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# TRAINING EFFECTIVENESS OF VISUAL AND MOTION SIMULATION


By

Wayne L. Waag

OPERATIONS TRAINING DIVISION
Williams Air Force Base, Arizona 85224



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This interim report was submitted by the Operations Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224, under Project 1123, with HQ Air Force Human Resources Laboratory, Brooks Air Force Base, Texas 78235. Wayne L. Waag was the Principal Investigator for the Laboratory.

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MARTY R. ROCKWAY, Technical Director
Operations Training Division

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Commander

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A review of the literature concerning the training effectiveness of visual and motion simulation is presented in this report. Although there exist much pilot opinion and in-simulator performance data, their extrapolation to training effectiveness information is questioned. The present review focuses on data obtained through the application of the transfer-of-training methodology. The results are discussed in terms of study design factors, and recommendations are made wherein additional research data are needed.

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## PREFACE

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# TRAINING EFFECTIVENESS OF VISUAL AND MOTION SIMULATION

## I. INTRODUCTION

Advances in simulation technology make available a wide variety of sophisticated systems and subsystems for combination into a training device that best meets the demands of the user. 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, rapid placement of any aircraft position, and self-confrontation are examples of training-oriented features. Other options currently available to the user are designed to increase the potential for training effectiveness by increasing the fidelity (or realism) of the device. Full field-of-view visual systems of a variety of types, synergistic six-degrees-of-freedom platform motion systems, G-seats, and G-suits are typical of fidelity-oriented hardware.

Users are placed in a position of deciding how many of these features are necessary for the intended use of the device. They must define the training requirements and estimate how much the various options can contribute to achieving those objectives. They must also determine the value of the expected benefits relative to the cost of the hardware capability required to yield these benefits. Unfortunately, the users are too often in the position of having to make such decisions in the absence of sufficient information.

Behavioral research can provide information relative to several important criteria: (a) user acceptance, (b) the feasibility of training tasks which cannot be practiced in the aircraft (e.g., some emergency situations, missile evasion techniques), and (c) training effectiveness. An evaluation of the training effectiveness of a device is one of the most important types of information for the user. Unfortunately, it can be one of the most time-consuming and difficult research areas. Recently, Caro (1977) 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 at least two candidate systems followed by a comparative performance evaluation in the criterion system (aircraft performance). 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.

The intent of the present effort is to review the training effectiveness literature with respect to motion and visual simulation. 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. Although there exist much pilot opinion and in-simulator performance data, extrapolation of these data to training effectiveness information is questionable. Table 1 presents a summary of the studies reviewed in this report.



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*Table 1.* Study Summary

| | Study | Motion | Visual | Simulator | Aircraft | Tasks | Transfer | Pages In Report |
|---|---|---|---|---|---|---|---|---|
| 1. | Williams and Flexman (1949) | | X | 1-CA-2 Link | SNJ | Basic A/C Control, Stalls Traffic Patterns Skills | Positive | 4, 36 |
| 2. | Flexman, Matheny, and Brown (1950) | | X | 1-CA-2 Link | Private | Basic Contact Takeoff, Landing | Positive | 4, 36 |
| 3. | Brown, Matheny, and Flexman (1951) | | X | 1-CA-2 Link | Private | Landing | Positive | 5, 36 |
| 4. | Payne, Dougherty, Haslor, Skeen, Brown, Williams (1954) | | X | 1-CA-2 Link | SNJ | Final Approach | Positive | 6, 36, 40 |
| 5. | Flexman, Townsend, and Ornstein (1954) | | X | P1 | SNJ/T-6 | Basic Contact | Positive | 6, 36 |
| 6. | Poe and Lyon (1952) | | X | SNJ Link | SNJ | Basic Flight | None | 7, 36, 39, 40 |
| 7. | Crooman (1959) | | X | SNJ Link | SNJ | Approach and Landing | Positive | 7, 36 |
| 8. | Woodruff and Smith (1974) | X | X | T-4G | T-37 | Basic Instruments and Contact | Positive | 8, 29, 36, 37 |
| 9. | Woodruff, Smith, Fuller and Weyer (1976) | X | X | ASPT/T-37 | T-37 | Basic and Advanced Contact, Instruments Navigation, Formation | Positive | 9, 19, 30, 36, 37, 39, 40 |
| 10. | Martin and Wang (1978a) | X | X | ASPT/T-37 | T-37 | Basic Contact Landing, Stalls | Positive | 10, 34, 37, 39 |
| 11. | Martin and Catanzo (1980) | X | X | ASPT/T-37 | T-37 | Takeoff, Straight-In Approach Landing | Positive | 11, 35, 37, 39, 42 |
| 12. | Natanpsky, Wang, Weyer, McFadden, and McDowell (1979) | X | X | ASPT/T-37 | T-37 | Basic Contact Approach/Landing | Positive | 11, 31, 35, 37, 39, 42 |
| 13. | Browning, Ryan, Scott, and Smode, (1977) and Browning, Ryan, and Scott (1978) | X | X | 2F87F | P-3 | Basic Contact | Positive | 12, 36 |
| | | | | 2F87F | P-3 | Approach/Landing | | 13, 39 |
| 14. | Ryan, Scott, and Browning (1978) | X | X | 2F87F | P-3 | Instrument Approach/Landing Takeoff (w/engine aborts) aborts) Landing (w/engine out) | Positive | 13, 32, 34, 42 |
| 15. | Thorpe, Varney, McFadden, Le Master, and Short (1978) | | X | 707(Boeing Co. and American Airlines | KC-135 | Traffic Pattern Approach/Landing | Positive | 14, 37, 39, 40, 42 |

