronic classrooms, training laboratories, and simulators, for use with these systems. The Aeronautical Training Recorder (ATR), described in this roadmap, will also interface with the database. The database will contain a host of data models for use in training. Libraries of practice scenarios, ranging in complexity from basic hands-on cockpit management tasks to entire aircraft training missions will be accessible to students via appropriate training devices for given levels of skill. The database will also contain student records and current status in the program. Proficiency profiles, based on student training

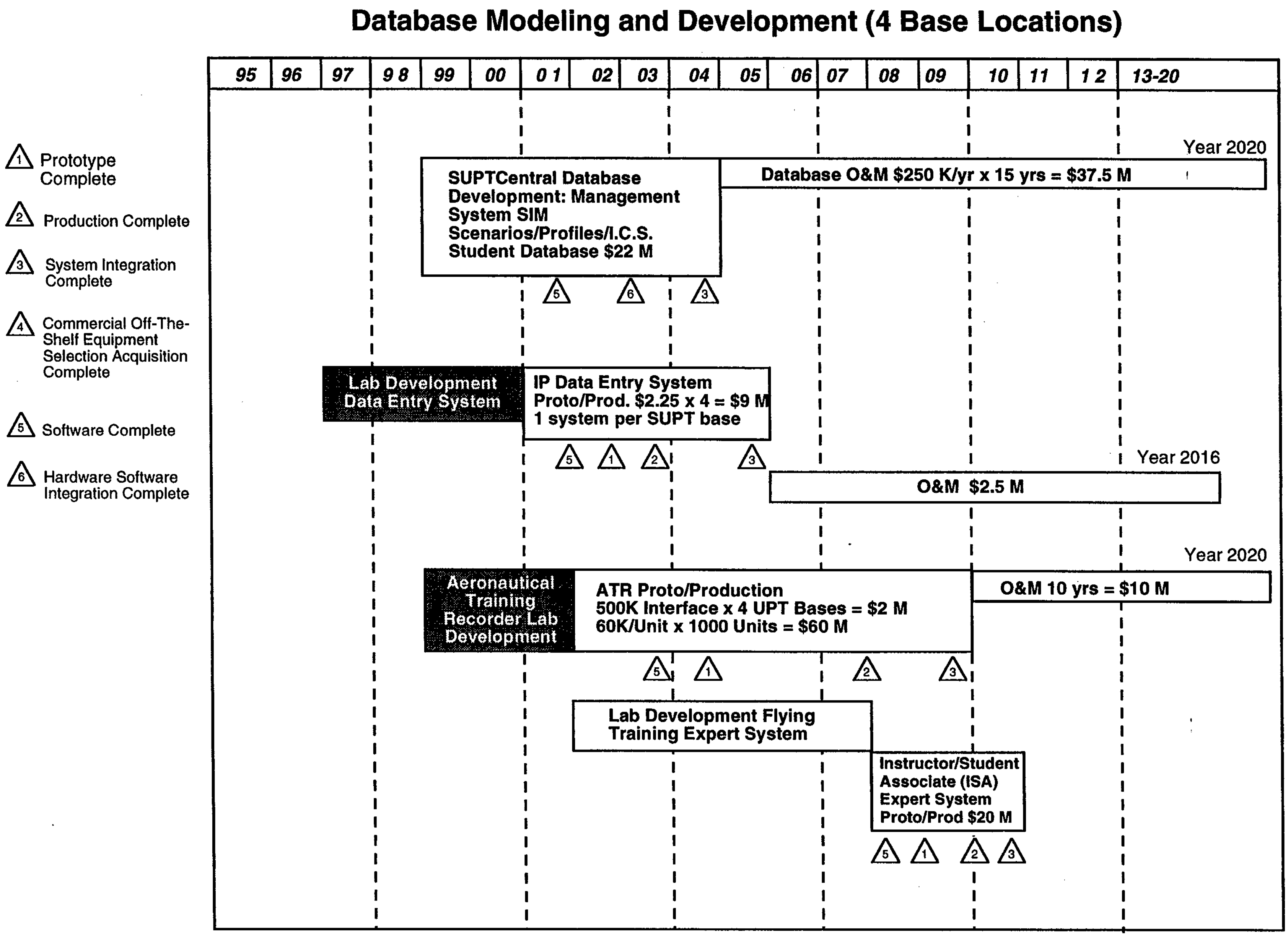

Figure 8

Database Modeling and Development

performance data, will be used to diagnose individual training needs and activities. Eventually, the database will provide automated training guidance, integrating student training records and providing training guidance. The central database will improve time and training for gorund training resource management. Implementation of the student performance data system will enable students to build knowledge and flying skills more rapidly and thoroughly. It will provide managers with much more explicit information for cost benefits determinations and program accountability. An overview of benefit-cost analysis applied to the R&D in this report is provided in Appendix B.

IP Data Entry System. This addition to student-training functions will provide the flight instructor with a convenient, effective means to annotate student performance during aircraft sorties. The model developed for SUPT will be preceded by preliminary R&D at AL/HRA, to be completed by FY2000. Prototyping and production will begin in FY2001 and be completed by FY2005, with O&M projected through FY2020. This system will be the first enhancement to the hub database, however, its development will be accomplished almost concurrently with the central system itself.

Aeronautical Training Recorder (ATR). Database development will also include development and integration of the ATR and Flying Training Expert System as phased system enhancements. The program is based on installation of systems aat four user locations (SUPT bases). ATR data recording will include IP Data Entry System inputs as designated by the instructor for debriefs. The net effect sought from ATR implementation is reduced time to student proficiency in the aircraft. As with other technologies, an advanced period of R&D by AL/HRA (to be completed by FY2001) will precede device prototyping and production (to be completed by FY2009). The development and integration of this technology will extend over a considerable time period and envisions gradual system upgrades as state-of-the-art advances in expert systems become operational. O&M for the program will begin when the basic system goes on line in SUPT, about FY2005 and will extend through FY2020.

Instructor/Student Associate (ISA). Finally, this roadmap shows a program for ISA development. This system is intended for use in the simulator and possibly the training aircraft. A five-year laboratory lead-in period is envisioned beginning in FY2002 as a specific application of maturing expert systems technology anticipated within industry. Lead-in R&D will focus on SUPT training tasks in order to provide needed databases.

Figure 9, SUPT Training Laboratory. Lead-in R&D for the training laboratory includes part-task training and instructional simulation concepts developed within the laboratory and elsewhere, combined with current microcomputer technologies. These efforts, ongoing currently, will be the foundation for the design and integration of the training laboratory as an innovation into the SUPT program. It is possible that training capabilities for all basic cockpit procedures and navigational skills can be built into a single, multifunction HOTAS system which could shorten development of the prototype to two years. The production phase is projected for a three-year effort to completely equip all SUPT squadrons. The training laboratory will contain medium-level fidelity cockpits to train HOTAS and basic navigation instrument skills. The complementing visual display systems will be developed concurrently with the cockpits. Display technology may consist

