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An Application of High Fidelity FTDs for Ab Initio Pilot Training: The Way Ahead

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ABSTRACT

Decreases in simulation costs and increases in aircraft training costs led to the need for further investigation into the application of simulation-based training. Researchers conducted an eighteen-month study using ab initio student pilots as participants. This study applied a Federal Aviation Administration (FAA) approved, Part 142, flight-training curriculum that included 60% flight training device (FTD) use. Researchers identified five causal factors that warranted further investigation. The causal factors identified were visual fidelity, procedural similarity, dynamic flight environment, difficulty of task, and visual scanning and response. These causal factors have the potential to affect transfer of training (ToT) from simulated flight to aircraft flight. Steps are being taken to optimize training while considering the causal factors.

INTRODUCTION

The training value of aircraft-specific simulation has long been recognized, but typically, the costs have been too expensive for all but a few ab initio pilot training schools and centers. Flight training devices (FTD) have demonstrated utility for "a variety of aeronautics applications such as training, research and development, and accident investigations" (Chung, 2000, p. 14). Increases in fidelity and decreases in costs have made FTDs a viable training option for the ab initio training segment. Increasing cost efficiencies through application of simulation for training necessitates continued investigation (Macchiarella & Doherty, 2007).

Rising fuel costs, increasing insurance costs, and increasing costs associated with modern complex aircraft and avionic systems have boosted operating expenses for training aircraft. Training schools and centers can recoup some of these ascending costs by using cost efficient FTDs (Macchiarella & Brady, 2006).

Flight training devices are an efficient medium for training pilots. Technological advancements in computer processing speeds and storage capacity are leading to increased capabilities. Contrastingly, FTD costs are decreasing for a given level of fidelity and functionality (Chung, 2000). Simulation also saves time by enabling trainers to position the student pilot into the exact situation required to learn specific skills (Liu, Blickensderfer, Vincenzi, & Macchiarella, in press). This capability saves time by cuing up the FTD to a desired point to initiate training instead of having to take a large portion of the training flight just to arrive at the desired point. With this approach, students can focus more time on training. The learning principles of exercise and intensity are maximized by focusing on the to-be-trained task (Federal Aviation Administration, 1999). Additionally, simulation offers more options to training centers. With the same number of physical airplanes, a training center can increase its number of student pilots using simulators. The combination of these factors can justify the increased use of FTDs for ab initio pilot training purposes.

Defining fidelity requires addressing a vast array of factors that concern how well a simulator mirrors reality. The multifarious use of the word fidelity makes it difficult to agree upon a definition. A widely accepted definition is "The accuracy of the representation when compared to the real world" (Department of Defense, 2007). Kaiser and Schroeder (2003) describe four different forms of fidelity. These forms are physical, visual, motion, and cognitive. Physical fidelity relates to the tangible form of the simulation that matches the actual appearance of its real-world counterpart. Visual fidelity involves the relationship between the visual scenes viewed in the simulation compared to the scenes experienced by a pilot in the real world aircraft. Motion fidelity describes the relationship between the movement dynamics of the simulation to the movement dynamics of the simulated system in the real world. Cognitive fidelity relates the mental activities engaged by the pilot while in simulation, to the cognitive activities performed by the pilot in the aircraft (Doherty & Macchiarella, 2007).

Fidelity is often a crucial factor to cost-efficient simulator design. The main issue in simulation development addresses the degree of fidelity designed into a device to meet the identified need of the user. Roscoe and Williges (1980) clearly describe this relationship. These authors identify the best balance of fidelity and cost as the “honey region” (p. 195).

Recently developed FTDs often include visual systems, force cueing, and aerodynamic modeling characteristics. These attributes were not readily available when the Federal Aviation Administration (FAA) first defined and then regulated how nonmotion-based flight simulators could be used for pilot training (Macchiarella, Arban, & Doherty, 2006). High fidelity and relatively low cost FTDs are now available for ab initio pilot training.