Table 1 (*Continued*)

| | Study | Motion | Visual | Simulator | Aircraft | Tasks | Transfer | Pages In Report |
|---|---|---|---|---|---|---|---|---|
| 16. | Brictson and Burger (1976) | X | X | 2F103 NCLT | A-7E | Night Field Carrier (FCLP) and Night Carrier Landings (CQ) | Positive | 16, 36, 39 |
| 17. | Brictson (1978) | X | X | 2F103 NCLT | A-7F | Night FCLP and CQ | Positive | 16 |
| 18. | Gray, Chun, Warner, and Eubanks (1980) | | X | ASPT/A-10 | A-10 | Conversion and Conventional Weapons Delivery | No Control Group (Positive) | 17, 24, 36, 39 |
| 19. | Reid and Cyrus (1974) | | X | FFT | T-38 | Formation | Positive | 18, 36, 38 |
| 20. | Reid and Cyrus (1977) | | X | FFT | T-37 | Formation | None | 18, 36 |
| 21. | Martin and Wang (1978a) | X | X | ASPT/T-37 | T-37 | Aerobatics | Positive | 19, 31, 34, 37 |
| 22. | Payne, Semple, Farmer, Spring, Sanders, Wimer, Carter, and Hu (1976) | | X | LAS/WAVS | F-4 | Basic Fighter Maneuvers | Positive | 20, 36, 39 |
| 23. | Pohlmann and Reid (1978) | X | X | SAAC | F-4 | Basic Fighter Maneuvers | None | 21, 32, 34, 39 |
| 24. | Gray and Fuller (1977) | X | X | ASPT/T-37 | F-5 | Convention Air-to-Surface Bomb Deliveries | Positive | 22, 32, 34, 37, 39 |
| 25. | McGaugh and Holman (1977) | X | X | CH-47FS | CH-47C | Basic Flight and Procedures Takeoff, Auto Rotations, Approaches | Positive | 25, 36, 39 |
| 26. | Bynum (1978) | | X | UH-IFS | UH-1 | Night Transition Tasks | None | 26 |
| 27. | Keunce (1974) | X | | GAT-2 | Piper Aztec | Instruments | Positive | 28 |
| 28. | Jacobs (1976) | X | | GAT-2 | Piper Cherokee Arrow | Instruments | Positive | 28, 34 |

## II. VISUAL SIMULATION

The technology of visual simulation is expanding rapidly. Most flight simulators are currently being procured with visual systems. Many older instrument flight simulators are currently being retrofitted with some type of visual capability. Despite its costs, 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 air. 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. 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. One of the first controlled transfer-of-training studies was reported by Williams and Flexman (1949) in which basic aircraft control, stalls, and traffic pattern skills were taught in a 1-CA-2 Link trainer simulating the SNJ aircraft. The visual scene consisted of a 270° circular screen (cyclorama) 11 feet high placed 7 feet from the trainer. The screen was a white cloth unmarked except for 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 (1950) attempted to determine whether training in the 1-CA-2 SNJ trainer 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 also provided for takeoffs and landings. The visual landing scene consisted of a blackboard, which would be rotated about its horizontal axis, placed in front of the trainer. A rough perspective view of a runway was drawn on the blackboard. At the beginning of an approach, 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. The results indicated that students receiving simulator pretraining performed significantly better in that (a) a higher percentage passed the flight check, (b) checkridge scores were higher, and (c) fewer students failed four or more flight check items. Despite these findings demonstrating the value of the simulator training, no direct assessment of the value of approach/landing training was made. To specifically evaluate the value of such training, a follow-on study was completed in which aircraft landing performance was specifically assessed (Brown, Matheny, & Flexman, 1951). The results indicated that, following 3 hours of approach/landing simulator pretraining, students in the experimental group ($n = 10$) 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 and 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 (1951), an experimental landing display projector was developed for use on the 1-CA-2 SNJ 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, & Williams (1954) evaluated the effectiveness of the device for training the final approach to a landing. Students in the experimental group (n = 6) received simulator pretraining until proficiency criteria were reached. Both the experimental group and the control group (who received no simulator pretraining) were trained to the same proficiency criteria in the SNJ aircraft. The following savings were obtained: (a) number of trials to reach proficiency: 61%, (b) number of errors to reach proficiency: 74%, (c) number of errors per trial: 50%, (d) number of errors on the first trial: 67%, and (e) number of errors on the first five trials: 55%. Analysis of the actual landing (touchdown) data also revealed significant savings even though the landing task was not taught in the simulator.

