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16. Abstract

In 2002 the FAA, academic and industry partners established the FAA/Industry Training Standards (FITS) program whose purpose is to modernize General Aviation (GA) pilot training. The FAA recognized the need to modernize training standards for pilots who would use new avionics technology that integrate the GPS (Global Positioning Systems) with the autopilot along with multifunction displays capable of depicting flight path, weather, terrain and traffic information. These avionics and displays are touted as improving safety by enhancing pilot *Situational Awareness* and reducing pilot workload. The new technology has highlighted the need for programs to train and certify pilots to use the avionics suites. The instrumentation places new demands on pilots including changes in the level and distribution of pilot workload during a flight, the need to manage and integrate information from multiple displays, navigate complex menu structures, and program navigation computers. The literature describing the FITS program argues that the current structure and content of GA pilot training programs will not adequately prepare pilots for the challenges of using these technologies (FAA, 2003a; Glista, 2003b; Wright, 2002). The FITS curriculum attempts to address these issues by stressing training of risk management (RM), situational awareness (SA), aeronautical decision making (ADM) and single-pilot resource management (SRM). It also proposes to change pilot instruction to make it more *relevant* to real world flying by relying on scenario-based training (SBT). FITS proposes to emphasize the use of scenarios as a means to practice the integration of individual skills as they might occur in the real world. For instance, a student pilot might be instructed to plan a flight from Wichita, KS to Kansas City, MO. The student would perform all the tasks necessary to plan the flight including preflight checks, route planning, checking the weather reroute etc. During the flight the student would demonstrate individual flight skills including turns, climbs, navigation, and communication while executing the scenario. The purpose of this project was to review research related to the proposed initiatives and to identify future research needs to support the long-term objectives of FITS. In addition to reviewing pertinent academic and government literature, the objectives of FITS were reviewed with representatives of the FAA, academic and industry partners. At present FITS materials provide few details regarding important components of the training initiative including decision making, the training requirements of advanced avionics technology and its effects on situation awareness. Future work should draw on an extensive academic literature and on lessons learned from prior industry experience when similar avionics technologies were introduced to commercial aviation. Also, clear distinctions should be made between SBT as employed in FITS and SBT used by the military and in commercial aviation. These are very different programs.

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ABBREVIATIONS

ACM	Air Combat Maneuvering
ADF	Automatic Direction Finder
ADM	Aeronautical Decision Making
AGATE	Advanced General Aviation Transport Experiments
CAAA	Civil Aviation Authority Australia
CRM	Crew Resource Management
DME	Distance Measuring Experiments
DOT	Department of Transportation
DTRDB	Department of Transport and Regional Development Bureau
EMS	Emergency Medical Services
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FITS	Federal Aviation Administration/Industry Training Standard
FMS	Flight Management System
FTD	Flight Training Device
GA	General Aviation
GAMA	General Aviation Manufacturers Association
GAO	General Accounting Office
GPS	Global Positioning System
GWIS	Graphical Weather Information System
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
LOFT	Line Oriented Flight Training
LTM	Long-Term Memory
MFD	Multifunction Display
NASA	National Aeronautics and Space Administration
NEXRAD	Next Generation Weather Radar
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
PCATD	Personal Computer based Aviation Training Device
PTS	Practical Test Standard
PTT	Part-Task Training
RM	Risk Management
SA	Situational Awareness
SATS	Small Aircraft Transportation System
SBT	Scenario-Based Training
SRM	Single-pilot Resource Management
STM	Short-Term Memory
TAA	Technically Advanced Aircraft
TAWS	Terrain Awareness & Warning System
TCAS	Traffic Alert and Collision Avoidance System
VMC	Visual Meteorological Conditions
VOR	Very High Frequency Omni-directional Range
WHCASS	White House Commission on Aviation Safety and Security

EXECUTIVE SUMMARY

In 2002 the FAA, academic and industry partners established the FAA/Industry Training Standards (FITS) program whose purpose is to modernize General Aviation (GA) pilot training. The FAA recognized the need to modernize training standards for pilots who would use new avionics technology that integrate the GPS (Global Positioning Systems) with the autopilot along with multifunction displays capable of depicting flight path, weather, terrain and traffic information. These avionics and displays are touted as improving safety by enhancing pilot *Situational Awareness* and reducing pilot workload. The new technology has highlighted the need for programs to train and certify pilots to use the avionics suites. Glass cockpits place new demands on pilots including changes in the level and distribution of pilot workload during a flight, the need to manage and integrate information from multiple displays, navigate complex menu structures, and program navigation computers. The literature describing the FITS program argues that the current structure and content of GA pilot training programs will not adequately prepare pilots for the challenges of using these technologies (FAA, 2003a; Glista, 2003b; Wright, 2002). The FITS curriculum attempts to address these issues by stressing training of risk management (RM), situational awareness (SA), aeronautical decision making (ADM) and single-pilot resource management (SRM). It also proposes to change pilot instruction to make it more *relevant* to real world flying by relying on scenario-based training (SBT). FITS proposes to emphasize the use of scenarios as a means to practice the integration of individual skills as they might occur in the real world. For instance, a student pilot might be instructed to plan a flight from Wichita, KS to Kansas City, MO. The student would perform all the tasks necessary to plan the flight including preflight checks, route planning, checking the weather reroute etc. During the flight the student would demonstrate individual flight skills including turns, climbs, navigation, and communication while executing the scenario. The purpose of this project was to review research related to the proposed initiatives and to identify future research needs to support the long-term objectives of FITS. In addition to reviewing pertinent academic and government literature, the objectives of FITS were reviewed with representatives of the FAA, academic and industry partners. At present FITS materials provide few details regarding important components of the training initiative including decision making, the training requirements for advanced avionics technology and its effects on situation awareness. Future work should draw on an extensive academic literature and on lessons learned from prior industry experience when similar avionics technologies were introduced to commercial aviation. Also, clear distinctions should be made between SBT as employed in FITS and SBT used by the military and in commercial aviation. These are very different programs.

1. INTRODUCTION

In 2002 the FAA, academic and industry partners established the FAA/Industry Training Standards (FITS) program whose purpose is to modernize General Aviation (GA) pilot training. The program was motivated by several factors including GA accident rates, the introduction of advanced avionics technology and an anticipated diversification of the aviation market place. In 1998 the FAA strategic plan (FAA, 1998) set the goal of reducing GA accidents 20% by the year 2007. This goal was established between the FAA and the DOT after an earlier White House Commission on Aviation Safety and Security Report (WHCASS, 1997) called on the FAA to reduce fatal commercial aviation rates by 80%. The FAA also recognized the need to modernize training standards for pilots who would use new avionics technology including those that integrate the GPS (Global Positioning Systems) with the autopilot along with multifunction displays capable of depicting flight path, weather, terrain and traffic information (see Figure 1 and 2). The third cited motivation for the FITS program was an anticipated shift in demographics in that a significant percentage of the population would choose to live removed from major cities (Wright, 2002). It is predicted that this population will come to rely upon on-demand air taxi services for transportation to and from major urban centers thereby averting the travel complications associated with the established air-carrier hub and spoke systems (Norton, 2004). It has also been argued that the availability of new higher performance personal aircraft with advanced avionics would allow more individuals to fly themselves safely to their destinations. (However, see the report on SATS (2002; TRB, 2002) for another view of these projected developments.)

Figure 1: Cockpit of a Cessna 182 equipped with the Garmin G1000. Courtesy of Cessna Aircraft Company.

Whether the market for on-demand point-to-point air taxis exists is debatable; however, it is clear that the demand for advanced avionics is large and growing. These and other proposed avionics and displays including the “Highway in the Sky” and the “cockpit associate” concept are touted as improving safety by enhancing pilot *Situational Awareness* (SA) and reducing pilot workload. Independent of its potential benefits the introduction of new technology has highlighted the need for programs to train and certify pilots to use the avionics suites. General aviation OEM’s now offer advanced avionics as standard equipment on many aircraft models (e.g., Beechcraft Bonanza’s A36, Cessna

182, Cirrus SR22, Diamond DA-40). The capabilities and functionality afforded a GA pilot by the new avionics approaches that of a commercial aircraft operated by two crew members. In the case of commercial, charter and corporate pilots, they must undergo recurrent proficiency instrument training in the aircraft they fly at regular intervals (Glista, 2003a). No such requirement exists for GA pilots.

