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Final Report On The Simulation And Training Device Technology Task Force Study: For The Naval Training Equipment Center, Orlando, Florida

G. Vincent Amico

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UNIVERSITY OF CENTRAL FLORIDA
INSTITUTE
FOR
SIMULATION AND TRAINING



TASK FORCE REPORT
ON
SIMULATION AND TRAINING DEVICE TECHNOLOGY

MAY, 1983

Sponsored by:
Naval Training Equipment Center
Orlando, Florida

University of Central Florida
Institute for Simulation & Training
Orlando, Florida 32816

FINAL REPORT
ON THE
SIMULATION AND TRAINING DEVICE TECHNOLOGY
TASK FORCE STUDY

FOR THE
NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FLORIDA

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FOR THE

INSTITUTE FOR SIMULATION AND TRAINING
UNIVERSITY OF CENTRAL FLORIDA
ORLANDO, FLORIDA

MAY, 1983

SIMULATION AND TRAINING DEVICE TECHNOLOGY

TASK FORCE STUDY

TABLE OF CONTENTS

	<u>Page</u>
1.0 Introduction	1
2.0 Background	1
3.0 Project Approach and Results Summary	2
3.1 Technology Forecasting	3
3.2 S & TD Technology Assessment and Needs Analysis	5
3.3 Research Identification	5
4.0 Task Force Personnel	8
5.0 General Recommendations	9
6.0 Subtask Reports	11
I. Advanced Simulation	11
II. Human Factors	38
III. Computation Systems	58
IV. Training Value	68
V. Maintenance Training	104

SIMULATION AND TRAINING DEVICE TECHNOLOGY

1.0 Introduction

In response to the Naval Training Equipment Center's RFQ Number N61339-82-Q-0018, the University of Central Florida's Institute for Simulation and Training conducted a research project concerned with the assessment and forecast of the simulation and training device (S & TD) technology pertinent to the Center's current and future needs. This report summarizes the results of that project.

2.0 Background

The NTEC Research Department is currently conducting more than fifty projects in exploratory, advanced and engineering development of simulation and training device (S & TD) technology. In recent years, several factors have combined to make planning and execution of those projects progressively more complex: a) The cross-disciplinary nature of S & TD work requires an unusually broad spectrum of engineering and behavioral science skills; b) because capabilities in simulation-related hardware/software are evolving rapidly, careful attention to technology trends and forecasts is required to avoid obsolescence of products before project completion; c) a lack of focused funding for basic research in simulation technology and chronically limited exploratory development budgets create a heavy dependence by S & TD on industry and university research efforts to provide the general technology base in which S & TD developments can be anchored.

The interaction of the above factors makes it necessary to continually evaluate ongoing development programs within a dual context. First, are anticipated products relevant to major training issues in the time frame of five to ten years in the future? Second, are programs making appropriate use of knowledge and engineering capability available or expected in that time frame? These questions require an in-depth comparison of training needs and issues to

the projected technology base of the 1990's, identification of technology gaps expected under continuation of current trends, and an identification of basic research required to close or reduce expected gaps. The purpose of this project was to provide such an analysis for use in long-term S & TD planning.

3.0 Project Approach and Results Summary

Work on this project was initiated in June, 1982 with several orientation meetings involving project task force members and representatives from the Naval Training Equipment Center in Orlando, Florida. During these orientation sessions a variety of approaches to the problem of S & TD technology assessment and forecasting of needs were reviewed relative to the feasibility and potential effectiveness of these approaches in identifying potential technologies appropriate to Naval training device needs. After reviewing several structured approaches, the decision was made to relate the primary thrusts of the technology assessment activities to the three functional laboratory organizations within the NTEC Research Department. In addition, the Task Force elected to include technology assessments in the areas of "Training Value" and "Maintenance Training" since these areas were deemed to be of particular importance to future Naval S & TD technology development.

Based on those decisions, the project was divided into five subtask areas as follows:

<u>Subtask</u>	<u>Technology Area</u>
I	Advanced Simulation
II	Human Factors
III	Computation Systems
IV	Training Values
V	Maintenance Training

Individual members of the task force were then assigned to these subtasks depending on their interests, education and experience backgrounds.

The research project was carried out in four phases as follows:

<u>Phase</u>	<u>Activity</u>
1	Project subtask orientation and literature search
2	Existing technology assessment
3	New technology identification and needs analysis
4	Research need identification and description

3.1 Technology Forecasting

In order to provide a basis for the technology assessment tasks, the Task Force reviewed a number of literature sources involving technological assessment and forecasting techniques and approaches. Generally speaking, a definition of technological forecasting has not been specifically formulated to date. One reason that a "simple" definition has been elusive is that various researchers see different meanings at different levels of planning. For example;

at the policy planning level --

technology forecasting is the classification of scientific-technological elements determining the future boundary conditions for organizational (corporate) development.

at the strategic planning level --

technological forecasting in the recognition and comparative evaluation of alternative technological options, or in other words, the preparation of the technical decision agenda.

at the operational planning level --

technological forecasting is the probabilistic assessment of future technology transfer.

Essentially, the Task Force activities were oriented to the strategic planning level, i.e., the recognition and comparative evaluation of alternative technological options.

Basically, a technological forecast is the forecast of invention, innovation, or diffusion of some technology. Because technological change is so closely linked to social and economic factors, most organizations do not engage in strictly forecasting technology, but instead try to forecast technology related change.

Forecasting of invention is based mostly on informed opinion, but other approaches, such as the "envelope curve" approach can be used. In this method certain technological parameters are plotted over long periods of time, and the curve is then extrapolated to some future date.

Most forecasting is done on the diffusion of an existing technology rather than predicting invention. There are a number of approaches to forecasting the diffusion of technology. One approach analyzes historical diffusion curves, another tackles diffusion on an industry by industry, or even a product by product basis.

The diffusion of technology takes place in a complex socioeconomic environment, and each forecast can only be as accurate as the assumptions upon which it is based. For example, the change in national productivity can be taken as an index of one kind of technological change. Thus, projections of productivity are in this sense projections of technological change. The diffusion of computer technology into the simulation and training device development process is another example of the technological diffusion process which has probably had a decided impact on both the thru-put and effectiveness of training programs. However, the contribution of that particular technology to the overall improvement of thru-put and effectiveness might be difficult to isolate and measure.

Because of the difficulty in predicting invention or "imagineering" as it is often referred to, most of the work of the Task Force was focused on the

potential for technological change through technological adaptation or diffusion.

3.2 S & TD Technology Assessment and Needs Analysis

During the early stages of the project, each of the subtask groups conducted a background study of S & TD technological development within each of the subtask areas. This was accomplished by means of literature searches and by interviews with personnel at the Naval Training Equipment Center (NTEC) in Orlando, Florida. The background study, although not exhaustive because of time limitations, provided a basis and a point of reference for an assessment of the developmental processes and the state-of-the-art in S & TD technology in each of the subtask areas. Based on those assessments and further discussions with NTEC personnel, the subtask groups attempted to identify new S & TD technological areas which they felt would enhance the Navy's training program cost and effectiveness.

Comprehensive reports on technology assessment and needs analysis for each subtask area are included in Section 6.0 of this report.

3.3 Research Identification

One of the more significant end results of a technology assessment and forecast is the identification of research activities that will be needed to provide the foundation and background information necessary for the development and implementation of new technologies or the diffusion of existing technologies into new application areas. Thus, during the later stages of the study project the task force personnel were asked to identify areas of research which were related to the technological needs within the subtask areas. Although not intended to be exhaustive, the following listings represent areas wherein research activities, either basic or exploratory, would provide a contribution to the S & TD technology development process:

Subtask I - Advanced Simulation

1. Computer Image Generation -- develop ability to create "real time" scenes possessing real world detail with a resolution comparable to the human eye.
2. Artificial Intelligence -- develop training equipment with artificial intelligence systems that are self-modifiable.
3. Human Electrical Signal Measurement -- develop means to unobtrusively measure the vector direction of a students' eyes to a resolution of one degree or better.

Subtask II - Human Factors

1. User Acceptance -- develop prediction model(s) for user acceptance of new training systems and devices.
2. The Learning Process and Concept of Transfer -- develop basic concepts of learning to provide for more effective transfer to operational requirements.
3. Training Model Instructional Support -- develop instructional design models for new areas of technology.
4. Organizational Communication -- develop effective means of communicating S & TD research and operational findings to S & TD professionals.
5. Assessment of Team Training Effectiveness -- develop methods of evaluating student performance and crew performance in a manner which is non-threatening to the student but which provides realistic feedback.
6. Stress Simulation -- determine the conditions and types of training devices most suitable to simulating the psychophysiological activities of stress.

7. Decision Analysis and Risk Assessment -- identify the parameters of decisions and the weighting of risk factors related to alternative courses of action in S & TD activities.

Subtask III -- Computation Systems

1. Animation -- develop low cost microcomputer animation graphics to support training exercises.
2. Data Base Technology -- develop relational data bases for training activities that require large volumes of data to be stored and retrieved at very high access rates.

Subtask IV -- Training Value

1. Training and Cost Effectiveness Models -- develop simplified methods to assist in media selection and cost versus effectiveness trade-offs for devices which support advanced (complex) training.
2. Combat System Team Training -- develop team training approaches which will permit decomposing the tactical team into its individual members and provide the data and voice links to and from other equipment and team members through an intelligent computer system.
3. Training and Cost Effectiveness Models for Combat Team Training -- develop methods and models for team training and cost effectiveness measurement.

Subtask V -- Maintenance Training

1. Electronic Job Aids -- Further investigate hardware design for improved keyboard arrangement and visual display, and software design for hierarchical levels of detail.
2. Diagnostics -- investigate diagnostics for formal training, improved techniques, simplified equipment system design and training by simulation.

3. Maintenance Operations -- investigate improved techniques and robotic applications.
4. Personnel/Equipment Allocation -- investigate queuing, scheduling, and forecasting innovations.
5. Psychological Aspects -- investigate adaptive training programs, adaptive job descriptions, adaptive supervision and career management.

4.0 Task Force Personnel

The research project was carried out by an interdisciplinary task force group whose members were assigned to the subtask areas indicated in Section 3.0 according to their interests, education and experience backgrounds. The University of Central Florida task force members and the technological areas wherein their review efforts were concentrated were as follows:

Subtask I -- Advanced Simulation

Dr. B.W. Patz -- Department of Electrical Engineering
and Communication Sciences

Dr. G.E. Whitehouse -- Department of Industrial Engineering
and Management Systems

Subtask II -- Human Factors

Dr. G.W. Orwig -- Department of Educational Services

Dr. J.J. Turnage -- Department of Psychology

Subtask III -- Computation Systems

Dr. C.E. Hughes -- Department of Computer Science

Subtask IV -- Training Value

Mr. G.V. Amico -- College of Extended Studies

Dr. G.F. Schrader -- College of Engineering

Subtask V -- Maintenance Training

Dr. L.L. Smith -- Department of Industrial Engineering
and Management Systems

In addition, Dr. L.M. Trefonas, Vice President for Research and Dean of Graduate Studies, and Dr. J.R. Burr, Director of Sponsored Research, served as advisors for the task force. Dr. G.F. Schrader, Associate Dean of Engineering, served as chairman of the task force.

The activities of the task force were expertly assisted and guided by Dr. S.C. Collyer from the NTEC Visual Technology Research Simulator who served as technical advisor to the task force during the first half of the project. Dr. R.E. Reynolds from the NTEC Human Factors Laboratory served in a similar capacity during the second half of the project. Mr. Glenn Hohman, Head of Strategic Planning for NTEC, served as liaison advisor for the NTEC directors office and the Research Department. Those people and many others in the NTEC organization were extremely helpful to the task force in providing briefings and making information resources on S & TD technology available to the task force.

5.0 General Recommendations

History has taught us that in any technological endeavor within an organization, technological progress normally continues by means of a series of step functions as long as internal and/or external forces exist to maintain pressures and incentives for continued progress. Once these pressures and incentives are diminished or fail to exist, then the technological step functions tend to diminish in size and frequency. Thus, managers of technical organizations must continually experiment with ways and means of stimulating and facilitating technological invention, innovation, and diffusion within their organizations. The interaction of technical personnel with their peers both inside and outside of an organization is one way of stimulating the exchange of information and ideas for technical change.

During the conduct of this project such an interaction did take place between a considerable number of professionals at NTEC and the UCF task force

personnel, and it is reasonable to assume that exchanges of ideas did take place that were of mutual benefit. Since both organizations are vitally interested in the improvement of education and training processes, and improved methods and devices for their delivery, it would appear that some continued interchanges of this type on a somewhat structured basis would continue to be mutually beneficial. Thus, it is recommended that consideration be given to possible ways and means of implementing further interactions of this and other types. Specifically, it is recommended that the Executive Committee for the Institute for Simulation and Training consider the implementation of one or more of the following mechanisms for S & TD technology interchanges between NTEC and UCF personnel:

1. Establish a basic research discussion group composed of equal numbers of NTEC and UCF professionals who will meet on a regularly scheduled basis to identify S & TD basic research needs and opportunities.
2. Establish a regularly scheduled seminar or colloquia series wherein selected groups or individuals from NTEC and/or UCF (or invited guest lecturers) might present briefings and discussions of existing or pending research projects of interest to both NTEC and UCF professionals.
3. Establish within the Institute Director's office a direct data link with the existing RDT & E Manpower, Personnel, Training, and Simulation and Training Device data base.

SIMULATION AND TRAINING DEVICE TECHNOLOGY
TASK FORCE STUDY

SUBTASK I - - ADVANCED SIMULATION

TECHNOLOGY ASSESSMENT
and
NEEDS ANALYSIS

SUBTASK I - - - - ADVANCED SIMULATION
TECHNOLOGY ASSESSMENT AND NEEDS ANALYSIS

TABLE OF CONTENTS

	<u>Page</u>
1.0 Introduction	13
2.0 Assessment of Past Technology	13
2.1 Sensor Simulation	13
2.1.1 Visual System	14
2.1.2 Motion System Research	15
2.1.3 Field of View Research	16
2.1.4 Electromagnetic Sensors	17
2.1.5 Sonar Simulation	19
2.2 Computer Systems	20
2.2.1 Microcomputer Application	20
2.2.2 On-Board Trainers	21
2.2.3 Embedded Simulation	23
2.3 Software	23
2.3.1 Software Considerations	24
3.0 Technology Needs Analysis	26
3.1 Introduction	26
3.2 Visual System Technology	26
3.3 Applications of Artificial Intelligence	32
3.4 Applications of Human Electrical Signal Measurements	34
References	36

Simulation Technology Assessment

1.0 Introduction

Although the research programs in simulation technology and training methodology have contributed substantially to today's cost and training effective devices, there are two factors which support a strong research program in these areas. (21, 22) First, the demands placed on human operators of current and projected weapon systems make the task of effective training much more difficult. Secondly, there is a continuing need to improve the overall effectiveness of Naval training as a base for improved operational readiness. This portion of the technology assessment will review simulation technology. After an assessment of current technology and research tasks already planned or programmed, a basic research needs analysis will be made. This in turn will lead to specific basic research proposals.

The simulation technology can be divided into three major categories, these being: sensor simulation, computer technology and software. Each of these major categories may have a number of subdivisions.

2.0 Assessment of Past Technology

2.1 Sensor Simulation

One of the major advantages of training devices comes from its ability to simulate sensors associated with various tactical platforms. Numerous research programs have been initiated and the results of these programs have been beneficial. There are areas where continued research is still necessary if training devices are to be effective in training combat teams.

Early sensor simulation development projects focused on three areas. The first was visual simulation. Why consider visual simulation as a sensor? Human operator visual performance is still one of the primary sensor inputs to vehicle operation and weapon control systems. The other

two sensor areas were radar and sonar. These two sensors are the long-range eyes and ears of aircraft, ships and submarines.