In 1953, the 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 (Flexman, Townsend, & Ornstein, 1954). 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 (a) significantly better flying performance of the simulator trained group as measured by Daily Progress Record Sheets, (b) significantly better checkride scores of the simulator trained group using independent check pilots, and (c) no differences as indicated by a research type flight check, attrition data, and 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 were also accomplished by the U.S. Naval School of Aviation Medicine evaluating the effectiveness of the SNJ Link trainer. Poe and Lyon (1952) provided instruction in the SNJ trainer during Pre-Flight School. Eighty-five cadets received 5 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 between the two groups were found. Creelman (1959) 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 flights.

The results of these studies conducted by the Air Force and the Navy and by the University of Illinois, conclusively demonstrated that visual simulation training produced significant transfer to subsequent performance in the SNJ aircraft. Significant transfer was shown for basic contact skills and the final approach to a landing. Following these initial efforts, the author is unaware of any contact transfer of training studies accomplished prior to the establishment of the Flying Training Division (now known as the Operations Trainining Division) of the Air Force Human Resources Laboratory in 1969. In 1970, the T-4G flight simulator was delivered to the Flying Training Division at Williams AFB, Arizona. The T-4G was 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-degrees-of-freedom platform motion system. An Electronic Perspective Transformation (EPT) visual system was attached which enabled normal straight-in approaches from 4 miles out, no flap and simulated single engine configurations, touchdowns, landing rolls, and takeoffs to be trained. The visual field of view was 44° x 28° 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 (1974). 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 3 hours in the T-37 aircraft or approximately 10%. These comparisons were made 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) was made operational. The ASPT is equipped with two T-37 cockpits. Each cockpit has a full field-of-view visual display (± 150° horizontal by + 110°, − 40° vertical) of computer-generated images, a six-degrees-of-freedom platform motion system, and a 16 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 36-inch cathode ray tubes. A complete description of the ASPT may be found in a report by Gum, Albery, and Basinger (1975).

Upon acceptance of the device, Woodruff, Smith, Fuller, and Weyer (1976) conducted an exploratory study to investigate the utility of the ASPT as a full mission simulator in the basic phase of Undergraduate Pilot Training (UPT). Block training was provided for basic contact, advanced contact (aerobatics), instruments, navigation, and formation. Upon completion of each block of training in the ASPT, the student proceeded to the aircraft for corresponding 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. T-37 contact checkride scores were significantly higher for the ASPT-trained group. 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 UPT (Martin & Waag, 1978a). 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 ASPT, except for the presence or absence of platform motion cueing. The G-seat was not used.

The simulator training syllabus consisted of 10 ASPT sorties covering instruction on a large number of basic contact maneuvers, including basic air work (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 due to safety considerations. It was observed, however, that a substantial number of the experimental students were able to successfully 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 considered 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 Cantaneo (1980) compared the effectiveness of ASPT training using a night scene versus a day scene. The night scene was modeled to closely approximate commercially available point light source computer-generated imagery (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 significant transfer for the ASPT-trained students but no differences between the day and night groups.

Nataupsky, Waag, Weyer, McFadden, and McDowell (1979) 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: (a) platform motion, full field of view (300° x 36°), (b) no platform motion, full FOV, (c) platform motion, limited field of view (48° x 36°), and (d) no platform motion, limited field of view. 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, all students were evaluated on their 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. One airline (American Airlines, 1976) 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 hour for the Boeing 727. However, it should be recognized that these were highly experienced pilots who already had a great deal of flight time.

In 1976, the US Navy accepted delivery of Device 2F87F, an operational night trainer for the P-3, a four engine turboprop aircraft. The 2F87F is a high fidelity device equipped with a six-degrees-of-freedom platform motion system and TV model board visual system with a 50° horizontal by 38° vertical field of view. Browning, Ryan, Scott, and Smode (1977) 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 9.6 for the experimental groups. No differences were obtained for average check flight grades. The average number of landings in the aircraft to become proficient was reduced 31%, from 52 to 36. Furthermore, the experimental students committed significantly fewer errors per landing than did the control group. There were fewer errors per landing for the experimental group on their fourth P-3 sortie than for the control group on their sixth sortie.

In a follow-on effort, Browning, Ryan, and Scott (1978) 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 SF87F. 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 have a higher probability of demonstrating proficiency in the aircraft on earlier flights than did students not trained to proficiency.

Although data from these two studies had demonstrated positive transfer of training using the 2F87F, there was some concern that such benefits did not include the final phase of landing due to poor handling characteristics of the simulator. To answer this question, Ryan, Scott, and Browning (1978) designed a study in which the experimental group (n = 19) received no flare or touchdown practice during landing training in the simulator. Subsequent airborne performance of this group was compared against a control group (n = 27) in which flares and touchdowns were practiced. Trials to criterion were significantly fewer (17 vs. 37) for the group receiving the flare and touchdown training. Such data clearly demonstrate the effectiveness of visual simulation training for the landing phase of the maneuver as well as the final approach phase.

Thorpe, Varney, McFadden, LeMaster, and Short (1978) 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 TV/Modelboard system. For convenience, they are designated Day, Night, and TV. Thirty recent UPT graduates transitioning into the copilot position of the KC-135 (a tanker 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. Due to the non-availability of government facilities, training was accomplished in Boeing 707 commercial flight simulators rented from the Boeing Aerospace Company (Day system) and from the American Airlines Flight Academy (Night and TV systems). Each student received up to a maximum of 8 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 or four repetitions of the approach and landing. Upon completion of the two evaluation sorties, each student entered the normal KC-135 copilot training program. Final evaluations which each student received at the end of training were recorded.