The instrumentation places new demands on pilots including changes in the level and distribution of pilot workload during a flight, the need to manage and integrate information from multiple displays, navigate complex menu structures, and program navigation computers. Unlike older *steam-gauge* knob and dial systems, the avionics supplied by manufacturers such as Chelton, Honeywell, Garmin, and Avidyne do not function nor necessarily look alike increasing the possibility for negative transfer of learning when transitioning between different avionics packages. The literature describing the FITS program argues that the current structure and content of GA pilot training programs will not adequately prepare pilots for the challenges of using these technologies (FAA, 2003a; Glista, 2003b; Wright, 2002).

The changes in pilot instruction proposed by FITS represent changes in the content and delivery of pilot instruction (SBT, integrated *ab initio* and instrument rating). The FITS curriculum attempts to address these issues by stressing training of risk management (RM), situational awareness (SA), aeronautical decision making (ADM) and single-pilot resource management (SRM). It also proposes to change pilot instruction to make it more *relevant* to real world flying by employing SBT. The SBT approach is summarized well by the armed services' mantra "Train the way you fight, fight the way you train." FITS has adapted this mantra for GA pilot training and refers to it as "train the way you will fly and fly the way you train". FITS proposes to emphasize the use of scenarios as a means to practice the integration of individual skills as they might occur in the real world. For instance, a student pilot might be instructed to plan a flight from Wichita, KS to Kansas City, MO. The student would then perform all the tasks necessary to plan the flight including preflight checks, route planning, checking the weather reroute, etc. During the flight the student would then perform the individual flight skills including turns, climbs, stall recovery, navigation, and communication while executing the scenario. The instructors' role is to allow the student pilot to perform the flight tasks with a minimum of interference. This allows the students to practice the skills as they would in the real world thus increasing the transfer of learning to real world flying. Finally, FITS will also explore the potential of a combined ab initio and instrument rating as a means of reducing the time and cost of pilot training.

The academic partners, including Embry-Riddle Aeronautical University and the University of North Dakota flight training program are responsible for developing pilot training materials that adhere to the approach described above. A number of pilot training materials are currently available at the FITS website (http://www.faa.gov/avr/afs/fits/index.cfm) including generic private/instrument, recurrent and transition training master syllabi. In addition to developing generic training materials the academic institutions in conjunction with the FAA will review materials submitted by aircraft and equipment manufacturers to ensure that they meet FITS criteria.

The pilot training programs developed by FITS will not result in new FAA regulations or changes in policy. Rather the FAA will recognize FITS compliant training as an industry technical standard. The advantage of this approach is that it allows a rapid response to changes in the aviation industry and does not require the lengthy review necessary to establish new regulations.

The purpose of this project was to review research related to the proposed initiatives and to identify future research needs to support the long term objectives of FITS. In addition to reviewing pertinent academic and government literature, the objectives of FITS were reviewed with representatives of the FAA, academic and industry partners.

2. ADVANCED AVIONICS

One of the touted benefits of using advanced avionics in GA aircraft is a reduction in accidents through improved *Situational Awareness* (SA) and reduced pilot workload that increase the "available safety" (FAA, 2003b). New avionics will provide the pilot with near real time weather information (NEXRAD images), traffic avoidance (TCAS), Terrain Awareness & Warning Systems (TAWS) and GPS-driven moving map displays for navigation. Although more information is often desirable from the pilot's perspective it does not necessarily result in improved decision making (Slovic, 1981) or safety. This is illustrated by a recent analysis of accidents involving Technically Advanced Aircraft (TAA) (FAA, 2003b). The FAA defines TAAs as aircraft having a "minimum of an IFR-certified GPS navigation system with a moving map display, and an integrated autopilot" (FAA, 2003b). The analysis was motivated by accident rates for TAAs that were "not substantially lower than the accident rates of comparable newly produced non-TAAs, as had been expected" (FAA, 2003b). The findings of the report state that the problems identified were typical of previous introductions of advanced avionics technology and also reflect common pilot judgment errors.

Although, new technology can reduce or eliminate some classes of errors it can in turn introduce new failure error modes or systems failures (Sarter, Woods, & Billings, 1997; Wiener, 1988) which require new pilot skills and knowledge. It also redistributes pilot workload from the execution of manual or perceptual-motor acts of flying an airplane to higher level cognitive demands associated with supervisory control that involve monitoring and integrating information from multiple sources. The human factors literature is replete with examples of incidents from the aviation, maritime, industrial, and medical fields illustrating the vulnerabilities of automated systems (Casey, 1993). Nevertheless, these industries have benefited from increased automation and they have accumulated a wealth of experience that could benefit FITS.

We conclude from our review that existing FITS initiatives may not adequately prepare a pilot to reap the benefits of the advanced technology. The following sections identify a number of issues that the proposed GA pilot training programs should address by documenting the impact of automation on user behavior and highlighting human factors issues related to the design of the interface.

Figure 2: Cockpit of a Diamond DA40 equipped with an Avidyne Enterga suite. Courtesy of Avidyne Corporation.

2.1 Past Introductions of Advanced Avionics

Glass cockpits similar to those being introduced in GA first became available in commercial aviation with the introduction of the Boeing 757/767 and Airbus A310/320. The transition to glass cockpits can be challenging as pilots have reported that the switch to a highly automated aircraft is more difficult than the transition between aircraft with conventional avionics (Sarter & Woods, 1997; Sarter et al., 1997). After a number of incidents and accidents, the FAA in 1996 commissioned a study of the interface between the flight crew and automated systems on highly automated aircraft. Although the level of automation in commercial aviation and GA differ in terms of degree and sophistication, many of the problems associated with automation identified in FAA technical reports and in later academic and government technical literature are pertinent to GA (Dekker & Hollnagel, 1999; DTRDB, 1998; Sarter et al., 1997). These problems include poor pilot understanding of the function and design of automation, automation induced complacency, user reports of increased risk taking, degradation of basic instrument or other manual flight skills, poor design of the instrument interface, and an unfavorable effect on SA.

2.2 Pilot Understanding of Automation

An FAA report (1996) and a survey of commercial pilots conducted by the Australian Department of Transport and Regional Development conclude that pilots do not have an adequate understanding of aircraft automation. This conclusion is supported by numerous examples of pilots being surprised by the unexpected behavior of the aircraft automation. (Sarter et al., 1997) have argued that automation surprises reflect an incomplete or incorrect *mental model* of the system's design and function. Through interaction with a system a user develops a mental model representing their understanding of the system's operation, its components and interaction among those components. The mental model enables the user to predict the operation of the system in response to a given input (Norman, 1983). The fidelity of the mental model may be critical as it determines the degree to which the pilot can rely on the model to accurately predict the systems response to different inputs during emergencies.

Pilots' inaccurate or deficient mental models of automated systems may arise from training programs that emphasize operating the system and not how various system functions are implemented and interact (Sarter et al., 1997). Training that relies on the rote memorization of system descriptions and function does not facilitate the development of an accurate mental model whereas conceptual knowledge or "how-it-works" training may. This form of training has been shown to facilitate the learning of procedures and results in greater retention than rote memorization (Kieras & Bovair, 1984). To date we are not aware of any study that identifies the unique skills and knowledge required for a GA pilot to use automation effectively. Such information would be particularly relevant to decisions regarding the content and emphasis of training on automated system's that is to be included in FITS training syllabi.