2.1.1 Visual Systems

Considerable emphasis was placed on visual systems for aircraft in the early research. Two areas were pursued: carrier landing (1950-12BK5, 1966-2H87, 1963-2H53) and air-to-air combat (1959-2F151). The skills required to land an aircraft on an aircraft carrier safely were developed through extensive practice. The initial phases of training were conducted ashore followed by carrier qualifications at sea. The motivation for safety was probably primary but there was also an economic factor.

Numerous attempts were made to solve the technical problems (1950 12BK5 Carrier Landing Trainer, 1966 2H87 Advanced Carrier Approach and Landing Trainer) of visual simulation. It was not until the mid-seventies that a successful night Carrier Landing Trainer was developed by LTV. Evaluations that have been conducted report on the effectiveness of these systems in conducting carrier qualifications. (18, 19, 20)

Training in air-to-air combat was the other area where substantial performance benefits were projected. The motivation in this case was the limitations placed on air-to-air exercises. Other significant factors were weapon effectiveness and first engagement survival rates.

Here again there were many attempts to develop air-to-air combat training systems (1959 USAF F151 Air-to-Air Gunnery Trainer). Technological limitation prevented these systems from succeeding. The requirement for a wide field of view and high resolution (ability to detect aircraft and determine orientation at ranges approaching those experienced in actual combat was necessary) represented conflicting objectives. Research simulators used by DOD, Air Force ASPT, Navy VTRS-OMS, NASA,

Northrop LAMAR, McDonald Douglas, MAC I, II, III, Vought ultimately formed the base for air-to-air combat trainers. (Air Force-ASAL and Navy 2E6-ACMT).

There is still an active exploratory and advanced development program in the area of visual systems that is being pursued by the Services. Equipments that have been introduced within the past few years have resulted in a series of problems that are associated to trainee physiology. Visual and motion cueing conflicts were causing "simulator sickness."

As well as trying to resolve the physiological issues in current systems, the research program is being directed toward obtaining improved performance.

2.1.2 Motion System Research

Since motion is perceived through stimulation of several physiological receptor systems (visual, vestibular, haptic, and auditory), many designers and users of flight training simulators have felt it was necessary to utilize platform motion systems to provide the vestibular and some of the haptic stimuli. This has, by no means, been a unanimous point of view. In fact, the subject has been controversial in the flight training community for quite some time.

The reasons for the controversy are manifold, not the least of which is cost--including purchase, facilities and maintenance. Other factors are compatibility with certain visual displays, false cues in certain maneuvers, safety and reliability.

There is a great deal of motivation to eliminate platform motion systems.

The high resolution wide field of view requirement is being approached through eye-matching bandwidth techniques (Head or eye tracked displays).

Computer image generation technology is being directed toward increased image detail. The model board T-V technology has all but been abandoned for new developments.

2.1.3 Field of View Research

The challenge of providing a cost and training effective wide field of view, high detail density visual environment to the trainee in a flight simulator is being answered by developments in both the generation and display of visual imagery. To overcome the inefficiency and cost of filling the large field of view using multiple television projectors giving butted images, various techniques are being developed for concentrating high image detail in an area of interest (AOI) which is usually of high resolution and set within a larger field of view of low resolution. (4, 5)

The eye tracked systems offer the greatest potential for high performance to cost ratio, with a resolution of 1 - 1 1/2 arc minutes per pixel in the eye pointing direction (and so effectively in any direction) with the need for only two CIG channels. A key question is whether an eye-directed inset can appear natural to the pilot and whether he will be able to perform with such a system without eyestrain or other physiological problems. It is certainly to be hoped that the funding identified to support the NAVTRAEQUIPCEN HND and the ASD/YW/NAVTRAEQUIPCAN EDIT remains available as these two systems represent the two main alternatives - on-head mounting and off-head mounting - and only properly carried out integration and testing will allow the best system to be chosen.

Although the primary thrust of the visual technology research has been directed toward aircraft applications, there are a number of other programs today that are applying visual system technology to meet training needs. These applications include tank driving, gunnery and ship handling.

2.1.4 Electromagnetic Sensors

Simulation technology satisfied early training requirements for electromagnetic and acoustic sensors. The task was somewhat easier than the visual task. In its most simple form, electronic signals were gated into simulated or actual cathode ray tubes (CRT's). This permitted a variety of targets to be introduced into training scenarios. Since those first generation electromagnetic and acoustic sensors were very simple, the models that generated the targets could also be simple.

Although early radar trainers were basically interested in representing moving targets, there was a requirement to show ground return for use in radar navigation training. The ultrasonic trainer was developed late in World War II to satisfy this need (AN/APS-T3, 1944). The system used an analogy between sound waves in water and electromagnetic waves in air to obtain terrain returns. A relief map was used to produce the desired return.

Radar Landmass Simulation

Although target echoes experienced some refinement, the major research thrust was in the area of radar landmass simulation. The evolution consisted of the following phases. Initially the effort went into larger and larger tanks to obtain greater terrain coverage. (AF UltraSonic Trainer, 1960). However, water tanks had their problem, not dissimilar to the large gantries associated with visual system model boards. The next thrust was to replace the water tank and use a flying spot scanner over a large relief map (1955-152-4). The gantry problems remained and the low resolution performance of the flying spot scanner generally resulted in unacceptable performance. The next phase resulted in what is called the factored transparency method. (1960-1525). Radar return characteristics

were encoded into large plates of glass, one with intensity versus X-Y position and another with elevation or Z data versus X-Y. Signals from a flying spot scanner were processed and combined to form the ground return image.

These systems suffered from poor performance caused by two reinforcing effects. Compression of the terrain data onto a plate (30" x 30") and the resolution of the flying spot scanner limited the usefulness of the display to the air navigation mission. There was insufficient resolution for radar bombing or surface ship navigation.

With the advent of digital technology a concerted research effort was undertaken to see if digital technology could improve the performance of radar simulation (Digital Radar Land Mass Study). Through a combination of government and industry research efforts digital technology made its way into specific training device development projects. Initial applications were in the ground controlled radar approach and carrier controlled approach systems. It was later applied to the early warning systems and the air navigation and fire control system. The application of digital radar landmass techniques to the surface ship radar navigation problem solved one of the long standing training requirements (1970 T5F12 - Surface Radar Navigation Trainer).

The challenge of today is to achieve the same type of cost effective success in the infrared and low light level TV sensor simulation that has been achieved in radar systems. The dynamic infrared simulation problem is an order of magnitude greater than the radar simulation problem. Time varying radiation characteristic and the high resolution system requirements create astronomical data base and data manipulation problems.

2.1.5 Sonar Simulation

The sonar simulation technology experienced a completely different set of design issues. One issue related to the sound propagation phenomena and the other related to the spectral analysis of target sounds. As sonar sets became more sophisticated, their detection range increased and their ability to analyze target sounds improved.

Then, as a result of these operational system improvements, the modeling of target radiated noise and the propagation loss requirements became more complex. The target radiated noise being simulated has to be injected into the operational sonar receiver. This requires that target noise contain the power spectrum that is based on its operating mode. The spectrum must then be attenuated as a function of propagation loss based on range. The frequency dependence of propagation loss complicates the computations. Producing sonar returns that satisfy training objectives has been difficult. The variability of the ocean contributes to the problem. Specifying modeling requirements at the outset of a program is difficult. System shortfalls are usually identified during system tests. Experienced sonar operations make judgements about the quality or realism of the displays.

Thus, in the sonar simulation field the improvements in sensor performance have demanded more sophisticated modeling of targets and the ocean environment. In general sonar simulation technology is usually playing catch-up. There has been no major research undertaking to support this simulation area.

2.2 Computer Systems

Simulator technology is basically dependent on computers to solve the system equations in real time. Because computers form the basic component of training devices, there had been a long association between the Office of Naval Research and the Special Devices Center (now the Training Equipment Center) in post World War II thrust in computer technology.

The dramatic advancements being made in computer technology together with substantial reductions in cost opens up a number of possibilities for the improvement of training systems. The micro-computer either alone or along with video disc technology offers one such possibility.

2.2.1 Micro-Computer Application

At present there are many new and powerful micro-computer systems available. These systems could lead to effective low cost simulation devices. The Army has developed the MACE/Micro-Disc System. MACE is an improved version of the Army's Computer Assisted Map Maneuver Simulation I (CAMMS-1), modified to operate on a low cost personal microcomputer-videodisc (Micro-Disc) system. Map boards are replaced with military maps stored on a videodisc and displayed on color monitors. Unit location, status and action are shown in a graphical map overlay generated by the microcomputers. Operators/analysts can examine the simulated battle situation by scrolling the map using a joystick. The overlay is keyed to map coordinates and scrolls with it. In addition, the operator can zoom to focus on a selected area. The areas displayed can range from 4 to 40 km on a side.

The Micro-Disc System employs distributed processing supported by multiple personal microcomputers and video-disc players sharing a common hard disk mass storage unit. This distributed processing

architecture and local area networking permits graceful degradation in the event of failure of one of the microcomputers; an exercise can continue to function with other microcomputers in the system performing the functions of the disabled microcomputer. Local area networking also permits easy expansion of the system for more complex simulation.

The cost of reproducing trainee station hardware at a number of sites that are dedicated to the training function is having a major impact because of budget constraints. Therefore for the last few years there have been some initial thrusts into alternative methods of providing the required training. These alternatives have been titled "Embedded," or "On-Board" training. Both of these concepts are predicated on the availability of low cost high performance microcomputers that can be interfaced with the operational system, whether it is an aircraft, a ship, a submarine or a tank. This concept brings the training to the operating forces.

2.2.2 On-Board Trainers

Since the 1970's, companies have been developing operational training program materials for use on board surface ships, submarines, and aircraft. These programs have been oriented toward providing an individual ship or squadron with the capability to increase its operational performance in a particular warfare area through a series of scenario-based exercises, utilizing the unit's own inherent training assets and capabilities. These programs have been evolutionary and as the programs have matured, many problems have arisen which have complicated program organization, development, fleet implementation, and overall use of the materials. These problems

include: confusion and lack of understanding of the nature of onboard training; lack of documentation for combat systems; conflicting or non-existent operational guidance; limitations of imbedded training modes and systems; inability to keep pace with system upgrades and modifications; difficulties in implementing programs and materials; and difficulties in sustaining interest and use in Fleet units. Each of these problems has been encountered and dealt with, with varying degrees of success.

The key to the solution of these problems is the successful development of microcomputer based technology with the ability to implement changes efficiently and timely.

The future of the onboard operational trainer can lead to a means of providing a source of information that previously was supplied by key experienced personnel or mentors. This capability can be provided to the ASE team or in fact, any sensor or combat team. A trainer can be configured for each major sensor group and it can become a source of operability information providing not only a training capability but a library of operation guidelines, a source of maintenance information, and also an interactive means of managing operations for each team. Basically, the system can become a permanent source and focus of information storage that can aid with the operations, maintenance, training and readiness for the sensor team: a source that is consistent from ship to ship and a permanent complement to the ship's force.

2.2.3 Embedded Simulation

Embedded simulation embraces the concept of using the real vehicle, artificially stimulated in a controlled manner, for the purpose of training operators in the use of the vehicle equipment. All the advantages of a controlled training environment, safety, malfunction training, etc. associated with dedicated simulation apply, together with greatly reduced capital costs and added operational flexibility. TRIAD, a prototype simulation complex was developed for helicopter pilot training that incorporates embedded simulation principles. TRIAD comprises three major components; a computer/linkage/peripheral complex, an out-the-window CIG visual display system and a Bell 206 Helicopter, each integrated together to demonstrate the feasibility of embedded simulation for pilot training while maintaining certification on the aircraft configuration. The extension of this concept to military aircraft, ships, submarines and tanks will be dependent in large part by the ability to add the simulation equipment and interface it with the tactical hardware. Space, weight and environmental factors indicate that microprocessor technology may provide the required solution.

2.3 Software

With software becoming the major component of a training device, increased attention is being focused on the problems associated with the development and life cycle support of software. Issues such as: the accuracy and completeness of operational equipment data used in the simulation models; the frequency of change resulting from changes in the operational system or the training objectives; the magnitude and complexity of instructional features such as scenario generation, computer aided or managed instruction, performance measurement; and adaptive training all impact the software development and support process.

The frequency of program changes, for whatever the causes, places increased attention on the ability of the software development system to respond in a timely and cost effective manner. The situation here is considerably different from most systems where change is experienced but not with the frequency or magnitude that occurs on real time training systems.

2.3.1 Software Considerations

Software intensive training equipment has become the standard for current and foreseeable future training equipment procurements. Software support for these software intensive devices is an ever increasing burden which must be undertaken by the most efficient manners possible. Aid for modification of software support has been addressed by software tools developments that facilitate modifications, testing and baseline configuration management of these software intense devices. Configuration management, the phase of software support which is often neglected or given too little priority until the day of reckoning arrives, results in software configuration loss or error. A tightly controlled software configuration of a software intensive device is perhaps as important as the configured software itself.

The NTEC Software Support Facility (SSF) has evolved into a concentrated central software support resource with which any modification or development activity can effectively implement software baseline changes while remaining within the guidelines of a strong configuration management. The automated configuration management system at the SSF provides software baseline protection and control, ease of baseline maintenance, and full development/modification visibility during the support baseline

life-cycle. This automated and centralized environment permits a common contact point, a common set of procedures, and a single, common management of all supported device baselines under SSF configuration management. MIL-STD 1644A is the primary requirement that provides a common set of rules enabling various established baselines from various origins to be managed by a single generic configuration processing system. Older device baselines that were not designed by the requirements of MIL-STD 1644A may require additional effort to modify their structure and to provide the necessary support data for the automated configuration management system.

3.0 Technology Needs Analysis

3.1 Introduction

This section discusses three subject areas of importance to simulation technology:

1. Computer Image Generation - Visual Systems
2. Applications of Artificial Intelligence
3. Applications of Human Electrical Signal Measurement

Clearly these topics cut across boundaries for partitioning and establishing responsibility for various aspects of training. Training technology can be broadly partitioned as human factor, advance simulation concepts, and computer systems, but no one area can be easily divorced from the others when attempting an assessment of the past technology or creating an estimate of needs.

3.2 Visual System Technology

Many examples exist when one needs to be trained to accomplish complex tasks requiring vehicle control based upon what an operator sees in the world: pilots, ship handlers, tank crews, etc. For example: pilots receive a substantial portion of their training while "flying" a simulator with a visual display to maintain proficiency in landing, combat and safe handling of hazardous or emergency procedures.

All the questions relating to scene fidelity, motion cues, field of view, etc. have not been answered yet. One reason is that no one has been able to create a "real time" scene having real world fidelity to the accuracy of which a person is capable of resolving. Current technology allows one to create real time scenes (ie. TV fields at 60 per second and

TV frames at 30 per second) with scene complexity in the 2000 to 8000 edge range for about one million to three million dollars.

Eye resolution is sensitive to a number of parameters, a few of which are: motion, light intensity, contrast, color or hue, and the person. Further eye resolution is not constant across the field of view, but peaks along the line of sight vector.

One can characterize a nominal eye as follows:

1. Resolution of at least 3 arc minutes along the line of sight but no more than 1/3 arc minute, if effects such as the ability to see the light reflected from a 10 foot strand of spiders web at 100 ft is properly simulated (ie. sensitivity of about $3 \cdot 10^{-3}$ arc minute)

2. TV display rate is sufficient to reduce display flicker below a level perceived by most people

3. Intensity sensitivity of 1% when the intensity variation is across a long, well defined contour (ie. Mach Band) but only about 10% when intensity variation is over contrasting regions without long smooth boundaries.

Current technology only satisfies the display rate and the intensity sensitivity requirements economically. Fine detail resolution to better than 10 arc minutes is not considered economical and hence is only attempted at research facilities. One is still limited by the absolute lack of the ability to create complex scenes beyond 8000 edges in real time. Current display systems do not attempt to tailor the display resolution to the qualities of the eye. Rather, the systems produce the best resolution and detail with available equipment compatible with the money available for the display.

