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THE USE OF SIMULATORS FOR TRAINING IN-FLIGHT AND EMERGENCY PROCEDURES

(11)

by

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SUMMARY

The use of simulators for training in-flight and emergency procedures has received increased emphasis as a result of the decreased availability and high cost of fuel. This report examines the nature of pilot skills and suggests a strategy for using flight simulators to acquire and maintain them. Salient characteristics of state of the art simulators and the visual display system capabilities they provide for training contact flying tasks are described. Research on transfer of learning from simulator to aircraft in a variety of training tasks is reviewed. The use of simulators as aircraft substitutes and their integration within an array of ground training media are compared and contrasted to illustrate the cost-effectiveness potential of these two approaches. The rationale for and the characteristics of a simulator-oriented emergency procedures training program which emphasizes pilot decision making skills are presented. The development of aircrew performance measurement systems for use in evaluating, refining and documenting simulator training effectiveness is reported. An interpretation of the impact of current developments on the future use of simulators is offered and a list of conclusions provided.

I. INTRODUCTION AND OVERVIEW

THE FUEL RESOURCE PROBLEM

The oil embargo following the Yom Kippur War in 1973 and subsequent establishment of a cartel by the oil producing and exporting countries of the Middle East focused interest on the increased costs and decreased availability of fuel supplies for use in support of military flying training. These international developments forced recognition of the fact that military air forces would have to find alternatives to in-flight training which would insure maintenance of the high levels of pilot skill and mission readiness required by national defense policy. The resulting problem is how to furnish acceptable training for combat aircrews to guarantee the required levels of mission readiness while minimizing the use of fuel resources.

Additional emphasis of the flying training problem involves recent development of a number of high performance aircraft systems, such as the F-14, F-15, F-16, F-18, A-10, and AWACS of the United States military air forces, which created a requirement for additional transition and qualification training of aircrews for these systems. The training problem is further exacerbated by the relatively low flying experience levels of today's military pilots compared with the flying experience of the pilots of ten and twenty years ago.

SIMULATION AS A SOLUTION

Approaches to solving the array of flying training problems have appeared with the development of state of the art high capability simulators, equipped with visual display systems which furnish opportunities for simulator training in a variety of contact flying tasks for the first time. These new flight simulators have demonstrated a potential to generate substantial transfer of training to the aircraft (1). Meanwhile, research in training methods and media has shown how the new flight simulators may be used to increase their training effectiveness, extend their utility over a broader range of flying training requirements and, as a consequence, further improve their potential to supplement flying training in the aircraft (2). The high cost of new aircraft systems and the increasing cost of operating them thus may be partially counterbalanced through use of the efficient and economical training methods and devices currently being prepared for integration within tomorrow's military flying training programs.

Until recently, training managers have regarded flight simulators as aircraft substitutes. Simulators have been designed to be as much like the aircraft as possible. The trainee then could fly the simulator as he would fly the aircraft and the simulator's training value would be judged on the basis of how much like the aircraft it was and its effectiveness would be calculated in terms of the flying hour reduction in a training program in which it was used.

NEW ROLE OF THE SIMULATOR

A shift in emphasis of the role of the simulator in flying training has recently emerged (3). According to this view, the flight simulator is seen as supporting the acquisition/maintenance of flying skill rather than providing a substitute in-flight environment on the ground. Thus, the simulator may be used to improve a trainee's readiness to take maximum advantage of subsequent training/practice opportunities and becomes one of an array of training devices which vary in their cost, complexity, capabilities and representativeness from those of the academic classroom through audio-visual materials, video tape, film, part-task training and mission simulators to the aircraft (4). In addition, the new emphasis of flying training simulation defines the value of any training device in terms of its training

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effectiveness, that is, its effectiveness in providing practice opportunities which lead to the acquisition of transferable skills (1, 3).

OVERVIEW

Before proceeding further with this report on the use of simulators for training in-flight and emergency procedures, it may be useful to look ahead to the series of upcoming topics to aid the reader to see the interrelationships among and the cumulative meaning of the various sets of facts and interpretations to be presented. Given the flying training problem created by the growing fuel shortage, the increased complexity and sophistication of today's high performance aircraft systems, coupled with the decreased flying experience levels of current aircrew personnel, the following chapters will seek to formulate a solution by generating compelling new combinations of older (and some newer) ideas.

In Chapter 2, the essence of the pilot's flying skill is described to serve as the basis for understanding what a pilot must learn during his flying training. The analysis explores the need for a pilot to look ahead to develop his aircraft control requirements as an inevitable corollary of operating an aircraft in an elastic medium. The result of this interpretation is a picture of the pilot as flight planner, anticipator and detector of problems and finely-tuned information processor dedicated to safe, successful achievement of mission objectives.

With a cognitively oriented, information processing concept of the pilot's task in mind, a strategy for using simulators in flying training is developed in Chapter 3 in which ground training is seen as preparing and familiarizing the learner with his task so he can make the most of his training opportunities in the aircraft. Specifically, the concept of the simulator as aircraft substitute is shown to foster development of more costly and complex training devices than are required to achieve effective transfer of learning from simulator to aircraft. Conversely, use of flight simulators to prepare the student to take greater advantage of his subsequent flight training leads to more effective use of simulator capabilities and permits development of simpler, less expensive devices which no longer must replicate the aircraft in every way possible to achieve training effectiveness.

Chapter 4 traces the growth and development of simulation in military aviation training from the early days of behind-the-lines training in obsolete aircraft to the structured flying training programs of today. Increased implementation of ground-based training programs has been paralleled and preceded by continuous advances in the state of the art of flight simulation equipment. Salient features of current flight simulators, including the use of digital computers to control operation of the aircraft cockpit equipment, flight dynamics math model and visual and motion/force cueing systems are described briefly to illustrate how more and more contact flying tasks are being trained in simulators as their capabilities to support such additional training are demonstrated.

Following the brief description of state of the art simulators, the results of major studies of transfer of learning from simulator to aircraft are reviewed in Chapter 5. In this review, which includes an explication of the limitations of existing data and the several problems associated with transfer studies in flying training, a picture of the effectiveness of simulator training emerges in which there are no instances of significant negative transfer. Such an outcome is interpreted as suggesting that simulator training in which flying tasks can be practiced and learned will lead to improved trainee performance in the aircraft.

A description of the distinctive characteristics of the employment of flight simulators in two current training programs is provided in Chapter 6. The roles of the simulator in the US Air Force's Air Training Command Undergraduate Pilot Training program and the American Airlines' Pilot and Copilot Qualification Training program are compared and contrasted. Examination of these different programs illustrate how use of the simulator as aircraft substitute and the integration of the simulator within an array of ground training media have demonstrated their cost effectiveness.

While the employment of simulators in emergency procedures training has been one of the constants in flying training programs virtually from the beginning, in Chapter 7 a new and slightly different approach is described. The typical emergency procedure is practiced, learned and then tested in a simulator because it cannot be practiced safely in the aircraft. In the new approach, referred to here as Situational Emergency Training, the emphasis has been shifted from the fast, accurate execution of a perfectly memorized sequence of actions to a judgmental, problem solving process by the aircrew member confronted with an emergency situation. Situational Emergency Training focuses on the pilot's analyzing the situational aspects of the emergency condition in the context of his mission, deciding what to do to deal with the problem and taking the appropriate action(s) so that he may make a safe landing as soon as possible.

The final substantive chapter of this report describes progress made in the development of automated pilot performance measurement systems for implementation in current flight simulators. The goal of these simulator performance measurement system development efforts is to provide objective, quantitative evidence of the result of simulator training for use by students, instructors, training managers, researchers, simulator designers and procurement officers. The objective, quantitative data generated by the simulator performance measurement systems then may be applied to evaluate and document the success of students, guide instructors, help training managers fine-tune their programs, and aid researchers, designers and procurement officers make efficient decisions about what is required and which alternative will provide the best training at the lowest cost.

In the last chapter a projection of the future use of simulators in flying training programs and a list of conclusions based on and supported by the facts and ideas presented in the preceding chapters are offered in an interpretation of the impact of current developments on the future use of flight simulators. Here a picture of future flying training is developed in which more different kinds of simulators are used to satisfy a wider variety of training requirements with increased efficiency and economy. Improved organization and integration of tomorrow's simulator and aircraft training also are projected as a consequence of the greater realization of flight simulators' training potential through application of modern training methods and the refinement of current programs made possible by exploiting the implementation of automated aircrew performance measurement systems.

A list of conclusions is presented to close this report. These conclusions reflect both the extent and the limitation of information describing the current use of simulators for in-flight and emergency procedures training.

II. THE ESSENCE OF THE PILOT'S FLYING SKILL

CHARACTERISTICS OF FLIGHT OPERATIONS

Basic characteristics of aircraft operations will be examined in this chapter to develop a description of the essence of a pilot's flying skill which transcends the explanatory limits of an older notion of pilot skill as hand-eye coordination. Before proceeding with this investigation, the implications of controlling an aircraft's flight path in three-dimensional space will be considered, and the implications of the requirement for developing plans to accommodate a variety of conditions which may arise during a flight will be described to establish a starting point for the analysis which follows.

Aircraft operate in an elastic medium and are controlled by means of a pilot's manipulation of the aircraft's control surfaces. The speeds at which all aircraft normally operate prevent abrupt changes in flight path and require that such changes be accomplished gradually and smoothly enough to avoid departure from controlled flight. Thus, the pilot must know or become familiar with the maneuvering characteristics of an aircraft and be able to control its flight path as required to accomplish all maneuvers within its performance capabilities to achieve the objectives of a flying maneuver or mission[2].

In addition to mastering flight maneuvers, a pilot must know the requirements for controlling an aircraft throughout a mission or he must have such requirements information available to guide him in controlling the aircraft's flight path and managing its operation. Because flying operations often are conducted under variable environmental conditions, it is a practical necessity that a pilot know of a number of alternative means which can be used to achieve mission objectives if for any reason prior plans or requirements information no longer apply during a mission due to environmental or aircraft status changes. Consequently, pilots are trained, qualified and periodically evaluated on the discipline, accuracy, efficiency, completeness and safety of the aircraft control and system management procedures they use in accomplishing flying missions.

THE PILOT'S DYNAMIC ENVIRONMENT

As a result of operating an aircraft in a dynamic, three-dimensional environment and practicing flying maneuvers, a pilot learns and knows the maneuvering characteristics of his aircraft and, given sufficient information and understanding of the requirements of a mission, can plan (formally or informally) what he must do to satisfy the mission requirements (5). Through his familiarity with his aircraft and knowledge of the mission requirements, a pilot can satisfy the requirements accurately, efficiently and safely. To deal effectively with his momentary aircraft control tasks, the pilot must project the current status of his aircraft into the near future time-space, evaluate this projection in terms of the remaining mission requirements and take appropriate control actions to continue satisfying them. This kind of behavioral process has been described by Hull (6) and may be assumed to support the pilot's projection of current aircraft states into the future in order to determine his aircraft control action requirements.

If/when an error is projected, the pilot will make the control inputs he has decided will reduce to a practical minimum the error remaining after he reprojects the consequences of his corrective action ahead into the next mission increment. The detection of an existing error or an error emerging from the projected future aircraft status serves to trigger this behavioral process rather than merely informing the pilot of the error or the amount of error to be eliminated and illustrates the pilot's predominantly looking-ahead orientation (7). Thus the pilot uses the current state of his aircraft not as the basis for correcting errors if they are present, but instead projects the current state ahead and makes his subsequent control actions based on the projection and what must be done to optimize the future state of the aircraft with respect to remaining mission requirements (8, 9).

THE PILOT'S MISSION PLAN

Having established that the pilot bases his aircraft control actions on projections of his current state, it can be seen that ordinarily he is not responding to any existing stimulus pattern when a control action response is made. Instead the pilot responds to his projection of the future state of the aircraft or to an idea referred to here as his mission cognitive structure or plan which represents the mission and his aircraft's position in this mission.

Given the assumption of a pilot with a mission plan to guide him in his manipulation of the aircraft during a flight, it is easily seen that the skilled pilot will bring to his mission planning those of his previous experiences he believes to be relevant. As he begins to develop his plan, a pilot will consider and evaluate an array of potential procedures and maneuvers with which he can achieve his mission goals. From the array of alternatives, the pilot will select those which appear to represent

[2] The term mission will be used in place of flying task or flying maneuver because it covers a greater range of flight operations and because what is valid for flying tasks or maneuvers is assumed to hold for missions.

the best mission plan. For example, he may consider duration of the flight, fuel available, weather, load data, takeoff and landing conditions, terrain to be overflown, possible emergency conditions and alternative means for dealing with them. In addition, pilots typically consider other information which appears to be relevant based on their perception of the circumstances of the mission in order to tailor the plan to what they believe is an optimum combination of their capabilities and mission requirements.

AIRMANSHIP

The completeness, elaborateness, accuracy and adequacy of the mission plan on which a pilot relies during a mission often furnishes an index of his experience and skill, sometimes referred to as his airmanship. These characteristics of a pilot's mission plan also furnish an index of the probable success of his mission. A pilot whose missions plans are relatively complete and comprehensive will be more likely to encounter fewer surprises during a mission, and because of his greater preparation can be expected to deal with such unplanned events or emergencies as he may experience with less difficulty than a pilot less well prepared.

With the more experienced pilot whose mission plans are relatively complete and comprehensive, it can be assumed that he will make appropriate use of the plan during a mission to maximize the smoothness, accuracy and eventual success of the flight. Therefore, at any instant during a mission, a highly skilled pilot may be expected to be dealing with the projection ahead of as many of the alternatives considered in developing the mission plan as he believes relevant or applicable (10).

SITUATION AWARENESS

If an increment of the pilot's mission plan is taken as a point of reference, the experienced pilot can be expected to exhibit what has come to be known as situation awareness, a comprehensive appreciation of what is going on and what will happen next. That is, because of the completeness of his mission plan and his projection ahead of the relevant alternatives, his situation awareness will be relatively high at any instant (11). In addition, we can see that the quality of the pilot's situation awareness is related directly to the quality of the plan he has developed, his understanding of mission requirements and his ability to satisfy them.

If this rationale is valid, it can be concluded the pilot's task is essentially cognitive in nature. It can be concluded further that the development of the pilot's skill may profitably be organized around his mission planning task requirements in order to facilitate the growth of his situation awareness, probably the best single indicator of his general overall pilot ability, or airmanship.

SUBSYSTEMS MANAGEMENT AND AIRCRAFT CONTROL

The analysis of the essence of the pilot's flying skill presented here focuses on aircraft control tasks because the requirement for pilot cognitive behavior is more obvious with them than with the pilot skill involved in operation of such on-board equipment as the communication, navigation or other electronic subsystems. A close look at management of aircraft subsystems, however, will reveal that the pilot's performance requirements for their operation are very much like those involved in aircraft control except that they are characteristically more step-by-step and less continuous in nature. The similarity may be clearly seen by considering the timing, sequencing and integrating aspects of the subsystems management task.

Thus it appears that the key to a pilot's effectiveness lies in his ability to develop comprehensive mission plans and to use them in order to know what to look for, where and when to look for it, and what to do with it once he finds it in controlling and managing his aircraft system during a mission (12). It appears also that these essential pilot skills involve the seeking and processing of information and represent primarily the operation of his repertory of cognitive processes (13).

III. A STRATEGY FOR USING SIMULATORS IN FLYING TRAINING PROGRAMS

SIMULATOR FIDELITY

It is axiomatic that performance on a task is facilitated if the acquisition of ability to perform the task is accomplished in a learning environment similar or identical to the environment in which performance on the task will be evaluated. In flying training, this compelling notion has stimulated an unceasing search for a learning environment for student pilots as much like the performance environment, the aircraft, as state of the art flight simulator technology can provide.

This state of affairs has led to development of simulators which incorporate as many aircraft-like features as possible. Simulators which are more like the aircraft, as determined by quantitative measures/the ratings of experienced aircrewmen are said to be more realistic or have higher fidelity. Conversely, simulators which are less like the aircraft are identified as less realistic or lower fidelity devices. Accordingly, it is assumed that more realistic/higher fidelity simulators are better, more effective training devices and vice versa. Thus the search for more realism and higher fidelity continues (3).