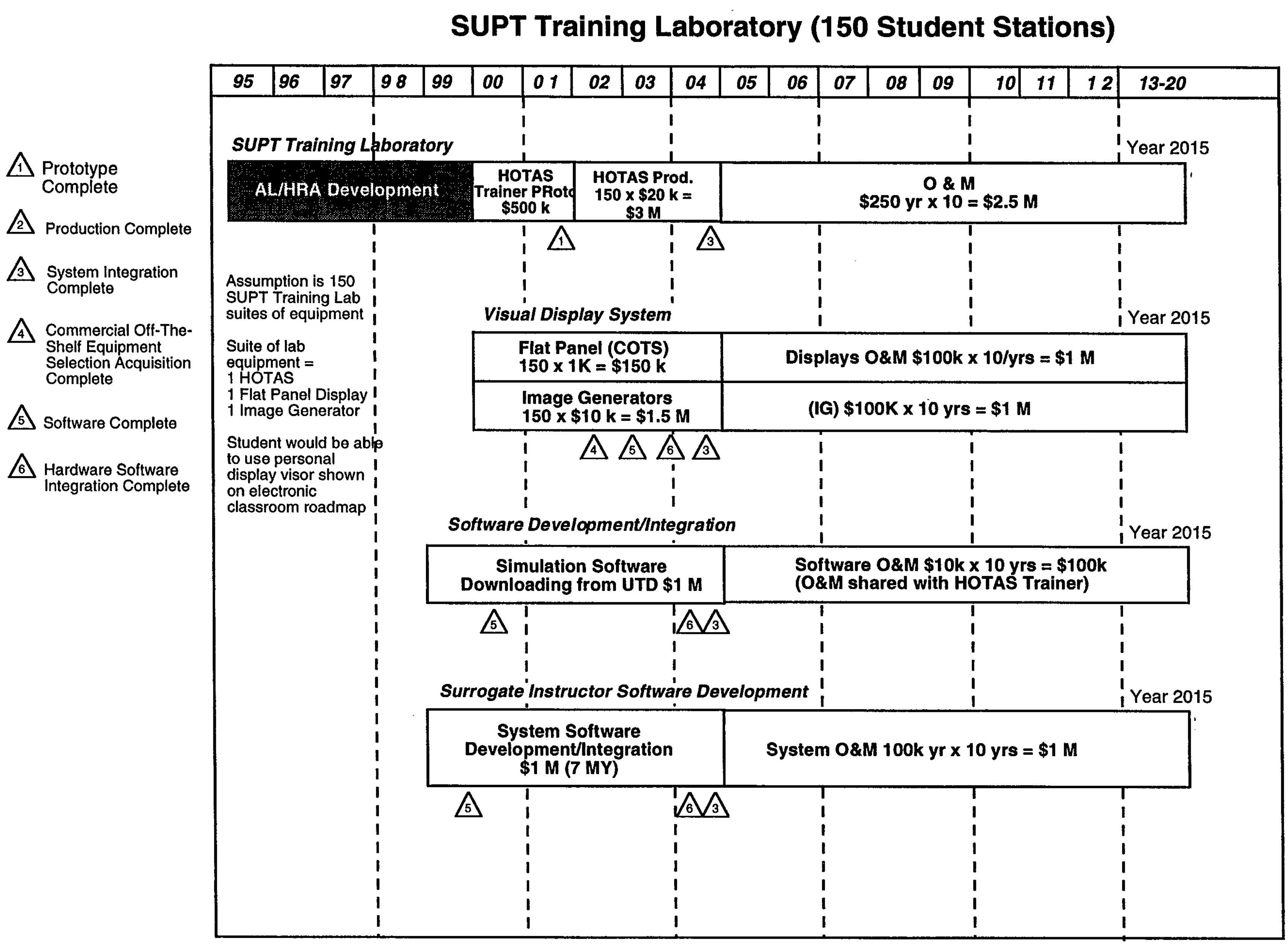

Figure 9

SUPT Training Laboratory

of either DART or HMD technology and digital image generators. Costs shown for these systems include integration with cockpits. Commercial, off-the-shelf components for visual displays and image generators will be assembled and integrated.

The training laboratory will require two additional developments. The first is training software which includes modification and integration of available UTD software with HOTAS cockpits. The dual implementation will save development costs and increase training efficiency. O&M software costs include currency upgrades throughout the life cycle. Instructional software development will also be included in this effort. Flight scenarios developed for the simulation training laboratory will incorporate instructional strategies and feedback techniques to aid student skill acquisition. All software for the training laboratory will be managed by the SUPT hub computer system. The second development is an enhancement for the training laboratory. The goal will be to produce a surrogate instructor pilot (expert system) specifically for use in the training laboratory. This system is intended to obviate the need for live instructors in the training lab.

Figure 10, Electronic Classroom. This section includes technology upgrades for CAI and classroom training hardware (LSDs, personal computers, and desktop training stations). Modernized classrooms will integrate state-of-the-art instructional technology with syllabus content. Students will engage in individual training, team training, and instructor/student coaching activities using these devices. Students will access the hub computer system via personal computers to monitor their proficiency profiles and advance according to individual progress and on-line skill assessments.

AL/HRA plans the development of prototype electronic classroom technologies during FY96 to FY98. This R&D effort, entitled the Aircrew Integrated Learning System (AILS), will provide needed analytical and developmental foundations to support SUPT academics. Hardware for this system is envisioned as commercial, off-the-shelf media. Courseware development will comprise the major portion of this effort. System prototyping and integration is projected for completion in FY2004 with O&M beginning then and extending thorugh FY2020.

Costs shown in the two lower boxes in this roadmap represent development of a library of courseware and academics media. We assume AETC's media production resources will be available to satisfy requirements for these materials. Therefore, no costs are included in this roadmap for development of academic media materials.

Developing electronic classroom technology for SUPT assumes modernizing 40 classrooms (10 classrooms x 4 SUPT bases). Basic components (commercial, off-the-shelf items) to equip the environment are shown in the roadmap. Systems are shown separately, but in concurrent development beginning in FY99 and extending through FY2004. Costs shown for component systems include time and costs required for selection, acquisition, integration, and testing as "turnkey" systems for SUPT classrooms. The 6 ft x 8 ft, high-resolution LSDs will be integrated with image generators for computer animation and simulation. All students will be issued PETs for continuous use throughout the training cycle and access to desktop training stations equipped with HMDs at strategic locations throughout the training base. PET training stations will network with other PETs, LSDs, UTDs and the SUPT hub computer to enable students to engage in self-monitoring of

Electronic Classroom (40 Classrooms)