Hence one can characterize visual system technology as follows:

1. The ability to create "real time" scenes possessing real world detail with a resolution comparable to one's eyes is lacking.
2. Research to produce variable resolution displays tracked to the eye's pointing vector are in progress.
3. Research to produce real time image generation equipment capable of 10,000 to 100,000 edges is in progress.
4. Methods of mapping and reducing to code large gaming areas, such that the complex real world scenes may be characterized to a computer image generation system are in progress.
5. Typical means of creating the wide field of view required for many training environments are:
 - a) CRT's. With the boundaries of the CRT's corresponding to struts or partitions in the operator's window on the world.
 - b) Eidofor projectors.
 - c) Research is under way with titus and protitus displays and with laser generated scenes employing mechanical or electrical beam steering mechanisms.

One may judge from this description of the state of the art in visual simulation that the following needs must be met either through continuing research programs identified, expanding research and development efforts, or establishing new programs. Since economy is a driving factor in systems

in the million dollar range, the development of a visual system matching display resolution to the eye's requirement appears to be of high priority. For example, a display possessing about 1 arc minute resolution in a ± 10 degree pyramid centered at the eye's view vector and processing about 5 arc minute resolution for a 60 degree vertical and 120 degree

horizontal field of view requires about 2×10^6 pixels (ie. picture elements). This corresponds to two high resolution displays as opposed to 18 displays with 1 arc minute resolution over the entire 60 degree x 120 degree field of view.

In order to make an area of interest (AOI) visual display workable one must be able to rapidly and accurately measure the eye's pointing vector and the display's pointing vector. The minimum accuracy required for the display tracker is the pixel resolution everywhere within the range of view. For example, a pilot's cockpit is modeled as ± 90 degrees for the range of view and 1 arc minute for display resolution then an accuracy of 1 part in 5,400 is the minimal required. However, to accommodate tolerance one desires an accuracy of 1 part in 54,000. This is beyond the current state of the art, and one should continue research and development aimed at producing a display tracker having a resolution of greater than one part in 10,000.

The accuracy requirements for an eye tracker are on the order of ± 1 degree. If the actual high resolution projection region is larger than the high resolution region seen, then only nominal accuracy is required to identify where the projected high resolution need be created.

The advent of high speed digital processing and vast secondary storage has clearly shifted visual simulation away from model boards and into Computer Generated Imagery. However, the following needs still exist:

1. A means is needed to automatically convert real world gaming area information into the high resolution detail needed for nap of the earth flight or other high resolution scenes. One may imagine a multi pass procedure which uses the Vought approach of acquiring a large number of digitized images of the gaming region. Then, an intermediate step of intensity compensating the digitized images across image boundaries.

Finally, a reprojection of the compensated digitized images onto a set of scene planes, similar to a Honeywell system, such that one could retrieve the digitized scene from one of a hierarchy of digitized images possessing the resolution required for creating the current scene.

The concept of creating the data base for any Computer Image Generation method off-line from real world data offers the potential of producing display resolution to specified tolerance in real time. Such off-line, non real time activity would allow one to specify display detail resolution, determine the data base parameters which guarantee the desired detail, and estimate the computing power required to create the scene in real time. If the next generation of CIG is to create high detail in real time, then it is reasonable to anticipate it will be memory intensive rather than processor or computation intensive. Hence, CIG systems which make maximum use of the computationally intensive steps needed to decipher real world imagery (i.e. photo reconnaissance, maps, terrain data, etc.) into memory intensive hierarchical data bases required for high detail real time systems are necessary developments.

2. A means is needed to produce eye limited resolution images in real time for less than one million 1983 dollars. Current research into producing high detail real time scenes may be categorized into two areas: numerical computation and image or picture mapping. The property of the numerical computation methods, is that the scene is modeled via fixed formulas whereby parameters are applied to the formulas to allow point by point or region by region calculation to define the displayed scene. As the scene complexity increases both the formula complexity, parameter number, and number of computations increases. Since computer processing hardware has not shown the improvement that memory hardware has shown (ie. memory cycle time decreasing by about a factor of two and memory cost

decreasing by about a factor of every 2 to 3 years since 1970 and projected for the next 10 years), one suspects that computationally intensive procedures will, in general, be inferior to memory intensive procedures over the next 10 years.

Memory intensive CIG procedures essentially map stored images from world coordinates to display coordinates. Hence, the only computations required fall into three categories: projection of images, comparing range to determine visible pixels, predicting the field of view such that the image buffers will always retain correct scene data/images. A hierarchical data base limits the mapping computation required to meet anti-aliasing requirements and allows one to place an upper bound on the primary memory that would be required for such a system. For example, if the display produces 10^6 pixels and one allows occulting and transparencies to 10 levels with the ability to predict the field of view to $\pm 15\%$ of the actual field of view vector over the time it takes to transfer images from secondary memory (ie. video disk of about 0.3 sec) to primary memory, then about 16 mega words of images would be required. If the scene consists of optical as opposed to FLIR or some other detector generated display, then a word would be at least 22 bits (21 bits for 1% color intensity and one bit for transparency) and possibly limited to 34 bits (10 bits for each of three intensities and 4 bits for various transparency factors). Using a 1983 memory cost of about \$2000 per megabyte, then the primary memory cost would range between \$90,000 and \$200,000. Hence, the processing and secondary memory costs would clearly dominate a \$1,000,000 visual system.

3. The display means does not appear to be a limit of current visual systems. Light level requirements appear to be satisfied by using high gain reflective material on a surface sufficiently far removed from a nearby co-located projector or by using multiple CRT's or Eidofor's to

project the display to the student's display windows. Hence, this area does not appear to have critical items limiting high resolution displays.

In summary, the dominant technological needs for visual systems appear to be:

1. Display and eye position measuring equipment having an accuracy of at least 1 part in 10,000.
2. Means for automatically transforming real world imagery into appropriate CIG image data.
3. Systems costing less than \$1,000,000 (ie. 1983 dollars) for producing imagery of at least 1 arc minute resolution but matched to the eye's resolution requirements

3.3 Applications of Artificial Intelligence

There seems to be no AI technology in training which meets all the following definition of an intelligent unit:

1. The unit accepts information, senses inputs or receives stimuli
2. The unit distinguishes between data or factual information and algorithmic or formula information stored in the unit's memory.
3. The unit has "goal formulas" which may be invoked by the unit to measure progress toward achieving its goals or any one of its set of goals.
4. The unit has the ability to modify its algorithms, or formulas, as well as its data. It can also create new formulas or algorithms. Hence, the machine learns.

5. The unit can assess consistency. That is the machine can apply its known algorithms to measure its level of understanding or ignorance. If one has a set of data which is supposed to be described by an algorithm (ie. predict future, estimate past, or correlate with present) then the machine shall be able to calculate the accuracy of the algorithm as more and various data/input is accumulated. The consequence is that the unit

shall have the ability to search for the truth by modifying its algorithms until all input/data is understandable (ie. predictable, correlatable, or matches the estimates of the past) in terms of the algorithms in the machine.

Present training equipment under the class of artificial intelligence seems to possess fixed programs which are NOT self-modifiable (ie. they do not possess theorem solver capability). The present systems termed AI interact with users to guide them along a path whose tree structure has been entirely defined by the AI program creator(s). For example, one can present a situation of one of a possible set defined within a menu and follow through the choices/situations keyed to the original menu. This Expert System method is based on equipment which is severely memory limited. This philosophy does not readily lend itself to the "user's vocabulary" and/or the user's spelling. For instance, if one were to use a system at a library to search information on artificial intell(e)gence then a misspelling would fail to find any data.

The expert system is needed in training. The need is clearly present for any programmed instruction. A maintenance training aid to guide the student through complex equipment problems is also obvious. However, the system calls for a secondary storage media, like a set of video disks, to hold the course or training syllabus which allows a user's vocabulary and the user's spelling.

The capability of allowing a user's spelling should not be difficult to incorporate into expert systems. This suggests masking of key words if an exact match is not found and then quering the user about the key words.

The impact of such information intensive systems is manifold. The following are a few examples:

1. People can be readily trained at their own pace, as if by their own personal tutor. As long as the tutor is relatively insensitive to the user's language flaws.
2. People responsible for maintenance of equipment would be able to use video disk Expert Systems to learn the equipment to help diagnose faults, to guide the replacement of spares, or to guide equipment repair

The intelligent unit is a step beyond the Expert System. A few of the uses to training of an intelligent unit are as follows:

1. To serve as a model for identifying various algorithms students employ while performing specific tasks.
2. To serve as a model for determining the value of students' algorithms.
3. To allow the intelligent unit to search for and identify effective algorithms for most effeciently performing tasks.
4. To serve as a model for partitioning tasks into their separate skill requirements
5. To serve as a student so that one could measure various teaching strategies results, while at the same time clearly defining the "natural abilities" of the student.

3.4 Applications of Human Electrical Signal Measurements

In order to achieve an area of interest CIG system one must be able to unobtrusively measure the vector direction of the students' eyes to a resolution of one degree or better. Since the eye is an electric dipole, research into developing an eye vector sensor using electrical pick-offs is needed. A number of problems need to be solved to accomplish this aim. However, the successful development

of an electrical probe (i.e. pick off) for measuring eye pointing vector would also be useful for brain wave measurement. If one could create an effective sensor for accurately and reliably measuring the time varying electric field at a sufficient number of points on the head (i.e. brain), then with successful research one would be able to correlate these "brain waves" with actual mental processes. For instance:

1. One may be able to correlate successful pilot performance with an array of "brain wave" sensors and eventually diagnose the detail of some types of faulty performance.
2. One may be able to correlate the "brain wave" array measurements with successful and unsuccessful candidates for a wide range of tasks. One would anticipate a variety of successful strategies are employed by various people. The ability to categorize "brainwave patterns" would aid in interviewing to discover these strategy differences and eventually evaluating their strategic power.
3. One may be able to monitor "successful training." To recognize daydreaming, confusion, frustration and other such negative aspects of training. The goal is to keep the student interested so the student will be self motivated to be on task. But when time is critical, any aid which can effectively correlate with learning improves overall mission performance.

Research into both eye position measurement and into unobtrusive brainwave measurements can benefit training.

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SIMULATION AND TRAINING DEVICE TECHNOLOGY
TASK FORCE STUDY
SUBTASK II - - HUMAN FACTORS
TECHNOLOGY ASSESSMENT
and
NEEDS ANALYSIS

SUBTASK II - - - HUMAN FACTORS
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TABLE OF CONTENTS

	<u>Page</u>
1.0 History and Organizational Structure of the Human Factors Laboratory	40
2.0 Current Projects	42
3.0 Assessment of Current Needs	46
3.1 User Acceptance	46
3.2 Examination of the Learning Process and the Concept of Transfer	49
3.3 Development of Training Models/Instructional Support	51
3.4 Organizational Communication	52
3.5 Evaluation/Measurement and Team Training	53
3.6 Stress Simulation and Motivational Studies	54
3.7 The Use of Decision Analysis and Risk Assessment Training and R&D Program Development	55
4.0 Summary and Priorities	56
5.0 Bibliography	57

Existing Technology Assessment and Needs Analysis
of the Human Factors (HF) Laboratory

1.0 History and Organizational Structure of the Human Factors Laboratory

The Human Factors Laboratory (N-71) operates under the aegis of NTEC's Research Department (N-7). There are two branches of the HF lab; Training Techniques Development (N-711) and Training Applications (N-712). The lab interacts with the Laboratory Services Division (N-72), the Advanced Simulation Concepts Laboratory (N-73) and The Computer Systems Laboratory (N-74) in RDT&E program areas.

The lab administers the 6.2 (exploratory development) and 6.3 (advanced development) tech base program in simulation and training devices (S&TD) and thus serves as an interface between basic research (designated as 6.1 funding) and engineering development (designated as 6.4 funding). The Office of Naval Research sponsors 6.1 programs, the Office of Naval Technology sponsors 6.2 programs; 6.3 and 6.4 programs are funded by Air Systems Command. NTEC staff have indicated that, because of organizational, geographical and communications barriers within the sequence of research to production, there is "lots of room for obstacles" in the project flow area. In addition, 6.2 prototype funding is administered on a block-funding basis whereas 6.3 and 6.4 programs are line-funded items, thus potentially producing different organizational objectives within the developmental system. Although it is not the purpose of this report to attempt reorganization of naval research activities, it seems worthwhile documenting briefly what appear to be fundamental barriers in S&TD concept attainment. Communications problems in R&D means that often good ideas never "get in the pipeline," inter-laboratory politics can interfere with overall research missions, and, for the Human Factors Lab in particular, there

are often no general engineering design guides for human factors considerations. Organizational communications needs will be addressed under the current needs section of this assessment.

The Research Department has recognized the following problem areas: (1) RDT&E programs are not sufficiently acquisition-oriented, (2) there is a lack of a single, multi-platform oriented sponsor for the tech base program, (3) there is no stable laboratory core program and (4) the need exists for a RDT&E funding vehicle to ensure management/support stability. Various recommendations have been made to alleviate these problems, including lab restructuring allowing for maximum flexibility and responsiveness in (1) instructional technology, (2) realtime computer technology and (3) sensor simulation technology. The RDT&E tech base objectives to establish a viable in-house experimental capacity and to optimize the flow from 6.2 and 6.3 feasibility demonstrations and experimental applications to 6.4 production warrant support.

2.0 Current Projects

Current projects within the Human Factors Laboratory relate to basic operational problems of decreased instructor availability and trainee quality/quantity, cost/unreliability of operational equipment for training and limited opportunities for on-the-job training. The problems are coupled with an increased demand for training equipment. Projects follow two broad objectives: (1) to integrate humans into training systems and (2) to enhance training system effectiveness. The thrusts of instructional technology R&D are (1) instructor productivity, (2) training effectiveness, and (3) cost control.

Instructor productivity is achieved by reducing instructor staffing requirements and work loading for individual instructors. Current projects in this area include: (1) voice technology as instructor's assistant, (2) artificial intelligence techniques, (3) instructor/operator station design, and (4) automation of instructor support functions. As an example of work in this area, the Submarine Advanced Reactive Tactical Training System (SMARTTS) provides trainee information through pre-exercise briefing, information displays, alternative tactics, and post-exercise debriefing. Instructor support is provided by an exercise selection library, exercise setup, performance evaluation, instructor's console, training control, instructor's handbook, and automatic integrative target.

Training effectiveness is achieved by automated performance measurement systems, trainee performance feedback, and training effectiveness evaluation techniques.

Cost control is achieved by low cost training systems, part task training approaches, and maintenance training and aiding.

Listed below are several examples of ongoing research related to the Human Factors Laboratory:

A. Instructor/Operator Station Design Guidance #2716

This project examines instructor/operator station designs which give no thought to the person/machine interface. The result is frequently an excessively complicated, difficult to operate instructor console. The problem will be analyzed in two phases. Phase I will assemble a list of problems and deficiencies while phase II will use the collected data to develop a series of documents which will aid in the design and development of future stations.

B. Acceptance of Training Innovations #3773

This area is discussed in detail under Current Needs.

C. Evaluation of Simulator Sickness #3775

Numerous reports of sensorimotor disturbances following aircraft simulator training have occurred. This project is attempting to: (1) identify features of simulator design and use in training which contribute to simulator sickness, (2) determine relevant individual differences among trainees that may increase susceptibility and (3) develop methods of preventing recurrences in future simulator procurements and current devices.

D. Embedded/Organic Training Technology #1715

This project is attempting to develop alternative methods for implementing advanced training assistance technology in on-board (organic) training applications.

E. Low-Cost Applications of Emerging Computer Technology #0744

This project is evaluating the effectiveness of low-cost computer assisted instruction used for the training of equipment troubleshooting problems. The study is utilizing students at the Basic Electricity and Electronics School at the NTC in Orlando.

F. Voice Technology as the Instructor's Assistant #1713

This project is developing techniques for application of intelligent automated speech technology to aid the instructor.

G. Maintenance Training and Aiding R&D Requirements #2715

This project will provide a data and planning tool to continually assess and update the Navy's maintenance training and aiding R&D requirements.

