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Technical Report

Calspan Corporation
Buffalo, New York 14221

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AN ASSESSMENT OF THE ROLE OF SIMULATORS
IN MILITARY TACTICAL FLIGHT TRAINING
(Volume II Assessment Based on Literature Survey)

C.R. Chalk and R. Wasserman

Calspan Report No. AK-5970-F-1 – 001-2

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The objective of this study was to assess the use of simulators in military tactical flight training. The assessment was made on the basis of information obtained from a literature survey and a survey of individuals in industry and government agencies who are knowledgeable about flight simulators, military tactical flight training and related matters. Forty six organizations were visited during the survey. Assessments are made of the use of simulators for training the →

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) following flight phases or tasks: cockpit procedures, instrument flight, emergency procedures, takeoff and landing, formation flight, aerial refueling, dynamic failures, ground attack, training of maneuver limits, recovery form uncontrolled flight, air combat and nonpilot crew stations. Other aspects of the use of simulators for aircrew training are discussed and problem areas requiring research and development effort are identified.

PREFACE

This document was prepared by Calspan Corporation under Contract MDS903-76-C-0274. The contract was performed for the Office of the Assistant Secretary of Defense, Office of the Director, Planning and Evaluation. The project was monitored by Maj. George Burkley.

In the performance of this contract, Calspan visited and interviewed personnel of many government agencies and private companies. The cooperation of these organizations and the individuals interviewed is acknowledged.

In preparing this report, Mr. Wasserman was responsible for documenting the literature review. Volume II of this report is based on the information gathered in this survey of existing literature.

Volume I of this report is based on the survey interviews performed primarily by Mr. C.R. Chalk.

The opinions expressed in this report are those of the authors and are not necessarily shared by the Department of Defense. Publication of this report to document the study and to promote the exchange of information and ideas in no way implies DOD sanction of the views expressed herein.

EXECUTIVE SUMMARY

1. This is a final report (for the period 15 April 1976 to 30 September 1976) on the Assessment of the Role of Simulators in Military Tactical Flight Training, based on a literature survey conducted by Calspan Corporation, Buffalo, New York. The object of this volume of the report is to detail the data obtained relating to flight simulation (in general) with specific attention directed towards the use of flight simulation devices for tactical flight crew training.

2. This study indicates that there is insufficient objective data available with which to perform hard trade studies to analyze various training options, or to demonstrate the cost-effectiveness of tactical flight training simulators. The cost-effectiveness of many simulation capabilities, e.g. instructional features, is not well documented. Little information is available on the impact of various levels of "cue" fidelity or "cue" interaction on transfer-of-training. The existing state-of-the-art appears to be limited in its capability to permit substitution of simulator hours for flying hours, except primarily for procedural (normal or emergency) and instrument flight phases. The state-of-the-art is sufficient to provide supplemental training in the tactical mission, provided the courses are tightly controlled.

3. Short-term priorities should be established to determine minimum device requirements to obtain the desired training objectives, improve the maintainability and reliability of existing flight simulators, and evaluate the proper training and utilization of instructors to provide efficient and effective use of existing facilities.

4. To achieve significant reductions in the flight hours required for military tactical mission training, continued research and development is required, specifically directed at visual and motion system requirements and mathematical modeling of aircraft (especially at flight envelope extremes). In addition, it may be necessary to assess the application of

parallel digital computer concepts and modifications to existing numerical solution techniques to minimize the impact of digital computer limitations on the simulation of tactical aircraft and representative mission environments for training.

5. Alternatives to the use of simulation to conserve limited fuel resources and reduce ordinance costs are feasible and a detailed assessment of the following areas is recommended:

- fuel efficient engine development for aircraft
- fuel efficient trajectories using optimal control theory
- development of low cost airborne instrumentation system to simulate ordinance
- development of low cost in-flight simulation capability
- develop more effective 'wash-out' screening procedures

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Section I
LITERATURE SURVEY INTRODUCTION

The objective of the contract performed by Calspan was to examine the application of specific training devices (i.e., flight simulators) to tactical flight training for military application. This application assessment would be made using information gathered from surveys of literature, industry and government agencies. The following report is directed at the literature survey phase of this study. A survey of information relating to flight simulation (in general) was performed with specific attention directed towards tactical flight crew training. It should be said at the on-set, that although a significant body of literature relevant to flight simulation is available, the quantity of information specifically addressed to the tactical environment is relatively sparse (almost non-existent for operational equipment). Hopefully this is not a result of the technique used to survey the existing literature. In addition, every attempt was made to be objective in examining the literature, however, to be realistic the subjective biases of the reviewers tend to filter through. Thus, a detailed set of references specifically used for this study will be listed. The reader is welcome to examine the data base and formulate his own opinions.

This discussion will be divided into the following specific areas: First, the methodology used to perform the survey will be reviewed. Data obtained will then be presented as applicable to general areas of interest. This will be followed by discussion of documents, that were available to the study, and are reasonably specific to the military mission. Finally, the section will summarize observations made from the literature survey concerning the present state-of-the-art, short term vs. long term alternatives, technology impact, and review various alternative solutions to achieve specific goals. The specific goals are extracted from Dr. Allen's article appearing in Commanders Digest (Reference 1). However, while the article lists these goals as the major objectives for developing flight simulators, they are possibly more general, that is, they are the broad goals of a military pilot training program. These goals are listed as follows:

- reduce costs associated with training and operating
- improve and maintain the skills required for combat readiness in experienced aircrew, and
- develop better pilots and aircrew members.

While the order of these goals presented above is somewhat inverted from the order presented in the referenced paper, it should be noted that this was done intentionally. It appears that the primary driving function in the most recent development and military commitment to flight simulators is basically directed at reducing training costs. This may be done directly by substitution of "cost-effective" simulator training hours for flight time, or indirectly by supplementary training using flight simulators, such that flight training hours are used more effectively, or by a combination of both techniques. However, as will be shown later in this report, the requirements imposed on the state-of-the-art of simulator training technology will be influenced by the choice of substitute or supplement.

Section II
LITERATURE SURVEY METHODOLOGY

Recently, Calspan Corporation, under Contract to the B-1 Systems Project Office, performed an examination of the Systems Approach to Training for the B-1 aircraft. Several technical reports were prepared under that program among them was the Simulation Technology Assessment Report (STAR), Reference 2. This document, published in July 1975, summarized the state-of-the-art in both engineering and behavioral aspects of simulation as determined for that time frame and to some degree, as applicable to developing requirements for B-1 training device systems. This publication also contains an extensive bibliography of documents applicable to flight simulation. This bibliography has served as a "jumping-off" point for conducting the literature survey required by this present study of simulator application to military tactical flight training. The time frame associated with the present contract would not permit an extensive review of all the literature available. Thus a technique was developed in an attempt to "optimize" the data collection process within the time and bugetary constraints. The reports used for the B-1 SAT Program were obtained and screened. The screening processes consisted of the following steps:

(1) Report was classified as either being of primary or secondary interest to the study (subjective evaluation).
(2) Reports were screened chronologically and reclassified when more pertinent or recent data were obtained.
(3) Reports were classified as to subject matter, since on certain occasions the title could be misleading on content.

As an illustration of the process, it became obvious during the literature survey of a chronological progression by many authors describing various concepts or devices. Typically, for a device, the initial report or conference paper would discuss the device feasibility, followed by a later report describing the development of the device and its potential, then followed by documentation of problems in the integration of the various capabilities of the device, and finally some limited information on the utilization of the device for training. This progression also exists for many training concepts. Thus, any assessment would therefore tend to be chronological. It was therefore decided to attempt to concentrate the emphasis of detailed examination on the past six years, not ignoring the previous years, but primarily relegating that data to a background role. This approach was deemed desirable also because of the various documents, including the STAR report, which have reviewed and summarized much of the past. Since the STAR document was based on literature up through and including 1974, it was necessary to extend the data base into 1976. This was accomplished by searching the primary authors and sources used for the STAR document, reviewing recent Calspan acquisitions lists, cross-referencing literature and symposiums reported in the bibliography of recent documents and performing computer searches using Calspan and NTIS facilities. In addition, recent military/government publications (e.g. Aerospace Safety), and commercial journals (e.g. Aviation Week) were surveyed to obtain pertinent literature. By no means should it be interpreted that an exhaustive literature survey was conducted, since this would have been outside the scope (level-of-effort) associated with this phase of the contract. No doubt, there are many documents presently available that were not obtained for this survey, or which could not be used because translation of foreign language reports would not have been timely, or that were in the publication process during the time allocated to obtain the data base. However, it is the opinion of the author that the data base collected from the literature review and the observations made from this information will not be significantly modified by a more extensive and exhaustive literature search. Thus, in keeping with the spirit of the times, the literature survey could be considered to be "cost-effective."

Section III

FLIGHT SIMULATION FOR THE TRAINING OF MILITARY TACTICAL FLIGHT CREWS

Introduction

This section is based on the data obtained from the literature survey. Thus the observations can only be based upon that information which the various disciplines and organizations involved in flight training via flight simulators are willing to publish or present at various meetings. Data and opinions obtained during the phase of this study that involved discussions with simulator equipment manufacturers, government simulator procurement and research organizations, and using organizations (both military and commercial) will not be presented in this discussion. This section will be organized by subject matter, however, it is extremely difficult to organize a discussion in this manner due to the significant interaction of the various areas of interest. Therefore, some redundancy may become apparent while reading the subject material to follow; every attempt has been made to minimize this duplication except where necessary to reinforce pertinent points in the discussion. The intention of the following material is to present observations based on the literature survey on the following issues:

- Simulator Philosophy
- State-of-the-Art
- Training Transfer
- "Objective" Performance Measurement
- Simulator Acceptance Testing
- Cues and Fidelity
- SAT/ISD
- Instructor Workload
- Requirements
- "Cost-Effectiveness"
- Documented Pilot Opinions on Simulation (both military and commerical)
- Alternatives and/or Improvements Affected by Technology
- Attitudes, Reliability and Maintenance

In summary, it can be stated unequivocally that there are insufficient data available with which to perform hard trade studies to evaluate options. This has been the case in the past, and to some degree what has past may very well be prologue. Several significant achievements have been made, or are in the process based on the application of current technology to simulator equipment. As an example, Computer Generated Imagery has made significant advances in the past few years, however it is not quite capable yet of replacing images generated via model boards (nor is there any reason to believe that such a replacement is either necessary, desirable, or the most cost-effective solution). However, the questions being asked about visual simulation today, are still essentially the same questions as were asked over the past many years (e.g. how much field-of-view, resolution and detail is required?). Thus to some degree the equipment used for simulation has become more complex, sophisticated and hopefully more reliable and flexible, however, in almost every case the fundamental questions relating the application of simulation to flight training (especially for the specific application pertinent to this study) remain relatively unanswered. Simulation, to some degree like magic, is an attempt to create illusion, and is still fundamentally an art, rather than a science. Perhaps, this point can be illustrated from a paper by Johnson and Roscoe (Reference 3), entitled "What Moves, the Airplane or the World?" This article published in 1972 reviewed literature written for the past 36 years pertaining to motion-relationship variables, display presentation, and the effects of these interactions on pilot performance. Their finding was significant - "Experimental findings reported range from suspect to inconclusive. The best experiments from the standpoint of scientific rigor have been conducted in fixed-base simulators, the applicability of which is suspect in questions involving physical motion. There has been no conclusive flight experiment dealing directly with the basic issues discussed." They then go on to state, " The Questions Must be Answered in Flight." It is our impression that the data about to be offered in this section will lead the reader to a similar conclusion concerning the application of flight simulators to military flight training for tactical missions, the data is inconclusive and answers must be applicable to the environment in which the threat must be treated, the pilot must be capable of performing his function in the aircraft in the air in a hostile situation. As simply stated by Captain W.A. Woodin, CAA and J.D. Cowell, BOAC in Reference 4, the simulator can never be an aircraft. An aircraft is always an aircraft, while a simulator attempts to behave like an aircraft. There are both advantages and disadvantages to this unique situation. The remainder of this discussion will attempt to summarize the relative advantages, and disadvantages applicable to the military mission. In addition, it will be hopefully demonstrated that the question of substitute vs. supplement is quite real. Based on the existing information, and present state-of-the-art, supplementary training has been demonstrated with a certain measure of success (TAC ACES), however there was no data available during this review that could justify any objective decision to substitute simulator hours for flight hours for the tactical mission especially on a routinely operational basis.

Simulation Philosophy

As a part of the literature survey, it was decided to attempt to examine the reasons presented in the literature for the relatively large military and commercial commitment to simulator utilization for flight training. However, it may be important to first attempt to list those attributes of a training situation which allow a learning procedure to occur. According to Drs. Huddleston and Rolfe (Reference 5), in order to learn, the following ingredients are required (although the relative importance of these features are not discussed):

- The individual being taught must possess the aptitude and ability to learn.
- The individual must be motivated to learn.
- An environment where practice of what is to be learned must exist, in which the trainee can receive feedback which identifies the correctness of his response.
- A situation where his performance can be evaluated, in order to demonstrate that learning has occurred.

To these above mentioned items, it is obvious, that the attitude of the instructor towards the features and conditions of the learning environment will also impact on the process. The above reference further goes on to state that while the flight environment can provide the features required for learning, it also introduces other features which are restrictive or potentially undesirable. These additional characteristics are classified by the author as:

- Impossibility (e.g. gaming area, weather, etc.)
- Expense (e.g. O & M costs, weapons cost)
- Danger (e.g. training accidents, etc.)

These features of the aircraft then, according to the authors help establish a good case for simulation. Dr. Allen (Reference 1), although he lists three major objectives for simulation (develop better pilots, maintenance and improvement of combat ready skills, cost reduction) maintains that the primary interest of the DOD in modern simulation (if properly used) is the development of the better end product, rather than cost. However, at the same time, he also states (essentially as a blessing in disguise) that the fuel shortage of 1973 resulted in a sudden increase in simulator usage. The article also lists the factors which have influenced the emphasis on simulation by DOD to replace (substitution) flying time:

- Development of new aircrews with military skills.
- Maintain or enhance those skills (military) more effectively in experienced aircrews.
- Demonstration of the "ideal" maneuvers and procedures
- Repeated practice in short time with instructional features (e.g. instant replay).
- Performance evaluation based on measurements and analysis by simulator computer system.
- Elimination of risk in practicing edge of the envelope maneuvers, or in practicing tactical maneuvers in a simulated hostile environment.
- Direct savings in fuel, and other operating costs.