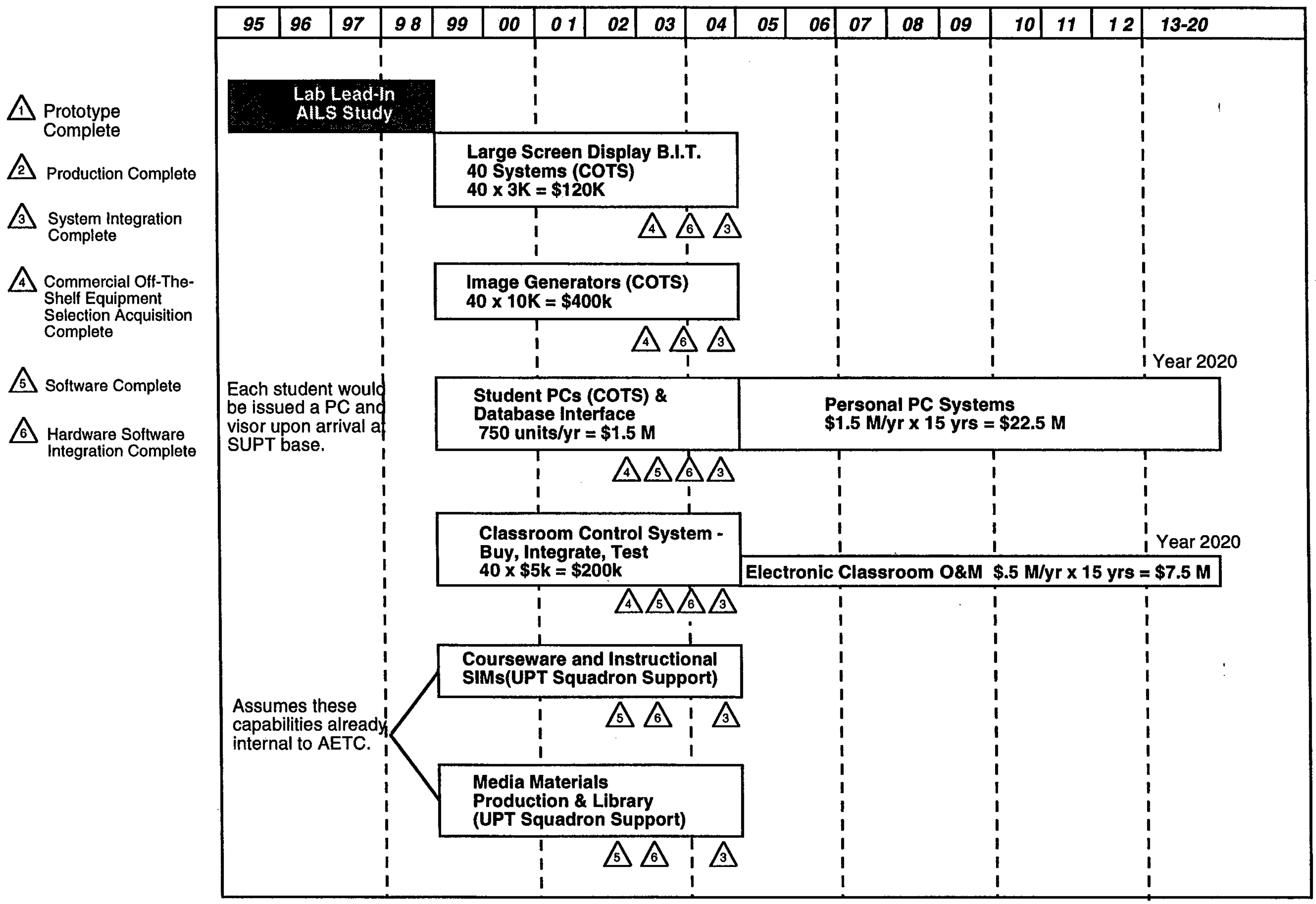

Figure 10

Electronic Classroom

performance; to individualize training activities according to the student's current level of ability and training experience; and to provide for team training activities that involve two or more students or student/instructor teams. We anticipate that frequent upgrades will be required to maintain electronic technology currency. Therefore, it seems reasonable that students would retain PETs following SUPT completion, with PET replacement absorbed as recurring upgrade costs ($2K/student). This would preclude accumulation of obsolete equipment, maintain state-of-the-art systems, and benefit students as they enter CCTS.

Classroom instructors will control presentations and otherwise manage training activities via a classroom control console. Instructors will monitor student learning and modify content as needed to insure achievement of course objectives. Instructors' activities will include teaching and coaching certain individual training events, monitoring and advising students on their use of the proficiency profile system and automated trainers, and managing team training activities.

CONCLUSIONS

We believe the modeling and simulation technologies described in this report can improve SUPT in general and the six identified training challenge/problem areas in particular. While these six areas were the ones most often mentioned during the interviews, they were not the only areas of need described by the IPs. It is important to recognize that acquiring these technologies would benefit many, if not all, other areas of the SUPT syllabi as well.

A key issue is how these technologies would be integrated into the existing SUPT syllabi given the fullness of existing programs. We assume syllabi length would not be expanded merely to accommodate new training media. We are confident that all of the technologies recommended can generate sufficient training efficiency to more than offset the R&D efforts needed for their implementation within AETC programs. This would result from replacing less efficient existing training materials and methods and reducing training task loads via new M&S tools.

Another important issue is the potential created by these innovations to improve student progress through the training cycle and their level of pilot ability on graduation from the program. Our analysis leads us to believe that these innovations could enable SUPT to move beyond the traditional "lock-step" pattern and produce even higher levels of pilot skill. Rather than basing individual student advancement exclusively upon an average or group-determined pace, students could advance individually as they meet prescribed performance criteria. By this, we are not advocating total self-paced progress, because experience with that method shows some trainees may finish so fast or slow that program management processes cannot be accommodated. Rather, students would progress individually within blocks of group-oriented instruction. When a student finishes a block before others, advanced pilot practice activities can be employed until the rest of the group is ready for the next block. Thus, students with outstanding aptitude would continue striving to reach their full potential instead of simply waiting for the majority to catch up. Thus, the proficiency-advancement method would not only ensure that individual students receive optimal training at the time they need it, but also would help identify and promote the most capable pilots.

This report has described Phase I of AL/HRA's M&S R&D effort. Phase II will apply the same analytical methodology to other AETC flying training programs. Phase II will target "schoolhouse" applications within selected CCTS. AL/HRA has considerable experience with such units and believes the methodology used for Phase I can be applied effectively for Phase II. In addition, we believe that many of the same M&S technologies identified for SUPT may also benefit CCTS.

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APPENDIX A

AETC QUESTIONNAIRE MATERIALS

AIR FORCE MODERNIZATION PLAN
AETC Flying Training
Mission Area Plan (MAP)

Date: ____________________ Unit: ______________________

CURRENT PILOT DATA:

Rank:_________ Rating:__________ Total Flight Hours: __________

HISTORY (Prior Aircraft)

Aircraft	No. Hours/Ratings	Command/Organization

1. What qualification level were you prior to this assignment?

   a. Mission/Package Commander
   b. Aircraft Commander
   c. First Pilot
   d. Flight Lead
   e. Evaluator Pilot (Stan/Eval)
   f. IP
   g. Other ______________________

2. Where was UPT instructor on your duty preference list?

   a. First
   b. Near the top
   c. Near the bottom
   d. UPT Instructor was not on my list of duty priority choices

3. How long have you been a UPT IP?

Arrival Date ____________________ Today's Date ____________________

4. Do you enjoy being an IP?

   YES/NO
   Why?

5. From what major category of platform do you believe the most effective instructor pilots come?

a. Fighter
b. Bomber
c. Tanker/Transport
d. Other
e. It doesn't matter

Why?

6. Is it possible to predict which students will have difficulties?

YES/NO
If YES, How?

7. Is it possible to predict where the problems will occur?

YES/NO
If YES, How?

8. What can students do that might remove or reduce problems that are typically encountered?

9. Where do you believe the major training systems/resources "choke point" exists in the training pipeline?

Why?

10. Where do you believe the major student/learning training "choke point" exists that is a student problem area?

11. What method, medium, or technique do you use to get/keep the student on track and moving toward graduation?

12. If you believe it is a thinking problem for the student (thinking in an aircraft that operates above 360 kts for instance), what specifically do you think is difficult for him/her to understand?

13. If you believe that it is a conceptual problem, is it that the student has trouble understanding three-dimensional spatial concepts involved in any block (instruments, contact, formation, other, etc.)?

YES/NO
If YES, What?

Why?

14. If you believe that it is a procedural task (intercepting the ILS, landing pattern procedures, etc.) that a student has trouble, what parts or steps are most difficult?

Why?

15. Are there deficiencies in the training, resources, or equipment which contribute to this particular problem?

YES/NO
If YES, What?

Why?

