Cognitive skill degradation: Analysis and evaluation in flight planning

by

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

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ABSTRACT

The objective of this work was to identify the cognitive skills needed in flight planning and evaluate how they degrade over time. Cognitive skill degradation has been identified as a potential issue in information automation systems that manage and present relevant information to the flight crew. Much as physical piloting skills can degrade over time due to lack of practice, the cognitive skills associated with many aviation tasks may degrade over time if these skills have been automated and pilots no longer have a chance to practice them. To further evaluate cognitive skill degradation in information automation, two studies were conducted. The first study was an Applied Cognitive Task Analysis to find what decision points and skills are involved in flight planning. The second study examined the effects of skill degradation on performance, workload, and completion time, as a result of differing levels of reliance on automation. The first study determined that the skills found to be particularly vulnerable to skill decay were those that involved calculation and estimation. The second study found that automation as an aid did not suffice as a method for maintaining skills for flight planning tasks. It also showed that after a period of nonuse for the manual method, completion time and workload increased. The results of these studies provide insights into cognitive skill degradation in regards to aviation. Calculation and estimation were found to be particularly vulnerable to skill degradation. It was shown that after nine weeks the cognitive skills of calculation and estimation degraded for flight planning tasks. Additionally, it was found that using an automation aid did not suffice as a method for maintaining skills. By understanding which cognitive skills degrade as a result of reliance on automation, designers can develop mitigation techniques to counter cognitive skill degradation.

CHAPTER 1. INTRODUCTION

Problem Statement

The objective of this work was to identify the cognitive skills needed in flight planning and evaluate how they degrade over time. Cognitive skill degradation has been identified as a potential issue in information automation systems (Dorneich, McGrath, Dudley, & Morris, 2013; Hendrickson, Goldsmith, & Johnson, 2006; Archer, 2012; Casner, Geven, Recker, & Schooler, 2014).

The use of highly-automated systems in advanced cockpits is increasing in modern aircraft (Gillen, 2008). Automation is “a device or system that accomplishes a function that was previously, or conceivably could be, carried out by a human operator” (Parasuraman, Sheridan, & Wickens, 2000). Current display and control system technology on aviation flight decks has automated many of the tasks that pilots used to do on their own, resulting in lower workload, fewer errors, and increasingly safer and efficient airline operations (Kaber & Endsley, 2004; Wiener et al., 1991; Sherman, Helmreich, & Merritt, 1997; Helmreich, & Merritt, 2000).

These systems are highly reliable and failures are extremely rare (Endsley, 2017; Wickens, Mavor, & McGee, 1997). As a result, many pilot responsibilities have shifted from direct, hands-on control of the aircraft to that of a systems monitor, intervening only when the primary system fails or cannot perform a given task as well as the human operator. Due to this lack of practice, there is decreased situation awareness (SA), overreliance on automation, and the potential for cognitive skill degradation (Dudley et al., 2014). Without the consistent use of the piloting skills developed during training, pilot physical skill degradation is a looming and familiar issue (Parasuraman, Sheridan, & Wickens, 2000). With limited practice, these skills can degrade over time, therefore, recurrent training is essential for maintaining these skills. Technical failures in advanced glass aircraft negatively affect the flight deck instrumentation. When these failures transpire, pilots are required to use their basic manual instrument skills to safely land the aircraft (Gillen, 2008).

Automation in aviation is separated into three distinctive categories: information automation (IA), control automation (CA), and management automation (MA). Information automation involves managing and presenting relevant information to the flight crew (Abbott, McKenney, & Railsback, 2013). Control automation incorporates automation of the devices which directly impact the aerodynamics of the aircraft (Fadden, 1990). The third distinction was introduced by Billings (1997) which was management automation. This takes into account completing a mission efficiently and safely.

Information automation is unique from control automation and management automation that are also found on the flight deck. Whereas CA relates to the direct control (dynamics) of the aircraft and MA deals with mission oversight, IA encompasses all aspects of data collection (e.g., from sensors, databases, and human input), processing (e.g., filtering, prediction from models, and varying levels of abstraction), and presentation to the human operator(s) through any appropriate modality (e.g., visual, auditory, and tactile) (Billings, 1997; Nakamura, 2013). Information automation aids the flight crew in their task performance, decision making, and position awareness. Information automation involves automating some of the cognitive elements of a task that a human operator would usually perform. As such, it has distinct human factors issues that must be addressed separately from CA and MA issues. IA systems development are increasing due to the increasing demand for air travel (Dudley et al., 2014).

While IA in aviation is not a new concept, the amount of empirical data on the effects of these systems on the retention of cognitive skills is lacking. Anecdotal evidence that this is a potential safety issue is available through reports on the Aviation Safety Reporting System (ASRS) as well as National Transportation Safety Board (NTSB) accident investigation reports. Measurement and analysis of the effects of IA on cognitive performance is an important first step in understanding the root causes of these types of errors and in addressing them through mitigation recommendations that should be considered during the design of these systems.

For decades, the FAA has been concerned with the extent to which physical skills of pilots may degrade over time, particularly for those who fly periodically (Prophet, 1976; Billings, 1991). CA was introduced to ease the pilot workload of physically piloting the aircraft. Flight management systems (e.g., "autopilot") were developed to control aircraft pitch, roll, and yaw. As reliance on these systems increased, the opportunity to practice manually flying the aircraft decreased.

While the retention of direct, physical hands-on piloting skill is essential in responding to emergency situations, equally as critical is the retention of the cognitive skills. These skills allow pilots to maintain situation awareness at all times, quickly assess new situations, and make the best decision from the options available to them. As the implementation and responsibilities of automation systems are increasing, human operators are losing SA. One of the primary goals of IA systems is to reduce pilot workload and potential for error by offloading the cognitive tasks of the pilot. These systems leave pilots with the role of monitoring and intervening when necessary. However, monitoring highly reliable systems has been shown to be difficult for humans (Bainbridge, 1983; Parasuraman, Molloy & Singh, 1993). As pilots perform these tasks, the skills suffer from a lack of practice, and the potential for error when automation fails increases.

Cognitive skills are “the core skills your brain uses to think, read, learn, remember, reason, and pay attention” (LearningRx, n.d.). Tasks which are affected include: memory recall, calculations, situation assessment, making decisions, understanding alerts and warnings, predicting future states, and generating action plans. Cognitive skills require declarative and procedural knowledge. Van Merriënboer (1997) defines the term declarative knowledge to refer to representations of objects and events, and how they are related to other objects and events. It can be distinguished as “knowing what.” The term procedural knowledge is used to refer to the processes based on representations and procedures. It is the knowledge that can be characterized as “knowing how” the knowledge that allows us to do things. Procedural knowledge is goal-specific and more difficult to articulate and verbalize in comparison to declarative knowledge (Van Merriënboer, 1997; Anderson, 1989). It is important to understand the different types of knowledge, how they are acquired, and how they decay in order to mitigate the loss of knowledge.

Skill decay concerns “the loss or decay of trained or acquired skills (or knowledge) after periods of nonuse” (Arthur, Bennett, Stanush & McNelly, 1998, pp. 58). Cognitive skill degradation is the reduction of thinking, reasoning, and decision-making skills. If a function which involves decision making is consistently executed by automation, it will eventually lead to human operators’ loss of skills in performing that function (Parasuraman, Sheridan, & Wickens, 2000). It has been found that if practicing of a task is suspended, forgetting happens (Ebbinghaus, 1885; Argote, Beckman, & Epple, 1990). Forgetting occurs when performance is delayed regardless of if there is an interference of the task (Anderson, 1985;

Kolers, 1976). A study by Argote, Beckman, & Epple (1990) indicated a rapid rate of learning depreciation over periods of non-practice, in some cases as much as 97% following a one year period (Gillen, 2008). Another study found that after regular practice of a skill stopped, considerable retraining of the skill was necessary (Wagner, 1995; Gillen, 2008).

Frequently, loss of situation awareness is a contributing factor for accidents (Endsley, 1996). SA, a function of IA systems, is a person's mental model of the world around them. It is critical to effective decision making and control in dynamic systems. This construct can be impacted by the implementation of automation systems (Endsley, 1996). The accident at the Three Mile Island nuclear power plant was attributed to an over-ride by the human operators of the automated emergency handling system. The operators interpreted the displayed information regarding an excessive coolant level when in reality the problem was too little coolant (Wickens, 1992). The understanding of the displayed information was incorrect which led to grave consequences. Additionally, pilots have reported serious difficulties regarding the understanding of what their automated systems are doing and for what reasons (Sarter & Woods, 1992; Wiener, 1989). These difficulties relate to awareness as a whole including automation awareness and mode awareness.

Without practice, cognitive skills are susceptible to degradation – fully automating a function eventually will lead to skill decay manually due to forgetting and lack of practice (Rose, 1989; Wickens, 1992). If an off-nominal event occurs and the automation does not act as planned, the results can be disastrous (Gao, Lee, & Zhang, 2006). The quality of results can be lessened through various aspects such as missed steps, longer decision times, and loss of situation awareness and noticing. Negative consequences as a result of automation have been hypothesized to include increased complacency and decreased vigilance (Wickens &

Flach, 1988; Bowers, Deaton, Oser, Prince, & Kolb, 1995). Crew complacency is often mentioned as a consequence of automation related to monitoring performance (Parasuraman, Molloy, & Singh, 1993; Wiener, 1981). Individuals learn, retain, and lose information differently (Kurtz, 2014). It is important to understand which cognitive skills are vulnerable in order to determine what is an effective approach to mitigate the loss of them.

To further evaluate cognitive skill degradation in information automation, two studies were conducted. Flight planning was chosen since it incorporates various cognitive skills and an element of automation. Two studies examined flight planning and the cognitive skills involved. The research attempted to understand 1) what cognitive skills are degraded as a result of increased reliance on automation, 2) which tasks could suffer due to cognitive skill degradation, and 3) the effects of cognitive skill degradation over time.

Thesis Overview

This thesis is structured as shown in Table 1. Chapter 1 provides an introduction to the research and discusses the motivation behind the thesis. Chapter 2 provides the literature behind the methodologies used as well as the background for understanding the existing research. Chapter 3 provides an Applied Cognitive Task Analysis of a flight planning task to capture the cognitive demands a pilot faces while completing the task. Chapter 4 presents an evaluation of cognitive skill degradation regarding a flight planning task to see what the effects of cognitive skill degradation are. Lastly, Chapter 5 concludes this thesis and includes a summary, implications, contributions of this research, and potential future work.

Table 1. *Thesis overview.*

Chapter	**Title**
Chapter 1	Introduction
Chapter 2	Related Work
Chapter 3	Applied Cognitive Task Analysis
Chapter 4	Evaluation on Cognitive Skill Degradation in Information Automation
Chapter 5	Conclusion

CHAPTER 2. RELATED WORK

Introduction

The research areas relevant to the work in this thesis are cognitive skills, cognitive skill acquisition, and cognitive skill degradation. It is important to determine what a cognitive skill is, how they are acquired, and what differentiates a novice from an expert. Once those skills are defined, the operator must retain those skills so that they do not decay. The consequences of this skill degradation are briefly reviewed.

Cognitive Skills

Rasmussen's SRK (skill, rule, knowledge) is a model to address human behavior in different levels based on their level of expertise (Rasmussen, 1983). Cognitive skills may be more vulnerable to decay if the operator has a low level of expertise. This is due to a lower level of experience with the skill, therefore it is lost more easily in comparison to a high level of experience and practice (Prophet, 1976).

Human behavior can be separated into three levels: skill-based, rule-based, and knowledge-based. The distinctions of skill-, rule-, and knowledge-based behavior describe different decision-making processes which depend on an individual's level of expertise (Rasmussen, 1983). Skill-based behavior is the highest level of expertise, it interprets information and processing are done at a sub-conscious level. Rule-based behavior applies rules to situations that are similar to situations from past experience and training. Knowledge-based behavior applies previously learned information to solve unfamiliar problems.

The skill-rule-knowledge (SRK) model of behavior is related to cognitive information processing. Others have proposed similar models of expertise (Fitts, 1964; Anderson, 1982) and human error (Reason, 1990). Improving decision making depends on supporting effective SRK based behavior (Wickens, Mavor, Parasuraman, & McGee, 1998).

Skill Acquisition

Bloom's Taxonomy

It is important to understand how skills are acquired to better understand how they degrade. Bloom & Krathwohl (1956) developed a set of learning objectives in education which could help guide development of curriculum and assessment tools. Bloom's taxonomy identifies different levels of skills that have been acquired based on learning and what differentiates them from one another. Bloom's taxonomy consists of six levels of learning, where each level builds upon the previous level. According to the taxonomy, learning begins at the remembering level and progresses up the pyramid until reaching the creating level. The six levels are remembering, understanding, applying, analyzing, evaluating, and creating. Anderson (2006) defined each as:

- Remembering: "Can the student recall or remember the information?"
- Understanding: "Can the student explain ideas or concepts?"
- Applying: "Can the student use the information in a new way?"
- Analyzing: "Can the student distinguish between the different parts?"
- Evaluating: "Can the student justify a stand or decision?"
- Creating: "Can the student create a new product or point of view?"

These six levels aid in understanding how knowledge develops and classification of such levels.

Novice versus Expert

Different models of how people make decisions have been developed over time. Varying levels of expertise affect the strategies involving in decision making. Expertise has a significant role in allowing people to develop and maintain SA while encountering large amounts of data or complex systems (Endsley, 2016). Novices to a system or situation will be overloaded in gathering and understanding information in comparison to an expert. Novices are more limited by attention and working memory. This is due to the need to read all displays and interpret data to assess a situation. Novices do not have the experience base to interpret information quickly and properly understand the significance of the information. This can be problematic in a dynamic environment with external stresses (Lee, Kirlik. & Dainoff, 2013). Novices tend to make more mistakes, be fearful, and need validation for their actions. Experts, on the other hand, compare what they have experienced to construct their ideas. Experts have a basis to compare things to, while novices rely on experts when beginning (Daley, 1999).

Novice and experts take different approaches to solving problems. There are five levels of learning as described by Benner (1982). The five levels are as follows: novice, advanced beginner, competent, proficient, and expert. Novices are beginners with little to no experience with a situation. They are taught about situations in terms of objective attributes which can be recognized without situational experience. Advanced beginners are typified by marginally acceptable performance, they are able to notice recurrent meaningful aspects of a situation. Competency is shown by the ability to establish a plan based on considerable conscious, abstract, analytic contemplation of the problem. Proficiency is characterized by someone who perceives the situation as a whole rather than by aspects. Experience teaches proficiency by showing typical events and what to expect in a given situation. Finally, at the expert level, there is no longer a need for analytical principles, experts have an intuitive understanding of a situation and can efficiently solve the problem at hand. They also are able to anticipate future problem situations (Benner, 1982).

Cognitive Skill Degradation

Situation Awareness and Automation Awareness

As highly complex systems are more automated, operators lose the ability to keep track of what decisions the system is making, therefore inhibiting their skill practice. As they lose automation awareness, operators act more as a passive decision-maker, monitoring in order to decide if intervention is necessary to prevent errors (Kaber, Omal, & Endsley, 1999). Additionally, as operators become more of a monitor and engage in less of the problem solving itself, they lose awareness of the external situation. Thus operators lose situation awareness (SA) of the context as well as automation awareness. The lack of awareness and practice may lead to cognitive skill degradation.

Situation awareness (SA) is a construct which is fundamental for human decision making in a wide number of domains, from driving in challenging environments to command and control of space operations (Lee, Kirlik, & Dainoff, 2013). SA is often used to portray a user's awareness of the meaning of changes in their environment (Durso & Gronlund, 1999). Endsley (1995) defines SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Maintaining SA is a difficult task amongst various jobs and environments. For example, pilots report that a large portion of their time is spent ensuring their mental picture of the current situation if current and accurate. This is true for other work domains, where complex systems contain abundant information that changes rapidly (Lee, Kirlik, & Dainoff, 2013).

Automation awareness is an operator's awareness of the system current state, reasoning, and logic. In general, it has been found that humans are less aware of change in a system when those changes are completed by another agent, being automation or another human, compared to when they execute the changes themselves (Endsley, 1996; Kaber, Omal, & Endsley, 1999). This is partly due to the fact that the operator cannot maintain a good "picture" of the system when they are not actively evaluating information to lead to a decision. As operators decrease in automation awareness, the may not be reinforcing their model of the decision-making process.

Loss of Skill

Stefanidis, Korndorffer, Markley, Sierra, & Scott (2006) examined the proficiency of highly complex skills over a period of time if those skills are not practiced regularly. Notably from this, surgery skills of residents declined by 40% after a 15 month period of non-use. Despite excellent initial training, complex skills diminished in the absence of routine clinical use (Stefanidis, Korndorffer, Markley, Sierra, & Scott, 2006; Gillen, 2008).

Cognitive skill degradation is critically important following prolonged automation use. A simulation study where a human operator was using a telerobotic arm for hazardous material removal found that after the automation failed, performance was better with a mid-level of decision automation compared to high-level (Kaber, Omal, & Endsley, 1999; Parasuraman, Sheridan, & Wickens, 2000). "Out-of-the-loop" unfamiliarity can occur for high-level automation where the operators experience vulnerabilities such as lower SA, unbalanced mental workload, complacency, and skill loss (Wickens, 1995). This could lead to a safety issue if the system has a malfunction. Therefore, the design must take into consideration these vulnerabilities in order to ensure safety and reliability (Parasuraman, Sheridan, & Wickens, 2000).

Due to airline policies, advances in automation, and increases in long-haul flights, the opportunities to fly an aircraft manually has decreased significantly. This effects a pilot's chance to practice and maintain manual flying skills (BASI, 1998; Gillen, 2008). In order to address this problem, various airlines have simulators for pilots to practice their manual flying skills. However, a survey of pilots resulted in 85% of pilots stating that they preferred to practice their skills while on the job in a real aircraft. 43% of pilots stated that their manual flying skills had degraded since they started flying advanced aircraft (BASI, 1998). Without practice, skills learned while in training decay over time. Recurrent training is necessary to mitigate the loss of these skills (Helmreich, Merritt, & Wilhelm, 1999).

The focus of previous work has primarily been physical skills of piloting. However, flying aircraft also required cognitive skills, and increasingly some of the cognitive functions are being automated. These cognitive skills in general include calculating, comprehending, reasoning, prediction, and decision making (Anderson, 1982). In aviation, there is concern that the same phenomena seen with physical skill degradation may be relevant for cognitive skills. The license renewal requirements by the FAA for maintaining piloting skills are often outdated and not appropriate for current aircraft technologies (Gillen, 2008). These procedures include manually flown instrument approaches or emergency descents. Further research must be done to evaluate how pilots can best maintain their cognitive and physical flying skills, the level of reliability for automation in the cockpit, and license renewal requirements (BASI, 1998; Gillen, 2008).

CHAPTER 3. APPLIED COGNITIVE TASK ANALYSIS

Introduction

The primary goal of a task analysis is to describe the tasks and plans required of a user to accomplish a specified goal (Militello & Hutton, 1998). There are various methods for tasks analysis which are useful for different purposes and design phases. Cognitive task analysis (CTA) methods focus on illustrating cognitive elements which are used in decision making and judgments. They typically begin with high-level descriptions of the task based on interviews or observation methods. Information about cognitive cues and strategies used to accomplish a given task through in-depth interviews with subject matter experts (SMEs) (Seamster & Redding, 2017). The CTA process aids experts in articulating knowledge that is difficult to verbalize in an easily understandable way. These analyses are helpful in the design phase to understand difficult elements and common errors which occur (Koh, Koedinger, Rosé & Feldon, 2015).

Militello & Hutton (1998) developed the applied cognitive task analysis (ACTA) method by adapting CTA to be more streamlined and usable. The aim was to develop a technique which would enable designers to evoke critical cognitive elements from SMEs within a specific task. There are various techniques within ACTA: task diagram, knowledge audit, simulation interview and cognitive demands table. The techniques complement each other and are intended to look at different aspects of cognitive skills.