Sarter, Woods and Billings (1997) have stressed training that supports a users' active exploration of various systems options and interactions among systems instead of teaching a standard mental model. Activities such as "free play" simulator sessions (DTRDB, 1998; Sherman, 1997) can promote the development of a more detailed mental model of the contingencies and interactions among automated systems which is essential if a pilot is to effectively trouble shoot system malfunctions in flight. This view receives some support from the survey data collected by (DTRDB, 1998). Pilots were asked how training could be improved during transition training to highly automated aircraft. Fifty-eight percent of pilots who addressed automation said they would prefer more simulator training with the flight management computer (FMC) trainer. The requests appear to reflect a need for more time to further explore system functions and thereby consolidate their understanding of the system. Pilot requests for more training time on simulators of advanced avionics have been also been reported by Cessna Aircraft for their new aircraft equipped with the Garmin G1000 (K. Ortega, personnel communication, August 24, 2004).

2.3 Pilot Trust and Automation Induced Complacency

Pilot confidence or trust in advanced avionics tends to be high (St. George & Nendick, 1997) which increases the potential for complacency and the inappropriate use of the technology. Survey data show that many private pilots report occasionally or never cross-checking GPS data against other sources (ADF, VOR, DME) and relying almost exclusively on GPS instead of maps (St. George & Nendick, 1997). Data from commercial aviation show similar trends (DTRDB, 1998). The DTRDB survey of commercial aviation pilots found that 16% reported they were less likely to refer to instrument charts on aircraft with advanced technology and 13% believed all the information they needed for the safe conduct of a flight was in the flight management system (FMS). The failure to cross check data from automated systems increases the likelihood of pilots failing to detect input errors or system malfunctions. Input errors can occur during the programming of aircraft systems. Likewise, the accuracy of GPS position information changes as the availability of satellites varies or the signal is masked or shielded by terrain or aircraft parts. Complacency or a false sense of security does not necessarily represent an absence of motivation or professionalism but may be engendered by user interactions with highly reliable automated systems where failures rarely occur. Imploring human operators to monitor and be vigilant for rare events is ineffective given the humans poor performance in sustained attention tasks.

2.4 Effects on Situational Awareness (SA)

The data cited above illustrate some of the ways in which enhanced avionics and automation can affect SA. Advanced avionics can also reduce SA because the pilot is less involved in the manual control of the aircraft. Previously, the pilot had to continuously monitor and process information about position and various systems functions as a basis for future manual control inputs. With automated systems these demands are greatly reduced. Consequently, the pilot is not required to monitor the systems as frequently, or process the information to sufficient depth to detect data input errors or system problems. A pilot of an automated aircraft may have less SA, just as a car passenger is likely to have poorer SA than a driver. Automation may give rise to pilot feelings of being "along for the ride" (Wiener, 1988). Rather than a *Pilot in Command* one might refer to this situation as a *Passenger in Command* (S. Casner, personal communication, August 27, 2004).

In the advent of a failure, the pilot will be missing states of knowledge including possibly the position of the aircraft relative to terrain or obstacles. In the DTRDB survey (DTRDB, 1998), 14% of respondents reported instances of finding their aircraft unexpectedly close to terrain. This view receives some support from a recent study (Casner, 2004a). Two groups of pilots were instructed to fly a course with a number of waypoints. One group of pilots flew the course using standard navigation instrumentation and maps as reference and the other group was allowed to program the flight using GPS navigation instruments. Upon completing the flight pilots were then asked to repeat the flight without the use of maps or the GPS as a reference. The pilots' accuracy was measured in terms of their distance from each waypoint. The pilots who initially flew the course using a map and standard navigation instruments performed significantly better than pilots who used GPS.

This result is not entirely surprising for several reasons. First, the data cited earlier show that pilots using GPS and moving maps displays are not as cognitively involved in the navigation of the aircraft, cross checking the scene outside the window with sectional charts, and other navigation aids. Second, because terrain information and information regarding the aircraft's course are available on aircraft displays the pilot does not need to commit it to memory. However, should the display fail these two factors would work to undermine awareness of spatial position.

2.5 Effects on Pilot Risk Taking

The availability of more detailed weather information can increase the likelihood of pilots electing to fly in marginal conditions or use the information for other than its intended purpose. For instance, Latorella and Chamberlain (2002; Latorella & Chamberlain, 2002) reported pilots' tendency to use a Graphical Weather Information System (GWIS) tactically to avoid hazardous weather conditions even though the temporal or spatial resolution of the weather information was insufficient for this purpose. A survey of pilots participating in the Capstone project (FAA, 2002a) indicated increased risk taking. Under Capstone, 200 Alaskan aircraft were equipped with a multifunction display (MFD), GPS and datalink. A survey revealed that 84% of the pilots reported "there would be or already is" an increased tendency to fly under lower visibility conditions using the displays. Roughly half of the pilots agreed that there was an increased tendency to engage in other risky behaviors including flying at lower altitudes under low visibility conditions, flying closer to hazardous terrain features, etc. Nendick and St. George (1995; 1997) reported an increased likelihood of flying in bad or marginal conditions in pilots using GPS. This could further increase accidents involving pilots authorized to operate in visual meteorological conditions (VMC) flying into instrument meteorological conditions (IMC) (O'Hare & Wiegmann, 2003) and supports the need for training on decision making and risk management in the FITS curriculum.

2.6 Design of the Automation Interface

Another factor that can contribute to pilot error in automated aircraft is the design of the equipment interface. Both the FAA and Australian reports cited complex, cluttered, difficult to read displays, difficult to detect warnings, prompts or mode change (DTRDB, 1998; FAA, 2003c), the absence of standardization in the look of displays within and between manufacturers, as well as the functionality (similar controls that do different things) and system messages that are difficult to understand. These issues increase the difficulty of using the avionics, learning to use new or different suites, and increase the likelihood of negative transfer of learning where the correct response is directed at the wrong, but similar, target (control, button, or menu option). In addition, programming navigation instrumentation requires considerable attention increasing pilot head-down time at inopportune moments (FAA, 2002a, 2003c) thus decreasing a pilot's SA. This issue was cited as the predominant safety problem associated with TAAs. An effort spearheaded by the General Aviation Manufacturers Association (GAMA) Cockpit Standardization Group is addressing some of these issues. With industry and FAA participation, the group is developing standards for display design symbology, and the pilot interface (GAMA, 2004).

The training requirements of advanced navigation instrumentation like GPS are likely to be greater than for conventional navigation instruments. Modern avionics require mastery of software interfaces, procedures for programming avionics and navigation of menu hierarchies. (FAA, 2003c) investigated the usability of advanced GA cockpit navigation displays during simulated instrument flight conditions. They reported that after 2 to 3 hours of training, pilots still made errors and required assistance from experimenters to perform certain functions. A recent study found that pilots did not show proficiency in many IFR GPS skills even after ground study and five practice flights (Casner, 2004b). These data provide justification for the approach adopted by Australia wherein pilots are required to attend training and be flight tested before receiving an endorsement to use a GPS display for IFR conditions (CAAA, 2000).

2.7 Effects of Automation on Pilot Skills

Advanced avionics may have deleterious effects on flying skills as pilots spend increasing amounts of time in a supervisory/monitoring role rather than flying the aircraft. Interestingly, a significant number of pilots in an Australian survey (51%) agreed that they "preferred to hand fly part of every trip so as to maintain their skills, and 43% of believed that their flying skills had declined since they had started flying advanced technology aircraft (DTRDB, 1998). This finding is not unique having been reported previously by a number of researchers (Sherman, 1997; Wiener, 1988). Similar concerns have been expressed by GA pilots (Sclair, 2004) regarding the impact automation on basic instrument flight skills.