16. Instructors have observed that some students just seem to have to make certain errors first--that is, to stumble through a task once or twice before they learn enough "about" the task to begin to learn the task and perform correctly.

a. Do you agree? YES/NO

b. If so, are there any examples from the syllabus you feel fit this description?

c. Why do you think this happens?

17. Students typically screw up learning some tasks. What three are done the most?

a.

b.

c.

18. What method, medium, or technique do you use in those areas identified to get/keep the student on track and moving toward graduation?

19. What areas of air training need more emphasis (e.g., instrument, contact, formation)?

20. What areas of academic training need more emphasis (e.g., aero, meteorology, instruments, etc.)?

21. Are there any areas of this simulator portion of the program that need more emphasis (e.g., EPs or instruments), or could use enhancements/upgrades?

YES/NO
If YES, What?

22. From your own experience, have you ever thought that some students seem to learn better from certain types of training media, methods, or devices?

YES/NO
If YES, What type?

Why?

23. How many hours do you feel a student should study each day outside the scheduled training hours?

24. Should voluntary simulator/training aid use after duty hours count against crew rest?

YES/NO

25. Could you identify any problems with IP (PIT) training?

YES/NO
If YES, What?

26. What would you do to change Air Force UPT?

Why?

FOR SCHEDULE WRITERS/PLANNERS

1. What kind of training (OJT, etc.) program do schedule writers have?

2. Do some planners seem to write a more efficient schedule than others?

   YES/NO
   If YES, Why?

3. Considering the normal obstacles encountered in the training process, what is the greatest difficulty?

   a. Weather
   b. Aircraft availability
   c. Instructor availability
   d. Student availability/readiness
   e. Other

4. Do you use any type of electronic systems/computerized scheduling programs to assist you in your scheduling process?

   YES/NO
   If Yes, What?

5. Do you believe that developing a NEW, or user friendly computerized scheduling system would be of any benefit to your tasking?

   YES/NO
   If No, Why not?

6. What scheduling functions give you problems?

7. What training information (e.g., student does DNIF, academic completions for the day, sortie completions) do you need to accomplish your job?

8. Are your needs for information being met well?

YES/NO

9. What impact does alternating early week/late week have on your scheduling of students?

a. None
b. Very little
c. Some
d. Much
e. Very much

10. How drastically does "standing down" a student impact training continuity and the scheduling workload?

a. None
b. Very little
c. Some
d. Much
e. Very much

11. If you use electronic scheduling devices, how does the computer handle "standing down" a student?

APPENDIX B

BENEFIT-COST ANALYSIS

THE DEVELOPMENT OF BENEFIT-COST ESTIMATION METHODS FOR TECHNOLOGICAL IMPROVEMENTS IN UNDERGRADUATE PILOT TRAINING

William C. Moor and Barbara G. Nelson

Introduction

The Aircrew Training Research Division of the Armstrong Laboratory (AL/HRA) is actively engaged in research on the development of an enhanced and improved undergraduate pilot training program. The U.S. Air Force (USAF) desires, insofar as possible, that proposed capital expenditures be based on a benefit-cost comparison among all competing alternatives (Dept of the Air Force, 1988). The purpose of this project is to develop a method of applying the technique of benefit-cost analysis to the evaluation of proposed technology-based systems which are intended to provide improved undergraduate pilot training (UPT) for the USAF. A difficulty exists because even though benefit-cost analysis is a widely documented and well understood technique, the mechanisms for establishing and measuring benefits are not universally defined and must be developed for each specific application.

There is a general consensus in the economic literature that a benefit-cost analysis is appropriate for any government program that involves an impact on a segment of the population (Maciariello, 1975; Pearce, 1983; Steiner, 1980). Enhancing the UPT for the USAF meets this criterion. Therefore, alternative methods of providing such training should be amenable to this analysis.

There is also a general agreement (Maciariello, 1975; Pearce, 1983; Oxenfeldt, 1979) that a benefit-cost analysis includes:

1. A specification of the goal(s) or objective(s) which the programs are intended to achieve.

2. An enumeration and definition of the alternatives which are proposed as mechanisms for reaching these goal(s).

3. A definition of the means of evaluating the benefits derivable from each alternative. This includes the definition of the means of converting benefits into quantitative (dollar measurable) terms.

4. A definition of the means of evaluating the costs required to implement each alternative.

5. A completed analysis showing the computed incremental benefit/cost (B/C) ratios for all alternatives being evaluated. Alternatively, incremental net benefits may be used as a basis for evaluating alternatives).

Application: Goal

The specific goal for the alternatives to be evaluated in this review is "to enhance the training of pilots through an improved undergraduate training program." Therefore, the benefit-cost analysis should provide a means of comparing any alternative which has the capability of achieving this goal.

Application: Alternatives

The Aircrew Training Research Division of the Armstrong Laboratory has developed a Problem Area/Solution Matrix in which the areas of highest utility have been estimated. Table 1 presents this matrix and indicates specific areas for which preliminary benefits estimates have been developed. With the rapid technological improvements made in microcomputers and vision systems, it is possible to construct relatively inexpensive, high performance simulation systems and databases that could be used to meet many of the training enhancement needs of the Air Force. The difficulty would be to select the system, or systems, which would provide the greatest training benefit at a cost within budgetary limitations. Providing a benefit model that would be applicable to the possible solution systems and technologies, either currently available or proposed, would help to alleviate this difficulty. The focus of this evaluation would be on an Air Force-wide implementation of simulation systems rather than the design or use of any single system.

Application: Evaluating benefits

A Benefits Estimation model has been developed which demonstrates a complete method of benefit-cost analysis of the enhanced training alternatives and provides a means of computing the values for this analysis in a manner that is very straightforward (utilizing LOTUS 1-2-3 spreadsheets). The model includes the capacity to evaluate and compare the training environments as an explicit element. The following assumptions have been made in the development of the benefits estimation model:

1. Simulation-based systems would be implemented as pairs in the UPT squadrons.

2. Although implemented in pairs, the benefits estimation is based on a single system.

3. A level of skill can be defined and measured for each area and can be scaled to a range of 0.0 to 1.0.

4. A minimum number of aircraft hours must be spent training each skill (to confirm/familiarize/verify that the skill exists).

5. No reduction in total scheduled flight hours per trainee will occur. Any "loss" of light hours in training on the simulator system will be flown in training other skills.

Table 1. Problem Area/Solution Matrix

Developed at HRA for estimated areas of application, used for development of benefits estimation.

This matrix is restated because the row and column numbers are used to identify benefits estimation tables.

= Preliminary benefits estimator prepared for this cell.

		Column Identification: Possible Solution Systems/Technology									
		Large Classroom Monitor	3-D Projections	Video Media	CAI Improvements	Instructional Simulation	Electronic Kneepad	Aeronautical Training Recorder	Simulator Networking	DART Visual	T-37, T-38, T-1 Multi-Task Trainer
Row Number	Row Identification: Problem Areas	Column Number: 1	2	3	4	5	6	7	8	9	10
1	Overhead Traffic Pattern	3	3	3	2	3	3	3	2	3	2
2	Position Interpolation	2	1	1	2	3	1	1	0	0	2
3	Fix-to-Fix Navigation	2	1	1	2	3	1	2	0	0	2
4	Formation Flight	2	2	3	1	3	3	3	3	3	3
5	Low-Altitude Flying	2	0	2	2	2	3	3	2	3	3
6	Instructor Pilot Continuation Training	2	2	2	3	2	3	2	2	2	2

Entries in the matrix refer to the estimated applicability of the possible solution to the problem area.