As part of the Human Factors 6.3 R&D program for FY83, support was requested for a part-task trainer for missile envelop recognition, a part-task trainer for air intercept control, and a personal electric aid for maintenance (PEAM).

One of the major projects which is indirectly related to the need to determine cost-saving designs, training features, and fidelity levels of low-cost trainers is the Visual Technology Research Simulator (VTRS) utilization project, #0785. The objective of this project is to provide hardware and software design criteria for future trainer/simulator procurements by means of both hardware and human performance research.

Another important project which addresses the disparity between weapon system complexity and the availability of skilled technicians is the Personal Electronic Aid for Maintenance (PEAM) project, #2790, which employs human factors considerations for user compatibility to design, develop and test the PEAM.

In the 6.4 area, there are important projects involving team training. The Naval Tactical Data System (NTDS) Laboratory, the OUTBOARD Operator/Team Trainer and Shipboard "Organic" Combat System Team Trainer (CSTT) address the need for personnel making up the team to practice

together until their actions are as automatic as the equipment they operate. With the OUTBOARD trainer, for example, training scenarios will be developed which maximize the training of the teams by comprising many actions into a shorter time interval, thus creating problems and confusion requiring extra efforts.

Within the human factors area in training equipment, a number of unfunded but high priority requirements have been identified. Among these are:

- Missile Envelop Recognition Trainer
- Low-Cost Applications of Emerging Technology (e.g., (AI program)
- Embedded/Organic Training Technology
- Maintenance Training and Aiding
- Voice Technology as Instructor's Assistant
- Artificial Intelligence Techniques for Subject Matter Expert Information

As for future directions for the Human Factors program in training equipment, there are no new efforts scheduled to commence until FY85.

Technology development will be coordinated with requirements dictated by approached advanced and engineering development projects scheduled during the next five years; the present human factors will remain stable.

3.0 Assessment of Current Needs

Given the background of budget cuts or decrements which impact the programs carried out by the Human Factors Laboratory, it appears necessary to work within the existing, funded S&TD project framework to develop 6.1 research in support of important, but selective, ongoing programs.

There are numerous basic research possibilities within this programmatic arena which emanate from a variety of need areas. In this section, an attempt will be made to analyze basic human factors research needs. First we will present a comprehensive listing of currently identified needs and discuss several of these needs in depth. Subsequent reports will delve further into more of these basic research needs.

3.1 User acceptance

A fairly common problem in any complex training environment is that of a lack of User Acceptance. For what appears to be a variety of reasons, even the most carefully designed, most technologically advanced training system may be under-utilized. While a lack of user acceptance can be examined with a focal point on either the learner or the instructor, the latter seems to be of greater impact in military training. Stoffer, Blaiwes and Britson (1) have outlined several reasons for making improvements in the acceptance of new training systems:

- A. Significant advances in effective training technology remain to be incorporated into the Fleet. There are definite "gaps" in certain areas between available technology and its applied use.
- B. A variety of low-cost, low-fidelity approaches to training system design are now under development. While degree of fidelity has been shown to be the most important factor in gaining user acceptance in a training system, research is showing that extreme fidelity, and the concurrent

extreme costs, are not always required to achieve an acceptable level of performance in trainees.

C. There is an increasing need to introduce and to have accepted training improvements as early as possible. There is a need to reverse the trend toward ever increasing time spans required to develop new weapons systems and their related training materials.

D. Training technology will be increasingly integrated into ongoing fleet operational systems. The success of on-board training techniques depends critically upon the willingness of personnel to accept such innovations.

E. An especially critical problem of accepting flight simulators as flight hour substitution devices now exists. There is a discrepancy of viewpoints between higher command echelons of the Navy and local training commands which have resulted in underutilization of aviation training devices.

F. Operational tasks and equipment are becoming increasingly complex and human error correspondingly more probably and costly. As a result, economics will mandate a heavier reliance upon training substitutes for operational environments.

While the above reasons for attempting to improve user acceptance are fairly specific, an over-all survey of the available literature indicates a common theme: The degree of user acceptance for any particular training device is a critical factor in establishing its true training value.

A wide variety of factors appear to enter into the scope of user acceptance. In many cases where resistance to a new technology is encountered, blame is placed upon the trainers. While there is an inherent resistance to change in some situations, other factors appear to be more important. Communications and involvement seem to be very important. When the trainers

have had major input into the initial needs assessment and design stages, and the finished product accurately reflects those perceived needs, user acceptance has been quite high. At the same time perceived needs may not be real needs. For example, many trainers feel that the use of a real device in training is critical, and if a real device simply can't be supplied, then the substitute must be as much like the real object as possible. Research has shown, on the other hand, that many tasks can be taught with only low fidelity models of the real device. In a situation like this, effective communication becomes a critical factor in final user acceptance.

As critical a factor as user acceptance appears to be, initial research into it is just now getting a good start. Wylie and Mackie (2) have produced an excellent review of the literature and a model for predicting organization acceptance of technological change. The Human Factors Laboratory of NTEC has a project under way which will attempt to identify and quantify user acceptance factors in an attempt to build a predictive model for future instructional planning (3). The goals of this project are to:

- A. Predict user acceptance (rejection).
- B. Tie acceptance problems (and successes) to specific variables.
- C. Incorporate acceptance considerations into cost-benefit and training effectiveness design analyses.
- D. Provide a systematic approach to the introduction and implementation of new training developments.

At the present, these two projects appear to represent the leading edge in examinations of the user acceptance problem. While these studies will produce a noteworthy advance, considerably more research is required on the topics. Stoffer, Blaiwes and Brictson accurately summarize the field by comparing it to

the advent of the Instructional Systems Development (ISD) era. "At this point very little science has been developed in the area, and, at best, current practices represent a very under-developed art." It will take ambitious funding of the above-mentioned projects, and further projects like them, to create a system of user acceptance technology.

3.2 Examination of the Learning Process and the Concept of Transfer

The ultimate value of S&TD Training depends on the extent to which skills learned in training transfer to operational experience. Skills learned must either be essentially the same as those needed to perform in practice or else must enable a student to learn other or additional skills more quickly. This process is called transfer of training.

Transfer is a complex process, depending not only on what is learned, but on how and under what conditions the learning occurs. Caro, Shelrutt and Spears (4) have noted that personnel responsible for many aircrew training device (ATD) activities view transfer as a simple, almost mechanical process. They believe that transfer will occur only when: "(1) the same stimuli are provided in the ATD that are provided in the aircraft, (2) a student is able to do the same things with the ATD's controls that he would do with the controls in aircraft and (3) the feedback that he receives from operation of those controls is the same as it would be in the aircraft."

Transfer will occur given sufficient stimulus and task fidelity. However, to rely only on stimulus and response fidelity constrains training device design and utilization because some of the more important aspects of transferable skill learning are ignored. This approach also results in expensive high fidelity devices when in some cases high fidelity is not necessary.

To understand the concept of transfer more fully it is necessary to examine (1) cue development, (2) cue and response discrimination and (3) generalization. These factors relate to what is generally called "psychological fidelity," a concept which is basic to transfer of S&TD training.

It has been established in many transfer studies that device and aircraft stimuli are associated responses need not be physically similar for transfer to take place. Prophet and Boyd (5), for example, showed that cockpit procedures training in a simulated cockpit made of photographs, plywood and dowel rods, transferred to an aircraft as well as did corresponding training in a device of high physical fidelity. Bunker (6), in an experiment in which experienced pilots were asked to fly a simulator with a new CIG system, noted that pilots do not key on "naturalness" of a ground scene, but abstract from it certain characteristics such as gradients that they have learned to interpret. Explanations for this type of phenomenon must involve the equivalence of stimulus and response meanings which emphasize cues rather than stimuli (i.e., information provided by stimuli rather than physical characteristics of the stimuli themselves).

This overall psychological process of seeking and recognizing familiar cues in changing situations is an instance of "mediation." Mediation of all types promotes every aspect of military training and performance. Therefore, instead of leaving mediational processes to develop on their own, this procedure should be specifically examined so they can be targeted in training objectives. Basic mediational learning research can lead to more efficient and effective instruction through the study of such factors as knowledge acquisition (i.e., cognitive training), informing the learner about his actions (i.e., feedback) and guiding the learner (i.e., guidelines). Such research can also provide guidance regarding the degree of physical fidelity which may be acceptable under

differing learning conditions.

3.3 Development of Training Models/Instructional Support

While these areas were not examined in detail for this report, they were mentioned by staff members of the Human Factors Laboratory as being areas in need of additional research. Specific instructional design models are required for new areas of technology. While existing general ISD models can serve for the development of content in many situations, more advanced models are required for situations as follows:

- A. A subject matter expert on board a ship needs to create a training module to cover an improved maintenance technique he has found. No instructional support staff is available, so an automated system is required to guide the SME through the design and implementation procedures with a minimum of distraction.
- B. A new form of technology (voice recognition, for example) has a potential application in a training system. A model is required to predict the cost effectiveness of implementing such a feature based upon factors unique to the training system and that particular technology.
- C. An automated instructional design model could be far more effective if it could receive feedback from operational systems. Such a model would require extensive integration into the current training procedures. Automated collection of learner performance characteristics would have to be considered in the design of training devices themselves, and procedures would need to be developed to feed the data back to the design model.

The ISD methodology provides an appropriate framework for directing attention to instructional process concerns and does provide for some learning analysis functions. (It should be noted that the actual role of ISD or

systematic learning analysis in determining the requirements for a design of training simulators is minimal, and in the Air Force virtually no continuation training simulator programs have been developed on the basis of substantial ISD input).⁴ However, ISD provides only general guidance concerning how to apply learning analysis. For example, ISD states that feedback is important to learning. What is really needed for designers of training equipment and training programs is a specific information base covering factors such as how to provide feedback, when to provide it, how to handle the task specifics of feedback, and similar instructional management factors.

While several current projects address aspects of the above problem areas, further research is required.

3.4 Organizational Communication

One of the fundamental problems cited in conversations with NTEC Research Department staff is the difficulty in keeping informed of research and operational findings inside and outside the lab and being able to incorporate information into design decisions in an efficient manner. There are various levels of analysis to this problem and the situation is by no means unique.

Caro et al. (4) attempted to determine the role of ISD team personnel in aircrew training device (ATD) design. Although one would assume these personnel would be influential in specifying characteristics ATDs, such was not the case for a number of reasons. Rather than being influential in specifying characteristics of ATDs, such was not the case for a number of reasons. Rather than being influential in defining ATD designs, "ISD teams generally must accept as resource constraints the devices to be made available for the training programs they design."

A number of books (7, 8, 9) treat the subject of communication among scientists and engineers. At the practical level, the solution to communication barriers may be as simple as establishing an in-house dissemination vehicle or coordinating more broadly inclusive planning, progress and review meetings. Establishment of coordinated goals among departments might also help. The possibility of basic research fostering organizational improvements in R&D communication can directly influence the efficiency and effectiveness of S&TD programs.

3.5 Evaluation/Measurement and Team Training

There is a need to evaluate student performance and crew performance in a manner which is not threatening to the student but which provides realistic feedback. The concept of feedback and reinforcement is basic to learning strategies. Performance measurement of operators or teams controlling a complex tactical situation has never been successfully accomplished. Past research has addressed only a segment of the training performed on flight simulators and the single target submarine approach problem. Although programs such as TACTS, PAAS, PACE, and APARTS offer suggestions, key performance parameters for complex tactical exercises have not been identified from the multiplicity of available choices. Research should treat the role of measurement in managing instruction (e.g., pacing, sequencing, etc.) and in the handling of factors such as feedback and guidance (e.g., when, what kind, how much, contingencies, etc.). In addition, the use of measurement for system quality control is also an aspect of this process management concern.

Associated with the above research, there is a need for skill/task oriented research with reference to improved crew training and extended team training. This latter term refers to the training of pilots or crews in an extended interactive simulation context with other relative personnel and systems.

Attention should also focus on adaptive strategies when the system is degraded by personnel for mechanical failures. The potential gains in effectiveness and cost savings from such system-interactive training should be considerable if the research is done to support effective program development.

3.6 Stress Simulation and Motivational Studies

Associated with the previous research needs is the need to study both individual and team performance under varying degrees of stress and to develop methods to mitigate such stress. High fidelity training devices are often preferred to low fidelity devices because of their ability to reproduce the "pucker" factor. Further research is necessary to ascertain the conditions and types of training devices most suitable to simulating the psychophysiological activities of stress.

Other motivational studies are also needed to address such issues as intrinsic enhancement to learn, versus extrinsic reinforcement contingencies, the merits of positive versus negative reinforcement in training and the transfer of motivational supports in training to operational experience.

The Human Factors lab is currently performing a study using video games as a motivational tool to improve training, but such studies are few and far between. Far more recognition should be given to motivational factors, particularly in maintenance training where ability factors may be lagging.

One area for research, for example, would be in determining the most appropriate mix of trainee abilities, skills and motivations with automatic test equipment complexity. If equipment becomes too complex, it is likely that the user may lose sufficient degrees of feelings of personal efficacy and control to counteract performance gains achieved by automation.

3.7 The Use of Decision Analysis and Risk Assessment Training and R&D Program Development

Although some work has been performed in analyzing the requirements and methodology for decision training in conventional military training systems (10), decision analytic tools can also be useful in other areas of program development and R&D funding. Research can be helpful in identifying the parameters of decisions and the weighting of risk factors identified with alternative courses of action.

4.0 Summary and Priorities

The Human Factors Laboratory at NTEC has provided a number of topics for potential research. The topics range from the psychology of human learning through the need to understand the fundamental translation processes involved when two different groups of professionals attempt to communicate. In all cases, however, emphasis is upon a more effective integration of learners into a training environment.

These topics were not presented in any particular order of priority. In part, they were presented in their order of "discovery." Because of the logical flow of research, broad topics like "User Acceptance" were examined first, and narrower topics like "Stress Simulation" came later. This does not imply one to be more important than the other.

In attempting to establish a list of five potential topics for research, the authors decided it would be most sensible to establish priorities based on the levels of need and interest the topics currently reflect in the Human Factors Laboratory and our literature surveys. While this is definitely a subjective process, it is an acceptable method of comparing such widely diverse topics. The following list represents the results, with rank number 1 representing the most pressing topic:

1. User Acceptance (3.1)
2. Stress Simulation (3.6)
3. Transfer of Training (3.2)
4. Organizational Communication (3.4)
5. Training Models (3.3)

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SIMULATION AND TRAINING DEVICE TECHNOLOGY
TASK FORCE STUDY
SUBTASK III - - - COMPUTATION SYSTEMS
TECHNOLOGY ASSESSMENT
and
NEEDS ANALYSIS

SUBTASK III - - - COMPUTATION SYSTEMS
TECHNOLOGY ASSESSMENT AND NEEDS ANALYSIS

TABLE OF CONTENTS

	<u>Page</u>
1.0 Animation	60
1.1 Needs	60
1.2 Objectives	60
1.3 Problem Overview	61
1.4 Low Cost Systems	61
1.5 A Proposed System	62
2.0 Data Base Technology	63
2.1 Needs	63
2.2 Data Base Machines	63
3.0 Artificial Intelligence	65
4.0 Summary	65

TECHNOLOGY ASSESSMENT AND NEEDS ANALYSIS

1.0 Animation

Several areas have been identified in which the research interests of the UCF Department of Computer Science are compatible with the goals and needs of NTEC. The first of these areas is low-cost animation both as a design aid for higher fidelity systems, and as a useful tool in its own right.

1.1 Needs

Many devices that students at the Naval Training and Equipment Center must learn to use are extraordinarily complex. This complexity can result in prohibitive cost or unacceptable danger when training is done on the real delivery system. But it can be more costly to send out an improperly trained individual.

One way to deal with this need is to deliver some or all of the training through computer simulations that use animation to provide the visual cues occurring in the actual environments. The utility of this approach has been shown in expensive systems and more recently in medium priced workstations such as those provided by Bolt, Beranek and Newman in their steam propulsion simulation called Steamer.