2.8 Research Questions concerning Pilot Instruction and the Use of Advanced Avionics

Due to the limited time available and cost of training, difficult decisions are required concerning what and how much time to spend on various aspects of automation during GA pilot training. For instance, what specific functions and features of the automation should training emphasize (FAA, 2002a)? Will instruction include training in the management of the information as a function of the phase of flight, including when to turn off automation and take control of the aircraft (Wiener, 1988)? In a related matter, will the nomenclature and organization of menus (menu hierarchy, options, etc.) be standardized across manufacturers or will each system require a pilot to receive a different endorsement? In the past, aircraft instrumentation looked and functioned similarly even if designed by different manufacturers. This is not the case when one compares the avionics provided by manufacturers such as Avidyne and Garmin. The design and organization of the interface, including menu structures, labels, etc., differ considerably. It is also possible that the failure modes and paths will differ, given that they reflect different automation philosophies and design. This is of concern in the case of a pilot who rents aircraft with different avionics suites. Research on mental models indicates that users do not necessarily create and maintain device-specific mental models (Norman, 1983). Also, the boundaries between mental models and their details can become fuzzy when they have not been used regularly. Recurrency and regular proficiency checks may be an important part of training to use advanced avionics.

3. SCENARIO- VERSUS PART-TASK TRAINING

There are several ideas that appear central to a scenario-based training (SBT) approach: 1) improving the transfer of training to real world flying by practice that emulates the execution of tasks in the real world, and 2) de-emphasis of traditional part-task training (PTT) involving the repeated practice of individual skills until proficiency, substituting practice of skills in context. This approach to training is strongly influenced by the constructivist approach to education (Cobb, Wood, & Yackel, 1991).

The constructivist approach rejects traditional models of teaching where knowledge is disseminated through lecture from a teacher to students who scrupulously write each spoken word. Complex concepts are mastered by learning individual facts or ideas that serve as the building blocks for later more advanced principles. Only later is the knowledge applied to the real world. The constructivist approach attempts to capitalize on students' natural curiosity and enthusiasm by introducing the big concepts and advanced ideas first, which create a context for concepts, and information that are the basis for advanced principles. To maximize learning, examples drawn from the real world are used in instruction. This allows the students to learn the concepts and see their relationship to larger encompassing idea rather than in isolation and out of context through rote memorization. Instead of lecturing, the instructor serves as a resource to students as they explore the problem, identify important concepts, and acquire the basic skills needed to address a specific problem. The purported benefit of this approach is increased learning by acquiring the facts and skills through experiential learning in a natural context. Applied to pilot instruction, the goal of scenario-based flight training is to acquire and refine skills and knowledge in the context of executing a flight to a particular destination. Thus, rather than flying to a practice area and executing approaches, turns, climbs, etc. these maneuvers are practiced in the order in which they naturally occur during a flight. This approach to training shares some philosophical positions with *Situated Learning* (Lave, 1988) and in practice is similar to a number of training methods including *learning by doing* (Gagne, 1962) and *whole-task training* (Lintern & Wickens, 1991).

3.1 SBT Training Programs

3.1.1 SBT in the Military

While the origin and history of SBT is beyond the scope of this report, it can be argued that the modern concept of SBT emerged from Naval Aviation. In response to relatively low kill ratios of air-to-air engagements achieved in Southeast Asia, the Navy created a graduate-level flight school to train Air Combat Maneuvering (ACM) and weapons systems employment. The Fighter Weapons Training School used actual aerial combat scenarios that pitted students against instructors who used enemy tactics and aircraft representative of the adversaries they would encounter during combat. By the end of the Vietnam conflict, naval air combat kill ratios had returned to the level achieved during World War II. The mantra "train like you fight, fight like you train," has since spread throughout the military to include almost every aspect of training for complex systems.

3.1.2 SBT in Commercial Aviation

SBT soon found its way into commercial aviation. In 1978, FAR 121 was amended to allow airlines to use Line Oriented Flight Training (LOFT) as part of recurrent training. LOFT is designed to simulate actual situations that pilots may encounter while "flying the line." The scenarios are systematic and include any and all actions taken during a flight including preflight checklists, weather briefings, and maintenance checks, as well as advanced training such as crew resource management and decision-making skills.

The use of SBT has become ubiquitous in military training. It is also being used in training of air traffic controllers, aircraft maintenance mechanics, law enforcement officers, and emergency medical first responders (Lai, Entin, Dierks, Raemer, & Robert, 2004). Despite the ubiquity of SBT and the vast amount of research pertaining to its implementation and use, we have not found empirical research demonstrating that SBT is a more effective or efficient means of training. A study showing improved transfer of training, reductions in cost- or improved safety would seem appropriate given the changes and investments necessary to implement a successful SBT program.

One disadvantage of SBT is that high cognitive workloads can interfere with the initial acquisition and the rate of development of individual skills (Nissen & Bullemer, 1987; van Merrienboerg, Kirschner, & Kester, 2003). This fact is reflected in the well-known phrase among flight instructors, "the cockpit is a terrible classroom". The activity and stress levels experienced during flight may offer few opportunities to reflect on one's decisions be they good or bad, thus potentially diminishing learning benefits. As outlined by Schneider (1985), SBT makes a number of assumptions regarding the presumed relationship between real-world training and training effectiveness that are suspect. It assumes, for instance, that the frequency of events and their order in the real world is optimal for learning, and that each scenario presents the opportunity to practice the essential components of each task (Schneider, 1985). "Learning by doing" may be a relatively inefficient way to acquire skills that have a significant procedural component: examples include communication with air traffic control, instrument flight, etc. In such instances, learning the list of actions to perform may contribute more to effective learning of the task than practice of the final task (Gagne, 1962). In addition, students may spend valuable time repeating skills that they have already mastered to get an opportunity to repeat those components that require further practice (Anderson, Reder, & Simon, 2000).

The benefits of SBT will depend on what skills or abilities one seeks to train. For instance, PTT has the advantage of reducing the cognitive demands associated with managing multiple tasks and typically results in faster skill development than is observed in whole-task training (Brown & Carr, 1989; Schneider, 1985). However, performing in a complex multi-task environment, like flying, requires the development of strategies for controlling attention and for coordinating numerous subtasks. The pilot must decide what to attend to and how much attention to allocate to each task. They must prioritize the tasks and decide how often to monitor specific gauges or instruments. These skills are more effectively trained as part of a whole-task than a PPT paradigm (Kramer & Larish, 1996; Schneider & Fisk, 1982). Recently, a hybrid training strategy called *varied-priority training* has shown promise as an alternative training paradigm (Fabiani et al., 1989; Gopher, Weil, & Siegel, 1989). Varied-priority training embeds PTT within whole-task training. Participants are asked to perform multiple tasks but the emphasis placed on the different task components is varied across training sessions or blocks. The advantage of this approach is that students learn how to coordinate and manage multiple tasks while reducing the processing loads that interfere with the acquisition of individual task skills. To date, the published studies show that varied-priority training is effective in training both component and task management skills (Gopher et al., 1989; Kramer, Larish, & Strayer, 1995) and may be applicable to more complex aviation training environments.

3.1.3 Comparison of LOFT SBT and FITS SBT

We have not identified any research that directly compared SBT to skill- or part-task training curriculums. The primary advantage of SBT is that the training environment is more realistic, more representative of the actual working environment; thus transfer of training may be greater. Although the FITS definition of SBT is very similar to that of LOFT training (see definitions below) and cites its use by commercial aviation and the military, the training methods described in the FITS literature differ in a number of ways from those used by the military and commercial aviation.

> (per Guidelines for Line-Oriented Flight Training, NASA Conference Publication 2184, p. 6,Lauber & Foushee, 1981).
>
> Line-Oriented Flight Training (LOFT): refers to the use of a *training simulator* and a highly structured script or scenario to *simulate* the total line operational environment for the purposes of training flight crews. Such training can include initial training, transition training, upgrade training, recurrent training, and special training, e.g., route or airport qualification training. The appropriate term should appear as a prefix with LOFT, e.g., "Recurrent LOFT," to reflect the specific application
>
> (per FITS Master Instructor Syllabus: TAA Scenario Based Instructor Guide V1.0, p. 3)
>
> Scenario Based Training (SBT): SBT is training system that uses a highly structured script of *real-world experiences* to address flight-training objectives in an operational environment. Such training can include initial training, transition training, upgrade training, recurrent training, and special training. The appropriate term should appear with the term “Scenario Based,” e.g., “Scenario Based Transition Training,” to reflect specific application

The main differences in definition include:

1. Use of simulator (LOFT) versus real world (FITS)
    - Simulation allows the behavior to unfold in such a way that the desired event requiring student response, decision is reached. Scenario developers emphasize the need to constrain the student’s behavior. Training in real world situations does not allow this level of control.