Analysis of subsequent performance on the two aircraft evaluation sortie revealed a statistically reliable difference between the TV group and the two CGI groups. No differences were found between the Day and Night groups; however, the Night and Day groups performed significantly better than did the TV group 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 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 these simulator-trained students initially performed at a skill level comparable to the average student copilot who is well along in the training program.

For fighter attack aircraft, even less information is available regarding the effectiveness of visual simulation training for transition tasks. Brictson and Burger (1976) 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-degrees-of-freedom motion system. The visual system has a 40° horizontal by 30° vertical field of view and presents a colored 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 (44%) for the control group.

Since failure leads to recycling in which the student drops back to the next class, the use of the NCLT for remedial training was investigated. Brictson (1978) 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 engagements) was higher when compared with 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, Chun, Warner, & Eubanks (1980) recently completed a study to determine the effectiveness of ASPT training for students transitioning into the A-10, the Air Force's newest attack aircraft. The ASPT, originally a T-37 simulator, was modified to an A-10 configuration for training transition and surface attack skills.

Obtaining data from a valid control group was not possible because all non-fighter-experienced pilots converting to the A-10 must receive the ASPT/A-10 training syllabus. Nonetheless, little difficulty was encountered for ASPT-trained students transitioning into the aircraft. On their first overhead pattern sortie, these students 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 the fighter-experienced group 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 most critical and demanding tasks in military aviation. At present, there exist only a few devices which can provide such training. A simplified formation flight trainer (FFT) was developed for the Air Force Human Resources Laboratory in the early 1970s. It was designed as a part-task trainer which would provide closed-loop practice for all formation tasks learned during the T-38 phase of UPT. The device enabled the student to "fly" a TV camera which views a model of the simulated lead aircraft. The resulting image was then projected onto a wide screen which the student views 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 (1972).

The effectiveness of the FFT was evaluated by Reid and Cyrus (1974) in two separate studies. In Study I, 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, 5 hours of FFT instruction were as effective as 2 hours of aircraft instruction. The same design was used for Study II. 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 (Reid & Cyrus, 1977), the same design was used to determine the effectiveness of the FFT for the T-37 phase of UPT. The FFT was modified to provide a T-37 visual image. Furthermore, the dynamics were changed to approximate the T-37, although the cockpit and controls remained the same. A total of 61 subjects participated in the study. The results indicated that the UPT syllabus group performed significantly better on their checkride than did 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 changes in the device is unknown.

The only other effort to evaluate formation simulator training was an effort by Woodruff et al. (1976), described previously, using the ASPT. In that study, the data revealed a savings of 13% and a Transfer Effectiveness Ratio (TER) of 1.00. At the time of the study, a number of equipment problems 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.

**Aerobatics and Air Combat Maneuvering**

The ability to provide training for aerobatics and air combat maneuvering has only become possible with 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. (1976), revealed that 6.2 hours of instruction in the ASPT resulted in only a 4% savings of aircraft time. Recently, Martin and Waag (1978b) 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 ($n = 12$): (a) Motion, (b) No Motion, and (c) Control. Students in the two experimental groups received five ASPT sorties covering instruction on eight aerobatic tasks. The control group did not receive any ASPT pretraining. All students were subsequently evaluated in the T-37 aircraft by their normal flightline IPs. The obtained data suggested only 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* 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, Spring, Sanders, Wimer, Carter, & Hu (1976) conducted 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 Northrop Large Amplitude Simulator/Wide Angle Visual System (LAS/WAVS). The LAS/WAVS has a spherical, wide-angle screen which provide a 210° horizontal field of view. A maneuverable adversary aircraft, as well as earth-sky image, is projected onto the screen. Training was provided for basic fighter maneuvers such as barrel roll attacks, high yo-yos, and rolling scissors. 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 greatest transfer effects were demonstrated for the rolling scissors. The superiority of the experimentally trained group was also reflected in the grades assigned by the instructors. These differences were maintained throughout the entire tactics syllabus of instruction.