Researchers at Embry-Riddle Aeronautical University (ERAU) completed an eighteen-month project examining the use of FTD-based simulation for ab initio pilot training. The FTDs applied in the research were equipped with enhanced visual systems and enhanced aerodynamic modeling. Three of the four forms of fidelity (i.e., physical, visual, and cognitive) were readily observable during the research.

TRANSFER OF TRAINING

Transfer of training (ToT) is a methodology for measuring the knowledge, skills, and attitudes (KSA) acquired from a training environment and subsequently demonstrated during real world application. The training goal is to have positive transfer of KSAs from simulation to task performance in the aircraft. Positive transfer manifests itself as reduced time on task and reduced training cost necessary to master a real world task. Negative transfer is possible. It is evidenced by a decline in skills, perseverance, or motivation from the trainee’s standpoint. Positive transfer is desired (Liu et al, in press). The concept of ToT is the most common method to measure the degree of skill transfer between simulation and performance in the aircraft in order to determine simulation effectiveness (Roscoe & Williges, 1980).

Evidence exists indicating that flight training in simulators can yield a high positive transfer to performance in real flight. Although previous studies demonstrated the effectiveness of simulation for flight training, questions remained regarding how effective simulation is for training initial flight skills for ab initio pilots. Findings in prior work have generated mixed results (Rantanen & Talleur, 2005). It is necessary to investigate further the effect of FTDs as these devices relate to ab initio pilot training. Researchers have shown that learning and skill acquisition can be transferred from one setting to another similar setting (Gerathewohl, Mohler, & Siegel, 1969).

Three major factors of particular interest that affect the transfer of training are identical elements, stimulus and response, and trainee motivation. Increased identical elements between simulation and actual flight can manifest an increased rate of transfer (Thorndike, 1906). Osgood’s (1949) description of stimulus and response contrasts this position. Transfer of training can be obtained using training tasks and/or devices that do not exactly duplicate the real world condition. However, these devices do maintain the correct stimulus-response relationship (e.g., an FTD used to teach any psychomotor flight task). Motivation and attitude need to be considered as factors in training effectiveness assessment. If motivation is lost or the trainee does not progress at a suitable rate then he or she will fall behind (Liu et al, in press). A trainee with a well-established foundation of skills will aid the learning and development of new skills. When pre-existing skills have a positive affect on the development of a new skill, the change in skill is referred to as positive transfer. Conversely, hindrance of new skill acquisition by pre-existing skills is called negative transfer. Both can be measured by a transfer effectiveness ratio (TER) (Roscoe & Williges, 1980).

Calculating the TER requires counting the practice number of iterations for a task until experimental and control group participants achieve prescribed levels of proficiency in their respective training programs. The TER is calculated by subtracting the number of iterations of a task in the aircraft for experimental group from the number of iterations of the same task performed by the control group. This resultant number is subsequently divided by the number of iterations in the simulator (i.e., an FTD) performed by the experimental group (Roscoe & Williges, 1980). Higher TERs indicate greater transfer from simulation to the real world condition (e.g., a TER of 1.0 indicates a higher level of transfer than a lower TER like 0.4) A TER of one indicates that for each iteration in the FTD, an iteration is saved in the airplane. All positive ratios demonstrate savings in airplane flight for the experimental group. The TER equation is:

$$TER = \frac{C - E}{E_{(FTD)}}$$

METHODS

Participants

The ERAU study used experimental group training with a hybrid curriculum utilizing FTDs and airplanes. The control group trained solely in airplanes. Certified Flight Instructors (CFI) performed the data collection for both groups. The CFIs were standardized in data collection to facilitate reliability and validity. Fifty two undergraduate students participated in this research; 26 were assigned to each group. Participants volunteered for the research and were randomly assigned to a group. All participants were regularly enrolled undergraduate students studying Aeronautical Science at ERAU. The attrition rate for the participants in this training cohort was 27%. Thirty eight participants were used for research data collection and final statistical analysis. (See Table 1.) The mean age of the control group was 18.5 years and the mean age of the experimental group was 18. The mean flight hour total time at the start of the research was 0.24 hours. Flight costs for research participants were normalized to the university's regular flight costs; students received a stipend to participate. Each participant possessed, as a minimum, a current Class III Medical Certificate.