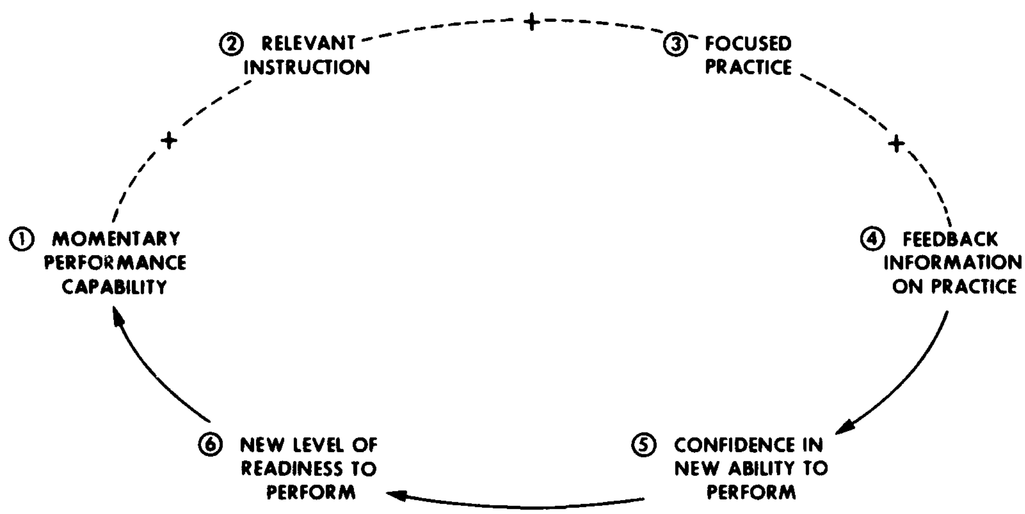
In developing a strategy for using simulators in flying training which goes beyond the concept of simulator realism/fidelity in which more is better and most is best, it will be necessary to consider a number of ideas which bear on simulator utilization. They will then be integrated into a new whole, which, it is hoped will possess greater explanatory power than the realism principle.

BASIC LEARNING PROCESSES

It may be profitable to note at the beginning that learning is an active, automatic, continuous and cumulative process. Learning is not something done to a learner. It is the student who learns, more than it is the instructor who teaches. In addition, it should be pointed out that learning isn't guaranteed through use of a collection of instructional paraphernalia. Instructors may foster learning more effectively by arranging and sequencing the presentation of appropriate training environments than by use of training aids and devices. It has been observed that any performance that can be practiced can be learned and any performance that can be learned can be transferred (2). This suggests that as a learner acquires the ability to perform a task, he becomes more able to learn succeeding training tasks more easily. That is, mastery of later tasks is built on the foundation of earlier learning.

This building block approach is an application of the concept of the matching of training task requirements or demands to the individual trainee's level of ability so that the next training task is slightly more difficult than the last (14). Thus the learner is stimulated to attempt the next training task without unacceptable risk of failure. When the problem of the match of task difficulty and trainee ability has been solved satisfactorily, the sequence and content of successive training tasks will build the trainee's skill and his confidence in his ability to exercise his skills in attacking successive training problems. A diagram of this hypothesized process is shown in Figure 1.

FIG. 1 THE PROCESS OF DEVELOPING CONFIDENCE IN ONE'S ABILITY TO PERFORM A TASK



IMPLICATIONS OF SIMULATOR REALISM/FIDELITY

With these basics in mind, the simulator realism/fidelity issue can be examined further. It is a fact that current flight simulators are more expensive than older training devices. And it is a fact that they are significantly more capable of supporting a wider variety of flying training tasks than older flight simulators and are generally regarded as more realistic, higher fidelity devices. These facts are taken as evidence that simulator capability and realism/fidelity are positively and closely related to simulator cost.

Because realism is an important factor in the design of simulators, there is a tendency to develop devices which will simulate as much of a complete aircraft mission as possible. This combines with the growing mission capabilities of current aircraft and results in more complex and more costly simulators. Given the mission simulation capabilities state of the art devices possess, it can be seen then that in any single training session, typically focused on individual training tasks, it is unlikely that more than a small proportion of the simulator's mission capabilities will be exercised. In addition, Povenmire and Roscoe (15) have shown that training in a simulator is more effective prior to the student's first practice of his training in the aircraft and that its effectiveness diminishes thereafter.

It can be seen also, assuming typical budgetary constraints, that increasing simultor realism/fidelity and incurring the higher costs involved will lead to fewer devices being procured, fewer pilots trained in them and fewer opportunities for the capabilities of the simulators to be used for training purposes. This rationale suggests the search for more and more realism and fidelity may be self-defeating as far as overall cost-effective simulator training is concerned.

One final example of the paradox of simulator fidelity warrants attention at this point. The principal reason for including a relatively costly cockpit motion system in a flight simulator is that the aircraft moves in flight and therefore the simulator should be capable of moving like the aircraft in order to be more realistic and thus provide more effective training. It is obvious, however, that all cockpit motion systems are inherently incapable of providing realistic or high fidelity motion cues since they are all invariably fastened to the ground and cannot accurately duplicate aircraft motion during flight, other than for relatively mild maneuvers in which pitch and roll rates are low and of brief duration (16, 17). Research data on the training effectiveness of cockpit motion systems will be reviewed later in this report.

DEVELOPING A SIMULATOR STRATEGY

The above considerations, on which the development of a strategy for using simulators in flying training is based, can be summarized as follows:

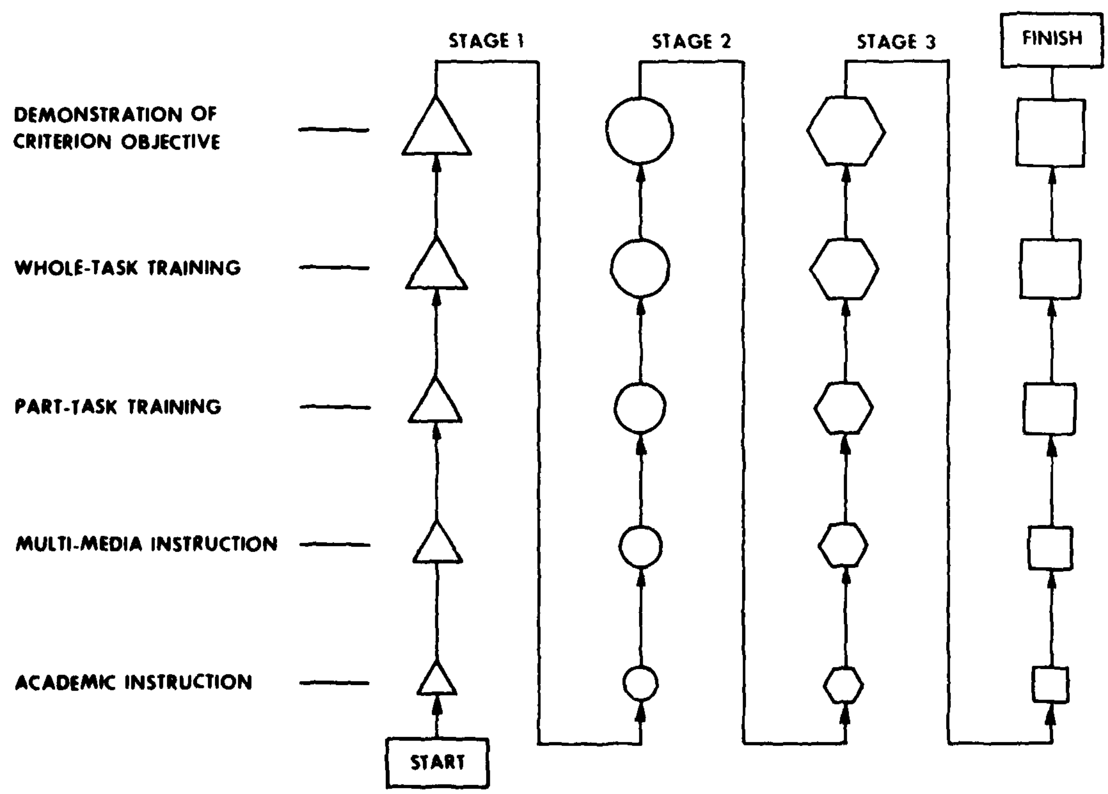
1. While it is intuitively obvious that the more a simulator is like an aircraft, the more likely it will be an effective training device; it is also clear that as the operational characteristics of a simulator approach those of an aircraft, the complexity and cost of the device will increase.

2. As the capabilities of a simulator to support full mission training increases, the difficulties of exercising all of its capabilities in any training period increase and its cost-effectiveness will decrease.

3. Rather than using a realism/fidelity criterion for evaluating simulator training value, determine its training effectiveness by means of a transfer of training test.

One integration of these ideas is a concept of least-cost, sequenced, multimedia training, diagrammed in Figure 2. This concept applied to flying training leads to an array of training aids that increase in their complexity and representativeness to provide a series of training environments matched to the trainee's discriminative and cognitive readiness to deal with them (4). Figure 2 shows an array of training media that begins with conventional academic instruction and ends each stage of training, e.g., the pre-solo, advanced contact, instruments, navigation and formation stages of undergraduate pilot training (18), with a criterion objective performance evaluation in the aircraft. The least-cost, sequenced, multimedia model is based on the building block approach to skill acquisition and on the obvious economy and ease of scheduling training aids by using the simplest and least expensive media possible at all stages of training. In addition, it accommodates the results of Fleishman's (19) factor analytic studies of performance at different stages of learning. A by-product benefit of this model is that it requires less expensive training media and fewer high fidelity, full mission simulators and consequently may be acceptably cost-effective.

FIG. 2 LEAST-COST, SEQUENCED, MULTI-MEDIA TRAINING



This approach is one form of a flying training program which would result from the straightforward application of Instructional System Development (ISD) procedures as described in US Air Force Pamphlet 50-58 (20). It will be used as a conceptual framework for the review of behavioral research presented in subsequent chapters. Before considering research evaluations of the training effectiveness of flying training simulators, however, it will be useful to describe briefly some of the salient characteristics of current state of the art devices in the next chapter.

IV. CHARACTERISTICS OF STATE OF THE ART FLIGHT SIMULATORS

DEVELOPMENT OF FLIGHT SIMULATION TRAINING

Military training managers have understood intuitively that combat is the only reality and historically they have simulated the ttle environment by using combat equipment for training purposes. This represents an initial development of a training simulation and the concept subsequently has been accepted as necessary and sufficient for effective aircrew training.

During World War I, flying training took place at staging airfields behind the front lines using operational as well as obsolete aircraft. Special flying schools were set up further from the combat zone where basic training was given in a variety of obsolete aircraft (21, 22, 23). The same mode of training was carried forward during World War II (24). In addition, the use of segments of operational equipment began to appear in aircrew training programs. Late in World War II, rudimentary flight simulators were developed and the expansion of ground training as a component in flying training programs began (25).

Since the initial appearance of the flight simulator, there has been a steady proliferation of instructional media applied in flying training programs. Success of many of these applications has been documented, for example, by Reid and Cyrus (26), Eddowes et al. (4), and Smith, Waters and Edwards (27).

CURRENT FLIGHT SIMULATOR CAPABILITIES

It is a challenge for current aircrew training technology to provide the elements of the training environment that will most effectively and economically facilitate acquisition and maintenance of the performance capabilities needed to meet combat mission requirements. Today's flight simulators possess significantly greater capabilities for supporting aircrew training than those of previous generation devices. The new simulators, when equipped with visual display systems, can generate training environments in which aircrews can acquire and practice normal, emergency and combat maneuvers. These devices also can be used to support training in basic and advanced contact flying and instrument and navigation procedures.

Through incorporation of a variety of advanced instructional features, such as problem freeze, performance replay, malfunction insertion and automated performance measurement, current simulators provide capabilities needed for improved instruction. In addition to furnishing training and practice in flying maneuvers which cannot or need not be taught in the aircraft, state of the art simulators can be used as teaching tools rather than as substitute aircraft. They can prepare aircrew trainees to take maximum advantage of their next training tasks, whether they are presented in another simulator or an aircraft.

The increased training capabilities of modern flight simulators are the result of synergistic integration of digital computer, visual display and motion cueing systems. Simulator operations controlled by digital computers have gradually replaced older analog and hybrid systems. They have achieved greater speed, accuracy and range of flight maneuvers that can be simulated; and, in addition, permit easier, less expensive and faster modification when it is necessary, for example, to update the aircraft flight performance characteristics or to change the operation of the whole system to improve its training potential.

The inclusion of motion cueing systems in state of the art flight trainers typically involves one of a variety of motion simulation mechanisms which generate onset cues as a maneuver is initiated, and, subsequently "wash-out"[3] the onset cues as a stabilized state is attained. There are a number of types of cockpit motion mechanization schemes and a variety of means for actuating them. An alternative motion cueing system, the g-seat, has recently been developed and used in several simulator requirements studies (28, 29). In g-seat systems, air or fluid is used to control the inflation and deflation of cells in the aircrew seat pan and seat back panels to create and relieve pressure on the pilot's back, buttocks and thighs, analogous to sustained g-forces during higher performance maneuvers characteristic of air-to-surface weapon delivery and air-to-air combat maneuvers.

The development and incorporation of wide field-of-view (FOV) visual displays within modern flight simulators is a significant factor in the dramatic increase in simulator training capabilities. These visual displays typically rely on the control capabilities provided by the digital computers with which virtually all current simulators are equipped. There are three major types of visual display schemes for simulators: television-model board, projected imagery, and computer-generated imagery. Although hybrid combinations of the three types have been and are being developed, the following description of simulator visual display systems will focus on their salient characteristics.

3 "Wash-out" refers to the gradual removal of a roll/pitch onset motion cue at such a low rate that a pilot will not notice the "wash-out" motion of the simuator cockpit.

TV-model board systems are the oldest of current simulator visual display systems. They involve a model terrain board and a TV camera which is driven across the model board by the simulator's computer as the aircraft it simulates performs various contact maneuvers. The imagery picked up by the camera is projected onto a viewing screen in front of the pilot/copilot stations. TV-model systems have been widely used to provide a visual display of the landing maneuver for instrument letdown and approach training. Such systems focus on the relatively low performance maneuvering associated with around-the-airport contact training. The training capabilities of TV-model visual systems are limited by the size and content of the model board which in turn determines the contact maneuvers which can be practiced within the simulated visual environment.

Projected imagery displays involve the use of either a film, a model or a computer-generated image to furnish the basic display input, which is processed electro-optically and projected onto a curved or dome-shaped screen. The distance from the aircrew station is such that the pilot views the display as he would from the cockpit of an aircraft. Dome-type visual simulation systems have been used in situations where good quality detail is important and judgments of range and range-rate are important aspects of training. Projected imagery displays have been used in air combat maneuvering, formation flight, and aircraft carrier landing training systems.

The development of computer generated visual display systems has introduced a new area of technology into aircrew training simulation. Computer generated imagery (CGI) systems involve computerized generation of a visual environment through the use of lines or edges presented on a cathode ray tube (CRT) or by discrete point light source elements controlled to form the in-flight visual environment desired to support instruction and practice of a theoretically limitless variety of training tasks. Dynamic changes in the CGI display during a training exercise are controlled by the simulator's central digital computer.

The visual environments produced by CGI systems may be modified or replaced by other visual environments without acquiring additional equipment. Once developed, the visual environment models may be stored and used again rapidly and easily. Because of this capability, CGI systems are not limited in content or extent and represent a substantial increase in performance capability over the older TV-model and projected imagery simulator visual display systems.

The next chapter will present a comprehensive detailed review of research data describing flight simulator training effectiveness.

V. TRAINING EFFECTIVENESS OF FLIGHT SIMULATORS

DETERMINING THE SIMULATOR TRAINING EFFECTIVENESS

Advances in flight simulation technology make available a wide variety of sophisticated systems and subsystems for combination into a training device that best meets the demands of a training manager. Many of the options are designed to increase the training value of a device by making it possible to implement innovative instructional and training methods. The capability for real-time automated performance measurement and feedback, adaptive training, programmed demonstrations and review by the pilot are examples of training-oriented features. Other options currently available are designed to increase training effectiveness by increasing the performance capabilities of the device. Wide field-of-view visual systems of a variety of types, synergistic six degree-of-freedom platform motion systems, g-seats, and g-suits are typical of fidelity-oriented hardware.

The training manager now has to decide how many of these features are necessary for the intended use of the device. To make such decisions, he must define the training objectives and estimate how much the various options can contribute to achieving them. He must also determine the value of the expected benefits relative to the cost of the hardware capability required to yield these benefits. Unfortunately, the training manager is often in the position of having to make such decisions without sufficient information.

Behavioral research can provide information relative to several important criteria: (1) user acceptance; (2) the feasibility of training tasks which cannot be practiced in the aircraft (e.g., some emergency situations, missile evasion techniques); and (3) training effectiveness. Evaluating the training effectiveness of a device is one of the most important types of information for the training manager. Military training managers have indicated they are primarily interested in this type of research results (30). Unfortunately, suitable training effectiveness data can be time-consuming and difficult to generate. Recently, Caro (31) has summarized methods of evaluating simulator training effectiveness. Of those procedures, he indicated that the transfer of training methodology is "most appropriate to determine whether simulator training has improved subsequent operational performance."