Chapter Overview

In this chapter, an ACTA was performed to better understand the cognitive demands a pilot encounters when planning a flight. The first step in an ACTA is developing an understanding of the domain and what vocabulary is common to the task. Next, experts have to be identified to serve as participants (ideally two or more experts). Finally, the interviews must be structured to obtain necessary information to elicit the subtasks, decision points, and skills for a specific task. Six SMEs were interviewed for the ACTA, and the four ACTA techniques were applied to acquire insight into visual flight rules (VFR) flight planning for general aviation pilots.

The goal of this ACTA is to better understand what aspects of the flight planning task are susceptible to errors; and what the cognitive skills are that are required to complete the task. By understanding the task in depth, it will aid in the design of systems and training to address difficult cognitive elements. A better understanding of the cognitive skills required in-flight planning will aid in the prediction of which cognitive skills might degrade over time.

Methods

Objectives of CTA

The goal of the CTA is to find what decision points and skills go into the task of flight planning task. This is through breaking down the skills and procedural knowledge into categories and elements which reflect how SMEs manage operational tasks and challenges.

Job Description and Primary Tasks

The job description for the task is any pilot that has flight planning experience. The task involves planning a flight from one location to another, determining waypoints, calculating fuel requirements, and completing a flight plan document. The role of the pilot beyond flight planning includes holding an aviation license, maintaining flight hours, navigating, aviating, and communicating with the air traffic towers.

Flight planning is the process of creating a flight plan which describes a future flight. There are two main aspects of this process: calculation and compliance with FAA requirements. Calculation involves fuel requirements, distance from the origin to destination, and time en route. Calculating fuel involves determining the route, altitude, winds, and speed by optimizing fuel amount and time en route (Tokadli, 2015; Federal Aviation Administration, 2018). Fuel consumption is affected by variables such as winds, altitude, and weight on board. The pilot must take into account these factors to create an optimal plan. Weather affects the route which a pilot can safely fly, therefore the forecast affects these calculations.

Safety regulations require a minimal amount of fuel on board to take while flying and account for any diversions. Pilots must take into consideration any notices for the airspace they are flying through (e.g., closures) while planning. Along with airspace notices, airport conditions are critical to be aware of. Aircraft must maintain a certain distance from clouds and the ground while performing a visual flight which affects the altitude they fly at. Finally, preflight inspection is required to determine the airworthiness of their aircraft by performing a walk-around inspection to assess the aircraft condition.

Creating a fully optimized flight plan requires significant calculation, therefore automation aids in this process. Calculations can be made using a manual device such as an E6-B flight computer and sectional, or they can be made with the help of computer programs.

Participant Selection

The study consisted of six (five male, one female), with an average age of 37 (range: 21-62). The participants consisted of two professional pilots, three flight instructors, and one experienced general aviation pilot. Pilots had an average of 1,100 flight hours (range: 200-2,800). Airplanes that the participants have flown include: Beechcraft Bonanza, Cessna 172, Cessna 182, Cirrus SR22 TN, F-15, F-16, Piper Cherokee, Piper Comanche, Piper PA28R, Piper PA44, Piper Warrior, RU12, and Socata TBM. All of the participants hold a private pilot license, while four also hold a commercial pilot license, and one holds a military and air transport license. When asked how familiar each was with the E6B, four participants answered "very familiar, I use it frequently," and two participants were "slightly familiar, I use it occasionally." Five participants also noted other methods they use online tools such as SkyVector, ForeFlight, and iFlightPlanner to assist in the flight planning process.

Data Gathering Procedure

Data collection was split into two phases: the interview and simulation interview. The interview portion goal was to collect data for the task diagram and knowledge audit. The simulation interview goal was to introduce a challenging scenario for pilots to complete and gain information about the cognitive demands of the task.

Interview

The pilots were asked a series of questions in order to elicit a step-by-step procedure for flight planning. If their response suggested having to make a decision (use of verbs such as "think," "decide," and "choose") then they were further prompted to talk about the criteria for each decision. If the participant had difficulty coming up with a response (e.g., responding "that's a hard question") then the question was rephrased for further clarification. These interview questions were based on knowledge audit probes and the simulation interview. Below, in Table 2, the interview questions are shown along with the rationale for asking them. This rationale is based on the ACTA methodology by Militello & Hutton (1998) and the questions were altered slightly to apply to the aviation task.

Table 2. *Interview question rationale based on methodology from Militello & Hutton (1998).*

Question	Probe category	Rationale
Can you walk me through the process of planning for a flight?	Big picture	Experts are able to assess a situation by understanding all elements of it while novices may only see small elements rather than the big picture. Seeing the big picture allows the expert to see how elements affect each other.
How do you plan for future events?	Past and future	Experts are able to understand how a situation arose and what possible outcomes are ahead. This allows them to address problems before they occur.
What do you take into consideration when planning a flight?	Big picture	Experts are able to assess a situation by understanding all elements of it while novices may only see small elements. Seeing the big picture allows the expert to see how elements affect each other.
How do you pick the optimal route?	Job smarts	Experts are able to work efficiently and not waste time or resources.
How does the weather affect the fuel you carry?	Noticing	Experts are able to look at patterns and cues to develop strategies which a novice may not see.

Table 2. *(continued).*

Question	Probe category	Rationale
How does the weather affect the fuel you carry?	Noticing	Experts are able to look at patterns and cues to develop strategies which a novice may not see.
Is there a time when you walked into the middle of a situation and knew exactly how things got there and where they were headed?	Past and future	Experts are able to understand how a situation arose and what possible outcomes are ahead. This allows them to address problems before they occur.
Can you give me an example of what is important about the Big Picture for this task? What are the major elements you have to know and keep track of?	Big picture	Experts are able to assess a situation by understanding all elements of it while novices may only see small elements. Seeing the big picture allows the expert to see how elements affect each other.
Have you had experiences where part of flight planning just "popped" out at you; where you noticed things that others usually do not catch? What is an example?	Noticing	Experts are able to look at patterns and cues to develop strategies which a novice may not see.
When you do this task, are there ways of working smart or accomplishing more with less -- that you have found especially useful?	Job smarts	Experts are able to work efficiently and not waste time or resources.
Can you think of an example when you have improvised in this task or noticed an opportunity to do something better?	Opportunities / Improvising	Experts can improvise based on previous experience with comfort, they are also able to see opportunities to be more efficient and take them.
Can you think of a time when you realized that you would need to change the way you were performing in order to get the job done?	Self-monitoring	Experts are able to assess their own performance and make necessary adjustments. Novices may not know how to improve or are not aware of their performance.

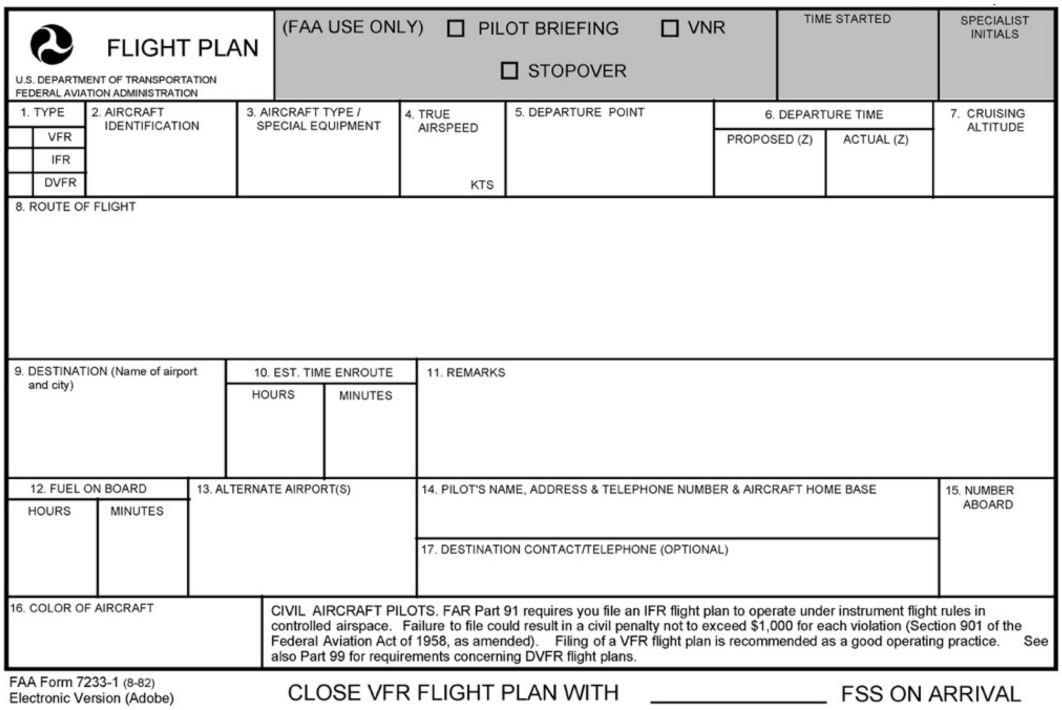
Table 2. *(continued).*

Question	Probe category	Rationale
Can you describe an instance when you spotted a deviation from the norm, or knew something was amiss?	Anomalies	Experts can easily spot abnormal events or deviations while novices are unaware of what is atypical. Experts are able to notice when something that was supposed to happen, doesn't.
Have there been times when the equipment (ex. flight planning software, information services, etc.) pointed in one direction, but your own judgment told you to do something else? Or when you had to rely on experience to avoid being led astray by the equipment?	Equipment Difficulties	Novices typically believe what the equipment outputs and do not know when to be skeptical of an error.

Simulation Interview

The simulation interview better allows the interviewer to understand the cognitive processes within the context of a specific example. This is completed through presenting the participant with a challenging scenario and observing how they complete the task.

The pilots were provided the FAA 7233-1 form to complete during the simulation interview (see Figure 1). They were also given an E6-B flight computer to calculate various elements such as speed, heading, time, and fuel requirements (see Figure 2).



FLIGHT PLAN

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

(FAA USE ONLY) ☐ PILOT BRIEFING ☐ VNR ☐ STOPOVER | TIME STARTED | SPECIALIST INITIALS

1. TYPE: VFR / IFR / DVFR
2. AIRCRAFT IDENTIFICATION
3. AIRCRAFT TYPE / SPECIAL EQUIPMENT
4. TRUE AIRSPEED — KTS
5. DEPARTURE POINT
6. DEPARTURE TIME — PROPOSED (Z) / ACTUAL (Z)
7. CRUISING ALTITUDE
8. ROUTE OF FLIGHT
9. DESTINATION (Name of airport and city)
10. EST. TIME ENROUTE — HOURS / MINUTES
11. REMARKS
12. FUEL ON BOARD — HOURS / MINUTES
13. ALTERNATE AIRPORT(S)
14. PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE
15. NUMBER ABOARD
16. COLOR OF AIRCRAFT
17. DESTINATION CONTACT/TELEPHONE (OPTIONAL)

CIVIL AIRCRAFT PILOTS. FAR Part 91 requires you file an IFR flight plan to operate under instrument flight rules in controlled airspace. Failure to file could result in a civil penalty not to exceed $1,000 for each violation (Section 901 of the Federal Aviation Act of 1958, as amended). Filing of a VFR flight plan is recommended as a good operating practice. See also Part 99 for requirements concerning DVFR flight plans.

FAA Form 7233-1 (8-82)
Electronic Version (Adobe)

CLOSE VFR FLIGHT PLAN WITH ______________ FSS ON ARRIVAL

Figure 1. *FAA Form 7233-1 for flight planning.*

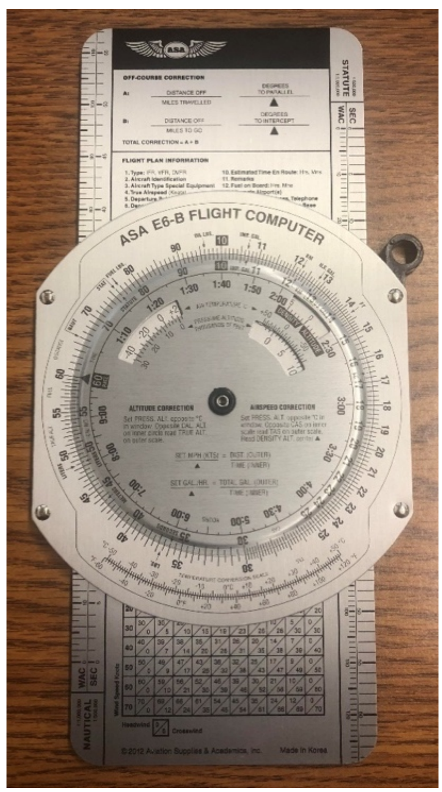


Figure 2. *ASA E6-B Flight Computer.*

The scenario given to the pilots was as follows:

You will do the flight planning stage for a flight from Ames to Minneapolis. You are flying a Cessna 172 with the fuel capacity of 42 gal. The range of the aircraft is 435 nautical miles, cruise speed is 115 knots, and the direct distance between KAMW and KMSP is 174 miles. Please fill out the FAA 7233-1 form and plan each step out loud. All of the information at each waypoint is provided as well as a map with weather information, and an E6-B flight computer. Afterward, I am going to ask you a series of questions about how you would approach this situation."

The pilots were provided a sectional (see Figure 3) of the Ames, IA to Minneapolis, MN including weather information from SkyVector.com (see Figure 4).

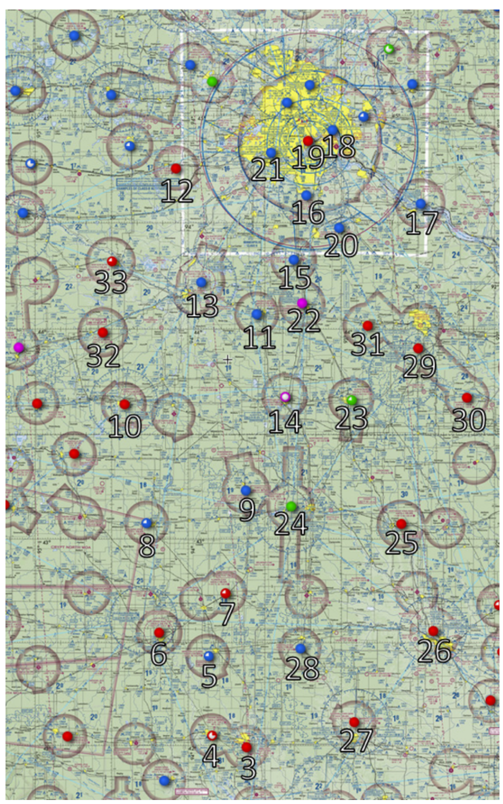


Figure 3. *Numbered sectional provided to the pilots.*

An example of the information from the weather station on the map is shown in Figure 3. The pilots were all provided with the same weather information to provide consistency in the scenario provided.

The pilots were provided a dry erase marker to draw on the sectional as desired. The experimental questionnaires, interview questions, and simulation interview materials are provided in Appendix A.

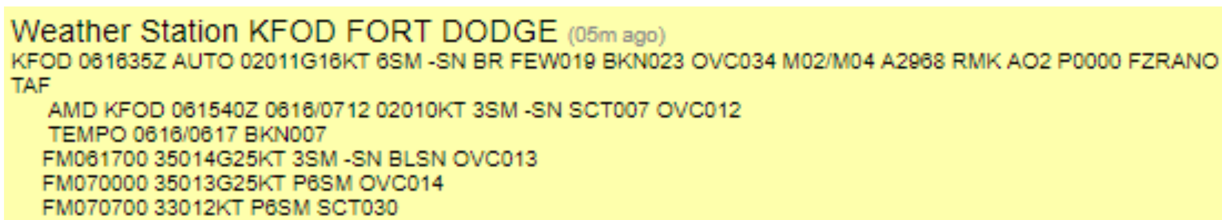

Weather Station KFOD FORT DODGE (05m ago)
KFOD 061635Z AUTO 02011G16KT 6SM -SN BR FEW019 BKN023 OVC034 M02/M04 A2968 RMK AO2 P0000 FZRANO
TAF
AMD KFOD 061540Z 0616/0712 02010KT 3SM -SN SCT007 OVC012
TEMPO 0616/0617 BKN007
FM061700 35014G25KT 3SM -SN BLSN OVC013
FM070000 35013G25KT P6SM OVC014
FM070700 33012KT P6SM SCT030

Figure 4. *Weather station information at Fort Dodge, IA.*

During the scenario, the pilot was asked to speak out loud any decision points or observation points they encountered. Following the scenario, a series of questions were asked to elicit deeper information. The responses to these questions provided information as to the cognitive demands of flight planning. The simulation interview questions are shown in Table which were altered slightly from Militello & Hutton (1998) to apply to the aviation task.

Table 3. *Simulation interview question rationale based on methodology from Militello & Hutton (1998).*

Question	Rationale
As the pilot in this scenario, what actions, if any, would you take at this point in time?	To understand the SME's situation assessment of the scenario presented to them.
What do you think is going on here? What is your assessment of the situation at this point in time?	To understand what actions the SME would take based on the information from the scenario.

Table *3. (continued).*

Question	Rationale
What pieces of information led you to this situation assessment and these actions?	To understand what critical cues lead to decision making.
What errors would an inexperienced person be likely to make in this situation?	To understand what potential errors could occur and the differences between novices and expert decision making.

Knowledge Representations Techniques

Narrative accounts of incidents and examples were reviewed to complete the task diagram, knowledge audit, simulation interview, and cognitive demands table. The interview audio was recorded and then transcribed manually. The transcripts were separated by interview question and input into a spreadsheet to compare between pilots. The interview responses were reviewed to identify themes, catalog cues, and patterns, as well as create a synthesized/integrated narrative from patterns.

Task Diagram

The task diagram interview provides the researcher with a general overview of a task and calls attention to difficult cognitive elements of the task. This helps the research know what to probe for further in the interview.

Knowledge Audit

The knowledge audit determines what the aspects of each task and subtask are in terms of examples. This technique inquiries about specific examples in the SMEs experience, and uncovers different aspects of expertise. This includes determining decision points and the cues/strategies to complete those decisions. From these examples, the SME is asked to identify the cues and strategies used, along with why it is potentially difficult for novices.

Simulation Interview

The third technique is the simulation interview. This allows the researcher to observe a SME in the context of a specific challenging scenario. Observing the SME allows for the researcher to pick up on cues that the SME may not verbalize, and allows for an understanding of situation assessment. This simulation interview identifies key decision points, what cues led them to those choices, and identifies common errors that occur. This information leads to determining events, actions, assessments, critical cues, and potential errors.

Cognitive Demands

The last technique is the cognitive demands table. This offers a way to consolidate and synthesize the data from various interviews. This goal of this table is to aid in understanding what makes certain cognitive elements difficult, what common errors are made, and finally, the strategies used to complete the subtasks within a specific task.

Procedure

The duration of the study was approximately one hour per participant. Each interview was conducted in an isolated environment where the pilots had a clear workspace to utilize. After signing a consent form, the pilots completed a survey to collect basic demographic data (see Appendix A). They were briefed about the experiment and given the opportunity to ask questions. Next, pilots were asked a series of interview questions to elicit information for the task diagram and knowledge audit. Following this interview, the pilots were briefed on the scenario for the simulation interview and proceeded to complete the task. Following the scenario, additional questions (see Appendix A) were asked to gain further information for the cognitive demands of the task. The entire study had audio recorded which would later be transcribed by the interviewer to obtain full responses from the pilots.

Results

Hierarchical Task Analysis

Figure 5 presents the HTA as a result of the task diagram interview. The task was broken into eight main steps with various sub-steps to complete the task. This flight plan procedure is applicable to a general aviation VFR flight.