Pohlmann and Reed (1978) completed a study designed to determine the contribution of platform motion to the initial acquisition of basic fighter maneuver skills, the same tasks studied by Payne et al. (1976). The study was accomplished on the Simulator for Air-to-Air Combat (SAAC), a device comprised of two F-4 cockpits mounted on a synergistic six-degrees-of-freedom motion system. The visual display consists of eight pentagonal CRTs which provide a 296° horizontal by 150° vertical 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 visual system technologies that were applicable to air-to-surface weapons delivery. Because of its CGI 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 training (Hutton, Burke, Englehart, Wilson, Romaglia, & Schneider, 1976). At the same time, the Tactical Air Command requested that AFHRL initiate research studies to determine 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 furthermore, since the ASPT was the only system considered capable of training such tasks, the Flying Training Division initiated a study to determine (a) the extent to which generalized, conventional air-to-surface weapons delivery training in the ASPT transferred to a specific aircraft, and (b) the contribution of six-degrees-of-freedom platform motion to the transfer of training from simulator to aircraft (Gray & Fuller, 1977). 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 on F-5B operations. At this point, students in the Control group flew two data collection sorties n the F-5B aircraft, performing two 10°, 15°, and 30° bomb deliveries on each sortie. Each student in the two experimental groups received eight 1-hour training sorties in the ASPT on 10°, 15°, and 30° bomb deliveries. At the end of simulator training, each student 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 the TAC qualification criteria, the number of bombs which were scorable on the range, circular error, and IP ratings. The two simulator groups performed significantly better than did the control group for all measures except the IP ratings. The two experimental groups dropped about twice as many scorable bombs, as well as 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 substantial transfer of training did occur when a generalized, low fidelity simulation was used certainly questions 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 were also provided weapons delivery training on the ASPT (Gray et al., 1980). The surface attack syllabus consisted of three 2-hour sorties. To date, only 17 students have completed the program. The results, however, appear quite dramatic. On their first sortie, the average circular error for the 30° dive bomb event was substantially less than the TAC criterion for qualification. In fact, it was about the same as the average circular error for experienced fighter pilots on their sixth sortie. Thus, the ASPT-trained UPT graduates reached the same proficiency level on their first sortie in the aircraft. The last class of ASPT-trained students received weapons delivery training in the aircraft first, thereby providing control 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

The author is aware of only two studies which have evaluated the effectiveness of visual simulators for rotary wing training. In 1977, the 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-degrees-of-freedom platform motion system and has a camera-model visual system which provides a 48° horizontal by 36° vertical field of view 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 (McGaugh & Holman, 1977). Two independent studies were completed: the first assessed the effectiveness of the CH-47FS for novice pilots transitioning into the CH-47; and the second assessed the effectiveness of the CH-47FS for maintaining mission readiness skills.

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 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 (TERs) were computed on the basis of total time and 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 pilots who were qualified and current in the CH-47, received 5 hours of instruction and practice in the CH-47FS per month over a 6 month test period. Such practice was in addition to their mission essential flying in the CH-47 aircraft. A control group of 16 pilots received only their normal mission essential flights in the CH-47. Checkrides were administered at the beginning and end of the 6-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 posttest checkride revealed no differences. A pretest/posttest 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 lack of improvement may have been due to limitations of the visual system.

Byrum (1978) reports a transfer-of-training evaluation of a three window night visual, point-light source system attached to a UH-1 flight simulator. An experimental group (n = 14) received simulator training to proficiency on five night transition tasks followed by evaluation sorties in the UH-1 helicopter. A control group (n = 7) received only the helicopter training. All sorties were flown at night. Analysis of tests to criterion data, as well as IP rating data, evaluated in the aircraft revealed no enhancement of performance as a result of the simulator training. In his discussion, Byrum points out a number of experimental control problems which may have lead to these findings.

### 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. For tasks other than transition, few studies have been accomplishment because only recently have wide-angle visual systems necessary to perform certain tasks been available. Nonetheless, the data thus far suggest that significant transfer can be obtained through visual training of formation and surface attack weapons delivery skills. For aerobatic and air combat skills, only a modest amount of transfer has been demonstrated

## III. MOTION SIMULATION

The technology of motion simulation has expanded in a rapid manner similar to that of visual simulation. Today, there exist a variety of devices which give force cueing information. These include platform motion systems, G-seats, G-suits, stick shakers, and buffet/vibration systems. They are designed to provide either onset or sustained cue information. Unlike the addition of a visual system, force cueing devices enable the pilot to perform only a few additional tasks which would 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 learning to fly 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 exist much speculation and many analytic arguments concerning the necessity for force cueing information. There is evidence that single- and dual-axis tracking performance is enhanced as a result of motion simulation. Furthermore, performance in the simulator may be enhanced under certain conditions. However, the extent to which this additional cueing enhances the training value of the device has only recently been questioned.

Koonce (1974) reported a study which investigated the effects of refresher instrument training in a Singer-Link GAT-2 trainer on subsequent performance in a Piper Aztec. The GAT-2 trainer is mounted on a limited 2-1/2-degrees-of-freedom platform motion system. Two groups were trained with the aid of motion cueing: one with a washout drive philosophy, the other with sustained drive philosophy. A control

group was trained without motion cueing. Each pilot received two simulator sorties followed by an aircraft checkride. During the two simulator sorties, the two motion groups performed significantly better than did the no-motion group. However, in the aircraft sortie, the no-motion group performed better than did the two motion groups, although the differences were only marginally significant.

In a follow-on study, Jacobs (1976) trained novice students in the GAT-2 Trainer and subsequently evaluated their flight performance in a Piper Cherokee Arrow. Thirty-six students were divided into four groups who received (a) simulator training with normal washout motion, (b) simulator training with directionally random motion, (c) simulator training with no motion, and (d) aircraft training only. Each student in one of 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, the washout motion group committed significantly fewer errors than did the no motion group. Errors in the random washout group were similar to those of the no motion group. Analysis of the aircraft data reveals (a) significant transfer for all three groups in terms of time to criterion, trials to criterion, and number of errors and (b) 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.