In the transfer study design, preliminary training is given in the simulator (pretraining) followed by a comparative performance evaluation in the aircraft (criterion system). In most cases, one or more experimental treatments are compared with some standard (control) treatment. For example, a comparison of the relative training effectiveness of two visual systems would require three groups--one trained with visual system A, a second trained with visual system B, and a third receiving no simulation pretraining. A comparison of subsequent performance in the aircraft between groups one and two provides an estimate of the relative effectiveness of visual systems A and B. Comparing the combined performance data of the first two groups with the performance of the third group (control) provides an estimate of the overall effectiveness of the simulation training. The demonstration of effective transfer of training is a prerequisite for making any definitive statements concerning the relative effectiveness of alternate systems.

In the following paragraphs, the training effectiveness literature will be reviewed with respect to simulator motion and visual systems. The addition of either or both of these systems adds significantly to procurement as well as operations/maintenance costs. For this reason, it is necessary to insure that such added costs are justified in terms of an improved training capability which is evidenced by enhanced piloting skills in the aircraft. The present review will focus on data obtained through the application of the transfer of training methodology, since such information seems most relevant to this issue.

VISUAL SIMULATION

The technology of visual simulation is expanding rapidly. Most flight simulators are being procured with visual systems. Many older instrument flight simulators are being retrofitted with some type of visual capability. Current visual simulation systems can cost up to six million dollars. Despite its cost, the potential value of a visual system is great since it presents the opportunity to train tasks which otherwise would have to be learned in the aircraft. Furthermore, it offers the possibility of substantial cost savings, especially for those aircraft which have high operating costs. Such potential is witnessed by recent attempts to extend visual simulation training into such areas as air combat, weapons delivery, and aerial refueling. Most studies to date have focused on visual simulation training for fixed wing aircraft. Because of the relatively large number of studies and diverse missions which are simulated, they are presented according to task categories. Finally, the value of visual simulation for rotary wing training will be addressed.

Transition

The acquisition of basic contact skills including takeoffs and landings has been studied most frequently. The first series of controlled studies was accomplished at the University of Illinois' Institute of Aviation. Williams and Flexman (32) taught basic aircraft control, stalls and traffic pattern skills in a 1-CA-2 Link trainer simulating the SNJ aircraft. The visual scene consisted of a 270° circular screen (cyclorama) eleven feet high placed seven feet from the trainer. The screen was an unmarked white cloth with the exception of a black horizontal line representing the horizon and several reference marks indicating climb/descent attitude and heading. No takeoff/landing simulation was provided. Two groups of 24 students participated in the study. The experimental group received simulator training prior to aircraft training while the control group received only the aircraft training. The simulator-trained group required 62% fewer trials to reach proficiency, committed 75% fewer errors, and required 62% less flight time.

In a later study, Flexman, Matheny and Brown (33) attempted to determine whether training in the 1-CA-2 SNJ Link would enable students to pass their flight check with only 10 hours (as compared to the normal 35) of aircraft instruction. In this effort, contact training was provided for takeoffs and landings. The visual landing scene consisted of a blackboard, placed in front of the trainer, which could be rotated about its horizontal axis. A rough perspective view of a runway was drawn on the blackboard. At the beginning of a landing, the instructor held the blackboard approximately at a 45° angle. The instructor then gradually reduced the angle to simulate the approach to the runway. As the blackboard approached the horizontal plane, the trainer appeared to be near the ground. Compared to students not trained this way, students receiving simulator pretraining performed significantly better in that: (1) a higher percentage passed the flight check; (2) checkride scores were higher; and (3) fewer students failed four or more flight check items. No direct assessment of the value of approach/landing training was made. The value of such training for aircraft landing performance was specifically assessed in a follow-on study (34). The results indicated that students in the experimental group (N=10) following three hours of approach/landing simulator pretraining committed significantly fewer errors in 15 aircraft landings than did the control group (N=10) which received no simulator pretraining. Such data demonstrate that positive transfer effects are possible, even with very crude, low fidelity training devices.

Despite the demonstrated value of the "blackboard" visual scene, it was obvious that other essential cues were missing. Based on an analysis of runway perspective by Bell (35), an experimental landing display projector was developed for use on the 1-CA-2 SNJ Link trainer. The runway image was controlled by heading and altitude information from the 1-CA-2 and was displayed on a screen located in front of the trainer. Payne, Dougherty, Hasler, Skeen, Brown and Williams (36) evaluted the effectiveness of this device for training the final approach to landing. Students in the experimental group (N=6) received simulator pretraining until proficiency criteria were reached. Both the experimental group and control group (who received no simulator pretraining) were trained to the same proficiency criteria in the SNJ aircraft. The following savings were obtained: (1) number of trials to reach proficiency - 61%; (2) number of errors to reach proficiency - 74%; (3) number of errors per trial - 50%; (4) number of errors on the first trial - 67%; and (5) number of errors on the first five trials - 55%. Analysis of actual landing (touchdown) data which was not trained in the simulator also revealed significant savings.

In 1953, the US Air Force accepted delivery of the P1 simulator, essentially the same device (1-CA-2) used at the University of Illinois in earlier studies. In order to evaluate the effectiveness of the device for contact training, 95 aviation cadets were divided into two groups (37). The experimental group received 40 hours of simulator training and 100 hours of T-6 (SNJ) aircraft instruction. The control group received 130 hours of T-6 aircraft instruction with no simulator training. At the end of training, both groups were evaluated according to certain criteria. The results indicated: (1) significantly better flying performance of the simulator-trained group as measured by Daily Progress Record Sheets; (2) significantly better checkride scores of the simulator-trained group using independent check pilots; and (3) no differences as indicated by a research-type flight check, attrition data, or accidents. Ninety-two percent of the flight instructors felt that the simulator-trained students were "equal to" or "better than" the control group in terms of overall proficiency.

Several studies at the US Naval School of Aviation Medicine also evaluated the effectiveness of the SNJ Link trainer. Poe and Lyon (38) provided instruction in the SNJ Link during Preflight School. Eighty-five cadets received five hours of training in the device. The performance of this group during the initial stages of flight training was compared with a control group of 100 cadets who did not receive the simulator pretraining. Criteria included attrition data, flight efficiency data, extra rides required, instructional flight grades, and checkride scores. No statistical differences in performance between the two groups were found. Creelman (39) reported that students trained in the SNJ Link with a contact landing display performed significantly better than students who received either no pretraining or simply viewed films of contact landings. The simulator trained group received higher performance ratings on their aircraft approaches, required fewer practice landings prior to solo and received fewer unsatisfactory flight grades.

The results of these studies conducted by the University of Illinois, the US Air Force and the US Navy conclusively demonstrated that visual simulation training produced significant transfer to subsequent performance in the SNJ/T-6 aircraft. Significant transfer was shown for basic contact skills and the final approach to a landing. Following these initial efforts, the authors are unaware of any other similar transfer of training studies accomplished prior to the establishment of the Operational Training Division of the Air Force Human Resources Laboratory in 1969. In 1970, the Laboratory received the T-4G flight simulator, an updated ME-1 trainer which simulates the T-37 aircraft, the Air Force's primary jet trainer. It consisted of a T-4 cockpit mounted on a two degree-of-freedom platform motion system. A Singer SPD Electronic Perspective Transformation visual system was attached which enabled training in normal straight-in approaches from four miles out, touchdowns, landing rolls, and takeoffs. The visual field of view was $44^{o} \times 38^{o}$ and the image was provided in full color at infinity.

The effectiveness of the T-4G for providing both contact and instrument training was evaluated by Woodruff and Smith (40). Twenty-one students were given pretraining in the T-4G followed by an evaluation of their subsequent performance in the T-37 aircraft. Training in both the simulator and aircraft continued until proficiency criteria were attained. For the contact phase, the simulator pretraining resulted in an average savings of three hours in the T-37 aircraft or approximately 10%. These comparisons were against the length of the normal syllabus being used at that time. Mid-phase contact checkride scores revealed no differences when compared against the scores of other students not receiving the simulator pretraining.

In 1975, the Advanced Simulator for Pilot Training (ASPT) initiated research operations at the Operational Training Division. The ASPT is equipped with two T-37 cockpits. Each cockpit has a full field-of-view visual display ($\pm150^{o}$ horizontal by $+110^{o}$, -40^{o} vertical) of computer-generated imagery (CGI), a six degree-of-freedom platform motion system, and a sixteen panel pneumatic g-seat on the left seat (student position). The visual system uses an infinity optic display with the exit pupil located at the student's eye position. The scene is projected through seven 37" diameter cathode ray tubes. A complete description of the ASPT may be found in a report by Gum, Albery and Basinger (41).

Upon acceptance of the device, Woodruff, Smith, Fuller and Weyer (42) conducted an exploratory study to investigate the utility of the ASPT as a full mission simulator in the basic phase of Air Force Undergraduate Pilot Training. Training in the ASPT was provided for Basic Contact, Advanced Contact (Aerobatics), Instruments, Navigation, and Formation Flight. Upon completion of each block of training in the ASPT, the student proceeded to the aircraft for additional instruction. Eight students received ASPT pretraining while a control group of eight students did not. Proficiency advancement was used for all instruction in both the simulator and aircraft. The resulting aircraft hours savings were 45% for Basic Contact; 4% for Advanced Contact; 38% for Instruments; 13% for Navigation; and 13% for Formation. For the ASPT-trained group, T-37 contact checkride scores were significantly higher. This effect persisted into the T-38 training phase in which checkride scores were again significantly higher for the simulator-trained group.

Subsequent to this demonstration of the training effectiveness of the ASPT, a number of studies have been accomplished using the transfer of training design to evaluate alternative hardware configurations. The first study addressed the contributions of platform motion cueing to the acquisition of basic contact, approach, and landing skills in Air Force Undergraduate Pilot Training (UPT) (43). Twenty-four preflight UPT students with no previous jet piloting experience were randomly assigned to one of three treatment groups (n=8): (a) Motion; (b) No Motion; and (c) Control. Those students assigned to the control group received the standard syllabus of preflight and flightline instruction. The students in the two experimental conditions received identical pretraining in the ASPT with the exception of the presence or absence of platform motion cueing. The g-seat was not used.

The simulator training syllabus consisted of ten ASPT sorties covering instruction on a large number of basic contact maneuvers, including basic airwork (turns, climbs, etc.), slow flight, stalls, takeoffs, straight-in approach and landing, the overhead pattern, and the touch-and-go. Following simulator pretraining, the students were evaluated on two special aircraft sorties by research instructor pilots (IPs) as well as on all sorties prior to solo by their normal flightline IPs. The control group did not receive the special data rides for safety considerations. It was observed, however, that a number of the experimental students were able to perform takeoffs and overhead approaches and landings on their first aircraft ride. An analysis of the data collected by flightline IPs revealed significantly better performance by the ASPT-trained groups for all tasks evaluated. The percent savings in terms of trials rated Unsatisfactory were 51% for takeoff; 48% for straight-in approach; 33% for straight-in landing; 42% for overhead pattern; 37% for overhead landing; 77% for slow flight; 61% for power-on stalls; and 55% for traffic pattern stalls.

While there is evidence that positive transfer occurs for even the crudest of visual scenes, there is little data comparing the relative effectiveness of alternative approaches to visual simulation. Martin and Cataneo (44) compared the effectiveness of ASPT training using a night scene vs. a day scene. The night scene was modeled to closely approximate commercially available point light source CGI visual systems. A generalized airport scene was modeled for both the night and day scenes, so that the simulator was not specific to Williams AFB. Twenty-four UPT students were divided into three groups (n=8): (a) Day; (b) Night; and (c) Control. The day and night groups received three ASPT training sorties in which instruction was provided on the takeoff, straight-in approach and landing, and the touch-and-go. The control group received no ASPT pretraining. Following simulator pretraining, students (including the controls) were evaluated on their second and fifth aircraft sorties by their flightline IPs. The data revealed signficant transfer for the ASPT-trained students but no differences between the day and night groups.

Nataupsky, Waag, Weyer, McFadden and McDowell (45) completed a study to determine the interaction of motion and field-of-view (FOV) on the acquisition of transition skills. Four groups of eight novice UPT students were trained in the ASPT under the following conditions: (1) platform motion, full FOV (300^{o} x 150^{o}); (2) no platform motion, full FOV; (3) platform motion, limited FOV (48^{o} x 36^{o}); and (4) no platform motion, limited FOV. Each student received four ASPT sorties in which the takeoff, steep turn, slow flight, and straight-in approach and landing were instructed. Following ASPT instruction, each student was evaluated on his first T-37 aircraft ride. Due to safety considerations, a control group was not possible. Neither motion, field-of-view, nor their interaction impacted subsequent performance in the aircraft.

For training-type aircraft, it is clear that visual simulation training aids the student in effectively transitioning into the airborne environment. For large transport aircraft, the results are more dramatic, especially within the airline industry. With the introduction of flight simulators, American Airlines (46) successfully reduced flying time for their Captain upgrade program from 18.3 to 1.3 hours for the Boeing 707 and from 20.6 to 1.0 hours for the Boeing 727. However, it must be recalled that these are highly experienced pilots who already have a great deal of flight time.

In 1976, the US Navy accepted delivery of Device 2F87F, an operational flight trainer for the P-3(C), a four-engine, turbo-prop aircraft. The 2F87F is a high fidelity device equipped with a six degree-of-freedom platform motion system and TV model board visual system with a 50^{o} x 38^{o} field-of-view. Browning, Ryan, Scott and Smode (47) completed an evaluation of its training effectiveness in which the contribution of its visual system was one of the primary considerations. An experimental group (n=27) received six sorties in the 2F87F followed by four P-3 sorties. The controls (n=74) received three sorties in Device 2F69D (the old simulator with no visual system) followed by six P-3 sorties. Aircraft hours were reduced from 15 for the control groups to 8.6 for the experimental groups. No differences were obtained for average checkflight grades. The average number of landings in the aircraft to become proficient was reduced 31% from 52 to 36. Furthermore, experimental students committed significantly fewer errors per landing than the control group. The errors per landing for the experimental group on their fourth P-3 sortie were less than those of the control group on their sixth sortie.

In a follow-on effort, Browning, Ryan and Scott (48) collected additional data for a group of pilots (n=10) who received aircraft training only--that is no simulator pretraining with either device 2F69D or device 2F87F. The average number of aircraft hours required for proficiency was 15.1, the same number for those students (n=58) receiving training in the device 2F69D, the old operational flight trainer. This compared to only 8.6 hours required by the group (n=27) receiving training in the 2F87F. The number of aircraft landings required for proficiency was 17 for the 2F87F-trained group as compared with 50 for the aircraft-only group. It was also reported that students trained to proficiency in the simulator had a higher probability of demonstrating proficiency in the aircraft on earlier flights than students not trained to proficiency. These data clearly demonstrate the effectiveness of visual simulation training for large transport-type aircraft.

Thorpe, Varney, McFadden, LeMaster and Short (49) reported a transfer of training study designed to determine the relative training effectiveness of three visual systems: a Day/Night Color CGI system; a Night-Only Point Light Source CGI; and a TV/Model Board system. For convenience, they are designated Day, Night and TV. Thirty recent UPT graduates transitioning into the copilot position of the KC-135 (an in-flight refueling aircraft) were given training on the visual traffic pattern, approach and landing. These subjects were divided into three equal groups, each receiving simulator training using one of the three visual systems. Training was accomplished in Boeing 707 commercial flight simulators rented from the Boeing Aerospace Company (Day system) and the American Airlines Flight Academy (Night and TV systems). Each student received up to a maximum of eight hours of training in the simulator with instruction provided by KC-135 instructor pilots. Following instruction in the simulator, each student flew two sorties in the KC-135 aircraft. On each sortie, the student flew three to four repetitions of the approach and landing. Upon completion of the two evaluation sorties, each student entered the normal KC-135 copilot training program. The final evaluations each student received at the end of training were recorded.

Analysis of student performance on the two aircraft evaluation sorties revealed a statistically reliable difference between the TV group and the two CGI groups. The Night and Day (CGI) groups performed significantly better than the TV group. No differences were found between the Day and Night groups. These differences were observered on the last two segments of the task, the final approach and landing. The data revealed that the Day and Night groups improved their performance from the first to the second evaluation sortie. The TV group, however, revealed no improvement. The major areas of weakness for the TV group were in the glidepath and landing segments of the task, with substantially more extreme deviations in the latter stages of the glidepath. Such trends were not evident in the performance of the Day and Night groups.

Resources did not permit the incorporation of a true control group in the design of the Thorpe et al. (49) study; that is, a group receiving only the two aircraft evaluation sorties with no simulator pretraining. However, to obtain an estimate of the effectiveness of simulator training, the final checkride scores of students participating in the study were compared with those of students in previous and subsequent classes. Reliable differences were obtained with 60% of the simulator-trained students receiving a "Highly Qualified" evaluation compared with only 30% of normal students (non-simulator trained) receiving this score. This finding was further supported by the judgment of experienced instructors who felt the simulator-trained students initially performed at a skill level comparable to the average student copilot well along in the training program.