1.2 Objectives

The Navy, as well as others with the responsibility for training a large, diversified audience in the use of high technology is finding itself more and more committed to providing simulated, rather than real-life experiences. This choice is sometimes necessary since the real-life activity is too dangerous, or is just too expensive to carry on. Simulation also provides the opportunity to tailor the experience to an individual's needs rather than to a set of more general goals.

One of the most useful tools in simulation is animation. This is an integral part of flight simulators and anti-tank trainers. In the future we can expect more animation to be used in such subjects as decision making exercises, equipment familiarization and failure diagnosis. But before this use can become widespread, it will be necessary to create affordable, easy to use systems in which low to medium fidelity animation can be developed and delivered. It is to that goal that we propose to direct ourselves.

1.3 Problem Overview

In the very near past computer graphics systems that could provide the resolution needed for decent animation were expensive and hard to use. Recent advances in the area of large scale and very large scale integrated circuits technology have radically reduced the cost of such systems. Yet, certain aspects of the human interface have seen relatively little improvement. Animation is still a batch process, not allowing for real-time display and editing, even during the prototyping stage.

Several systems are now in existence to help with the human interface, so far as writing the scripts for animation. Anima II at Ohio State reduces the preparation time by providing a user interface that is geared more to the animator than to the computer technician. By employing a notation similar to that used in music, the Dial language developed at Brown attempts to make the parallelism of events more obvious. Even so, these systems are still primarily batch oriented. The animation is developed one frame at a time, and recorded for later display. Moreover they require high cost host systems.

1.4 Low Cost Systems

Although feature film quality animation is still an expensive process, requiring high powered machines and displays with enormous color variations,

medium fidelity, real-time animation is now possible using inexpensive microcomputers. The major advance that makes this possible is graphics chips as those used in the Atari, Commodore and Texas Instruments low end computers. These chips are capable of simultaneously controlling the movement of several screen objects. The computer's main processor does not need to be concerned with erasing redrawing figures, in order to simulate motion. This, in effect, means that parallelism can be achieved cheaply by the use of inexpensive, special purpose processors.

The problem with low-cost graphics systems is the lack of a good user interface. Most microcomputer animation is performed in assembly language and Basic, with a small amount done in Pascal. The only advances seen here are in animation libraries such as the Atari routines developed by Fox and Waite, and the Pascal system of Moshell and Hughes.

1.5 A Proposed System

We feel that a major advance in low-cost animation is achievable when the design of animation hardware, software and the user interface are treated as one integrated project.

Our steps will be to determine:

- i) the animation effects required to support training exercises.
- ii) a user-friendly way of describing and editing animation sequences.
- iii) a compact representation for these sequences.
- iv) the hardware necessary to achieve a pleasing graphical display of the effects represented in the user's description.

Each of these design steps will be carried out in unison. It is our intention to avoid the temptation to add fancy graphics features that are not addressable through the standard user interface.

The user interface is perhaps the most challenging phase. Anima II and Dial are two possible models, but so is the object-oriented interface provided by Xerox's Smalltalk-80 system. We plan to experiment with several such approaches. During these experiments we will build prototype graphics processors using bit-sliced technologies. When a final choice is made, we will then commit to a VLSI implementation.

2.0 Data Base Technology

2.1 Needs

Many of the training activities carried out at NTEC require large volumes of data to be stored, and then retrieved at very high access rates. With an increased emphasis on the use of computers to carry out much of the training process, the need for an effective way to quickly process data base queries becomes even more critical.

2.2 Data Base Machines

Relational data bases are becoming more and more common due to the close association of this computer representation to the logical views we may wish to take. Queries of such data bases are translated to operations on relational tables, e.g., select all entry in relation R, where the occupation field is laborer. Simple operations refer to only a single relational table. More complex queries may involve looking at a relation that can be inferred from the contents of several tables.

To make the above clearer, we can consider a data base that consists of two relational tables. The first associates people, as represented by their names, with their occupations. The second associates occupations with OSHA categories, and the labor union to which people with this occupation normally belong.

Relation 1

<u>Name</u>	<u>Occupation</u>
Adams	Trucker
Baker	Professor
Drake	Trucker
Elgin	Miner
Everly	Auto Worker
Martin	Steel Worker
Travers	Teacher

Relation 2

<u>Occupation</u>	<u>OSHA</u>	<u>Union</u>
Auto Worker	2	UAW
Miner	1	AMA
Professor	6	AFT
Steel Worker	4	Teamsters
Teacher	5	AFT
Trucker	1	Teamsters

With just relation 1, we can answer such queries as, "Print Name, where Occupation=Trucker." The more complicated query, "Print Name, where Union=AFT," requires us to first join the two relations together, using the common Occupation field to guarantee proper alignment. We then select only those entries where the Union field is AFT. Finally, we project and print the name fields of all selected entries.

Relational data bases can be implemented on conventional architectures, but might better be performed on multiprocessor systems that dedicate a processor to each relational table.

The objective of this project is to build a multiprocessor relational data base machine and to study the effectiveness of this configuration in answering user queries. The processors are loosely connected via a common bus with one processor acting as a bus arbitrator as well as the interface to the external world. The relational data base is partitioned across the secondary stores of

the processors, with each processor managing the portion of the data base under its control.

A user query received by the interface processor is decomposed into basic relational operations and forwarded to the appropriate processor(s) for execution. Thus support for both inter and intraquery parallelism is set up by the system. The processing of the basic relational operations is built into each processor with very little communication required with other processors, except for complex operations that join multiple relations.

This multiprocessor architecture for a database machine offers an attractive alternative to the sequential nature of processing offered by other approaches.

3.0 Artificial Intelligence

Current advances in computer hardware have far outdone advances in software. The gap promises to become even wider with the advent of fifth generation machines. Software must catch up by taking bold steps into the realms of artificial intelligence. The dreams of programs that understand, dreams that were so mocked during the 1970's, must become the realities of the 1980's. Of particular importance to the training requirements of NTEC are advances in natural language understanding and in the development of expert systems.

4.0 Summary

We have found that there are three technological areas that are being researched by the Computer Science Department at UCF and that can have a positive impact on the work being carried out at NTEC. These areas are low-cost animation, data base machine architectures and artificial intelligence.

Our interests in animation systems derive from two existing efforts. One

involves the design of user interfaces that allow non-programmers to develop animation software as part of training packages. To date our work here has been oriented towards high school teachers, but the lessons learned should carry over to those developing Naval training exercises. Our second related effort is in VLSI design. A high level animation chip is an interesting test case for the VLSI design procedures we are developing.

Our contribution to data base retrieval problems are greatly aided by the fact that we have interest and expertise in both the software and hardware aspects.

Finally, we have developed natural language interfaces to improve people's problem solving skills in several areas, including the programming of applications programs for banks. The methods used in solving these problems can easily apply to several categories of needs felt by NTEC.

SIMULATION AND TRAINING DEVICE TECHNOLOGY

TASK FORCE STUDY

SUBTASK IV - - - TRAINING VALUE

PART I - TECHNOLOGY ASSESSMENT

and

NEEDS ANALYSIS

SUBTASK IV - - - TRAINING VALUE
TECHNOLOGY ASSESSMENT AND NEEDS ANALYSIS
TABLE OF CONTENTS

	Page
1.0 Introduction	69
2.0 Methods and models for assessing simulator cost and effectiveness	71
2.1 Need for cost and effectiveness models	71
2.2 Existing methods and models for assessing simulator training cost and effectiveness	72
2.2.1 U.S. Army models	73
2.2.2 U.S. Air Force models	75
2.2.3 U.S. Navy models	76
2.3 Measurement commonalities and definitions for cost effectiveness	73
2.4 Macro-view of current cost-effectiveness model applications and their relative degree of utility in simulation training planning	81
3.0 Review of task categories and their suitability/ adaptability to simulation	86
4.0 Review of media options and their relative cost- effectiveness in accomplishing training in certain task categories	88
5.0 Needs analysis	91
References	95
Appendix 1 - Training Value Citations from NASA database	97
Appendix 2 - Training Value Citations from NTIS database	102

SUBTASK IV - - - TRAINING VALUE
TECHNOLOGY ASSESSMENT AND NEEDS ANALYSIS

1.0 Introduction

The basic research and exploratory development programs are designed to give the Navy the most cost effective training systems and equipments. These training systems provide the operating forces with the skilled operators and maintainers for the Navy's tactical weapon systems. But, in today's computer technological explosion, the sophistication and complexity of weapons systems places an additional challenge on the Navy's training programs. Just as weapon system technology is changing to provide the most cost effective defense posture, so must the training systems that provide the skilled manpower change.

The objective of this study was to determine the state-of-the-art in the measurement of the value of simulation training practices in military training activities, and to assess the need for new approaches or improved methodologies to be used in evaluating simulation training value. As indicated in Section 2.0 of this report, most of the previous work done in the area of training systems evaluation has been focused on the development of methodologies for measuring the cost and effectiveness of such systems. It is felt however, that before a given training system design can be evaluated, it is first necessary to determine a value base for training which will permit the determination of the worth of a particular system to the user. This suggests that some measure of benefit to the user be made for such a training system, possibly in terms of cost savings for training and improved operational effectiveness for the military system under consideration. With this investigation and analysis completed an assessment can then be as to where a research investment can lead to the increased efficiency of the training system.

The interest in the subject of training value has resulted from questions concerning effectiveness that are frequently raised during the planning, programming and budgeting process for training systems and equipment. Training systems and major devices are subjected to the same critical review and priority determination as are the tactical systems which they will support. Although cost and training effectiveness evaluations have been conducted, they cover only a limited portion of the overall military training system (Ref. 1). Even in this most recent paper, the authors caution the reader to use the information carefully. The cases that are used to develop quantitative cost effectiveness data are limited and show variation in cost but always are less expensive to operate than the operational system. The transfer effectiveness is handled more subjectively but is generally at least as good as training on the operational system. There are very few cases where intensive controlled experiments have to be conducted to determine the cost and training effectiveness of a training device.

Why should the issue of training value be pursued? The summary of the effectiveness studies reported on by Orlansky, String and Chatellier cover the areas of flight training including transition training of pilots, maintenance training and computer aided and computer managed instructions (Ref. 1). The flight training studies relate basically to flying skills rather than to the tactical employment of the aircraft. The maintenance area had very few experiments upon which to develop data. The maintenance training experiments cover a wide range of maintenance levels and operational systems. The maintenance levels include: operational or line maintenance, intermediate and depot maintenance. Operational systems cover a wide range of complexities and technologies. The 15 evaluation studies in the maintenance area represents a very small sample. The computer aided and managed instructional systems are most common in the basic skill training areas. Application of this technology

has been very limited in the system-specific training areas.

The ability of planning and acquisitions managers to address the effectiveness of alternatives in the training of operators, maintainers and teams is severely limited. They have relatively few tools to assist them. In the absence of those tools, program decisions are made on the basis of the experience factor. The inventory of training equipment for the services in these areas is extensive. This indicates that the arguments are logical and supportable in the planning process. The question that isn't answered is, how often are programs killed because there was inadequate cost and training effectiveness data to support the planning? These data can be summarized as follows:

1. Cost and effectiveness studies have only been conducted for a small number of components of the training systems with small samples.
2. The inventory of training devices is extensive.
3. Many training needs do not have the cost and training effectiveness data necessary to support the budget process.

2.0 Methods and models for assessing simulator cost and effectiveness.

2.1 Need for cost and effectiveness models.

One of the primary functions on top management in an organization is to make objective decisions based on the best available data. One of the tools available to managers is the use of various models to support the decision process. But the development of a viable, practical and reliable model is not a simple task. Training system top management is faced with the same issue in the decision process as are the other components of the Department of Defense. In fact, at some point in the process they become a recommender or supporter of training programs and training equipments rather than the ultimate decision

authority. Therefore, the need for effective models to support management objectives is essential.

The first question one must ask is, do any training and cost effectiveness models exist within the services of the Department of Defense? In order to answer this question two literature searches were initiated, one within the Department of Defense (Ref. 3) and the other through NASA (Ref. 4).

The literature search led to the development of the bibliography set forth in Appendices 1 and 3. These Appendices contain the references which were considered relevant to the training and cost effectiveness issues. Then selected references were ordered for detailed review and analysis.

The initial effort of that review and analysis was to trace the development of training and cost effectiveness models in each of the three Services: Army, Navy and Air Force. In undertaking the analysis such questions as model applicability, effectiveness, and frequency of use were addressed. From this analysis an assessment of the current status of such models was attempted.

The results of this phase will then determine the specific scope and depth of the next phase of the investigation. If the existing models are being utilized and are effective, the investigation would then look into the reasons why there is no experimental data to support the decision models. If there is little utility of existing models, what are the reasons that limit its usefulness or application?

2.2 Existing methods and models for assessing simulator trainer cost and effectiveness.

The next task involved in a detailed review of the cost and training effectiveness models identified in the literature search for the three services: Army, Navy and Air Force. The search did not reveal any Marine Corps models.

2.2.1 U.S. Army Models

Of the two Army related references (Ref. 4 and Ref. 5) which were obtained, only one that in fact reported on any Army Training and Cost Effectiveness Models is Ref. 4. The report was prepared for the U.S. Army Research Institute for Behavioral Sciences and was issued in September of 1980.

The report is especially valuable since it summarizes the characteristics of a number of Cost and Training Effectiveness Models that were reported on in the literature. Eleven models are reviewed and the essential features of the models were summarized. The models that were cited include:

1. Training Efficiency Estimation Model (TEEM), Jorgensen and Hoffer - 1978 (Army).
2. Training Consonance Analysis (TCA), Hawley and Thomasen - 1975 (Army).
3. Coordinated Human Resource Technology (CHRT), Goclowski, et. al.- 1978 (Air Force).
4. Training Effectiveness, Cost Effectiveness Prediction (TECEP), Braby, et. al. - 1975 (Navy).
5. Combined Arms Research and Analysis Facility (CARAF), BDM - 1976 (Army).
6. Method of Designing Instructional Alternatives (MODIA), Carpenter-Huffman, et. al. - 1977 (Army).
7. Digital Avionics Information System - Training Requirements Analysis Model User's Guide (DAIS/TRAMUG, Czuchny, et. al. - 1978 (Air Force).
8. Training Developers Decision (TDDA), Piere, et. al. - 1979 (Army).
9. B-1 SAT, Sugarman, et. al. - 1975 (Air Force).
10. Army CTEA Methods in Current Use (9 cases listed and each case briefly described).

11. Methods for the Analysis of Training Devices/Simulations. No basic model exists. The estimating models are generally inadequate *(Wheaton, et. al. - 1976). Not considered within scope of the study since the process is complex and detailed.

The report then goes on to describe the methods devised by the contractor to meet the CTEA methodology needs. The first method is empirical. It is to be used for predicting training programs and estimating their effectiveness. The second method is an interim procedure for dealing with the trainability issue while more refined methods are developed, and the last being a cost model.

The general CTEA model is shown in Figure V-1 of Reference 4. This model indicates the procedures to follow recognizing that conditions are different on every project. Table V-1 shows the method available for each phase of the process. Of particular interest to this investigation is the method cited for estimating training effectiveness. The report states that three methods for the estimation of effectiveness appear possible:

- (a) Analysis of how well a proposed training program "fits" the task to be trained.
- (b) Expert judgment about the relative effectiveness of a set up proposed programs.
- (c) Generalization of the demonstrated effectiveness of the training programs of one task to the training programs of all nearly identical (analogous) tasks.

The following metrics were obtained from the effectiveness models set forth in Table V-1.

1. The TEEM efficiency ratio =

score of an estimated program with real world constraints divided by the score of an idealized program with no constraints.

2. DIVAD GUN method = ordered ranking of alternatives by a panel of experts with experience in closely related systems.
3. Analogous task method = empirical effectiveness of analogous task is applied to the target task.
4. TRAINVICE Method.

Obtain an estimate of effectiveness for each subtask trained by a device. The separate estimates are then combined to obtain an overall device effectiveness.