- Indirect savings including wear and tear, equipment losses, personnel losses, reduction in bases and personnel etc. required for training, and increase effective use of runways and airspace.

At the AIAA 11th Annual Meeting in Washington, D.C., a paper was presented on the cost effectiveness of simulation. The authors of this paper state " -- economy is the reason for simulation in the first place ---." For the military application they state the following are the major causes for extensive military simulation training programs (Reference 6):

- Economic considerations
- Safety of flight training
- Improved flight training

With the last two factors being of special importance for emergency and abnormal situations.

A very direct statement concerning the subject of simulation, was presented by J. Nicholl (Reference 7). Although he lists the various well known reasons for simulation (e.g. training improvements arising from simulator facilities not available in the aircraft such as freeze) he goes on to state "If simulators did not save the airlines money they would not exist, and however valid the other reasons are, we would have no difficulty in convincing ourselves that training in the air was better in every respect!" Although this statement was directed at the airlines, it is probably much more general in scope.

In the October 1974 issue of Aerospace Safety, Capt. Jerome T. Bellen (Reference 8) states that the economic reasons for simulation would be sufficient justification, and he proceeds to the trimmings such as safety. In addition, he attributes the characteristic of "ultra realism" to simulators. While it is necessary to use the assumption of realism to some degree to justify the desired impact of simulation on flight training, ultra realism may be a slight (and at this point in the state-of-the-art) non-objective exaggeration.

Major General Oliver W. Lewis, USAF, article in the Air University Review (Reference 9) essentially tells us that the continuing squeeze of defense dollars, permits only one option - efficiency. Training stands out as an area because of the high individual training costs, and it is necessary to make flight training more efficient. The article then continues into simulation as the new approach to training in the Air Force. To quote from this article, "Simulation, properly used, stands out as our best bet for simplifying the learning tasks of the pilot trainee and improving the quality without increasing the cost of training."

In a recent speech to the AIAA, Brigadier General Benton K. Partin USAF again emphasized that among the significant reasons for the increased interest in the use of simulation for military aircrew training is lower cost (both from fuel savings and from aircrew training costs). However, he also recognizes several of the shortcomings of the state-of-the-art, essentially the determination of training requirements and what is the effectiveness of the various devices for training various tasks.

Colonel H.A. Goodall in his article in the Air University Review "Simulation: A Threat to Tactical Air Power," appears to be a voice for the opposition. He discusses the recent impression that because some training was done with simulators in the past, that now many feel that "cheaper simulator hours could be traded on a one-for-one basis with more expensive actual flying hours." As will be presented later, there is no experimental basis for such a judgment, especially directed at complex tactical tasks. The appropriate transfer experiments have not yet been performed. It is Colonel Goodall's opinion that "the savings expected from simulation in tactical mission units portend a potentially serious deletion of air power." He then goes on to state "Simulation should be viewed as supplementary training aimed at maintaining aircrew skills ----- ." Thus simulation "should be considered additive to enhance skills, not a trade-off." This appears to be in accordance with the recommendation of a Flight Simulator Symposium held in January 1954 and referred to by Dr. Flexman, et. al. in Reference 10 "flight simulation flying time is not a substitute for, but rather a complement of, airplane flying hours."

Essentially then the die has been cast. The primary reason for the increased emphasis on simulation is cost, saving limited defense dollars. It is indicated by the proponents of the use of simulators that not only will they save monies but also produce a better pilot. For the tactical combat mission, this point of view is at best an opinion, unsubstantiated by experimental evidence. It then appears that there are essentially two schools of thought on the use of simulation that are emerging (that can have significantly different impact on development costs):

- Substitute Training
- Supplemental Training

If the primary motivation is cost reduction, then one should recognize that alternatives may exist. The case for substitution sometimes refer to Apollo, however, for that situation, there was no alternative so the choice of simulation for training was not only logical, but essentially the only choice possible. This is not necessarily true for military training if the primary motivation is cost reduction. The fact that ordinance use can be simulated does not necessarily restrict this capability only to a ground-based simulator. Relative to the use of the aircraft for training, the development of more cost effective in-flight trainers is equally possible, especially since this would tend to negate some of the monies required for motion and visual research, the application of modern control theory to "optimize" fuel consumption not only for training but also for routine operational flights present attractive alternatives. In addition, training economies could be accomplished by utilization of a more effective process to determine pilot candidates. According to Dr. A. Diehl, U.S. Navy TAEG, in Reference 11, "Approximately <u>25%</u> of all entering candidates fail to graduate as Naval Aviators." He suggests that the inefficiency in screening candidates for military undergraduate aviation training could be improved using a synthetic selection concept which requires a relatively inexpensive, unsophisticated simulator. A "wash-out" minimization program could possibly be coupled with other alternatives reducing training costs by 25% without the use of sophisticated complex simulators and their required support facilities. In addition, the supplementing concept could be used with relatively less complex training devices, to maximize the effectiveness of flight training hours. These various alternatives for cost reduction in military training will be further discussed in other sections of this report.

State of the Art

The intent of the following discussion is to review the state-of-the-art in training simulation. In order to place this assessment in a proper prospective, it is of interest to review those questions most asked as to what improvements are required, or in what areas further research and/or development are deemed necessary. It is not our intent in this discussion to summarize the general characteristics of simulation devices, this is most satisfactorily done in the STAR report, Reference 2. In addition, the STAR report includes a review of the behavioral aspects of simulation, so it is not considered necessary to repeat this in depth. Instead, we will proceed initially with a rather historical approach. This will be accomplished essentially by reviewing the recommendations that have been presented at various conferences and/or meetings concerning simulation in general and simulation for training aircrews in particular.

In August 1963, at Columbus, Ohio, the AIAA held a meeting on simulation for aerospace flight. The following observations are made from the various papers presented at that meeting concerning what were considered to be either problem areas or significant deficiencies. The approach being that if we know this information, then we obtain an indirect assessment of the existing state-of-the-art. Rather than review each paper in detail, the following presents a summary of the questions raised in the various papers and studies reported at the conference (Reference 12):

- Visual
  - lack of resolution inherent in T.V. projection
  - lack of peripheral visual cues
  - perceptual fidelity priority over engineering fidelity
  - pertinent stimuli in appropriate sequence

- requirements for design:
  - field-of-view
  - necessary detail, acquity
  - color
  - light level of picture
  - mission specific details
- time lag between pilots control action, visual and motion must be less than 50-60 milliseconds.

- Motion/Visual Interaction
  - need quantitative data on contribution of motion to improving illusion of visual display
  - need data on cue substitution

- Motion
  - need studies to define influence of cockpit motion over a wide range of flight tasks

- Computational Requirements
  - digital effects on numerical stability

- Model Requirements
  - aircraft representation, minimize

- Impact of Facility on Crew Coordination Training
  - improvements in performance using specialized simulator training only significant for those tasks excluded in actual flight practice, not learned in a classroom setting, or using conventional simulator training

- Fidelity Determination
  - possible use of "subjective" pilot rating/sensitivity data

Essentially the principal recommendations resulting from this conference appear to be the need for extensive research on both visual display systems to provide definitive design parameters and to evaluate motion required or cues required pertinent to the selected task. Proceeding now to a Symposium conducted on Flight Training Simulators in London (Reference 13); a review of those papers indicate the following simulation deficiencies or problem areas:

- Substantial improvements required in:
  - visual attachments
  - motion systems
  - reliability and maintainability of simulation equipment

- Visual
  - need increased field-of-view
  - need improvement in resolution
  - need improved picture quality
  - need research on task dependency and related field-of-view
  - what level of simulation fidelity is required
  - what cues predominant in complex task
  - need to establish appropriate requirements
  - need research on how visual cues interact/combine with other cues to form the perceptions used by the human operator as basis for decision
  - main limitations make it impossible to recreate outside visual scene

- Motion
  - necessary fidelity to meet training requirements in different flight phases is a question
  - necessary fidelity to obtain aircrew acceptance/satisfaction
  - further advances in the effectiveness of motion systems requires research on cue interactions
  - need accurate motion "threshold" data

- need reliable and non-spurious motion 'cues'
- what number and which degrees of freedom are necessary for a particular task

- Instructor
  - need study to investigate instructor workload
  - qualifications of instructor for training are task dependent
  - attitude of instructor and influence on success/failure of training
  - proficiency requirements for instructor
  - instructor console requirements/data presentation
  - intelligent use of device and device features

- Performance
  - to assess must first be able to define task
  - inpact on various types of information on pilot performance
  - performance may not be appropriate, perceptual fidelity should indicate similar responses (control strategy) with flight
  - need to determine just what a pilot does in flight
  - need study to replace subjective instructor rating using computed performance against a standard

- Maintainability and Reliability
  - digital computer may be more accurate and consistent but not necessarily more reliable than analog
  - high serviceability calls for inclusion of well-tried hardware techniques; R & D techniques and high serviceability may not mix under operational conditions

- Motivational Research
  - absence of fear in simulator could result in detraction from training
  - what does "transfer" really mean
  - interaction between device, student and instructor

- Requirements
  - should conduct research to establish minimum consistent requirements to make proper compromises, especially for visual systems
  - little experimental work performed to date to determine the level of simulation necessary for adequate transfer
  - motion system should be designed to provide desired information with minimum excursion

- Cost-Effectiveness
  - increasing simulation system complexity to attain increased training value will impact cost-effectiveness. Assumptions on hours and operating costs very significant on any trade study

Thus between 1963 and 1970, the list of questions grew as the industry obtained experience with the complex and sophisticated equipment. The next symposium reviewed was the AGARD Conference held at Ames in March of 1970 (Reference 14).

Following a panel discussion, the following subjects were considered for future research that should be coordinated by AGARD:

- Definition of existing simulator visual and motion limitations
- Specification on simulator capability and required fidelity for visual and motion systems

- Research in Human Perception
  - sensing visual and motion cues
  - relative importance of cues
  - compensation between various cues
  - modeling of physiological system and pilot behavior
- Quantitative methods for measurement of pilot workload
- Standardization of low altitude disturbance model.

Essentially at the conclusion of the meeting at Ames, the simulator people gathered felt they had come a long way since the early "Link" trainers however:

(a) considerable work remains to improve visual and motion generation

(b) need to make system "cost-effective"

(c) Need more data on pilot behavior, since he is the "inevitable" judge of both aircraft and simulator.

Next, let us list the conclusions/recommendations from a more recent AGARD Simulation Conference (Reference 15). These observations are listed below:

- need improved math models
- need better prediction of aircraft dynamic derivatives, nonlinearities and unsteady effects at high angle-of-attack
- need to improve/standardize turbulence model
- need to improve resolution and detail of computer generated visual displays
- proper generation of motion cues remains a fundamental problem due to limited excursion capability
- need more information about human vestibular system to improve motion drive logic
- methods used to measure and evaluate pilot workload/ performance need improvement

- most elaborate simulator is not necessarily 'cost-effective' - need more data in order to trade

The preceeding historical data indicates that many basic questions related to the state-of-the-art of the application of simulators remain unanswered. There are strong indications of technology improvement, however it appears for example that one is still concerned with required resolution and field of view of visual systems. Perhaps the most significant development is that in 1963 model boards generated the images while now the image is generated at times by a computer. That the current state-of-the-art is somewhat limited can be further determined from the list of problems discussed by General Partin in his address to the AIAA meeting in Dayton recently. The specific problem areas mentioned were as follows:

- Task Determination
- Transfer Ratio
- Visual Cues, e.g., FOV, Detail and Realism
- Motion Cues
- Cue Interaction
- Simulation of Sensors
- 'Objective' Performance Measurement
- Aircraft Data on Edge-of-the-Envelope
- Cost of Motion, CIG and Display Systems
- Simulator Certification

It appears then, that the list of problems with simulation remains relatively extensive. Finally on this review of the state-of-the-art, there is a recent paper co-authored by D.R. Gum and R.R. Swab (Reference 16), entitled "Technology Challenges in Flight Simulation." This paper represents possibly the most recent and general assessment of current simulation technology applicable to military aircrew training. Their conclusion is that "the state-of-the-art in many areas is <u>adequate</u> to support the acquisition of effective training devices which will allow considerable aircraft flight training time to be saved." However, an examination of their simulation technology assessment table indicates that for fighter aircraft, only 5 areas out of 20 were considered <u>adequate</u>, while

4 of 20 were considered to be essentially beyond the capability of present technology even for initial simulation capability. The remaining 11 areas were considered to be feasible but required either performance improvement or cost reduction. Most significantly the areas considered by them, to be essentially inadequate at present, are required for the tactical mission (e.g. air-to-surface and low level navigation). Thus the existing state-of-the-art appears at first glance to be severely restricted. This may very well be true, if one desires to use the simulator as a direct substitute for flight time which appears to be the underlying concept used by Gum and Swab in their paper. This then still raises the question, how satisfactory is the present state-of-the-art, not to substitute for flight time, but to supplement flight time? Data to be presented in the discussion of the TAC ACES program indicates that the latter is a lot closer to short term realization using existing hardware capability then the former.

Transfer of Training

Inherent in the justification for any training device is the basic assumption that what is learned in the simulator can be used in the aircraft, hopefully in a rather positive way. In order to quantize such a concept, especially if it becomes necessary to perform cost-effectiveness studies, a set of calculable parameters have been historically defined and used. This set of quantities, that report to determine the effectiveness of the device are called by the name "Transfer of Training." It was pointed out by Hammerton (References 17 and 18), that basically the various formulas used for transfer can be classified into two basic groups:

- 'measurement' of savings in training
- 'measurement' of initial performance immediately following the transfer to the real world

He concludes that these two 'measurements' are often conflicting terms of device evaluation, and which measures are used are normally dependent upon the need of the user. It becomes apparent, that for specific tasks, the relative importance of "first-shot" transfer may be very important to the use of simulators for tactical training. It is of little value to note as Hammerton and Tickner do in Reference 19, that even when initial transfer is poor, that the effect may be very transient and recovery to stabilized performance proceed at a rapid rate, if the pilot does injury to himself or to his vehicle during any initial performance demonstration. However, again in this reference, cost considerations appear. The authors consider that the practical significance of transfer experiment conclusions are clearly dependent upon the impact of economic considerations. They state that "good initial transfer must be weighed against the increasing cost of realistic simulation." In Reference 18, it can be observed that the number of training trials in the simulator are normally neglected in the determination of the device effectiveness. This point is further examined by S.N. Roscoe in several articles, among them References 20 and 21. Although these references indicate that extended training in a simulator can produce significantly diminishing returns, the true value of a simulation device must include such additional considerations as the impact of weather, availability of aircraft, etc. That could make it advantageous to use a simulator even though the effectiveness of the device has diminished to the point that it is no longer "cost-effective" to use the training device. This then implies that when the choice is some training vs. no training, the choice is for some training although that specific training could be somewhat ineffective.