The research utilized aircraft and FTDs obtained from the university's regular training fleet.

The Cessna C-172S "Skyhawk" was used for flight training aspect of the research.

Table 1. *Research Groups*

	Male	Female	Totals
All Flight - Control	14	4	18
Experimental	15	5	20

The Frasca 172 FTD was used for 60% of the training for the experimental group's curriculum. A Level 6 FTD, the device used at ERAU, is defined as a non-motion training simulation that is aircraft specific (Federal Aviation Administration, 1992). This device was further equipped to handle the high angle of attack envelope necessary to train ab initio pilots. Enhancements to the FTD include, longitudinal and lateral-directional propeller destabilizing effects, longitudinal and lateral-directional gyroscopic effects, p-factor, stall model, and an asymmetric wing lift (i.e., spin). These additions, which achieved the desired fidelity, prompted the ERAU researchers to refer to these FTDs as being *Level 6 Plus*. The visual system provides a 220-degree out-of-the-cockpit view of the flight environment (see Figure 1). Air vents in the cockpit blow air on the pilot to represent cabin airflow levels experienced in flight. RPM settings, flap movements, stall warning, airspeed, and engine power determine the aural cues. The radio and intercom systems functionality match actual radio and intercom systems in a C-172S (see Table 2) and have the capability of being networked with other FTDs for a fleet wide simulation. (Macchiarella, Arban, and Doherty, 2006).

Table 2. *C-172S Capabilities.*

Variable Omni Range Radio
Distance Measuring Equipment
Global Positioning System
NAV II Avionics
Garmin 430
Instrument Landing System

Research Design

The study used two groups. The control group was trained solely in the C-172S and the experimental group's training utilized the C-172S and the FTD.

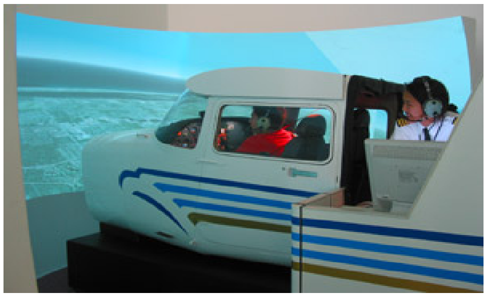

Figure 1. FTD with instructor workstation

The independent variable was the training platform. There were 34 dependent variables, which represented the number of iterations necessary to achieve the PTS standards for 34 tasks associated with Private Pilot Certification.

Procedure

The participants in the research received the same academic ground training as regular Aeronautical Science students. However, the students involved in the research were assigned to specific flight blocks. These blocks provided only the prescribed curriculum to its respective groups. All flight training used a building block approach (Federal Aviation Administration, 1999). Training was applied in stages. Once enrolled in a stage, the participant completed the prescribed curriculum. The tasks were progressive and had to be completed before starting the next stage. Students assigned to the experimental group had to perform to practical test standards (PTS) prescribed levels of performance for each task in simulation before attempting it in an airplane. The training sessions were scored. Upon completion of a training session, the instructor pilot placed a data collection form in a designated location for processing and evaluation by the researchers. The experimental curriculum contained 60% simulated flight and 40% airplane flight for a total of 69.7 hours of flight training. Students in the experimental group training with the FTD had approximately 28 hours of flight in the real aircraft. The control group's curriculum was comprised of 100% aircraft flight.

MANOVA

Researchers calculated a multivariate analysis of variance (MANOVA) to conclude if the number of flight iterations performed in airplane flight to achieve PTS were significantly lower for the experimental group. A MANOVA analysis was chosen to reduce the possibility of a Type I error given the large number of dependant variables. There were no tasks with significantly higher mean iterations for the experimental group in the airplane. For all dependent variables $p = 0.05$ with 1, 36 degrees of freedom (see Table 3).

