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Impact of Electronic Flight Bag on Pilot Workload

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by

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Graduate Capstone Project Chair, Dr. Dahai Liu, Professor,
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Department of Graduate Studies in partial fulfillment
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Abstract

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The increase of automation in the aviation industry pose challenges to human performance. To attest this point, studies about aircraft accidents reveal that pilots' response to automated systems are always not coherent. Research findings suggests that pilots' interaction with automated systems in highly demanding tasks situations results in the increase in workload and if they are unable to resolve it in time, it will compromise flight safety. Therefore, in the interest to further explore the impact of automation on human factor constructs, the study aimed to investigate the impact of Electronic Flight Bag (EFB) on pilot workload. The study measured the workload experienced by pilots in a visual flight rule approach in expected and unexpected situations with the use of EFB and paper chart displays. The National Aeronautics and Space Administration -Task Load Index was used to measure pilot workload. The results showed a significant difference in pilot workload between expected and unexpected approach indicating the influence of pilot workload during highly demanding tasks. However, there was no significant difference in pilot workload between the use EFB and paper at approach. There was also no significant interaction between approach and display. It is suggested that future studies to increase the sample size and explore more demanding flight situations that allows further use of EFB functionalities.

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Chapter I

Introduction

The impact of automation on a human operator (i.e., pilot) has continuously influenced key human factor constructs such as mental workload and reduced situational awareness (Parasuraman, Sheridan & Wickens, 2008). Interestingly, this contradicts to the general opinion that automation facilitates the betterment of human performance which is to reduce workload and improve situational awareness (Endsely, 1996; Parasuraman et al., 2008). However, aircraft accident reports reveal the opposite. It indicates that there is a lack of interaction between pilot and the automated systems, especially during key phases in flight which require high complex tasks (i.e., landing, takeoff or deviation). These tasks can occur unexpectedly which can lead the pilot to respond to the situation with inadvertent inputs which can compromise flight safety (Endlsely, 1996; Parasuraman et al., 2008). Further studies on pilots working in automated environments describe that their ability to manage mental demands (i.e., attention, perception and memory) during flight is significantly reduced due to the non-sequential flow of information from the systems. As a result, they struggle to comprehend the meaningfulness of the information and hence it leads to increased workload (Parasuraman et al., 2008).

The continuous use of automation in aviation is set to continue. Aircraft manufacturers continue to build aircrafts with highly automated capabilities (i.e., head up display with night vision and strong data link connectivity between ground and air). These technologies are not only available to commercial aircraft but are also increasingly adapted by pilots flying general aviation (GA) aircrafts (Chandra & Kendra, 2010).

Similarly, one such recent entrant to the modern aircraft cockpit is the Electronic Flight Bag (EFB) (Chandra, 2003). The inclusion of EFB in cockpits became popular among pilots as it offered an easy access to digitalized display of paper-based charts, checklist and other relevant aeronautical documents. This is in contrary to the past where pilots had to carry heavy suitcases filled with loads of paper-based aeronautical documents. They were not only heavy, but also took a considerable amount of space in the aircraft cockpit (Haddock & Beckman, 2015). Although, there are advantages in using EFB, it also raises significant level of safety risks which needs to be addressed. For example, according to the Aviation Safety Reporting System (ASRS), there are significant percentage of EFB related incidents reported by pilots that had significantly affected aircraft operations during complex task activities (Chandra & Kendra, 2010). Furthermore, the National Transport Safety Board (NTSB) has recorded that major aircraft accidents involving EFB has resulted in loss of life and costly damages to the aircraft (Chandra & Kendra, 2010). Thus, it could be said that even though EFB have a purposeful use for pilots, its impact on flight safety is still of a concern and its impact on human factor constructs such as workload needs to be further researched (Chandra & Yeh, 2006).

Significance of the Study

From the above introduction on automation it can be understood that it's utility towards reducing pilot workload is debatable, and with the introduction of EFB, its impact on pilot workload must be researched. According to ASRS, pilots acknowledged that the zooming and panning for information in EFB during critical flight tasks has resulted in them deviating their attention away from key flight instruments during flight. This in turn has a significant impact on flight safety (Chandra & Kendra, 2010). As EFB are becoming increasingly popular, their uses among commercial and GA pilots will continue to rise. Taking note that the impact of automation on human performance is crucial, the need to study the impact of EFB on pilot workload becomes necessary (Endlsely, 1996; Parasuraman et al., 2008). Therefore, this study investigates the impact of EFB on pilot workload.

The study measured and statistical analyzed the perceived workload experienced by the pilot during approach (i.e., expected and unexpected approaches). It also showed whether the perceived workload experienced by the pilots was influenced by the visual formats of display (EFB and paper) charts used during the flight. From the aspect of automation and its influence on workload, findings from this study shed a greater insight about the influence of EFB on pilot workload. The study has also showed that the influence of demanding tasks during an approach can influence pilot workload. Finally, the study provided an overall conclusions and recommendations for future research on EFB and its impact on pilot workload.

Statement of the Problem

As technological innovations continue to evolve, the increase in automation in the aircraft cockpit is here to stay (Chandra & Kendra, 2010). In GA the use of electronic flight devices such as EFB by pilots to retrieve aeronautical information for flight operations pose a safety risk. For example, according to the ASRS reports by pilots there were 37 safety incidents caused by EFB (ASRS,2018). Furthermore, the NTSB reported that two major aircrafts accidents involving EFB had caused damage to the aircraft and loss of lives (Chandra & Kendra, 2010). In the year 2016, NTSB reports indicated that pilots from the GA category were involved in 213 fatal accidents. It is also indicated that the rise of flight hours in GA have risen over the years. According to safety reports, 36% of aircraft fatalities occur mostly during final approach and landing (NTSB, 2019; Chandra & Kendra, 2010). These indicators bring attention to the problem on whether the accident rates in GA can be influenced by pilot workload, particularly with the use of EFB during complex flight tasks.

Purpose Statement

The purpose of this study is to measure pilot workload when flying an expected and unexpected approach using EFB and paper charts. Results from this study validated the argument whether the independent variables approach (expected and unexpected) and display (EFB and paper) have a significant impact on the dependent variable which is pilot workload.

Research Hypothesis

The following research hypothesis were tested in this study.

H_{01}: There will be no significance difference in pilot workload between expected and unexpected approach.

H_{02}: There will be no significance difference in pilot workload between the use of EFB and paper charts.

H_{03}: There will be no significant interaction between display (EFB and paper) and approach (expected and unexpected).

Delimitations

Since the time allocated for the research only spans within one academic semester the researcher can only access flight students with private license within the Embry Riddle Aeronautical University (ERAU). Furthermore, the flight environment simulated can only be based on a GA light weight aircraft (i.e., Cessna 172 Skyhawk) as ERAU flight students use them for their flight training. Thus, the study cannot represent the whole pilot population in the aviation industry.

Limitations and Assumptions

One of the limitations is the small sample size used in the study. Due to tight project schedule and the availability of participants the researcher had to work with a smaller sample size of 16 participants. Also, the Elite-P1 135 Basic Aviation Training Device (BATD) simulator in the Research in Transportation Systems (CERT) laboratory is not a high-fidelity simulator thus it cannot mimic an actual cockpit environment. It is also assumed that the individual flying skills and familiarity in using the simulator may not be the same for all the participants. Since ERAU student pilots are familiar with the EFB Foreflight software it was assumed that they can operate it.