This metric is qualified in the report. "It is also important to note that since there is not a way to combine the effectiveness estimation metrics of both training devices and training programs to yield a single metric as an estimate of the effectiveness of the training program with the device, the estimation of the effectiveness of the training device and the effectiveness of the training program must be considered as separate issues."

2.2.2 U.S. Air Force Models.

Of the two Air Force references selected for detailed review, one was actually a reprint of the relative cost and training effectiveness study of the 6883 (Ref. 6) three-dimensional simulator and actual equipment (1980). The other was a Master's thesis entitled, "A Cost Effectiveness Approach for Air Crew Training with Laser Guided Tactical Weapons (1973) (Ref. 7).

No model was referred to as the basis for predicting the training cost effectiveness of the 6883 Test Station Simulator. In the conclusion of the report the statement is made that students trained on the simulator performed as well as the students trained on the actual equipment. It was also pointed out that actual training benefits of the simulator were probably not realized because the simulator was designed in view of a "replacement" philosophy.

Given a "supplemental" objective improved performance becomes a major factor and an analysis of cost benefits in light of different levels of performance skill is more appropriate. Cost effectiveness is computed as the cost per student hour using the simulator and the actual equipment life cycle cost projections.

The Master's thesis written by Maj. Claude G. Kincaid in 1973 (Ref. 7) treats the employment of an aircraft in a tactical mission. From that standpoint it is the only document in the literature reviewed that addresses tactical training. Although simulators were considered they were not pursued because at the time the study there were no simulators with a tactical weapon delivery capability. Various other alternatives were considered in the study.

The tactical training problem selected for the thesis is fortunate. A well recognized metric exists to measure performance of the trainee. This metric is the circular error average (CEA) or the circular error probable (CEP). Another interesting aspect of this training scenario is that cost effectiveness includes the cost of the various alternative weapons that would be used to perform the training. The other studies or models do not consider the cost of weapons expended.

Although there were no direct citations of Air Force documents that contained Training and Cost Effectiveness Models, two references of Air Force Models were cited in (Ref. 4). Since they are included in Army sections they will not be addressed separately here.

2.2.3 U.S. Navy Models

The U.S. Navy has focused considerable effort on the evaluation of the cost and training effectiveness of proposed instructional delivery systems that has resulted in the development of a fairly comprehensive evaluation model, the TECEP technique (Ref. 8). Some early work by Willis and Peterson in 1961

(Ref. 9) on the application of learning theory principles to training device planning provided a basis for the delineation of Naval task categories. That work apparently set the stage for some work done by Chenzoff and Folley in 1965 (Ref. 10) on training analysis by means of the task analysis method. Additional work done by Rhodes, et al. in 1970 (Ref. 11) provided a means for analyzing and selecting media options, and further work done by Bernstein and Gonzales in 1971 (Ref. 12) on learning and retention provided important groundwork for delineating task category priorities for instructional delivery systems.

In 1972 a prototype Training Effectiveness and Cost Effectiveness Prediction (TECEP) Model was developed by Braby, et. al. (Ref. 8). The TECEP technique is a method for optimization of training media allocation on the basis of fixed training effectiveness and minimum cost. The overall model consists of three sub-models, each of which could function independently if so desired by a user. The sub-models are media substitution and selection, life cycle cost, and optimization. The TECEP approach involves nine steps as follows:

1. Task description and analysis.
2. Description of personnel characteristics.
3. Grouping of training tasks and training stages.
4. Determination of useful media options.
5. Calculation of media cost factors.
6. Selection of guidelines on media substitution and transfer.
7. Selection of primary and alternative mixes of media.
8. Optimization for least cost.
9. Economic analysis and instructional system recommendations.

In order to test its feasibility, the TECEP model was applied to the TA-4 aircraft training system. This involved a training analysis of the TA-4

training program so as to determine possible media substitutions. Using A-4 pilots, a mix of training media was selected for each task from possible media alternatives, such as classroom, cockpit procedures trainer, Device 2F90, Device 2F90 with wide angle visual, aircraft plus instructor and actual carrier landing.

So as to facilitate the optimization process the TECEP model was computerized. The outputs of the computer were:

- (1) media life cycle cost per utilization hours for all media considered
- (2) media hours per trainee for the existing system and an optimal system selected by a linear program
- (3) an alternative cost comparison between the existing system and the system chosen by the linear program

The basic assumption of the TECEP model is that the alternative training systems proposed will all produce personnel trained to an equal level of proficiency. In other words, it is assumed that each alternative is designed to have equal training effectiveness. This is a reasonable assumption given that the same degree of expertise and judgment has been supplied in the selection of media options and other trade off decisions in the TECEP evaluation process. Unfortunately, the model is not capable of identifying or selecting (from among the feasible set) the most efficient media. The model does not utilize any optimization criteria for ascertaining effectiveness or efficiency. This appears to be the most significant weakness of the model and more or less limits its use to cost trade-offs between alternative media sets.

2.3 Measurement commonalities and definitions for cost effectiveness.

One of the objectives of this technological assessment was to determine if there are any commonalities in the measurements used for training cost and

effectiveness. It is obvious from the data previously presented that there is no common metric for the measurement of training effectiveness. This conclusion is particularly significant. The fact that there are continuing research efforts in the area of training effectiveness given recognition to the importance that simulation and training devices as well as automated instructional systems are playing and will continue to play in the future. There is also a recognition that a great deal more must be understood of the role that simulators and training devices can play in increasing the efficiency of training as well as reduce its costs.

All of the models that were reviewed addressed the cost effectiveness issue. The cost metric developed in the Air Force report on the relative cost and training effectiveness of the 6883 three-dimensional simulator (Ref. 6) versus actual equipment is the cost per student hour. Although there were some slight differences in computation of costs, they all generally included acquisition as well as life cycle support costs for alternative systems. The Master's thesis of Capt. Kincade (Ref. 7) introduced the element of expending weapons and the cost of those weapons in achieving a prescribed proficiency level. In the training and cost effectiveness report on military training systems of Dr. Orlanky and String & Chatelier (Ref. 1) tactical weapon delivery exercises were not addressed.

In summary it can be stated that there is no measurement commonality for training effectiveness. Stated in another way, there is no common metric that is well understood and its significance accepted in the planning for and managing the acquisition of new weapon systems. The similarity or differences in tactical and non-tactical metrics may be interesting to explore now that visual systems have opened up areas in tactical training that were not previously possible. Specifically, air-to-ground weapon delivery and air-to-air combat.

2.4 Macro-view of current cost-effectiveness model applications and their relative degree of utility in simulation training planning.

The initial phase of the technological assessment addressed the identification of training and cost effectiveness models and the determination of the existence of one or more measurements that were basic or generic in nature. In this phase of the assessment, effectiveness measurement experiments were reviewed to determine what portion of the total training system of the Navy could be supported and justified based on proven experimental data.

In order to perform this analysis it will first be necessary to briefly define the Navy training system with simplified models as shown on Figures 1 and 2. Given the model, then the current inventory of training equipment will be identified with the various training programs. With these data available, the result of training effectiveness/cost effectiveness evaluations can be related to specific training programs. The results of this analysis would establish that a portion of Navy training programs are supported by effectiveness data. This does not imply that training programs and their associated training equipment are ineffective. It merely means that there is no experimental data to support the training effectiveness.

Another useful concept that would assist in this analysis is the "level of training concept." This level of training structure has been depicted in Figure 3 as a pyramid. The base level of the pyramid is visually referred to as the basic skills level. This level generally equates to recruit training and "A" schools in the Navy's Training Command. The aids and devices in the inventory which support these schools are usually of low dollar value but quantities are large. The second level can be divided into two sublevels. The first sublevel is associated with individual operation and maintainer training programs for

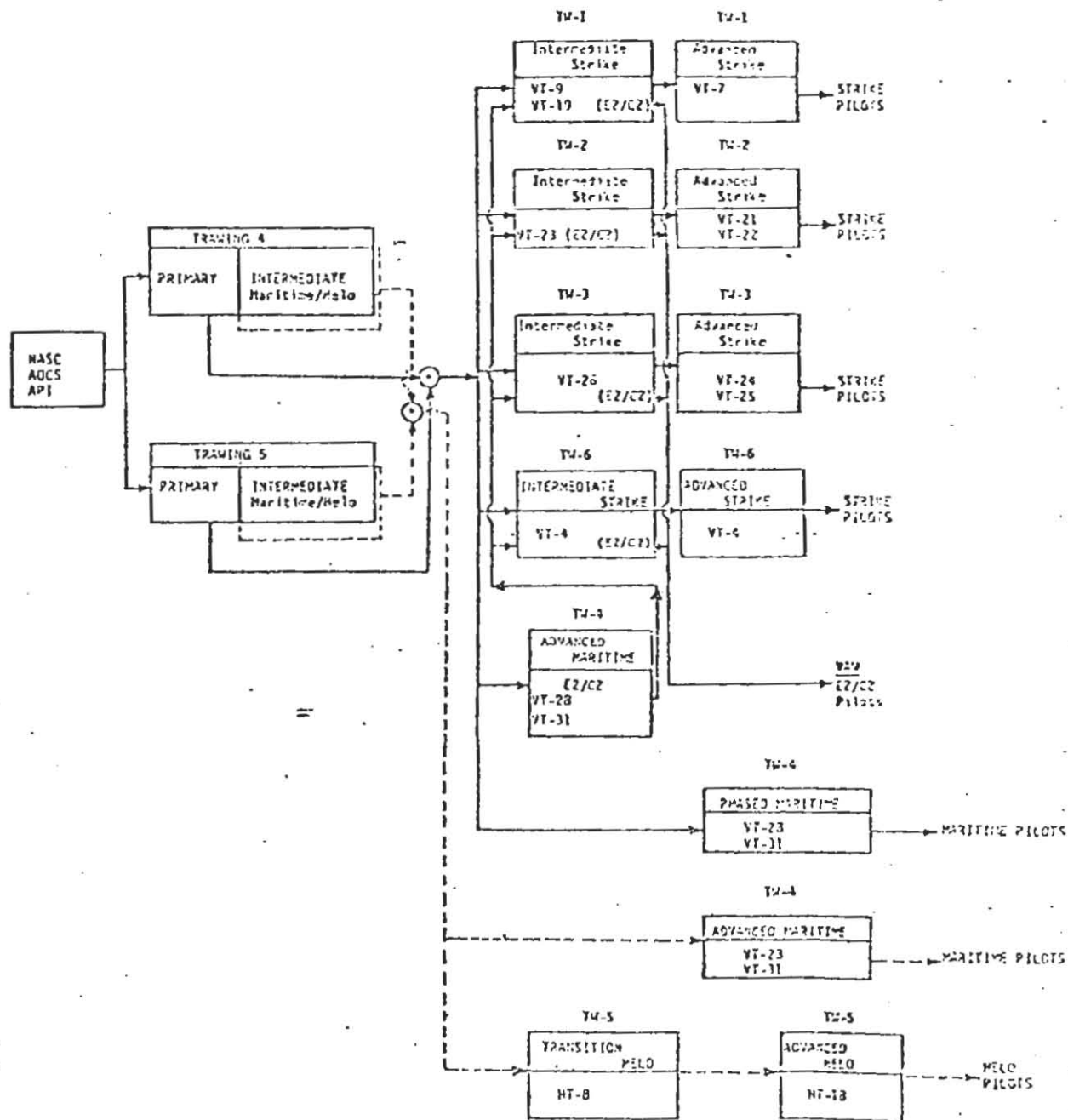
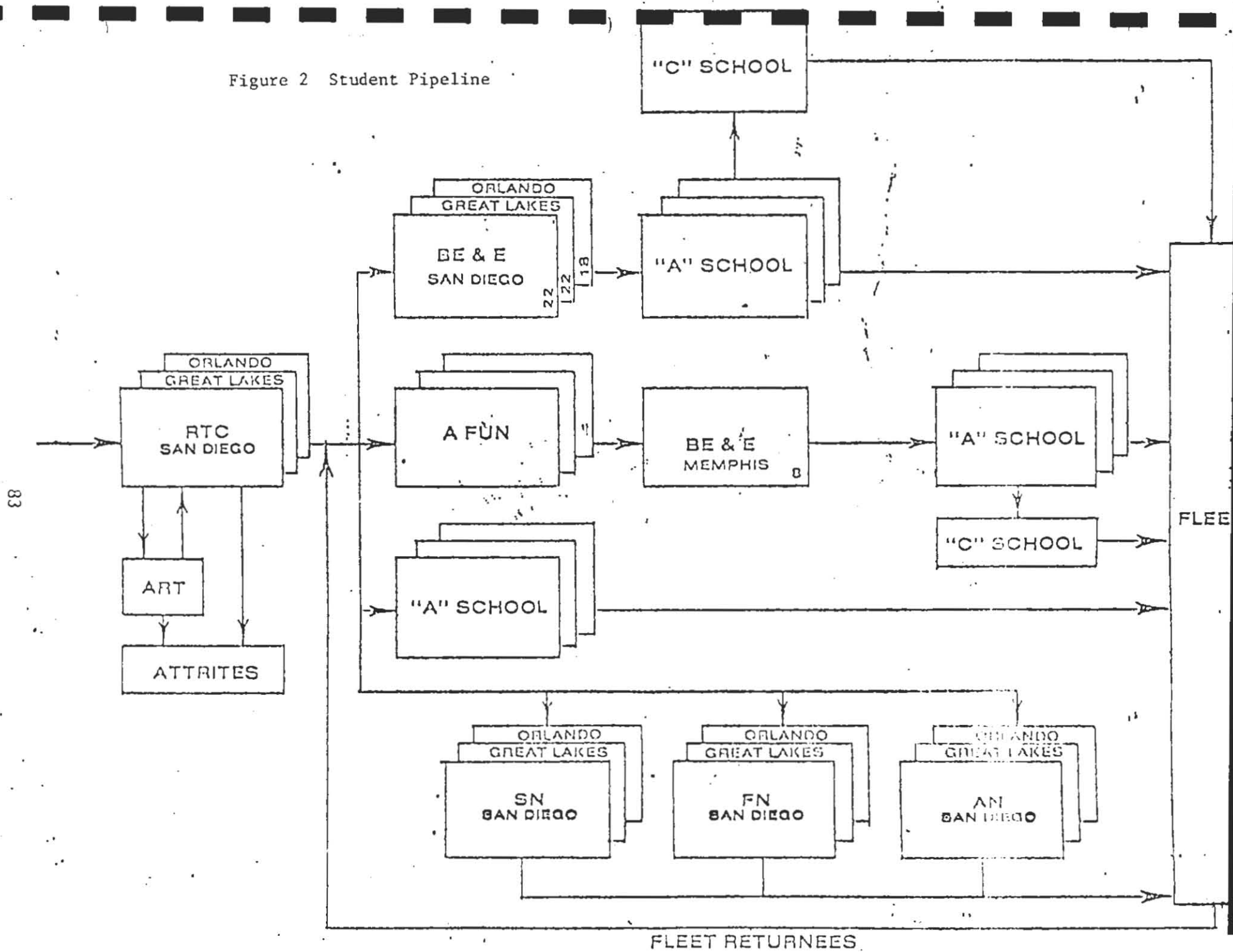


Figure 1. Naval Aviator Training Pipelines
(Reference: TAEG REPORT 116)