DISCUSSION

The focus of this research was to quantify the TER from simulation to real world performance in an airplane. A by-product of this effort was the identification of five possible causal factors that influenced the implementation of the FTD-based flight training curricula. The five causal factors were *visual fidelity*, *procedural similarity*, *difficulty of task*, *dynamic flight environment*, and *visual scanning and response*. The researchers examined the TERs, training environment, and student pilots to hypothesize the affect of these factors and the associated implications for ToT. It is realized that cost savings can be obtained from utilizing a combination of FTD flight and actual aircraft flight versus just aircraft flight. The objective was to have 40% of the time spent in the aircraft and 60% in the FTD. However, by the end of the research period the percentage of simulated flight decreased. Instructor pilots implemented extra training modules immediately prior to the Private Pilot certification check ride; the researchers did not try to control this occurrence due the experimental nature of the application of a high degree of simulated flight. Individual instructors remain responsible for the success of each student pilot at Private Pilot certification.

At the end of the research the training curricula consisted of 45.5% of FTD flight and 54.5% aircraft flight; this percentage of simulated flight was a large portion of the curriculum's training effort. Researchers performed post-hoc analysis of the curriculum, TERs, and causal factors to help optimize the ratio of FTD-based flight to real flight. Future Private Pilot curricula will likely be comprised of 58.1% FTD flight and 41.9% aircraft flight.

Table 3. *Transfer Effectiveness Ratio (TER) Scores for 34 Private Pilot Task*

	TER	*F*	*p*
Preflight Inspection*	0.64	76.98	0.00
Cockpit Management*	0.72	37.84	0.00
Engine Starting*	0.59	67.16	0.00
Taxiing*	0.77	19.58	0.00
Before Takeoff Check*	0.82	71.75	0.00
Traffic Patterns*	2.19	17.58	0.00
Normal and Crosswind Takeoff and Climb*	0.57	18.40	0.00
Normal and Crosswind Approach and Landing*	2.1	31.76	0.00
Soft-field Takeoff and Climb	0.06	0.10	0.76
Soft-field Approach and Landing	0.32	1.45	0.24
Short-field Takeoff and Max Performance Climb	0.13	0.63	0.43
Short-field Approach and Landing	0.27	1.17	0.29
Forward Slip to a Landing*	0.48	5.67	0.02
Go-Around/Rejected Landing*	0.51	4.23	0.05
Steep Turns*	0.32	4.22	0.05
Rectangular Course	0.32	2.77	0.10
S-Turns	0.53	3.30	0.08
Turns around a Point	0.2	0.20	0.66
Pilotage and Dead Reckoning	0.09	0.10	0.75
Diversion	-0.02	1.06	0.31
Lost Procedures	0.18	1.27	0.27
Navigation Systems and Radar Services	0.1	0.63	0.43
Emergency Approach and Landing*	0.69	4.97	0.03
Systems and Equipment Malfunctions	0.41	2.57	0.12
Straight-and-Level Flight (IFR)	0.09	0.45	0.51
Constant Airspeed Climbs (IFR)	0.1	0.09	0.77
Constant Airspeed Descents (IFR)	0.05	0.13	0.72
Turns to Headings (IFR)*	0.3	3.99	0.05
Recovery from Unusual Attitudes (IFR)	0.09	0.72	0.40
Radio Communication Navigation Systems/Facilities & Radar Services*	0.82	5.50	0.02
Maneuvering During Slow Flight*	0.38	10.75	0.00
Power-Off Stall*	0.27	6.82	0.01
Power-On Stall*	0.34	9.79	0.00
After Landing, Parking and Securing*	0.74	26.92	0.00
* indicates a significant F value.			

The Way Ahead

The results of the research illustrated that the experimental group required fewer trials to achieve standards in the aircraft when compared to the all-flight control group. Thirty-three of the 34 PTS tasks in the FTD demonstrated positive transfer (See Table 3). In addition, over half of the tasks were significantly different between the groups (Doherty and Macchiarella, 2007).

Instructional designers have the opportunity to realize cost efficiencies with FTD-based training. The cost benefits made available through FTD use can be gained in about two years once the costs of acquisition are amortized (Cardullo, 2005).