- 3 = Highly applicable
- 2 = Applicable
- 1 = Marginally applicable
- 0 = Not applicable

6. Any scheduled flight hours "lost" (due to inclement weather, maintenance, etc.) would be spent using the simulator system.

7. A level of the retention of skill can be defined and measured for each area and can be scaled to a renge of 0.0 to 1.0.

The Benefits Estimation model uses two approaches in determining the estimated benefits. Estimated benefits could result from Simulator Networking which would include the possible solutions or technologies of Instructional Simulation, Simulator Networking, DART Visual and the T-37, T-38, T-1 Multi-Task Trainer. The general model for these areas of benefits estimation is presented in Table 2. Estimated benefits could also result from Non-Simulator Based Training Systems which would include the possible solutions or technologies of Large Classroom Monitor, 3-D Projections, Video Media, CAI Improvements, Electronic Kneepad and the Aeronautical Training Recorder. The general model for these areas of benefits estimation is presented in Table 3. Table 4 presents the computation equations used in each of these approaches. In use, estimates of the variables used in these equations are established by the user with the benefits estimations being computed automatically. As indicated in Table 1, very rough estimates of benefits derivable for a sub-set of the possible areas of technology application have been developed based on input from HRA experts. The tables showing these estimates are presented in Appendix A to this report.

Application: Costs Estimation

The cost model was developed, as closely as possible, according to the rules and procedures currently in use by the Air Force. The development of the model is more a case of selecting than defining or deriving the key cost elements which must be used in evaluating organizational alternatives. Table 5 presents the general cost model using these cost elements. The information was extracted from Air Force Regulation 173-15, Economic Analysis and Program Evaluation for Resource Management.

The data for the variables in the cost model came from interviews with AL/HRA personnel who were very familiar with the commercial simulation device market (M. Thomas, personal communication, June 27, 1990), Air Force cost estimating manuals (Directorate of Engineering and Services, 1988; Grant and Thornley, 1987; Woolsey, 1987), and civil service and military pay rates (Air Force, 1990). The following assumptions have been made in developing the cost estimate model:

1. Each organizational alternative will be manned by military and civil service personnel.

2. All buildings and equipment will be acquired new.

3. All computer based equipment will have a definable but relatively short economic life.

Table 2. Benefits Estimation
Use of simulation systems to enhance training in generalized activities
NUMBERS IN THIS SHEET DO NOT APPLY TO ANY SPECIFIC SIMULATOR SYSTEM

Estimated Total Benefit of 1 simulation system	$1,704,067

Variables, Constants and Intermediate Computed Results Used for Benefit Estimation
Variables, Constants and Intermediate Computed Results
Used for Benefit Estimation

NAME OF THE ELEMENT	VALUE ASSIGNED	RANGE NAME
Cost of the aircraft ($/aircraft)	$8,000,000	AIRC$
Marginal cost of flying the aircraft ($/hr)	$1,500	AIRC$_HR
Probability of loss of aircraft (/hr)	0.0000002	AIRCPROB
Cost of instructor pilot time ($/hr)	$48	IP$_HR
"Cost" of the IP ($)	$10,000,000	IP$
Cost of trainee time ($/hr)	$20	TRN$_HR
"Cost" of the trainee ($/trainee)	$6,000,000	TRNEE$
Time spent in THIS training (hrs/trainee)	40	FORM_HR
Transfer Ratio	0.3000	TRANRAT
Operation days/week/simulator (dys/wk)	5	DYS_WK
Operation hours/day/simulator (hrs/dy)	16	HRS_DY
Operation weeks/year/simulator (wks/yr)	50	WKS_YR
Percent uptime	0.9000	UP_PER
Percent time the simulator is used for THIS training	1.0000	FORM_PER
Total hours the simulator is used for THIS training (hrs)	3600	SIMHRS
Hours of aircraft time "lost" per year (hrs/yr)	100	AIRC_LST
Syllabus hours for THIS training (hrs/trainee)	40	SYLBHRS
Proportion of time the instructor flies in same aircraft as trainee	0.8000	IP_PROP
Proportion of time per sortie spent in THIS TYPE OF training	0.6000	SRT_PROP
Proportion of time the IP is able to spend evaluating the trainee during flight	0.6000	EVAL_PR

Table 2. Cont'd
Benefits Estimation Results Using Equation Estimators

IDENTIFICATION OF EQUATION AND EQUATION	ESTIMATED BENEFITS	RANGE NAME
Benefit due to aircraft not being destroyed +SIMHRS*TRANRAT*AIRC_*AIRCPROB	$1,728	AIRC$BEN
Benefit due to trainee not being killed +SIMHRS*TRANRAT*TRNEE_*AIRCPROB	$1,296	TRN$BEN
Benefit due to IP not being killed +SIMHRS*TRANRAT*IP_*IP_PROP*AIRCPROB	$1,728	IP$BEN
Savings in aircraft use due to simulation +SIMHRS*TRANRAT*AIRC__HR	$1,620,000	AHRS$BEN
Benefit due to increase in THIS TYPE OF training time +SIMHRS*TRANRAT*SRT_PROP*(IP__HR*IP_PROP+TRN__HR)	$37,843	TRN$_EFF
Benefit due to increased efficiency of use of IP time +SIMHRS*TRANRAT*IP__HR*IP_PROP*FORM_PER	$41,472	IP$_EFF

Table 3. Training Systems Benefits Estimation Worksheet
Use of new training systems to enhance training in generalized activities
VALUES IN THIS SHEET DO NOT REFER TO ANY SPECIFIC TECHNOLOGY

Estimated Total Benefit of a new training system	$441,826

Variables, Constants and Intermediate Computed Results Used for Benefit Estimation

NAME OF THE ELEMENT	VALUE ASSIGNED	RANGE NAME
Level of skill achieved under the current syllabus and conditions	0.3000	L_C
Number of hours in the current syllabus for training in this skill	25.00	H_C
Proportion of instructor hours/student hours - current syllabus	0.5000	P_C
Cost of instructor pilot time ($/hr)	$48	I_$
Cost of trainee time ($/hr)	$20	S_$
Level of skill achievable with the proposed training system	0.5000	L_N
Number of hours expected when using the proposed system	20.00	H_N
Proportion of instructor hours/student hours - proposed system	0.3333	P_N
Number of students per year undergoing training	200	N_S
Number of instructor hours current spent training this skill	2500	I_HRS
Retention of skill under new technology	0.15	RS_NEW
Retention of skill under old technology	0.08	RS_OLD

Benefits Estimation Results Using Equation Estimators

IDENTIFICATION OF EQUATION AND EQUATION		ESTIMATED BENEFITS	RANGE NAME
Benefit due to training efficiency based on student costs	86666.66667	$86,667	STUD_EFF
Benefit due to training efficiency based on instructor costs	312031.2031	$312,031	INS_EFF
Benefit due to increased retention of skill	43128.37534	$43,128	RSKILL

Table 4. Computation Equations Used to Estimated Benefits Resulting from Simulator Networking

1. Benefit due to aircraft not being destroyed.
(Total hours the system is used)X(Transfer Ration) X (Cost of the aircraft)X(Probability of the aircraft being lost)

2. Benefit due to the trainee not being killed.
(Total hours the system is used)X(Transfer Ratio) X (Cost of the trainee)X(Probability of the aircraft being lost)