- To assure that the decision point is reached with some degree of reliability; scenarios should be performed in a simulated rather than real world environment.
- Development of scenarios is an iterative process which involves creation, evaluation, revision, reevaluation, etc.

2. Properties of highly structured scripts:

   - All LOFT scenarios and flight segments should be designed on the basis of a formal and detailed statement of *specific objectives* and desired end products.
   - Experience with LOFT indicates that scripts should be as detailed as possible
   - Communications should be scripted and utilized verbatim. The pacing and timing of the scenario should be precisely specified so that the instructor knows exactly when and how to introduce each element of the scenario.
   - Sub-scenarios should be designed in anticipation of crew actions. The only way to know what actions may be taken is to test and evaluate scenarios to identify the novel ways in which actors behave.
   - After development, scenarios should be carefully tested; revisions will almost always be required.

3. Effective only in context of a total training program:

   - It is not a replacement for maneuver oriented flight training or “batting practice.”
   - One of the absolute prerequisites of effective cockpit management is a highly skilled, highly knowledgeable pilot.
   - LOFT is not a training program, but rather a tool to contribute to the overall objectives of a program. (Lauber & Foushee, 1981)

Training programs, both military and civilian that have incorporated SBT into their curriculum have undertaken systematic and thorough analyses of the knowledge, skills, and procedures required by the domain. Information gathered from these analyses is used to design the scenarios in a manner that insures that the appropriate skills necessary for successful completion of the task are trained. Lai et al. (2004) used a battery of knowledge elicitation techniques drawing from a variety of experts (i.e. domain experts, psychologists, instructors, etc.) to identify fundamental activities and tasks required of the trainees. Researchers developing scenarios for military training have employed a variety of cognitive task analysis methodologies to identify critical training needs (Cannon-Bowers, Burns, Salas, & Pruitt, 2000; Cohen, Thompson, Adelman, Bresnick, & Shastri, 2000; Oser, Cannon-Bowers, Dwyer, & Salas, 1997). Researchers have also used detailed taxonomy of errors that are used to develop specific tasks within the scenarios (Greitzer, Pond, & Jannotta, 2004; Lai et al., 2004). The taxonomy goes beyond the mere classification of errors (such as that used in HFACS) to determine the cognitive basis of the error. By understanding the root-cause of the error, specific interventions can be designed into the scenario. Typically these various methods are used together as part of an iterative process to design and validate the individual scenarios. Our review of the training syllabi published on the FITS website give no indication that such analyses were used to select scenarios or identify content for training.

The military and commercial SBT use simulation because it allows a high level of control to ensure that the trainee confronts specific situations designed to aide in the development of certain skills. One of the problems of using time in the airplane to train complex skills like decision making is that no two flights are the same. As pointed out by Schneider (1985), in the real world, events are not designed to optimize learning. Consequently, the situations one seeks to create may not materialize due to weather, traffic, ATC requests or earlier decisions made by the student.

The canned scenarios published on the website are pre-scripted flight plans similar to a typical dual cross-country flight. FITS' curriculum may be more accurately described as structured cross-country flight training (SCFT). A name change is in order to reduce confusion and emphasize what is actually being done.

3.2 Research Questions Concerning Pilot Instruction

The literature describing FITS training provides few details regarding how to develop or manage a scenario in a SCFT program, or whether such a training program should be employed for all levels of pilot training. Given the literature reviewed above a number of important issues need to be addressed including identification of training objectives that would benefit most from SCFT, comparisons of SCFT and *varied-priority training,* and details of how to implement SCFT. The following questions address these and related issues.

1. How will scenarios to be selected?
2. What properties should individual scenarios contain?
3. What skills and competencies should a pilot have when training shifts to scenarios?
4. Will SCFT be used for *ab initio* training or will it be used exclusively for instrument flight training or transition training?
5. How will pilot performance be measured?
6. What type of feedback will the pilot receive and when will s/he receive it?
7. How will performance deficiencies be addressed: by repetition of the scenario or by practice on the specific deficiency?
8. How frequently should individual skills be represented in a scenario to ensure competency?
9. What new skills will SCFT require of the flight instructor community?
10. What guidance materials will be available to aid flight instructors in developing and managing SCFT?

4. DECISION MAKING

A comparison of accident rates across different sectors of aviation shows that GA has a significantly higher accident rate than both commercial and corporate aviation (NTSB, 2004). The technologies being introduced to GA cockpits may reduce GA accident rates through the touted benefits of improved SA. They may positively impact a number of leading causes of GA accidents including controlled flight into terrain and weather related decision making including 'VFR into IMC' (GAO, 2000). Although, ≈2% of GA accidents are weather related, they account for 11% of GA fatalities that occurred between 1990 and 1997 (Wiegman & Goh, 2000).

Access to information alone does not represent a sufficient basis for expectations of enhanced safety. Central to the FITS strategy is a general emphasis on higher order skills including risk management (RM), situational awareness (SA), aeronautical decision making (ADM) and single-pilot resource management (SRM). This focus is justified given the central role that these skills are believed to play in accidents. An early study by Jensen and Benel (1977) found that 51.6% of fatal accidents (between 1970-1974) were associated with decision errors. More recently, Weigmann and Shappell (1997) reported that decision errors remain a major causal factor in 30% of GA accidents.

4.1 Training in Judgment

Although the accident statistics identify a weakness in pilot decision-making, it is unclear why GA pilot training programs fail to teach this skill. The FAA requires pilot instruction in aeronautical decision making but offers minimal guidance to flight instructors of how this should be done. To date, most safety-related initiatives addressing weather-related accidents have consisted of motivational and experiential based approaches (Wiggins & O'Hare, 2003). However, training programs that identify dangerous behaviors (i.e., *scud running*) and advise individuals of the dangers of such behavior have little effect (Halpern, 1998, 2000). The absence of transferability of knowledge to real world settings may result from: 1) content (i.e., emphasis on wrong knowledge and/or skills) and 2) pedagogical style (i.e., part-task training versus SBT). If pilot decision-making failures were related to one or both of these factors then the primary focus of future research would be to identify the fundamental skills and knowledge a pilot should master and the form that instruction should take. At present, the literature does not identify which is the primary culprit in failures of GA decision making.

The FITS training program assumes that both factors are implicated in accidents and emphasizes SCFT, training in risk management, situational awareness, resource management, and aeronautical decision making. Given this emphasis, several issues need to be addressed regarding how training in decision making will be performed (other than it being scenario-based):

1. What are the specific critical thinking skills which are not currently taught that support good decision making?
2. What types of training experiences facilitate development of critical thinking skills?
3. How can critical thinking skills be evaluated?

The literature on FITS provides no answers to these questions but suggestions may be found in the literature related to expert performance and training of critical thinking skills. Some of this literature is discussed below.

4.2 Expert Performance

We often solicit the opinions of “experts” when confronted with difficult problems or when seeking confirmation of decisions. We believe experts possess skills that allow them to identify correct, more efficient, or alternative solutions quickly and reliably. Studies of experts in other domains, including chess and medicine, have identified a number of skills that distinguish experts from novices. For instance, expert chess players were able to consider more options and their potential outcomes (Charness, 1981) than novices. Experts remembered the positions of chess pieces even after a brief exposure (Chase & Ericsson, 1982; de Groot, 1978). Randomly positioning the pieces nullified the experts advantage.