It should be noted that inherent in a measure of training transfer is the assumption of stabilized performance. Obviously, to measure the effectiveness of a device, one must be able to define a task, and a performance index. However, if the performance index is ill-conditioned then the true value of the device as determined from 'measurement' of training transfer is somewhat suspect. Unfortunately, as will be discussed later, there appears to be little agreement on the "best" way to combine specific activities in complex situations (i.e., aerial combat) to yield adequate performance, Reference 22. Thus when a task becomes complex it may be either impossible or impractical to define a meaningful measurement of performance. Under this situation, which is most relevant to tactical flight training it then becomes impossible to evaluate the device effectiveness using the transfer-of-training concept. However, in Reference 23, the authors state that the potential for the modern flight simulator to produce cost savings and improve the quality of training is dependent upon validated transfer of training. Thus the inability to describe a performance reference for the determination of device effectiveness (transfer of training) is a significant problem area.

Let us recall that the purpose of the "measured" transfer of training falls into the class of measures that can be used to determine the effectiveness of a training device or more completely a training system. An obvious goal for a training program is to enable the student upon course completion to be able to adequately perform his required tasks in an operational situation. Using the concept of the Osgood training surface (Reference 24), then the training device effectiveness can be directly related to the level of response similarity to a given stimulus both in the aircraft and in the flight simulator. This similarity, could be measured relatively to a desired performance (providing the performance standard is definable)or possibly more directly by the similarity of control actions between the simulator and the aircraft.

Before examining some of the existing literature on transfer of training results, it is considered necessary to raise one point of caution. It has been suggested in several references that terminal performance measures may be an index of the training effectiveness of a device. That is, for example, probability of a hit in a weapons delivery task. This may create a pin-ball machine effect if not properly used. To note that a students time on target increases with training in the simulator (as measured in the simulator) may be nothing more than a measure of the pilots adaptation to the environment of a particular training device and should not be considered a measure of device effectiveness unless it can be demonstrated that the skills learned in the simulator can be readily applied to the actual environment without extensive pilot adaptation. In the final analysis, the pilot must perform his mission in the aircraft, and following in a logical sequence the value of any training concept/device/system must eventually be validated in the operational environment, and by using appropriate tasks. The total impact of the training effectiveness of a system may not be measurable until some time downstream. This requires a post-performance study period. An illustration of this situation, is the recent newspaper articles that are indicating that the "new math" has become suspect. What was reported to be a significantly improved approach to the teaching of mathematics may have created the situation where the students can easily identify whether or not a number may be greater than, or less than, or related by set theory to another number, however, the question remains for certain commercial applications "how well can they make change for a dollar." This post-performance impact of simulated training was also reported in a Navy study on the substitution of flight simulator time for aircraft throughout instrument training in the Advanced Jet Syllabus in 1972. In essence, while the performance of the experimental group (simulator trained) and the control group were related to establish transfer ratio's in the task, subsequent analysis in more advanced stages indicated a statistically significant degradation of performance by the experimental group. This then implies that transfer of training is highly task dependent, strongly device dependent, and possibly quite fluid or definitely quite iterative and may only be truly significant at the time of measurement. If we quote from Reference 23, the authors state relative to what they refer to as Classical Transfer of Training. "The classical transfer approach has a place in the initial validation that particular innovations <u>can</u> be effective, but it probably is less than adequate for continued assessment and refinement of real-world flying training programs. It is too cumbersome to carry out and often the results are too specific and non-generalizable. A major limitation exists in the difficulty of obtaining sufficient subjects and maintaining good experimental controls." Thus any numerical representation of 'measured' transfer should be qualified and caution should be exercised such that generalizations are <u>not</u> made of this data to dissimilar devices or training programs. In essence, each training program must be evaluated on its own merit. In Reference 25, S. Mudd indicates that there are several limitations that can render the transfer-of-training evaluation concept to be less than satisfactory:

- Inapplicability where system being simulated is not yet operational.
- Inapplicability where simulated system is so complex it may not be feasible to use an "untrained" control group.

- Approach requires each new device/concept be evaluated for transfer effects.
- Technique does not readily provide data directly for modifications to improve the performance of a given device.

In addition one cannot neglect scheduling problems, and motivational problems in attempting to obtain transfer data. As is discussed in Reference 26, the RAF encountered problems in attempting to perform proper streaming trials. In essence the experimental crews did not like flying additional exercises on the simulators while their counterparts flew aircraft. It is further interesting to note, that this cited reference is describing experiments presently being conducted by the RAF to determine the effectiveness of training devices procured six years ago. This is rather typical of the literature. We could not find data that could be used to properly document transfer effects for tactical military training. There is some data available on transfer between simple simulators and private aircraft, and in many cases for procedual and instrument flight training (e.g. References 27 and 28 among the more recent data). The existing data can be summarized to indicate that positive transfer can be obtained from ground based flight simulators to the operational environment for both relatively skilled or naive subjects in relatively simple flight tasks or in training for procedual tasks. It is not obvious from the data format that stabilized performance was obtained prior to the transfer. The data does indicate that for these tasks, and using relatively simple part-task trainers, that transfer ratios on the order of .250 to .60 are presently within the state-of-the-art of simulator training systems. Reference 29 indicates that a transfer ratio of .40 was achieved using a relatively simple formation flight trainer.

It would then appear that a possibly logical and potentially cost-effective approach to reducing training cost while improving quality would be to concentrate on improving the transfer ratio of part-task trainers. One could achieve significant savings in fuel consumption for those tasks that have already been demonstrated as highly trainable in a relatively simple simulator rather than to extrapolate (with significant risk) from simple tasks to highly complex tactical missions. Obviously, in terms of judgment as well as analysis extrapolation involves more risk than interpolation. Further thought and research is required to establish transfer-of-training for the highly skilled and complex tasks associated with weapons delivery for essentially non-existent devices for routine operational usage. If it is deemed, based on judgment, desirable to procure advanced (and costly) training devices, then the building block philosophy used by the Air Force Simulation SPO is a logical approach; however, every component of the system must be evaluated for its impact on device effectiveness. One additional cautionary note should be raised, the impact of the attitude and compentance of the instructor as well as his training in the effective utilization of the features of the training system could be more significant in determination of training effectiveness than many of the physical characteristics designed into the system. That is, as has been stated in many references, while a good instructor can compensate for a poorer device, a poor instructor can detract significantly from a good device (e.g. Reference 4). As stated in Reference 30, "Instructor Pilot quality is crucial to simulator training effectiveness."

Thus perhaps instead of using transfer experiments to determine how much simulator flight time can be substituted for flight time or just how complex does a simulator have to be to determine the relative effectiveness of training with simulators , it might be more rewarding to examine what simulators have already accomplished and concentrate on improving those characteristics to achieve fuel economy in training and reduce flight training costs. That is, first "optimize" the use of the existing state-of-the-art, rather than to extrapolate data to procure devices that cannot be 'objectively' substantiated for the intended mission.

Training Device Concepts

In this discussion we will attempt to review information available on several concepts associated with improved "cost-effective" utilization of training devices. It should be noted that again the literature is rather sparse on documentation of the value of such instructional aids as problem 'freeze', adaptive learning, etc. In fact, as will be shown in this section, there appears to be more warnings on the use of special instructional features than on the documented validation of the increase in training effectiveness for a device equipped with these special features.

The following list presents a majority of these features:

- problem 'freeze'
- engagement record/replay
- reset
- automated flight training system
- performance monitoring
- automatic demonstration
- hard copy printout
- exercise 'speed up'
- automatic malfunction insertion
- automated opponent ('iron pilot')
- instructor station layout

For this discussion it would seem a good idea to group these features to distinguish between those devices or concepts that are incorporated to save time, and those devices that are assumed to enhance training or alternatively reduce instructor workload.

Those features introduced to a flight training simulator to save time are essentially 'speed up' capability, reset capability and to some degree 'problem freeze' although the latter may have some instructional use. Examination of the literature for comments concerning these features reveal that the primary remarks addressed to this capability indicate proceed with caution. That is, that this capability is considered to be rarely used properly and when used normally destroys the illusion that the trainee is in an aircraft rather than a simulator. In his presentation to the Royal Aeronautical Society, D.P. Davis, Chief Test Pilot for the CAA (Reference 31) had the following comment:

- "Reset is useful for test flying simulators; if its use for line pilots can be avoided, it should be."

He essentially suggests that the exercises should be conducted as one would in an aircraft. With respect to freeze, he considers this capability as "alarming" and goes on to suggest "freeze should never be used to avoid a crash....." With respect to exercise 'speed up' his opinion is that although this capability may be attractive as a time saving device, this feature can "clearly destroy realism and should never be used with regular line crews." Although his comments are directed at the airlines, they are essentially more general. That is, instructional features which tend to destroy or significantly modify the realism of a training situation should be avoided in that exercise. This does not mean that such features may not be of value, e.g. in setting up a problem or initially validating a simulation device. The opinion expressed is concerned with the usefulness of these capabilities to enhance learning by destroying reality. Similar cautionary advice is also presented by Wooden & Cowell in Reference 4.

On the utilization of the record/playback capability available with modern simulators, the views expressed in the literature appear to be much more diverse. For example, in his presentation to the Second Flight Symposium of the Royal Aeronautical Society in May 1973 (Reference 32) Captain Thomas of UAL states that "We have found that most of the instructors do not use the record/playback capability of the simulator; rather than having the pilot spend time watching an approach, they much prefer to have the pilot fly another approach." Reference 33 indicates that the instructor pilots used in the reported program carried over a flight training philosophy to the simulator, to maximize every minute for training. However, it is indicated that "replay was used when sufficiently important." During the conducting of the TAC ACES II program (Reference 34) it was determined from pilot questionnaires that engagement replay was considered as the most valuable instructional feature, however the operation of this system is complicated and could not be consistently used in a timely fashion. One recommendation of the TAC ACES II program was simplification of console procedures to provide rapid and accurate record/playback system operation. Thus it appears from the literature, that the record/playback feature can be a useful instructional aid when:

- it does not interfere with the training exercise
- it is simple to operate
- it can be used in a timely fashion

J. H. Goodier (Reference 35), states that the record/playback feature "will enable the student to do much more practice on his own and will relieve the instructor of repetitive work." He made that statement in 1970, and to date it appears that this goal has yet to be achieved, possibly due to the complexity of the record/playback system operation, or improper training of the instructor in the use of this capability. However, we should not overlook, perhaps from the military point-of-view a highly significant aspect of the record/playback capability, that is for debriefing crews after a training exercise. As discussed in the April 1976 issue of Aerospace Safety by Captain John E. Richardson concerning the use of ACMR computer capability for debriefing. "The display gives the student total recall of the mission. Each maneuver can be reviewed and analyzed, greatly increasing the value of each training sortie." Thus in review, there does appear to be a consensus that the record/playback feature can enhance training. Again, it must be stated, that there has been no experimental evidence offered comparing the training effectiveness of a training system with and without the utilization of this capability. In addition, through the use of pre-recorded tapes it is possible to use the record/playback capability to demonstrate certain control motion, instrument and visual (if available) relationships that exist when the exercise if flown in a "desirable" manner, possibly obtained by the instructor "flying" the training device and recording for demonstration purposes his mission. If as stated by Goodier in Reference 35, that there is an opinion among psychologists "that lessons are best learned when there is

10% explanation
25% demonstration
65% practice "

then it seems reasonable that the more efficiently the explanation and demonstration phase can be accomplished, the more effectively the device can be used for its primary teaching role - practice. Again, the review of the literature has primarily indicated the feasibility of automated demonstration rather than the effectiveness or efficiency of this capability. However since it can be obtained almost as a "freebie" when a record/playback capability is required, there is little reason to attempt to determine whether or not a device should have this feature once it is deemed desirable to incorporate the more extensive record/playback feature. The question that still remains with respect to automated demonstration, is really when and how to use it? Additionally, if this capability can also relieve the instructor of some of his more routine workload, by making the demonstration phase more efficient, this in itself tends to indicate a potentially desirable feature.

One of the more recent developments in training techniques applied to the flight simulator is the apparent emergence of automated adaptive flight training systems. Within the past few years, assisted by the application of the digital computer to flight training systems, automated adaptive training has developed from a training concept, through some initial feasibility studies and now into an evaluation stage as recently discussed at the NTEC Conference, November 1975. Prior to discussing the most recent results, it is of some value to review the concept, therein coming to a realization of the requirements and assumptions involved in the creation of an automated adaptive teaching capability. Fundamentally, from our review of the literature, the following definition stated by Kelley is used to identify Adaptive Training as a concept within which either "the problem, the stimulus, or the task is varied" as a function of performance. Thus as indicated in Reference 36, the three fundamental elements are:

- task variables that can be adjusted to change the level of task difficulty
- a consistent measurement of performance
- a method for automatically relating task difficulty with performance, such that the level of difficulty in a task increases as skill (measured by performance) increases.