3. Benefit due to the instructor pilot not being killed.
(Total hours the system is used) X (Transfer Ratio) X (Cost of the instructor pilot) X (Proportion of time IP flies with the trainee) X (Probability of the aircraft being lost)

4. Benefit due to increase in training time through use of the simulator.
(Total hours the system is used)X(Transfer Ratio) X (Proportion of sortie time spent training the skill) X (Proportion of time the IP flies with the trainee)X(Hourly cost of the IP) + (Hourly cost of the trainee)

5. Savings in aircraft use due to simulation.
(Total hours the system is used) X (Transfer Ratio) X (Marginal Cost of Flying the Aircraft)

6. Benefit due to increased efficiency of use of IP time.
(Total hours the system is used) X (Transfer Ratio) X (Hourly cost of the IP) X (Proportion of time the IP flies with the trainee)X(Percent of time the network system is used for training the skill)

Computation Equations Used to Estimate Benefits Resulting from Non-Simulator Based Training Systems

1. Benefit due to training efficiency based on student costs.
((Number of hours in current syllabus for this skill) X ((Level of skill achievable with proposed system)/(Level of skill achievable with current training)) - (Number of hours expected when using proposed system)) X (Number of students being trained) X (Hourly cost of trainee time)

2. Benefit due to training efficiency based on Instructor Pilot costs.
((Number of hours in current syllabus for this skill) X ((Level of skill achievable with proposed system) / (Level of skill achievable with current training)) - (Number of hours expected when using proposed system)) X (Number of students being trained) X (Hourly cost of IP time) X ((Proportion of instructor hours to student hours under current syllabus) / (Proportion of instructor hours to student hours using the proposed system))

3. Benefit due to increase retention of skill resulting from the use of new learning technology.
(Retention of skill with the new technology/Retention of skill with existing technology) X (Number of hours of training required using existing technology/ Number of hours of training required using the new technology) X ((Proportion of instructor hours to student hours under current syllabus) / (Proportion of instructor hours to student hours using the proposed system)) X (Hourly cost of IP time + Hourly cost of student time) X (Total number of students per year)

Table 5. Specific Technology or System for Which Costs are Being Estimated

THE VALUES ENTERED IN THIS TABLE DO NOT REFER TO ANY SPECIFIC TECHNOLOGY OR SYSTEM

Information extracted from AF Regulation 173-15, March 1988, "Economic Analysis and Program Evaluation for Resource Management, Cost Analysis", Department of the Air Force, Headquarters USAF, Washington D.C.
Standard Terms and Areas Identified as those to classify or describe categories of cost.

	Estimated Costs	Notes and comments
1. Life-cycle Costs (LCC) - Total Annual Costs - acquisition to disposal of a particular alternative. Discounted values for costs.	$1,987,139	
2. Non-recurring Costs - One time costs, unique to a specific phase of a project.		
a. Research and development costs	$1,000,000	
b. Investment costs - costs associated with the acquisition of equipment, real protery start-up costs.		
1) Costs of acquisition, rehabilitation or modification of land, buildings, machinery, equipment, and any long term computer software costs.	$500,000	
2a) Costs of acquisition, rehabilitation, or modifications of other capital items such as furnishings and fittings required for the project.	$100,000	
2b) Cost of acquisition, rehabilitation, or modification of high technology equipment such as computers which has a very such economic life.	$2,500,000	COMP_CST
3) The cost of plant rearrangement and tooling associated with the project.	$100,000	
4) The costs of freight and insurance required by the project.	$25,000	
5) The value of nonrecurring services received from others.	$35,000	
6) The costs of leaseholds required for the project.	$20,000	
7) Working capital and current assets on hand or on order.	$50,000	
8) Imputed value of existing Air Force assets to be employed on the project.	$200,000	
TOTAL VALUE OF ALL NON-RECURRING COSTS	$6,517,139	CAP_CST

Table 5. Contd

	Estimated Costs	Notes and comments
3. Recurring Costs - Annual costs required to operate and maintain a program or project.		
a. Personnel Costs - All direct and indirect costs related to both civilian and military personnel.		
1) Gross pay	$100,000	
2) Retirement and disability, health, and life insurance.	$25,000	
3) Sick leave and annual leave	$10,000	
4) Holiday pay and other	$5,000	
5) Change of station or Duty pay	$10,000	
6) Retirement pay	$10,000	
7) Travel, per diem, moving expenses	$15,000	
8) Training.	$25,000	
b. Supplies and Material		
1) Directly consumed	$100,000	
2) Transportation costs	$10,000	
3) Handling, storage and protection of material	$5,000	
4) Cost of utility services	$45,000	
c. Maintenance and Repair Costs	$150,000	
TOTAL VALUE OF ALL RECURRING COSTS	$510,000	ANN_CST

Sunk costs should not be counted, but may be shown separately for information.
Depreciation should only be used to estimate terminal values.
In general, a discount rate of 10% should be used with a mid-year convention. Certain specific instances may call for a different assumption but generally not viewed as necessary.

DISCOUNT RATE USED IN THIS TABLE 10.00% INT

Economic Life

1. The economic life of a project or asset is the time during which benefits from it may reasonably be expected to accrue to the Air Force.
2. Economic life plus project lead-time determine the time period to be considered when conducting an economic analysis.
3. Economic life of a project or asset is set by the shortest of its physical life, technological life, or mission life.
4. If necessary, a residual value will be determined to be used as a terminal value.
5. Comparing assets with different economic lives.
   a. Use terminal value for the longer lived alternative.
   b. Use common denominator approach (Least Common Multiple (LCM) of lives).

ECONOMIC LIFE USED IN THIS TABLE FOR "NORMAL" LONG-LIVED CAPITAL ITEMS 20 N_LONG

ECONOMIC LIFE USED IN THIS TABLE FOR "SHORT" ECONOMIC LIVES SUCH SUCH AS COMPUTERS 3 N_SHORT

Sensitivity analyses should be performed.

4. All capital equipment and real property will have a definable and relatively long economic life.

5. The discount rate and economic lives are defined by the user and entered into the spreadsheets.

Application: Benefit-Cost ratios

The table developed for presenting the important elements of the benefit-cost analysis is shown in Table 6. This table establishes both the net benefit minus costs and the benefit-cost ratio for the technology being evaluated.

Conclusion

This study developed a preliminary benefits-cost procedure and model for the evaluation of proposed technology based systems which are intended to provide improved Undergraduate Pilot Training (UPT) for the USAF. It created the operational procedures necessary to acquire all data required for estimating benefits and costs. In addition, in a very preliminary way, the study completed an operational test of these procedures demonstrating their feasibility.

Obvious areas requiring future work are apparent. These include improvements and refinements in the methods of:

1. acquiring and using the variables for benefits estimation;

2. validating the benefits computation equations;

3. validating the application areas;

4. justifying and supporting the listed assumptions; and

5. determining the general usability of the operational procedures.