For fighter-attack aircraft, little information is available regarding the effectiveness of visual simulation training for transition tasks. Brictson and Burger (50) report an evaluation of Device 2F103, a night carrier landing trainer (NCLT) for the A-7E aircraft. Device 2F103 consists of an A-7E cockpit with a night only, point light source CGI visual system mounted on a three DOF motion system. The visual system has a $40^{o}H \times 30^{o}V$ field-of-view and presents a color image of the deck lighting and visual landing aids of several carrier types. A syllabus was developed consisting of 6.5 hours which enabled about 85 simulated night carrier landings to be accomplished. The experimental group, consisting of 26 novice pilots, received training in the device while a control group (n=27) did not. Performance during Field Carrier Landing Practice (FCLP) and Carrier Qualification (CQ) clearly demonstrated the effectiveness of the simulation training as measured by an objective landing performance score and boarding rate. For the experimental group, only one student failed CQ compared with seven for the control group.

Since failure leads to recycling in which the student drops back to the next class, the question of the use of the NCLT for remedial training was raised. Brictson (51) developed a technique for identifying students in need of remedial training and also a syllabus of instruction using the NCLT. In an experimental evaluation, students trained with this syllabus received higher scores during FCLP and CQ. Furthermore, their boarding rate (successful approach and touchdown) was higher than that of groups receiving the normal NCLT syllabus of instruction. The data from these two studies clearly demonstrate the effectiveness of visual simulation training for night carrier landings.

Gray, Warner, Eubanks and Chun (52) recently completed a study to determine the effectiveness of ASPT training for students transitioning into the A-10. The ASPT, originally a T-37 simulator, was modified to an A-10 configuration for training transition and surface attack skills. On their first overhead pattern sortie, students trained in this simulator demonstrated proficiency enabling them to land out of their fifth pattern. Experienced fighter pilots transitioning into the A-10, however, were landing out of their eighth pattern. Although scores from this do not represent true control group data, they do illustrate the effectiveness of the training.

Formation

The acquisition of skill in formation flying is one of the more critical and demanding tasks in military aviation. At present there are only a few devices which can provide such training. A simplified formation flight trainer (FFT) was developed for the US Air Force Human Resources Laboratory in the early 1970s. It was designed as a part-task trainer which would provide closed-loop practice for nine formation tasks learned during the T-38 phase of UPT. The device enabled the student to "fly" a TV camera which viewed a model of the simulated lead aircraft. The resulting image of the lead aircraft was projected onto a wide screen which the student viewed from a simplified T-38 cockpit. Horizon and cloud cover imagery could be provided by a programmed point light source projection of a spherical transparency. A detailed description of the device can be found in Wood, Hagin, O'Connor and Myers (53).

The effectiveness of the FFT was evaluated by Reid and Cyrus in two separate studies. In Study I (26), 70 UPT students in the T-38 phase of training were randomly assigned to one of three groups. The FFT group received five sorties of instruction in the FFT, an orientation ride in the T-38 and finally a checkride in the T-38. A Limited Training group received only an orientation ride followed by the checkride. The UPT Syllabus group received two aircraft training sorties between their orientation ride and checkride. Results from the checkride indicated both the FFT and UPT Syllabus groups performed significantly better than the Limited Training group. However, no differences were observed between the FFT and UPT Syllabus groups. In other words, five hours of FFT instruction were as effective as two hours of aircraft instruction. The same design was used in a second study. The only difference was that an Air Training Command syllabus change had occurred in which students were given additional formation training during the T-37 phase. Using 48 students, the study was replicated. The results were the same thereby providing conclusive evidence that the FFT was an effective trainer.

In a follow-on study (54), the same design was used to determine effectiveness of the FFT for the T-37 phase of UPT. The FFT was modified to provide a T-37 visual image and its flight dynamics were changed to approximate those of the T-37, although the cockpit and controls remained the same. A total of 61 student pilots participated in the study. The results indicated that the UPT syllabus group performed significantly better on their checkride than either the FFT or Limited Training groups. Although the FFT group had higher scores than the Limited Training group, the difference was not statistically significant. The extent to which these results are due to the degraded fidelity of the device is unknown.

The only other effort to evaluate formation training in a simulator was an effort by Woodruff et al. (42), described previously, using the ASPT. In that study, the data revealed a savings of 13% and a Transfer Effectiveness Ratio (TER)[4] of 1.00. At the time of the study, a number of equipment problems were encountered which led to the decision to limit the formation training to only two sorties. Furthermore, for three of the eight students, these sorties were cancelled due to scheduling conflicts, so that the results were based on only five pilots. However, the high TER indicates that substantial savings may have been possible if additional sorties had been given.

[4] The TER is calculated by dividing the difference between the aircraft training time of the experimental and control groups by the difference between the simulator training time of the experimental and control groups (55). It provides a measure of the relative effectiveness of training which can be compared across different simulators and training programs.

Aerobatics and Air Combat Maneuvering

The ability to provide training for aerobatics and air combat maneuvering has been made possible by the development of wide angle visual systems. Two studies were completed in the ASPT in which there was an attempt to train aerobatic skills. The first, reported by Woodruff et al. (42), revealed that 6.2 hours of instruction in the ASPT resulted in only a 4% savings of aircraft time. Recently, Martin and Waag (56) reported an effort to determine the contribution of platform motion to the acquisition of aerobatic skills. Thirty-six UPT students were assigned to one of three treatment groups (n=12): (1) Motion; (2) No Motion; and (3) Control. Students in the two experimental groups received five ASPT sorties covering instruction on eight aerobatic tasks. The control group did not receive ASPT pretraining. All students were subsequently evaluated in the T-37 aircraft by their normal flightline IPs. The obtained data suggested a modest degree of transfer. Of the eight maneuvers trained in the ASPT, only one, the Barrel Roll, produced an overall significant transfer effect across the three groups. However, approximately one third of the ASPT-trained vs Control group a priori t-tests produced significant effects. In all cases, superior performance was demonstrated by the ASPT-trained groups. An examination of group means indicated the trends to favor the simulator-trained group for all except three of the measures taken. From these data, it is apparent that transfer of training did occur. However, the magnitude of the effect was not great.

Payne, Hirsch, Semple, Farmer, Sanders, Wimer, Carter and Hu (57) reported a study to determine the amount of transfer that can be obtained through simulation training of visual air combat tasks. Subjects were 16 Navy pilots transitioning into the F-4. The eight pilots comprising the experimental group received six training sorties in the Northrup Large Amplitude Simulator/Wide Angle Visual System (LAS/WAVS). The LAS/WAVS has a spherical, wide angle screen which provides a 210° horizontal field-of-view. A maneuverable adversary aircraft as well as an earth-sky image is projected onto the screen. Training was provided for basic fighter maneuvers such as barrel roll attacks, high yo-yos, rolling scissors, etc. All students were subsequently evaluated during their normal tactics syllabus which consisted of six sorties. Analysis of data reflecting final position outcome revealed the experimental group achieved superior final positions when compared with the control group. This held for starts at the neutral as well as offensive positions. Transfer estimates based on such outcomes ranged from 26% to 96%. The superiority of the experimentally-trained group also was reflected in the grades assigned by the instructors. These differences were maintained throughout the entire tactics syllabus of instruction. The greatest transfer effects were demonstrated for the rolling scissors. Although the experimental group had higher scores for all tasks, the differences were not significantly higher than the control group.

Pohlmann and Reed (58) completed a study designed to determine the contribution of platform motion to the initial acquisition of basic fighter maneuver skills, the same type of tasks studied by Payne et al. (57). The study was accomplished on the Simulator for Air-to-Air Combat (SAAC), a device comprised of two F-4 cockpits each mounted on a synergistic six degree-of-freedom motion system. The visual display consists of eight pentagonal cathode ray tubes which provide a 296°H x 150°V field-of-view. A camera model aircraft image generator and synthetic terrain generator provided the images for the visual display. Sixteen students received seven training sorties in the SAAC. All students, including six control students, were evaluated in subsequent aircraft sorties. One additional aircraft sortie was added to the normal syllabus to assist in the evaluation. An analysis of data collected in the aircraft revealed no enhancement of performance as a result of simulator pretraining. In fact, the trend was toward superior performance by the control group.

Air-To-Surface Weapons Delivery

In 1975, the Air Force Simulator Systems Program Office initiated an effort to evaluate existing simulator visual system technologies that were applicable to air-to-surface weapons delivery. Because of its CIG capability, one of the systems selected for consideration was the ASPT. A new environmental data base was created which included an airfield complex, a conventional gunnery range, and two tactical gaming areas. Of the systems evaluated, the ASPT was the only one considered capable of providing effective air-to-surface weapon delivery training (59). At the same time, the Tactical Air Command requested that AFHRL initiate research studies to demonstrate the training value of platform motion. Since air-to-surface weapons delivery was one of the task areas for which such information was desired and since the ASPT was the only system considered capable of training such tasks, the Operational Training Division initiated a study to determine: (1) the extent to which generalized, conventional air-to-surface weapons delivery training in the ASPT transferred to a specific aircraft; and (2) the contribution of six degree-of-freedom platform motion to the transfer of training from simulator to aircraft (60). Twenty-four graduates of fighter lead-in training were assigned to one of three treatment groups (n=8): (a) Motion; (b) No Motion; and (c) Control. Simulator pretraining was accomplished in the ASPT which simulates the T-37 aircraft while evaluations were conducted in the F-5B aircraft. Upon arrival at Williams AFB, all students received academic training in weapons delivery techniques and procedural training in F-5B operations. At this point, students in the Control group flew two data collection sorties in the F-5B aircraft, performing two 10°, 15°, and 30° bomb deliveries. At the end of simulator training, students in the experimental groups flew the same two evaluation sorties in the F-5B aircraft.

Four sets of analyses were conducted on data collected in the aircraft. Measures included the number of bombs meeting TAC's qualifications criteria, the number of bombs which were scorable on the range, circular error, and IP ratings. The two simulator groups performed significantly better than the control group for all measures except the IP ratings. The two experimental groups dropped about twice as many scorable bombs and bombs meeting the qualification criteria and produced an average circular error of about 25% less.

The results of this study clearly demonstrate that full fidelity simulation is not necessary for effective transfer of training. The T-37 is the primary jet trainer used in the initial stages of UPT while the F-5B is a high performance fighter. Prior to their two evaluation sorties, these students had never flown the F-5, although they had flown the T-38 which is similar to the F-5. The fact that generalized training in a T-37 simulator transferred to the F-5 questions the validity of the design goal of maximum fidelity.

As mentioned previously, the modification of one ASPT cockpit to an A-10 configuration was completed in 1977. In addition to transition training, recent UPT graduates entering the A-10 training program also were provided weapons delivery training on the ASPT (52). The surface attack syllabus consisted of three two-hour sorties. The results of the ASPT training for the first 17 pilots to complete training in the ASPT were dramatic. On the first bombing sorties in the A-10, the average circular error for the 30° dive bomb event was substantially less than the TAC criterion for qualification. It was about the same as the average circular error for experienced fighter pilots on their sixth sortie. A later class of ASPT-trained students received weapons delivery training in the aircraft first, thereby providing control group data. Average circular error on the first sortie for the 30° dive bomb event was approximately twice that of students receiving pretraining in ASPT. These data clearly demonstrate the effectiveness of the training.

Rotary Wing Studies

In 1977, the US Army accepted delivery of the CH-47FS operational flight simulator. The trainer was designed to simulate the CH-47C helicopter. It is mounted on a six degree-of-freedom platform motion system and has a camera-model visual system which provides a 48°H x 36°V field-of-view display in the forward window. It also has a "chin window" display which utilizes a synthetic terrain generator. The test and evaluation of the device incorporated a transfer of training study design. Two studies were completed: the first, assessed the effectiveness of the CH-47FS for novice pilots transitioning into the CH-47 (61); the second, assessed the effectiveness of the CH-47FS for maintaining mission readiness skills (62).

For the initial transfer evaluation, 24 student pilots were trained to proficiency in the CH-47FS. They were then given a checkride in the CH-47 aircraft, followed by instruction on those tasks beyond the capabilities of the CH-47FS as well as those tasks on which the student's performance was considered unsatisfactory. At the end of training, a final aircraft checkride was administered. The control group (n=35) received all instruction in the aircraft using the same proficiency advancement and checkride procedures. Training effectiveness ratios were computed on the basis of total training time and training trials for each maneuver. For total training time (exclusive of checkrides), the resulting TER was .72. On a breakdown by maneuver, TERs ranged from .40 to 1.50 for trials to criterion. For total time, however, the TERs ranged from -.43 to 1.69. As expected, the highest TERs were found for procedural tasks and the lowest for approaches and takeoffs. An evaluation of the final checkride scores revealed higher scores by the experimental group although the difference was not statistically significant.

In the second study, 16 aviators who were qualified and current in the CH-47, received five hours of instruction and practice in the CH-47FS per month over a six-month test period. Such practice was in addition to their mission essential flying in the CH-47 aircraft. A control group of 16 aviators received only their normal mission essential flights in the CH-47. Checkrides were administered at the beginning and end of the six-month test period for all participants. During the test period, there were no reliable differences between the groups in terms of mean CH-47 aircraft flight time. The pretest checkride indicated significantly better performance by the control group. The post-test checkride revealed no differences. A pretest/post-test comparison for the control group revealed no change in performance. For the experimental group, however, there occurred a significant enhancement of performance. Of the 35 individual tasks performed, significant improvement was observed on 26. The only areas not showing improvement were external load procedures and autorotations. It was speculated that this may have been due to limitations of the visual system.

Summary

Of the studies completed to date, most have focused on the use of visual simulation for transition training. With few exceptions, the overwhelming finding is that visual tasks learned in the simulator show positive transfer to the aircraft. The successful use of visual simulation training has been demonstrated for trainer, fighter and transport fixed-wing aircraft as well as for rotary wing aircraft. Such effects have been obtained for pilots initially transitioning into the aircraft, and in one instance, for enhancing the skill level of experienced pilots in an operational flying environment. Few studies have been accomplished for tasks other than transition. This is due to the limited availability to date of the wide-angle visual systems needed to provide suitable training on contact tasks. Nonetheless, the data thus far suggests that significant transfer can be obtained through simulator training of skills needed for formation and surface attack weapons delivery. Only a modest amount of transfer has been demonstrated for aerobatic and air combat skills.

MOTION SIMULATION

The technology of motion simulation also has expanded rapidly. Today, there are a variety of devices which can provide force cueing information. These include platform motion systems, g-seats, g-suits, stick shaker, and buffet/vibration systems. They are designed to provide either onset or sustained motion cue information. Unlike the addition of a visual system, force cueing devices enable the pilot to perform only a few additional tasks which would not otherwise be learned in the air. In most instances, force cues provide only secondary information to the pilot. In instrument flight, the pilot is trained to "fly" only by instruments and to ignore force cueing information. It is well known that motion cues are not essential for effective simulator training since pilots have been acquiring flying skills with the aid of fixed base devices for years. However, the extent to which these recently developed force cueing systems add to the effectiveness of simulation training in terms of increased transfer is unknown. There is evidence that single-axis tracking performance is enhanced as a result of simulated motion generated in a laboratory test apparatus (63). Furthermore, performance in the simulator may be enhanced under certain conditions. However, the extent to which this additional cueing in simulators enhances the training performance in the aircraft has only recently been questioned.

Koonce (64) reported a study which investigated the effects of refresher instrument training in a Singer-Link GAT-2 on subsequent performance in a Piper Aztec. The GAT-2 is mounted on a limited two-and-a-half degree-of-freedom platform motion system. Two groups were trained with the aid of motion cueing: one with a washout drive algorithm and the other with sustained drive algorithm. A control group was trained without motion cueing. Each pilot received two simulator sorties followed by an aircraft checkride. During two simulator sorties, the two motion groups performed significantly better than the no motion group. However, in the aircraft sortie, the no motion group performed better than the two motion groups, although the differences were only marginally significant.

In a follow-on study, Jacobs (65) trained novice students in the GAT-2 and subsequently evaluated their flight performance in a Piper Cherokee Arrow. Thirty-six students were divided into four groups which received: (1) simulator training with normal washout motion; (2) simulator training with directionally random motion; (3) simulator training with no motion; and (4) aircraft training only. Each student in the simulator-trained groups received four sorties in which the number and sequence of task repetitions were fixed. Training in the aircraft was accomplished on a proficiency basis. Within the simulator trained groups, the washout motion group committed significantly fewer errors than the no motion group. Errors in the random washout group were similar to those of the no motion group. Analysis of the aircraft data revealed: (1) significant transfer of all three groups in terms of time to criterion, trials to criterion, and number of errors; and (2) no reliable difference among the three simulator trained groups. The results of these two studies conducted at the University of Illinois indicate that motion cueing did not substantially enhance the transfer of training to the aircraft.