That reference also indicates several candidates that could be adjusted:

- environmental factor (e.g. turbulence)
- operator stress (e.g. modify life support system)

- simulated aircraft variables (e.g. SCAS gain)
- feel system variables (e.g. backlash)
- display variation (e.g. predictor display)
- problem generator (e.g. required maneuvers)
- task loading (e.g. communications)

While the author's of Reference 36, suggest the above list for its "breadth of choice" it is obvious that many of these potentially adaptive parameters would not necessarily be applicable to training in a specific aircraft. In essence, the primary variables used in feasibility and recent evaluation tests normally can be classified as either (a) environmental (wind velocity & direction, turbulence), or (b) stress related (i.e., emergency conditions). Critical to the use of an adaptive teaching concept is the ability to measure performance, to realistically select variables to modify the task, and to insure that the task difficulty changes introduced do indeed enhance the learning process. The most recent applications of an automated adaptive teaching system are presented in References 37 and 38 respectively. Essentially what has been demonstrated to date, is that potentially the adaptively trained student is equivalent to the conventionally trained student for the automated GCA and TACAN tasks. However, it also appears that there is still much to learn about this concept for these relatively simple tasks for which reasonable performance measures are possible. The extension of this adaptive concept to training in the tactical environment in which there is both complex skill interaction and a diversity of opinion on what truly represents adequate and measurable performance (Reference 22) is presently beyond the state-of-the-art. Not from the point of hardware, more from the point of software and our present understanding of skills required to achieve the desired performance in the tactical environment. It is this very inability to quantitize the "desired" performance on a continuous basis which also limits the application of transfer-of-training analysis to many critical military tasks to evaluate the effectiveness of a training device/ system. Thus if adaptive training is to be incorporated, it can only demonstrate its "cost effectiveness" in simple tasks, and should not be extrapolated into more complex tactical training tasks, since a fundamental requirement (a valid and reliable set of parameters that can be used to teach to desired performance) has not yet been determined for the tactical mission. There does, however, exist certain terminal or scoreable measures (e.g. time-on-target, or probability of hit) of performance, the question appears to be more of teaching than just by sheer repetition. One further note with regards to automated adaptive training, it should not be used in any way that would tend to create negative transfer and must be evaluated for each intended application. At present, automated teaching has been used in the GCA tasks which has also incorporated other features into the training system, i.e., "voice" system. From an overall point of view, since the services are still presently training GCA operators it may be more "cost-effective" to couple this training together than to provide separate training for each group. Some discussion on the value of coupled training using simulation is discussed by Major J. Alwon, RNLAF, in Reference 39.

With respect to hard copy printout, this feature can assist in both relieving the instructor of some basic bookkeeping responsibilities and give a direct indication of certain parameters to the pilot trainee to examine for progress. However, to obtain hard copy should not inconvenience or restrict the training exercise, as indicated in Reference 33. Fundamentally to serve as an aide to training, it is the timeliness of the data that is of fundamental importance. If the student must wait several days for off-line processing of data, its value as feedback is essentially minimized if not eliminated, however this off-line data processing could still satisfy a requirement to "track" the students performance. Direct on-line processing will have both hardware and software implications. While there is evidence that immediate feedback of performance in a task can improve subsequent performance in that same task (Reference 40), there is no data to indicate that the student reviewing a hard copy is any better than the insturctor telling the student for example what his rate of descent was at touchdown. There is evidence however that numerical information on terminal performance parameters may have an increased impact on subsequent performance than the use of general descriptive phases, as discussed by D.B. Armstrong and G. Musker in their paper presented at the Royal Aeronautical Symposium on Flight Training Simulator's (Reference 41).

While there is little doubt, that the insertion of malfunctions either manually by the instructor or automatically by a predetermined set of conditions should be part of a training simulator program (especially since one of the arguments in favor of simulation is reduction of risk in teaching emergency procedures, etc.) the more fundamental issue is how many are of value to the desired training. As discussed in Reference 32, recent training devices are required to store more malfunctions than are required to complete the training syllabus. This then indicates an inefficient use of computer storage and a potential waste of programming effort with of course the additional costs and demonstration requirements for acceptance. It then seems logical that by evaluating the desired level of proficiency and with some knowledge of critical malfunctions associated with certain aircraft, malfunction insertion can be made more effective. In addition, it could be highly undesirable in terms of crew motivation to use unrealistic malfunctions, or improper sequencing of malfunctions.

A recent training feature discussed in the literature for air-to-air combat training is the use of either a pre-programmed target using a canned maneuvering target (e.g. TAC ACES I) or programmable interactive threat aircraft (Reference 42). Another technique, which is discussed in Reference 33, used by Northrop was to develop the capability for the instructor to have a stick steering mode which gave him limited bogey control. During the TAC ACES I program it was determined that a "pre-recorded maneuvering target feature is of limited utility." The computerized "hostile" described in Reference 42 and the techniques presented in Reference 33 indicate the desirability of bogey control during a training exercise. There is no documentation in the literature surveyed that the observed increase in performance in the air-to-air combat role using a controllable "bogey" in simulation exercises transfers to the operational environment. However it must be remembered that improper training against a potential threat is highly undesirable and possibly disastrous (Operation Rolling Thunder), as discussed in International Defense Review, Reference 43.

With respect to the features desired or required for the Instructor/Console Operator Station, it becomes readily apparent that this feature, as are many others in the field of flight simulation, is still under development. To quote from Reference 33, " The instructor's console development was by far the most technically challenging aspect of the entire simulation program." Discussions at the Flight Training Symposium, held by the Royal Aeronautical Society, October 1970 indicate that there was "no knowledge of an investigation into the workload of the instructor." This point is somewhat repeated by Captain Thomas in his paper presented in 1973 (Reference 32). "Much research has gone into the design of automatic malfunction insertion, automatic feedback, record/playback, demonstration capabilities and other devices to make the instructor's job easier and more efficient. Yet it appears that very little effort has gone into finding out exactly what the instructor's job is." "In an effort to relieve the instructor of some of the time consuming tasks....., we have provided him with considerable trainer capability which he does not use." The author considers the application of the behavioral objective concepts to determine what the instructors job is of equal importance to the application of this methodology to the determination of aircrew functions required to perform the task. Throughout the literature, one can find statements which relate to the importance of the instructor, the training requirements and the capabilities required for a good instructor. To quote Ralph E. Flexman, " the instructor has been, and always will be, the most important variable in any training situation." The impact of the instructor is also most recently discussed in the Summary Report of the Task Force on Training Technology, Reference 44. However, in this reference, on the content dealing directly with flight training there continues to appear the message that the development of innovative concepts and strategies will lead to improvement of the cost-effectiveness of existing simulators and trainers. This may well, fall somewhat into the area of a desirable goal rather than a measurable goal. In agreement with the author of that section (Dr. Flexman) the literative review does indicate that more energy has been devoted to design and development of facilities, than on teaching strategies, obviously since there seems to be limited data at best on defining the job of the instructor. However, to some degree, it is necessary to have devices with which to perform the required experiments in a logical scientific manner, if one is attempting to gather data on the "cost-effectiveness" of an innotative, or for that matter, a more conventional teaching strategy or device or a training system. This report (References 44) goes on to state as a general observation that "There are no cost-effectiveness functions that would permit the comparison of the current with alternative training philosophies, methods, procedures, equipments and goals...... The implication is both clear and disturbing......many important decisions are being made without adequate, valid, quantitative basis in fact." This statement again indicates that it is necessary for the simulator industry, the engineering psychologists, and the military user to sit down and use the existing facilities to do their home-work first to attempt to obtain the data required to evaluate military flight training systems.

Thus, based on the literature review concerning training device instructional features and application of these features, one comes away with the impression that there presently exists no quantitative data that establishes the cost-effectiveness of these various specialized instructional features. There is some opinion that such capabilities should not be used to disturb the "realism" of a training exercise, and that the operation of such features should be timely and uncomplicated. The record/playback feature if properly used, could provide one of the desired characteristics of a training system, immediate feedback to the trainee. At the October 1976 meeting of the AIAA Working Group on Training Simulation, B. Cream of Human Resources Laboratory, Wright-Patterson Air Force Base outlined a recently initiated two-year program to systematically evaluate cost/training effectiveness of simulators and instructional features. The successful completion of this program would hopefully answer many of the questions raised in the preceding discussion.

Systems Approach to Training (SAT)

Perhaps one of the more innovative strategies recently extended to the flight training task has been the attempt to apply the concepts of system theory. This approach normally referred to as SAT or ISD (instructional systems development) has received some advanced publicity as a technique to "ensure that the most cost-effective training methods and equipment will be developed and processed." However, as Reference 44 indicates, "There is some question regarding the degrees to which it is being correctly implemented, and there is little or no evidence of its actually producing cost-effective results." This statement is reinforced in Reference 23 concerning the output of ISD teams to develop new flight training curricula and syllabi. "In some instances, the end-product has been a less than optimal use of the technology (ISD); several of these early programs were little more than adaptations of previous programs and perpetuated many of the existing inefficiencies." This reference then goes on to state what are limitations of the approach:

- Dependency on initial analysis such that inaccuracies can be locked in and inappropriate training program defined.

- Analysis must be performed by "trained" experts in the methodology.

It appears therefore that this concept may have numerous difficulties in the application stage, especially since the existing data base on task features required to be trained, as well as the minimum device requirements to provide such training is essentially non-existent for many tasks. Thus there appears to be a strong potential for GIGO (Garbage In, Garbage Out). Again, as the authors of Reference 23 reiterate, SAT approaches are complex and abound in the opportunity for error. Obviously a major source for error is in neglecting a portion of the task to be trained. The Specific Behavioral Objectives (SBO) concept, within the systems approach essentially assumes that the task can be well enough defined that it can be properly sequenced and that one can determine "what is required to accomplish the task", rather than "what is nice to know." Thus as discussed by Cream, et al in Reference 45, the behavioral data acquisition phase/process "assumes that all tasks can be reduced into more detailed subtasks and that task descriptions can be in the form of S/R (Stimulus/Response) descriptions". The application of this assumption to some of the less complex tasks (e.g. procedural) may be quite valid, however, the application is not quite as clear for some highly complex duties." Unfortunately, for military tactical training, the tasks can require complex and highly interactive human skills and it may be extremely difficult to develop an acceptable set of behavioral objectives. Reference 45 then goes on to discuss a new methodology for the determination of specific task data and the interaction of behavioral data in the design of training devices. This new methodology is essentially based on a subtractive concept. That is, assume that one can include all the capability in the trainer that is required, and then interact with the device user to delete unnecessary capability. This concept is somewhat opposite to the task analysis performed by the engineering psychologist to determine specific behavioral training objectives, however, in essence, both approaches are complementary. Perhaps the strongest issue for the approach suggested by Reference 45 is its dependency on interaction and iteration with the user for the justification of device capability. An extensive utilization of SAT/ISD methodology for specific application to developing a training system for the B-1 aircraft was recently completed by Calspan Corporation, Reference 2. In this document, the authors again caution that SAT is a "decision aid" not a panacea. This report again reiterates a significant problem with the SAT approach, that is, "the lack of quantitative relationships among the factors that affect the system." Thus, it appears that for the near term, the SAT approach for many tasks associated with military training systems will do nothing more than quantitize the relative merits of alternative training concepts based upon subjective bias of the group applying the methodology rather than using objective quantitative data which is required to properly apply the systems concept. Thus again, it appears, from examination of the various recent discussions concerning SAT, that to minimize the potential risk of extrapolation of an inadequate or improper data base, the methodology should only be used where the data has been established with reasonable certainty and reliability. It is of little value to apply SAT concepts if the decisions are actually being based on judgement anyhow, to establish the value of alternative training concepts/systems. In addition, if it is as truly complex to apply the SAT methodology as we are lead to believe from Reference 23, and if applied with inappropriate initial data can lead to specifying the wrong device, training program, etc., then one must consider this approach with extreme caution. The determination of appropriate data should logically precede the application of ISD to the procurement of new training systems. At the present, if we must rely on judgement, then it is essential that the ultimate user must significantly interact, on a continuous basis, with the personnel responsible for development and procurement of training systems, and vice versa. Perhaps a reasonable solution is to follow the Navy example and establish TAEG-type units as recommended by Ralph Flexman in Reference 44. This could then provide a framework to continually analyze and evaluate the application of training devices to a specific task and if nothing more could sharpen the judgement required for future procurement decisions.

Maintenance and Improvement of Skills

Earlier in this report, Dr. John L. Allen's article (Reference 1) was cited which indicated that one of the major objectives in the pursuit of flight simulators was the "maintenance and improvement of combat readiness in experienced aircrews." Thus, it was decided to explore the recent literature for data on skill retention, upgrading using simulators, and/or "proficiency" training. Again, it was not possible to exhaustively search the literature, however, several documents were found that are relevant to this subject.

Reference 46 reports an experiment on forgetting instrument skills. The authors indicate at the time the study was conducted (1971) that "there is little objective data on the rate and amount of forgetting of several response classes that comprise flying." The results of the study performed, using subjects "naive to flying" were the following:

- Discrete procedural responses are easier to forget than flight control responses.

- Retention loss was not influenced by the amount of initial training.

- Relearning procedures is dependent upon the amount of initial training.

The implication of this study is that for operational organizations it could be effective to provide relatively uncomplex training devices to maintain procedural response skills.

There are several articles also written which indicate that a majority of users feel that simulators are only valid for emergency and procedural training. This was reported as recently as 1973 by a survey conducted by the British Airline Pilots Association PEL/Training Study group. Data on the Airline Pilots attitude toward simulation in this country was not uncovered. An article recently did appear in Professional Pilot, June 1976, by John Lowery of FSI. The impact of this article is that simulators can and have indicated their capability to increase "proficiency while reducing training costs." The author, while directing his attention to essentially crew recurrency training suggests that "discussing it or touching the appropriate levers is only slightly better than not practicing at all." It is also interesting to note in the June 30, 1976 issue of the Convention News, in which FSI announces their new digital/visual Falcon 20 simulator, the new annual fee for FSI refresher training was increased by 33-1/3%.

In the literature examined, little data is available on the use of ground simulators for the improvement of combat-ready skills. The only statements uncovered were related to the TAC ACES programs (References 30 and 34) which indicate that:

- Pilot subjects considered programs would be of greater benefit to the inexperienced ACM pilot than to the experienced pilot.

- Necessary Air/Air skills "cannot be honed in the simulator."

Cue Fidelity Requirements

It is not the intent of this discussion to provide a complete review of motion cues, visual cues, aural cues, etc. and their interaction. There are many reports, articles, etc. available which address themselves to that task. Instead, it is the intent of the following to examine what is known about the impact of these cues on training, specifically directed at the tactical mission either from "objective" measurement or from subjective questionnaires. It appears that our understanding of cues required for training is at best limited, and at worst, "unquantified."