The experts’ memory advantage appears to be related to their more efficient encoding of information in long-term memory (LTM) that circumvents capacity constraints at earlier stages (i.e., short-term memory, STM) of information processing (Chase & Ericsson, 1982). Avoiding STM capacity limitations enables experts to resume a task after interruptions from unrelated activity that would otherwise interfere with the maintenance of information in STM (Charness, 1991). This may be the basis of expert pilots’ ability to handle multiple task demands effectively. Ericsson and Charness (1994) provide evidence that experts store and index information in LTM in a qualitatively different manner than novices’ allowing experts to readily recognize patterns by comparing the present circumstances to exemplars in memory. This skill could be vital when time-consuming deliberation of options (i.e., application of critical thinking strategies) is impossible and makes performance less susceptible to disruption by stress or other tasks. Experienced pilots exhibit similar memory skills that allow them to store flight related information without decay (Endsley, 1995). Interestingly, the improved memory skills of experts appear to be domain specific and they do not generalize to other tasks (Ericsson & Charness, 1994).

Experts’ ability to select only task-relevant information facilitates their management of multiple demands. They are more selective about the details they commit to memory. Medical experts out perform medical students in identifying and recalling important pieces of presented information (Boshuizen & Schmidt, 1982; Chase & Ericsson, 1982), whereas medical students could recall more information in general. Studies of pilots corroborate these findings. Beck (Wiggins & O'Hare, 2003) and Rockwell and McCoy (1988) found that experienced pilots were more efficient in acquiring and evaluating details of weather-related information. These and other studies suggest that novices lack an understanding of the utility of different cues (Schvaneveldt, Beringer, Lamonica, Tucker, & Nance, 2000; Wiggins & O'Hare, 2003).

Finally, experts employ different metacognitive skills in monitoring their own thinking process. They check progress made toward a goal, evaluate accuracy, make decisions about the use of time and mental effort, and search prior experience to find instances of situations similar to the current one (Cohen et al., 2000; Freeman & Cohen, 1994; Halpern, 1998). Experts are able to refine their understanding and knowledge by active learning strategies. Individuals become better thinkers and learners by developing the habit of monitoring their understanding and judging the quality of their learning.

4.3 Critical Thinking Skills Training

In light of what we know about the critical thinking skills of experts, the question arises whether novices can be taught to behave like experts? If so, can it be shown that the skills transfer to real world conditions? A number of studies report successful transfer of critical thinking skills to novices (see Halpern, 1996) and there is evidence that pilots who received decision-making training demonstrate better judgment (Buch & Diehl, 1984). Recently, the U.S. Army funded research to develop a critical thinking skills training program for battle field decision-making (Cohen et al., 2000). A theory of the cognitive skills necessary to make decisions on the battlefield was developed, as were training materials and methods for delivering the training on a CD or via the World Wide Web. The training was later utilized and found to be effective by the U.S. Army. Cohen et al. (2000) identified several essential features of critical thinking training, including: 1) explicit instruction and practice, 2) prior instruction on concepts and processing strategies to facilitate learning, 3) realistic, non-routine situations that are more challenging than an individual would likely face and 4) feedback focused on appropriate processes rather than correct responses. The components of critical thinking skills training proposed by Cohen et al (2000) are similar to those outlined by Halpern (1998). One important goal of this training is to facilitate development of the ability to rapidly recognize and respond to emergencies. Klein (1998) has stressed that this ability—the ability to rapidly recognize cues and identify the current situation as an example of a prototype—is what distinguishes experts from non-experts.

The training approach described above can be contrasted with a *normative* approach (Von Neumann & Morgenstern, 1953), which describes how an individual “should” choose between two alternatives under ideal conditions given the *utility*, or worth of a specific outcome to the decision maker. Training content includes logic and decision theory, calculations of probabilities of different alternatives and their utility when outcomes are uncertain. Training in normative decision-making may not be particularly useful in emergency conditions where responses must be immediate, alternatives and their probabilities are unknown and the operators’ capacity to entertain different options is compromised by stress, the capacity of STM, and the demands of other tasks. However, tools are needed to aid pilots in making decisions that are not under time constraints or high levels of stress, such as risk assessment. The Personal Minimums Checklist is an example of one such tool. It applies a normative approach in a tool designed to evaluate a variety of risk factors in preflight checklist. The development, use (by ab initio and experienced pilots) and effectiveness of such tools need further study.

It is important to acknowledge potential limitations of relying on expert reasoning processes as a basis for modeling the behavior of novices. Experts are not infallible and often fall short of optimal performance (Shanteau, 1992). Individuals may rely on intuition and gut feelings to make important decisions, or they may resort to heuristics to reduce the mental workload associated with complex reasoning tasks (Dhami, 2003; Tversky & Kahneman, 1973, 1974). Consequently, it is important that the utility of the cues and strategies reported by experts be independently confirmed. In many situations, these heuristics will result in correct decisions, especially when the decision maker is knowledgeable about the domain. However, heuristics often fail when applied to new problems or domains.

Finally, relying on experts requires that one identify and capture the performance of experts by selecting a criterion for distinguishing between novice and experts that is not arbitrary and that captures the essential features of expert performance in the area of interest (i.e., weather decision-making) (Ericsson & Charness, 1994). In aviation, novice and expert pilots are typically distinguished on the basis of flight hours or type ratings. These criteria are essentially arbitrary and do not account for the varied types of experiences that are presumably the basis of expertise.

4.4 Research Questions Concerning Pilot Instruction and Training on Decision Making

Although studies have demonstrated that novices can acquire some of the sophisticated cognitive abilities and skills of experts, to date no one has developed training strategies that support the rapid development of these abilities (Ericsson & Charness, 1994). Typically, extended practice (>50 hours) is necessary to approach performance levels comparable to that of experts in restricted domains. Achieving the level of competency of experts may take years of experience. In light of this, what should be the goal of decision-making training for a pilot completing *ab initio* training? Bell and Mauro (1999) propose a training strategy that “accelerates the transition from novice to expert with modeling and efficient learning experiences and direct teaching of support structures (e.g., critical thinking skills) while teaching rules to keep the novice safe.” Modeling in this context refers to learning decision making by observing the behavior of more experienced pilots or through demonstration.

Any proposed method of decision-making training should satisfy several criteria in order to have a chance of being adopted by the flight instructor community:

1) Instruction should not increase the length of pilot training and thereby the cost to the student.
2) Teaching the relevant subject matter should not require additional skills of Part 61 and 141 flight instructors.
3) Proficiency in decision-making should be measurable.

4) The cost of training materials to the instructor and student should be minimal.
5) Transferability of skills to real world should be demonstrable.

5. STANDARD VERSUS COMBINED PRIVATE AND INSTRUMENT RATING

A combined curriculum was originally developed under the Advanced General Aviation Transport Experiments program (AGATE, 2001) with the stated goal of reducing training time and cost by 25%. An evaluation of this combined curriculum was attempted but it was largely unsuccessful due to a number of unforeseen problems out of the experimenters' control. Consequently, only 8 of the 81 students who originally agreed to participate in the evaluation completed the flight training program. Summary data from the report showed that the students in the combined curriculum required 45% fewer trials to meet Practical Test Standards (PTS) for maneuvers tested in the study but required 20 more hours than those in the standard flight training group to pass the final check ride. No meaningful conclusions can be drawn from this data given that six students completed the standard flight training program and only two completed the combined training program. Nevertheless, the AGATE report (AGATE, 1999) concludes that the combined training program "represents a *very significant reduction* in the amount of training required" (italicized in the original document).

Interest in combining initial pilot training and instrument flight training is not new. A number of earlier studies (Creelman, 1955a, 1955b, 1955c, 1956; University of Illinois Institute of Aviation, 1956); (Jolley, 1958) conducted by military and civilian organizations have evaluated integrated training programs. Perhaps most pertinent is a report by the University of Illinois Institute of Aviation where they sought to train private pilots within an allotted 40 hours who could pass the private pilots license exam and demonstrate an "appreciable" ability to fly on instruments. All 18 students involved in the study successfully completed the program.

Recently, Middle Tennessee State University received federal funding under the SATS program to construct and evaluate a flight training resulting in combined private and instrument rating for TAA's (P. Craig, personal communication, November 30, 2004). The program employs a detailed FITS inspired curriculum. The purpose of the research is to determine whether training using advanced avionics and an integrated curriculum is superior to a traditional training program using aircraft equipped with standard avionics (i.e., steam gauge). Proficiency will be evaluated in terms of performance on the PTS and compared to historical data. Although, the research may identify differences between the two curriculums it does not allow any conclusions to be drawn regarding whether the differences are attributable to the syllabus, the avionics technology, or the instructors due to the experimental design.