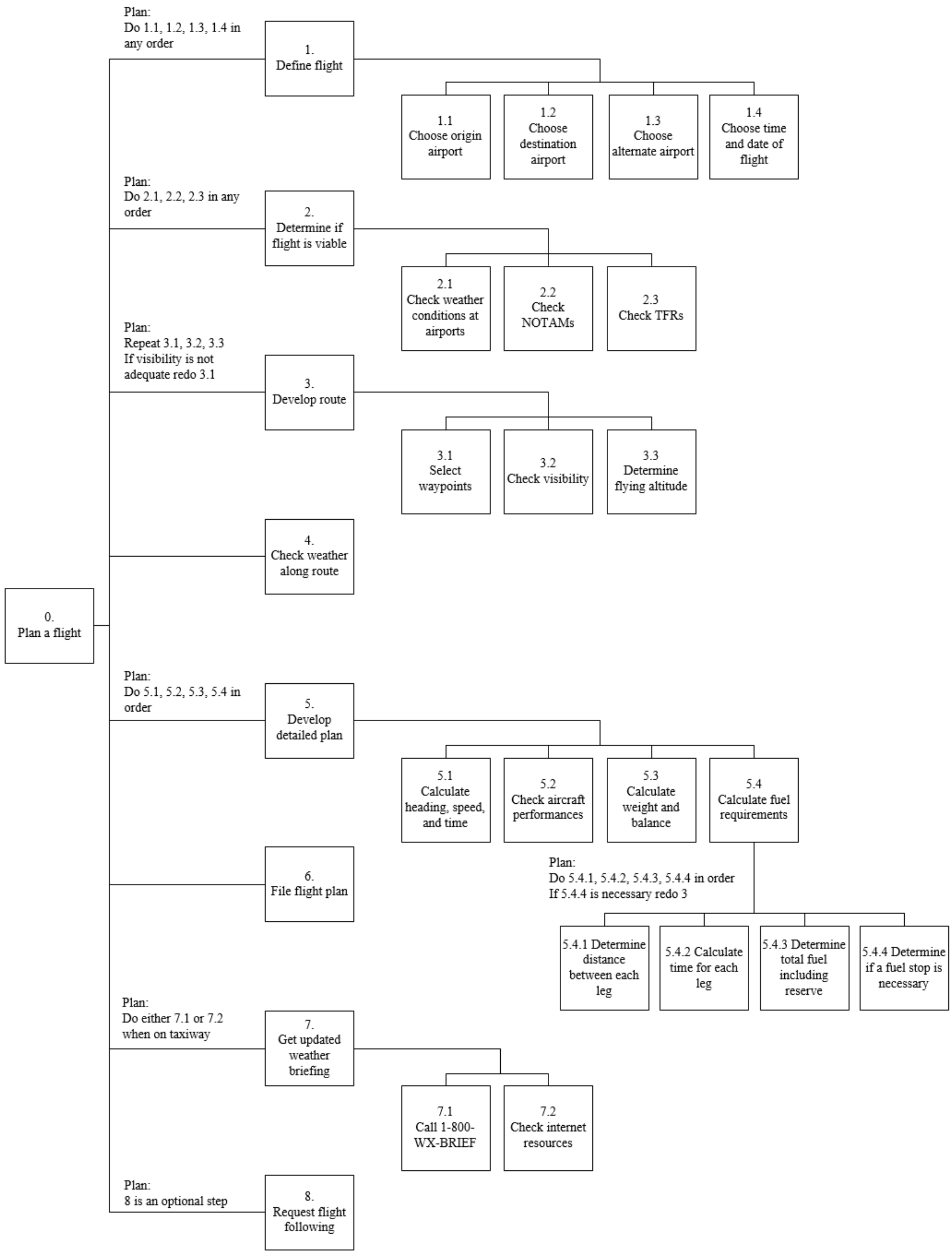


Figure 5. *Hierarchical task analysis for planning a general aviation VFR flight.*

Knowledge Audit

Table 4. *Knowledge audit.*

Aspects of expertise	Cue and strategies	Why difficult?
Past and Future Need to plan a new route; gathering information from various sources to understand the situation	Roughly map flight to determine waypoints Talk to other pilots with more experience Watch videos of approaches into destination airport Understand jargon and communication with ATC	Novices are less familiar with the routes Novices have difficulty planning for things change
Big Picture Assessing route and environmental conditions to determine if there is a viable flight plan	Determine time and distance between waypoints Review weather along the route Review NOTAMs for origin and destination Review turbulence reports Review TFRs Look at weather terminal forecast Review runway conditions Calculate fuel requirements Calculate speed, heading, and flight time Calculate weight and balance	"Get-there-itis": determination of a pilot to get to a destination, even when conditions for flying are dangerous External pressures
Noticing Reading NOTAMs for destination airports	Read NOTAMs first so you do not plan the entire flight to a closed airport Distribute the workload with another pilot if possible Work efficiently so weather does not change by the time the flight is filed	Unfamiliarity with NOTAMs codes
Noticing Changes in the weather	Review the direction of the winds to look at headwinds and tailwinds Review NOTAMs for origin and destination Review TFRs	Winds change at various altitudes
Job Smarts Work efficiently	Starts with the big picture and scale down Use electronic apps Distribute the workload with another pilot	Novices may take too long to calculate, risking outdated environment information Planning things out of order (i.e. determining waypoints before looking at weather report)

Table 4. *(continued).*

Aspects of expertise	Cue and strategies	Why difficult?
Opportunities/ Improvising Navigation tools and techniques	Use electronic apps to help calculate variables (i.e. weight and balance, fuel, winds, etc.) Double check inputs if calculations seem off	Noticing miscalculations
Self-Monitoring Adjusting and streamlining	Roughly plan ahead days before Understand the performance characteristics of your aircraft Expose yourself to new information (i.e. talk to other pilots, read articles, etc.) Follow a procedure for how to plan	Comfortable doing things the same way and not learning how to improve
Anomalies Calculations seem off	Recheck input numbers for calculations Expectation of what is correct	Novices not being aware that numbers are wrong
Equipment Difficulties Equipment malfunctions	Double check information with ATC Pay attention to the equipment readings Be prepared for things to malfunction Understand emergency procedures	Understanding how the equipment works to see if something is wrong Novices may hesitate to question ATC

Simulation Interview

Table 5 describes the results from the simulation interview table.

Table 5. *Simulation interview task results.*

Events	Actions	Assessment	Critical cues	Potential errors
Construct flight plan	Determine origin, destination, and alternate	Is there enough fuel Are the runway conditions sufficient	Airport is closed or open	Planning the flight without checking if the airport is viable
	Develop initial route	Are the waypoints close enough from one another Is the altitude viable to fly at	Check aircraft manual for aircraft performances	Novice may try to stay at one altitude the entire flight Developing an inefficient route and wasting fuel

Table 5. *(continued)*.

Events	Actions	Assessment	Critical cues	Potential errors
Construct flight plan	Determine origin, destination, and alternate	Is there enough fuel Are the runway conditions sufficient	Airport is closed or open	Planning the flight without checking if the airport is viable
	Develop initial route	Are the waypoints close enough from one another Is the altitude viable to fly at	Check aircraft manual for aircraft performances	Novice may try to stay at one altitude the entire flight Developing an inefficient route and wasting fuel
	Check weather forecast	Is visibility above minimum Are there weather conflicts Are there high winds	Visibility > 300 ft for day Visibility > 500 ft for night Icing en route	Believing that the weather forecast won't change Believing the weather at the station is the same for any altitude
	Check weather conditions at airports	Is there hazardous weather that could affect takeoff and landing	Moisture or icing on runway	Not checking the terminal forecast
	Check NOTAMS	Are there any closures Are there runway conditions to be aware of	Airport is closed or open Runway is closed or open Lighting on runway is broken or working Hazardous conditions exist	Novices may not be familiar with all of the NOTAM codes
	Check TFRs	Are there any restricted airspaces	Airspace is closed or open	Novices may not remember to check TFRs
	Calculate weight and balance	Is the weight and balance in line with aircraft specifications	Check aircraft manual	Incorrectly inputting the values for weight and balance

Table 5. *(continued).*

Events	Actions	Assessment	Critical cues	Potential errors
	Calculate speed, heading, flight time, and total fuel	Is a fuel stop required Is there a tailwind or headwind Is the time en route within level of comfort to fly at	Aircraft can hold fuel needed	Not taking into account fuel use for takeoff and landing
File flight plan	File with ATC	Is the flight ok to perform	Approval from ATC	Taking too long to plan a flight that weather conditions have changed
Taxi runway	Obtain updated weather	Is there a need to replan	Weather has changed drastically or not	Overconfident that changed weather won't affect safety
	Request flight following	Was flight planning provided	Approval from ATC	

Pilots were asked to draw their route on the laminated map provided during the simulation interview. Figure 6 is a representation of the combined routes each pilot chose.

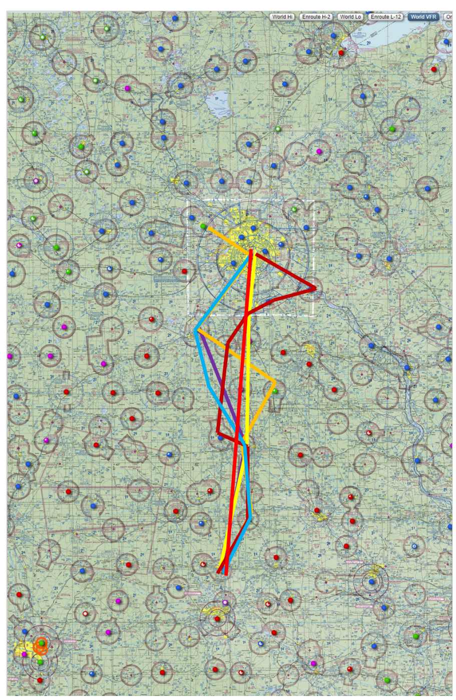


Figure 6. *Combined routes from simulation interview on map.*

Cognitive Demands

Table 6 describes the cognitive demands obtained from the simulation interview with the pilots, where the rationale behind the questions was explained in Table in the Methods section.

Table 6. *Cognitive demands.*

Difficult cognitive element	Why difficult?	Common errors	Cues and strategies used
Knowing how to deal with uncertainty of future	Unfamiliarity with the route	Overconfidence Wasted time	Speak with experienced pilots Watch videos Look at terminal forecasts Train for off-nominal situations
Noticing when something is not right	This skill comes with experience	Trusting automation fully Not understanding how the automation is calculating Not understanding NOTAM codes	Learn how to do calculations by hand first and practice it Double check what inputs were used Be able to assess the situation Double check the information given Speak with experienced pilots
Assessing the viability of a flight	Various elements come into play, and it is more difficult with less experience and familiarity	“Get-there-itis” External pressures Misreading NOTAMs Wasting time	Start by looking at weather report Do not let external pressures compromise safety Understand NOTAM codes
Synthesizing the preflight information	Have to consolidate various data to create a bigger picture	Misinterpreting information	Review with a more experienced pilot Obtain information from manuals or ground operators

Based on the interviews with pilots, Table 7 shows a list of cognitive skills required during flight planning.

Table 7. *Cognitive skills in flight planning with definitions based on Merriam-Webster (2018) and ACTA interviews.*

Cognitive Skill	Definition	Example
Calculating	To determine outputs by mathematical processes	Calculating the required fuel for the flight
Estimating	To form an approximate judgment of what the calculation should be	Estimating what the required fuel will be prior to exact calculation
Noticing	The condition of being warned or notified of something that could hinder the flight plan	A NOTAM states that the destination airport has a runway which is closed
Organizing	To arrange all information by systematic planning	Laying out all materials needed to efficiently plan
Controlled processing	To process all variable which requires substantial mental resources	Look at the big picture of all the information to formulate a plan
Reasoning	To comprehend, infer, or think in a rational manner to ensure that all information seems accurate	A headwind will require more fuel
Problem-Solving	To find a solution to a problem	A storm is approaching from the West and the pilot must determine how to avoid it
Scanning	To examine given information systematically in order to obtain data	Overview all information to see if anything pops out that needs attention
Anticipating	To foresee issues and deal with in advance	Reviewing the weather forecast
Predicting	To declare or indicate in advance	Knowing that the weather will be more variable in the summer months
Pattern recognition	To perceive to be something based on frequency or experience	Being diverted at a major airport in a small plane, therefore planning to be diverted in the initial plan
Communicating	To convey knowledge or information about an idea	Talking with the control tower
Prioritizing	To determine order based on importance	Looking at the weather report before calculating fuel requirements

Discussion

Implications

The results show that skills which involve calculating different variables can be difficult for novices and with practice and time they improve. This implies that with the lack of practice and large time between doing these tasks, the skills may degrade. From the interviews, pilots mentioned that cognitive skills such as noticing when something does not look right are gained from experience and prone to error for novices. A similar phenomenon was noted in an ACTA for helicopter landing tasks by Minotra & Feigh (2017). Pilots mentioned that they prefer using automated methods to perform flight planning due to its efficiency and reliability. This is true when all inputs are correct. Pilots also noted that they try to detect if the outputs seem correct by deciding if the numbers approximately match their expectations.

Pilots were questioned about common errors that novices were likely to make, and they stated that inexperienced users are prone to mistakes because they may trust the automation fully (in their experience of using tablets to calculate preflight information while flight planning), and may not question the outputs given. These mistakes include incorrectly inputting values into an automation aid or using a provided online template for aircraft specifications that contain errors. Pilots mentioned that it is important to make sure a template is accurate for their specific aircraft before they rely on the calculations it provides. Calculation errors were often attributed to incorrect input values, and the inability to notice when the numbers do not look correct can lead to issues when in flight. For example, if the distance calculations are missed that effects fuel calculations which can be dangerous in flight if not correct. Pilots reported that they felt it was vital to learn how to do these tasks manually before graduating to automation aids. This was due to the need to develop estimation and noticing skills.

Pilots reported during the interviews that overconfidence was another issue common to inexperience. The results showed this was often due to novices succumbing to external pressures (‘get-there-itis’ is the desire to get to a destination, even when conditions for flying are dangerous). Novices can lose the big picture of a task if they are fixated on tasks rather than the entire problem (Minotra & Feigh, 2017). Strategies pilots use to combat overconfidence are focusing on safety and the viability of a flight. Pilots must be able to determine the viability through the skill of looking at different preflight information and assessing the feasibility.

A common theme throughout the interviews was trust in automation. If a pilot trusts completely in the automation and it steers them wrong, they may not notice. The general theme was using automation for exact calculations, and manually estimating the approximate values. It was stressed how automation can make things efficient, however, a good pilot knows what the automation is doing and can check the output as they receive them to see if they look correct. There is a human error aspect with inputting incorrect values into the automation aid, which novices are prone to doing. Novices can fail to verify information given by automation if they are overloaded with tasks (Minotra & Feigh, 2017).

From the interviews with pilots, the task of flight planning was discussed in depth to learn more about what cognitive skills and demands are required to complete the task. This involved breaking the task into its various sub-tasks, identifying decision points, and determining what errors could be made by novices. The skills most difficult for novices were those that involved calculation and estimation. Calculation includes heading, speed, time en route, and fuel requirements. Calculation is a difficult skill that relies on working memory and requires the pilot to synthesize various variables, then properly use them in order to receive an accurate output. Without practice, users may lose the skill of doing a mental check to determine if the numbers seem reasonable and proceed to use them regardless. Wan & Huon (2005) state that unexpected performance degradation, or 'slips', occur when someone performs under pressure. This is commonly known as 'choking under pressure'. If a pilot has not performed a task manually and returns to performing a task manually, they may be prone to more errors in both the calculations and the overall process steps.

The other skill which the SMEs mentioned is difficult for novices are tasks that involve estimation. This involves determining an approximate value for the output, and checking if the calculation matches the estimation. If the calculation does not seems right, the pilot needs to recalculate to ensure it is correct. Similarly, recognizing requires the pilot to look at the big picture of the weather report, information at each weather station, and synthesize the 'story' of the area. This includes concluding what areas to avoid, what altitudes to fly at, and the winds of each area. This is a difficult skill as it is strengthened with time and practice as pilots learn to identify cues through experience (Minotra & Feigh, 2017). Continual practice reinforces this ability, therefore if a long period of time has occurred between utilizing estimation skills, a pilot is more prone to losing their ability. How long between instances where the skill is used before there is a loss of skill is less known and should be investigated further to see how individuals lose skills over times of nonuse.

Assumptions and Limitations

One of the limitations of the ACTA is that it does not always capture non-cognitive attributes that are needed in order to fully understand a task. This could include access to resources and interpersonal relationships. Furthermore, it is assumed that experts can accurately articulate the difficulties of a novice and remember the performance capacities and capabilities of a beginner.

Conclusion

From this study, cognitive skills in regards to flight planning were identified. The level of difficulty each skill has was identified for novices as well as experts, and what common mistakes are made. The skills identified were: calculating, estimating, noticing, organizing, controlled processing, reasoning, problem-solving, scanning, anticipating, predicting, pattern recognition, communicating, and prioritizing. These skills are used in order to complete the task in an efficient manner to create a safe and accurate flight plan. In particular, pilots identified calculation and estimation as skills that are being particularly vulnerable to degradation.

Further studies need to focus on a specific task that is susceptible to degradation. An experiment to determine how skills decay within flight planning would lead to a greater understanding of this construct. Based on tasks that are vulnerable to degradation, mitigation factors can be investigated and tested. The skills which were found to be vulnerable were calculation and estimation. Within flight planning, this would include calculating heading, speed, time en route, and fuel requirements. Estimation would also involve these calculations and the ability to determine if they are sound. From this, we want to further explore if automation is a sufficient aid in maintaining skills for manual tasks. This is an important step in understanding why skills degrade and how to stop them from degrading as quickly. Cognitive skills such as calculation and estimation within fight planning are vulnerable to decay. This is due to the nature of them requiring time, experience, and working memory (Wan & Huon, 2005). Without the consistent practice of these skills, they are susceptible to degradation. Based on the results of the ACTA analysis, an experiment was conducted to further investigate the effects of cognitive skill degradation over time through the use of an automation aid for the task of flight planning.

CHAPTER 4. EVALUATION ON COGNITIVE SKILL DEGRADATION IN INFORMATION AUTOMATION

Introduction

Portions of this chapter appeared in Volz et al. (2016). My role in the work and the project included experimental design, lead researcher for the experiment, data analysis, and the write-up of the manuscript.

Even though studies have looked into information automation in aviation, the amount of empirical data on the effects of these systems on the retention of cognitive skills is less deeply examined (Fadden 1990; Parasuraman, Sheridan, & Wickens, 2000; Bass & Pritchett, 2008; Dudley et al., 2014). Measurement and analysis of the effects of cognitive skill degradation on performance are needed to understand the effects of increased reliance on automation.

The purpose of this research was to investigate the effects of cognitive skill degradation through the use of automation. From the ACTA in the previous chapter, it was determined that within flight planning there are two skills types that are particularly vulnerable to decay: calculation and estimation. This would include calculating heading, speed, time en route, and fuel requirements. Estimation involves pilots making estimations of reasonable values for a calculation, and using them to check the outputs of automation to determine if they are sound. This work explores the effect of prolonged use of automation on these skills. This ultimately can lead to mitigation techniques to reduce degradation. As described in Chapter 3, pilots felt that without the consistent practice of these skills, they may be susceptible to degradation.

The use of an automation aid is expected to result in performance degradation over time. Participants were randomly placed into three experimental groups (manual, alternating, or automation) and asked to perform flight planning calculations as an experiment task. Over the course of nine weeks, participants performed the task five times, once every two weeks. The manual group used the manual method throughout the experiment, the alternating group switched between the manual and automated method every trial. The automation group used the manual method for the first trial, the automated method for the three consecutive trials and then went back to using the manual method during the last trial. The automation group showed the most performance degradation and highest workload, while the alternating group presented reduced performance degradation and workload, and the manual group showed the least performance degradation and workload. This work provides the foundation for the design of guidelines and recommendations for IA systems in order to prevent cognitive skill degradation (Volz et al., 2016).