In a recent article appearing in Astronautics and Aeronautics, September 1976, Captain Terry L. Balven, USAF, Simulator SPO indicates that "We need to know better what cues aircrews use in performing their missions. And we need to know what fidelity these cues must have for effective training." In the previous issue of the same publication, Dr. Philip A. Reynolds of Calspan Corporation, reporting on the results of the recent AIAA Visual and Simulation Conference in Dayton, states "The papers presented and the remarks made by the panel and the audience make it clear that simulation has not yet been defined well enough for training purposes (military)." The panel discussion which occurred at the meeting was also described in the article by Dr. Reynolds. One result of that discussion was that "The panel unanimously urged the audience to get to the heart of the question: compare ground with actual flight data." At that same conference, Brigadier General Benton K. Partin, USAF, stated in his address "We now have several types of six degrees of freedom platforms, g-seats, and g-suits available. However, we need to establish the contribution of these motion cueing devices in the various training tasks and which device or combination of devices can most effectively provide these cues. We must establish the effects of visual detail, realism and field-of-view on effectiveness of training in visual maneuvers ranging from takeoff and landing to air-to-air and air-to-surface weapons delivery. Finally, we need to develop an understanding of how all of these various cues interact in training of aircrew trainees and aircrew transitioning to and maintaining proficiency in fighters, bombers, or transports." General Partin then went on to indicate that AFSC is examining those areas where there are information voids in training effectiveness and he also placed some challenges before the R & D community. The most recent AGARD Conference on Flight Simulation, held in The Netherlands, included recommendations directed at cue requirements, i.e. "proper generation of motion cues remains a fundamental problem.".

In examination of the literature for data concerning the impact of various cues on training, it appears that there is more data of a subjective nature than objective. However, one fact remains clear, it is impossible for the ground base simulator to duplicate the real world situation. One must take advantage of the human perceptual process to create a desired and cost-effective illusion of reality sufficient to obtain the required level of training. To quote from the address by Jack A. Adams to The Society of Engineering Psychologists, (Reference 47) in 1971, "I would not consider the money being spent on flight simulators as staggering if we knew much about their training value, which we do not. We build flight simulators as realistic as possible, which is consistent with the identical elements theory of transfer of Thorndike, but the approach is also a coverup for our ignorance about transfer because in our doubts we have made costly devices as realistic as we can in the hopes of gaining as much transfer as we can." If we examine the panel discussion at the recent AIAA Visual and Motion Simulation Conference, April 1976, we find the following comment offered by Dr. Charles Hutchinson, AFOLR Life Sciences Division: "I think that it is important that we unlearn what we "know" about flight simulators because what we "know" could prove to be an expensive and inefficient hang-up. If we "know" that a flying training simulator has, or should have, a 6 DOF motion system and a visual system of "specifiable" fidelity, we "know" something that is not based on evidence produced by studies of the effective transfer of learning from training device to aircraft."

Now the question remains, after this rather bleak introduction into "cues" as to what do we think we know either experimentally or logically about these cues. The amount of data we have, for example, on the impact of motion on training effectiveness appears to be contained in essentially two reports. However, there are considerable data available on attempts to examine task performance with and without motion, etc. In addition, we have documents which at least present to us some subjective data on cue impact and there have been some recent attempts to do a "preliminary" investigation of various effects of cues. In order to present this data in a reasonable format, we shall first separate the "cues" into motion related cues (e.g. moving platforms, g-seats), visual cues, and additional cues for "realism" (e.g. aural).

At a recent Symposium held in April 1976 by the Royal Aeronautical Society, J. Gundry presented essentially a survey paper entitled "Man And Motion Cues", (Reference 48). This paper is somewhat similar in content to the same author's presentation at the recent AIAA Conference, but does provide more extensive background data than the latter paper. In this paper, the author essentially attempts to catalogue motion in an aircraft into primarily two effects:

- Advantageous — provide pilot with useful information
- Disadvantageous — motion sickness, spatial disorientation

The author then proceeds to a discussion of simulation. He introduces his thought about present state of knowledge of motion effect on pilot training: "Unfortunately there is no experimental evidence that the presence of flight simulator motion aids <u>training</u>." Of course, taken from the opposite point of view, there is no experimental evidence that <u>appropriate</u> motion cues distract from training. The author then goes on to illustrate by reference that "the presence of motion has a beneficial effect upon pilot performance." He then states that this is of little importance to the training activity if there is no effect on training. However, how does one really measure the effect and what devices are applicable to conducting the required experiment is not discussed. In addition, Reference 48 then summarizes several reports which first of all either indicate a modification of pilot transfer function parameters and/or control activity such that in the presence of motion these characteristics were more representative of flight data than when motion was not present. If one was to apply a "perceptual" fidelity argument, then it would appear that the presence of motion does elicit a response/stimuli situation more representative of the real world than when motion is not present. In addition, there are papers which tend to indicate that as the vehicle dynamics become less stable or more unstable, then the presence of motion was required to maintain control by the pilot. In certain situations, control by vision alone was not possible (Reference 49). Thus, from these observations, it is possible to build a "perceptual" case for motion in training, most logically for emergency and failure states at the minimum. With specific regard to the subject of engine failure training for the KC-135, Reference 50 reports that "the pilots trained with a motion system performed significantly better than those without a motion system." In addition, this reference goes on to indicate a visual/motion interaction by the statement "In almost all cases, the improvement in training effectiveness gained when both the visual and motion systems were used was vastly superior to the incremental gain achieved by using either system alone." Studies recently reported by McLane and Wierwille (Reference 51) also indicate that for the less complex task of controlling an automobile, that motion (as well as audio) cues had a significant influence on driver performance. Spring, in his AIAA paper (Reference 33), informs us that when the simulator motion was turned off, the Navy IP's universally felt that there was a significant reduction in realism, and that there was "no enthusiasm for the simulation with this limitation." However, as the author states "It should be recognized that the effect of motion on motivation and the effect on transfer of learning are not necessarily the same." On the subject of motion, he states "The debate as to the quantitative utility of motion for air combat training will continue until hard evidence is obtained." It should be noted that some recent attempts to obtain "hard evidence" have not put the matter to rest. In a recent paper entitled "Platform Motion in Flight Simulators: Critical or Nice?", Dr. Hagin of AFHRL/FT summarizes the results of recent studies of motion/visual cues using ASUPT. It is of value to review this article because to some, ASUPT represents today "the pinnacle in the state-of-the-art in full mission simulation capability" (Reference 1). The value of the cited studies is questionable since the quality of the motion and visual systems for ASUPT to provide timely output is suspect (Reference 52). However, Reference 53 does inform us that these studies performed by AFHRL/FT neither strengthen nor weaken "the case for platform motion as being critical to the achievement of substantial training transfer." It is also interesting to note that in one of the cited experiments, motion was considered "detrimental" to efficient simulator training and "that three of the four motion trained students experienced air sickness in the aircraft while none of the no-motion trained students did." This may be indicative of the quality of the motion system for ASUPT rather than generalization of the inappropriateness of motion for training. Thus, concerning the value of motion cues, all that can be said is there exists a significant void, however, one can state that if motion cues are provided they must be realistic and not produce false cues to the pilot. In addition, motion systems should be reliable and easily maintained if they are to be used properly. With regard to the SAAC motion system as used during TAC ACES II, one recommendation is: "The SAAC Motion System should not be used for BFM/ACM." Another is a recommendation to reconsider motion required in future air-to-air simulators because the participants in TAC ACES II asserted a degradation in training realism with the presence of motion. Thus, while the data available is not sufficient to determine the cost-effectiveness of motion in military tactical training, several observations can be made:

- Motion can have a significant impact on aircrew motivation.
- Motion appears to provide a perceptual environment closer to the real world.
- No motion appears to be better than poor motion for training applications.
- Motion requirements are dependent upon task and vehicle dynamics.

- Additional research on motion cues using appropriate and adequate facilities is required, with appropriate hardware and software requirements (time delays, washout circuits).

In terms of visual cue requirements,it is obvious that for the tactical military mission it is essential to provide appropriate visual cues. The area of concern is the out-the-window cues required for the training situation to represent the real world. Again,as with motion, there is considerable evidence that time delays can have significant degrading impact. In a paper presented before the AIAA in 1963, M. Aronson states: "Studies of the effect of time lag between the pilot's control action and the feedback of the movement have shown that it should be in the order of 50-60 milliseconds to create the illusion that the pilot is controlling the situation." Reference 52 indicates that the ASUPT had delays (both software and hardware) of several times the value cited above and interestingly, motion lagged visual. A study cited in Reference 52 indicated that with visual cues only, time delay and iteration rates could be the difference between the ability of the pilot to perform a formation flying task successfully. Concerning the requirements for external visual cues in the air-to-air situation, Reference 54 states: "Obviously, external visual cues are required, but little is known of the specific cue requirements for air-to-air combat or if the interactions among visual and other control cues are important in flight simulation." This paper then goes on to describe an evaluation performed using a simple checkerboard display to provide some limited visual terrain cues. The study concludes that the display evaluated has low subjective realism but high utility. It should be noted that no experimental data or transfer data was presented in the reference. A recent paper presented by Heintzman and Shumway (Reference 55) essentially leads us back to an observation made by D. R. Tait in 1970, that is, total visual simulation of a complete flight is neither feasible nor practical in the immediate future. Compromises are required based on the device effectiveness to provide satisfactory training. The most cost-effective visual system may be a composite of the various systems available. Concerning visual system technology, Reference 55 states that the following questions remain to be answered, "as to what field of view, brightness, and resolution may be required for specific tasks." These questions are not necessarily new (References 56, 57, and 58). It is obvious from the literature that they have not yet been satisfactorily addressed and as a result "objective" data is not available to specify cost-effective visual systems for tactical combat training. Again, as stated before with motion cues, the visual cues presented should not be antagonistic to the user. For example, while there is little data to indicate the impact of color to visual simulation fidelity, there does exist some data to indicate that color can influence pilot control characteristics (Reference 59) and some additional data to indicate that under certain conditions the addition of color may be more distracting to the pilot than useful (Reference 60). Thus, it appears that again, a significant distraction factor provided by an inadequate cue representation will reduce the desired effectiveness. At present, in the world of visual simulation, there appears to be a significant movement towards the use of computer-generated images, and the need to increase the number of edges, etc. Very little data could be found on to what extent the external view of the world can be simplified. One paper was uncovered which describes an experiment and some preliminary results directed at eliminating unimportant/unnecessary real world information to minimize CGI requirements, Reference 61. The stated purpose of the experiment is to establish data to allow a reasonable trade between CGI cost or complexity and requirements. The preliminary results indicate that pilots do use texture cues for height estimation and that regardless of the degree of "stylization" there is a greater tendency for height error than distance error. Since a learning process was observed, perhaps it suggests that the human visual experience has normally been more concerned in distance judgement rather than height. This is somewhat reinforced by the observation in the cited paper that height judgement of pilots is better than nonpilots. Of course, this last statement leads us to another point, since it is the pilot we are attempting to understand in the training situation, and since differences have been observed between the performance of pilots and nonpilots in various simulation experiments, research into the training effectiveness of a flight simulator, or on the impact of various cues on the training situation should use an appropriate subject as well as a facility capable of providing an applicable environment.

To complete this discussion, let us now spend some time examining additional cues. These cues (e.g. aural) can be used to enhance the subjective realism of a simulation and can also influence the performance of the subject. As discussed in Reference 51, for example, the removal of an aural cue provided by an engine noise generator reduced the subject's performance with respect to velocity control. In addition, the aural cue tended to mask spurious noises generated by the motion drive system. Again, there is little data available that objectively examines the impact of these additional cues such as noise, buffet, etc.; however, as reported in Reference 60, there is subjective data that both engine and aerodynamic noise cues are considered by a majority of both military and commercial pilots to be either necessary or desirable for simulation. In a study reported by Starke and Wilson (Reference 62), it was determined that the simulation of buffet and vibration was considered as "essential in the simulation of flight near the edge of the performance envelope ...." The authors continue, "While transfer studies have not been accomplished with respect to fidelity requirements, it is expected that anything but complete simulation of buffet would be pointless in preparing pilots to make best use of their aircraft in air-to-air combat." They consider, aside from the cockpit motion system, that a system to provide vibration and buffet cues relative to angle of attack is required to provide flight essential cues.

If one wishes to then generalize from the literature survey performed, only one immediate conclusion appears to be obvious, that is, there is not any data that can substantiate from objective training effectiveness consideration, the necessary or the desirable cues, the appropriate cue interaction, etc. required to provide appropriate fidelity for the training situation. It is also somewhat obvious that many existing simulation facilities such as SAAC and ASUPT may be presently inadequate for use as a facility to examine the effectiveness or fidelity requirements on many cues. It is also obvious from a review of the existing data, that a device promised to provide high fidelity simulation is of little value if it introduces significant spurious/distracting cues or is not reasonably reliable or cannot be easily maintained. These last two items will have a significant impact on any cost-effectiveness study that requires abnormally high utilization rates for a complex device in order to justify its procurement. It also appears that it may be better to eliminate a cue in a training situation than to provide what is considered to be a "false" cue.

Simulator Data Requirements/Acceptance Evaluation

During the literature review, it became obvious that there was much subjective data which indicated a significant inadequacy of existing simulators. While many pilots felt that simulators could be used for procedural training and emergency training, the general handling qualities area was considered to be inadequate. Thus, it appeared to be of value to survey the literature for some definitive reports on simulator data requirements and acceptance evaluation procedures. It is obvious that the full potential of the flight simulator cannot be approached without a reasonable ability on the part of the device to present to the pilot the flying qualities and performance characteristics of the actual aircraft. In other words, to instill confidence in the subject that the time spent in the simulator is being used effectively, the program should be "credible", that is, the ultimate user must be reasonably sure, at least perceptually, that the simulator "flies like the aircraft."