6. USE OF PERSONAL COMPUTER-BASED AVIATION TRAINING DEVICES (PCATD)

PCATDs may provide an alternative means of reducing pilot training costs and of training higher-order pilot skills. The findings of FAA-funded research (Taylor et al., 2003) indicate that practice on a PCATD is at least as effective as practice in an airplane or in a Flight Training Device (FTD) in meeting FAA recency of experience requirements for instrument flight. PCATDs are a combination of software and hardware packages for a standard home personal computer that emulate an airplane cockpit and controls (FAA, 2002b). FTDs emulate a specific cockpit environment and typically have a higher level of fidelity than PCATDs. However, FTDs are more expensive, costing as much as $30,000, while a PCATD costs $5,000 or less. In addition to being more affordable to flight schools and individual instructors, PCATDs are also less costly to maintain.

Current FAA regulations (advisory circular 61-126) specify certification requirements for PCATDs along with the standards for which a PCATD can be used in lieu of actual flight. For Part 61 schools, 20 hours of FTD or flight simulator time can be used in place of actual flight time. Of those 20 hours, 10 can be accrued on PCATDs. For Part 141 schools, up to 15 hours of can be simulated. Of those 15 hours, 10 can be accrued on PCATDs. The PCATDs appear to hold promise as a tool for improving training effectiveness and efficiency while controlling time and costs.

Research has shown that PCATDs are effective training tools for a number of skills including teaching new pilots instrument tasks (Taylor et al., 1999) and some aircraft maneuvers (Ortiz, 1994). There is evidence that training costs may be reduced even after the time on PCTAD is taken into account (Ortiz, 1994; Taylor et al., 1999). Ortiz (1994) trained college students with no previous flying skills to perform a simple maneuver, either in a PCATD or in an airplane. The PCATD did not decrease the total time of training; however a cost benefit analysis showed that using a PCATD would save the pilot money by eliminating actual flight time. Taylor and colleagues (1999) investigated transfer of training and found that most of the benefits of training on a PCTAD are obtained in the early stages, with little transfer of training benefit when reviewing already learned tasks, unless some time has passed since the task was last performed. PCATDs have also been shown to be useful in maintaining instrument proficiency (Talleur et al., 2001). The PCTAD may be effective in maintaining proficiency in skills that are more discrete (i.e., procedural), and which degrade more over time if unpracticed (Mengelkoch, Adams, & Gainer, 1958). This could be important in modern avionics suites that require the user to navigate menu structures and program the navigation computer. (FAA, 2003c) found that 50% of the pilots in their study required assistance in programming a GPS system. Although the pilots in their study had varying degrees of familiarly with the system, this finding is important because pilots may forget the complex programming procedures for their avionics if they fly infrequently.

Interestingly, most PCATD studies (Koonce & Bramble Jr., 1998; Talleur, Taylor, Emanuel Jr., Rantanen, & Bradshaw, 2003; Taylor et al., 1999) report that positive transfer of training effects are obtained for instrument maneuvers that entail procedural components (Smode, Hall, & Meyer, 1966), and less transfer for flight tasks that are more perceptual-motor in nature. A GAO (1999) report on PCATDs cites comments by experts (Talleur et al., 2001) that "the main value of PCATDs is in teaching procedures and concepts, rather than the complete set of skills needed to fly." A similar finding was reported for PCTAD training on rotary aircraft (Johnson & Stewart, 1999). This suggests that PCATDs are less effective in training of the "Physical Airplane" or the "stick and rudder" aspect of flying a plane (Dennis & Harris, 1998). This is reflected in the way PCATDs are being employed by flight training schools. A survey by (Wiggins, Hampton, Morin, Larssen, & Tronscoso, 2002) found that PCATDs were primarily used for private pilot and instrument training with a focus on procedural knowledge.

To date, studies of PCATDs clearly demonstrate flight training benefits, and there is limited evidence that they will also reduce the cost of training. The PCATD can help maintain procedural skills and may also prove effective in training higher-level skills such as decision making. A number of recent studies suggest that PC scenario based training can be effective in improving decision making skills of first responders (EMS) (Lai et al., 2004), security personnel (Greitzer et al., 2004), and army infantry (Cohen et al., 2000).

7. CURRENT STATUS OF THE FITS PROGRAM

The FITS program proposes to modernize GA pilot training by adopting a system safety approach and emphasizing the use of technology, training in risk management, and emphasizing SCFT. Given this review of the pertinent literature we believe that much work needs to be done to provide the details of the specific training programs that would justify this initiative. For instance, FITS related publications provide little guidance on training issues related to advanced avionics or how to specifically improve higher-order cognitive skills related to aeronautical decision making, risk management, situational awareness, and single-pilot resource management. An assumption underlying much of FITS is that "scenario-based training" will improve pilot decision making without identifying the specific knowledge or cognitive skills that are to be trained. Also, the flight instructor is provided few tools to adequately discriminate between good and bad skill performance.

To date we have found little evidence that the published FITS training syllabi heed past lessons learned or were influenced in any large measure by pertinent research findings from decision-making, training, human factors and automation literature. It is hoped that these issues will be addressed in the near future. Nevertheless, the training syllabi are available and are being used by a number of aircraft manufacturers. Although, the FITS approach was to be employed in all of GA flight training it is currently limited to training pilots transitioning to TAAs.

The extant research literature does provide guidance to the developers of the FITS training program on many issues; however, there exist a number of significant gaps in our knowledge related to the effectiveness of different types of training, critical thinking skills training, training objectives for advanced avionics, effects of automation on pilot skills, and the potential benefits of PCATDS for pilot training. To aid this endeavor we have outlined five research requirements (listed below) pertaining to each of these areas for future FAA research funding. A more detailed description of each research requirement can be found in Appendix A.

Comparison of structured cross-country flight training (SCFT) and standard flight training:

a. Does SCFT and standard flight training result in comparable levels of proficiency?
b. What skills are best acquired via SCFT vs part task training (PTT)?
c. When in pilot training should training shift from PTT to SCFT?
d. Is a hybrid training strategy (i.e., varied-priority training) a viable alternative to PTT and SCFT?

Development of critical thinking skills training for general aviation

a. What are the fundamental skills of effective decision making, risk management, resource management and situational awareness?
b. What should be the goals of critical thinking skills training for different levels of pilot skill including *ab initio* and instrument license?
c. How do you increase the transferability of the skills to real world conditions where decisions are made under stress and time pressures?
d. What is the impact of advanced on avionics on pilot decision making?

Identification of learning objectives for aircraft equipped with advanced avionics

a. What are the skills and knowledge associated with using steam gauge versus glass cockpits and how do they differ?
b. How do the task demands associated with each differ as a function of phase of flight?
c. What core knowledge should a pilot of glass cockpit demonstrate?

Understanding the effect of automation on piloting skills

a. How does the use of automation affect a GA pilot's manual flight skills?
b. How is pilot competency in programming advanced avionics affected by layoffs of different duration?
c. Does training in automation philosophy improve the use of automation?
d. What is the potential for positive or negative transfer of learning between advanced avionics developed by different manufacturers?

Use of PCATDs in pilot training
  a. What pilot decision making skills and knowledge can be effectively taught using PCATDs?
  b. Does a PCATD reduce of the time and cost of pilot training?

Finally, noticeably absent from the FITS program literature is a statement of a target goal either in terms of reduced GA accidents or increased training effectiveness as measured by time, cost or proficiency. Given the absence of any specific goals, one might argue that there is little to justify the expenditure of time and money needed to develop the training program. The absence of specific targets or performance goals will make evaluation of the success or failure of the FITS program difficult to ascertain.