The only other studies of platform motion effectiveness have been conducted by the Operational Training Division of the US Air Force Human Resources Laboratory. Most have been described in the previous section concerning the effectiveness of visual simulation; for these cases, only the findings pertinent to the question of platform motion will be discussed. Part of the study reported by Woodruff and Smith (40) concerned the effectiveness of the T-4G simulator for instrument training. The use of this device, which is mounted on a two DOF motion base and has a limited visual system, resulted in an average reduction of 10.1 flight hours in the T-37 aircraft. Use of the T-4, which is the same trainer without motion or visual systems, resulted in an 8.1 flight hour reduction. The difference (10.1 vs 8.1 hours), however, was not statistically significant.

In the exploratory study investigating the utility of the ASPT as a full misson simulator in the basic phase of UPT (42), half of the students were trained with platform motion (n=4) and the other half without (n=4). No significant differences were obtained for either required simulator hours or required aircraft hours. This finding was obtained for the basic/presolo, advanced contact, instruments and navigation phases of training.

Following final acceptance of the ASPT in 1975, an unpublished exploratory study was conducted which evaluated the contributions of platform motion to the acquisition of basic contact skills. Two groups (n=4) were trained to proficiency in the simulator and subsequently evaluated in the T-37 aircraft. No differences in either simulator or aircraft performance were obtained. In a subsequent effort, Martin and Waag (43) addressed the same question using more rigorous control procedures and a larger sample size. As discussed in the previous section, two groups of students (one trained with motion, the other without), received ten sorties of instruction in the ASPT on basic contact skills. Subsequent evaluations in the T-37 aircraft revealed substantial transfer of training. However, with respect to the two experimental groups, i.e., Motion and No Motion, no statistically reliable differences were found for either performance in the simulator or subsequent performance in the aircraft. In the aircraft, this finding was observed for student performance on two special data sorties at the beginning of training, and for their performance up to the pre-solo check.

In a subsequent study, the evaluation of platform motion effectiveness was extended to aerobatic skills since motion cues should be more prominent for such tasks (56). As discussed in the previous section, the data revealed only a modest degree of transfer to the aircraft. A comparison between the Motion and No Motion groups revealed some small, although inconsistent performance differences during simulator training. Of those individual aircraft measures demonstrating significantly better performance by the simulator trained groups (13 of 40), none revealed a reliable effect due to motion.

Since both of these studies used a wide field-of-view (300°H x 150°V), it was speculated that peripheral visual cues may be imparting "motion" cues. If such were the case, then platform motion may have a greater effect for narrow field-of-view visual systems. To investigate this hypothesis, Nataupsky et al. (45) conducted a transfer of study varying motion and field-of-view. As noted above, four groups received four ASPT training sorties followed by a data ride in the T-37 aircraft. The aircraft data revealed no reliable effects due to motion, field-of-view, or their interaction. Within the simulator, data collected on each of the four sorties revealed no reliable effects due to field-of-view or its interaction with motion. The motion groups performed significantly better for the Takeoff, Slow Flight and Straight-in Approach/Landing as measured by IP ratings and for the Straight-in Approach/Landing as scored by the ASPT automated measurement systems. Since these efforts were evident on the first measured trial and no signficant motion by trial interactions were found, it seems likely there existed initial group differences.

Gray and Fuller (60) studied the contribution of platform motion to the acquisition of weapons delivery skills and its subsequent transfer to the aircraft. As previously discussed, the training was highly successful. With regard to platform motion, no differences were found for either performance in the simulator or subsequent performance in the aircraft. It must be remembered, however, that training was provided in a T-37 simulator while the transfer evaluation was conducted in the F-5 aircraft. Although it is clear that the addition of platform motion during simulator training did not enhance the transfer to the aircraft, the generality of such findings is questionable due to the dissimilarity of aircraft dynamics during training and evaluation.

Pohlmann and Reed (58) attempted to determine the value of platform motion cueing in the acquisition of basic air combat skills. Data collected during aircraft evaluations revealed the training to be ineffective. In fact, the trend was toward better performance by the Control Group which received no simulator pretraining. Since transfer of training was not demonstrated, data bearing on the motion issues were not considered meaningful.

DISCUSSION

Taken at face value, the literature suggests that the addition of a visual system will enhance the training value of the simulator whereas the addition of a platform motion system will have little effect. However, there are dangers in attempting to draw conclusions from diverse and often unrelated research studies. The research goals in these studies vary widely; the experimental design and measurements are different. Each of these factors will have an effect (usually unknown) upon the study outcome. In the following section, the effect of study design factors will be addressed.

Research Objectives

At the outset, the stated intent was to review the literature regarding the training effectiveness of motion and visual simulation. Training effectiveness was defined in terms of enhanced performance in the airborne environment as a result of simulation training--in other words, transfer of training. It should be readily apparent that only some of the reviewed studies have attempted to directly address this question. The best examples have been efforts addressing the contributions of platform motion to training effectiveness (56, 58, 60, 65). In those studies, training was given under alternative motion cueing conditions and compared with the results of identical training without motion. A comparison of performance between such groups enables one to directly assess the effect of the motion cueing. Such an approach, however, has not been used to evaluate the effectiveness of visual systems. In many instances, it would not be warranted; e.g., tasks in which external visual cues are absolutely necessary, such as formation, aerial refueling, and air combat.

However, many visual tasks, especially for transition training, have or can have a large instrument component. Many of these tasks can be flown from cockpit instruments even though the intent is to make use of external visual cues. In the event that the visual cues are not adequate, pilots will resort to the use of instruments. It seems likely that because of this large instrument component of transition tasks, estimates of visual training effectiveness may be inflated. To date, the authors are unaware of any transfer studies which have been completed wherein one control group received training for the same tasks under instrument conditions only. Until such efforts have been accomplished, the actual benefits of visual simulation training for transition will remain unknown.

Furthermore, some of the studies reviewed were concerned with the evaluation of the effectiveness of simulation training in which the visual training per se represented only a fractional part. In most instances, evaluations have centered around a single system. Only a few efforts have attempted to study differential transfer as a function of visual system characteristics (44, 45, 49), despite the fact that such information is vital to the procurement process. Consequently, there is ample evidence that visual simulation training is effective, but little data to guide decisions on the visual system requirements for specific applications.

Experimental Design and Control

In addition to differing research objectives, there are also differences in experimental design which characterize the literature. Most studies have been designed to evaluate the effectiveness of a single simulator training program. In such situations, the desired approach has been to train to proficiency in both the simulator and the aircraft. Estimates of transfer effectiveness could be obtained by comparison with a group trained to proficiency in the aircraft only. Despite the desirability of this approach, it has been used in only a few studies (32, 36, 61). Some studies have trained the experimental group to proficiency in the simulator and aircraft and subsequently made comparisons against the hours in the normal syllabus (40, 42). Other studies have defined a fixed number of simulator and aircraft hours and made comparisons against a "standard" syllabus in terms of final proficiency evaluations (26, 33, 37, 47, 54). Still others have employed a fixed number of simulated and aircraft hours or sorties (34, 38, 39, 50, 52, 57).

Studies of differential transfer, that is, comparing different simulator training conditions, present an added problem. The investigator has the option of either training the simulator groups to proficiency or providing a fixed number of trials. While training to proficiency should theoretically optimize the transfer, it makes interpretation difficult in the event there are differences in trials to criterion in the simulator as well as differences in aircraft performance. In such instances, the variable of interest is confounded with training time. Furthermore, there is the added danger that training both groups to proficiency in the simulator may enhance the likelihood of no differential transfer. On the other hand, use of a fixed trial procedure may reduce the overall effectiveness of the training, thereby increasing the variability of subsequent aircraft performance and reducing the power of the design. Despite this danger, most studies of differential transfer have used a fixed training procedure (43, 44, 45, 56, 58, 60). Only two studies (40, 42) used a training to proficiency approach, and in each case, the differential transfer aspects were only a secondary consideration. Thorpe et al. (49) used a combination procedure in which each pilot received a fixed number of simulator training sorties unless proficiency criteria were reached earlier.

There are also differences in terms of the degree of experimental control exercised during simulator training. Primarily, two approaches have been used. Some studies have provided simulator instruction in a manner equivalent to operational training. No special procedure or sequence of training was followed. Other studies, however, have attempted to strictly control the instructional process in terms of a fixed sequence and number of events or specific criteria for advancement to the next task. For the most part, these studies concerned with differential transfer have attempted to rigorously control the content and sequence of the instructional syllabus whereas those evaluating the training effectiveness of a single system have used the more traditional operational approach. However, for some studies, the report did not provide sufficient information so that it seems likely that few special instructional control procedures were followed. The extent to which such differences affected study outcomes is unknown.

Proficiency Assessment

Perhaps the most critical aspect of the transfer of training study is the assessment of aircrew performance. The use of reliable, valid, and sensitive indices of proficiency is essential. Measurements are needed to determine proficiency in both the simulation and airborne environments. In the studies surveyed, measurements have ranged in sensitivity from attrition data to deviations from a desired glidepath as measured by sophisticated radar equipment. Despite this wide range, most studies have relied upon judgements of experienced flight instructors. Some studies have attempted to minimize the subjective aspects of instructor evaluation by requiring him to "record" performance rather than "evaluate" performance. In these cases, observations such as maximum/minimum altitude, airspeed at touchdown, etc., would be recorded. This approach was used in some of the earlier University of Illinois studies in which proficiency was defined in terms of these behavioral criteria. Despite the desirable objectivity of such an approach, it requires specialized instructor training to be used successfully. Furthermore, the possibility remains that important indicators of proficiency may be overlooked using this approach.

Other studies have attempted to capitalize on the expertise of the flight instructor and incorporate his judgment into the flight evaluation. In some instances, he has been asked to evaluate performance along a continuum from unsatisfactory to excellent (26, 43, 45, 54, 58, 61). Other studies have required instructors to evaluate performance in relation to some normative criteria, e.g., the top 3% of students you have instructed (38, 49, 50, 57).

Only a few studies have made use of automated objective scoring procedures wherein no instructor judgments were required. Objective in-simulator performance scoring has been used for basic contact and approach/landing skills (43, 44, 45) and weapons delivery training (52, 60). In the aircraft, even fewer studies have used objective data. Brictson and Burger (50) recorded glidepath data for a portion of the pilots using radar equipment. Objective bomb delivery scores were used by the two previously mentioned surface attack studies (52, 60).

Each of the techniques discussed thus far has been applicable to the evaluation of performance on a repetition-by-repetition basis. In other words, a student's performance might be considered Good on the first trial, Fair on the second, Good on the third, and so on. The demonstration of proficiency on one trial does not guarantee the same level of performance on the next. The definition of proficiency in terms of continued acceptable performance creates additional problems. Some studies have resorted to a single instructor judgment as to when the student is considered "proficient" (42, 47, 48, 61). Other studies have defined proficiency in terms of a set number of task repetitions, each of which had met proficiency criteria. For example, Payne et al. (36) required three successive repetitions in which all criteria were met on each trial. Thorpe et al. (49) required five successive repetitions. Other studies using a fixed number of training trials or evaluation sorties have not had to develop such an overall definition of proficiency.

Sample Size

Reported sample sizes have varied substantially. They have ranged from a low of four subjects per group (42) to a high of 100 subjects per group (38). The choice of sample size is usually dictated by economic and operational constraints rather than measurement sensitivity and the desired power of the experimental design. The relationship between behavioral variability, measurement sensitivity and the sample size is straightforward. Greater variability of performance and reduced measurement sensitivity lead to a requirement of larger sample sizes. Failure to increase the sample size will reduce the power of the test to detect differences in the event they actually exist. This is especially critical for relatively small effects. It should be apparent that studies of differential transfer, e.g., a comparison of alternate visual systems or motion versus no motion are most vulnerable to this problem. The effect of simulation training vs. no training is likely to be substantially larger than training in System A vs. training in System B. Therefore, studies of differential transfer require a larger number of subjects to maintain a certain degree of power given the same training and measurement procedures.

A survey of the reviewed literature, however, reveals just the opposite. In general, studies of differential transfer have used smaller sample sizes. The extent to which these sample sizes have led to the predominant finding of "no differences" is unknown since such efforts have generally attempted to exert greater experimental control thereby reducing behavioral variability and increasing statistical power. Perhaps it is safe to conclude only that larger sample sizes would have been desirable.

Task Selection

For most transfer of training evaluations of an operational simulator training system, the selection of tasks to be trained does not present a major problem. In most instances, instructors fly the simulator to subjectively determine which tasks can be realistically flown. Based on their opinions, a training syllabus is developed and subsequently evaluated. For differential transfer studies, however, the selection of tasks to be trained presents some interesting questions.

The strategy of most differential transfer of training studies has been to select tasks which are relevant to the question of interest, provide intensive training for only those tasks, and evaluate the transfer to the aircraft. In comparing three visual systems for KC-135 training, Thorpe et al. (49) selected the circling approach and landing for training. Since this task is the most critical and visually dependent task flown in the KC-135, such a choice seemed appropriate. Likewise, Martin and Cataneo (44) chose takeoffs and landings for a comparison of Day vs Night training using a narrow field-of-view visual presentation. Again, such a choice seems reasonable since they are the two most important tasks requiring visual cueing which are trained in Air Training Command's new Instrument Flight Simulator.

Nataupsky et al. (45), in an effort to determine the interactive effects of motion and field-of-view, chose the takeoff, slow flight, steep turn and straight-in approach and landing for training. Since the primary visual cues for these tasks are located directly in front of the simulated aircraft, it is questionable whether they were good choices for evaluating field-of-view effects. Likewise, the choice of tasks to evaluate the contributions of platform motion to training effectiveness has stirred controversy. Two types of motion cueing have been distinguished, force cues resulting from pilot input and force cues resulting from environmental or aircraft configuration changes (66). The first type has been referred to as maneuver motion; the second, disturbance motion. The studies to date have focused primarily on tasks having a large maneuver motion component. Since there is some in-simulator performance data to suggest that motion may not enhance the performance of such tasks under stable aircraft conditions, the selection of such tasks to evaluate motion cueing has been questioned.

Generalizability

One of the key issues in any research effort is the extent to which the results have application beyond the immediate conditions of the study. This requires the investigator to have an understanding of the critical dimensions which may impact the study outcome and thereby generate a design which will maximize the generality of the results. Although it is known that factors such as aircraft type, pilot experience level, and type of task may affect the outcome, little attempt has been made to integrate these in some coherent fashion. Furthermore, there has been a failure to quantify the critical dimensions of motion and visual systems, except in the most rudimentary way (e.g., On vs. Off or Day vs. Night, etc.). In other words, there exist no quantifiable models of visual and motion simulation which enable testable hypotheses to be generated which subsequently might lead to generalizable findings. Until such models are developed, progress will occur in a precarious fashion at best.

A look at the studies to date may provide some understanding of the failure to provide a set of generalizable findings. Most transfer of training evaluations have been problem-oriented. Studies have been done to answer specific questions. What is the value of a night carrier landing trainer? Can simulator time be substituted for P-3 aircraft time without a decrease in proficiency? Which is the best available visual system for the KC-135 simulator? Are platform motion systems required for fighter simulators? The research community, in its attempt to provide "real-world" solutions for today's problems, has failed to develop the framework for obtaining data for tomorrow's issues.

The Fidelity Issue

A key example of a failure to "look-ahead" concerns the fidelity of simulation necessary to insure transfer of training. There is no question that for many tasks full fidelity simulation is not necessary. Pilots have been aided by very low fidelity trainers for years. Furthermore, many of the research studies cited in this report clearly document the fact that the flight simulator does not have to duplicate the aircraft in order that training be effective. If full fidelity is not necessary, then exactly how much is required? Unfortunately, this question cannot be answered until other issues are addressed.

First, at a very basic level, what skills transfer from the simulator to the aircraft? It is observed that the transfer for some tasks is quite high; for others, quite low. Little is known regarding the underlying basis of these observed differences. Basic research is needed which clearly identifies those elements of simulator training which transfer to the aircraft. For example, computer-generated imagery visual systems are often very cartoonish. Yet, there is evidence to suggest that they provide more effective training than terrain model board systems which more closely duplicate the real world environment. It is apparent that the key variable is not the physical fidelity of the system. Research is needed to identify those critical elements which do account for these observed transfer effects.

Once these critical transfer elements have been defined, it is necessary to derive the relationship between the degree of fidelity and the amount of transfer. It is at this point that trade-offs can be generated between costs associated with increased fidelity and costs associated with providing training in the aircraft. It may be that for some tasks, the aircraft is the most cost effective training device. Until this information is available and a valid cost-effectiveness model developed, the queston of how much fidelity is needed will remain unanswered. Because of our current inability to match training and fidelity requirements, it is likely that simulators will continue to be procured under the design goal of maximum fidelity.