The remainder of this discussion will present observations made from the literature survey on aerodynamic data package requirements and also observations made on the topic of simulator fidelity assessment directed toward acceptance testing. These two subjects are definitely interrelated since it appears that one of the great shortcomings of existing simulation equipment is to produce a representative flying qualities environment. Even for the case of simulators used for training in the Airline environment, the following opinion was expressed in 1974 (Reference 31) by D. P. Davies: "Flight Simulation has made good steady progress over the years and is now being given significant credit for its ability to reproduce aircraft flying qualities in a device on the ground. However, the simulator world is tending to claim too much credit for its present level of achievement." He then goes on to give advice to the various parties involved in a simulation program, which in essence provides the framework for an acceptance program:

- Advice to airframe manufacturers

    - supply an accurate data package
    - update data
    - provide pilots to simulator manufacturers and users

- Advice to the simulator manufacturer

    - insist on an up-to-date data package from the airframe manufacturer
    - develop a current test pilot capability

- Advice to the simulator operator to achieve a high quality simulator

    - do not "twiddle" to achieve good handling qualities
    - use the best assistance from simulator manufacturers and airframe manufacturers
    - develop your own competent staff
    - insist on an accurate up-to-date data package

- Advice to the simulator operator on use of the simulator

    - essentially maintain the realism of actual flight, do not use training features in an inappropriate manner or permit abuses because the "simulator is a simulator and not an airplane"

Thus, it appears that the initial and possibly most fundamental concern, and logically so, is the accuracy of the data package. According to D. A. Clutz, Reference 63, those portions of the data package most poorly defined, in general, are the aerodynamic coefficients, the control coefficients and the cockpit and surface control characteristics. It is well known that this data is critical to the design and use of an aircraft so it becomes essentially a logical extension to believe these parameters should also be considered critical to the flight simulator. The questions which remain are more related to who is responsible to supply the data, what level of complexity is required in the data, and in addition, what is the impact of the real time digital computational effects or the impact of other system dynamics on the handling qualities/performance fidelity achieved by the training device. This last question is obviously not as simple as just implementing the data in real time. In his article recently published on the U.S. Army new approach to this problem area, Lt/Col Robert L. Catron reminds us of the following fact:

- definitive data which describes the aircraft handling qualities/ characteristics for all required flight conditions, etc. is simply not often available.

He then also reminds us of the reason why this is more often the situation than not:

(1) developing a precise math model is not a primary goal of the airframe manufacturers
(2) there are often "holes" even in the most rigorous flight test programs
(3) flight test can be made obsolete as the aircraft evolves through the development phase
(4) extensive flight testing to provide an accurate data package update can be quite expensive.

The articles then go on to describe the new approach, based on establishing a qualified, experienced evaluation team. However, the use of an evaluation team can still involve several problems, relating to the "accuracy of the pilots perception", Reference 63:

- relationship of pilots aircraft to the average aircraft of the type required for the training device
- pilot currency and proficiency in the test being conducted
- pilot adaptation to the simulator.

On this last issue, various estimates indicate after about 4 to 8 hours on the simulator, the pilot may no longer be able to provide valid judgments on discrepancies between the handling qualities/performance of simulator and the aircraft (References 63 and 64). In addition, these judgments are subjective and may require extensive coordination by a team of pilots, engineering, flight test, computer and simulation experts to resolve problems into a valid hardware or software fix. An approach, to attempt to quantitize these subjective evaluations into a form that can be more readily used in engineering analysis has been suggested in Reference 25. Nevertheless, it appears that there are essentially two fundamental issues, not so much that good data is required but more so who should be responsible for providing the data, and then what is the most effective and efficient concept to apply to acceptance testing.

On the subject of the validity and adequacy of the data, we should remember that normally during the design of an aircraft, an initial data package is developed by the airframe manufacturer for use in an engineering simulator. While this data package may not be as complete as the simulator manufacturer would desire (for certain obvious reasons) it is the best guess for the initial design/handling quality studies performed by the airframe prime (provided of course he is obligated to perform a simulation). The flight testing of the aircraft itself against its specification will supply significant data if properly obtained, either by classical analysis or by more recent computer systems developed for flight test. Parameter identification techniques can be utilized, to also provide additional data, or at least evaluate the adequacy of the existing data package. For an aircraft in operational use, another source of data are the using command pilots and aircrews. However, complaints must be transferred into viable fixes to the training device, and there is some indication in the literature that the simulator manufacturers have been ineffective in this task, (Reference 64), possibly as a result of a breakdown in communications between simulator specialists and operational pilots. References 52 and 64 also indicate that increasing the capability of a training device (e.g. adding an external visual flight system) can magnify existing simulator discrepancies, and training value could subsequently suffer without proper system integration or modification. For example, the relationship between the visual and motion time delay for a given device could influence the ability of the pilot to detect the motion delay, Reference 52.

Reference 64, presents the program team concept used by the U.S. Navy in an attempt to improve the fidelity of a flight training device. Essentially this approach applied a team concept, involving personnel with various capabilities and backgrounds, doing their thing and interacting to identify and quantify device fidelity problems. The approach used to validate the simulator involved the use of performance and stability and control tests essentially equivalent to those required of the aircraft. The procedure involved an iterative process, examining the fidelity at various levels of device complexity, e.g., fixed base first, then add motion system and re-evaluate, etc. This approach appears to be reasonable and successful, but it also indicates that perhaps the device was initially accepted with insufficient testing. That is, the modeling problems were always there in the data package. There are, however, no discussions presented on the impact of the improper model data on any students trained in the device prior to the fidelity improvement exercise.

In summary, it appears that a properly coordinated team effort, with designated responsibility is essential to both obtaining a valid data base for the model and to provide acceptance testing. It is deemed essentially that the government personnel charged with airframe system development responsibility and their counterparts charged with simulator system development interact in controlled manner to insure a proper data base is provided. Flight testing will most definitely have to be performed and data well documented especially at the edge-of-the-envelope if the training to be provided on a simulator at those conditions is expected to be meaningful. It becomes highly possible for negative transfer to occur at these critical conditions, thereby increasing the potential risk on "first-shot" transfer to the aircraft. A reasonable set of requirements to obtain an appropriate data base, designate responsibility and establish the framework for development of acceptance testing procedures can be obtained by following the advice of D.P. Davies (Reference 31) augmented by the Simulation Criteria Enhancement approach advociated by D.A. Clutz in Reference 63. The recent experience obtained by the U.S. Army and U.S. Navy in their acceptance testing the fidelity improvement programs provides valuable insight into how to develop team testing procedures that are required to insure a reasonable level of credibility in a training device.

Pilot Survey on Simulation

As has been stated many times in this report, it was very difficult, if not impossible, to obtain objective evidence of the value of simulators for training the complex skills required by pilots especially for a tactical situation. Most of the data obtained in the literature survey, seemed to be judgments made by government/military personnel committed (for whatever reasons) to simulation, the "expert" opinions of engineering psychologists and claims for devices made by people with a vested interest in the future simulation procurement (manufacturers, training organizations, etc.). Thus it was decided, if one is to search for opinion, then search for the opinion of the ultimate user, the pilot. Specific surveys have been recently obtained in the TAC ACES program (this will be the subject of a subsequent section in this report), the purpose of this section is to report on a more general survey obtained on the attitude and opinions expressed by both military and commercial pilots on the various facets of flight simulators used as training devices (Reference 60). This reference reports on a study conducted by the RAF using military pilots and the British Airline Pilots' Association using Airline Pilots to obtain user opinions on:

- problem areas
- system benefits
- future system goals
- establishing priorities

It should be noted, that if a similar general survey has been conducted by U.S. Military Organizations or Airlines Pilots' Association it was not uncovered during our literature survey. The importance of these surveys, should not be minimized since they can be very useful for determination of those facets of a training device that would increase the credibility of the device in the mind of the ultimate user. The data to be presented in the remainder of this discussion is extracted from Reference 60. The reference is separated into first the RAF data and secondly the Airline Pilots data. This separation will be maintained for the convenience of any reader who desires to cross check with the original data presented in the cited reference.

RAF DATA

- Motion Simulation - Assessment of roll and pitch simulation indicated that the majority of pilots surveyed considered the existing systems as "quite realistic" however approximately 30% of the pilots indicated that the systems were considered as unrealistic.

- Motion System Requirements - These requirements appear to be task/type aircraft dependent. Examination of the data for the tactical situation indicates that a majority of pilots surveyed consider roll, pitch, turbulence and vibration as either "necessary" or desirable. The sway degree of freedom was either not evaluated or not recommended, the table in the reference is not clear on this subject. Yaw degree of freedom had split opinion (essentially 50% returns considered as desirable, and 50% as undesirable) for the interceptor task, but definitely considered necessary for the low level attack task. The surge and heave degrees of freedom were essentially split for the low level task, however, the majority of data appears to indicate a desirability for these degrees of freedom. While this data indicates some pilot priorities on motion requirements, as the authors state " clearly some rigorous work is still required to identify those motions which enhance training, those which do not affect training but do influence the trainee's attitudes to the simulator, and those which can be safely dispensed with. Some similar work on pilots attitudes on required motion is presented by Starke and Wilson in Reference 62.

- Visual Simulation - assessments of existing visual flight attachments for ground taxi, take-off and landing flight phases indicate that while many thought that the attachments were quite realistic for these phases, again almost 30% or more consider the fidelity as unrealistic.

- Visual Simulation Requirements - in all cases, pilots indicated the outstanding requirement for visual simulation was for take-off and landing phases. For the low level attack requirements, the mission phase and examination of aircraft handling in the air the survey data indicated a preference for visual simulation capability. Interceptor pilots indicated the predominant requirement for visual simulation capability was essentially for take-off and landing.

- Required Visual Systems Improvements - the vast majority of the military pilots indicated that greater field-of-view was the single most important required improvement for visual simulation. This was followed by collimation and greater depth of focus, while the next priority went to increased resolution. Information of this type is valuable in establishing research objectives.

- Auditory Simulation - the significant majority of pilots, especially for the low level attack mission consider engine noise and aerodynamic noise as necessary and desirable for simulation. While the data indicates that the present capability for engine noise simulation was considered realistically done, the data indicates that improvement is required for aerodynamic noise, which was considered to be "not very realistic", at best, by the majority of respondents.

- Handling Qualities Simulation - the stated aircrew requirements for maximum fidelity in this area appears to be unsatisfied. The majority of pilot responses indicate that the existing simulation capability in this area was at best unrealistic.

- Training Value of Simulators - in general, the authors indicate that it can be supposed that the aircrew were relatively satisfied with simulator training. In the question of simulator time requirements in conversion, the majority of pilots responding to this question saw "no requirement for changing the time allotted." Concerning time distribution for other training areas (e.g. mission execution and general handling, most respondents felt unqualified to address that topic. While 70% thought that the use of the simulator in training was successful, the simulator was rated highest in training emergencies. It was considered less effective relative to the aircraft for mission training and essentially considerably less useful for general handling. Of the pilots surveyed, 45% or more agreed that the simulator checks were adequate for predicting performance in the aircraft, however 50% of all respondents were not in favor of "objective" (computer determined) performance assessment. This could indicate that pilots prefer to be taught and evaluated by their peer group according to the authors. A survey conclusion is that "the usefulness of the simulator for other than procedual work and emergencies was thought to be limited."

- Training Instructor Requirements - in excess of 90% of the aircrews surveyed thought that the instructor should be current on the aircraft being simulated, and that teaching ability was required. Instruction in teaching techniques was considered to be either necessary or desirable by 99% of the aircrews responding to the questionnaire. The reference states that attitude of the trainees towards the simulator for training can be significantly influenced by the role and status of the instructor.

- Conclusions Based on RAF Survey -
  - Although current motion systems appear to be considered reasonable, improvements in the quality of simulation may be desirable.
  - Visual systems need improvements, most likely in field-of-view, depth-of-focus, and image collimation
  - Simulation of engine and aerodynamic noise is considered highly desirable.
  - Simulation for other than procedual work and emergencies was considered limited, however, it was considered satisfactory at least for these two cited training areas.

The remainder of this discussion will present a summary of the data obtained from the Airline Pilots responses to a questionnaire on the value of simulators for training and checking pilot performance. The following list indicates the most significant criticisms of the various simulation facilities in terms of descending order:

- Poor Simulation of Aircraft Handling Characteristics
- Poor Motion Simulation
- Motivational Problems
- Poor Simulation/Representation of Cockpit, Controls, etc.
- Simulator Reliability

The survey indicated that opinion was essentially split, on pilot/aircrew satisfaction with the refresher training/competency checks and instrument ratings renewals as performed in the simulator, between "satisfied" and "not satisfied." Again, as in the RAF study, the majority thought that procedures and emergencies were trainable in the simulator, while handling practice could not be performed. Concerning motion, it appears that pitch followed by yaw and roll were considered as motion requirements for simulation. As with the RAF data, the majority of Airline Pilots thought that engine noise, aerodynamic noise, etc. were either necessary or desirable for simulation. The existing simulations appear to be adequate in representing engine noise, however, improvement is required to adequately simulate aerodynamic noise. With respect to the value and adequacy of existing visual flight attachments, the ratings appear to be strongly correlatable with the training device, however, at best they were considered as useful for some maneuvers. Many responses indicated that the visual simulation was inadequate/distracting especially with color. In general, there appears to be a general approval of the training presently obtained in the simulator, especially to obtain more practice without demonstration of competency. In summary, these results tend to generally reinforce the results obtained from the RAF study. Again, while these results are obviously subjective, they demonstrate some short term goals that are considered by the trainee to be desirable and would tend to increase the 'credibility' of flight simulator training. The pilot appears to be willing to accept this training, at least for procedural tasks and emergencies. The cited paper concludes on the importance of achieving greater serviceability and consistency from training devices, that required utilization would interfere with the desire to provide pilots with "free time" for training in the simulator, and that it may not be economic to build devices with the complexity required to achieve "zero time".

The results of the cited pilot surveys indicate that using simulation devices for standard procedural and emergency procedures training would be acceptable to experienced military pilots. Our previous discussion indicated that it was also procedural skills that were most easily forgotten. Thus simulator training could prove to be the most efficient method for teaching and maintaining pilot proficiency of procedural skills.

Full Mission Simulation (A Case History)

It becomes apparent from a review of the literature that there seems to have been placed in motion a military commitment to obtain full mission simulation devices. This appears to have been brought about by several factors, but primarily motivated by the desire that reduction of flight hours cannot reduce the combat readiness requirements. In additiion, the argument for training in simulators to reduce risk while examining tasks in a hostile environment (i.e., the impossibility criterion) has also been cited as a justification for needing full mission simulation capability, although it is also recognized that the simulator, no matter "how realistic it may be in the military application, never can nor will replace live flying experience, " Reference 39. Thus, while there appears to be strong justification for such a device, the question is can the full mission simulator be delivered and is it "cost-effective" to develop such a training system. A search was performed to attempt to examine the full mission simulator. The only fairly well documented background on this level of capability appears to be related with the RAF experience concerning the Phantom Full Mission Simulator. It was deemed to be of value to this present study to summarize this particular case history in a chronological manner.