Definitions of Acronyms

AC	Advisory Circular
ANOVA	Analysis of Variance
APLC	Airport Performance Laptop Computers
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Controller
CERT	Cognitive Engineering Research in Transportation Systems
COTS	Commercially off-the-shelf
EFB	Electronic Flight Bag
ERAU	Embry Riddle Aeronautical University
FAA	Federal Aviation Authority

GA	General Aviation
IFR	Instrument Flight Rules
IRB	Institutional Review Board
NASA-TLX	National Aeronautics and Space Administration -Task Load Index
NTSB	National Transport Safety Board
SME	Subject Matter Expertise
VFR	Visual Flight Rules

Chapter II

Review of the Relevant Literature

The introduction of automation in aircrafts over the last two decades have provided a dynamic and reliable aircrafts. As the need for flying keeps increasing, the requirement for aircrafts to operate efficiently and yet safely in demanding flight environments has become necessary (Salas & Marino, 2010). Manufactures continue to find ways to automate flight instruments and equip the flight crew with up-to-date technologies aimed to facilitate the demands of aircraft operations. However, interestingly the increased automation has not reduced aircraft accidents (Chandra, 2003).

The gap in the interaction between the pilot and automation still exists and as a result human factor constructs such as mental workload, situational awareness and fatigue continue to influence human performance and still pose as hazards to flight safety (Harris, 2011). The following chapters will review the influence of automation on human performance particularly on pilot workload followed by the impact of Electronic Flight Bags (EFB).

Influence of Automation on Pilot Workload

One of the key advantages of EFB is its ability to relieve pilots from handling various paper-based charts and checklists while operating the aircraft (Babb, 2017 b). With EFB pilots have the advantage in viewing high-resolution sectional charts, approach charts, weather charts and various aeronautical documents which are essential for the operation of the flight. Furthermore, with the incorporation of global position systems (GPS) in EFB pilots can view moving airfield maps which indicate the pilots ‘own ship’ location. With these capabilities it can be said that EFB are well suited to reduce the workload of the pilots (Babb, 2017b). However, it can also be argued that the supervision of EFB when flying could add to the existing pilot workload and may impact the overall workload experienced by the pilot, especially during critical phases of flight with extreme time pressures (i.e., unexpected deviation or weather conditions) (Babb, 2017b).

According to (Salas & Marino, 2010; Archer, Keno & Kwon, 2012) studies about workload indicates that human operators experience newer hazards in an automated setting. Interestingly it is further explained that the expected work reduction from automation may transform to other means of added workload to the human operator in the future operations of the system. For example, one of the safety issues reported in the ASRS was that the pilots had problems in zooming and panning the contents in the EFB to a level that is legible (ASRS, 2018). The pilots were concerned about missing some of the key pieces of the information in the EFB which was necessary to navigate the flight safely (ASRS, 2018). This incident clearly shows that the troubleshooting attempts by pilots outside the perimeter of their primary tasks not only consumes their time but it also become an additional mental load to the existing workload (Archer et al., 2012). Thus, it can be said that the use of EFB during critical phase of flight can be detrimental to flight safety (i.e., during approaching or deviation) (Archer et al., 2012).

Human Performance and Workload

One of the most discussed aspect of human performance is workload. According to (Harris, 2011) the increased workload experienced by the human operator can escalate to the increase in error rates and hence directly compromise safety. It also influences the minimization of productivity and increases the operators stress levels (Harris, 2011). This further reaffirms the point that relationship between workload and performance are interrelated. For example, figure 1, illustrates a hypothetical relationship between human performance and workload (Harris, 2011, pp 45-46). The horizontal axis represents the incremental workload over a span of time while the vertical axis represents the operator's performance levels (Harris, 2011). Phase A illustrates the initial stage of the mission where the operator's performance is at the peak (Harris, 2011). The reason is because the operator can successfully manage the demands of the task, resulting high levels of performance (Harris, 2011).

From a human factor perspective, it can be also said that the operators mental (cognitive) state has been raised (i.e., increased level of attention). The graph continues to illustrate the decline in human performance after some time with increase in workload (phase B). Phase B also serves the point that the ability for the operator to handle complex tasks is severely reduced (Harris, 2011). Finally, phase C indicates the complete exhaustion of the operator cognitive state in which his ability to handle the demands of the task are extremely reduced and thus resulting extreme workload. At this point the operator, would have experienced increased level of workload resulting low levels of work performance (Harris, 2011).

The graph, also provides as well served comparison to describe the relationship between workload and human performance of a pilot (Harris, 2011). For example, phase A can be represented, as the initial phases of flight (i.e., during takeoff) in which the pilot experience a high state of alertness and can handle various task demands required to fly the aircraft safely (Harris, 2011). Phase, B represent a state where the pilot become mentally exhausted and have trouble in managing the task demands. This decline in human performance could occur in a subsequent period in flight after takeoff. Phase B further asserts the point that the pilot's initial mental and physical state can deteriorate over time and impact workload. For example, this can occur when pilot is exposed to unexpected deviations or system malfunction resulting increased task complexity and demand highest level of attention to rectify the situation (Harris, 2011). If the pilot is unable to cope with these demands in time the occurrence of phase C is inevitable. In this phase the pilot is likely to exhaust his mental and physical state, resulting an extreme decline in maintaining a high level of human performance with increasing workload which could eventually compromise the safety of the flight (Harris, 2011).

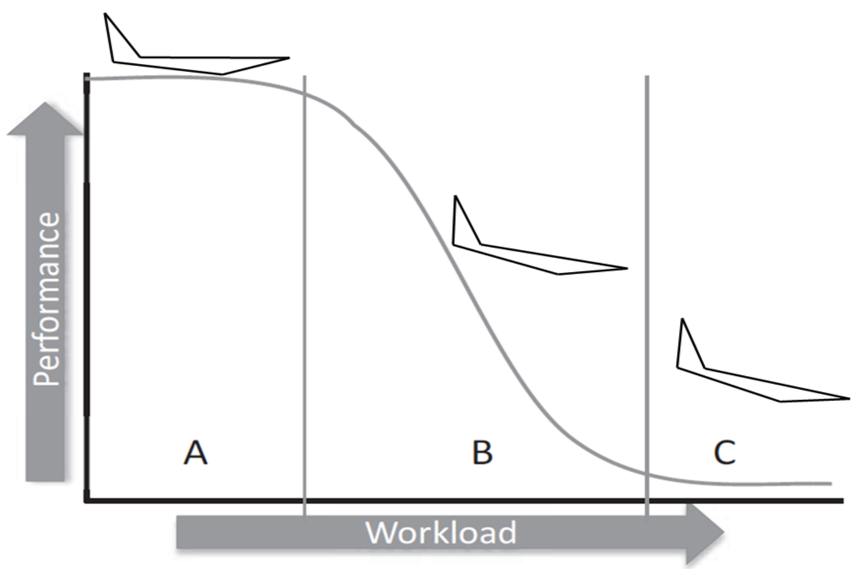

Figure 1. Hypothetical relationship between workload and performance. Adapted from Human Performance on the Flight Deck (Harris, 2011).

Electronic Flight Bag (EFB)

Background. The name EFB took its roots from the traditional flight bags carried by pilots, which contained numerous numbers of paper-based flight checklist, aeronautical charts, weather charts and volumes of manuals (Ates, 2017). Flight bags do not only occupy cockpit space but it adds a considerable amount to the overall weight of the aircraft especially lightweight aircrafts flown in GA where every gram of weight is a concern for flight performance (Schwartzentruber, 2017). These documents (i.e., navigational charts, manuals and advisories) are key resources for flight operations especially during the critical phase of flight, (i.e., during approach) (Babb, 2017a). The pilots need to access them quickly and view them while in flight without compromising flight safety (Babb, 2017a). In most situations, these charts are clipped onto the control yolks for easy visibility (Babb, 2017a).