VI. CURRENT PRACTICES IN THE USE OF SIMULATORS

DEVELOPMENT OF SIMULATOR TRAINING PROGRAMS

Development of plans for use of a simulator in a flying training program typically precedes the purchase of flight simulation devices which provide capabilities for training, practice and evaluation of flying tasks which could not be trained using existing simulation devices of the to-be-revised training program. Under these circumstances, a fresh look at the total training program package often follows and some form of a training system analysis may be made if enough time and money are available. The objective of such an analysis is to increase the efficiency, economy, safety or other salient attributes of the overall training operation. The analysis may reveal opportunities for program changes which will achieve various training improvements. Since inclusion of a new simulator guarantees a revision of an existing training syllabus, other productive modifications to training often can be included at little extra cost in time or money.

SIMULATOR AS AIRCRAFT SUBSTITUTE

At this point, the requirements, intentions, and concepts of the training managers very likely determine how the simulator(s) will be employed within the new training program. By considering the potential of the simulators in question, the training manager may conceive of them as taking the place of the aircraft. This approach asks the question, "What tasks can be trained in the simulator?" Once the tasks that can be trained in the simulator are identified, the program is modified accordingly, leaving the remaining training tasks to be taught using the aircraft. This type of application of simulators is simple, straightforward, practical, effective and often results in gratifying energy and cost savings through reductions in flying hours required for training. Diehl and Ryan (67) have produced an extensive review of research results to demonstrate the effectiveness of the simulator as substitute for the aircraft in flying training.

An example of this kind of non-integrated training program development can be seen in the US Air Force Air Training Command's (ATC) new Instrument Flight Simulator (IFS). The IFS will be used to provide instrument procedures training in both T-37 and T-38 phases of UPT. Training in the IFS will replace aircraft instrument training with the exception of the instrument phase checks which will be given in the appropriate aircraft. The ATC syllabus (68) shows a reduction of about 35 flying hours as a result of use of the IFS for all simulator instrument training.

INTEGRATED SIMULATOR TRAINING

In contrast, a training manager with an analysis of the overall training situation before him may conceive of flight simulators as additional training aids rather than as substitutes for the aircraft. In this case, he may consider a variety of training media which vary in cost, complexity and representation of the in-flight environment and evaluate a variety of ways to arrange their use to generate an effective training program. In this type of program, new training material is introduced through lecture/discussion, some form of group instruction, or through the use of media-oriented individualized instruction. This is followed by a progress check and additional instruction as appropriate to achieve the training objectives. Part-task training aids then may be employed to provide realistic practice in limited operation of equipment systems. In successive lessons, the learner acquires the ability to perform the tasks required of him one by one, and as he learns, he can be instructed in the way these part-tasks are integrated in real time in accomplishing the criterion task he is learning to perform.

Once the part-tasks are mastered, the learner is prepared to take maximum advantage of practice opportunities in the flight simulator, which he is now ready to deal with competently and productively. In the simulator the learner can practice the entire task in real time, evaluate his performance, make corrections in the way he handles the demands of the task and eventually acquire the skills needed to perform at the required level of proficiency. At this point, the trainee may be evaluated in the simulator and subsequently in the aircraft or given his checkride directly in the aircraft. Thus the check/evaluation routine becomes, in addition, a validation/verification of training success. Following completion of check flight, the learner may proceed to the next phase which can be organized in much the same way. Should the trainee not pass his demonstration/check exercise, he and his instructor can determine what additional practice is needed and return to the simulator to refine the performance until he is ready for reevaluation. Such a sequence illustrates one of the simulator's chief instructional virtues, its capability to create specific training exercises which can be tailored to match a trainee's specific need for practice.

An example of the integrated use of simulators in flying training can be seen in the American Airlines' Transition and Recurrency programs for Captains and First Officers (46, 69, 70). The American Airlines program begins with study of technical information using handbooks, manuals and a variety of audiovisual media. System operations training is then given using part-task trainers in addition to verbal and visual instruction. Trainees progress through the program on a proficiency basis. They complete a sequence of training/practice flights in an appropriate simulator where they demonstrate their readiness to pass an American Airlines evaluation in the aircraft. Following this evaluation, the trainee routinely is given an FAA certification check.

RECONSIDERING THE ALTERNATIVES

Both substitution and integrated simulator training have substantial systematic strength and both have demonstrated their utility and effectiveness (46, 67, 70). The simulator substitution approach tends to emphasize the intuitively obvious fact that the simulator is not really like the aircraft and therefore may be viewed as a less than desirable substitute. In such cases, the result may be less than optimum utilization of the simulator due to the its relative lack of realism. Thus the non-integrated approach tends to limit the effectiveness of a simulator's application as a teaching tool because of its non-identity with the aircraft.

On the other hand, the integrated approach to simulator utilization in flying training defines a teaching role for the simulator which is based on its instructional strengths. In this instance, the simulator's training effectiveness does not depend on its aircraft-like flying characteristics, fidelity/realism or other similar attributes which in nearly every case will drive the cost and complexity of a simulator higher than is needed in order for it to be used effectively for transfer of training in the aircraft (3). Consequently, the integrated simulator-aircraft flying training program is less vulnerable to unwarranted criticism, may generate greater instructor and trainee acceptance and lead to higher cost-effectiveness than non-integrated programs. To conclude this discussion of current alternative simulator applications, it should be noted that regardless of the orientation of the training managers and instructional system developers, instructors typically use the simulators effectively and will learn to "train-around" their limitations to exploit their capabilities and minimize their deficiencies (71).

VII. FLIGHT SIMULATORS USED FOR EMERGENCY PROCEDURES TRAINING

CURRENT EMERGENCY PROCEDURES TRAINING

With many of today's aircraft systems, particularly transport and fighter-type aircraft, there are a number of emergency conditions that can arise during flight operations which are too dangerous to train in the aircraft. Engine failure on takeoff or landing or various maneuvers associated with departure from controlled flight are examples of such emergency conditions. From the beginning, one of the signficant strengths of the flight simulator has been to support training in procedures for dealing with emergencies which cannot be learned, practiced, or evaluated safely in the aircraft. As a consequence, the use of flight simulators for emergency procedures training has increased steadily and development of simulator technology has included attention given to increasing the scope and quality of emergency procedures training capabilities in state of the art devices.

The emergency conditions which can occur in an aircraft system and the aircrew procedures specified to deal with them properly are included routinely with presentation of technical information on normal operation conditions and procedures. Often the determination that an emergency condition exists is based on detection of an operational parameter above or below the normal range; for example, high exhaust gas temperature or low oil pressure. Other types of emergencies are signaled by a discontinuity in a normal operation, such as engine failure or electrical system malfunction.

THE SEQUENCE OF EMERGENCY PROCEDURES

In any case, an emergency condition is defined in terms of the information available to the crew for use in determining when an emergency exists. The emergency procedures which are required to correct the emergency conditions are defined as a sequence of actions to be taken by the crew which include the detection and recognition of additional signals to be checked by the crewmember to permit him to evaluate the effects of the emergency procedures he has accomplished. The desired sequence of aircrew actions in the event of an aircraft emergency condition are:

1. Detect the indication that an emergency condition exists.

2. Recognize the specific characteristics of the emergency.

3. Recall the specific procedures to be accomplished to correct the emergency condition.

4. Accomplish the emergency procedures promptly and accurately.

5. Make an appropriate assessment of the effects of the result of the corrective actions and accomplish additional emergency procedures if indicated (72).

In practice, emergency procedures training consists of memorizing specific sequences of actions. Mastery of emergency procedures is verified in a verbal or written classroom test or in a simulator test exercise.

In classroom and simulator emergency procedures tests, practice may occur only if the trainee fails to exhibit the exact correct verbal responses or procedural actions required. This is a result of the relatively simple characteristics of many emergency procedures which require substantially more rote memory than perceptual-motor, discrimination or cognitive skills. Since some emergency conditions may be corrected more easily if they are detected quickly, speed in completing an emergency procedure is rated highly provided no procedural errors are made. Thus, it can be seen that emergency procedure training involves learning the sequence of action requirements and practicing the procedures until they can be performed quickly and without error following the first signal of an emergency condition.

SIMULATOR EMERGENCY TRAINING

In the simulator, emergency procedure training involves periodic testing of the simple procedural sequences for speed and accuracy. Depending on the characteristics of the simulator in which the emergency procedures are practiced and evaluated, the signal of an emergency condition may be programmed as a normal element in a broader simulator training session. For example, in a session which involves instrument approach and let-down procedures, the instructor may decide to insert an ILS indicator failure between the inner marker and breakout under the overcast. When the indicator failure occurs, the trainee will be evaluated in terms of his prompt detection of the emergency condition and his performance of such aircraft control and subsystems management tasks as are specified for the emergency that has been simulated.

At this point in the description of the use of simulators for emergency procedure training, it is appropriate to deal with realism/fidelity issue once again as it relates to generating in a trainee the ability to perform an emergency procedure in the context of a substantial mission segment under the relatively stressful conditions of high task load. In emergency procedure training, the actual realism/fidelity of a flight simulator is unchanged. The situation in which the emergency is presented, however, may be made more realistic and the resulting situational realism may be the key to effective simulator emergency procedure training. In this case, situational realism does not depend on the engineering accuracy or other design characteristics of the simulator but instead on the reasonableness and believability, that is, the cognitive realism of the emergency condition given the context in which it is presented to the trainee.

SITUATIONAL EMERGENCY TRAINING

Having thus identified the cognitive aspects of emergency procedure training, it should be emphasized that the simulator's function in generating cognitive realism is substantial but not critical. That this is in fact the case has been demonstrated in a new approach to emergency procedures training called Situational Emergency Training (SET) (72). This approach is based on the essential situational aspects of the emergency condition and involves only a simple three-step procedure which the pilot must accomplish as soon as an emergency condition is detected:

1. Maintain control of the aircraft.

2. Analyze the situation and take the most appropriate corrective action.

3. Land the aircraft as soon as possible.

SET emphasizes detection of an emergency condition in terms of normal mission activities where the pilot either suddenly or gradually recognizes the presence of an abnormal state. At this point, he maintains control of the aircraft and analyzes the situation which may be relatively simple or may involve a multi-step information seeking and signal verification process. Once the trouble is clearly understood, the pilot must determine the appropriate course of action and execute it. This typically involves anticipation of the interaction of his corrective actions with the solution of the immediate problem and the end goal of a safe landing. Such activities represent instances of the effective exercise of judgment under stressful, often life and death conditions. It appears also to be what experienced pilots do under actual emergency conditions. It is clear that SET is focused on training good judgment.

Considering the properties of a SET program, it can be seen that the emergency procedure training can be conducted in many instructional environments, including a flight simulator. There are indications that the SET program has been effective in the case for which it was developed (72). Since emergency procedure training has been successfully conducted in simulators using the older, procedures-oriented approach, there is no reason to expect that the SET approach will not work as well by using flight simulators to more fully prepare the trainee to acquire the judgment ability needed to deal efficiently and safely with the emergency procedures which he may at any time be required to accomplish as part of daily flight operations.

VIII. FLIGHT SIMULATOR AIRCREW PERFORMANCE MEASUREMENT

REQUIREMENTS FOR SIMULATOR PERFORMANCE MEASUREMENT

Effective utilization of aircrew training devices is dependent upon the development of adequate measures of pilot performance. A training device is effective to the extent that it enhances the pilot's ability to fly the aircraft. The evaluation of transfer of training requires the measurement of his proficiency, in both simulator and airplane. This chapter will discuss the development of automated performance measurement (APM) systems for application to flight simulation. Following discussion of the requirements for APM systems, specific application to two devices--a research simulator in which the APM focuses on the pilot and an operational full mission simulator where crew positions in addition to the pilot (and co-pilot) are included in the APM system--will be presented.

Performance measurement may be defined as a set of rules which categorize and/or quantify behavior in terms of some pre-defined characteristic or attribute. It follows then that a clear understanding and precise definition of what is to be measured is essential. Thus a set of rules which assign a specific category or number to a specified instance of behavior must be developed and careful consideration must be given to the definition of the rules so that the measurement process becomes as precise as possible. These characteristics represent the what and how of measurement. However, the measurement process always occurs within the context of a specific environment and the results are used by specific individuals. These practical considerations represent the why and for whom of measurement and are of great importance since they will, to a large extent, influence and shape the what and how of measurement. The design, development, and implementation of APM systems for flight simulators requires that the following factors be considered: (1) the definition of measurement requirements; (2) the selection of tasks for which measures are to be developed; (3) the definition of performance measures; (4) the development of task segmentation logic; (5) the development of summary assessment scores; (6) the definition of performance feedback and display capabilities; (7) the definition of data storage and analysis capabilities; and (8) system configuration and implementation considerations. Each of these will be discussed below.

SIMULATOR PERFORMANCE MEASUREMENT DEVELOPMENT

Why measure aircrew performance? Considering the spectrum of military aviation, these reasons for aircrew performance measurement are suggested: (1) assessment of aircrew proficiency; (2) training system development; (3) training device evaluation/simulator certification; (4) prediction of future aircrew mission effectiveness; and (5) research and development. Of these, the assessment of aircrew proficiency is probably the most important, especially for application to operational training devices. Measurements of flying proficiency reflect the degree to which training objectives are met and generally specifies any performance errors committed. The necessity of insuring that all aircrews meet minimum proficiency standards cannot be overemphasized. The ability to assess proficiency also is necessary for the proper design of training programs.

Since most flying training programs are a mixture of ground-based and airborne instruction, the assessment of proficiency in both domains is necessary for the development of a training system. Thus measurement of aircrew proficiency is necessary to evaluate the effectiveness of training devices and the program within which they are used. The purpose of ground-based training is to enhance performance in the aircraft. The application of the transfer of training methodology as a means of evaluating the effectiveness of ground-based training is dependent upon aircrew proficiency assessment. It follows then that certification of flight simulators in terms of their training effectiveness is also dependent upon an adequate measurement capability.

A closely related consideration is the user of measurement information. Who has need for measures of aircrew performance? An inspection of flying training programs suggests that a variety of people use such information, but that the depth or content may vary significantly. The basic unit of flying training remains the student and his instructor. The greatest need for accurate, detailed information is at this level. The instructor needs diagnostic information which he can use to evaluate his student's performance, isolate his errors, and provide effective remediation. In addition, the student requires the same diagnostic information. Furthermore, he needs such feedback in a timely manner if it is to be maximally effective.

The job of the syllabus designer is to structure an optimum training syllabus. Within limitations, he must specify which training tasks are to be performed, the sequence of these tasks, and the number of repetitions for each. Although performance measurement information is necessary, the level of detail is not as great as that required by the student or instructor. In most instances, the syllabus designer is interested in the proficiency levels demonstrated for each task using the existing syllabus. Such data is useful for recommending syllabus revisions. The training manager also uses performance measurement information as a tool for making administrative decisions which could impact the training program. In most instances, he does not need the level of detail required by the instructor or syllabus designer.

In addition to requirements resulting from the intended use and user of an APM system, there are basic measurement requirements which must be met. The first of these is reliability. Considering the measurement of pilot performance, two sources of variability must be distinguished--variability due to the measurement process and variability due to the pilot. Of concern here is variability due to the measurement process. To the extent that application of the measurement process to the same behavior produces the same number or category, the process is said to be reliable.

The second basic requirement is validity. Although several types have been enumerated, the one most appropriate for performance measurement is content validity. It demands that the most salient behavioral components be incorporated into the measure. To the extent that the measurement addresses all of the criterion-referenced objective descriptions of the behavior students must acquire during training, the content validity will be high. A second type of validity is predictive validity. A measurement is valid to the extent that it is useful in predicting some outcome--for example, proficiency at the end of training, combat effectiveness, etc. For tasks in which the criterion-referenced objectives are vague or unknown, this type of validity assumes greater importance.

A third basic requirement is sensitivity. The resulting measurement must be sufficiently sensitive for its intended use. Although a pass-fail measure may be of sufficient sensitivity for the needs of the flying training manager, it would be of little value for the instructor or syllabus designer. In this case, there is a need to match the sensitivity of the measurements with the needs of the user.

The selection of tasks for which measures will be developed is largely a function of the intended use and user of the APM system. At the most elemental level, pilot behavior can be described as an integrated sequence of continuous display scanning and control movement responses. At the other extreme, pilot behavior might be described in terms of mission effectiveness within a combat environment. At intermediate levels, the individua' task such as a barrel roll attack, or a class of tasks such as air-to-surface weapons delivery might be selected. It should be apparent that there exists a hierarchy of measurement. As one moves up this hierarchy, measurements tend to become less specific and more abstract since they are based upon more information.