This case history essentially starts with an article presented in 1970 Royal Aeronautical Symposium (Reference 65), primarily concerning concept, proceeds to an article presented in 1973 (Reference 66) concerning what was achieved and suggesting an interim solution to the deficiency of the device and is presently concluded by a most recent presentation at the 1975 AGARD Conference on Flight Simulation. This case history documents a situation where based on a lack of background expertise, the "inspired guesswork" did not produce the desired capability. As will be indicated by the following presentation, the gap between the best laid plans and the realities of simulation capability have not yet produced the desired training potential for the simulation facility under discussion.

Reference 65 sets the stage, as it provides to us the background discussion as to the need for full mission simulation, the general hardware requirements, the obvious advantages (aside from financial and flight safety), how the device will be utilized and the commitment to the device, especially considering that they "do not provide an end in themselves but rather, by supplementing the decreasing flying hours available from our limited resources, they help to keep the point of the services needle sharp." Our next document, presented in 1973 (Reference 66), states: "Training results and opinion within the Service have shown that our significant commitment to the use of sophisticated full mission flight simulators has yet to produce the degree of productive training that was initially envisaged." The limitations cited, based on operational experience for this lack of achievement, are the following:

- Servicing problems
- Reliability and maintainability of the systems
- Limitations in the visual systems
- Restrictions in gaming area
- Lack of qualified simulator instructors
- Difficulties with building facilities
- Service contention with respect to the value of motion and visual systems

This reference goes on to tell us that the Air Staff, based on the inability of the full mission simulator to "effect the improvements and savings in flying hours," instituted a task to quantify "the value of flight simulation to the military training task." The reference informs us that the Air Staff required this to be achieved "by scientific methods." Obviously, the time for guesswork was coming to abrupt finish and a long term commitment had been formulated to investigate this task. However, an "Interim Policy" was also formulated. This was to first of all progressively relegate to the simulator all instrument training and secondly, to evaluate what areas which do not receive adequate training in flight could be supplemented by the use of the simulator. The long term policy would be to use streaming trials to evaluate and quantify "the value of various device capabilities." The author states "We believe that our withdrawal from the full mission concept is both realistic and rational; future simulators will be tailored to meet the specific requirements of the particular training task." This appears to be a commitment to part-task training devices. To conclude this case history, at least for the present, a recent report by a member of the Ministry of Defense was presented at the AGARD Conference held in The Netherlands in 1975 (Reference 26). In essence, this article informs us that the "Long Term" research policy toward quantification of the value of this full mission simulator in terms of:

- Flight hours that can be substituted
- Device capability/complexity

is on-going. Thus, the "hard" data is not in yet and the true value of full mission simulation still remains quantitatively undefined. Thus, to review the facts of this case:

- Subjective assessment was used to justify procurement of devices to achieve desired benefits

- Subsequent operational experience did not indicate the desired goals were being achieved

- The high cost and complexity of these devices has prompted a study to determine and quantify the training effectiveness of full mission simulation

- The "answers" are not yet available

Thus, from this case history, it appears to be highly desirable to review any planned procurement of full mission simulation capability and determine whether or not dedicated part-task trainers could not prove a more viable and presently more "cost-effective" solution to training requirements. In the opinion of the authors, based on the literature survey, the case for the full mission simulation cannot be based on the demonstrated practicality of such a complex training device although such capability would appear to be both desirable and potentially technically feasible. While a need may exist, the present state-of-the-art of simulation technology does not appear to be able to support a "cost-effective" tactical full mission simulator. As recently concluded by Gum and Swab in Reference 16, "The state-of-the-art is adequate in many areas to support the acquisition of effective training devices which will allow considerable aircraft flight training time to be saved. Much development remains to be done in order to satisfy all of the using command needs and to permit training simulators to achieve their full potential."

TAC ACES I and II

As part of the data base for the literature survey, two documents were furnished to us concerning the TAC ACES program (References 30 and 34). These programs are based on a TAC established requirement to supplement existing F-4 air-to-air combat flight training using existing state-of-the-art simulation facilities. The TAC ACES I program was performed on an industrial simulator (VACS), while the TAC ACES II program was performed on the SAAC simulator. The purpose of this section is to review the conclusions and recommendations of these documents as they impact on current state-of-the-art simulator technology to provide adequate "supplemental" training. It should be remembered that there have not been any streaming trials conducted to evaluate the transfer effectiveness of the training received by the pilot participating in the TAC ACES programs. Any evaluation performed of the effect of the simulator training on air-to-air combat proficiency is based on improvements in score in the device (which could be nothing more than a pinball machine effect) and subjective statements made by the pilots who participated in the program. It should be stated at the onset of this review that both documents indicate that there was sufficient lack of realism that could result in "development of bad habits" and "negative training" unless the courses are conducted as a highly controlled, short term training program. For the programs conducted, these devices were operated as dedicated part-task training devices. Significant deficiencies were noted and some improvements indicated as required to continue the training program concept, although on both programs a majority of subjects considered the value of the training received (even with the fidelity limitations) as either good or excellent. This suggests that some dedicated training program, with the ability to relate academics quickly with a facsimile of the operational environment can be effectively used to supplement aircraft training even with reduced fidelity. The results of the programs do not justify any extrapolation that the training provided could be used as a substitute for actual simulated air-to-air combat training in the aircraft. It is significant to note also that one of the better uses of the simulator was considered to be "switchology," indicating that possibly the most effective training that can be presently provided by these devices is in procedural skills required for air-to-air combat. The results of these programs indicate that full mission simulation capability for the tactical situation is not presently state-of-the-art, however, with correction of certain deficiencies supplementary training with dedicated part-task devices is achievable in the short term, but requires a highly controlled training environment. The following list indicates the significant simulation deficiencies identified from pilot comments on the TAC ACES I program:

- Target aircraft imagery is inadequate
- Cockpit control loading is unrealistic
- Fidelity of aircraft handling qualities and performance is deficient, especially at high AOA
- Weapons scoring was inadequate
- AIM-9 seeker tone unrealistic

- Prerecorded maneuvering target is of limited value
- Visual altitude cues were inadequate
- Engagement scene display format
- Target presentations were unsuitable for formation flying
- "g" indications ineffective, tendency to use excessive g, could lead to bad habit
- Program limited to 1 on 1, cannot explore operational tactics
- Simulator layout restricts aft visibility and use for training in DCM

Even with these limitations, the overall opinion of the pilots participating in the TAC ACES I program considered it to be valuable training especially for an inexperienced ACM pilot. Caution is indicated due to device limitations and the possibility of developing bad habits because of the lack of realism. The comments indicate that most pilots considered it as a good ACM/BFM procedural trainer and a complement to actual flight. Perhaps some of the most revealing comments on the value of the TAC ACES I training program were the following: "Any realistic training is better than what we currently have, which is nothing." "The simulator would be of least benefit to highly experienced pilots because it would make very little addition to their state of proficiency or learning. The simulator would not provide the finer points of air combat that could only be achieved in an actual situation (real aircraft)." The primary recommendations presented with respect to the TAC ACES I program appear to be the following:

- TAC ACES I be continued as a supplement contingent upon correction of the significant deficiencies
- Fidelity of target aircraft images be improved
- All aircraft math models be improved to provide realistic handling qualities/performance
- External visual altitude cues be provided
- Cockpit motion requirements be reviewed

Unfortunately, a review of Reference 30 did not indicate pilot comments that indicated directly that motion capability was not missed or necessary in the training program. In fact, there are several comments indicating potential problems due to lack of appropriate "g" simulation, stick feel during maneuvers, and inadequate acceleration/deceleration cues. Nevertheless, in general, the TAC ACES I program has indicated the potential value of concentrated training in ACM/BFM, with the use of a simulation device to augment switchology skills and help develop and maintain "a sense of situational awareness." TAC ACES II was directed at the use of the SAAC simulation facility to develop an air-to-air combat training program to some degree built on the lessons being learned during TAC ACES I exercise. While this program also indicated limitations in equipment, it was considered valuable by the participants. It was determined during this program that the "SAAC did not have the total fidelity needed to support the training program objective of quality training." However, this document (Reference 34) also states "Every participant indicated that the simulator training increased the value of the course beyond that of one that offered only lectures and discussions. The simulator training allowed immediate reinforcement of classroom discussions, helped develop timing and hand-eye coordination, and provided a direct (practical) application of academic training." Thus, it was concluded that "TAC ACES II provided a beneficial supplement to current air-to-air training programs." This was determined from pilot program evaluation and critiques. One recommendation reached on this program concerning the necessity for motion, based on the false cues presented by the SAAC motion system is an over-generalization. The only appropriate observation is that no motion may be less distracting and bothersome to the pilot during ACM training in a simulator than the existing SAAC motion system and associated drive logic. Overall utilization of the SAAC was restricted due to facility failures and maintenance downtime and it was concluded that the 36.1% in commission rate could not support the training program sufficiently and that continuation programs "should not be scheduled in the SAAC until maintenance can support an 80% utilization rate." The other primary limitations/deficiencies that were identified in this program using the SAAC facility were:

- Visual simulation fidelity needs improvement
- Math model does not provide appropriate fidelity for performance and handling qualities parameters

- G-seat program needs improvement, "can't quite simulate the real feel of positive, negative, and zero G."
- AOA warning tone missing, important cue to provide stall warning
- Missile envelopes unrealistic
- Capability for sun to conceal target is highly desirable
- Lack of cue to alert defender of weapon employment by attacker
- Record/playback is complicated to operate, and at times could not provide timely data

As previously discussed, the limitations of the SAAC indicated that while it could support a short-term highly controlled training program that could be of benefit, the device "could lead to developing bad flying habits." It also appears that one of the most limiting features of the SAAC was the excessive maintenance downtime. Both TAC ACES I and TAC ACES II have indicated the essentially existing state-of-the-art technological capability exists such that simulation facilities to supplement current air-to-air training programs is realizable. The devices used,even with their lack of fidelity, did provide a beneficial program to review and relate academics, procedures and situation awareness. The message also comes through that the improvement in maintainability and reliability of such facilities is essential to support any reasonable training program. Based on pilot comments documented in References 30 and 34, the technology used on VACS and SAAC for the TAC ACES I and II program can presently provide supplementary training in a controlled environment but cannot be used as a flying time substitute for the air-to-air task.

A-10 Aircrew Training Device Trade Study

A trade study jointly prepared by TAC/AFSC was released April 1975 which investigated four alternatives to aircrew training device requirements. As a result of the various assumptions used in this study, it was determined that a full mission simulation capability was the "minimum satisfactory solution to TAC's stated aircrew training requirements because it is the only option which provides simulation of the operational environment under which the A-10 pilot is expected to perform." The executive summary continues:

"Given that the assumptions listed in this document are accurate, full mission simulation is also the most cost effective alternative and will afford pilots the means of developing and practicing all the tactics and skills needed to make the A-10 an effective weapon system." The lesson to be learned from the case history of a full mission simulation device is that while the concept is valid and potentially desirable if you have to produce combat ready aircrews with minimum time in aircraft; there exists no hard evidence on which to quantify the effectiveness of full mission simulation capability, and that a device developed in the immediate past did not live up to expectations. Thus, if we are to learn from history, it is of necessity to review the assumptions made and evaluate their criticality. It must be remembered that a trade study is essentially "crank turning" based on the cost equations used. The solution is critically tied to the assumptions on device substitution, and device costs and device utilization rates. Thus, any study of this type is no better than the assumptions used. In order to determine the true value of the A-10 trade study, it is obviously necessary to evaluate the risk associated with the assumptions used. In general, based on the presentation of the RAF experience with the world of full mission simulation and the fidelity deficiencies of existing devices used in the TAC ACES programs as well as the maintenance problems associated with the operation of complex simulation facilities, it becomes questionable as to the realism of the A-10 trade study assumptions. Significant questions arise on these assumptions that could challenge the validity of the conclusions reached, however, if the assumptions are correct then obviously the conclusions are valid. The following discussion is an attempt to document a challenge to the A-10 trade study assumptions, based on the data obtained in the literature survey. This discussion should not be considered as exhaustive, however, the observations are considered valid. To some degree, the existing state-of-the-art was addressed in the A-10 trade study, however, the implications of the existing deficiencies in the state-of-the-art and the required/assumed device capabilities did not receive the level of attention required to indicate if such devices are presently feasible or practical. Examination of the device descriptions indicate that except for the adaptive training features, the HIFS is essentially state-of-the-art. The field-of-view and visual requirements for the VS and FMS are not considered to be practical at this point in time. While the visual system essentially appears to be a derivative of the SAAC system, the TAC ACES II study determined that "the fidelity of the imagery was poor" and improvements required, at least in the air-to-air task. The value or level of fidelity for a ground attack task has not yet been documented for the SAAC visual system, to the best of our knowledge, from the literature survey. Thus, it appears that extensive research and development may be required to determine the minimum level of fidelity required for the visual external world simulation. To some degree, this subject has been discussed, researched and reviewed for many years (i.e. Reference 67. At this writing, the results of our literature survey indicate the existing state-of-the-art for fidelity of visual simulation is not adequate for the intended purpose of the VS and FMS devices. In addition, an attempt to create a 2v1 capability on SAAC for the TAC ACES II was unacceptable and this has direct implication on the desired tactics training capability of the FMS. Thus, before proceeding to the other assumptions, it appears that FMS is presently not practical especially from an operational point of view. However, since we can assume that someone will be willing to foot the bill to do the required research and development in a timely manner such that the desired system capability becomes practical during the life cycle of the aircraft, there still remains another significant problem area. There still remains the subject of the appropriateness of the substitution of simulator hours for flight hours (transfer effectiveness ratio). At this point, it should be remembered that transfer effectiveness is training system and task dependent, and little or no "hard" data is available except primarily for instrument and procedural tasks. Even at this, the A-10 trade study tends to use the more optimistic, rather than average value of transfer effectiveness ratios documented in the literature. This then impacts on the trade study by effectively overestimating the value of simulator training and thereby resulting in "optimistic" cost effectiveness for a device, especially for the VS and FMS devices. This tends to result in a minimum number of simulator hours (and a significant reduction in flight hours) to reach a desired proficiency with respect to not using a simulator. This fact, coupled with the assumed high availability hours for the device (5000 per yr) result in procurement of minimum number of devices, thus minimizing front-end costs. Examination of step 11 in Appendix F indicates that the TFTW must achieve essentially 5000 hours/year/cockpit for the FMS. This implies an in-commission rate of essentially 100%. If we can assume that the SAAC represents a device similar to the desired A-10 FMS, during the TAC ACES II program the SAAC facility only could support a 36.1% in-commission rate on scheduled hours. This then indicates another questionable area with respect to the A-10 Trade Study. The maintainability and reliability of existing devices may be inadequate without significant product improvement programs to support the required utilization rate. If as concluded in Reference 34, a desirable in-commission rate is 80% to support a training program, this factor should be "cranked" into the cost-effectiveness study, especially since the probability of maintenance downtime usually increases with the complexity of the device. It is considered unrealistic not to assume that a device as complex and sophisticated as the A-10 FMS will not be subject to "Murphy's Laws", especially during a training session. Another factor that must be examined is the assumption that ordinance costs can only be reduced by use of the VS and FMS simulator devices. It is apparent from an examination of data concerning the Airborne Instrumentation System (AIS) used at the Air Combat Maneuvering Range, and data presented in References 68 and 69 as well as experience gained using instrumentation in SAC Bomb Competitions that it is not only feasible but within the state-of-the-art to simulate weapons delivery using the actual aircraft as the training device. The impact of this technology can significantly influence the A-10 Trade Study by reducing the armament costs associated with the actual aircraft phase directly, and indirectly challenge the use of the simulator for training the weapons delivery/tactics part-tasks. The last challenge to the assumptions is based on the projected aircraft operating costs, etc. vs. the simulator. According to the data published in the A-10 Trade Study each flying hour saved at the Training Wing may well save $429, while each flying hour saved at the Tactical Wing may well save $361. The hourly cost of the simulator varies, by using agency and by device, with the range between $78.48 and $105.45 hourly O & M/cockpit. Data published recently in U.S. Army Aviation Digest, (Reference 70) indicates that the approximate cost of one hour of instrument training on Device SFTS 2B24 was $65, which tends to lend credibility to the estimated operating cost for the HIFS A-10 device. An article in the October 4th, 1976 issue of Aviation Week and Space Technology by B. M. Elson indicates that Boeing figures it costs $280/hr to use a 727 simulator using a GE visual system. The display system uses forward view and side view with the field of view of each segment 30 degrees vertically by 40 degrees horizontally and television tubes capable of 1,200 line resolution (2.7 arc-min of angular resolution). While obviously there are significant differences between an A-10 FMS and a 727 flight simulation device, the cost of operating the A-10 FMS of approximately $100/cockpit hour may be optimistic. While a sensitivity study was performed to examine increasing fuel costs and increasing munitions costs, thus making the simulator amortization occur somewhat sooner, a sensitivity study was not performed to evaluate the impact of a significant increase in simulator O & M costs especially for the VS and FMS devices. Effectively, the sensitivity studies that were performed could be considered to be one-sided to make the simulator appear more cost-effective and to definitely make option III (Full Mission capability) more "cost-effective." Thus the results of the Trade Study are not necessarily "objective" and most of the assumptions related to the substitution of simulation hours for flight hours cannot be justified by "hard" experimental evidence for those tasks that make the FMS result in the most "cost-effective" device. The data available in the literature does tend to support the assumptions relative to the HIFS, assuming that the cost per device of approximately 5.7 million is correct. There is also some concern about the increased capability costs when going from the HIFS to the VS to the FMS. While the additional features of the VS appear to be a realistic increment ($\sim$3.0 million) over the cost of the HIFS, the increment of approximately .55 million to obtain FMS capability from the VS device appears to be optimistic, especially to create the additional visual simulation capability and cockpit coupling required for the FMS training device.