Table 6. Technology Based Enhancements for Undergraduate Pilot Training

Name of Application Area	Sample in Table 2
Name of Technology	Sample in Table 2

Summary of Benefits Estimation

Benefits Estimated for:

Area 1	$1,728
Area 2	$1,296
Area 3	$1,728
Area 4	$1,620,000
Area 5	$37,843
Area 6	$41,472
TOTAL ANNUAL BENEFITS ESTIMATED	$1,704,067

Summary of Costs Estimation

Costs Estimated for:

Capital - Long Life	$4,017,162
Capital - Short Life	$2,500,000
Annual	$510,000
TOTAL ANNUAL EQUIVALENT COSTS ESTIMATED	$1,987,141
NET ANNUAL BENEFITS - COSTS	($283,074)
BENEFIT-COST RATIO BASED ON THE ABOVE	0.85755

Constants used in the above estimation

Discount Rate	10.00%
Long Life	20
Short Life	3

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APPENDIX A to BENEFIT COST ANALYSIS

ESTIMATED BENEFITS COMPUTATION FOR A SELECTED SET OF TECHNOLOGY APPLICATION AREAS

Table A-1. Benefits Estimation
Use of SIMULATOR NETWORKING to enhance training in OVERHEAD TRAFFIC PATTERN (OTP)

Estimated Total Benefit of 1 simulator networking system (cockpit) **$1,693,829**

Variables, Constants and Intermediate Computed Results Used for Benefit Estimation

NAME OF THE ELEMENT	VALUE ASSIGNED	RANGE NAME
Cost of the aircraft ($/aircraft)	$8,000,000	AIRC$
Marginal cost of flying the aircraft ($/hr)	$1,500	AIRC$_HR
Probability of loss of aircraft (/hr)	0.0000003	AIRCPROB
Cost of instructor pilot time ($/hr)	$48	IP$_HR
"Cost" of the IP ($)	$10,000,000	IP$
Cost of trainee time ($/hr)	$20	TRN$_HR
"Cost" of the trainee ($/trainee)	$6,000,000	TRNEE$
Time spent in OTP training (hrs/trainee)	35	OTP_HR
Transfer Ratio	0.3000	TRANRAT
Operation days/week/simulator (dys/wk)	5	DYS_WK
Operation hours/day/simulator (hrs/dy)	16	HRS_DY
Operation weeks/year/simulator (wks/yr)	50	WKS_YR
Percent uptime	0.9000	UP_PER
Percent time the simulator is used for OTP training	1.0000	OTP_PER
Total hours the simulator is used for OTP training (hrs)	3600	SIMHRS
Hours of aircraft time "lost" per year (hrs/yr)	100	AIRC_LST
Syllabus hours for OTP training (hrs/trainee)	35	SYLBHRS
Proportion of time the instructor flys in same aircraft as trainee	0.8000	IP_PROP
Proportion of time per sortie spent in OTP training	0.4000	SRT_PROP
Proportion of time the IP is able to spend evaluating the trainee during flight	0.6000	EVAL_PR

Benefits Estimation Results Using Equation Estimators

IDENTIFICATION OF EQUATION AND EQUATION		ESTIMATED BENEFITS	RANGE NAME
Benefit due to aircraft not being destroyed	2592	$2,592	AIRC$BEN
Benefit due to trainee not being killed	1944	$1,944	TRN$BEN
Benefit due to IP not being killed	2592	$2,592	IP$BEN
Savings in aircraft use due to simulation	1620000	$1,620,000	AHRS$BEN
Benefit due to increase in OTP training time	25228.8	$25,229	TRN$_EFF
Benefit due to increased efficiency of use of IP time	41472	$41,472	IP$_EFF

Table A-2. Training Systems Benefits Estimation Worksheet

Use of VIDEO MEDIA to enhance training in FORMATION FLIGHT

Estimated Total Benefit of video media $130,819

Variables, Constants and Intermediate Computed Results Used for Benefit Estimation

NAME OF THE ELEMENT	VALUE ASSIGNED	RANGE NAME
Level of skill achieved under the current syllabus and conditions	0.3000	L_C
Number of hours in the current syllabus for training in this skill	25.00	H_C
Proportion of instructor hours/student hours - current syllabus	0.5000	P_C
Cost of instructor pilot time ($/hr)	$48	I_$
Cost of trainee time ($/hr)	$20	S_$
Level of skill achievable with the proposed training system	0.4000	L_N
Number of hours expected when using the proposed system	25.00	H_N
Proportion of instructor hours/student hours - proposed system	0.5000	P_N
Number of students per year undergoing training	200	N_S
Number of instructor hours current spent training this skill	2500	I_HRS
Retention of skill under new technology	0.18	RS_NEW
Retention of skill under existing technology	0.1400	RS_OLD

Benefits Estimation Results Using Equation Estimators

IDENTIFICATION OF EQUATION AND EQUATION		ESTIMATED BENEFITS	RANGE NAME
Benefit due to training efficiency based on student costs	33333.33333	$33,333	STUD_EFF
Benefit due to training efficiency based on instructor costs	80000	$80,000	INS_EFF
Benefit due to increased retention of skill	17485.71429	$17,486	RSKILL

Table A-3. Training Systems Benefits Estimation Worksheet
Use of ELECTRONIC KNEEPAD to enhance training in FORMATION FLIGHT

Estimated Total Benefit of electronic kneepad	$107,846

Variables, Constants and Intermediate Computed Results Used for Benefit Estimation

NAME OF THE ELEMENT	VALUE ASSIGNED	RANGE NAME
Level of skill achieved under the current syllabus and conditions	0.3000	L_C
Number of hours in the current syllabus for training in this skill	25.00	H_C
Proportion of instructor hours/student hours - current syllabus	0.5000	P_C
Cost of instructor pilot time ($/hr)	$48	I_$
Cost of trainee time ($/hr)	$20	S_$
Level of skill achievable with the proposed training system	0.3800	L_N
Number of hours expected when using the proposed system	25.00	H_N
Proportion of instructor hours/student hours - proposed system	0.5000	P_N
Number of students per year undergoing training	200	N_S
Number of instructor hours currently spent training this skill	1500	I_HRS
Retention of skill under new technology	0.24	RS_NEW
Retention of skill under existing technology	0.1900	RS_OLD

Benefits Estimation Results Using Equation Estimators

IDENTIFICATION OF EQUATION AND EQUATION		ESTIMATED BENEFITS	RANGE NAME
Benefit due to training efficiency based on student costs	26666.66667	$26,667	STUD_EFF
Benefit due to training efficiency based on instructor costs	64000	$64,000	INS_EFF
Benefit due to increased retention of skill	17178.94737	$17,179	RSKILL

Table A-4. Training Systems Benefits Estimation Worksheet
Use of AERONAUTICAL TRAINING RECORDER to enhance training in FORMATION FLIGHT

Estimated Total Benefit of the Aeronautical Training Recorder	$117,980

Variables, Constants and Intermediate Computed Results Used for Benefit Estimation

NAME OF THE ELEMENT	VALUE ASSIGNED	RANGE NAME
Level of skill achieved under the current syllabus and conditions	0.3000	L_C
Number of hours in the current syllabus for training in this skill	25.00	H_C
Proportion of instructor hours/student hours - current syllabus	0.5000	P_C
Cost of instructor pilot time ($/hr)	$48	I_$
Cost of trainee time ($/hr)	$20	S_$
Level of skill achievable with the proposed training system	0.3500	L_N
Number of hours expected when using the proposed system	23.00	H_N
Proportion of instructor hours/student hours - proposed system	0.5000	P_N
Number of students per year undergoing training	200	N_S
Number of instructor hours currently spent training this skill	0	I_HRS
Retention of skill under new technology	0.60	RS_NEW
Retention of skill under existing technology	0.26	RS_OLD

Benefits Estimation Results Using Equation Estimators

IDENTIFICATION OF EQUATION AND EQUATION		ESTIMATED BENEFITS	RANGE NAME
Benefit due to training efficiency based on student costs	24666.66667	$24,667	STUD_EFF
Benefit due to training efficiency based on instructor costs	59200	$59,200	INS_EFF
Benefit due to increased retention of skill	34113.71237	$34,114	RSKILL