If these charts accidently fall on the cockpit floor, it can be difficult to retrieve them as the cockpit spaces are usually very small. They are also prone for wear and tear (Cahill & Donald, 2006). The earliest adopters of EFB were the FedEx pilots in the 1990s (Babb, 2017a). Their flight deck was equipped with laptop computers, referred to as Airport Performance Laptop Computers (APLCs) (Babb, 2017 b). The APLC can perform aircraft performance calculation, e.g. determining aircraft's runway stopping distance or calculating the maximum takeoff weight of the aircraft (MTOW) (Babb, 2017 b). The arrival of hand-held devices with touch screen capabilities encouraged aircraft manufacturers to collaborate with software developers specializing in flight management software such as Jeppesen, Foreflight and Garmin to develop solutions to migrate paper-based forms to electronic copies which can be easily accessed by pilots using hand held devices (Ohme, 2014). Soon software developers were able to migrate the paper versions of aircraft documents and incorporate aircraft performance applications into an electronic platform which can be viewed in hand held tablets (Babb, 2017 b).

The initial introduction of these tablets was known as commercially off-the-shelf (COTS) tablets sold by computer manufactures and software developers such Apple®

iPad and Microsoft® Surface Pro. Due to the reliable computing power, high resolution displays, affordable price and portability the tablets become attractive solution to the traditional flight bags (Ates, 2017; Schwartzentruber, 2017).

Advantage. Over the years the utility of EFB and its use in the aircraft cockpit has been well received by pilots (Haddock & Beckman, 2015). According to Federal Aviation Administration (FAA) "EFB is any device, or combination of devices, actively displaying EFB application" (FAA, 2017, p. 2). One of the key advantages of using EFB is that it replaces the traditional use of paper based aeronautical documents to electronic versions (Haddock & Beckman, 2015). Pilots are now able to access and view real-time relevant aeronautical documents (i.e., sectional charts, weather charts or safety circulars and advisories) in high resolution using EFB. In addition, EFB can also be used to conduct and record aircraft performance assessments (i.e., calculation of aircraft maximum takes of weight) for pilots (Haddock & Beckman, 2015).

Pilots can use the performance results to ensure there are within the acceptable limits for safe flying. Furthermore, this information can also be sent to the aircraft owner (i.e., airlines) via wireless communication (Haddock & Beckman, 2015). Another advantage of EFB is that its application software can be tailored around airline requirements. For example, airlines may want their pilots to fly air routes with ideal aircraft settings to yield maximum operational outputs (i.e., prescribed carbon emission limits on certain air routes) (Haddock & Beckman, 2015). In such circumstance EFB software applications can be designed around these parameters thus helping the aircrew to achieve the expected operational requirements set by airlines (Haddock & Beckman, 2015). Furthermore, the default settings programmed into the EFB software application can prevent the pilot from inputting incorrect values which could influence flight safety. When compared to the paper-based assessments which were more manual and cumbersome to use (Haddock & Beckman, 2015).

The shift from paper to electronic copies allows pilots to use the EFB as a one stop access to manage all aircraft documents. EFB serves as an intermediate role between the pilot and the airlines by providing a transparency of aircraft operational records (i.e., pilot records on system issues in air and on ground). It provides an avenue for airlines to digitalize pilot task processes or validations which was traditional done in paper (i.e., go around checks, fuel loading documents) (Haddock & Beckman, 2015). In addition, this not only prevents manual errors from occurring but also prevents aircraft documents being lost. The aeronautical documents in electronic versions in EFB provides flight crews to perform flight management more efficiently than before and the reliance of paper is hugely reduced. Another key advantage of using EFB is that it offers high-speed internet connectivity for the pilot to send and receive timely feedback about the aircraft health and flight safety matters to the aircraft stockholders (i.e., airlines or maintenance contractors) (Ates, 2017; Chandra 2003).

EFB standards and regulations. The utility of EFB also encounters some key standardization. For example, according to FAA Advisory Circular (AC) 120-76D, it states that COTS based tablets can be used as EFB (FAA, 2017). Interestingly, it also states that small noncommercial aircraft operations under Part-91 category do not need to obtain FAA approval to use COTS as an EFB (FAA, 2017). However, it mentions that the users need take note of FAA (AC) 120-76D in regards to EFB testing and documentation requirements. Whereas large commercial aircrafts operating under Part-

121 and 135 will need to seek FAA approval for the use EFB (FAA, 2017). Based on the recent AC 120-76D circular, EFB are now recognized based on the type of application that run on them e.g. Type A and B. This is helps to identify EFB based on their operational roles in the flight deck, e.g. critical or non-critical functions (FAA, 2017). Another concern about EFB is the variance found in the aeronautical chart formats offered in them (Babb, 2017). For example, according to FAA, software manufacturers developing Jeppesen aeronautical charts for EFB do not have to comply with the chart formats approved by International Civil Organization (Babb, 2017). This creates a situation where pilots need to be familiar with two different types of charts whenever they are using them. This raises a situation if the need for pilots to transit between different EFB to utilize both chart types could introduce confusion and may impact flight safety (Babb, 2017).

EFB safety concerns. Human factor considerations between the man-machine interfaces place an important role in flight safety (Salas & Maurino, 2010). Numerous safety accidents have shown that physical and cognitive limitation of the human operator need to be carefully addressed before placing them in an automated environment, e.g. workload, physical or mental stress and sleep deprivation (Parasuraman, et al., 2008). Similarly, the use of EFB in flight has also raised several safety concerns. For example, according to the safety report by the U.S Department of Transport, there were 37 flight safety incidents and/or accidents that occurred at the initial EFB implementation period between 1995 to 2006 (Chandra & Kendra, 2009). Some of these events include runway incursion, spatial deviation, incorrect weight and balance computation (Chandra & Kendra, 2009). One of the earliest EFB based aircraft accident occurred on July 31, 1997 when a Federal Express (FedEx) McDonnell Douglas (MD-11) aircraft crashed while landing during night at Newark International Airport in Newyark, New Jersey (Chandra & Kendra, 2009). A few years later in December 8, 2005, a Boeing 737-700 aircraft belonging to Southwest Airlines (SWA) arriving in the night from Baltimore to Chicago Midway International Airport in Chicago overshot the departure end of the runway causing it to strike through the airfield fences and crash onto an automobile on the roadway, killing a child passenger (Chandra & Kendra, 2009). The post investigation report from both accidents revealed that the aircrew misinterpreted the landing distance shown in the EFB (Chandra & Kendra, 2009). The accidents reiterate the point that the need to pay careful attention to human factor considerations involved between the man-machine interaction in a highly automated environment (i.e., aircraft cockpit) must be addressed (Joslin, 2013).

Automation Biasness

One of the reasons cited for skill degradation among pilots is due to their over reliance on automation (Casner, Geven, Decker, & Schooler, 2014). Automation bias is the use of automation as a heuristic substitute to attentively gather and process data (Parasuraman, et al., 2008). It also refers to two types of errors; omission and commission of errors (Parasuraman, et al., 2008). Omission of errors happens when the human operator fails to detect the inconsistencies in the automated systems e.g. the operator fails not notice that the EFB software fails to notify the user that the push notification is turned off (German & Donna, 2016).