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9. APPENDIX A

Comparison of Traditional Flight Training Program to that of a Structured Cross-country Flight Training Program

Sponsor: XXXX Sponsor POC: XXXX

Requirement Statement: This study will compare the traditional flight training program to that of a structured cross-country flight training program, as described by FAA/Industry Training Standards (FITS).

Background: The FAA Industry Training Standards (FITS) program suggests that traditional skill-based curriculums are no longer adequate for pilot training given the emergence of Technically Advanced Aircraft (TAA). The advent of TAA with advanced avionics suites place new demands on pilots, which are not addressed by current training curricula. FITS intends to implement SCFT in an effort to address these needs.

The proposal to shift pilot training to SCFT requires evidence demonstrate equal or greater pilot proficiency. To date no such evidence exists. Recently, a hybrid training strategy called *varied-priority training* has shown promise as an alternative training paradigm. Varied-priority training embeds PTT within whole-task training. Participants are asked to perform multiple tasks but the emphasis placed on the different task components is varied across training sessions or blocks. The advantage of this approach is that students learn how to coordinate and manage multiple tasks while reducing the processing loads that interfere with the acquisition of individual task skills. Published studies show that varied-priority training is effective in training both component and task management skills and may be applicable to more complex aviation training environments. Currently, there is no published research that directly compares a SCFT program to traditional part-task or varied-priority training programs. More specifically, given the cost-sensitive nature of general aviation pilot training, it is important to identify the effectiveness of a SCFT program as compared to traditional flight training or a varied-priority training program?

Output: A comparison of the effectiveness of a traditional part-task flight training program to SCFT and the hybrid varied-priority training. Analysis should include a comparison of average training time (including ground and flight instruction), training costs, and pilot performance on standardized FAA exams (written, oral, and flight).

Development of Critical Thinking Skills Training Program for General Aviation

Sponsor: XXXX Sponsor POC: XXXX

Requirement Statement: The goal of this project is to improve GA pilot training by identifying the critical thinking skills to support effective decision making and develop a program to train and evaluate those skills.

Background: Accident statistics identify a weakness in pilot decision making but it is unclear why GA pilot training programs fail in instructing these skills. To date most safety-related initiatives have consisted of motivational and experiential based approaches; however, training programs that identify dangerous behaviors (i.e., *scud running*) and that advise individuals of against such actions are not very effective.

New avionics technologies are supposed to improve pilot situational awareness and enable better decision making. However, the new information sources may bias decision making in unexpected ways. For example, research has identified a tendency among pilots to use a Graphical Weather Information System (GWISs) tactically to avoid hazardous weather conditions even though the temporal or spatial resolution of the weather information was insufficient for this purpose. Evidence of increased risk taking has been reported by pilots interviewed as part of the Capstone project. Under Capstone, 200 Alaskan aircraft were equipped with a multifunction display (MFP), GPS and datalink. Pilot self-reports revealed that 84% of the participating pilots reported that "there would be or already is" an increased tendency to fly under lower visibility conditions using the displays. Roughly half of the pilots agreed that there was an increased tendency to engage in other risky behaviors including flying at lower altitudes under low visibility conditions, fly closer to hazardous terrain features, etc. New pilot training curriculums being developed under the FITS program will attempt to address these issues by focusing on the training of risk management, information management, and aeronautical decision making. At present it is unclear how training in decision making and other critical thinking skills should be implemented. More specifically, what judgment or metacognitive skills should be the focus of training and how can the effectiveness of such training could be evaluated.

Output: A report that describes the rationale, development, and evaluation of a program to train critical decision-making skills. Recommendations should include how such training could be integrated within constraints of existing GA pilot training programs including *ab initio*, instrument and recurrency training.

Identification of Learning Objectives for Aircraft Equipped with Advanced Avionics

Sponsor: XXXX Sponsor POC: XXXX

Requirement Statement: Identification of the unique knowledge and skills needed to operate a GA aircraft with advanced avionics

Background: The FITS (FAA/Industry Training Standards) proposes to modernize aviation pilot training while also improving training effectiveness and safety. The FITS training program will first target new and experienced pilots who are transitioning to technically advanced aircraft (TAA) and who use the aircraft for transportation rather than recreation. TAA like the Diamond DA-40 come equipped with integrated multifunction displays capable of displaying a variety of new information sources (GPS, near real time weather information, terrain maps) in addition to standard aircraft instruments. It is believed that this information will improve pilot situational awareness and thereby reduce accident rates. These developments will require the creation of new pilot training programs for initial, transition and recurrent training. The new training programs developed by FITS will emphasize single-pilot resource management as the pilot of newer aircraft must monitor, select and integrate information from multiple displays.

A pilot of these aircraft will need to manage more information sources that can increase work loads during critical phases of flight or during emergency situations. The availability of more information sources will require training in the management and prioritization during different phases of flight. Researchers have identified a number of important issues related to pilot training and use of advanced avionics. These issues include problems with mode awareness, poor pilot understanding of the design and operation of the automation, new error paths, degradation of basic instrument skills and other manual flying skills, tendency for pilots to continue to program their selves out of trouble rather than turning off automation and taking control. There is also some evidence that situational awareness may be diminished under some circumstances in aircraft with advanced avionics. These findings suggest that operating an aircraft with advanced avionics may require a different subset of skills than flying an aircraft equipped with steam gauges.

Output: The research report identifying the relevant skills and knowledge needed to operate a highly automated aircraft, an evaluation of the impact of advanced avionics on situational awareness, manual and instrument flight skills, and recommendations regarding proficiency requirements for use of advanced avionics.

Understanding the Effect of Automation on Piloting Skills

Sponsor: XXXX Sponsor POC: XXXX

Research Statement: This study will investigate 1) the impact of automation on pilots' manual flight skills 2) how pilot competency in programming advanced avionics is affected by layoffs of different durations and the potential for positive or negative transfer of learning between advanced avionics developed by different manufacturers.

Bacground: *Glass cockpits* similar to those currently being introduced in GA first became widely available in commercial aviation with the introduction of the Boeing 757/767 and Airbus A310/320. The transition to glass cockpits can be challenging as pilots have reported that the switch to a highly automated aircraft is more difficult than the transition between aircraft with conventional avionics Although the level of automation in commercial aviation and GA differ in terms of degree and sophistication many of the problems associated with automation identified in FAA technical reports and in academic and government technical literature are pertinent to GA. These problems include degradation of basic instrument or other manual flight skills, potential for negative transfer of learning between different avionics suites produced by different manufactures, and declines in pilot programming of avionics following periods of low flying activity. Understanding the impact of automation information is important for providing guidance to the FAA and pilots regarding potential problems in use of automation.

Output: A report that describes 1) the impact of automation on pilot manual flight and instrument skills, 2) the effects of periods of low flying activity on pilot recall of programming procedures and use of automation, and 3) negative or positive transfer of learning resulting from the use advanced avionic developed by different manufacturers.

Development and evaluation of Personal Computer-based Aviation Training Devices (PCATDs) for Training in Decision Making.

Sponsor: XXXX Sponsor POC: XXXX

Requirement Statement: This study will compare the effectiveness of PCATDs in training situational awareness, aeronautical decision making, risk management, and single-pilot resource management.

Background: FAA funded research has shown that practice on a PCATD is at least as effective as practice in an airplane a Flight Training Device (FTD) in meeting FAA recency of experience requirements for instrument flight. The PCATDs also appear to hold promise as a tool for training decision making for ab initio pilots.

Research has shown that PCATDs are effective training tools for a number of skills including teaching new pilots' instrument tasks and some aircraft maneuvers. There is some evidence that training costs may be reduced even after the time on PCTAD is taken into account. An investigation of transfer of training showed that most of the benefits of training on a PCTAD are obtained in the early stages of training and that there is little benefit (in terms of reduced transfer of training) when reviewing already learned tasks unless some time has passed since the task was last performed. PCATDs have also been shown to be a useful tool in maintaining instrument proficiency.

Output: 1) Development of a PC/Web based pilot decision making training program and, 2) An evaluation of the effectiveness of such training.