Methods

Research Objectives and Hypothesis

The objective of the study was to examine the effects of cognitive skill degradation over time through the use of automation. Two hypotheses resulted from the ACTA results in Chapter 3:

H1. The use of an automation aid is expected to result in larger skill degradation than the use of manual flight planning over time.

H2. Reliance upon automation aids will lead to higher workload and completion time when the user is required to use manual when compared to the use of manual flight planning.

Participants

The study consisted of five visits spread out over nine weeks. A total of 59 undergraduate students from a large Midwestern university served as participants initially (32 male, 27 female), with an average age of 19.69 (range: 18-27). A total of 46 participants completed all five trials (26 male, 20 female), with an average age of 19.7 (range: 18-27). The experiment required participants to return every two weeks for nine weeks. Table indicates the number of participants that came to each trial, the cumulative attrition was approximately 22%.

Table 8. *Participant attendance for each trial.*

Trial	1	2	3	4	5
Participants at Trial	59	56	50	48	46

No participants stated that they had previous experience with flight planning. Participants have taken classes including Algebra (100%), Geometry (98%), Trigonometry (92%), Pre-Calculus (83%), Calculus (76%), and Statistics (61%).

Tasks / Scenarios

Participants were asked to conduct flight planning. In order to plan a flight, they had to calculate the following elements of a flight segment: heading, ground speed, flight distance, time en route, fuel consumption, or gallons burned per hour. Definitions and problem statement examples are shown in

Table below. Participants were asked the same problem statements each trial with different values for each variable.

Table 9. *Task descriptions and examples.*

Element	Description	Problem Statement
Heading	Direction the plane is pointed (must account for wind).	The weather report indicates that there are winds from 240° at 38 knots (KTS). Your course is 300° and your aircraft has a true airspeed of 165 KTS. Calculate the true heading and ground speed.
Ground Speed	Speed that the plane is flying relative to the ground.	
Flight Distance	Amount of space between the two endpoints of the flight.	The ground speed is 110 knots (KTS); your trip will take 1 hour and 40 minutes. Calculate the distance.
Time en Route	Length of time the plane is in the air.	The weather report has changed and the ground speed is now 125 knots (KTS); the distance of your trip will be 524 nautical miles. Calculate the time that your trip will take.
Fuel Consumption	Amount of fuel used by the plane during the flight.	Your aircraft burns an average of 7.5 gallons per hour; your trip will take 3 hours and 20 minutes. Calculate total fuel used.
Gallons Burned per Hour	Rate at which the fuel is being used up.	Your trip will use 62 gallons of fuel, and the trip will take 4 hours and 50 minutes. Calculate gallons burned per hour.

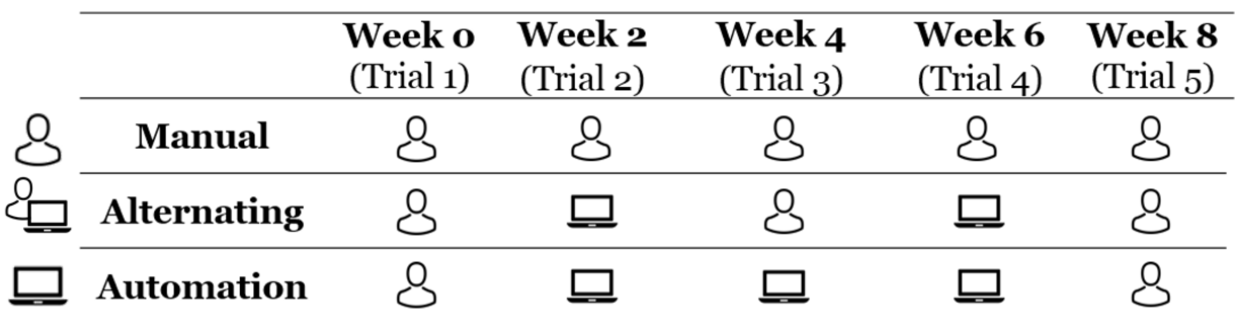
This experiment utilizes procedural and declarative knowledge types. An example of procedural knowledge in relation to the experiment is that the participant must know how to operate the manual apparatus. The participant uses declarative knowledge by understanding the meaning of each unit number provided.

Independent Variables

The independent variable was the *Experimental Group* (manual, alternating, and automation). Experimental groups were randomly assigned to each participant at the beginning of the study.

Participants were randomly placed into three experimental groups: manual, alternating, or automation. The manual group used an E6-B flight computer for every experiment trial. The alternating group switched between an E6-B flight computer and an E6-B emulator on a tablet every trial. The automation group used an E6-B flight computer for the first trial, used the automated E6-B for the three consecutive trials and then went back to using the regular E6-B during the last trial. See Table 10 below for a visual description of the schedule with the accompanying icon on the left side.

Table 3. *Experiment schedule.*



Dependent Variables / Metrics

The dependent variables (see Table 4) were workload and performance. The workload for each participant was measured subjectively by a NASA-Task Load Index (NASA-TLX). The performance was measured objectively by the rate of error in the calculation of flight planning task questions.

Table 4. *Dependent variables.*

DV	Measurement	Frequency
Performance	Between Groups: Percent correct	Every trial
	Within Group: Percent correct change between trial 1 and trial 5	N/A
Workload	Between Groups: NASA – TLX	Every trial
	Within Group: NASA – TLX change between trial 1 and trial 5	N/A
Completion Time	Between Groups: Time (min)	Every trial
	Within Group: Time change between trial 1 and trial 5	N/A

The performance was measured through the percent correct on three questions after each flight planning scenario.

Experimental Design

This was a 1x3 (manual, alternating, and automation) between-subject design. Each condition was tested once per trial (five trials). In training and the five trials, two scenarios were given. Each scenario consisted of three questions (See Appendix B). Throughout the experiment, the only alterations made were the numbers given in the problem statements. The difficulty in the questions remained the same. When the participant was using the automated method (see Figure 7b), specific paths were given in the instructions for each trial to ensure error would not occur while using the device.

Procedure

The duration of the experiment was nine weeks, where the participants came in every other week to perform flight planning tasks. After signing a consent form, participants completed a survey to collect basic demographic data. They were briefed about the experiment schedule and shown the instructions to a NASA Task Load Index (NASA-TLX). An initial training session was given to all the participants on how to use an E6-B via video and oral instruction. Next, the user would take a practice test to confirm their understanding which would be graded to see if they needed further assistance. If further assistance was needed, an experimenter would work with the participant individually to identify and correct any errors.

Once participants had completed the practice test with no errors, they were able to begin trial 1. There were a total of five trials, one trial every other week for a total of five visits. For every trial, the participants completed two scenarios consisting of three questions each. The user reported their trial start and end times, followed by an additional end time recording from the experimenter to ensure accuracy. It was intentional to not provide immediate feedback after each trial to participants because the experimenters did not want to intervene with the participants' skill set. After the scenarios, they were instructed to fill out a NASA-TLX questionnaire.

Data Analysis Plan

Satterthwaite approximation t-tests were used for comparing results between groups and trials. Post-hoc analysis was conducted by using Tukey's test for pairwise comparisons.

Assumptions and Limitations

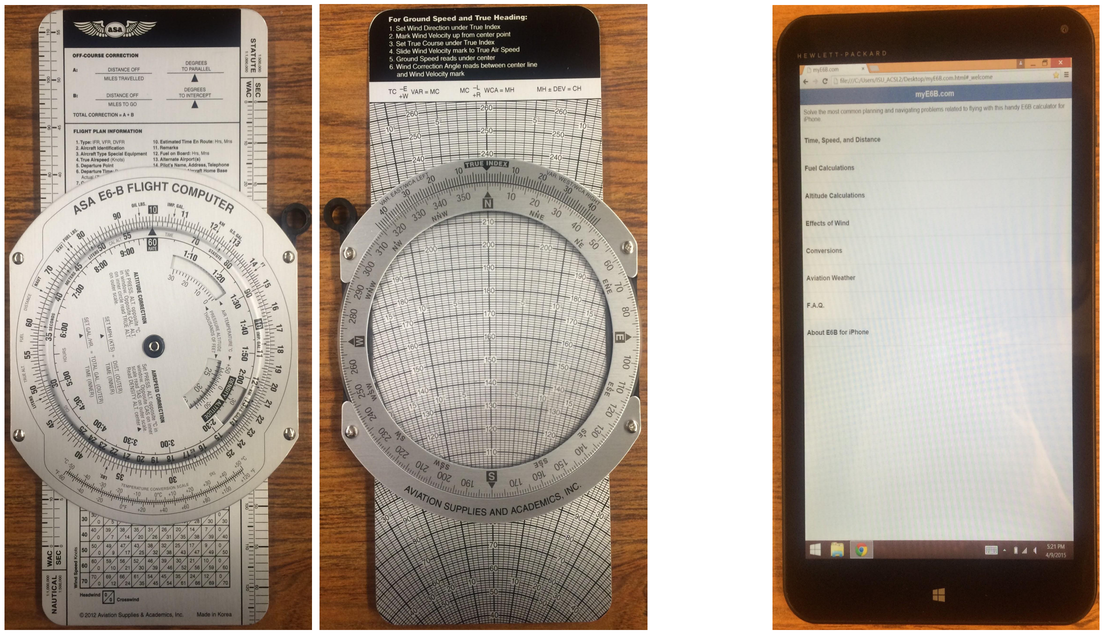
For the purposes of developing an empirical study to investigate skill degradation, assumptions were made. First, a given skill has been taught and learned to a sufficient level at the beginning of the study. Second, the primary cause of degradation is the insufficiently consistent use of a particular skill after it has been learned.

The experiment participants were all college students performing a simple task over the course of nine weeks. In addition, solving given problems requires an ability to interpret and understand the values by employing the E6-B flight computer. However, the degree of such ability is lower than that of a pilot, because the participants were not trained pilots.

Testing Environment

An experimental booklet was assigned to each participant. Six E6-Bs and five 8.1-inch tablets were purchased. A projector and speakers were utilized during training. While participants completed trials, they sat at separated workspaces to ensure privacy and individual work. During the training sessions, participants were sat together at a large conference table while the key personnel taught the methods.

Figure 7a shows the E6-B Flight Computer developed by Aviation Supplies & Academics, Inc. (2012). Figure 7b shows the HP Stream 8 32GB Windows 8.1 4G 8 inch Tablet. The speakers used during training were a Harman/Kardon multimedia speaker system, and the projector was a Hitachi CP-X880 multimedia projector XGA. SHARP Analog clocks were visible from every workspace for start and end times.



(a) (b)

Figure 7. (a) *ASA E6-B Flight Computer.* (b) *HP Stream 8 Tablet.*

Results

Satterthwaite approximation t-tests were used for comparing results between groups and trials. Post-hoc analysis was conducted by using Tukey's test for pairwise comparisons. The results are reported as highly significant for a significance level alpha < .001, significant for alpha < .05, and marginally significant for alpha < .10. The error bars represent standard error between participants within a group.

Performance

Figure 8 illustrates the average performance of the three groups over five trials. The main effect of group was highly significant ($F(2, 62.9) = 13.99$, $p < .001$). The main effect of trial was highly significant ($F(4, 171) = 39.17$, $p < .001$). The interaction was highly significant ($F(8, 171) = 18.81$, $p < .001$).

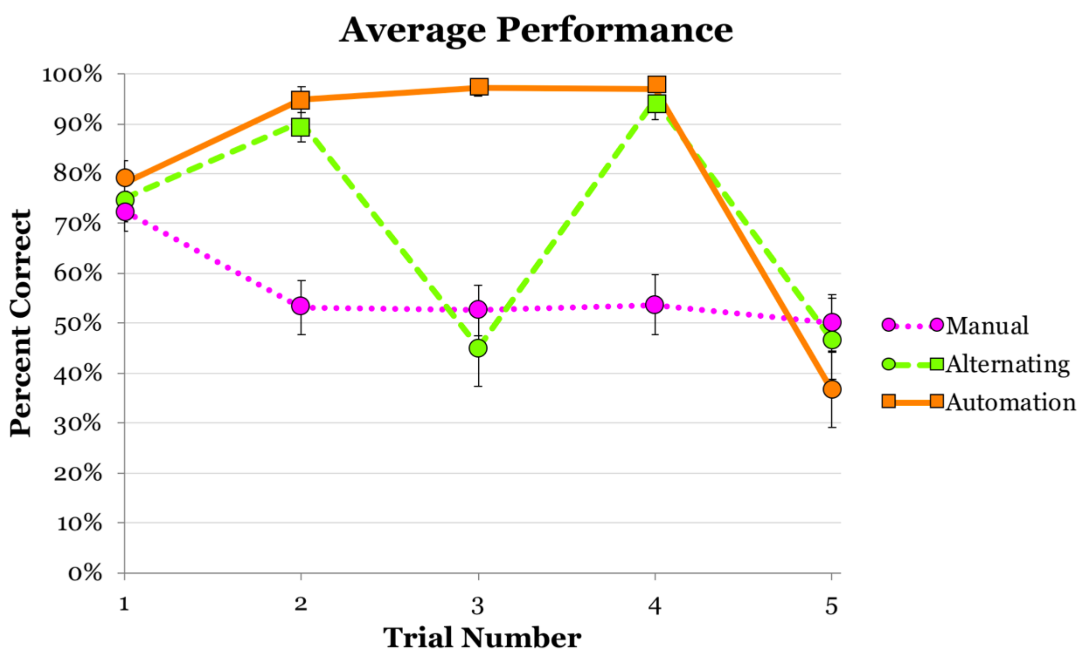


Figure 8. *Average performance of participants on flight task over five trials.*

The three groups performed with the manual method a different number of times (instances of manual) throughout the experiment. Figure 9 presents the average performance for only use of the manual method. The horizontal axis denotes how many times they have performed with the manual method.

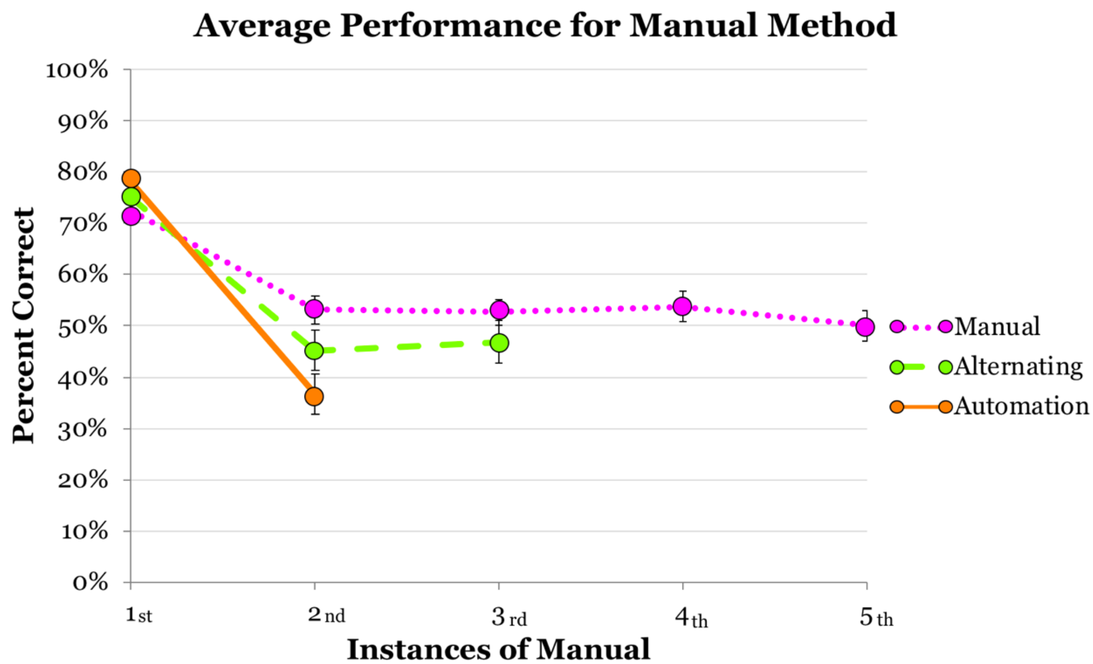


Figure 9. *Average performance for the instances of manual of participants over five trials.*

Comparing Trial 1 and 5 within Group

For the manual group, there was a significant ($t(217.5) = 3.26$, $p = 0.012$, $d = 1.08$) decrease in performance from trial 1 ($M = 0.73$, $SE = 0.04$) to trial 5 ($M = 0.50$, $SE = 0.06$). For the alternating group, there was a significant ($t(215.1) = 3.17$, $p = 0.017$, $d = 1.23$) decrease in performance from trial 1 ($M = 0.75$, $SE = 0.05$) to trial 5 ($M = 0.47$, $SE = 0.08$). For the automation group, there was a highly significant ($t(218.5) = 5.92$, $p < .001$, $d = 1.69$) decrease in performance from trial 1 ($M = 0.95$, $SE = 0.03$) to trial 5 ($M = 0.38$, $SE = 0.08$). Figure 10 illustrates the average performance for each group between the first and last trial.

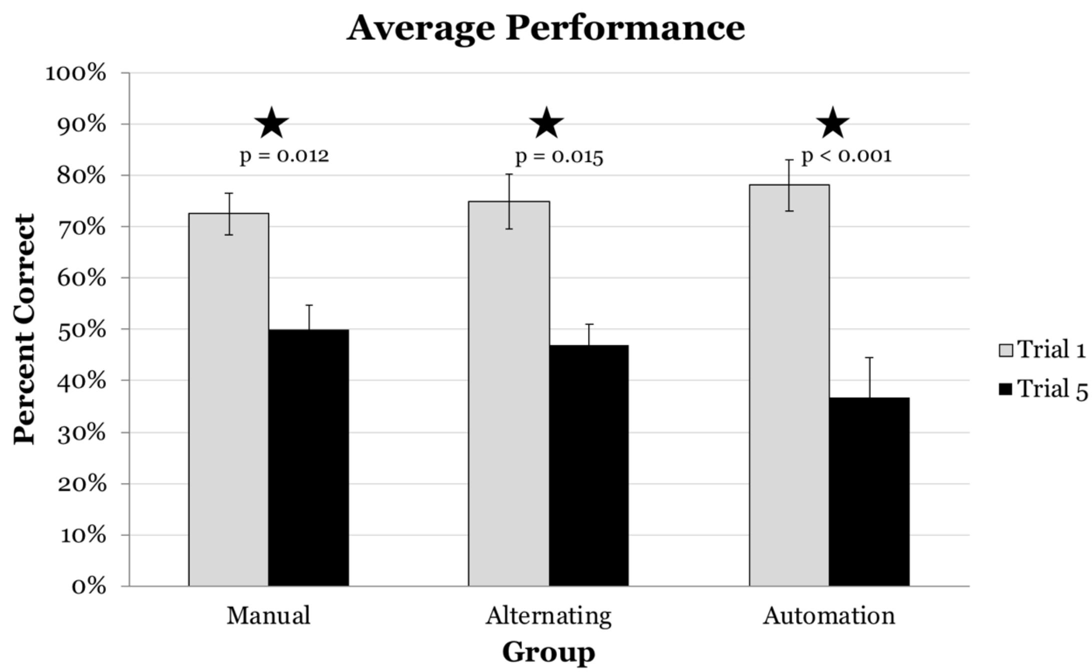


Figure 10. *Average performance of participants on flight task for each group for the first and last trial.*

Comparing the Change in Performance from Trial 1 to Trial 5 Between Groups

The main effect of group was significant for the change in performance, $F(2, 2) = 3.33$, $p = 0.045$. The change in performance was significantly ($p = 0.045$) greater in the Automated Group ($M = -0.40$, $SE = 0.06$) than the Manual group ($M = -0.20$, $SE = 0.06$). No other pairwise comparisons resulted in significant differences. Figure 11 illustrates the average performance for each group between the first and last trial.