The commission of errors happens when an operator follows the instruction from the automated systems without confirming them against other accessible data, or continues to follow the instructions regardless, receiving inconsistency data from other sources (German & Donna, 2016). For example, a pilot flying during dusk noticed that his EFB navigational chart linked to the internet display a mountainous terrain. However, the cockpit systems showed no irregularities to his flight path and the pilot continues to fly (Endsley, 1996; Dodd et al., 2014). If the pilots decide to verify his flight path again with the nearest air traffic controller (ATC), he could prevent a flight safety risk. If not, he would have commissioned for error voluntarily (Endsley, 1996). The above examples clearly show that automation bias occurs when human operators fail to develop a full and coherent understanding of the situation, due to the overreliance on automation and failure to monitor them appropriately.

Another factor that could influence automation bias is the social loafing attitude of human operators who regard themselves being less responsible, as the systems performance as expected to functions erroneously (Endsley, 1999). Complacency can also be another contributor to automation bias (German & Donna, 2016). This could occur during high workload periods where the operator may fail to adequately monitor the automated information due to diversion of attention to task that may result a loss in SA e.g. prioritizing certain tasks over another (German & Donna, 2016).

Skill Degradation

The notion that cockpit automation has significantly reduced pilots' agility, nimbleness, skill, proficiency or mastery cannot be ignored (Casner et al., 2014). One of the key studies on pilot skill degradation was done by Mangelkock, Adam and Gainrer in 1971(Casner et al., 2014). At the initial period of the experiment, the pilots were exposed to a good level of flying time, hereinafter they were given a four month break from all flying activities. Upon flying after the break, the researchers found that even though the "hand-eye" coordination of the pilots was still intact, the cognitive skills such as procedural steps, ability to perform mental calculation and identifying unusual conditions was significantly reduced (Casner et al., 2014).

The loss of manual flying skills due to automation can become a disadvantage during critical phase of flight if the aircrafts automated systems fail (Casner et al., 2014). The pilot must be able to reinitiate his though process in operating the aircraft manually. This not only will increase his workload but also his SA. If his ability to handle these situations is not present due to skill degradation it will likely to impact the safety of the flight (Casner et al., 2014).

Impact of Visual Displays

The impact to the human operator by automation could be further analyzed in terms of the human limitation such as perception, attention and memory (Salas & Mourino, 2010). In a "glass cockpit" setting, the human operator is surrounded by various instrument displays (Young, Fanjoy & Suckow, 2006). Each of these displays provide critical information that a pilot must monitor and process (Young et al., 2006). The visual displays can be regarded as the first level interface for the pilot to interpret the data shown in it (Salas & Mourino, 2010). In an automated environment, the ability to be in command of an operation depends on how the operator engages with the information visually presented based on the operator's perception, attention and the memory displays (Young et al., 2006).

Perception. Displays play a key role in human perception (Salas & Mourino, 2010). It is vital for a human operator to clearly observe the information presented in the display (German & Donna, 2016). If information is tightly spaced or inconsistent, the human operator will find it difficult to interpret the data. This can have a huge effect on the perceived information (Salas & Mourino, 2010). The visual stimulation to the operator through perceptual inputs such as auditory or tactile can motivate the operator's interactions with the display (German & Donna, 2016). Thus, it can be said the design of the display play a critical role on the operator's perception of processing critical data (German & Donna, 2016). Similarly, it is important for EFB to provide coherent display of information to help the operator accurately interpret them (German & Donna, 2016).

Attention. During flight, it is pivotal for the pilot to attend to various sources of data to execute his operations successfully (Salas & Mourino, 2010). Tasks requiring detailed attention should be displayed as key data while reducing irrelevant ones (Salas & Mourino, 2010). Since there are various displays in the cockpit, display sets that provide crucial data must attract the attention of the pilot so that it will be monitored closely (Endlsely, 2000). For example, EFB must provide features that attract the pilots sensory i.e. tactile or auditory to highlight critical information (Salas & Mourino, 2010).

Memory. Generally, information presented in the flight deck instruments are integrated with various sources to provide a coherent idea on the status of the flight (Salas & Mourino, 2010). Random informations are sometimes received from the instruments that can exhaust the operators' cognitive limits. The displayed data can be arranged to provide data in consistent manner to prevent mental exhaustion of the operators (Salas & Mourino, 2010). EFB should provide information in a manner not exhausting the operators mental state. This is essential during critical stages for flight where operators must attend to various data from the cockpit displays at a single space of time (Salas & Mourino, 2010).

From the above discussion, it can be understood that the impact of visual displays such as EFB has a direct impact on the pilot's perception, attention and memory (German & Donna, 2016). Thus, this attests to the implication it has on the pilots SA and workload, which would be investigated in the following chapters (Salas & Mourino, 2010; Endsley, 1999; Young et al., 2006).

Measuring workload (NASA – TLX)

From the above discussion, it is understood that the pilot performance is drastically reduced if he is not able to handle the task demands (Harris, 2011). This brings forth the question on how workload can be measured to further understand its influence on human performance (Harris, 2011). To address this issue the National Aeronautics and Space Administration (NASA) in Ames Research Centre developed an assessment survey called the NASA Task Load Index (NASA-TLX). The NASA-TLX is a multifaceted rating survey that serve for subjective assessment to measure workload (Hart, Battiste & Lester, 1984).

The NASA-TLX also provides an all-round workload score based on a weighted scale (NASA, 1986). The NASA-TLX consists of six levels of workload categories presented in a single page. Each workload category questions the participant about the level mental and physical demands exercised when conducting a task (i.e., physical demand, mental demand, temporal demands, performance, effort and frustration (NASA, 1986). The following describes the six NASA-TLX workload factors. A further detailed descriptors of these factors can be found in Appendix C.

Mental demand. Refers the level (i.e., high or low) cognitive activity exhibited by the participant to complete the task.

Physical demand. Refers the level of physical activity demonstrated during the task. It queries the participant on the level of strenuousness exercised to complete the task.

Temporal demand. Refers to the level of rush for time that was exhibited by the participant to complete the task.

Overall performance. Refers to how successful was the participant in completing the task.

Effort. Refers to how hard was it to complete the task in a combined level of mental and physical demands.

Frustration. Refers to how annoyed, stressed or hesitant was the participant in completing the task.

From the above discussion it can be understood, that workload plays an important role in human performance (Fernandes & Braarud, 2015). The pilot's workload is self-evaluated and his work performance is limited to his mental, physical state, emotions and time limitations which are beyond the complexity and demands of the tasks required of him (Fernandes & Braarud, 2015).

Similarly, it can be said that the workload of an individual can be easily influenced by the complexity of the task and the work environment thus affecting his work performance (Fernandes & Braarud, 2015). In such circumstances the use of NASA-TLX will help to understand the impact of workload on the human operator. Similarly, the NASA-TLX can be used as an assessment tool to measure the influence of workload when using a pilot uses an EFB during highly complex tasks work performance (Fernandes & Braarud, 2015).

Summary

The influence of automation on pilot workload continues to rise and with the increase in adoption of EFB into aircraft cockpits introduces newer levels of threats to pilot performance. There is a concern whether pilots can keep up to the increasing mental demands when using EFB during demanding flight tasks. Even though, the utility of EFB is recognized, they have also equally influenced aircraft accidents and continue to have standardization issues which is yet to be completely resolved.

The influence of automation has resulted pilot skill degradation and their overreliance to automation, which adds further to the increase in pilot workload. Furthermore, the influence of visual displays on the pilot's cognitive state, need to be equally addressed as perceived information from the may not always be accurate.

Finally, the need to relook the influence of EFB on pilot workload has become necessary but it also requires a standardized measurement of workload. This can be serviced by using the NASA-TLX. Measuring the pilot workload over the six categories of workload demands could provide a greater insight on the workload experienced by the pilot.