The definition of performance measures also is largely a function of the intended use and user of the APM system. Although a number of approaches to proficiency assessment have been proposed, a criterion-referenced methodology appears to be the most appropriate within the flying training environment. The criterion-referenced approach to measurement system development seeks to define the behavioral objectives for each task and subsequently to measure the degree to which these objectives are met. Despite the success of this approach, for many aircrew tasks, the criterion-referenced objectives can only be vaguely defined, so that the resulting measurements are not sufficiently sensitive. In these instances, research is required for the development of appropriate measurements.

The general approach taken for the development of objective performance measures has been to analyze each task into its component parts and define objectives for each component. A benefit of this approach with respect to measurement development is that it is usually easier to define behavioral objectives at such a level. Although a mission profile or an individual maneuver is a continuous event, it is easier to conceptualize them as a sequence of individually defined tasks or sub-tasks. In the development of rules for specifying the start and end conditions for each task, it is critical that logic rules unequivocally define when a task has been initiated and when it has been completed. The development of such rules which can be translated into computer logic presents certain problems. Some of these will be addressed in a subsequent description of APM system development efforts.

The analytical breakdown of tasks into their component parts requires that the individual measures of performance be summarized. Inherent in the definition of an overall assessment score is a value judgment concerning the goodness or badness of a particular performance. In other words, for each measure there is some performance standard which defines an "acceptable" level of performance. Since there is usually some deviation about the desired values, the question becomes how much deviation is "acceptable." Unfortunately, there are no completely acceptable, universal techniques for establishing standards of "acceptability."

The combination of the individual measures into a meaningful, single score also presents problems. For example, a single score will not provide information as to which parameter is producing the greatest deviation from an ideal flight path. Although each observed flight path will uniquely define a performance score, each performance score does not uniquely define a particular flight path. A given score could be obtained from an infinite number of flight paths. Thus, the obtained measurement provides little diagnostic information, and since there are no research data which can guide the APM system developer in properly weighing each measure to arrive at a summary score, the problems of developing a single score remains unsolved.

The utility of information generated by an APM system depends upon how well it is displayed to the user. The "acceptance" of the interface between the system and the user will greatly impact its perceived utility. Performance feedback requirements are greatest whenever the APM system is to become an integral part of the simulator training curriculum.

Consideration should be given to potential data storage and analysis requirements. The amount and types of information to be saved are largely dependent upon its intended use. Trade-offs are required since it is not feasible to store all information obtained during a given mission. Consideration also should be given to specific identifiers which would be of importance for subsequent analyses. Retrieval software should be sufficiently flexible to enable the user to analyze only the data he desires. For most operational applications, simple descriptive analyses should be sufficient.

Aircrew performance in the simulator can be scored in two modes, off-line and real-time. In the off-line mode, the parameters to be scored are recorded onto a storage medium such as magnetic tape or disc. This raw data then may be processed using an off-line computer program. Although this approach is of value for initial development and evaluation of scoring algorithms, it is of little value for training due to feedback delays. Real-time measurement, on the other hand, offers immediate feedback to the aircrew and eliminates the need for off-line processing. The requirements for its implementation, however, are much greater. First, it is necessary that the software for the scoring algorithms to reside on-line with the basic simulation program. To do this, sufficient memory core must be available for the added software as well as sufficient spare time so that the software can be raised without interfering with the basic simulation program. In addition, it is necessary that the sufficient peripherals exist so the results can be displayed and stored.

MEASUREMENT SYSTEM DEVELOPMENT FOR A RESEARCH SIMULATOR

The ASPT was developed to be a research tool capable of providing answers to questions concerning the design and effective utilization of advanced flight simulators. Despite the sophistication of the ASPT and its research potential, one key ingredient was lacking--an objective pilot performance measurement system. The development and implementation of an APM system was one of the initial efforts undertaken following delivery of the ASPT since this capability would become the foundation of future research to be accomplished in the device. This effort is described in Fuller, Waag, and Martin (73).

As noted above, the ASPT was desighed specifically to study how training is impacted by various simulator configurations and techniques and how such training transfers to the aircraft. Consequently, its measurement system should emphasize the most salient characteristics of the training process. Two key elements in the development of instructional systems are the definition of criterion-referenced objectives and the specification of performance standards. Thus, the measurement system must provide information on the degree to which the behavioral objectives and performance standards are met.

Consideration was given to the fact that there would be two users of measurement information in the ASPT--the researcher and the instructor pilot. For the researcher, it is necessary that measures are of sufficient sensitivity for evaluating relatively small effects. For the instructor, it is necessary that measures are meaningful and can be readily interpreted to trainees, and should be designed to provide diagnostic information.

Another requirement was simplicity. Most flight simulation devices output a relatively large number of aircraft state and control input parameters at a variety of sampling rates. Although there is a temptation to use all the data available, criterion performance should be defined only on those parameters which are critical to the successful execution of a maneuver. A parameter should be selected only if it is an essential component of a maneuver or if it has diagnostic or feedback value.

One additional requirement was that the measurement system should evaluate performance on a real-time basis. Diagnostic feedback is most effective when provided immediately after execution of a maneuver. To require extensive off-line processing of the data to arrive at performance measures would be unrealistic, except for the development of measures for hardware research. The necessity of real-time measurement further emphasizes the need for simplicity in developing measures of proficiency.

The focus of the ASPT APM system development effort was the individual flight maneuver. Within UPT, the individual maneuver represents the most fundamental unit of instruction. The intent was to select representative maneuvers from all phases of T-37 training thereby providing a measurement capability on a continuum from the simplest to the most complex tasks. The measurement development effort began with simpler tasks and progressed through more complex maneuvers. To date, the following scenarios have been implemented on the ASPT: (1) Transition Tasks - Straight and Level Flight, Airspeed Changes, Turns, Climbs/Descents; (2) Takeoff/Approach/Landing Tasks - Takeoffs, Tech Order Climbs, Slow Flight, Configuration Changes, Straight-in Approaches, Overhead Patterns, Touch-and-Go's; (3) Instrument Tasks - Rate Climbs/ Descents, Vertical S-A, Vertical S-D, GCA, Proceed Direct to VOR: (4) Aerobatics - Aileron Rolls, Barrel Roll, Loop, Split S, Cloverleaf, Cuban 8, Lazy 8; and (5) Formation - Fingertip.

To guide the definition of candidate performance measures, it was assumed that superior flying performance in the aircraft or the simulator has several characteristics which are reflected by available flight parameters. These include: (1) maintaining certain aircraft state parameters close to some defined criterion value; (2) avoiding excessive rates and acceleration forces so that the maneuver is executed smoothly; (3) accomplishing these objectives with the least amount of effort; that is, by minimizing control inputs; and (4) not exceeding procedural or safety limits established for the maneuver. For each of these characteristics, a candidate set of measures was defined.

Most maneuvers may be broken down into segments for measurement purposes. During each segment, certain aircraft state parameters should be held close to some ideal, or criterion value. The amount of deviation from these ideal values provides an index of performance. For example, a simple turn to a heading may be broken into three steady state segments. In the first segment heading, altitude and airspeed are the steady state parameters and deviations are measured from the criterion values. During the turn, altitude, airspeed and, bank are the steady state parameters. After rolling out of the turn, altitude, airspeed, and heading are the steady state parameters again, but now a new criterion value is established for heading.

The most common state parameters measured are altitude, airspeed, heading, and bank. However, complex maneuvers occasionally contain other parameters which should be held constant during part or all of the maneuver. These maneuvers usually require that a new state parameter be computed and the deviation be measured from the computed value. For example, during a traffic pattern, the pilot should be able to determine and maintain an angle of bank in the final turn which will enable proper runway alignment when he rolls out. The required bank in this case must be continuously computed using the current aircraft position and heading. The bank deviation is then computed by comparing the actual bank to the computed ideal value.

Although deviations from desired values provide an index of the amount of error at any one instant, it is necessary to summarize the information. For each parameter, both the arithmetic mean deviation and the root-mean-square (RMS) deviation are computed. In addition, a tolerance band is set for each steady state parameter. The percent of time during the maneuver that the deviation is above the tolerance, within tolerance, or below tolerance is computed. These time on tolerance measures were designed primarily for student feedback. Two other measures are also computed which have often been used in previous pilot performance data collection, the maximum and minimum values for each state parameter. Aside from these measures continuously computed over some portion of the maneuver, single values are also recorded at key points for certain maneuvers. For example, speed at rotation and speed at gear retraction are recorded for the takeoff. Since these values are dependent upon the specific maneuver, no common set of measures could be defined.

While the state parameter deviations are the primary measure of performance, certain other measures are computed which reflect how smoothly the maneuver is executed. They describe the rates and accelerations of the simulated aircraft about the vertical, longitudinal and lateral axes. Pitch, roll and heave were chosen since preliminary data indicated these axes to be the only ones delivering perceptible force cuing information. RMS rates and accelerations are computed for these axes to furnish smoothness measures.

The effort expended by the pilot may be determined by characteristics of the forces exerted on the controls and the distances the controls are moved. Five primary flight controls were investigated: (1) elevator (Y-axis); (2) aileron (X-axis); (3) rudder; (4) throttle; and (5) trim. Since the stick was considered the primary flight control, most measures were defined to characterize its movement. For elevator and aileron control, four measures were defined: (1) RMS position (deviation from zero point); (2) RMS movement; (3) RMS power (force times movement); and (4) number of reversals. For the elevator, both mean force and RMS force were also considered of interest. For rudder control, only two measures were defined: (1) RMS power; and (2) RMS movement. For throttle control, only one measure, RMS movement was defined. For trim control, one measure was defined, the percentage of time elevator force remained within some tolerance band.

Certain maneuvers require that the pilot perform some procedures in a specified time interval during the maneuver or that he maintain the aircraft within certain safety limits. The traffic pattern is a good example of this type of maneuver. The pilot must lower the speedbrake, landing gear and flaps at specified times during the approach. These types of procedures may be monitored in the APM system and logicals set true or false, denoting whether or not the procedure was accomplished in the appropriate time interval. In addition, certain safety limits have been established for the complex maneuvers. In the traffic pattern, an error logical is set if the final approach is too low or too slow or if touchdown occurs at some place other than the prescribed area on the runway. Since such errors are completely dependent upon the specific maneuver, no common set of measures could be defined.

Although maneuver execution is a continuous process, it may be conceptualized as integrated sequences of steady states and transitions. The fundamental flight attitudes plus transitions from one attitude to another form the conceptual segments for most maneuvers (74). In the 30° turn to heading, prior to the roll-in and after the roll-out, the desired angle of bank is zero. During the turn, however, the desired value is 30°. For the purpose of measuring deviation from desired bank angle, it is easier to divide the turn into three segments and measure the difference against a constant value for each segment than to generate a continuous function for the entire maneuver. Such maneuver segmentation has been utilized in most previous efforts (75, 76, 77).

While the segmentation approach appears straightforward, two problems can occur--the definition of the start/stop logic rules and the measurement of transitions. In the turn-to-heading example, when is it appropriate to start measuring deviations from the desired 30° angle of bank? The approach used in the present effort was to initiate a timer once a certain condition had been met and begin measurement once a certain amount of time had elapsed. In the turn-to-heading scenario, the timer was initiated whenever bank angle was greater than 15°. After three seconds, deviations from the desired 30° bank angle are scored. The delay time was based on the performance of experienced pilots. In this manner, scoring is initiated whenever the pilot should have achieved the desired bank angle.

For other maneuvers, start/stop logic rules were based on published Air Training Command (ATC) criteria. For example, start/stop logic for the climb used the rule that altitude lead point for level-off from a climb should be 10% of vertical velocity. In the steep turn, deviation from desired bank angle was computed until the command, "roll-out" was given. In each case, the key ingredient was that the logic rules would unequivocally determine that a particular segment had been entered or departed. The same logic approach was used to determine when to measure specific values such as rotation speed or vertical velocity at touchdown.

The second difficulty, the measurement of transitions, presents even greater problems for developing adequate measurements. First, some transition segments are relatively brief in duration. Thus, very little data can be obtained. Second, there are no readily defined criterion referenced objectives for these transition segments. And third, it is unclear how much performance during these transitions contributes to overall proficiency for the maneuver. Consequently, it was decided not to provide specific measurement for the individual transitions with the exception of those parameters which should be held constant (e.g., airspeed and altitude during a roll-in).

To develop summary assessment scores, a sample of ten experienced IP's flew five repetitions of a maneuver. Descriptive statistics on RMS error for each parameter were computed and confidence intervals established such that experienced pilots could be expected to stay within these limits 80% of the time. These limits were then used as tolerance bands for computing percentages of time above, within, or below limits and an overall time-on-target (TOT) score is computed as the maneuver progresses. This score is the percent of time all appropriate state parameters are simultaneously within tolerance. If one or more state parameter moves out of tolerance, the TOT score will not increase. The score will begin to increase again only after all parameters are back in tolerance. Maneuver segments were weighed according to their perceived importance by experienced IP's and the weights used in determining the summary scores.

Each maneuver has a unique CRT display format. The display may be generated on an in-cockpit CRT for student feedback and may be copied for use later in a debriefing. The display is designed to include alphanumeric titles and selected parameters available in the computer math models or in preprogramming. The percent high, on, and low scores, as well as the total score is displayed for each maneuver. In addition, error messages or other information may be displayed, depending on the particular maneuver.

A Student Data System (SDS) was developed for the storage of data collected during each exercise segment. Certain identification information also is stored as part of the segment data record. Some of the identifier information is manually input to the SDS and the remainder is automatically input from parameters available in the computer programs. The identifier information, primary performance measures, secondary performance measures, TOT scores, and error messages are transmitted for storage to a disc file immediately after a maneuver is completed. The data record is also displayed on a CRT at the console and output on a line printer for examination.

To minimize the requirements for performance data storage, it was necessary to develop a generalized retrieval system which could sort and perform some statistical analysis of data stored in the SDS. The present system is an off-line, batch-type program which accepts data cards as inputs to define the data to be returned and analyzed. The retrieval and analysis program allows the researcher to make a thorough inspection or preliminary analysis of the data while a project is underway or after it is completed. Other analysis routines can be added to the program to fit the requirements of a particular research design.

The ASPT preprogramming system provided the basic framework for the APM system wherein FORTRAN programs may be included in the ASPT software. These programs can access all parameters used in the flight simulation and perform computation in real time, as the simulator is being flown. The basic units of the preprogramming system are the exercise segments, complete programs designed to measure individual maneuvers. Each segment is composed of up to 16 separate cases.

The first case in each exercise segment, the initialization case, sets the simulator to the initial conditions selected for the maneuver. Intermediate cases contain the scoring logic, which determines the parameters to be measured during the maneuver. When certain conditional statements in the program are satisfied, selected messages, composed of any of 189 words, are transmitted through the communication system. These messages notify the pilot when to start the maneuver, provide him information during certain maneuvers, and notify him with a tone when maneuver scoring is complete.

The final case in each exercise segment is the endpoint case. When certain conditions are met which signify that the maneuver is complete, the simulator automatically freezes. Up to 12 exercise segments may be grouped into a single exercise. This allows efficient sequencing from one maneuver to the next. When a maneuver terminates and automatically freezes, the operator may manually unfreeze the simulator. This will automatically sequence it to the next exercise segment and the simulator will initialize for the next maneuver.

MEASUREMENT SYSTEM DEVELOPMENT FOR THE C-5A OPERATIONAL FLIGHT SIMULATOR (OFS)

Traditionally, aircrew performance evaluation in the USAF has consisted of standardization and evaluation (STAN/EVAL) checkrides administered by highly qualified flight examiners. Such subjective techniques have been used extensively in all phases of flight training. While they are generally adequate for certifying initial qualification, these techniques possess inherent weaknesses which limit their usefulness in certain applications. Because of such limitations, operational command training managers realized their need for improved performance measurement capabilities. In 1976, the Air Force Human Resources Laboratory and Military Airlift Command (MAC) initiated a cooperative effort to: (1) identify the mission task requirements for MAC aircrew members through an analysis of training syllabuses, STAN/EVAL performance criteria, and flying training records; (2) describe current and planned flight simulator and aircraft capabilities in terms of their use in generating mission performance measurement for MAC aircrew members; and (3) develop and evaluate an objective/quantitative measurement system for MAC aircrews based on the mission task requirements and the capabilities of the Command's flight simulation systems as well as its aircraft. The requirements study for this effort is described in Swink, Butler, Lankford, Miller, Watkins, and Waag (78). This APM system development effort is currently in progress.

In contrast to the research orientation of the ASPT APM system development, the goal of the C-5 APM system development effort is to determine the operational suitability and utility of an APM system within the training program. Because of the training orientation, it was readily apparent that the measurement system should fulfill certain requirements. Since the C-5 is a multi-crewed aircraft, it was necessary to assess proficiency for each crewmember in the performance of his assigned tasks as well as his performance in the coordination among crewmembers, the pilot, copilot, and flight engineer stations. The loadmaster was not included since coordinated training in the flight simulator is not provided for that crew position.