Table 4. *FTD and Airplane Use Percentages for Several Private Pilot Curricula*

	Airplane	**FTD**
ERAU Regular Curriculum	78.5%	21.5%
Experimental Curriculum – Percentage Goals	40.0%	60.0%
Experimental Curriculum - Final Percentages	54.5%	45.5%
Goal for Airplane and FTD Use - Immediate	67.5%	32.5%
Goal for Airplane and FTD Use - Objective	58.1%	41.9%

The cost savings associated with utilizing FTDs in place of aircraft can be advantageous. Currently, the university reduces private pilot certification flight training costs by 12.63% through the application of FTDs for flight training. As FTD usage increases and acquisition costs are amortized, monetary savings increase. The proximate cause of this situation is due to the hourly expense rate for the FTD being substantially lower than the hourly rate of aircraft. Future flight training curricula with higher levels of FTD use will lead to greater cost savings.

The *ERAU Regular Curriculum* (i.e., the Part 142 approved private pilot curriculum in use at the university) is comprised of 21.5% FTD flight and 78.5% airplane flight. This is the most expensive of the curricula when compared to curricula using greater levels of FTD-based training. This situation is due to higher airplane use (see Table 4). When comparing the *ERAU Regular Curriculum* to the *Experimental Curriculum - Final Percentages*, a 29.24% cost savings was realized. If the *ERAU Regular Curriculum* is compared to the curriculum percentages of *Goal for Airplane and FTD Use – Objective* (i.e., the objective curriculum based upon research, task analysis, and optimization of FTDs) a cost savings of 13.62% is realized.

Five Causal Factors

Visual fidelity, procedural similarity, difficulty of task, dynamic flight environment, and visual scanning and response were the five causal factors hypothesized to after transfer during the research. The 220° visual system of the FTD allowed for the presentation of a high degree of visual fidelity. ERAU instructional developers and simulation specialists are addressing causal factors as part of an effort to maximize the positive effect on training. Work has been accomplished and the training of ab initio pilots via FTDs will continue to be improved upon.

Visual Fidelity

A low fidelity visual scene at low-level flight altitudes provides poor cues for pilots training for ground reference maneuvers. The progression towards increased visual fidelity to enhance training scenarios is underway. The desire is that the students flying in the FTD will feel more as if they were in an actual aircraft. ERAU has assembled a team to enhance the visual fidelity in the FTDs. The team uses images (i.e., graphic art) that are photorealistic and placed at key locations in the virtual environment. Initiating a sense of vection is of paramount importance to the placement of these virtual entities. Vection is the perception of self-motion induced by visual stimuli (Department of Defense, 2007). New equipment (e.g., display projectors) have also been integrated to improve visual clarity and pixel count in the visual scene. One of several lower level lessons learned are typified by the realization that all visual system projector light bulbs should be replaced simultaneously, in any given FTD, to ensure consistent brightness. The optimization of the visual systems is an ongoing process for increased vection.

Procedural Similarity

Procedural similarity between training in the virtual environment and the real airspace affects transfer as reflected by TERs. Cognitive fidelity addresses the state of recognition and appreciation of a virtual world experience as authentic to the true world. Training scenarios in the FTDs' virtual environment airspace affected cognitive fidelity; realism was limited to the degree that the CFI could role play other air traffic and air traffic control (ATC) simulated airspace seemed to affect transfer to real world flights. ERAU is in the process of increasing the cognitive fidelity of its synthetic flight training environment through the addition of virtual air traffic (VAT) and voice recognition interactive virtual air traffic controllers. This addition will allow ab initio pilots to feel more realism during simulated flight. A significant portion of learning how to become a pilot is not only learning the maneuvers, but also being able to interact with ATC. VAT is intended to create a realistic training environment. These changes are designed to optimize FTD-based ab initio pilot training. The goal is to have student pilot thought processes in the simulator mirror the thought processes occurring during flight in real airspace.

ERAU and the Frasca Corporation have entered into a joint effort to produce a VAT environment. The objective system integrates a selectable, scalable simulation providing virtual air traffic and air traffic control. Student pilots will interact with the system based on input from a graphical instructor station. The pilot in the FTD will have access to all the normal functionality provided by the Frasca FTD. The virtual air traffic controller will understand the pilot's speech and have awareness of the pilot's flight situation and location.