Chapter III

Methodology

Research Approach

The aim of this study is to determine the impact on pilot workload with the use of EFB and paper navigational charts during approach. In order to measure workload experienced by the pilot the NASA-TLX is used after each flight scenarios. Prior to the research study the permission to conduct the research was applied to the Institutional Review Board (IRB) at Embry-Riddle Aeronautical University and it was granted. The IRB approval is shown in Appendix A and the informed consent form in Appendix B.

Design. The study has two independent variable (approach, display) and one dependent variable (workload score). Each of the independent variables has two levels; the approach factor with levels (expected, unexpected) and the display factor with levels (EFB, paper). The experiment for the study was based on within-subjects 2 x 2 (Approach [expected, unexpected] x Display [EFB, paper]) factorial design using Analysis of Variance (ANOVA). In the simulator, each participant flew four flight scenarios. In each of the flight scenarios the participant flew to a designated runway from a 3 nautical mile approach with an (a) EFB with expected approach, (b) EFB with unexpected approach, (c) paper with expected approach and (d) paper with unexpected approach. To control for order effect the researcher applied a partial counterbalancing technique using Latin square. This is a matrix design in which control the order of sequences of treatment scenarios received by the participants during the experiment. There was a total of 16 participants involved in the study. The statistics test used in this study was a within subjects two-way ANOVA with repeated measures. An alpha value of

5% was used to statistically analyze the workload score attained by each participant when exposed to the four flight scenarios. There were three statistical tests done to determine the main effects of the factors and interaction between them. The first statistical test determined the main effect for approach (expected and unexpected). The second test determined the main effect for display (EFB and paper) and the third test determined the interaction between approach and display.

Procedures. Once the participants arrive at the CERTS laboratory they were greeted and briefed about the purpose of the study and the safety risks involved in the experiment. The participants then received the informed consent form to seek their approval before going ahead with their participation in the experiment. Once the participants have signed the informed consent form, they proceeded to the flight simulator. At the Elite-P1 135 BATD simulator the participants were briefed about the key flight controls that to be used to fly the aircraft (i.e., control stick, flaps, rudder and breaks). The key flight instruments observed by the pilot in the simulator during the flight was the airspeed indicator and altitude meter.

The researcher took the role of an air traffic controller to instruct the participant to fly the desired air routes for each of the four flight scenarios. Once the pilot was seated at the simulator, a pre-flight instruction for each flight scenarios was given as show in Appendix J. The instruction includes the call sign for the Cessna 172 Skyhawk aircraft as Riddle141, the destination airport code, the initial approach distance at the start of the flight, which was 3 nautical miles straight in to the runway and a flight safety message. The ATC and pilot communication for the expected and unexpected scenarios is shown in Appendix I. Once a participant is finished with a scenario, he or she proceeded to complete the NASA-TLX for the workload experienced during that scenario. The NASA-TLX and a copy of the six workload factors were provided to the participants as shown in Appendix C and D respectively. Once the NASA-TLX was completed, the participant moved towards completing the next scenario based on the order of approach scenarios shown in Table 1. In each scenarios the participant received an EFB or a paper navigational charts to fly the aircraft to a designated airport runway. All the four flight scenarios were based on the Visual Flight Rule (VFR) approach. To prevent testing effects or regression towards the mean, the order of the flight scenarios was randomized using Latin square technique. Table 1 below illustrate the first four order of the scenario received by the participant. This order is repeated till the 16th participant completes the experiment.

Table 1

Order of flight scenarios tested

Participant	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	Expected Paper	Unexpected Paper	Expected EFB	Unexpected EFB
2	Unexpected Paper	Unexpected EFB	Expected Paper	Expected EFB
3	Unexpected EFB	Expected EFB	Unexpected Paper	Expected Paper
4	Expected EFB	Expected Paper	Unexpected EFB	Unexpected Paper

Once the participant completed all the four scenarios the researcher thanked the participant the time and presented them with the Starbucks $10.00 gift card as a sign of appreciation.

Expected scenario and flight path. In the expected scenario, the participant flew the aircraft to Front Range Airport (FTG) from a 3 nautical mile approach and landed on Runway 08. The participants initiated the scenario in the following manner. Once the participant has read the pre-flight instruction for the expected approach an EFB or a paper charts was provided depending on the order of scenario shown in Table 1. The researcher, then loaded the expected scenario in to the simulator. One the scenario is initiated on the screen; the researcher quickly took the role of the ATC to provide necessary navigational instructions to the participant to fly the aircraft.

The first instruction from the ATC to the participant is to maintain 6500 feet from a 3 nautical mile approach to FTG and advice ATC when the airport is insight. Once the ATC received a call back from the participant confirming the airport is insight, the ATC gave clearance to land on runway 08. Once the aircraft was landed the scenario was completed. The participant then procced to fill up the NASA-TLX. The paper charts are shown in Appendix G and H. While Appendix E and F show for EFB.

Unexpected scenario and flight path. In the unexpected scenario, after reading the pre-flight instructions the participant flew the aircraft to Front Range Airport (FTG) from a 3 nautical mile approach. While on approach to runway 8, the participant was instructed by ATC to take a diversion due to traffic on the runway and was instructed to land on the adjacent runway 35 instead. Once the participant has read the pre-flight instruction for the unexpected approach an EFB or a paper charts was provided based on the order of scenario show in Table 1. The researcher, then loaded the unexpected scenario in to the simulator. Once the scenario initiated on the screen, the researcher quickly took the role of the ATC to provide the necessary navigational instructions to the participant to fly the aircraft. The first instruction from the ATC to the participant was to maintain 6500 feet from a 3 nautical mile approach to FTG and make straight in for runway 8 and advice when airport is in sight. Once the ATC received the call back from the participant that the airport is in sight, the clearance to land on the runway 8 was given.

While on approach to runway 8, the ATC suddenly instructs the participant to divert the aircraft due to traffic on runway 8 and climb to 6500 feet. ATC then instruct the participant to fly right downwind and land on the runway 35 instead. Once the participant has landed on runway 35 the unexpected scenario was completed. The participant then proceeds to complete the NASA-TLX. The ATC communication and pre-flight instructions for expected and unexpected scenarios are shown in Appendix I and J respectively.

NASA-TLX. In the NSA-TLX, the participants were presented with the six workload factors; mental demand, physical demand, temporal demand, overall performance, effort and frustration. A detailed description of the six workload factors was also given to them. After reading the description the participant marked the level of workload experienced for the scenario, they flew from a scale of 0 to 100 for each of the workload factors. The NASA-TLX and its description are shown in Appendix C and D.

Apparatus and Materials

The Elite-P1 135 BATD simulator was used to conduct the experiment. This is a low fidelity flight simulator with similar flight controls of Cessna 172 Skyhawk aircraft which is commonly flown by the pilot students in ERAU. Figure 2 shows the simulator setup for the study. For each flight scenarios the participant flew an expected or unexpected approach with an EFB or with paper charts. In the scenarios with paper the participant was given a hard copy of the VFR sectional chart of the airport and the runway map while for EFB scenarios the participant received an iPad with ForeFlight software. Foreflight is an EFB software that provides electronic versions of sectional charts and other relevant aeronautical charts for the pilot. Foreflight is also commonly used by student pilots in ERAU for their flight lessons. Appendix E, F, G and H show the EFB and paper versions of the navigational charts used by pilot for the expected and unexpected approaches in the simulator.

Figure 2. Elite-P1 135 BATD simulator setting.