Other studies of platform motion effectiveness have been conducted by the Flying Training Division and are summarized by Martin (1980). Most have been described in the previous section concerning the effectiveness of visual simulation. In such cases, only the findings pertinent to the question of platform motion are discussed. Part of the study reported by Woodruff and Smith (1974) concerned the effectiveness of the T-4G simulator for instrument training. The use of this device, which is mounted on a two-degrees-of-freedom motion base and has a limited visual system, resulted in an average 10.1 flight hours reduction 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), however, was not statistically significant. Furthermore, the visual system was used periodically throughout the T-4G training, thereby providing the opportunity for additional bias in favor of the motion group.

In the exploratory study investigating the utility of the ASPT as a full mission simulator in the basic phase of UPT (Woodruff et al., 1976), 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 (1978a) 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 10 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. Within the aircraft, this finding was observed for student performance on two special data sorties at the beginning of training, as well as their performance up to solo.

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 (Martin & Waag, 1978b). 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 subjects (13 of 40), none revealed a reliable effect due to motion.

Since both of these studies used a wide field of view (300' horizontal by 150' vertical), it was speculated that peripheral 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. (1979) conducted a transfer study varying motion and field of view. As discussed in the previous section, 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 performance measurement system.

Gray and Fuller (1977) 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 (1978) 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, who received no simulator pretraining. Since transfer of training was not demonstrated, data bearing on the motion issues were not considered meaningful.

Ryan, Scott, and Browning (1978) studied the contribution of motion simulation to training in the 2F87F P3 simulator. The training device was equipped with a synergistic six-degrees-of-freedom motion platform. The experimental group ($n = 11$) received training without motion while the control group ($n = 39$) was trained with the motion system in operation. Training tasks included instrument maneuvers, takeoffs, and landings. Engine aborts on takeoff as well as engine-outs on landings were practiced. Data revealed fewer trials to proficiency for engine aborts on takeoff for the control group trained with platform motion. However, trials to proficiency data collected in the air revealed no significant effect.

To summarize, studies to date have failed to demonstrate that platform motion cueing enhances the effectiveness of simulator training. In no instance was performance in the aircraft significantly enhanced as a result of simulator training with platform motion. The last study reported (Ryan, Scott, & Browning, 1978) is of particular importance since several of the tasks trained (engine aborts on takeoff) are such that force cues serve an alerting function. The failure to demonstrate improved transfer of training for tasks in which force information serves as a primary cue seriously questions the value of platform motion.

## IV. 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. In many cases, study goals are different, and the experimental design and measurements are different. Each of these factors will have an effect (usually unknown) on 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. In simple terms, what is the additional training value resulting from the use of a motion system, a visual system, or both?

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 (Gray & Fuller, 1977; Jacobs, 1976; Martin & Waag, 1978a, 1978b; Pohlmann & Reed, 1978; Ryan et al., 1978). In those studies, training was given under alternative motion cueing conditions and then was 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 primarily 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. Although some studies have provided similar pretraining (e.g., Brictson & Burger, 1976), the author is 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 (Martin & Catanco, 1980; Nataupsky et al., 1979; Torpe, et al., 1978), despite the fact that such information is vital to the procurement process. Consequently, there is ample evidence that visual simulation training is effective, but there is very little data to guide decisions in terms of the necessary visual system requirements for specific applications.

### Experimental Design and Control

Since research objectives differ, 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 the criterion approach, it has been used in only a few studies (McGaugh & Holman, 1977; Payne et al., 1954; Williams & Flexman, 1949). 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 (Woodruff & Smith, 1974; Woodruff et al., 1976). 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 (Browning et al., 1977; Flexman, Matheny, & Brown, 1950; Flexman, Townsend, & Ornstein, 1954; Reid & Cyrus, 1974, 1977). Still others have employed a fixed number of simulated and aircraft hours or sorties (Brictson & Burger, 1976; Brown, Matheny, & Flexman, 1951; Creelman, 1959; Gray et al., 1980; Payne et al., 1976; Poe & Lyon, 1952).

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 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 (Gray & Fuller, 1977; Martin & Cataneo, 1980; Martin & Waag, 1978a, 1978b; Nataupsky et al., 1979; Pohlmann & Reed, 1978). Only two studies (Woodruff & Smith, 1974; Woodruff et al., 1976) used a training to proficiency approach, and in each case, the differential transfer aspects were only a secondary consideration. Thorpe et al. (1978) 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. Measurement 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 judgments of experienced flight instructors. Some studies have attempted to minimize the subjective aspects of evaluation by requiring the instructor to "record" performance rather than to "evaluate" performance. In such cases, observations such as maximum/minimum altitude, and airspeed at touchdown would be recorded. Such an 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 instructors and incorporate their judgment into the flight evaluation. In some instances, they have been asked to evaluate performance along a continuum from unsatisfactory to excellent (Martin & Waag, 1978a; McGaugh & Homan, 1977; Nataupsky et al., 1979; Pohlmann & Reed, 1978; Reid & Cyrus, 1974). Other studies have required instructors to evaluate performance in relation to some normative criteria; e.g., "the top 3% of students you have instructed" (Brictson & Burger, 1976; Payne et al., 1976; Poe & Lyon, 1952; Thorpe et al., 1978).

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 (Martin & Cataneo, 1980; Martin & Waag, 1978a; Nataupsky et al., 1979) and weapons delivery training (Gray & Fuller, 1977; Gray et al., 1980). In the aircraft, even fewer studies have used objective data. Brictson and Burger (1976) 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 (Gray & Fuller, 1977; Gray et al., 1980).