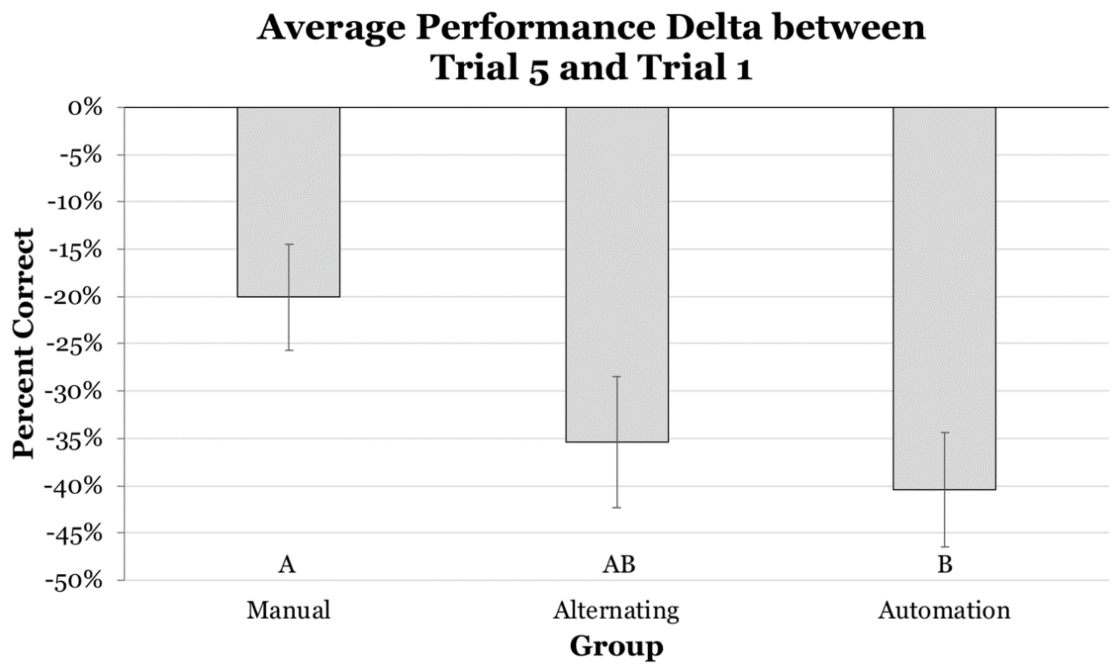


Figure 11. *Average performance of participants on flight task for the difference in each group between the first and last trial.*

Comparing Groups within Trial

At trial 1, there were no significant differences between groups. For trials 2, 3, and 4, there were no significant differences between groups performing the task with the same method (manual or automated). However, there were highly significant differences when any group used different methods. For example, at trial 3, alternating (M = 0.45, SE = 0.08) and automation (M = 0.97, SE = 0.02) showed highly significant differences ($t(190.1) = -6.45$, $p < .001$). At trial 5, there were no significant differences between groups.

Table 5, below illustrates a comparison between groups within trial along with the associated Tukey's test.

Table 5. *Average performance comparing groups within trial with Tukey's test.*

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's
Manual	0.73 0.04	a	0.53 0.05	β	0.53 0.05	B	0.54 0.06	δ	0.50 0.06	ε
Alternating	0.75 0.05	a	0.90 0.04	α	0.45 0.08	B	0.95 0.04	γ	0.47 0.08	ε
Automation	0.78 0.04	a	0.95 0.03	α	0.97 0.02	A	0.97 0.02	γ	0.37 0.08	ε

Comparing Trials within Group

Table 6, below, compares the average performance within group for each trial. For the manual group, trial 1 was significantly different from the other trials. For the alternating group, trials 1, 2, and 4 were significantly different from trials 3 and 5. For the automated group, trial 1 was significantly different from the other trials, as was trial 5.

Table 6. *Average performance comparing trials within group with Tukey's test.*

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's
Manual	0.73 0.04	a	0.53 0.05	b	0.53 0.05	b	0.54 0.06	b	0.50 0.06	b
Alternating	0.75 0.05	α	0.90 0.04	α	0.45 0.08	β	0.95 0.04	α	0.47 0.08	β
Automation	0.78 0.04	B	0.95 0.03	A	0.97 0.02	A	0.97 0.02	A	0.37 0.08	C

Average Workload

Figure 12 illustrates the average workload of the three groups over five trials. The main effect of group was not significant. The main effect of trial was highly significant ($F(4, 170) = 40.76$, $p < .001$). The interaction was highly significant ($F(8, 173) = 35.63$, $p < .001$).

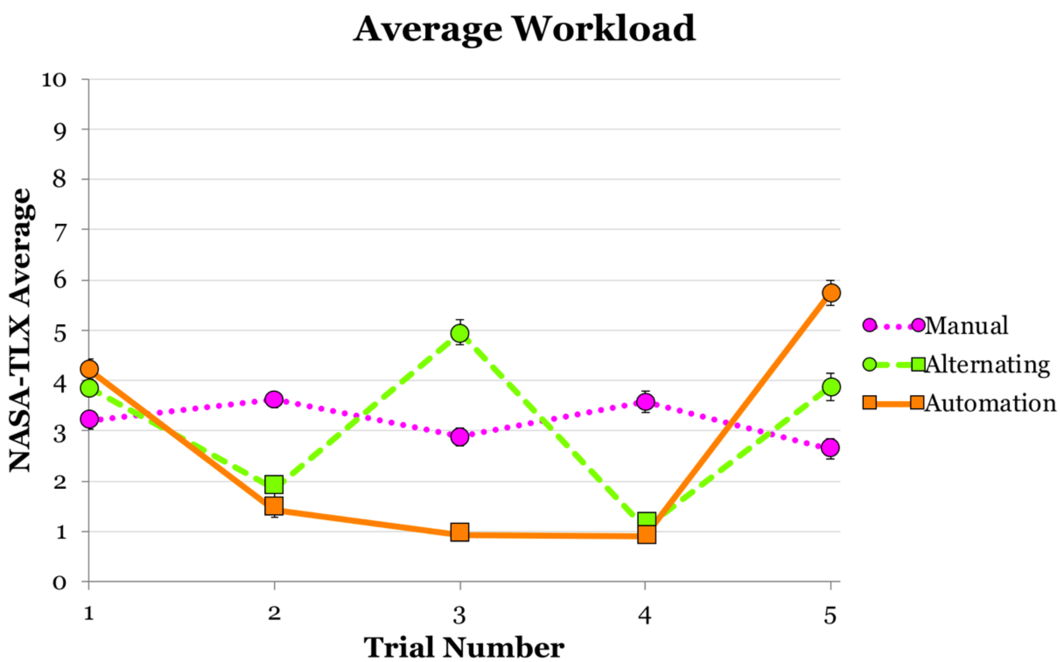


Figure 12. *Average workload of participants after flight task over five trials.*

The three groups performed with the manual method a different number of times (instances of manual) throughout the experiment. Figure 13 presents the average workload for only use of the manual method. The horizontal axis denotes how many times they have performed with the manual method.

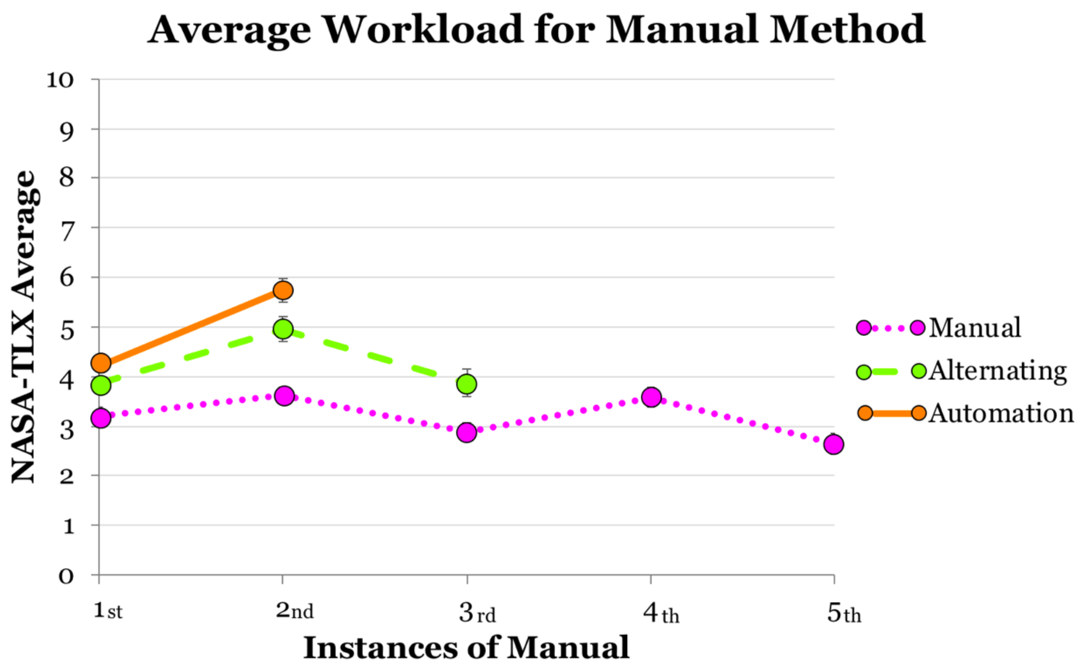


Figure 13. *Average workload for the instances of manual of participants over five trials.*

Comparing Trial 1 and 5 within Group

For the manual group, there was a no significant difference in average workload from trial 1 to trial 5. For the alternating group, there was a no significant difference in average workload from trial 1 to trial 5. For the automation group, there was a significant (t(221.8) = -2.97, p = 0.028, d = -0.82) increase in average workload from trial 1 (M = 4.21, SE = 0.43) to trial 5 (M = 5.74, SE = 0.48). Figure 14 illustrates the average workload for each group between the first and last trial.

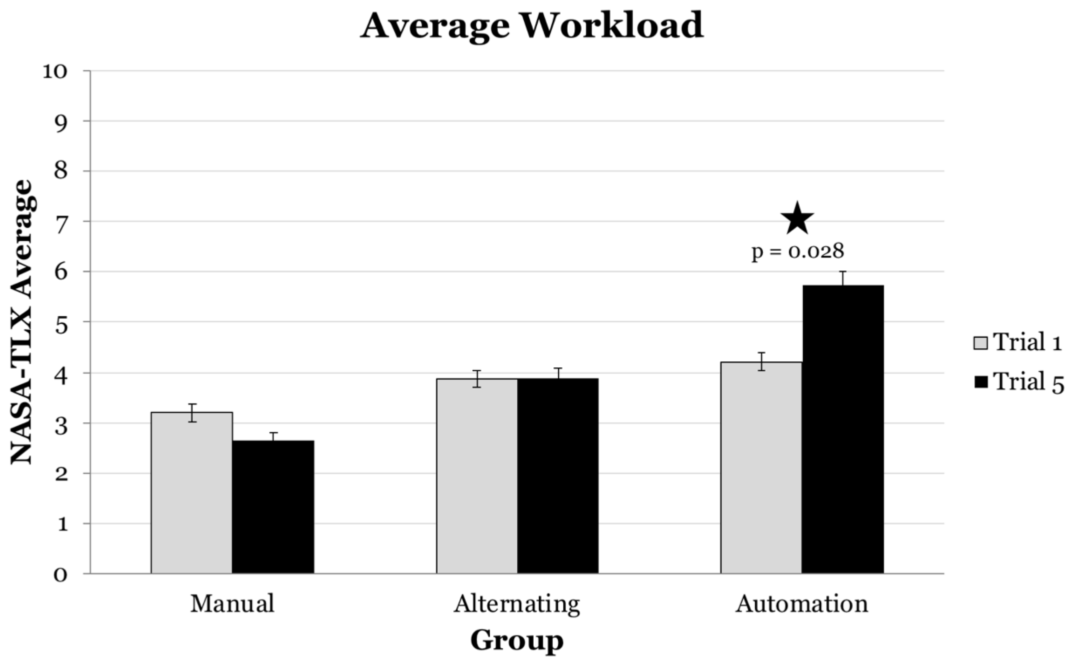


Figure 14. *Average workload of participants on flight task for each group for the first and last trial.*

Comparing the Change in Average Workload from Trial 1 to Trial 5 Between Groups

The main effect of group was significant for the change in average workload, $F(2, 2) = 4.73$, $p = 0.014$. The change in average workload was significantly ($p = 0.010$) greater in the Automated Group ($M = 1.29$, $SE = 0.44$) than the Manual group ($M = -0.55$, $SE = 0.41$). No other comparisons resulted in significant results. Figure 15 illustrates the average workload for each group between the first and last trial.

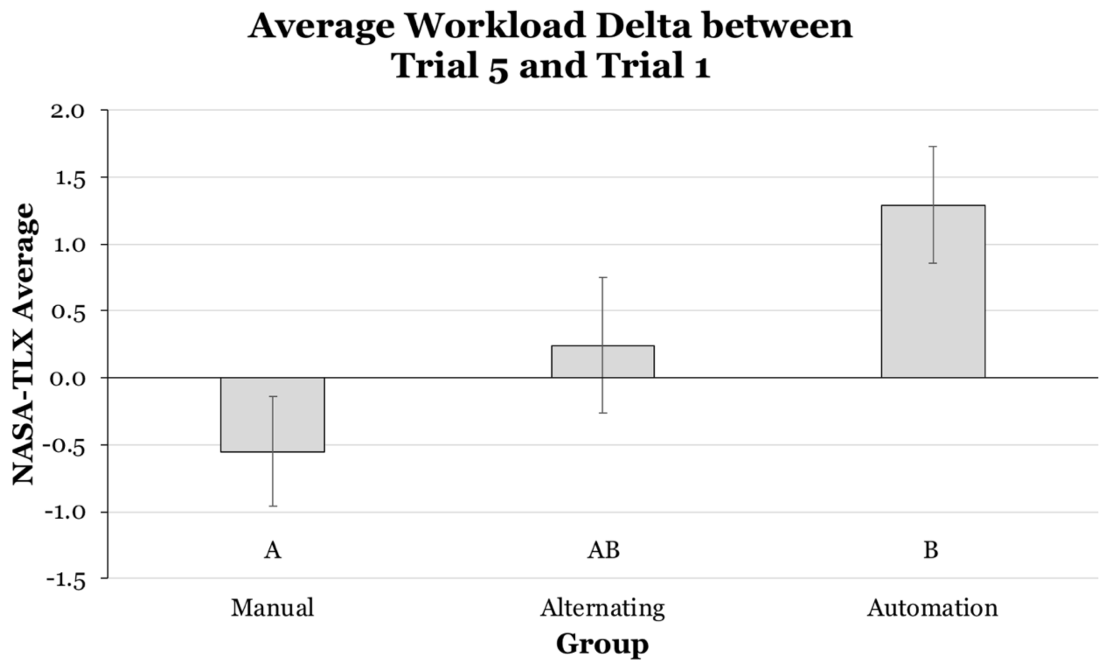


Figure 15. *Average workload of participants on flight task for the difference in each group between the first and last trial.*

Comparing Groups within Trial

At trial 1, there were no significant differences between groups. For trials 2 and 4, there were no significant differences in workload between groups completing the task with the same method (manual or automated). However, there were highly significant differences when any group used different methods. For example, at trial 4, manual (M = 3.58, SE = 0.41) and automation (M = 0.90, SE = 0.26) showed highly significant differences (t(155.4) = -5.00, p < .001). Other statistical results showed a similar pattern. At trial 3, every group was statistically different. Alternating group (M = 4.96, SE = 0.50) presented highly significant (t(168.7) = 7.48, p < .001) increase in workload compared to automation group (M = 0.92, SE = 0.20). Alternating group showed significant (t(167.4) = 4.01, p < .001) increase in workload compared to manual group (M = 2.89, SE = 0.35). In addition, manual group (M =

2.89, *SE* = 0.35) showed significant (*t*(152.6) = -3.81, *p* < .001) increase in workload compare to automation group (*M* = 0.92, *SE* = 0.20). At trial 5, there were significant differences in workload between every group. Alternating group (*M* = 3.88, *SE* = 0.56) presented a significant (*t*(160.3) = -3.04, *p* = 0.008) decrease in workload compared to automation group (*M* = 5.74, *SE* = 0.48). In addition, manual group (*M* = 2.64, *SE* = 0.42) showed a highly significant (*t*(154.1) = 5.67, *p* < .001) increase in workload compared to automation group (*M* = 5.75, *SE* = 0.48). Table 14, below illustrates a comparison between groups within trial along with the associated Tukey's test.

Table 7. *Average workload comparing groups within trial with Tukey's test.*

	Trial 1		**Trial 2**		**Trial 3**		**Trial 4**		**Trial 5**	
	M (SE)	**Tukey's**	**M (SE)**	**Tukey's**	**M (SE)**	**Tukey's**	**M (SE)**	**Tukey's**	**M (SE)**	**Tukey's**
Manual	3.2 0.35	a	3.6 0.32	α	2.9 0.35	B	3.6 0.41	δ	2.6 0.42	ε
Alternating	3.9 0.32	a	1.8 0.41	β	5.0 0.50	A	1.07 0.27	γ	3.9 0.56	ε
Automation	4.2 0.43	a	1.4 0.29	β	0.92 0.20	C	0.90 0.26	γ	5.7 0.48	κ

Comparing Trials within Group

Table compares the average workload within group for each trial. For the manual group, there was no significant difference between the trials. For the alternating group, trials 1, 3, and 5 were significantly different from trials 2 and 4. For the automated group, trial 1 was significantly different from the other trials, as was trial 5.

Table 15. *Average workload comparing trials within group with Tukey's test.*

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	M (SE)	**Tukey's**	**M (SE)**	**Tukey's**	**M (SE)**	**Tukey's**	**M (SE)**	**Tukey's**	**M (SE)**	**Tukey's**
Manual	3.2 0.35	a	3.6 0.32	a	2.9 0.35	a	3.6 0.41	a	2.6 0.42	a
Alternating	3.9 0.32	α	1.8 0.41	β	5.0 0.50	α	1.07 0.27	β	3.9 0.56	α
Automation	4.2 0.43	B	1.4 0.29	C	0.92 0.20	C	0.90 0.26	C	5.7 0.48	A

Completion Time

Figure 16 illustrates the average performance of the three groups over five trials. The main effect of group was significant ($F(2, 70.6) = 6.49$, $p = 0.003$). The main effect of trial was highly significant ($F(4, 174) = 6.31$, $p < .001$). The interaction was highly significant ($F(8, 174) = 16.44$, $p < .001$).