The virtual flight environment for the scenarios was delivered using X-Plane 11 flight simulator software. It is developed by a virtual reality (VR) gaming company called Laminar Research. The X-Plane 11 is suggested as having a robust VR simulation capability, in par with similar professional flight simulator software in the industry (X Plane, 2019). Furthermore, X-Plane 11 offers the Cessna 172 Skyhawk cockpit instruments and environments suitable to fly the four flight scenarios to conduct the experiment. Figure 3, shows an example of the simulator setting with X- Plane 11 when in use for the experiment.

Figure 3. Elite-P1 135 BATD simulator setting with X-Plane 11

Population and Sample

The study required 16 participants with a minimum attainment of private pilot license (PPL). The researcher recruited the participants from the pool student pilots and instructors from ERAU at Daytona Beach. The source of communication for the recruitment was done via electronic mail and paper flyer. To select the appropriate participants the researcher used Google survey to develop a demographic questionnaire. The questionnaire included the participants name, gender, age, pilot license, flight hours attained. In addition, a flyer about the recruitment for the study was posted around ERAU campus. To expedite the recruitment the researcher also communicated with the ERAU flight instructor department to reach out to student pilots. As a token of appreciation, the participants who completed the experiment were given a $10.00 Starbucks gift card.

Sources of Data and Collection Device

The workload score for each flight scenario was collected using a paper copy of the NASA-TLX. A sample of the NASA-TLX is available in Appendix C. Once the data was collected it was recorded in the researcher's laptop computer in Microsoft Excel.

Instrument Reliability and Validity

The Elite-P1 135 BATD simulator was successfully used in previous capstone studies. However, to ascertain the reliability of the simulator and the X Plane 11 software for this study, the researcher consulted a flight instructor in ERAU as a subject matter expertise (SME). A trial experiment of the study was done using the simulator with the SME representing as the participant.

The simulator functioned positively to all the experiment inputs and was verified by the SME. The workload scores for each of the four flight scenarios was then recorded and was analyzed with the SME.

Treatment of the Data

The signed informed consent forms of all the 16 participants and their completed NASA-TLX were kept in the personal folders which was only accessible to the researcher. The NASA-TLX include six workload factors which are mental demand, physical demand, temporal demand, overall performance, effort and frustration. Each of the scale in the NASA-TLX is shown as a 12-cm line which are divided into 20 equal intervals. The 21 vertical tick marks on each of the scale divides the scale from 0 to 100 with an increment of 5.

The participants marked the level of workload experienced from a scale of 0 to 100 in increments for each of the workload factors experienced either with the use of EFB or paper charts during the expected and unexpected scenarios. The overall workload scores obtained was then recorded into the SPSS statistical software in the researcher computer to test the research hypothesis. To maintain confidentiality of the records and the of participants, the laptop was password protected and only accessible to the researcher.

Chapter IV

Results

Once the workload data was collected, they were organized based on their variables and entered in the SPSS statistical software to test the three-research hypothesis. A 2 x 2 within-subjects ANOVA with repeated measures was done in SPSS. The following summarize the results obtained from the study.

Descriptive Statistics

Participant demographics. The study was conducted with N = 16 participants, out of which *n* = 3 were female and *n* = 13 were male. The average age of Male participants (*M* = 21.6, *SD* = 4.13) was higher than Female (*M* = 21.66, *SD* = 1.15). The number CPL were higher than PPL and 75% of the participants fall between 18-23 years of age. In terms of flight hours, 62.5% of the participants had 101-201 hours of flight experience. Table 2 summarizes the demographic profiles of the 16 participants in detail.

Table 2

Descriptive Statistics of Participant Demographics

Variable	Demographic	Frequency	Percentage (%)
Gender	Male	13	81.25
	Female	3	18.75
Age	18-23	12	75.0
	24–29	2	12.5
	Above 30	2	12.5
License	Private Pilot (PPL)	11	68.75
	Commercial Pilot	5	31.25
Flight hours	Below 100hrs	2	12.5
	101-201hrs	10	62.5
	202-302hrs	2	12.5
	Above 303hrs	2	12.5
Total		*n* = 16	100

Average workload for paper and EFB. Figure 4 bar chart illustrates that the average workload scores for EFB (*M* = 38.91, *SD* = 20.10) was higher than paper (*M* = 37.62, *SD* = 21.08).

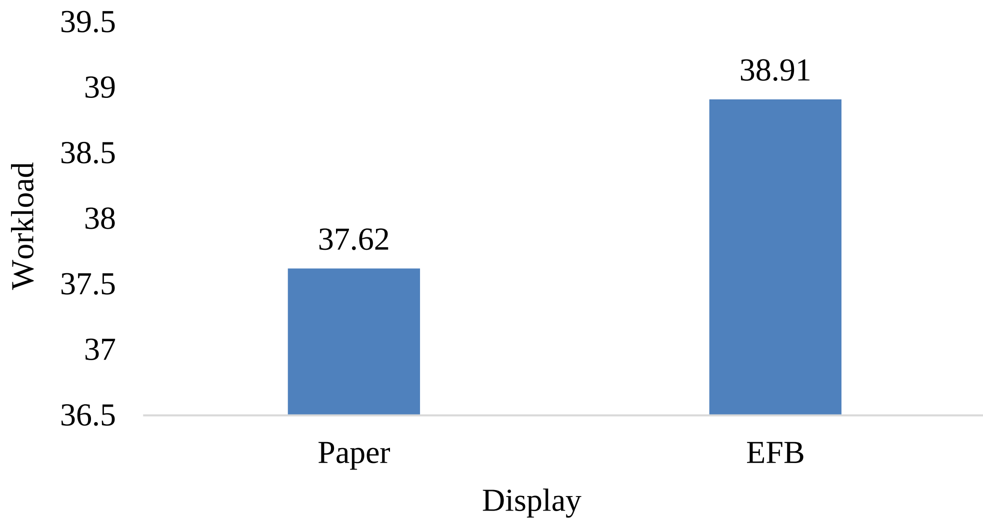

Figure 4. Average workload scores for paper and EFB.

Hypothesis Testing

First research hypothesis. The first research hypothesis tests for the main effect for approach. The null hypothesis is there will be no significance differences in pilot workload between expected and unexpected approach. With the alpha level set at .05, a within subject two-way factorial ANOVA showed a significant main effect for approach $F(1, 15) = 28.22$, $p < .001$, ($\eta_P^2 = .653$). Therefore, the null hypothesis was rejected. The average workload scores for unexpected approach (*M* = 47.41, *SD* = 21.21) was significantly higher than the workload scores for the expected approach (*M* = 29.11, *SD* = 18.67). The effect size is large thus it can be concluded that 65.3% of the variability in the pilot workload scores can be explained by the levels of approach (expected and unexpected) being tested. Figure 5 illustrates that the average workload for Expected approach was higher than Unexpected approach.

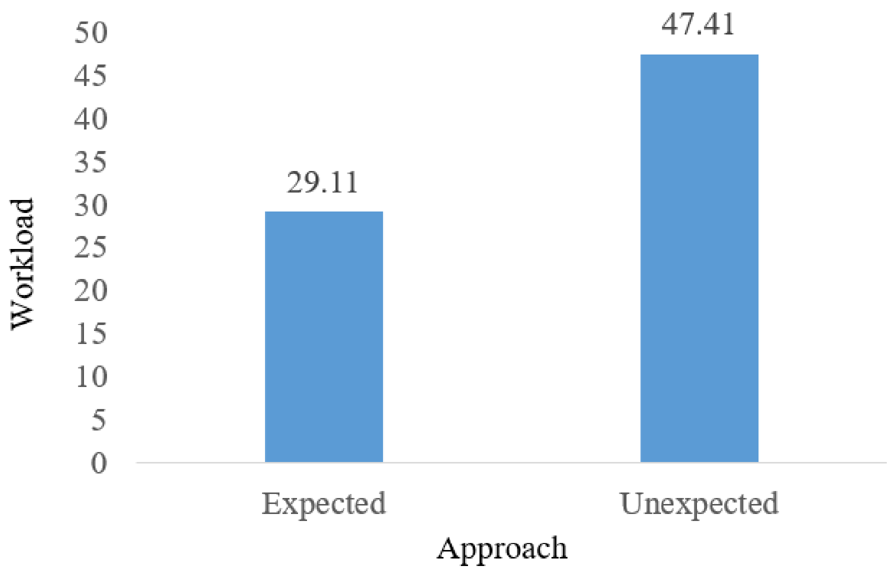

Figure 5. Average workload scores for expected and unexpected approach.