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" (Browning et al., 1977, 1978; McGaugh & Holman, 1977; Woodruff et al., 1976). Other studies have defined proficiency in terms of a set number of task repetitions, each meeting certain proficiency criteria. For example, Payne et al. (1954) required three successive repetitions in which all criteria were met on each trial. Thorpe et al. (1978) 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 (Woodruff et al., 1976) to a high of 100 subjects per group (Poe & Lyon, 1952). 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 required 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 versus no training is likely to be substantially larger than training in System A versus 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 that, 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 these 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 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. (1978) 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 Catanco (1979) chose takeoffs and landings for a comparison of Day versus Night training, using a narrow field-of-view visual presentation. Again, such a choice seems reasonable since they are the two most important tasks which require visual cueing and which are trained in Air Training Command's new Instrument Flight Simulator.

Nataupsky et al. (1979), 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: first, force cues resulting from pilot input, and second, force cues resulting from environmental or aircraft configuration changes. The first type has been referred to as maneuver motion; the second, disturbance motion. Studies to date with the exception of Ryan et al. (1978) have focused primarily on tasks having a large maneuver motion component. Since there are some in-simulation 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 (Caro, 1979).

### 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 versus Off or Day versus Night). In other words, there exist no quantifiable models of visual and motion simulation which enable testable hypotheses to be generated which might subsequently lead to some 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 very 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 to provide for the KC-135? 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 Issue of Fidelity

A key example of such a failure to "look-ahead" concerns the required fidelity of simulation necessary to insure effective 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 such information is available and a valid cost effectiveness model developed, the question of "how much fidelity" shall remain unanswered. Because of the current inability to match training requirements and the degree of fidelity, it is likely that simulators shall continue to be procured under the design goal of maximum fidelity.

## REFERENCES


American Airlines. *Flying training average hours captain transition program.* B-00-188E. Fort Worth, TX: American Airlines, 1976.

Bell, J.M. *A landing display for use with a contact flight simulator.* TR-SPECDEVCEN-71-16-8. University of Illinois: Department of Psychology, March 1951.

Brictson, C.A. *A-7 training effectiveness through performance analysis.* NAVTRAEQUIPCEN 75-C-0105-1. Orlando, FL: Naval Training Equipment Center, April 1978.

Brictson, C.A., & Burger, W.J. *Transfer of training effectiveness: A-7E night carrier landing trainer (NCLT), device 2F103.* NAVTRAEQUIPCEN 74-C-0079-1. Orlando, FL: Naval Training Equipment Center, August 1976.

Brown, E.L., Matheny, W.G., & Flexman, R.E. *Evaluation of the school link as an aid in teaching ground reference maneuvers.* Technical Report SDC-71-6-16-7. Port Washington, NY: U.S. Navy, Special Devices Center, March 1951.

Browning, R.F., Ryan, L.E., & Scott, P.G. *Utilization of device 2F87E OFT to achieve flight hour reductions in P-3 fleet replacement pilot training.* TAEG Report No. 54. Orlando, FL: Training Analysis and Evaluation Group, April 1978.

Browning, R.F., Ryan, L.E., Scott, P.G., & Smode, A.F. *Training effectiveness evaluation of device 2F87E, P-3 operational flight trainer.* TAEG Report No. 42. Orlando, FL: Training Analysis and Evaluation Group, January 1977.

Bynum, J. *Evaluation of singer night visual system: Computer-generated-image display attached to the UH-1 flight simulator.* Research Report 1199. Ft. Rucker Field Unit, AL: Army Research Institute, September 1978.

Caro, P.W. *Some factors influencing Air Force simulator training effectiveness.* HumRRO-TR-77-2. Alexandria, VA: Human Resources Research Organization, March 1977.

Caro, P.W. The relationship between flight simulator motion and training requirements. *Human Factors.* 1979, *21*, 493-501.

Creelman, J.A. *Evaluation of approach training procedures.* AD-89997. Pensacola, FL: US Naval School of Aviation Medicine, Naval Air Station, October 1959.

Flexman, R.E., Matheny, W.G., & Brown, E.L. *Evaluation of the school link and special methods of instruction in a ten-hour private pilot flight-training program.* University of Illinois Aeronautics Bulletin No. 8. Urbana, IL: The Institute of Aviation, University of Illinois, April 1950.

Flexman, R.E., Townsend, J.C., & Ornstein, G.N. *Evaluation of a contact flight simulator when used in an Air Force primary pilot training program: Part I. Over-all effectiveness.* AFPTRC-TR-54-38. Goodfellow AFB, TX: Basic Pilot Research Laboratory, Air Force Personnel and Training Research Center, September 1954.

Gray, T.H., Chun, E., Warner, H., & Eubanks, J. *Advanced flight simulator: Utilization in A-10 conversion and air-to-surface attack training.* AFHRL-TR-80-20. Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory, 1980.

Gray, T.H., & Fuller, R.R. *Effects of simulator training and platform motion on air-to-surface weapons delivery training.* AFHRL-TR-77-29, AD-A043 649. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, July 1977.