Figure 2 Student Pipeline



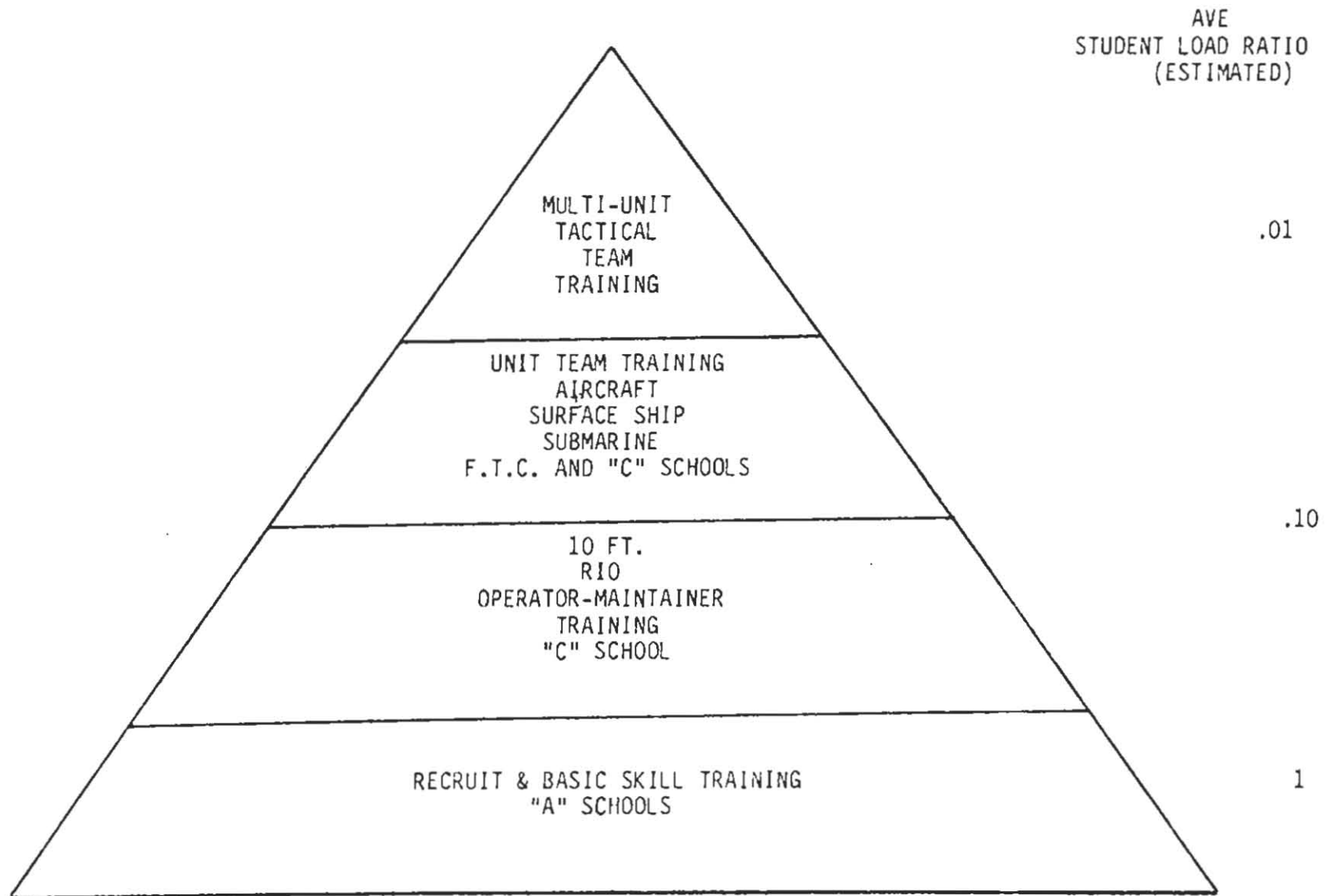


Figure 3. TRAINING SYSTEM STRUCTURE

specific equipments. The second sublevel is associated with single platform teams, such as submarine and surface ship combat system center teams, sonar teams, airborne ASW teams and the like. The "C" schools and Fleet Training Centers support these training programs. The largest percentage of the highly complex training device inventory support this training. The third level of training is the multi-unit coordinated tactical training. Tactical war gaming would also be included in this level. The number of trainees that require this level of training are few; the training systems that support this training are complex and expensive. The decision making skills are the critical training areas. Such factors as the assessment of the threat and the deployment of forces based on available resources would be key issues.

3.0 Review of task categories and their suitability/adaptability to simulation

Based on the training device distributed throughout the Navy's training system and the training programs where there is experimental evidence to support training and cost effectiveness one can conclude that only a fraction of the various categories of training have been formally validated. Again, this does not mean that training devices are not effective nor that simulators must be substituted for operational equipment in every case. It does mean that conducting controlled experiments is a very costly and time consuming process. This is evident from the limited number of studies that have been referenced. It also indicates that flight training has received special attention. The safety aspects of flight, the high cost of flight training as well as proficiency flying have caused a major and continuing focus on flight simulators, and rightfully so.

This background is presented to introduce the discussion of the task categories identified in Ref. 13. The bulk of the inventory of training devices supports individual operator and unit or multi-unit team tactical training. Without benefitting from an intensive analysis it can be assumed that a majority of the training scenarios include a majority or all of the task categories. Data previously presented points out the complexity and difficulty of applying ISD procedures to training devices. This deduction is indirectly supported by the lack of references in the literature reporting on the use of the various training and cost effectiveness models. Informal discussions with people in the training community tends to support the perception that these models are not frequently used. When they are used the applications tend to be in the areas of skill training.

This preamble to the review of the task categories and the suitability/adaptability to simulation sets the stage for what will become rather complex and difficult task. If we address single unit and multi-unit tactical team training it can be viewed as a large scale multi-input, multi-output system in which decisions must be made with varying degrees of filtering or noise in the communication links. The training process is further complicated since there may be more than one acceptable solution to the problem. If the training scenario involves a two-sided game, an additional complexity factor is added. A training and cost effectiveness experimental design for a full unit or multi-unit team training scenario can become too complex and thus too costly.

This places us in somewhat of a dilemma. The decomposition of a complex process involving numerous individuals into its detailed components or tasks is extremely complex. On the other hand it is extremely difficult to design training and cost effectiveness experiments that will validate the training provided by these systems. It appears as though the process of task decomposition offers the better choice of these two options. Task decomposition and analysis will lead to a better understanding of the individual tasks. This in turn will lead to a better understanding of the individual skill required, the best way to train for those skills considering time to achieve proficiency, retention and forgetting rates and the like. When these basic training objectives are defined they should result in aids and devices which are at the lower end of the cost spectrum.

This approach does leave the job of training an integrated teams to systems identical or similar to current team type trainees. (Individual operator training skills are not trained on complex team trainer devices.)

4.0 Review of media options and their relative cost effectiveness in accomplishing training in certain task categories.

The media options that are usually considered in cost and training effectiveness models are set forth in Table 1. These options were obtained from Table 4, p. 11 of Ref. 3. The objective of the TECEP Model is to achieve an optimum match of tasks, learning objectives, and the most cost effective instructional media. A review of the instructional media listed in Table 1 shows that the 20 media listed, a majority of them are at the low end of the cost spectrum. Those media are usually associated with the delivery of basic skills or information on the operation and maintainance of equipment weapon systems. In costing out these options a distinction must be made between the instructional material development costs and the delivery system costs.

When one looks at the training device end of the media selection matrix there are fewer alternatives. The cost of these systems are usually extremely high, some approaching the cost of the operational systems which they simulate. These devices usually support operational and single platform team training. This training device (Media) segment of the spectrum is the area that is not specifically addressed in (Ref. 4) because of its scope and complexity.

These data can only lead to one conclusion, there is insufficient theoretical or experimental data for inclusion in a general training device training and cost effectiveness model. The development of these data is not anticipated to be a simple task. The slope of the cost versus effectiveness/fidelity curve is steep; the incorporation of increased capability and fidelity results in geometric cost increases. Although each service has experimented with the "low-cost" trainer as an alternative to the traditional operational flight trainer or weapon system trainer, there is little in the literature that quantifies the cost versus task training effectiveness

relationships. The establishment of such relationships are essential if the training and cost effectiveness model are to be applied to major training system design discussions. These decisions are made during the concept formulation phase of the program. Another aspect of cost that generally has not been addressed relates to those cases when the cost of a training device actually exceeds that of the operational equipment that it supports. Are there circumstances where the operational equipment is not a suitable training vehicle? In these circumstances would it be more logical to use the power and effectiveness of simulation technology (given the effectiveness has been established) even if the training device acquisition cost equals or exceeds the cost of the operational equipment? In these cases other factors must be included in the cost model. These could include: safety (injury or death), potential damage or destruction of the operational system, need for extensive firing ranges to measure performance, lack of adequate tactical gaming areas, potential environmental impact, and the like.

The data on effectiveness of specific media is at best sparse for the major device (high cost). This lack of validated data forces decisions to be made on the basis of past experience and judgment. When there has been a significant increase in weapon system capability because of technological advancements there is the possibility that these judgments are incorrect. There is a logical argument to attempt to increase the knowledge base on training and cost effectiveness metrics for media/training devices at the high cost portion of the spectrum.

TABLE 1

MEDIA IN MEDIA SELECTION MATRIX

1.	CCTV	Closed Circuit Television Without Feedback
2.	PI (L)	Linear Programmed Instruction Text
3.	PI (B)	Programmed Instruction Text With Branching
4.	SRS (T/S)	Student Response System, Feedback to Teacher and Students
5.	SRS (AV)	Student Response System with Audio-Visual Program
6.	PIA	Portable Instructor Aids (projectors and recordings)
7.	CAI (MM)	Computer Assisted Instruction with Mixed Media
8.	LCD (AV)	Learner-Centered AV Devices - Carrel
9.	VTR	Portable Video Tape Recorder System
10.	LECT/TEXT	Conventional Classroom: instructor, lecture and textbook
11.	PA	Performance Aids
12.	Carrel/Mock-Up	Audio-Visual Carrel with Equipment Mock-Up
13.	SIM	Simulator
14.	SIM/AA	Simulator with Automatic and Adaptive Features
15.	PROC TNR	Computer Activated Procedure Trainer
16.	PROC TNR/AA	Computer Activated Procedure Trainer with Automatic and Adaptive Features
17.	Manual PROC TNR	Manual Procedure Trainer
18.	C/Gaming	Computer Gaming Trainer
19.	OP/SYS	Operational System
20.	OP/SYS & SIM	Operational System Plus Simulation

5.() Needs Analysis

As a result of the literature search and the analysis of the data one must conclude that there are no widely used and generally accepted training and cost effectiveness models. The majority of the effectiveness evaluations are summarized in Dr. Orlansky's et al. paper published in the Proceedings of the 4th Interservice Industry Training Equipment Conference (Ref. 1). As stated previously, the portion of the training equipment inventory covered by such evaluations is extremely limited.

The modeling effort which has been accomplished to date is basically cost effectiveness oriented and limited in application to low cost media. There is still a good deal of experience and judgment which must be exercised in the media selection when using the model for complex training devices. In addition these cost models are generally being applied to the low cost, individual, basic training portion of the training system. There is little evidence in the literature that would assist in media selection and cost versus effectiveness trade-offs for devices which support advanced individual and team training.

This implies that the basic components of a model that would be necessary for its construction are not available in a usable form or are unknown. The model components which are essential if training and cost effectiveness issues are to be addressed in the development of advanced training systems are in the area of single platform team training.

The task of applying the twelve basic learning algorithms, (Ref. 14) to complex team training scenarios is difficult. There is no information reprinted in the literature that has been reviewed to indicate that it has been successfully accomplished. In fact (Ref. 4) indicates that the task is difficult and complex. In order to develop the data for inclusion in a model there is need for basic research into the area of combat system team training.

The development of the components of the training and cost effectiveness model for team training probably should be constructed from the relationships of individual team members to the basic learning algorithms (Ref. 13). This suggests a matrix of team member to learning algorithms or tasks. Such a matrix would also give cues to the degree of interaction between team member and the relative importance of these interactions with respect to the tactical scenario.

A decomposition of the team task into its individual new components then permits the application of computer aided and managed instructional strategies into this area of training. Such issues as learning, retention, and transfer can be more effectively treated at the individual trainee level. The frequency and importance of the human links in the combat team must be developed if the individual operator's scenarios are to be representative of the tasks he must learn and achieve proficiency in. This requires the availability of an intelligent system to perform the role of other team members.

Given that such a team training strategy is viable, the other data needed to produce the model is the relationship between training effectiveness and cost. Although much has to be written about the general form or shape of the curve, there is little or no experimental data to establish this relationship to the degree necessary to produce ineditable model results. The difficult task is to develop a continuum of devices that cover the range from basic operator training to single-platform team-training. Costs relationships must then be developed for these various alternatives.

The task of determining the training device alternatives and their associated costs is complex since there may be many branches or paths in the instructional strategy. Once developed, the team member - task/algorithm matrix, will give some insight into the magnitude of the task. There are a number of sound reasons why this investigation into complex team training should be pursued. First there is little or no data in the literature which addresses training and cost effectiveness of combat teams. Cost models which have been developed usually address media at the low end of the cost spectrum, not complex training devices. The cost of tactical equipment which was used in operator and team trainers is becoming very expensive. This constrains the degree to which that equipment can be replicated in the training plan. Finally the decomposition of team training into the basic learning algorithm will facilitate the inclusion of performance, measurement, an essential prerequisite for effective individualized instruction.

In summary the investigation has concluded that there are no generally accepted and widely used training and cost effectiveness models. Models that are available are generally difficult to use and this has limited their use to the more basic training tasks. It is also concluded that it would be extremely difficult to expand the models to cover the complex devices used in advanced training. Complex team training requirements should probably be decomposed so that training could be conducted at the individual team member level. This would require the application of artificial intelligence systems to play the role of the other team members.

By proceeding in this way, maximum advantage is taken of previous model development efforts, eg. TECEP.

A secondary effort, and equally important is the development of the cost vs. effectiveness relationship on a quantitative basis. If the extended TECEP model is to provide meaningful information for decision making, it must have valid cost vs. effectiveness relationships within the individual training concept for team training.

Finally, with the information developed from the two preceding tasks, particularly the second task, methods of quantifying training value will be investigated. The cost vs. effectiveness function is the next phase of the research.

The basic research proposal concepts developed above address one of the most important areas of training research. The extension of effectiveness models to address training as well as the cost issue. In developing this concept it attacks one of the most difficult training areas, team training, through the application of artificial intelligence systems to replace interaction with other team members.

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APPENDIX 1

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APPENDIX 2

TRAINING VALUE CITATIONS FROM NTIS DATABASE

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SIMULATION AND TRAINING DEVICE TECHNOLOGY
TASK FORCE STUDY

SUBTASK V - - - MAINTENANCE TRAINING
TECHNOLOGY ASSESSMENT

AND
NEEDS ANALYSIS

SUBTASK V - - - MAINTENANCE TRAINING
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TABLE OF CONTENTS

	Page
1.0 Background	
1.1 Training in Maintenance	106
1.2 Traditional Training Programs	106
1.2.1 Formal Training	106
1.2.2 On-The-Job Training	107
1.3 Techniques of System Design Which Affect Training	108
1.3.1 Modularization	108
1.3.2 Automatic Testing	108
1.4 Job Aids	109
1.4.1 Paper Job Aids	109
1.4.2 Non-Paper Job Aids	109
2.0 Current Assessment	110
2.1 Traditional Performance Measures	110
2.1.1 Error Rate	110
2.1.2 Elapsed Maintenance Time	110
2.2 Contributing Factors	111
2.2.1 Low Enlistment Rate	111
2.2.2 High Attrition Rate	111
2.2.2.1 Retirement Attrition	111
2.2.2.2 Non-Retirement Attrition	112
2.2.3 Low Quality of Current Enlistees	112
2.2.4 Increase in System Sophistication	112
2.3 Cost Impact	113
2.4 Improvement Efforts	114
2.4.1 Program Efforts	114
2.4.2 Concept Efforts	114
2.4.2.1 Personal Electronic Aid for Maintenance (PEAM)	114
2.5 Current Results	115
3.0 Conclusion	118

1.0 BACKGROUND

1.1 Training in Maintenance

In general, training in maintenance is similar to other areas of training. The basic concepts of training value, human factors, simulation, and data processing all apply to maintenance training in manners similar to how they apply to other areas of training. However, close scrutiny of most U.S. military maintenance training programs reveals that past and current (i.e., generally traditional) training programs have not reduced the critical levels of those measures which are commonly used to gauge the degree of success in maintenance programs. (Ref. 1) If anything, the trend of these performance measures over the last decade has been for the worse. (Ref. 1) Consequently, new approaches and new concepts are needed in this area of maintenance training.