The original concept was that the C-5 APM system would be used to evaluate and document aircrew proficiency at the end of the training program. In this case, it was desirable that the APM system function in an automated, hands-off mode thereby ensuring standardization, reducing the instructor's workload and eliminating the possibility of manual record keeping errors. Since measurement is an integral part of training as well as evaluation, potential applications to simulator training sorties were considered. This led to the requirement for some degree of instructor intervention and control of the mission. Thus the instructor was provided the capability to alter environmental conditions, insert malfunctions, select different profiles for scoring and select alternative feedback displays. Another requirement was that the C-5 APM system provide real-time aircrew performance feedback to the instructor. A further feedback requirement was that the performance evaluation information be summarized and a hardcopy report be printed for debriefing purposes and further analyses after the training session.

Whereas the focus of the ASPT APM system was the individual flight maneuver, the C-5 APM system concentrated on the development of full mission profiles. Consequently, a C-5 simulator evaluation mission profile was constructed which represented a typical MAC airlift mission. Through interview and discussion with MAC training personnel, review of C-5 training documents, and study of the C-5 Flight Manual, the representative mission segments were determined. The resulting mission profile was designed to contain the activities required of the various crewmembers while performing their normal inflight duties. The mission also included contingencies and emergency situations which require crew coordination among various aircrew members and which are typical of operational mission malfunction/emergencies. Although development of a nominal mission profile provided an excellent vehicle for defining a candidate set of performance measures, its usefulness in training would be severely limited. For this reason, the C-5 APM system was designed to provide the capability to generate new mission profiles in an off-line mode. In this manner, mission scenarios could be developed for a variety of training situations.

Three categories of tasks were defined for implementation in the C-5 APM system: (1) checklists and procedures; (2) navigational profiles; and (3) parameter control. For each of these categories, a candidate set of measures were defined. Since operation of the C-5A is highly proceduralized, the measurement of the accuracy of checklist procedures performance represents a major task of the measurement system. The C-5 APM system differentiates among five types of checklists and procedures: (1) normal checklists; (2) emergency checklists; (3) normal procedures; (4) minor emergency procedures; and (5) major emergency procedues. Each checklist or procedure is comprised of a series of individual steps. Each step or block of steps may be designated as sequential or non-sequential. Non-sequential steps may be performed in any order while sequential steps require a definite order of occurrence. Three types of procedural errors are possible: (1) an omission error in which the step is either not accomplished or not completed within time allowances; (2) a constraint error in which a step is accomplished under inappropriate conditions; and (3) a sequence error in which the step is not performed in the correct order.

The C-5 APM system provides for real-time assessment of navigation profiles including: (1) takeoffs and instrument departures; (2) enroute; (3) holding patterns; (4) initial approach and non-precision final; and (5) ILS final approach and landing. Measured parameters consist of those relating to the maintenance of ground track and adherence to altitude restrictions. Computed measures include RMS deviation as well as time-within-tolerance percentages. The C-5 APM System also provides the capability to measure the degree to which certain parameters are held constant or maintained within certain limits. Each parameter may have multiple envelopes; for example, desired airspeed will vary according to the phase of flight. Computed measures include mean deviation and RMS deviation. Upper and lower limits can be established so that time-on-tolerance measures can be computed.

The start-stop logic rules for measuring aircrew procedures in the C-5 APM system are similar to those used in the ASPT. Each start/stop criterion consists of from one to five mathematical logical expressions, combined by a series of logical AND, ORs and NOTs. These conditions also may be grouped using parentheses. The problems associated with precisely defining these criteria are similar to those encountered in the ASPT development. This is especially true with respect to the initiation of automated procedures or checklist monitoring. The knowledgeable procedure writer will insure that procedure monitoring can begin as soon as possible. These scenarios must be considered limitations in the totally automated performance monitoring of the APM system. However, in the manual mode, the instructor always has the option of starting the monitoring of a procedure in advance of the malfunction activation. Thus, the C-5 APM system will be capable of providing maximum feedback concerning a procedure, regardless of such factors as the generality of the malfunction start conditions.

A consequence of developing full-mission profiles is that the number of individual tasks is large and the number of performance measures even larger. Consequently, it is necessary to summarize the data. To do so, different levels of assessment have been defined. At the most elemental level, performance measures for a single task can be summarized as a single score. At the next level, individual scores for all tasks belonging to the same group will be combined to form a single score. At the next level, each crew member receives a summary score for each group of tasks. At the highest level, these scores are combined to form an aircrew composite score for the entire mission.

To arrive at summary scores, a point system is used. Each measure within a given task is assigned a possible number of points. This reflects the relative importance of each measure within the task. Furthermore, rules are established for defining the number of earned points for a given performance. A critical weighting is associated with each measure which reflects the seriousness of the error in the event a certain level is not achieved. The earned points are summed and then reduced according to the criticality factors. The reduced earned points are divided by the possible points to produce a percentage. Initially, the point values and criticality weights to be implemented in the C-5 APM system will be the result of subjective instructor judgments. This approach will be used for the development of summary scores at each level of assessment.

Performance feedback during a mission will be provided by two CRT displays located in the cockpit. One will be used by the instructor pilot and the other by the instructor flight engineer. A line printer will generate a hard-copy debriefing report. Seven categories of displays and feedback will be included: (1) Mission sequence: summary displays of the sequences of tasks; (2) Mission plot: graphic presentation of aircraft progress with reference to ground track; (3) Route chart: graphic background displays corresponding to departure, enroute and approach plates; (4) Checklist/procedure: displays of pre-defined sequences of actions to be performed by crewmembers; (5) Error alert: message alerting instructor to crew errors as they occur in the pre-defined tasks; (6) Proficiency assessment: detailed alphanumeric displays relative to any specific pre-defined performance segment or task; and (7) Debriefing report: hard-copy, objective performance data with which the instructor may assess and evaluate performance.

During the course of a mission the C-5 APM system software will generate a file containing all data necessary for computing the overall assessment scores and production of the final debriefing report. All proficiency assessment scores will be stored on a disk cartridge for later retrieval. Editing capabilities will be provided so that only the desired data are retrieved. A statistical package also will be included so that the retrieved data may be analyzed. This analysis package was included in the prototype system to aid in follow-on test and evaluation of the C-5 APM system.

In the initial requirements study, the C-5 Operational Flight Simulator (OFS) was investigated to determine whether its present configuration would support implementation of an APM system. Because of limitations in the C-5 OFS computational system, it was decided that such an approach would not be feasible. It was concluded that the most cost-effective approach would be to augment the existing C-5 OFS by means of an autonomous strap-on system which would ride "piggy-back" on the basic simulation system. The approach would insure that the functional and physical characteristics of the C-5 OFS remain intact. Such a system employs a mini-computer and requires the development of a trainer interface which allows the system to capture all necessary data and to provide the necessary control over the host simulator.

The configuration of the C-5 APM system consists of three major functional groups. The first group consists of the operator interface hardware, a combined keyboard/CRT display in the Radio Aids Station, referred to as the System Control Terminal. The terminal, plus a line printer unit, will provide for APM operations control and documentation. Additionally, on the flight deck, displays and keyboards will be provided for the instructor pilot and for the instructor flight engineer to enhance the real-time feedback to the instructors. Using their keyboards, instructors may select various displays of information on their monitors, as well as control various aspects of the mission scenario. The second group consists of the trainer interface hardware with which two hardware interface units will acquire data from the C-5 OFS and control environmental and malfunction factors as related to the content of each mission scenario. The third functional group consists of the system control hardware, the major component of which is a fast, general purpose mini-computer. Software will control and implement all APM monitoring through an interface to disk and diskette mass storage units associated with the mini-computer.

APM SYSTEM VALIDATION

The most critical characteristic of any measure is its validity. For most complex tasks, there is no single necessary and sufficient test that can be applied to candidate measures to assess their validity. Therefore, several validation tests must be applied during the course of a measurement development effort. The type of validity most appropriate for the development of measures of pilot performance is content validity. It demands that the most salient behavioral components be incorporated into the measure. To the extent that the pilot performance measure addresses all relevant criterion-referenced objectives, the content validity will be high. It is clear that there is a relationship between the adequacy of the task definition and the validity of the resulting measurements. By taking the criterion-referenced approach in the development of performance measures in the ASPT and the C-5 simulator, a satisfactory degree of content validity was established.

Aside from content validity, measures should possess empirical validity. For objective measures of pilot performance, there are at least four criteria by which empirical validity may be established. First, the measures should successfully discriminate among pilots of different experience levels, for example, novice pilots vs instructor pilots. Second, these measures should be positively correlated with concurrent measures of performance such as IP evluations. Third, they should be sensitive to the effects of training. And fourth, objective measures of performance should be sensitive to performance decrements resulting from adverse environmental or pilot stress factors.

Unfortunately, no large scale validation study of the ASPT measurement system has been accomplished. Nonetheless, data collected within the context of specific research studies have provided some evidence of the empirical validity of the system. Waag, Eddowes, Fuller, and Fuller (79) found that the objective measures for six of the basic transition tasks flown under instrument conditions successfully discriminated between novice and experienced pilots. Furthermore, significant correlations between the objective measures and IP ratings were obtained.

In a study addressing the contributions of simulated platform motion to training effectiveness, Martin and Waag (43) used a unit weighting procedure to develop a single score for basic transition and takeoff/landing tasks. Using these scores, significant learning effects were demonstrated during simulator training for straight-and-level, airspeed changes, climbs/descents, slow flight, takeoffs, straight-in approaches/landings, and overhead patterns.

Nataupsky et al. (45) analyzed certain of the individual measures within a maneuver, and obtained significant learning effects for takeoffs, steep turns, slow flight, and straight-in approaches. In this study, moderate correlations between overall IP ratings and the total score currently computed in the APM system were obtained.

Irish et al. (28) and Irish and Buckland (29) studied the effects of various simulator configurations on the performance of experienced pilots. Two of the conditions involved various levels of turbulence and ceiling/visibility. Degraded performance as a result of these two adverse environmental conditions were reflected by the objective scores from the APM system and furnish additional evidence of its empirical validity.

Despite the fact that a large scale validation study has not been accomplished, the studies reviewed above provide evidence of the empirical validity of the ASPT APM system. Until an overall effort is completed, however, the ASPT and C-5 APM system should be considered as candidate sets of measures. Clearly, there is a need for further validation efforts of the ASPT and C-5 APM systems.

IX. FUTURE SIMULATOR TRAINING DEVELOPMENTS

PROJECTIONS

To complete this description of the use of simulators for training in-flight and emergency procedures, it may be useful to project current programs into the future and generate a preview of future simulator flying training developments. Taking into account the increasing seriousness of the diminishing availability of energy resources, it is reasonable to forecast an increase in the rate of exploitation of the capabilities of modern high performance flight simulators in future flying training programs. If flying continues to be a viable means of transportation and an integral part of world military forces in the future, it is inevitable that the use of flight simulators will increase. In addition, it is likely that the routine use of simulators with visual systems capable of supporting training in contact maneuvers will increase dramatically. Further, as more modern simulation systems enter service, training managers will discover new ways to use them, such as in military tactical and continuation training applications.

Today's high performance simulators, including those equipped with visual displays, often have been employed mainly for the initial training of beginning student pilots. Many airline training programs, however, have successfully demonstrated application of flight simulators in upgrade and in periodic certification training programs in which the trainees are experienced aircrew personnel. Extrapolating from these proven applications and considering the costs of continuation training, it may be decided that simulators should take over a share of the requirements for maintaining aircrew combat readiness. Should this occur, it can be seen that tomorrow's simulators may be designed with capabilities for supporting such continuation training requirements as multi-ship tactical strike missions or air combat maneuvering training in a variety of types of practice engagements. In other words, future flight simulators will not only involve the basic training of inexperienced pilots, but will take over portions of the bombing and air combat maneuvering training of fully-qualified, combat-ready aircrews. One further development can be forecast given development of such flight tactics simulators. These new devices may be located at different sites with their functions interconnected and integrated to provide extensive real-time combat training exercises. Such a development would represent an electronic version of the USAF's current Red Flag tactics training program (80, 81).

In this kind of future flying training development, the form of the engagement simulation system probably will be vastly different from that of current self-contained flight simulators. Studies reviewed elsewhere in this report suggest that realism and fidelity requirements have been routinely exceeded in state of the art simulators. Future research may be expected to describe more precisely how, how closely and in what way, the flight simulator must match the aircraft it simulates to be an effective, efficient and economical training aid. Meanwhile, a prediction appears warranted that future trainee stations in the kinds of tactics simulation systems discussed above will be less representative and much more austere than current simulator cockpits and that the complexity and elegance of the simulation model of the combat environment will be substantially reduced from simulator math models of today.

As increasing numbers of flight simulators with greater performance capabilities become available, they will undoubtedly be applied more frequently to accommodate a greater number of training requirements. In addition to their application in continuation training programs for experienced and qualified aircrew personnel, tomorrow's simulators also may be expected to serve as training tools to support practice and preparation for flight examinations, in mission rehearsal and in periodic refresher training to document aircrew qualifications.

The effectiveness of flight simulators in a broader array of training applications will in time demonstrate convincingly their substantial effectiveness and value in flying training. Similarly, training managers will learn that a much wider variety of simulators will satisfy their training requirements. This may lead to a requirement for more different kinds of simulators, each perhaps with more specific training functions and probably with more finely tailored and limited capabilities. A correlated decrease in simulator cost at no penalty in training effectiveness also may be feasible.

Given the viability of the above prediction, a need will become clear for an overall plan for organizing and integrating a structured program in which many different flight simulation devices participate to optimize the effectiveness of the training provided. Solving the problem of integrating the various elements of a comprehensive flying training program will be facilitated through the use of the performance measurement capabilities being designed into more and more flight simulators under development today. The performance measurement capabilities of tomorrow's flight simulators will furnish training managers with quantitative indices of their training effectiveness which may be used to guide in fine-tuning the integration of the devices in the training program. The same performance measures also may be used to assess individual progress and in this application serve as a basis for optimizing the trainee's readiness at each stage of his training to take maximum advantage of his next learning experience.

This discussion of future simulator developments describes flying training programs substantially different than many of those of today. The application of flight simulators in flying training will increase, driven by the scarcity and cost of fuel. Simulators will be integrated into initial and continuing training programs for use with inexperienced as well as fully-qualified aircrew personnel to achieve an increasingly wide variety of training objectives. Utilization rates of between 40 and 80 hours a week, 50 weeks a year, can be expected to realize the simulator's training cost-effectiveness potential. The capabilities of high performance digital computers will be exploited and refined to support the increased simulator training involvement in many contact and tactical training areas and to reveal and document requirements for training environment fidelity and realism. Finally, simulator aircrew performance measurement capabilities will be developed and applied to improve the effectiveness of instruction given individual trainees.

CONCLUSIONS

In view of the extent and the limitations of information describing current flying training technology, the following conclusions are offered, based on the material presented in this report:

1. The world's energy resource situation requires that flying training be accomplished in new ways which minimize use of petroleum-based fuels.

2. Flight simulators have proven to be effective training aids in nearly every test or application in a flying training program. In many simulator applications there is no compelling relationship between training effectiveness and fidelity/realism.

3. State of the art flight simulators have the potential for supporting a wide variety of contact training requirements as well as virtually all instrument training.

4. The training effectiveness of flight simulators may be optimized by integrating them into a flying training program in a number of different ways.

5. Successful assessment of aircrew performance has been demonstrated in state of the art simulators. Such performance measures may be used to evaluate the progress of individual aircrew trainees and to evaluate the effectiveness of the training program itself.

6. The flight simulators which evolve from today's devices will be organized around and dependent on high-performance digital computer systems which control the training environment and mediate the interaction between instructor personnel and the trainees.

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14. Abstract

The reduced availability and high cost of fuel has led to increased emphasis on the use of simulators for in-flight and emergency procedures training.

The nature of pilot skills is examined and the report suggests a strategy for the use of simulators to acquire and maintain them.

The salient characteristics of the latest flight simulator and the visual display system capabilities they provide for training contact flying tasks are described. Research on transfer of learning from simulator to aircraft in a variety of training tasks is reviewed. The use of simulators as aircraft substitutes, and their integration with other ground training media are composed and contrasted to illustrate the cost-effectiveness potential of these two approaches.

The rationale for and the characteristics of a simulator-oriented emergency procedures training programme which emphasises pilot decision making skills are presented.

The development of aircrew performance measurement systems for use in evaluating, refining and documenting simulator training effectiveness is reported.

The AGARDograph ends with an interpretation of the impact of current developments on the future use of simulators; a list of conclusions is provided.

This AGARDograph was prepared at the request of the Aerospace Medical Panel of AGARD/NATO.

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