Gum, D.R., Albery, W.B., & Basinger, J.D. *Advanced simulation in undergraduate pilot training: An overview.* AFHRL-TR-75-59(I), AD-A030 224. Wright-Patterson AFB, OH: Advanced Systems Division, Air Force Human Resources Laboratory, December 1975.

Hutton, D.P., Burke, D.K., Englehart, J.D., Wilson, J.M., romaglia, F.J., & Schneider, A.J. *Air to ground visual simulation demonstration. Final report, Project 2235.* Wright-Patterson AFB, OH: Simulator SPO, Aeronautics Systems Division, October 1976.

Jacobs, R.S. *Simulator cockpit motion and the transfer of initial flight training.* ARL-76-8/AFOSR-76-4. University of Illinois at Urbana-Champaign: Aviation Research Laboratory, Institute of Aviation, June 1976.

Koonce, J.M. *Effects of ground-based aircraft simulator motion conditions upon prediction of pilot proficiency.* TR ARL-74-5/AFOSR-74-3. University of Illinois at Urbana-Champaign: Aviation Research Laboratory, 1974.

**Martin, E.L.** *Training effectiveness of platform motion: Review of motion research involving the advanced simulator for pilot training and the simulator for air-to-air combat.* AFHRL-TR-79-51. Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory, 1980.

**Martin, E.L., & Cataneo, D.** *Computer generated image: Relative training effectiveness of day versus night visual scense.* AFHRL-TR-79-56. Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory, July 1980.

**Martin, E.L., & Waag, W.L.** *Contribution of platform motion to simulator training effectiveness: Study I — Basic contract.* AFHRL-TR-78-15, AD-A058 416. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, June 1978. (a)

**Martin, E.L., & Waag, W.L.** *Contribution of platform motion to simulator training effectiveness: Study II — Basic contract.* AFHRL-TR-78-52, AD-A064 305. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, September 1978. (b)

**McGaugh, M.F., & Holman, G.L.** *Operational test II of CH-47C synthetic flight training system (flB31)(SFTS).* AD-B022 470. Fort Rucker, AL: United STates Army Aviation Board, October 1977.

**Nataupsky, M., Waag, W.L., Weyer, D.C., McFadden, R.W., & McDowell, E.** *Platform motion contributions to simulator training effectiveness: Study III — Interaction of motion with field-of-view.* AFHRL-TR-79-25, AD-A078 426. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, November 1979.

**Payne, T.A., Dougherty, D.J., Hasler, S.G., Skeen, J.R., Brown, E.L., & Williams, A.C., Jr.** *Improving landing performance using a contact landing trainer.* SPECDEVCEN 71-16-11. Urbana, IL: University of Illinois, March 1954.

**Payne, T.A., Hirsch, D.L., Semple, C.A., Farmer, J.R., Spring, W.G., Sanders, M.S., Wimer, C.A., Carter, V.E., & Hu, A.** *Experiments to evaluate advanced flight simulation in air combat pilot training.* NOR-76-52. Warminster, PA: Naval Air Development Center, March 1976.

**Poe, A.C., & Lyon, V.W.** *The effectiveness of the cycloramic link trainer in the U.S. Naval School, pre-flight.* Project No. NM 001-058.07.01. Pensacola, FL: U.S. Naval School of Aviation Medicine, U.S. Naval Air Station, March 1952.

**Pohlmann, L.D., & Reed, J.C.** *Air-to-air combat skills: Contribution of platform motion to initial training.* AFHRL-TR-78-53, AD-A062 738. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, October 1978.

**Reid, G.B., & Cyrus, M.L.** *Transfer of training with formation flight trainer.* AFHRL-TR-74-102, AD-A009 638. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, December 1974.

**Reid, G.B., & Cyrus, M.L.** *Formation flight trainer evaluation for T-37 UPT.* AFHRL-TR-77-23, AD-A043 197. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, June 1977.

**Ryan, L.E, Scott, P.G., & Browning, R.F.** *The effects of simulator landing practice and the contribution of motion simulation to P-3 training.* TAEG Report No. 63. Orlando, FL: Navy Training Analysis and Evaluation Group, September 1978.

Thorpe, J.A., Varney, N.C., McFadden, R.W., LeMaster, W.D., & Short, L.H. *Training effectiveness of three types of visual systems for KC-135 flight simulators.* AFHRL-TR-78-16, AD-A060 253. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, June 1978.

Williams, A.C., Jr., & Flexman, R.E. *Evaluation of the school link as an aid in primary flight instruction.* University of Illinois Aeronautics Bulletin No. 5. Urbana, IL: The Institute of Aviation, University of Illinois, May 1949.

Wood, M.E., Hagin, W.V., O'Conner, R., & Myers, D.W. *Design of the simplified formation trainer.* AFHRL-TR-72-8, AD-754 973. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, March 1972.

Woodruff, R.R., Smith, J.F., Fuller, J.H., & Weyer, D.C. *Full mission simulation in undergraduate pilot training: An exploratory study.* AFHRL-TR-76-84, AD-A039 267. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, December 1976.

Woodruff, R.R., & Smith, J.F. *T-4G simulator and T-4 ground training devices in USAF undergraduate Pilot Training.* AFHRL-TR-74-78, AD-A008 197. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, November 1974.

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