Second research hypothesis. The second research hypothesis tests for the main effect for display. The null hypothesis is there will be no significance difference in pilot workload between the use of EFB and paper charts. With the alpha level set at .05, a within subject factorial ANOVA did not show a significant main effect for display $F(1, 15) = .091$, $p > .05$, ($\eta_P^2 = .006$). The average workload scores for EFB ($M = 38.91$, $SD = 20.10$) was not significantly higher than the average workload scores for paper charts ($M = 37.62$, $SD = 21.08$). Therefore, the null hypothesis was retained. As the effect size is small, it can be concluded that only 0.6% of the variability in the workload scores can be explained by the levels of display (EFB and Paper) being tested.

Third research hypothesis. The third research hypothesis tests for interaction between approach and display. The null hypothesis is there will be no significant interaction between the levels of display (EFB and paper charts) and the levels of approach (expected and unexpected). With the alpha level set at .05, the interaction between approach and display was not significant $F(1, 15) = 81.72$, $p > .05$, ($\eta_P^2 = .029$). Therefore, the null hypothesis was retained. The effect size is medium, only 29% of the variability in pilot workload scores can explain the interaction between the levels of approach and display.

In summary, the results have shown that there is a significant main effect for approach. However, there is no significant main effect for display and no significant interaction between approach and display. The following chapter will further discuss the possible reasons behind the results.

Chapter V

Discussion, Conclusion and Recommendation

The following paragraph will discuss the results by giving a wider insight on the possible reasons behind them. The chapter will also provide an overall conclusion and suggest few key recommendations for future studies relating to this topic.

Discussion

Pilot workload effect on approach. This test is to determine whether there is a significant main effect for approach. The aim of the test is to statistically find whether the two levels of approach (expected approach and unexpected approach) have a significant impact on pilot workload. This is an important test for the workload study as the literature on pilot workload suggests that pilots are subjected to high workload during the approach phase in flight. The researcher was expecting to find a significant effect for approach. That is during the unexpected scenarios, the workload would be higher than in expected scenarios. The results from the study indicate that the main effect for approach was statistically significant. The results also showed that the participants on unexpected approach experienced higher workload compared to expected approach regardless whether they were using EFB or paper charts. This reiterates the point that the increase in pilot workload due to the increased task demands during approach persists. The following discusses some of the reasons for this result.

Pilot experience. One key factor that could have contributed to this result is the number and level of experience of the participants involved in this study. For example, based on the demographics of student pilots involved in the study it is observed that the number of participants with private pilot license (PPL) was higher than the participants with the commercial pilot license (CPL). This leads to suggest that less flight experience (i.e., flight hours) by participants holding PPL could have contributed to the higher level of workload measured for the unexpected approach.

Unexpected scenario. Another factor for the result could have occurred due the nature of the task demands required to complete the unexpected approach. The unexpected task scenario involves participants to suddenly detour from their original approach from runway 8 to the adjacent runway 35. This require the participant to pull the aircraft up to 6500 feet to maintain altitude and re-look at the sectional charts and airport map for runway 35 while flying. Since this is a VFR flight, the participants must look at the simulator monitor and the flight charts to determine their position in air while looking for runway 35. Furthermore, these tasks were done while communicating with the ATC. Thus, it can be said that the cumulative task demands involved in the unexpected scenario could have influenced the pilots' workload.

Pilot workload effect on display. This test was done to determine whether there is a significant main effect for display. This is to statistically determine whether the two levels of display (paper charts and EFB charts) have a significant impact on pilots' workload. This is an important statistical test for this study as it decides whether the use of EFB as part of automation contributes to the influence to pilot workload. The researcher expected to find a significant main effect for display. However, the results indicate that the main effect for display was not significant. As shown in figure 2, even though the average workload obtained using EFB was higher than paper it was not significant. Thus, it suggests that neither the use of paper nor EFB charts have a significant impact on pilot workload. The following will discuss some possible reasons for this.

Sample size. One of the primary factors for the result could have been contributed by the reduced level of power in the study. The observed power for this test was .059. This means that based on the sample size of 16 participants there was only 0.59% chance of deducting a difference in pilot workload scores for display. This means that recruiting a larger sample size could have increase the power and hence it would have made the test significant. For this study, the only available participants were pilot students from ERAU. However, the response from the recruitments only garnered 16 students. Also, last minute drop outs from the study has also influenced the limited sample size.

Regression towards the mean. The secondary factor that could have been a threat to the internal validity is by the regression towards the mean effect (Privitera, 2017). This could have occurred due to the participants improvement in flying a scenario in the second time to a level closer to the mean of the participants true ability. For example, if the participant flew an expected approach using EFB chart earlier, and in the next scenario he or she flew the same unexpected scenario with an EFB, the participant would have flown the second scenario using the EFB to his or her true potential level than before. This in return would have caused the participant’s ability to manage the demanding tasks in a level closer to their true ability.

Testing effect. The third factor that could have been a threat to internal validity caused by the testing effect (Privitera, 2017). This is because during the study, the participants progressed from one scenario to another immediately after completing the NASA-TLX assessment. Thus, the retainment of knowledge from the previous scenario could have been in existence with the participant even when they proceeded to the next scenario. This result to an improvement in their ability to manage the tasks better. For example, if the participant's first attempt was to fly an unexpected scenario with paper charts and in the next scenario, he or she fly an unexpected scenario using EFB, the practice learned from the earlier scenario would have helped the participant to fly the second scenario better thus leading to an improvement in managing the demanding tasks involved in using the EFB.

Demanding tasks. The fourth factor could be the lack of demanding tasks involved in using the EFB. It is possible that the tasks tied to the use of EFB was not demanding enough to expose the participants to a higher level of workload. For example, in this study both the expected and unexpected scenarios were based on VFR approaches in a clear day. Thus, it only requires the participant to use the FAA sectional charts and the airport map to locate the runway. This would have led the participants to only utilize EFB functions which were necessary for an VFR approach (i.e., FAA sectional charts and airport map). Thus, the extensive use of other aeronautical functions in the EFB was not utilized.

Interaction between approach and display. This is to test whether the levels of display (EFB and paper charts) alter the levels of approach (expected and unexpected). The observed power for this test was .096. This means that based on the sample size of 16 participants there was only 0.96% chance of deducting an interaction between approach and display. The result show that the interaction between approach and display was not significant. This suggests that the use of EFB or paper display did not significantly influence the workload experienced by the pilot when flying either an expected or unexpected approach. As discussed earlier, the primary factor for this result continues to be the lack of statistical power in the study and the limited operational use of the EFB during the scenarios. Apart from the limited sample size and the factors discussed earlier the following could have also influenced the result.