Table A-5. Benefits Estimation
Use of SIMULATOR NETWORKING to enhance training in FORMATION FLYING

Estimated Total Benefit of 1 simulator networking system (cockpit) | $1,704,067 |

Variables, Constants and Intermediate Computed Results Used for Benefit Estimation

NAME OF THE ELEMENT	VALUE ASSIGNED	RANGE NAME
Cost of the aircraft ($/aircraft)	$8,000,000	AIRC$
Marginal cost of flying the aircraft ($/hr)	$1,500	AIRC$_HR
Probability of loss of aircraft (/hr)	0.0000002	AIRCPROB
Cost of instructor pilot time ($/hr)	$48	IP$_HR
"Cost" of the IP ($)	$10,000,000	IP$
Cost of trainee time ($/hr)	$20	TRN$_HR
"Cost" of the trainee ($/trainee)	$6,000,000	TRNEE$
Time spent in formation training (hrs/trainee)	40	FORM_HR
Transfer Ratio	0.3000	TRANRAT
Operation days/week/simulator (dys/wk)	5	DYS_WK
Operation hours/day/simulator (hrs/dy)	16	HRS_DY
Operation weeks/year/simulator (wks/yr)	50	WKS_YR
Percent uptime	0.9000	UP_PER
Percent time the simulator is used for formation flying training	1.0000	FORM_PER
Total hours the simulator is used for formation training (hrs)	3600	SIMHRS
Hours of aircraft time "lost" per year (hrs/yr)	100	AIRC_LST
Syllabus hours for formation training (hrs/trainee)	40	SYLBHRS
Proportion of time the instructor flys in same aircraft as trainee	0.8000	IP_PROP
Proportion of time per sortie spent in formation flying training	0.6000	SRT_PROP
Proportion of time the IP is able to spend evaluating the trainee during flight	0.6000	EVAL_PR

Benefits Estimation Results Using Equation Estimators

IDENTIFICATION OF EQUATION AND EQUATION		ESTIMATED BENEFITS	RANGE NAME
Benefit due to aircraft not being destroyed	1728	$1,728	AIRC$BEN
Benefit due to trainee not being killed	1296	$1,296	TRN$BEN
Benefit due to IP not being killed 1728		$1,728	IP$BEN
Savings in aircraft use due to simulation	1620000	$1,620,000	AHRS$BEN
Benefit due to increase in formation training time	37843.2	$37,843	TRN$_EFF
Benefit due to increased efficiency of use of IP time	41472	$41,472	IP$_EFF

Table A-6. Benefits Estimation
Use of SIMULATOR NETWORKING to enhance training in LOW-ALTITUDE FLYING (LAF)

Estimated Total Benefit of 1 simulator networking system (cockpit) $1,683,979

Variables, Constants and Intermediate Computed Results Used for Benefit Estimation

NAME OF THE ELEMENT	VALUE ASSIGNED	RANGE NAME
Cost of the aircraft ($/aircraft)	$8,000,000	AIRC$
Marginal cost of flying the aircraft ($/hr)	$1,500	AIRC$_HR
Probability of loss of aircraft (/hr)	0.0000002	AIRCPROB
Cost of instructor pilot time ($/hr)	$48	IP$_HR
"Cost" of the IP ($)	$10,000,000	IP$
Cost of trainee time ($/hr)	$20	TRN$_HR
"Cost" of the trainee ($/trainee)	$6,000,000	TRNEE$
Time spent in LAF training (hrs/trainee)	30	LAF_HR
Transfer Ratio	0.3000	TRANRAT
Operation days/week/simulator (dys/wk)	5	DYS_WK
Operation hours/day/simulator (hrs/dy)	16	HRS_DY
Operation weeks/year/simulator (wks/yr)	50	WKS_YR
Percent uptime	0.9000	UP_PER
Percent time the simulator is used for LAF training	1.0000	LAF_PER
Total hours the simulator is used for LAF training (hrs)	3600	SIMHRS
Hours of aircraft time "lost" per year (hrs/yr)	100	AIRC_LST
Syllabus hours for LAF training (hrs/trainee)	37	SYLBHRS
Proportion of time the instructor flys in same aircraft as trainee	0.7000	IP_PROP
Proportion of time per sortie spent in LAF training	0.4000	SRT_PROP
Proportion of time the IP is able to spend evaluating the trainee during flight	0.6000	EVAL_PR

Benefits Estimation Results Using Equation Estimators

IDENTIFICATION OF EQUATION AND EQUATION		ESTIMATED BENEFITS	RANGE NAME
Benefit due to aircraft not being destroyed	1728	$1,728	AIRC$BEN
Benefit due to trainee not being killed	1296	$1,296	TRN$BEN
Benefit due to IP not being killed	1512	$1,512	IP$BEN
Savings in aircraft use due to simulation	1620000	$1,620,000	AHRS$BEN
Benefit due to increase in LAF training time	23155.2	$23,155	TRN$_EFF
Benefit due to increased efficiency of use of IP time	36288	$36,288	IP$_EFF

Table A-7. Benefits Estimation
Use of the SIMULATOR NETWORKING SYSTEM to enhance continuation training for the INSTRUCTOR PILOT (IP)

Estimated Total Benefit of 1 simulator networking system (cockpit) | $1,132,070

Variables, Constants and Intermediate Computed Results Used for Benefit Estimation

NAME OF THE ELEMENT	VALUE ASSIGNED	RANGE NAME
Cost of the aircraft ($/aircraft)	$8,000,000	AIRC$
Marginal cost of flying the aircraft ($/hr)	$1,500	AIRC$_HR
Probability of loss of aircraft (/hr)	0.0000002	AIRCPROB
Cost of instructor pilot time ($/hr)	$48	IP$_HR
"Cost" of the IP ($)	$10,000,000	IP$
Cost of trainee time ($/hr)	$0	TRN$_HR
"Cost" of the trainee ($/trainee)	$0	TRNEE$
Time spent in IP training (hrs/IP)	20	IP_HR
Transfer Ratio	0.2000	TRANRAT
Operation days/week/simulator (dys/wk)	5	DYS_WK
Operation hours/day/simulator (hrs/dy)	16	HRS_DY
Operation weeks/year/simulator (wks/yr)	50	WKS_YR
Percent uptime	0.9000	UP_PER
Percent time the simulator is used for IP training	1.0000	IP_PER
Total hours the simulator is used for IP training (hrs)	3600	SIMHRS
Hours of aircraft time "lost" per year (hrs/yr)	100	AIRC_LST
Syllabus hours for IP training (hrs/IP)	20	SYLBHRS
Proportion of time the instructor flys the aircraft	0.8000	IP_PROP
Proportion of time per sortie spent in IP training	0.8000	SRT_PROP
Proportion of time the IP is able to spend evaluating the trainee during flight	0.0000	EVAL_PR

Benefits Estimation Results Using Equation Estimators

IDENTIFICATION OF EQUATION AND EQUATION		ESTIMATED BENEFITS	RANGE NAME
Benefit due to aircraft not being destroyed	1152	$1,152	AIRC$BEN
Benefit due to trainee not being killed	0	$0	TRN$BEN
Benefit due to IP not being killed	1152	$1,152	IP$BEN
Savings in aircraft use due to simulation	1080000	$1,080,000	AHRS$BEN
Benefit due to increase in IP training time	22118.4	$22,118	TRN$_EFF
Benefit due to increased efficiency of use of IP time	27648	$27,648	IP$_EFF