ERAU and Frasca are providing different resources during development. ERAU's focus will be on subject matter expert (SME) assistance for the design, development, and integration of virtual air traffic controller and semiautonomous/autonomous virtual air traffic functionality. ERAU will provide expertise for the development of proper air traffic phraseology for the local training environment to include necessary pilot and ATC radio calls for the voice recognition. The university will perform instructional design to develop scenario-based lessons that apply the system for pilot training. This process will be proofed during "beta" testing and usability testing. Frasca is performing integration of the hardware and software. Frasca's integration work will also provide a means of modifying airspace control measures and voice recognition abilities so the system is adaptable to a changing flight environment.

Difficulty of Task

Different flight tasks require varying and graduated levels of skill to perform the task to standard. Most ab initio pilots master the more demanding psychomotor tasks during the later stages of training. Soft-field Takeoff and Climb, Soft-Field Approach and Landing, Short-Field Takeoff and Climb, Short-Field Approach and Landing proved more difficult to master for participants in both groups during the research (see Table 3). Data suggested that these tasks were difficult to achieve regardless if practice occurred in an FTD or airplane.

Training to standard in the FTD did not seem to mitigate the difficulty of mastering these tasks. The sequencing of training tasks in the curricula had the goal of adhering to the building block principle of learning (i.e., a concept where knowledge and skills are best learned based on previous associated learning experiences) (Federal Aviation Administration, 1999).

The PTS serves as the measurement tool. It provided a set of observable tasks that could be verified by the instructor pilot during aircraft operations. Some tasks were more easily taught by the instructor pilots than others were. ERAU is examining the sequencing of difficult tasks (e.g., Short-Field Approach and Landing). Additionally, the PTS does not address other skills for flight that may account for variability in pilots. (Doherty & Macchiarella, 2007).

Dynamic Flight Environment

A dynamic flight environment includes all of the complexities of real world weather, environmental conditions, and air currents. Phenomena, such as weather and turbulence, continuously change and have been difficult to replicate exactly in an FTD. Without a radical redevelopment of the physics-based flight environment, ERAU is modifying its training scenarios to incorporate multiple varying degrees of weather phenomena. Scenario-based training that incorporates varying meteorological conditions is specifically designed for individual training modules. The researchers are unable to increase the fidelity of virtual weather, but will modify the scenarios to have more varying weather conditions.

Visual Scanning and Response

The application of the results of ERAU's research necessitates the need to isolate the factors associated with visual scanning and response while learning in the FTD. In the absence of proprioceptive stimuli, ab initio pilots training in an FTD rely only on their visual senses. The data indicated that tasks normally highly associated with a high degree of cueing from proprioceptive senses are being learned by students in the FTD (e.g., Maneuvering during Slow Flight, Power-Off Stall, and Power-On Stall). The curricula are based upon an integrated approach of practice (i.e., the student focuses attention outside of the aircraft, however, switches focus inside of the aircraft to flight and system gages to verify aircraft state) (Federal Aviation Administration, 1999). The researchers hypothesize that students learning to fly primarily in an FTD may have a heightened ability to verify aircraft state while gazing inside. Further research is necessary to isolate factors in this area.

CONCLUSION

Increasing cost efficiencies and increasing relative fidelity available with FTDs have influenced ERAU's decision to adopt FTDs and highly integrate these devices into its flight training curricula. The desired goal is to replace a significant number of flight hours that would be performed in a real airplane. ERAU's goal for FTD integration into its objective curriculum is 41.9% FTD-based flight. Using FTDs to this degree will realize a cost savings of 13.62 % when compared to the *ERAU Regular Curriculum*. Research at ERAU concluded that the degree of positive transfer, revealed during the study, warrants further application and refinement of its FTDs and the FTD-based curricula. ERAU researchers and instructional designers will continue to investigate causal factors affecting ToT and the optimized level of application of simulation in flight training curricula.

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