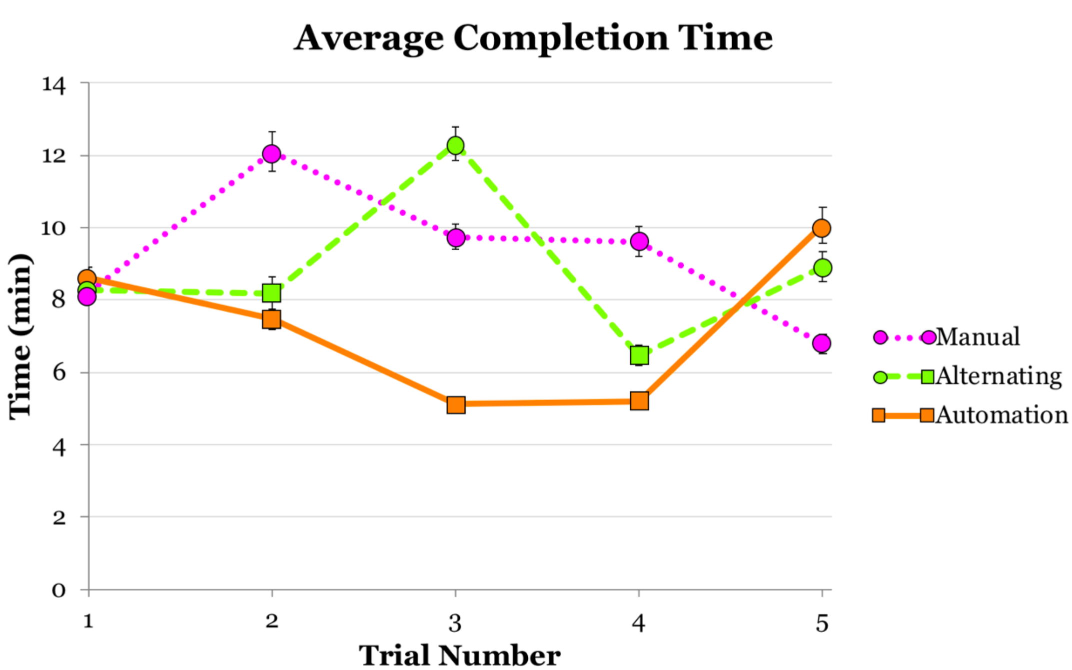


Figure 16. *Average completion time of participants after flight task over five trials.*

The three groups performed with the manual method a different number of times (instances of manual) throughout the experiment. Figure 17 presents the average completion time for only use of the manual method. The horizontal axis denotes how many times they have performed with the manual method.

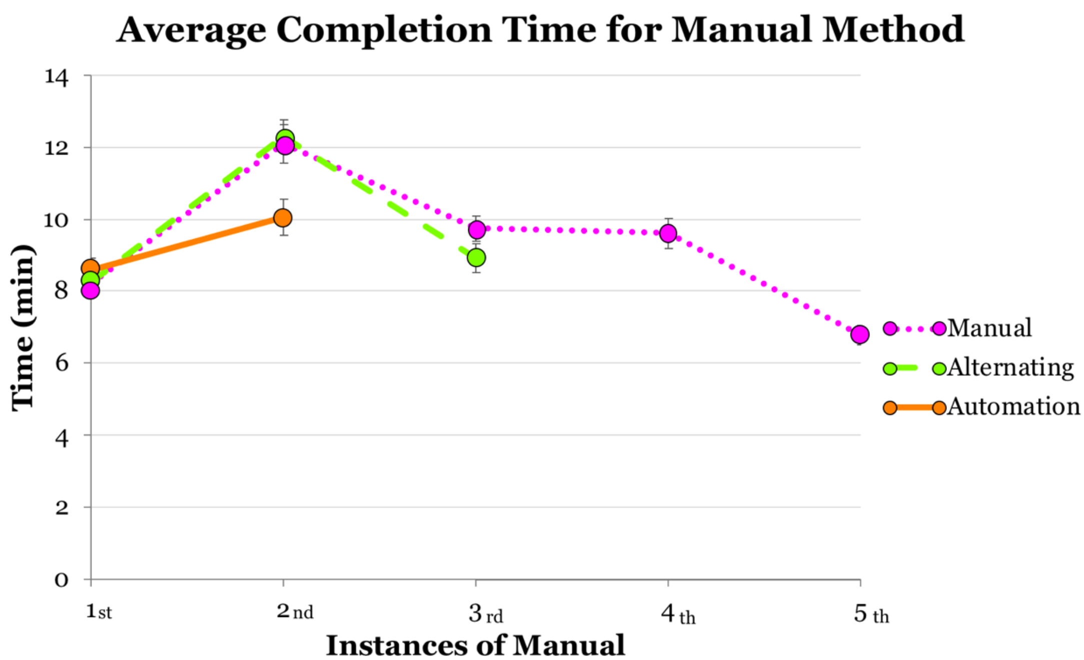


Figure 17. *Average completion time for the instances of manual of participants over five trials.*

Comparing Trial 1 and 5 within Group

For the manual group, there was a no significant difference in completion time from trial 1 to trial 5. For the alternating group, there was a no significant difference in completion time from trial 1 to trial 5. For the automation group, there was a no significant difference in completion time from trial 1 to trial 5. Figure 18 illustrates the average completion time for each group between the first and last trial.

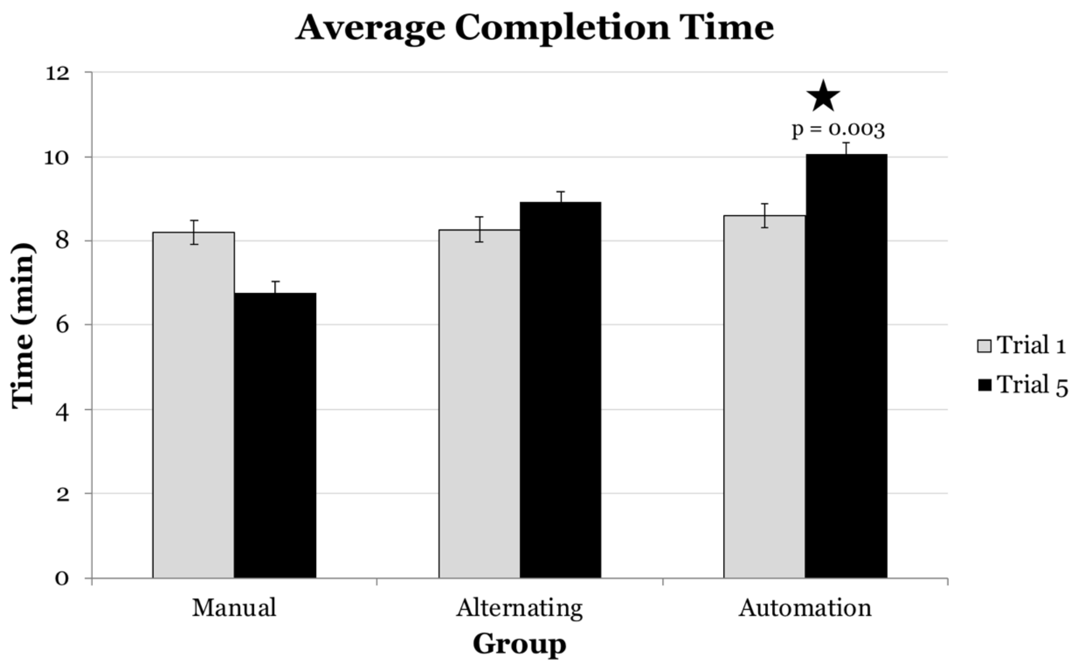


Figure 18. *Average completion time of participants on flight task for each group for the first and last trial.*

Comparing the Change in Completion Time from Trial 1 to Trial 5 Between Groups

The main effect of group was significant for the change in completion time, $F(2, 2) = 3.29$, $p = 0.047$. The change in average completion time was marginally significantly ($p = 0.059$) greater in the Automated Group ($M = 1.19$, $SE = 0.78$) than the Manual group ($M = -1.33$, $SE = 0.73$). No other comparisons resulted in significant results. Figure 19 illustrates the average completion time for each group between the first and last trial.

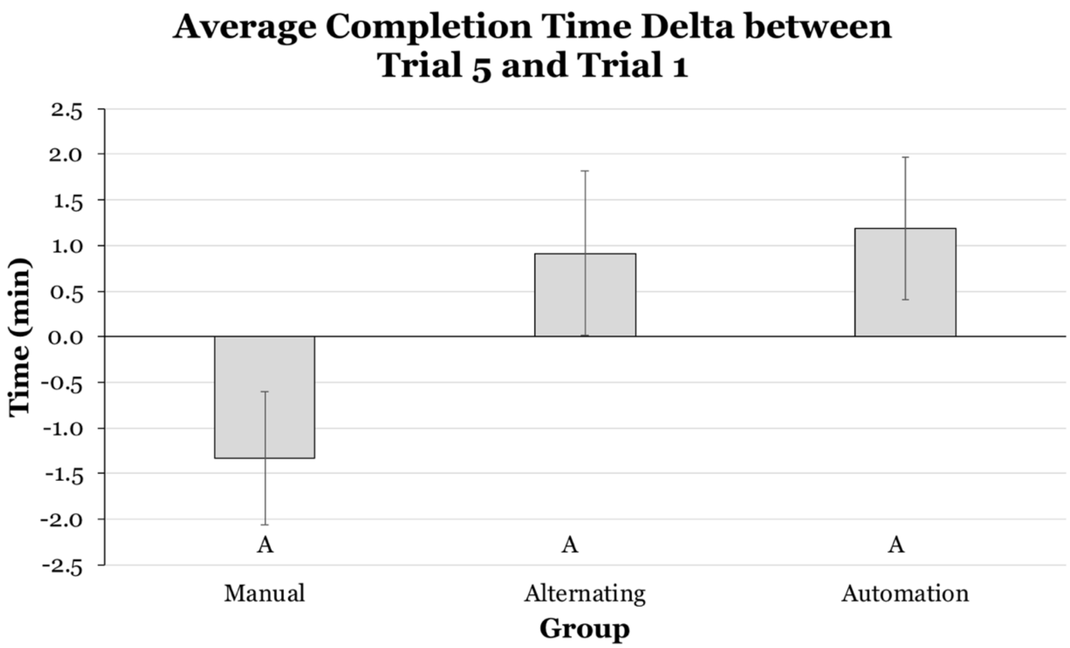


Figure 19. *Average completion time of participants on flight task for the difference in each group between the first and last trial.*

Comparing Groups within Trial

At trial 1, there were no significant differences between groups. For trials 2, 3, and 4, there were no significant differences between groups performing the task with the same method (manual or automated). However, there were highly significant differences when any group used different methods. For example, at trial 3, alternating (M = 12.31, SE = 0.92) and automation (M = 5.11, SE = 0.28) showed highly significant differences ($t(210.5) = 7.05$, $p < .001$). Other statistical results showed a similar pattern. At trial 5, there were significant differences in completion time between the manual and automation groups. Manual group (M = 6.78, SE = 0.52) showed a significant ($t(199.5) = 3.31$, $p = 0.003$) increase in completion time compared to automation group (M = 10.06, SE = 1.01). Table, below illustrates a comparison between groups within trial along with the associated Tukey's test.

Table 16. *Average completion time comparing groups within trial with Tukey's test.*

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's
Manual	8.2 0.46	a	12 1.1	α	9.7 0.70	B	9.6 0.93	δ	6.8 0.52	ε
Alternating	8.3 0.59	a	8.2 0.92	β	12 0.92	A	6.5 0.55	γ	8.9 0.82	ε κ
Automation	8.6 0.61	a	7.5 0.56	β	5.1 0.28	C	5.2 0.26	γ	10 1.0	κ

Comparing Trials within Group

Table 17 below, compares the average completion time within group for each trial. For the manual group, trial 1 was significantly different from trial 2, trial 2 was significantly different from all other trials, and trial 5 was significantly different from trials 2, 3 and 4. For the alternating group, trials 1 was significantly different from all other trials. For the automated group, trial 1 was significantly different from trial 3 and 4, trial 2 was significantly different from trial 3 and 5, trial 3 was significantly different from trial 1, 2, and 5, and trial 5 was significantly different from trial 2, 3, and 4.

Table 17. *Average completion time comparing trials within group with Tukey's test.*

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's	M (SE)	Tukey's
Manual	8.2 0.46	cb	12 1.1	a	9.7 0.70	b	9.6 0.93	b	6.8 0.52	c
Alternating	8.3 0.59	α	8.2 0.92	β	12 0.92	β	6.5 0.55	β	8.9 0.82	β
Automation	8.6 0.61	BA	7.5 0.56	BC	5.1 0.28	D	5.2 0.26	DC	10 1.0	A

Discussion

The study investigated the effects of cognitive skill degradation through the use of automation. Hypothesis H1 stated that the use of an automation aid is expected to result in larger skill degradation than manual over time. The hypothesis was fully supported. The automation aid did not aid in skill retention in comparison to using the manual method. Over the course of nine weeks, it was shown that the cognitive skill degradation was significantly larger for groups that used automation than those that used only manual methods.

Hypothesis H2 stated was that reliance upon automation aids will lead to higher workload and completion time when the user is required to use manual. The hypothesis was fully supported. When the automation group returned to the manual method in trial 5, their workload and completion time was higher than that of the manual group.

The results of this study show that the persistent use of an automation aid presented the highest level of skill degradation between the first and last trial. All three groups decreased in performance when comparing trial 1 to 5. Specifically, the manual group displayed the least degradation of performance. The alternating group demonstrated moderate degradation of performance. The automation group showed the highest degradation of performance.

Although all three groups experienced degraded results of performance over time, the manual group had the least amount of degradation whilst the automation group showed the highest degradation. This indicates that reinforcing the practice of a task manually mitigated skill degradation. The automated method of both the automation and alternating groups was not helpful to lessen skill degradation when completing manual tasks.

A possible explanation for the manual and alternating groups having less degradation in comparison to the automation group is the testing effect. The phenomena of the testing effect is described by Rowland (2014) as “engaging in a test over previously studied information can serve as a potent learning event.” Attempting to recall information has been shown to enhance learning (Kornell & Vaughn, 2016; Rowland, 2014). During the manual trials for these two groups, participants were retrieving the skills to use the E6-B, therefore enhancing their learning.

A potential reason why the manual group showed a decrease in performance from trial 1 to trial 2 is due to lack of feedback during the training. It was intentional to not provide immediate feedback after each trial to participants because the experimenters did not want to intervene with the participants’ skill set. It is possible that no feedback after each trial led to lower performance because participants did not know whether their approach was correct or not. However, they were trained to criteria before the trials began.

Reflecting upon workload, as more time elapsed between using the manual method, average workload increased. Using the automated method provides participants with a lower workload whilst using the aid, however, relying on automation increases workload when switching back to the manual method. For the alternating group, their workload was approximately the same between the first trial and last trial, which indicated that a mixture of using the manual method with the automated aid was helpful in not raising average workload.

The average completion time did not result in any significant differences between groups, however, trends can be observed. When the automated group switched back to the manual method, it took longer for them to complete the task than the other groups. This could be due to a long time in between practicing with the manual E6-B. This may indicate that practicing through the use of automation aids is insufficient as practice for a task to keep manual skills current. The manual group took longer the first time coming back to the study (trial 2), then continued to reduce completion time each trial following.

Calculation and estimation skills are thought to be vulnerable to decay because they require time, experience, and working memory (Wan & Huon, 2015). Participants were not consistently practicing these skills, therefore they were susceptible to degradation. The automation aid was not sufficient as practice for the alternative or automation groups when they were tested on the manual method. Gillen (2008) found that pilots using advanced glass aircraft technologies have experienced a significant degradation in their basic instrument flying skills. Pilots are aware of this decay, but still, have the confidence they can fly these maneuvers. This misplaced confidence can be dangerous if their skill performance does not match their believed skill level. Pilots who are competent in their basic instrument flying skills are shown to enhance their overall flying skills (Gillen, 2008).

Further studies need to establish how to mitigate skill degradation. The results of this study can be used to guide design. Measurement and analysis of the effects of IA on cognitive performance is an important first step in understanding the root causes of these types of errors and in addressing them through mitigation recommendations that should be considered during the design of these systems. These discussions should be addressed in future work and will expand the understanding of long-term effects of skill degradation.

Acknowledgments

The work in this chapter study was supported in part by the Undergraduate Research Assistant (URA) program in the IMSE department. Special thanks to the URA program coordinators Devna Popejoy-Sheriff and Leslie Potter. Rachel Dudley and Euijung Yang served as graduate student mentors, and were instrumental in their guidance and help in the research design. Thank you to the URAs: Elizabeth Lynch for her aid in developing test scenarios, Maria Dropps for her help running the experiment, and Nicole Kittleson for data transcription. Jeremy Hadler contributed as a statistics consultant in the data analysis portion.

CHAPTER 5. CONCLUSION

Summary of Findings

The objective this work was to identify the cognitive skills needed in flight planning and evaluate how they degrade over time. This was accomplished with two studies. The objective of the first study was to find what decision points and skills are involved in the task of flight planning. This is through breaking down the skills and procedural knowledge into categories and elements which reflect how subject matter experts manage operational tasks and challenges. The objective of the second study was to examine the effects of skills that are vulnerable to degradation over time through the use of automation.

The first study was an Applied Cognitive Task Analysis that determined what cognitive demands a pilot uses during flight planning. It determined which skills are difficult for novices and what errors may result. The cognitive skills identified were: calculating, estimating, noticing, organizing, controlled processing, reasoning, problem-solving, scanning, anticipating, predicting, pattern recognition, communicating, and prioritizing. The skills found to be particularly vulnerable to skill decay were those that involved calculation and estimation.

The second study was an empirical evaluation designed to detect the presence and magnitude of cognitive skills degradation as a result of differing levels of reliance on automation. It was intended to look at the skills which are vulnerable to decay in a specific task, and see how time and automation aids affect the performance. The task of flight planning was examined with a focus on calculation and estimation skills. This involved participants calculating heading, speed, time en route, and fuel requirements over the course of nine weeks. The study found that automation as an aid does not help in terms of practice.

It also showed that after a period of nonuse for the manual method, completion time and workload increased. In order to mitigate the degradation of these skills, the manual method must be practiced.

Implications

The results of these studies provide insights into cognitive skill degradation in regards to aviation. Calculation and estimation skills were found to be particularly vulnerable to skill degradation. It was shown that after nine weeks, these cognitive skills were degrading for flight planning tasks. Additionally, it was found that using an automation aid did not suffice as a method for maintaining skills. When relying on an automation aid, workload and completion time increase when the automation aid is removed. In flight planning, if a pilot relies on an automation aid and it outputs incorrect information, loss of calculation and estimation skills may prevent a pilot from realizing that something is wrong. Calculation skills include determining the proper values for speed, heading, time en route, and fuel requirements. Estimation involves determining an approximate value for the output, and checking if the calculation matches the estimation. Complacently accepting incorrect calculations could lead to incorrect fuel on board or improper weight and balance of the aircraft. If the calculation does not seems right, the pilot needs to recalculate to ensure it is correct.

Examining how pilots perform a flight planning task helps to identify the skills which are required to safely complete the task. By understanding which cognitive skills are difficult for a pilot, it can aid designers for training systems to determine what most needs focus.

Ultimately, these training systems will mitigate the degradation of cognitive skills, especially those which are vulnerable to decay.

Mitigation techniques include embedded training and recurrent training. Embedded training combines computer-based training with on-the-job performance. Evans (1988) defines embedded training as “training that is provided by capabilities built into or added into the operational system to enhance and maintain skill proficiency necessary to maintain or operate the equipment.” Embedded training is most applicable for tasks which rely at least partially on computers because the training is computer-based. This type of training is especially useful for people who just need occasional refresher training to keep up their skills. Embedded training should be considered for tasks when the task is critical with regard to safety concerns or when the task is moderate to high in cognitive complexity (Evans, 1988; Wickens & Flach, 1998). This type of training has the ability for aid pilots in retaining their manual flying skills while in low workload portions of the flight such as cruise.

Aviation simulators have achieved the level of technology where they can replicate virtually any real-world situation. Simulators have the ability to produce detailed terrain, off-nominal events such as equipment failures, challenging weather conditions, and more. One challenge in current simulation training software is to design a system that promotes learning and skill retention. In order to promote learning, the focus needs to be on the design of training systems which support complex skill acquisition (Salas, Bowers, & Rhodenizer, 1998). These skills need to be better understood so that it can be a focus of recurrent training for pilots.

Contributions

The contributions of this thesis work are described below:

1. Developed a detailed description of the process a pilot goes through while planning a VFR flight, cognitive skills they use, and challenges within the task of flight planning.
2. Identified the cognitive skills associated with the task of flight planning and determined which are the most vulnerable to degradation.
3. Evaluated the effects of reliance on an automation aid in regards to cognitive skill performance and demonstrated that skill degradation in flight planning can happen in as little as nine weeks.