1.2 Traditional Training Programs

Formal training or On-the-Job training are by far the most common training methods and the most extensively used. (Ref. 1) The methods are exactly the same except for the location of the training administration. Both methods provide training to the untrained by other trained and experienced individuals.

1.2.1 Formal Training

In this method the trainer or instructor is generally assigned to the training task as his/her primary duty. The trainers are well qualified, usually well experienced (this is not necessarily a firm prerequisite, however) in the specific area and usually are of median rank of authority and of seniority.

The training is conducted in a formal classroom manner. The actual work environment of the related task is generally ignored as long as such is not considered to be in the extreme. This classroom concept allows for the student (trainee) to teacher (trainer) ratio to be very large, often as large as 50:1 or higher.

The use of such auxiliary training aids as motion pictures, videotape, tape recordings, textbooks, homework, photographic slides, etc. tends to be very high in this training method. Also used to a high degree are such aids as simulation and static mock-ups of actual equipment configurations.

The cost per training hour in this method tends to be generally high because of the cost of quality instructors, the classroom facility, the training aids, the fact that no production is done during the training, and the cost of transporting the trainees to and from their permanent stations and of housing them during the training program. In the long run when such things as the classroom facility and the training aids are long since paid for, the overall cost per training hour of this method may drop somewhat. Naturally, the larger the enrollment the lower the cost per trainee hour.

1.2.2 On-The-Job Training

This training method differs from the formal method in that on-the-job training is not conducted in a classroom, but is performed on the job site. Training is provided by another experienced worker or a supervisor. Hence, the trainee to trainer ratio can be very small. There usually is no need for visual training aids because the trainee is able to observe the job situations in vitro. Another difference is that the environmental conditions of the job are experienced by the trainee during the training sessions.

The cost per training hour is generally low for this method in spite of the fact that the trainee to trainer ratio may be as low as 1:1. The key reasons for this are that there are no classroom facilities needed, none (or very few) training aids are used, that production is occurring during training from the outset, that the trainer is not required to be as qualified, and that the trainer is performing a production function during the conduct of the training program.

1.3 Techniques of System Design Which Affect Training

1.3.1 Modularization

Modularization is a technique of equipment design which causes each system to be comprised of many smaller subsystems each of which is a self-contained unit and as such can be removed from the system and replaced by a similar component quickly and simply. (Ref. 1)

Hence, modularization of a system causes the maintenance program of that system to be completely different than such programs for conventional systems. There is generally less emphasis on diagnostics and trouble-shooting in the new training programs, therefore requiring less judgement on the part of the maintenance operator. Thus, the training programs related to modularized systems are shorter and less expensive than conventional system training programs.

1.3.2 Automatic Testing

Automatic testing is another system design technique intended to assist the maintenance operator. The concept is based on the premise that competent diagnostic and trouble-shooting capability is the most difficult skill to achieve in maintenance operators. Hence, the system is designed with an integrated electronic check system which when queried by a maintenance operator will automatically isolate the trouble area and/or identify the specific problem itself. (Ref. 2)

Maintenance programs for systems with automatic testing capability tend to be shorter and less involved than for conventional systems. Therefore, the cost per hour of training is substantially less than for a conventional training program. It should be noted that the cost of design and the cost of manufacture of systems with automatic testing capability can be very high, however.

It is noteworthy that these two design concepts have no bearing on existing systems and the problems associated with their maintenance programs.

1.4 Job Aids

Job aids are devices which assist the maintenance operator while on the job. They are used as ready reference to the specific task and are for the maintenance operator to use at his/her discretion.

1.4.1 Paper Job Aids

The traditional job aid has been a paper one, or the technical manual. The technical manual has in detail virtually everything on or about a specific system. Presented therein are sections of the theory of operation, the system design, the method of manufacture, the installation specifics, and the use of each component of the system. A significant drawback to this type of job aid is that it is very difficult to keep it up to date (as maintenance methods change and systems modifications are made). Many maintenance errors have occurred because maintenance operators were using out-of-date manuals to assist them in their duties. (Ref. 2)

1.4.2 Non-Paper Job Aids

Such job aids are in the embryonic stage of development and as such cover a broad spectrum of design, technique, and type. Generally, they are attempts either to overcome the classical drawbacks of the paper job aid or to incorporate some new technology such as videotape or microprocessors.

The purpose of non-paper job aids originally was the same as that of the conventional paper aids. Recently, however, some proposed non-paper job aids are promising to do more, namely, to provide training as well as provide documentation. (See section 2.4.2.1)

The problem of updating the non-paper job aid is usually eliminated. This is because most non-paper job aid designs are electronically controlled and as such can be brought up-to-date by means of some simple process.

2.0 CURRENT ASSESSMENT

This section shall summarize the success level of current training programs in terms of two traditional performance measures. In addition a series of discussions on some contributing factors will be presented.

2.1 Traditional Performance Measures

In order to evaluate whether change is occurring in a system or program something must be measured in a quantifiable manner so that comparisons can easily be made. In current practice there are two such measures: Error Rate and Elapsed Maintenance Time.

2.1.1 Error Rate

Errors can occur in three different ways. They are identified by types. (Ref. 1)

Type I: Diagnosis of a good unit as bad

Type II: Diagnosis of a bad unit as good

Type III: The damaging of one unit while another is being worked on

The rate of errors by each type has been sufficiently large to cause many researchers and problem-solvers to dedicate much time in the development of new training programs, new training techniques, and new system designs. Yet the rate of errors of each type has increased annually for several years. (Ref. 1)

2.1.2 Elapsed Maintenance Time

This performance measure allows for the cost of maintenance to be quantified in terms of the loss of use of the down (out-of-service) system and in terms of the amount of labor hours the repair requires. (Ref. 1)

There is a direct correlation between error rates and elapsed maintenance time which is intuitively apparent. For each error of any type which occurs, the amount of time elapsed during the maintenance operation increases.

2.2 Contributing Factors

When the overall situation of maintenance (recruitment, training, attrition, etc.) is scrutinized, a number of conditions, facts, or tendencies is observed which has bearing on this problem. A few of the major contributing factors are presented and discussed in this section.

2.2.1 Low Enlistment Rate

Since the Viet Nam war the armed services have been experiencing greater and greater difficulty in replacing personnel at the normal attrition rate due to retirement. This is due in part to the gradual reduction in the size of the population in the 17 to 19 year old age group. (Ref. 3) In addition, the young people of the United States are not as attracted to a military career as they once were. Such factors as the lack of knowledge concerning the nature and location of the first assignment, the seemingly low pay scale compared to comparable civilian jobs, the high degree of travel (or assignment changes), and the low reputation of the basic training courses are significant contributors to this situation. (Ref. 3)

2.2.2 High Attrition Rate

There are two separate types of attrition, that of retirement and that of non-retirement.

2.2.2.1 Retirement Attrition

During the decade of the 1970's most of the career personnel from World War II (WWII) retired and in spite of the bolstering of the career ranks during the Korean and the Viet Nam wars the numbers were not large enough to compensate for the volume of departing WWII personnel. (Ref. 3) It is noteworthy that in a qualitative sense the dedication, motivation, and integrity aspects of the post-WWII personnel are perceptively of a lower order than these aspects were in WWII and pre-WWII personnel. (Ref. 3) In other words, the general character

of the military as a whole has made a transition in the last few decades in a deteriorating sense. It is difficult to be too specific about this transition since reliable data are not available, but it is clear that the problem of conducting successful initial training and up-grade training is more acute because of it. It is possible that the higher percentage of career personnel which retire prior to thirty years of service is due to the recent configurational changes in the retirement benefits program.

2.2.2.2 Non-Retirement Attrition

The military has been experiencing a new ailment, that of the difficulty of keeping new personnel past their first assignment. (Ref. 1) Apparently these first-timers are finding the military atmosphere in general is not what they expected. It is difficult to pinpoint the source (or sources) of this problem other than to recognize that it exists and observe that it accentuates the criticality of the overall problem identified in this report.

2.3.2 Low Quality of Current Enlistees

There has been a trend in the last several years of generally lower aptitudes and lower motivation of the new enlistees. (Ref. 1) This coupled with the marked increase in system sophistication (see Section 2.2.4) during the same period, has placed unbearable burdens for success on traditional training programs.

2.2.4 Increase in System Sophistication

In the past several years defense systems have undergone a large-scale up-grade operation. The new systems in virtually every case are extremely more sophisticated than their predecessors. (Ref. 1) This high level of sophistication is in the area of their scope and in their capability, but not in the area of their servicability. (Ref. 1) High sophistication in

servicability implies that the system first of all should not break down as often and as severely (e.g., solid state electronics) as previous systems, and then in the instances when a breakdown has occurred the malfunction should be easier to rectify than in previous systems (e.g., modularization).

Unfortunately, the high sophistication of the capability of new systems has not been paralleled by their sophistication of maintenance design. This can at least partially be attributed to the low bid concept of defense contract selection. System objectives are capability oriented and support/maintenance considerations are secondary in importance. Hence, when budgets are cut and when bids are revised the maintenance aspects are simplified and streamlined and sometimes even eliminated.

2.3 Cost Impact

The cost of today's defense systems is staggeringly high. So high it is that when expressing totals it usually is in the billions of dollars. It is unfortunately true that a large percentage of these expensive systems is at any point in time not operationally ready. (Ref. 1) There are many reasons for this situation among which are scheduled maintenance, operational misuse, operational damage due to normal wear-and-tear, improper design, and improper maintenance. Although there are insufficient data available to accurately quantify the cost associated with each cause, it is clear that based on the data on error rates and elapsed maintenance times, previously alluded to in conjunction with the extremely high front-end cost of the systems involved, the costs due to improper maintenance are very high indeed. And if the point has not already solidly been made, the cause for improper maintenance is largely the inability of present training programs to adequately prepare the current force of maintenance operators to handle current maintenance tasks.

2.4 Improvement Efforts

The described situation has been a major concern of the Department of Defence (DoD) for some years and the efforts made to improve this situation can be classified into two groups: Program Efforts and Concept Efforts.

2.4.1 Program Efforts

There have been so many program changes and new program initiations made in recent years that it is beyond the scope of this report to enumerate them. In general, the efforts have endeavored to improve the quality and quantity of new enlistees. The problems associated with non-retirement attrition (promotion, pay, assignments, etc.) have been much more difficult to change in the short-term and instead improvement efforts in this area have concentrated on the basic training, technical training, and up-grade training programs for maintenance operators. Such efforts in general have attempted to make these programs more pleasant, more modern, more pertinent and (sadly) less difficult. (Ref. 6)

2.4.2 Concept Efforts

Concurrent with the program efforts the DoD has investigated through independent research the possibility of changing the traditional concept of maintenance in hope of finding a method which will accommodate the caliber of the new enlistee and the new high sophistication of defense systems. Needless to say this has been no small order and the investigation continues. One concept has emerged from such research and has received much attention from several sources. This concept called the electronic personal job aid deserves specific mention.

2.4.2.1 Personal Electronic Aid for Maintenance (PEAM) (Ref. 1)

The PEAM concept is very simple: Eliminate all traditional training programs. The application of this concept to the current situation is not

simple at all, however. The current viewpoint is to issue each new enlistee designated for maintenance careers with a PEAM in the form of a hand-held microprocessor with a visual display capability and perhaps a synthesized voice communication capability. With the assumption of tabula rasa (that the enlistee knows nothing at the beginning) the PEAM coupled with the enlistee make a fully capable, fully trained team. Whenever a maintenance task is encountered, the enlistee queries his/her PEAM and is shown (and perhaps told) what to do step by step. Each step of the way the enlistee 'tells' his/her PEAM how things are going and the PEAM (being omniscient and omnipotent) adjusts its subsequent instructions accordingly. There are many apparent and innumerable subliminal rough edges to the PEAM concept, but if it can be assumed that in development these will be overcome, the concept has considerable merit. For instance, the problem of low quality at the enlistee level is solved because such would have no effect. The problem of high non-retirement attrition could be partially solved because of the low difficulty level of the task. The cost of development and application of this concept notwithstanding, it can be seen that the high cost of current training programs will be eliminated and the paucity of modularization and automatic testing capability in new systems would not be as worrisome as it now is.

2.5 Current Results

Unfortunately the results based on data for error rates and elapsed maintenance times are less than satisfactory as has previously been mentioned. Errors of all types continue to mount, and the elapsed maintenance times are climbing. These conditions are understandable when it is observed that there are lower numbers of new trainees all of whom are less qualified and less motivated than desired, which are being sent through traditional training

programs (which are certainly being conducted with the latest technology of teaching method and aids, but also are not compatible with the calibre of the trainees) and then being assigned to work on highly expensive and sophisticated equipment which is more difficult to diagnose and repair than ever before, in conjunction with a shortage of experienced senior personnel and unattractive career motivators. It is remarkable that the situation is not worse than it is.

It is quite apparent that all the funds being spent on conducting and improving the formal, on-the-job, and up-grade training programs is not solving the problem. Granted such may be preventing the problem from becoming severe, but there is not any measure of improvement that is evident.

Furthermore, it appears that in those systems which have design enhancements of modularization and/or automatic testing that the measures of error rate and elapsed maintenance time are not demonstrating impressive results. One possible conclusion from this evidence is that if the individual maintenance operators are not properly trained (or at least properly capable in some fashion) such planned features as modularization or automatic testing are not compensatory. Expressed in another way, if the maintenance operator does not know about the special features (as a result of no training, no experience, etc.) these features are useless.

Finally, the low enlistment rate coupled with the high non-retirement attrition rate comprises a situation which is not at all attractive. Speculative reasons behind this include the idea that the young inexperienced (and perhaps marginally trained) maintenance operators find the environment of working on expensive equipment with the lack of adequate supervision (in quality and quantity) uncomfortable and unregarding. Hence, their job performance

deteriorates and their job satisfaction is eroded and the non-retirement attrition escalates.

It is difficult to assess whether the concept efforts discussed in Section 2.4.2 have been successful because none of the new concepts have been designed into any system. It is possible to consider the idea behind modularization and automatic testing as a concept effort in that the problem was approached from the equipment point of view, i.e., make the problems easier to diagnose and easier to repair. Unfortunately, the results have not been favorable to support the idea that this concept is a successful approach. Perhaps if the new enlistees were better qualified, better capable, or better motivated this idea would be more successful.

It seems clear that a concept change is required in order to solve this problem. To be successful the concept would need to be flexible to adapt to different quality levels of the user and to adapt to changing system designs, design modifications, and higher levels of sophistication. Furthermore, the concept must enable the maintenance operators to solve specific maintenance problems quickly and with a minimization of error.

3.0 CONCLUSION

The program efforts discussed in Section 2.4.2 can generally be classed as failures because there is little evidence of improvement in the performance measures.

Judging from the magnitude of money tied up in DoD systems and the large proportion of these systems which is non-operationally ready at any point in time, there appears to be a significantly high potential for foundation level research support in a wide variety of areas in the maintenance training paradigm.

The following list of target areas (presented in order of priority for further investigation) summarized points made in this report and touches on some areas not discussed in this report. More information will be available in the next report.

1. Electronic Job Aid
 - 1.1 Hardware design - Keyboard, Visual Display
 - 1.2 Software design - Hierarchical levels of detail
2. Diagnostics
 - 2.1 Formal Training
 - 2.2 Improved Techniques
 - 2.3 Simplified Equipment System Design
 - 2.4 Training by Simulation
3. Maintenance Operations
 - 3.1 Robotics
 - 3.2 Improved Techniques
4. Personnel/Equipment Allocation
 - 4.1 Queuing Innovations
 - 4.2 Scheduling Innovations
 - 4.3 Forecasting Innovations
 - 4.4 Recruiting, Evaluation, Screening
5. Psychological Aspects
 - 5.1 Adaptive Training Programs
 - 5.2 Adaptive Job Descriptions
 - 5.3 Adaptive Supervision and Career Management

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