U.S. Navy UPT Task Analysis

A recent study, initiated at the request of CNET was performed by CNATA to verify current training procedures and curricula or to identify deficiencies requiring modification or improvement is documented in References 71 and 72. The Phase I study (Reference 71) presents data obtained by questionnaire from experienced fleet aviators and second-tour aviators in operational squadrons receiving newly designated pilots for additional training. The evaluators were required to rate specified UPT tasks in terms of frequency, criticality, and training adequacy (similar to the concept described by Cream in Reference 45). Questionnaires specific to particular training were used and the summary of the data, in particular, fleet determined underemphasized and overemphasized training tasks by community is presented in the Phase I report. Phase II of the study then used the data determined from Phase I with appropriate training effectiveness methodology to recommend a comprehensive program revision to obtain fleet desired training objectives by adjusting the curricula, training techniques and the devices selected. It is of interest to note that a study was initialized to evaluate the feasibility of using ACMR systems appropriately modified to provide training for various flight phases other than ACM. These training areas are representative of the areas currently envisaged by the A-10 Trade Study for full mission simulation capability using a ground training device. The U.S. Navy appears to be pursuing the unique capabilities of ACMR to provide improved training and consequent cost reduction. This indicates the possibility of modified ACMR as an alternative to complex ground simulation facilities and the viability of this potential should be explored in depth. The results of the Phase II study relative to the jet training requirements and the recommendations for simulation are reviewed in the subsequent discussion for the jet pipeline. The overall result of Phase II indicates that to meet fleet validated objectives, an increase in 21 flight hours and 45 simulator hours were required. The distribution of the change in hours was as follows:

- Basic – increase flight hours from 26.0 to 70 and introduce 39.0 hours on simulator, of which 27.2 flight hours and 33 simulator hours dedicated to instrument training (BI/RI).

- Jet Intermediate – decrease flight hours from 117.7 to 95.9 while increasing simulator time by 21 hours, of which 18 simulator hours were directed to instrument training with a reduction of 9 flight hours.

- Jet Advanced – decrease flight hours from 113 to 105.1, decrease simulator hours from 72 to 57, primarily as a result of change in emphasis of instrument training to basic and intermediate training phases.

To summarize the instrument time comparison, the current program requires 64.5 flight hours and 78.0 simulator hours, while the proposed program requires 63.0 flight hours and 109 simulator hours. Thus, for instrument training to achieve the desired objectives simulator training was increased by 31 hours while flight time was reduced 1.5 hours. The use of the simulator hours for the various training phases is as follows:

- Basic – 39 hours with 33 for instrument training with 6 OFT hours for cockpit procedures, practice normal and emergency procedures and a progress check.

- Jet Intermediate – 61.5 hours with 48 for instrument training and 13.5 OFT hours essentially for normal procedures, emergency procedures and selected malfunctions teaching and review.

- Jet Advanced – 57 hours with 28 hours for instrument training, 14 hours in OFT for procedures and 15 hours in the 2F-90 visual simulator (6 hours for familiarization, 6 hours for weapons (30^{o} bomb pattern) and 3 hours directed at carrier qualification.)

It should be noted that the 2F-90 visual simulator is not being used in this pipeline for any of the following tasks:

- night familiarization
- 10^{o} strafe
- 30^{o} rocket delivery
- 45^{o} bomb delivery

- ACM offensive tactics
- ACM defensive tactics
- ACM dissimilar tactics

All of the above are trained in flight rather than with the simulator, essentially based on an evaluation of what can be trained in the 2F-90 visual simulator. It is noted in the Phase II document that several practical considerations were used in developing curricula modifications, especially using the concept of maximum feasible substitution of simulator time for flight time. This is illustrated by the use of simulator hours. Of the total of 157.5 simulator hours, 109 hours are used for instrument training, 33.5 hours are used in an OFT for normal procedures, emergency procedures and malfunctions and 15 hours (less than 10% of total simulator hours) are dedicated to the visual simulator. Based on the data identified in the literature survey on training transfer, the use of simulation capabilities as outlined in the Phase II report seems quite realistic, and attempts to reduce costs by proper utilization of existing capability. It is also interesting to note that the Phase II study recommends continued study of the ACMR as a training tool and does not indicate or acknowledge a requirement for full mission simulation capability for a ground training facility. As stated in the Phase II report foreword, "Immediate accommodation to validated goals is the study's primary objective." The Phase II study was published on July 1975, unfortunately no additional documentation was available to determine reaction to the study recommendations for modifications to the various flight training programs in the U.S. Navy.

Section IV

SUMMARY

This section will be an attempt to summarize the application of flight simulators to military tactical aircrew training based on the data obtained from the literature survey and presented in this report.

While many who read this document may come away with a feeling that this report is basically negative, this was not the intent of the study. It is highly desirable when attempting to perform an objective assessment of simulation for the intended missions, to use objective data. Unfortunately, little or no objective data exist that would justify most of the assumptions used to "demonstrate" the cost-effectiveness of complex flight training simulators. Spending vast sums of money, to procure devices for which training effectiveness, maintainability and reliability cannot be demonstrated on even an experimental basis is not necessarily a viable solution for the military training problem. Conducting research using devices which are inherently limited to evaluate the impact of "cues" that cannot be adequately represented is just not good "scientific" technique. Attributing capability to devices to indicate that they have "ultra-realism" may be good for press releases, but should be relegated to the area of wishful thinking rather than technically feasible, practical or even achievable based on the existing state-of-the-art. On the other hand, that training devices can be effectively used to reduce flight time, has been documented, both by the Airlines and the Military in several reports, but primarily only in the training of procedures (both normal and emergency), malfunctions, general familiarization, and instrument flight training. While little transfer effectiveness data exist, there does appear to be a general rule of thumb emerging from the available data that "simulator time increases about twice as fast as airplane time decreases." In addition, recent programs have indicated that supplementary training in complex tasks, even using devices of limited fidelity, is practical. Thus it appears that to minimize cost, a viable short-term approach would be to maximize the use of the simulation facilities in those areas in which they have demonstrated training effectiveness and to develop this capability to maximize "cost-effectiveness" realistically. In addition, cost savings can be achieved by minimizing the undergraduate pilot washout rate by using more effective screening procedures. Alternatives to the use of simulation to conserve limited fuel resources and reduce ordinance costs are feasible, and a more careful assessment is required of the following areas:

- Fuel efficient engine development.
- Use of optimal control theory to develop fuel efficient aircraft profiles both for operational and training missions.
- Development of low cost airborne instrumentation systems that can be used to simulate weapons delivery using an aircraft and be recorded for future review by students.
- Development of relatively low cost, in-flight simulators for part-task training purposes using existing state-of-the-art technology.

In addition, and possibly most important, is the need to determine minimum device requirements to obtain the desired training objectives. Skill retention studies indicate that procedural skills are the most easily forgotten and fortunately this is an area where part-task simulation devices can be used effectively. Data have not been determined that indicate how simulators can enhance skill level, especially since the ISD concept is to train to proficiency. Whether or not the way these devices are used is also the most efficient requires additional research by the training psychologists. However, the first order of business is to be able to describe how the pilot functions in the task, and that answer can only be found in the air, not by using ground based flight simulation facilities.

There are also questions raised about the maintainability and reliability of flight simulation devices and product improvement programs such as those indicated recently in many journals by Link-Singer must be encouraged to obtain the full utilization potential from the training simulator. Thus, while substitution is possible in certain specific training areas, only supplemental training using simulators is presently practical for most tactical applications. Significant additional research is required to be capable of justifying complex full mission simulators on the basis of "objective" data.

For the tactical missions to be trained, it becomes obvious that a fundamental requirement is to determine what minimum level of visual fidelity is necessary to accomplish the desired training objective and to compare those research and development costs with the possible alternative of the development of low-cost airborne weapons simulation capability. As discussed by Captain John E. Richardson in Reference 73, concerning the use of the ACMR, "it is vital that every hour of flying time be productive." The use of facilities such as ACMR, the continued development of the Bomb Scoring System discussed in Reference 68, and the WASI concept prescribed in Reference 69 represent alternatives for realistic, efficient and co -effective utilization of flying time for tactical training.

Another area that must be evaluated is the proper training and utilization of instructors and console operators for training devices. The literature acknowledges that even the best device can be compromised and rendered ineffective and inefficient by improperly trained instructors. Thus, before a device can be used to train students, it is vital to qualify the instructor and provide the proper promotional incentives to retain capable instructors.

Significant problems exist in the determination of "objective" measures of performance that can be used to validate the effectiveness of a training system or the skill level of the trainee. At present, the technique appears to be to define a performance basis, measure deviations from the basis, obtain statistical measures of the error and then "massage" the data to obtain correlation with the "subjective" evaluations of an instructor. This approach cannot truly be considered "objective" since at almost each decision point subjective judgments are required, for example, defining the performance basis for a complex task, defining important errors and their appropriate thresholds, statistical analysis of errors rather than frequency analysis, assuming data is amenable to statistical analysis and finally using regression analysis to curve fit to the "subjective" instructor rating. Obviously, this last step puts a lot of credibility into the "subjective" approach so perhaps it may be more 'cost-effective' to provide a well-defined subjective rating scale, sensitive to the training objectives, than to put too much credibility, at present, into "objective" performance measurement. In addition, the literature indicates that pilots prefer to be evaluated by their peers rather than by a computer.

It is important to evaluate what motivates the professional military pilot that would encourage him to accept simulator training as important, especially to his survival in a combat environment. Giving the pilots flight pay for flying a simulator may be an interesting "carrot" to some, and obviously would not be rejected by all given no other choice. However, if the use of the simulator will not maintain the skills required, or improve skills to maintain or train aircrews to a combat ready status, then "carrot" dangling may not be sufficiently motivating to professionals.

The primary question still to be addressed, aside from the money issue, is the total impact of using flight simulators on the combat effectiveness of the entire force. As stated by Dr. Allen in Reference 1, "This effectiveness is dependent on a total team effort. Equipment, aircrews and ground support are integral parts of any successful combat operation. This integrated effort cannot be exercised through flight simulation." It should be noted that some of the alternatives discussed to the use of ground-based devices to train aircrews can exercise the total system.

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APPENDIX A

REVIEW COMMENTS

Draft copies of the two volumes of this report were reviewed by representatives of the following DOD Offices and Departments:

1. Office of Assistant Secretary of Defense
   Manpower and Reserve Affairs
2. Office of the Director of Defense Research and Engineering
   Research and Advanced Technology
3. Department of the Air Force
   Headquarters United States Air Force
4. Department of the Navy
   Office of the Chief of Naval Operations

The cover letters and detail review comments returned by these reviewers are included in Appendix B of Volume I. The authors have responded to a number of the review comments and have revised or added to the texts of the reports. Many of the review comments, however, express a different point of view or provide additional information that the authors believe should be made available to the reader and for this reason the review comments have been included in their entirety in Volume I of this report.