This thesis was conducted to further investigate cognitive skill degradation within the context of aviation. The results can inform future work to design and test mitigation techniques for cognitive skill decay.

Future Work

The current work focused on one task in one domain, with a narrow range of participants. Future studies will be needed to address these limitations. Research needs to explore more tasks within aviation as well as other domains. This would aid in understanding if cognitive skills degrade similarly across tasks and to what extent. Additionally, the second study was tested with students as participants. Using highly trained experts with years of experience in a realistic environment would better capture the complexity of cognitive skill degradation in operational domains.

Within exploration of cognitive skill degradation, studies should focus on participants within the domain. An area of future study is the effect of recurrent and embedded training techniques on the mitigation of cognitive skill degradation. Another factor that could be investigated is feedback to users on their performance and corrective techniques to improve their skills. Further studies need to establish how to mitigate skill degradation. Measurement and analysis of the effects of IA on cognitive performance is an important first step in understanding the root causes of these types of errors and in addressing them through mitigation recommendations that should be considered during the design of these systems. These discussions should be addressed in future work and will expand the understanding of long-term effects of skill degradation.

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APPENDIX A. APPLIED COGNITIVE TASK ANALYSIS EXPERIMENTAL MATERIALS

CONSENT FORM

INFORMED CONSENT DOCUMENT

Title of Study: **Applied Cognitive Task Analysis for Flight Planning**

Investigators: **Katie Volz (Industrial & Manufacturing Systems Engineering) and Michael Dorneich (Industrial & Manufacturing Systems Engineering)**

This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

INTRODUCTION

We are interested in understanding the thought process a pilot has while planning for a flight. Your participation is voluntary and you may quit at any time. In order to participate in this study, you must be at least 18 years of age, possess aviation experience, and plan on being able to attend the full interview.

For this study, you will be asked to do the following:

1. Read and sign an informed consent document.
2. Complete a survey to collect basic demographic data.
3. Complete the cognitive task analysis, which will consist of the following:
   a. Complete an interview to identify the steps for a flight planning task.
   b. Generate examples of previous flight planning situations.
   c. Complete a flight planning task to see how you would solve a realistic problem.

You will also be given a short debriefing at the conclusion of the experiment and a debriefing document will be given to you in case you have questions at the conclusion of the experiment.

DESCRIPTION OF PROCEDURES

If you agree to participate, you will be asked to attend one interview session. This will consist of identifying steps for a flight planning task, generating examples of previous flight planning situations, and completing a simulation interview to see how you would solve a realistic problem.

As you perform the tasks, audio data may be collected to ensure that the interview was captured fully. The audio data will be used to verify notes taken by the experimenters. We do not anticipate that the audio recordings will be disseminated to anyone outside the group of experimenters, but if it is, your voice will be distorted so that you will not be identifiable.

Your participation for the session is expected to last approximately 1 hour. In order to collect valid data for our research questions, we ask that you do not discuss this interview with anyone else.

RISKS

There are no foreseeable risks associated with the activities of this study.

BENEFITS

If you decide to participate in this study there will be no direct benefit to you. However, it is hoped that the information gained in this study will benefit society by increasing the understanding of how pilots plan for flight.

COSTS AND COMPENSATION

You will not have any costs based on your participation in this study. Upon completion of the study, you will be compensated for your participation according to the following criteria:

Professional pilot:	$25 gift card
Non-professional pilot:	$10

You will be paid according to the criteria above for the session attended, whether a session is completed or not. You will need to complete the Research Participant Receipt Form (RPRF) to receive this payment.

PARTICIPANT RIGHTS

Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide to not participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled. You must answer the questions truthfully and to the best of your ability.

CONFIDENTIALITY

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, auditing departments of Iowa State University, and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law. You will be assigned a participant number and all responses from you will only be identified by that number. A key linking the participant number to your contact information is made so that researchers can contact you for future research participation opportunities. The physical record of the key (participant identity to number) will be kept by the experimenters in a locked cabinet. Electronic data will be stored in a folder on CyBox, which will be accessible only to the PI and the key personnel. Also, if the results of this study are published, the identities of all participants will remain confidential.

De-identified information collected about you during this study may be shared with other researchers or used for future research studies. We will not obtain additional informed consent from you before sharing the de-identified data.

QUESTIONS OR PROBLEMS

You are encouraged to ask questions at any time during or after this study.

- For further information about the study contact one of the experimenters:
  - Katie Volz at kvolz@iastate.edu or
  - Dr. Michael Dorneich at dorneich@iastate.edu
- If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, Iowa State University, Ames, Iowa 50011.

****

PARTICIPANT SIGNATURE

Your signature below indicates that:

- You voluntarily agree to participate in this study.
- You are at least 18 years of age.
- The study has been explained to you.
- You have been given the time to read this Informed Consent Document.
- Your questions have been satisfactorily answered.

You will receive a copy of the written informed consent prior to your participation in the study.

Participant's Name (printed) ____

______________________________________ ______________________
(Participant's Signature) (Date)

PRE-EXPERIMENT SURVEY

The information contained in this questionnaire will help us understand the experiment results in terms of participant characteristics. All information contained herein will be kept confidential.

Profession / Major: ______________________________
Gender: ________ Age: _________
Have you ever taken ground school? Y / N When? _______

Do you have any piloting experience? Y / N
If yes, please answer questions 1 – 4 below,

1. Which of the following describe your piloting experience/certification (check all that appl y)?

	Experience	Certification
☐ Ultra-light	______	______
☐ Pre Student Certificate	______	______
☐ Student Certificate	______	______
☐ Recreational	______	______
☐ Sport	______	______
☐ Private	______	______
☐ Commercial	______	______
☐ Air Transport	______	______

2. Approximately how many flight hours do you have as a pilot? ______________
3. When was the last time you piloted an aircraft? ___________
4. Have you ever performed flight planning tasks? Y / N
5. What is your typical trip length for the past three years? (>300nm, >1000nm, >2500nm, r ange)
   ____
6. To how many different "typical" destinations do you fly for the past three years? _______
7. How often do you do flight planning? ____________________________
8. What method do you use to do flight planning? (Do you use tools, paper, etc.?)

____
____

9. What planes do you fly? (start with most frequent) ______________________________

____
____

How familiar are you with the E6B flight computer?

- ☐ Very familiar, I use it frequently
- ☐ Slightly familiar, I use it occasionally
- ☐ I have very little experience with it
- ☐ I have never used it
- ☐ I don't know what E6B is

INTERVIEW

Please answer the questions honestly and to the best of your ability. Any information given will be kept confidential.

Can you walk me through the process of planning for a flight?

How do you plan for future events?

What do you take into consideration when planning a flight?

How do you pick the optimal route?

How does the weather affect the fuel you carry?

Is there a time when you walked into the middle of a situation and knew exactly how things got there and where they were headed?

Can you give me an example of what is important about the Big Picture for this task? What are the major elements you have to know and keep track of?

Have you had experiences where part of flight planning just “popped” out at you; where you noticed things that others usually do not catch? What is an example?

When you do this task, are there ways of working smart or accomplishing more with less — that you have found especially useful?

Can you think of an example when you have improvised in this task or noticed an opportunity to do something better?

Can you think of a time when you realized that you would need to change the way you were performing in order to get the job done?

Can you describe an instance when you spotted a deviation from the norm, or knew something was amiss?

Have there been times when the equipment (ex. flight planning software, information services, etc.) pointed in one direction, but your own judgment told you to do something else? Or when you had to rely on experience to avoid being led astray by the equipment?

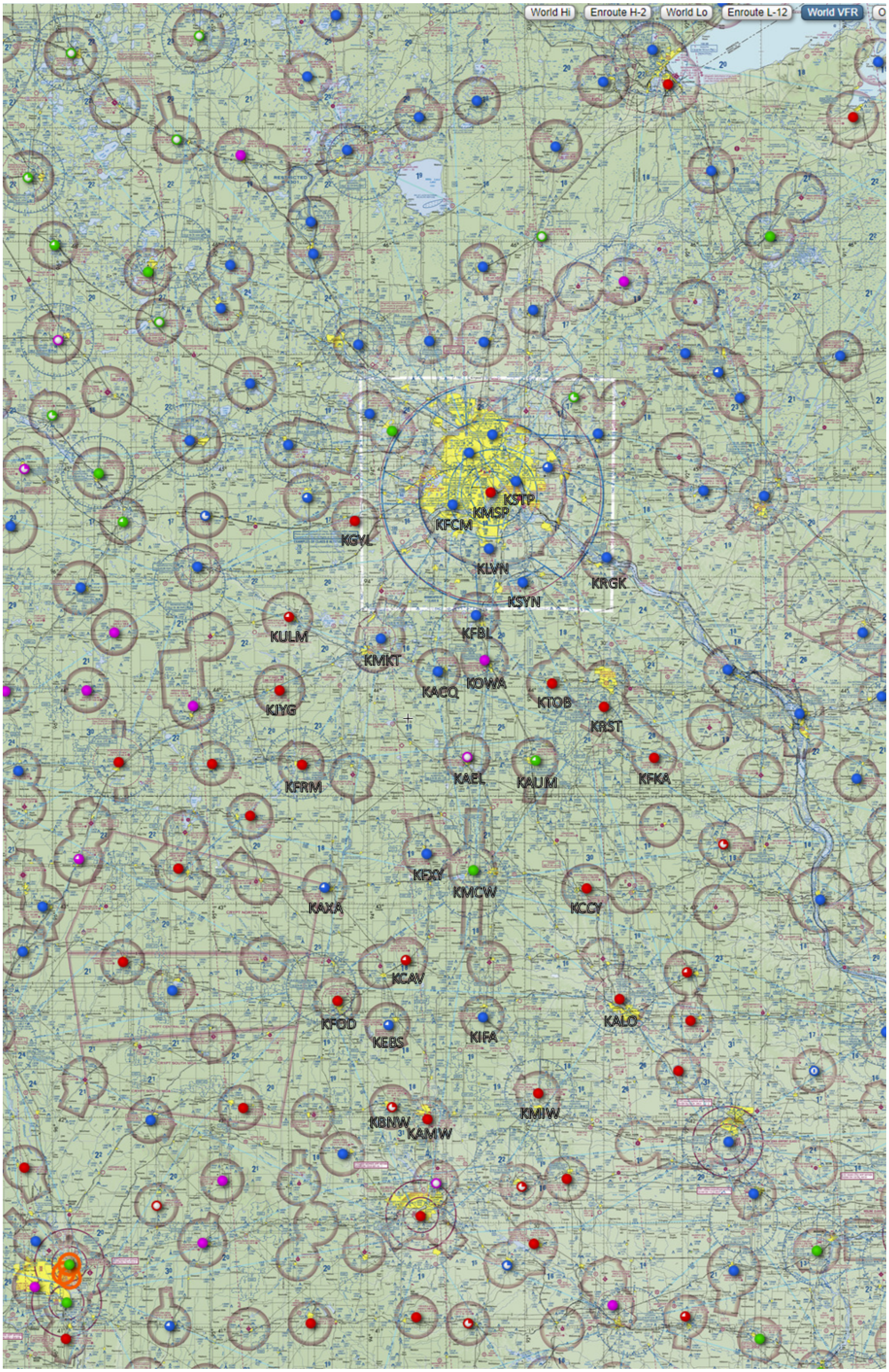
SIMULATION INTERVIEW

As you experience this simulation, imagine you are performing this task. We will now go through a simulated task, where you will do the flight planning for a flight from Ames to Minneapolis. Afterwards, I am going to ask you a series of questions about how you would approach this situation.

FLIGHT PLAN U.S. DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION	(FAA USE ONLY) ☐ PILOT BRIEFING ☐ VNR ☐ STOPOVER				TIME STARTED	SPECIALIST INITIALS
1. TYPE ☐ VFR ☐ IFR ☐ DVFR	2. AIRCRAFT IDENTIFICATION	3. AIRCRAFT TYPE / SPECIAL EQUIPMENT	4. TRUE AIRSPEED KTS	5. DEPARTURE POINT	6. DEPARTURE TIME PROPOSED (Z) ACTUAL (Z)	7. CRUISING ALTITUDE
8. ROUTE OF FLIGHT						
9. DESTINATION (Name of airport and city)	10. EST. TIME ENROUTE HOURS MINUTES	11. REMARKS				
12. FUEL ON BOARD HOURS MINUTES	13. ALTERNATE AIRPORT(S)	14. PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE 17. DESTINATION CONTACT/TELEPHONE (OPTIONAL)				15. NUMBER ABOARD
16. COLOR OF AIRCRAFT	CIVIL AIRCRAFT PILOTS. FAR Part 91 requires you file an IFR flight plan to operate under instrument flight rules in controlled airspace. Failure to file could result in a civil penalty not to exceed $1,000 for each violation (Section 901 of the Federal Aviation Act of 1958, as amended). Filing of a VFR flight plan is recommended as a good operating practice. See also Part 99 for requirements concerning DVFR flight plans.					

FAA Form 7233-1 (8-82)
Electronic Version (Adobe)

CLOSE VFR FLIGHT PLAN WITH ______________ FSS ON ARRIVAL


World Hi
Enroute H-2
World Lo
Enroute L-12
World VFR
KSTP
KMSP
KFCM
KGYL
KLVN
KRGK
KSYN
KFBL
KULM
KMKT
KAGQ
KOWA
KTOB
KRST
KIYG
KFRM
KAEL
KAUM
KFKA
KFXY
KMCW
KCCY
KAXA
KCAV
KFOD
KEBS
KIFA
KALO
KBNW
KAMW
KMIW

KAMW

Weather Station KAMW AMES (04m ago)
KAMW 061636Z AUTO 03012KT 2SM -SN BR SCT009 BKN016 OVC028 M02/M04 A2963 RMK AO2 SNB1554 P0000 T10171039

KBNW

Weather Station KBNW BOONE MUNI (05m ago)
KBNW 061635Z AUTO 02014KT 2SM -SN SCT009 SCT017 BKN049 M02/M03 A2962 RMK AO2

KEBS

Weather Station KEBS WEBSTER CITY (05m ago)
KEBS 061635Z AUTO 01014KT 10SM OVC012 M02/M04 A2965 RMK AO2

KFOD

Weather Station KFOD FORT DODGE (05m ago)
KFOD 061635Z AUTO 02011G16KT 6SM -SN BR FEW019 BKN023 OVC034 M02/M04 A2968 RMK AO2 P0000 FZRANO
TAF
AMD KFOD 061540Z 0616/0712 02010KT 3SM -SN SCT007 OVC012
TEMPO 0616/0617 BKN007
FM061700 35014G25KT 3SM -SN BLSN OVC013
FM070000 35013G25KT P6SM OVC014
FM070700 33012KT P6SM SCT030

KCAV

Weather Station KCAV CLARION (05m ago)
KCAV 061635Z AUTO 02010KT 1/2SM BR BKN015 OVC020 M03/M02 A2967 RMK AO2 PWINO

KAXA

Weather Station KAXA ALGONA (25m ago)
KAXA 061615Z AUTO 02015G22KT FEW013 FEW023 SCT029 M02/ A2970 RMK AO2 PWINO

KFXY

Weather Station KFXY FOREST CITY (05m ago)
KFXY 061635Z AUTO 03011G16KT 10SM BKN010 BKN019 OVC032 00/M02 A2969 RMK AO2

KFRM

Weather Station KFRM FAIRMONT MUNI (14m ago)
KFRM 061626Z AUTO 01020KT 2SM -SN BR OVC006 M01/M03 A2974 RMK AO2 PK WND 01026/1615 VIS 1 1/2V3 P0000 FZRANO

KACQ

Weather Station KACQ WASECA (05m ago)
KACQ 061635Z AUTO 02018G23KT 5SM BR OVC009 M01/M02 A2976 RMK AO2

KGYL

Weather Station KGYL GLENCOE (41m ago)
KGYL 061559Z AUTO 02014G21KT 1 3/4SM -SN OVC014 M02/M02 A2981 RMK AO2

KMKT

Weather Station KMKT MANKATO (44m ago)
KMKT 061556Z AUTO 02016G23KT 4SM -SN BR BKN011 OVC015 M01/M03 A2976 RMK AO2 CIG 009V012 SLP091 P0000 T10111028 FZRANO
TAF
AMD KMKT 061425Z 0614/0712 06010KT 3SM -SN BR SCT008 OVC020
TEMPO 0614/0616 1SM -SN BKN009
FM061700 02016G23KT P6SM OVC015
FM070100 34011KT P6SM BKN020
FM070900 32008KT P6SM SCT015

KAEL

Weather Station KAEL ALBERT LEA (38m ago)
KAEL 061602Z AUTO 05005KT M02/M03 A2969 RMK AO2 PWINO

KFBL

Weather Station KFBL FARIBAULT MUNI (01h 45m ago)
KFBL 061455Z AUTO 02009G15KT 1 1/4SM -SN OVC010 M02/M03 A2971 RMK AO2

KLVN

Weather Station KLVN MNPLS/AIRLAKE (15m ago)
KLVN 061635Z AUTO 03010G19KT 2 1/2SM -SN OVC019 M02/M03 A2979 RMK AO2

KRGK

Weather Station KRGK RED WING (15m ago)
KRGK 061635Z AUTO 04012G18KT 10SM OVC021 00/M05 A2977 RMK AO2

KSTP

Weather Station KSTP ST. PAUL (20m ago)
KSTP 061630Z 03015KT 1 1/4SM -SN BR FEW015 BKN025 OVC031 M02/M04 A2983 RMK AO2 P0000 T10171039

KMSP

Weather Station KMSP MINNEAPOLIS (03m ago)
KMSP 061647Z 04014G23KT 2SM -SN BKN022 OVC028 M01/M04 A2982 RMK AO2 SFC VIS 5 P0000
TAF
AMD KMSP 061459Z 0615/0718 04013G21KT P6SM VCSH OVC018
TEMPO 0615/0617 6SM -SHSN BKN015
FM061700 02014G21KT P6SM OVC020
FM062200 35012KT P6SM BKN020
FM070200 32008KT P6SM SCT020

KSYN

Weather Station KSYN STANTON (15m ago)
KSYN 061635Z AUTO 03018G22KT 7SM -RA OVC017 00/M03 A2976 RMK AO2 T10021031

KFCM

Weather Station KFCM MNPLS/FLYING CLD (12m ago)
KFCM 061638Z 03014G22KT 1 3/4SM -SN SCT017 BKN025 OVC050 M02/M06 A2980 RMK AO2 P0000 T10171056

KOWA

Weather Station KOWA OWATONNA (06m ago)
KOWA 061654Z AUTO 02012KT OVC010 M01/M03 A2975 RMK AO2

KAUM

Weather Station KAUM AUSTIN MUNI (05m ago)
KAUM 061655Z AUTO 03009G15KT 10SM BKN036 BKN080 M01/M03 A2970 RMK AO2

KMCW

Weather Station KMCW MASON CITY (07m ago)
KMCW 061653Z AUTO 02014KT 9SM BKN009 OVC037 M02/M03 A2970 RMK AO2 SNB26E43 SLP065 P0000 T10171033
KMCW 061645Z 0617/0712 02016KT 3SM -SN BR SCT008 OVC035
TEMPO 0617/0618 1/2SM SN OVC008
FM061800 01017G26KT 4SM -SN BLSN OVC011
FM070000 35017G24KT P6SM OVC014

KCCY

Weather Station KCCY CHARLES CITY (05m ago)
KCCY 061655Z AUTO 1SM -SN FEW004 BKN009 OVC012 M01/M01 A2967 RMK AO2 P0001

KALO

Weather Station KALO WATERLOO (06m ago)
KALO 061654Z 33007KT 3SM R12/3500VP6000FT -SN BR FEW013 FEW022 OVC028 M01/M02 A2963 RMK AO2 SLP045 P0002 T10111022 $
TAF
AMD KALO 061448Z 0615/0712 06006KT 1 1/2SM -SN FEW010 BKN025
TEMPO 0615/0617 3/4SM -SN BKN010
FM061700 02012KT 3SM -SN OVC020
FM062100 35016G26KT 4SM -SN OVC015
FM070100 34015G21KT P6SM OVC022

KMIW

Weather Station KMIW MARSHALLTOWN (07m ago)
KMIW 061653Z AUTO 05007KT 1 1/4SM -SN BR FEW011 BKN022 OVC039 M02/M03 A2963 RMK AO2 SLP044 P0000 T10171033

KIFA

Weather Station KIFA IOWA FALLS MUNI (05m ago)
KIFA 061655Z AUTO 36008KT 3SM -SN OVC010 M01/M03 A2966 RMK AO2 T10121034

KRST

Weather Station KRST ROCHESTER (13m ago)
KRST 061654Z 02015KT 2SM -SN BR OVC010 M01/M03 A2970 RMK AO2 SFC VIS 4 SNE13B25 CIG 007V012 SLP075 P0000 T10111028
TAF
AMD KRST 061246Z 0613/0712 06008KT 4SM BR OVC035
TEMPO 0613/0616 BKN007
FM061600 05012G20KT P6SM -SHSN OVC015
FM062100 01013G21KT P6SM OVC015
FM070300 35012KT P6SM BKN015

KFKA

Weather Station KFKA PRESTON (12m ago)
KFKA 061655Z AUTO 03008KT 7SM -SN BKN008 OVC017 M01/M03 A2969 RMK AO2 P0003 T10101030

KTOB

Weather Station KTOB DODGE CENTER (12m ago)
KTOB 061655Z AUTO 03015G19KT 10SM BKN009 BKN013 OVC023 M01/M03 A2972 RMK AO2

KJYG

Weather Station KJYG ST. JAMES (12m ago)
KJYG 061655Z AUTO 35015KT 2SM -SN OVC013 M02/M03 A2981 RMK AO2 VIS 1 1/2V3

KULM

Weather Station KULM NEW ULM MUNI (16m ago)
KULM 061655Z AUTO 02016G20KT 2 1/2SM -SN BKN015 BKN041 M02/M04 A2982 RMK AO2 VIS 1 1/4V4

Think back over the scenario. Please list the major events that occurred during the task. These events could include judgments or decision points. As you name them, I am going to list them in the left column of the board.

As the pilot in this scenario, what actions, if any, would you take at this point in time?

What do you think is going on here? What is your assessment of the situation at this point in time?

What pieces of information led you to this situation assessment and these actions?

What errors would an inexperienced person be likely to make in this situation?

APPENDIX B. COGNTIVE SKILL DEGRADATION EXPERIMENTAL MATERIALS

CONSENT FORM

ISU IRB # 1	14-266
Approved Date:	25 October 2016
Expiration Date:	27 October 2018

INFORMED CONSENT DOCUMENT

Title of Study: Assessing Cognitive Skill Degradation Due to Information Automation

Investigators: Michael Dorneich (Industrial & Manufacturing Systems Engineering), Euijung Yang (Industrial & Manufacturing Systems Engineering), Katie Volz (Industrial Engineering), and

This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

INTRODUCTION

We are interested in understanding the reduction or loss of a learned skill due to continued use of an information automation program. Your participation is voluntary and you may quit at any time. In order to participate in this study, you must be at least 18 years of age and plan on being able to attend a total of five experiment sessions, to be held on campus. The total duration of the study (between the first and final sessions) is expected to occur over 11 weeks.

For this study, you will be asked to do the following:

1. Read and sign an informed consent document
2. Complete a survey to collect basic demographic data
3. Complete the experiment tasks, which will consist of the following:
    a. Complete a training session to learn how to perform basic flight planning calculations using a manually operated E6B flight computer and a software package that performs the calculations for you.
    b. Perform the calculations for four different scenarios using one of the methods as assigned.
    c. Return for four follow-up sessions to perform the calculations for another set of four scenarios using one of the methods as assigned.
    d. Fill out a brief questionnaire after each session.
4. Complete a post-experiment questionnaire.

You will also be given a short debriefing at the conclusion of the experiment and a debriefing document will be given to you in case you have questions at the conclusion of the experiment

DESCRIPTION OF PROCEDURES

If you agree to participate, you will be asked to come in for five separate sessions to perform simplified flight planning tasks. The initial session will consist of training on how to compute the correct heading to fly and the required fuel for a flight. After you are trained to a sufficient level of performance, you will be given four different scenarios for which you will be asked to compute these values. The scenarios will consist of three flight legs drawn on a map, expected weather conditions, and airplane performance specifications. You will be randomly assigned to one of three groups doing several different scenarios.

As you perform the tasks, audio and video data will be collected and we will be measuring the accuracy of the results and the time to complete the tasks. The audio/video recordings will be captured from behind and efforts will be made to not capture your face. The audio/video data will be used only to verify manual data entries and notes taken by the experimenters. We do not anticipate that the audio/video recordings will be disseminated to anyone outside the group of experimenters, but if either is, your face will be blurred and your voice will be distorted so that you will not be identifiable.

Your participation for the first session is expected to last approximately 2 hours, including initial paperwork, training, and completion of assigned tasks and questionnaires. The subsequent sessions are expected to last no more than an hour.

In order to collect valid data for our research questions, we ask that you do not practice these tasks on your own between the experiment sessions.

RISKS

There are no foreseeable risks associated with the activities of this study.

BENEFITS

If you decide to participate in this study there will be no direct benefit to you. However, it is hoped that the information gained in this study will benefit society by increasing the understanding of how to mitigate the natural reduction of cognitive skills due to continued use of automated computation tools.

COSTS AND COMPENSATION

You will not have any costs based on your participation in this study. Upon completion of the study, you will be compensated for your participation according to the following schedule:

1st session: $10
2nd session: $ 5
3rd session: $ 5
4th session: $ 5
5th session: $30

You will be paid according to the schedule above for the sessions attended, whether a session is completed or not. In order for the results to be usable, however, attendance at subsequent sessions is dependent upon completion of previous sessions. If a session is missed, you will not

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be allowed to participate in any further sessions. For example, if you quit the 3rd session early, you will be paid for sessions 1 through 3, but your participation in the study will be terminated at that point and you will not be allowed to attend the 4th or 5th sessions.

You will need to complete the Research Participant Receipt Form (RPRF) to receive this payment.

PARTICIPANT RIGHTS

Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide to not participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled. You must make an attempt to correctly answer the calculation questions. Skipping questions does not disqualify you from participating in later experiment sessions.

CONFIDENTIALITY

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, auditing departments of Iowa State University, and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law, the particular results of your participation in this study will not be linked to your personal identity in any way. You will be assigned a participant number and all responses from you will only be identified by that number. The physical record of the key (participant identity to number) will be kept by the experimenters in a locked cabinet. Electronic data will be stored in a private folder on CyBox, which will be accessible only to the PI and the co-PIs. Also, if the results of this study are published, the identities of all participants will remain confidential.

The audio/video recordings will be encrypted and stored in a locked cabinet accessible only to the experimenters.

QUESTIONS OR PROBLEMS

You are encouraged to ask questions at any time during or after this study.

- For further information about the study contact one of the experimenters:
  - Dr. Michael Dorneich at dorneich@iastate.edu,
  - Euijung Yang at eui@iastate.edu,
  - Katie Volz at kvolz@iastate.edu, or

- If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, Iowa State University, Ames, Iowa 50011.

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PARTICIPANT SIGNATURE

Your signature below indicates that:

- You voluntarily agree to participate in this study.
- You are at least 18 years of age.
- The study has been explained to you.
- You have been given the time to read this Informed Consent Document.
- Your questions have been satisfactorily answered.

You will receive a copy of the written informed consent prior to your participation in the study.

Participant's Name (printed) ____

______________________________________ ______________________

(Participant's Signature) (Date)

Instructions for Automation Aid

E6B Emulator: http://mye6b.com/e6b.html#_welcome

Path for automated calculations:

1.
   a. Time Speed Distance -> Finding Distance
   b. Fuel Calculations -> Total Fuel Burned
   c. Effects of Wind -> Heading, Groundspeed & WCA

2.
   a. Time Speed Distance -> Finding Speed
   b. Fuel Calculations -> Fuel Consumption per Hour
   c. Effects of Wind -> Heading, Groundspeed & WCA

Training Test Questions

1. You are flying from Omaha to Sioux Falls. With this given information please do the following calculations below.

   a. The weather report indicates that there are winds from 300° at 45 knots (KTS). Your course is 120° and your aircraft has a true airspeed of 150 KTS.
   Calculate heading (degrees) and ground speed (KTS).

   b. The weather report has changed and the ground speed is now 125 KTS; your trip will take 1 hour and 40 minutes.
   Calculate the distance (nautical miles).

   c. Your aircraft burns an average of 10 gallons per hour; your trip will take 1 hour and 40 minutes.
   Calculate total fuel used (gallons).

2. You are flying from D.C. to Chicago. With this given information please do the following calculations below.

   a. The weather report indicates that there are winds from 230° at 20 knots (KTS). Your course is 100° and your aircraft has a true airspeed of 165 KTS.
   Calculate heading (degrees) and ground speed (KTS).

   b. The weather report has changed and the ground speed is now 195 KTS; the distance of your trip will be 500 nautical miles.
   Calculate the time that your trip will take.

   c. Your trip will use 45 gallons of fuel, and regardless of your previous answer, the trip will now take 3 hours and 55 minutes.
   Calculate gallons burned per hour.

Trial 1 Questions

1. You are flying from Denver to Casper, WY. With this given information please do the following calculations below.

a. The weather report indicates that there are winds from 40° at 40 knots (KTS). Your course is 150° and your aircraft has a true airspeed of 140 KTS. Calculate heading (degrees) and ground speed (KTS).

b. The weather report has changed and the ground speed is now 110 KTS; your trip will take 2 hours and 30 minutes. Calculate the distance (nautical miles).

c. Your aircraft burns an average of 8 gallons per hour; your trip will take 2 hours and 30 minutes. Calculate total fuel used (gallons).

2. You are flying from Des Moines to Iowa City. With this given information please do the following calculations below.

a. The weather report indicates that there are winds from 330° at 25 knots (KTS). Your course is 20° and your aircraft has a true airspeed of 180 KTS. Calculate heading (degrees) and ground speed (KTS).

b. The weather report has changed and the ground speed is now 160 KTS; the distance of your trip will be 100 nautical miles. Calculate the time that your trip will take.

c. Your trip will use 35 gallons of fuel, and regardless of your previous answer, the trip will now take 45 minutes. Calculate gallons burned per hour.

Trial 2 Questions

1. You are flying from Los Angeles to San Francisco. With this given information please do the following calculations below.

a. The weather report indicates that there are winds from 20° at 30 knots (KTS). Your course is 160° and your aircraft has a true airspeed of 190 KTS.
Calculate heading (degrees) and ground speed (KTS).

b. The weather report has changed and the ground speed is now 225 KTS; your trip will take 1 hours and 30 minutes.
Calculate the distance (nautical miles).

c. Your aircraft burns an average of 6 gallons per hour; your trip will take 1 hours and 30 minutes.
Calculate total fuel used (gallons).

2. You are flying from Des Moines to Minneapolis. With this given information please do the following calculations below.

a. The weather report indicates that there are winds from 170° at 45 knots (KTS). Your course is 40° and your aircraft has a true airspeed of 230 KTS.
Calculate heading (degrees) and ground speed (KTS).

b. The weather report has changed and the ground speed is now 200 KTS; the distance of your trip will be 340 nautical miles.
Calculate the time that your trip will take.

c. Your trip will use 45 gallons of fuel, and regardless of your previous answer, the trip will now take 1 hour and 30 minutes.
Calculate gallons burned per hour.

Trial 3 Questions

1. You are flying from Boise to Portland. With this given information please do the following calculations below.

   a. The weather report indicates that there are winds from 40° at 20 knots (KTS). Your course is 240° and your aircraft has a true airspeed of 210 KTS. Calculate heading (degrees) and ground speed (KTS).

   b. The weather report has changed and the ground speed is now 230 KTS; your trip will take 1 hours and 40 minutes. Calculate the distance (nautical miles).

   c. Your aircraft burns an average of 7 gallons per hour; your trip will take 1 hours and 40 minutes. Calculate total fuel used (gallons).

2. You are flying from New York to New Jersey. With this given information please do the following calculations below.

   a. The weather report indicates that there are winds from 150° at 35 knots (KTS). Your course is 125° and your aircraft has a true airspeed of 185 KTS. Calculate heading (degrees) and ground speed (KTS).

   b. The weather report has changed and the ground speed is now 130 KTS; the distance of your trip will be 175 nautical miles. Calculate the time that your trip will take.

   c. Your trip will use 30 gallons of fuel, and regardless of your previous answer, the trip will now take 1 hour and 10 minutes. Calculate gallons burned per hour.

Trial 4 Questions

1. You are flying from Seattle to Santa Fe. With this given information please do the following calculations below.

   a. The weather report indicates that there are winds from 100° at 25 knots (KTS). Your course is 265° and your aircraft has a true airspeed of 220 KTS. Calculate heading (degrees) and ground speed (KTS).

   b. The weather report has changed and the ground speed is now 250 KTS; your trip will take 2 hours and 55 minutes. Calculate the distance (nautical miles).

   c. Your aircraft burns an average of 20 gallons per hour; your trip will take 2 hours and 55 minutes. Calculate total fuel used (gallons).

2. You are flying from Orlando to Miami. With this given information please do the following calculations below.

   a. The weather report indicates that there are winds from 50° at 75 knots (KTS). Your course is 155° and your aircraft has a true airspeed of 205 KTS. Calculate heading (degrees) and ground speed (KTS).

   b. The weather report has changed and the ground speed is now 220 KTS; the distance of your trip will be 105 nautical miles. Calculate the time that your trip will take.

   c. Your trip will use 20 gallons of fuel, and regardless of your previous answer, the trip will now take 1 hour and 5 minutes. Calculate gallons burned per hour.

Trial 5 Questions

1. You are flying from Omaha to Des Moines. With this given information please do the following calculations below.

   a. The weather report indicates that there are winds from 130° at 40 knots (KTS). Your course is 25° and your aircraft has a true airspeed of 200 KTS.
   Calculate heading (degrees) and ground speed (KTS).

   b. The weather report has changed and the ground speed is now 200 KTS; your trip will take 1 hours and 25 minutes.
   Calculate the distance (nautical miles).

   c. Your aircraft burns an average of 11 gallons per hour; your trip will take 1 hours and 25 minutes.
   Calculate total fuel used (gallons).

2. You are flying from Tampa to New Orleans. With this given information please do the following calculations below.

   a. The weather report indicates that there are winds from 150° at 20 knots (KTS). Your course is 65° and your aircraft has a true airspeed of 190 KTS.
   Calculate heading (degrees) and ground speed (KTS).

   b. The weather report has changed and the ground speed is now 200 KTS; the distance of your trip will be 325 nautical miles.
   Calculate the time that your trip will take.

   c. Your trip will use 40 gallons of fuel, and regardless of your previous answer, the trip will now take 1 hour and 45 minutes.
   Calculate gallons burned per hour.

Post-Trial Knowledge Test

Please answer the following questions based on the previous two scenarios (all of these numbers were given). Do NOT review previous scenarios.

In Scenario 1…

1. What was the given course in degrees?

2. Your aircraft burned an average of __________ gallons of fuel per hour.

In Scenario 2…

1. What was the distance of your trip?

2. What was the true airspeed of your aircraft?

Post-Trial Survey (after 1st session)

Please select the answer from the choices provided. All the information gathered in this study will be kept confidential.

- How confident were you in performing these tasks?

1	2	3	4	5
Not at all				Extremely

- How difficult were these tasks?

1	2	3	4	5
Not at all				Extremely

- How would you rate the usability of the tool?

1	2	3	4	5
Not usable				Extremely usable

Please remember that in order to collect the data that we are attempting to collect, it is very important that you refrain from practicing these skills between experiment sessions. Your cooperation with this request is greatly appreciated.

Post-Trial Survey (after 2nd, 3rd, 4th, and 5th sessions)

Please select the answer from the choices provided. All the information gathered in this study will be kept confidential.

- How confident were you in performing these tasks?

1	2	3	4	5
Not at all				Extremely

- How difficult were these tasks?

1	2	3	4	5
Not at all				Extremely

- How would you rate the usability of the tool?

1	2	3	4	5
Not usable				Extremely usable

- How do you feel you performed during this session as compared with the previous session?

1	2	3	4	5
Much worse				Much better

Please remember that in order to collect the data that we are attempting to collect, it is very important that you refrain from practicing these skills between experiment sessions. Your cooperation with this request is greatly appreciated.

Post-Experiment Survey

Please select the answer from the choices provided. All the information gathered in this study will be kept confidential.

1. What, if any, was the most difficult part of the experiment?

2. What, if any, was the easiest part of the experiment?

3. What kind of strategies did you use when making your calculations?

4. How hard was it to remember how to complete the manual calculations from session to session?

1	2	3	4	5
Very difficult				Very easy

   Please explain:

5. How do you feel you performed in this session compared to the previous sessions?

1	2	3	4	5
Poorly				Extremely well

Please explain:

Thank you for participating in this experiment! Your cooperation is greatly appreciated.

APPENDIX C. IRB APPROVAL DOCUMENTS

APPLIED COGNITIVE TASK ANALYSIS

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 3/12/2018

To: Katherine Volz
3004 Black Engineering

CC: Dr. Michael Dorneich
3018 Black Engineering Bldg

From: Office for Responsible Research

Title: Applied Cognitive Task Analysis for Flight Planning

IRB ID: 18-037

Study Review Date: 3/12/2018

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

- (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures with adults or observation of public behavior where
  - Information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or
  - Any disclosure of the human subjects' responses outside the research could not reasonably place the subject at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.

The determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**
- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

  Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

  Detailed information about requirements for submission of modifications can be found on the Exempt Study Modification Form. A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then an Application for Approval of Research Involving Humans Form will need to be submitted and approved before proceeding with data collection.

Please note that you must submit all research involving human participants for review. **Only the IRB or designees may make the determination of exemption,** even if you conduct a study in the future that is exactly like this study.

Please be aware that **approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.**

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.

EVALUATION ON COGNITIVE SKILL DEGRADATION

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
1138 Pearson Hall
Ames, Iowa 50011-2207
515 294-4566
FAX 515 294-4267

Date: 10/30/2014

To: Dr. Michael Dorneich
3018 Black Engineering Bldg

From: Office for Responsible Research

Title: Assessing Cognitive Skill Degradation Due to Information Automation

IRB ID: 14-266

Approval Date: 10/28/2014 **Date for Continuing Review:** 10/27/2016

Submission Type: New **Review Type:** Expedited

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- **Use only the approved study materials** in your research, **including the recruitment materials and informed consent documents that have the IRB approval stamp.**
- **Retain signed informed consent documents for 3 years after the close of the study**, when documented consent is required.
- **Obtain IRB approval prior to implementing any changes** to the study by submitting a Modification Form for Non-Exempt Research or Amendment for Personnel Changes form, as necessary.
- **Immediately inform the IRB of (1) all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.
- **Stop all research activity if IRB approval lapses**, unless continuation is necessary to prevent harm to research participants. Research activity can resume once IRB approval is reestablished.
- **Complete a new continuing review form** at least three to four weeks prior to the **date for continuing review** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please be aware that IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. **Approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **IRB approval in no way implies or guarantees that permission from these other entities will be granted.**

Upon completion of the project, please submit a Project Closure Form to the Office for Responsible Research, 1138 Pearson Hall, to officially close the project.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.