Familiarity with EFB software and iPad. The fifth factor could be that the participant's familiarity with the EFB's Foreflight software. The student pilot from ERAU are familiar with the Foreflight software and iPad used as an EFB. As such they would have found operating the EFB manageable even in highly demanding task situations. For example, during the flight scenarios the participants using the EFB were seen zooming at the sectional charts and maps with their fingers in one hand, while moving the aircraft yoke with the other hand. Interestingly, this behavior was reported as a safety risk by the pilots in the ASRS reports. It could be possible that the participant's familiarly of the EFB Foreflight software and their ability to operate an iPad would have led them to a similar behavior when flying the scenarios at the laboratory.

Experimental realism. The third factor is the reduced level of experimental realism in the study. This refers to whether the simulated environment used in the study was realistic enough to trigger mental states of the participant, like when in the actual flight environment (Privitera, 2017). For example, the Elite-P1 135 BATD simulator is a low fidelity simulator. Unlike high fidelity simulators, it does not provide an enclosed environment of an aircraft cockpit with realistic flight instruments and communication devices. Furthermore, the absence of communication devices such as pilot headsets could have minimized the level of realism in communicating to the ATC. In overall, the reduced realism in the simulator could have influenced the measured workload in the study.

Project timeline. The first factor to consider is the limited timeline (16 weeks) that was available to complete the project. This includes the time taken to write the proposal to conduct the study and send to the IRB, making amendments to the proposal for final approval, recruitment of participants and scheduling them based on the availability of the simulator at the CERTS laboratory. These tasks eat into the existing timeline by four to six weeks. On the other hand, a larger time frame could provide the researcher more time to recruit a larger sample size to do the study or to do a pilot study first to detect any gaps in the experiment.

Conclusion

In conclusion, one key finding in this study indicates that the increase in task demand during unexpected approach has a direct influence to pilot workload. It also further points out that the use of EFB does not significantly influence pilot workload. However, the study also shows that given any increase in the task demands during unexpected situations it may lead to significant rise in pilot workload. The study has also shown that the influence to pilot workload due to the difference in the visual layout of paper and EFB charts do not significantly influence pilot workload. From the study it can also be seen that the utility of NASA-TLX to measure pilot workload was successfully administered in a simulated environment. It’s ability to address workload experienced during expected and unexpected approach provides a deeper insight about how demanding tasks can influence pilot workload. The study suggests that even though the general literature about the influence of automation on workload exists, this study demonstrates that its influence is still debatable. Finally, this study can serve as a base-line for future studies on EFB and pilot workload.

Recommendations

Increase sample size. From study it can be understood that the need to increase the sample size will improve the statistical power of the study. One of the ways this can be done is using sample size from past studies as a guide or by performing power analysis calculations. These calculations can be done through power analysis software such as G Power® to determine the sample size (Erdfelder, Faul, Lang & Buchner,2007). This is done by choosing the type of statistical test to be performed and entering statistical parameters from past studies as guide (i.e., effect size, mean and standard deviation) to determine the sample size for the new study

Future researchers can also consider to do the study in two phases. The first phase is a pilot study to determine gaps in the experiment design, variables and whether the results obtained are reliable. In the second phase they could make a better decision in either including or excluding the relevant variables which could influence the results.

Category of pilots. Future studies can specifically recruit pilots with instrument rating. This would expand the level of flight environment used in the study and the further use of EFB functions. For example, pilots with Instrument Flight Rule (IFR) rating are familiar with instrument approach procedures which require them to interpret way points, altitude limits and holding patterns in various metrological conditions. This opens the opportunity for the researcher in include more scenarios with demanding task in the experiment.

Increased level of demanding tasks. Future studies could also increase the level of tasks demands for unexpected task scenarios. This could include injecting sudden metrological variations in flight or changes to way points and flight holding pattern based on instrument approaches. Future studies can also consider the use of EFB during takeoff and straight level flight phases. For example, performing aircraft weight and balance calculation using EFB can be used in the scenario.

Duration and scheduling. Finally, the duration for future study could be expand to include two semesters instead of one. This is because, more time could be spent in designing the experiment, preparing IRB proposal and administrating the recruitment process. Also, time taken for participants response to the recruitment must also be considered as their availability may not match with the availability of the simulator. Thus, as a contingency plan future researcher can consider having standby participants as a replacement to prevent attrition in the study.

Experimental realism and physiological measurements. Future researchers could also consider increasing the level of experimental realism in the study. This may include placing the participants in high fidelity simulators with enclosed cockpit environment with inflight motion. The study may also include scenarios with a co-pilot setting to match real life environment. Apart from workload measurements, the study can also extend to measure the physiological levels affected by the pilot during the use of EFB. For example, measurement of pilot heartrate, muscular tension and head down time with the use of EFB during expected and unexpected scenarios can be studied as well.

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Appendix A

Permission to Conduct Research

Embry-Riddle Aeronautical University
Application for IRB Approval
EXEMPT Determination Form

Principal Investigator: Saravanan Suppiah

Other Investigators: Dr. Dahai Liu

Role: Student **Campus:** Daytona Beach **College:** Aviation/Aeronautics

Project Title: Impact of Electronic Flight Bag on Pilot Workload

Review Board Use Only

Initial Reviewer: Teri Gabriel **Date:** 01/24/2019 **Approval #:** 19-084

Determination: Exempt

Dr. Michael Wiggins IRB Chair Signature: Michael E. Wiggins, Ed.D. Digitally signed by Michael E. Wiggins, Ed.D. DN: cn=Michael E. Wiggins, Ed.D., o=Embry-Riddle Aeronautical University, ou=Aeronautical Science Department, email=wigginsm@erau.edu, c=US Date: 2019.01.24 14:42:45 -05'00' **Date:** 01/24/2019

Brief Description:

This study aims to measure pilot workload for anticipated and unanticipated task demands in a simulated flight environment using electronic flight bag (EFB) and paper charts. The study will measure response time taken by pilots to complete the tasks. A self-reporting workload questionnaire using the NASA-TLX will be used to measure the perceived workload of the pilots after completing the tasks.

☑ (A) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects;

☑ (B) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or

☐ (C) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a **Limited IRB review** (use the Limited or Expedited Review form) to make the determination.

This research falls under the **EXEMPT** category as per 45 CFR 46.104:

☑ (3)(i) Research involving benign behavioral interventions in conjunction with the collection of information from an adult subject through verbal or written responses (including data entry) or audiovisual recording if the subject prospectively agrees to the intervention and information collection and at least one of the following criteria is met: (Applies to Subpart B [Pregnant Women, Human Fetuses and Neonates] and does not apply for Subpart C [Prisoners] except for research aimed at involving a broader subject population that only incidentally includes prisoners.) (Does not apply to Subpart D [Children])

Appendix B

Informed Consent Form

INFORMED CONSENT FORM

Study on the Impact of Electronic Flight Bag (EFB) on Pilot Workload

Purpose of this Research [Expected duration and description of the procedure(s)]: I am asking you to take part in a research project that is led by Saravanan Suppiah, graduate student, Embry-Riddle Aeronautical University. The study aims to validate the impact of automation in human performance. The specific objective of the study is to measure the impact of Electronic Flight Bag (EFB) on pilot workload during critical flight tasks. The study requires you to fly four flight scenarios using the Elite-P1 135 BATD simulator with Microsoft Flight Simulator software. To complete the flight scenarios, you will use aeronautical charts both in a paper and digital forms which will be provided to you. An iPad will be provided for you to view the digital charts. The time taken to complete each flight scenarios will be recorded. At the end of each flight scenario, you will complete a NASA TLX workload questionnaire. The study will be conducted at the College of Aviation (COA) #131, CERTS Lab. The expected duration of the study is less than an hour.

Eligibility: To be in this study, you must be enrolled in college, a resident of the U.S. and 18 years of age or older.

Risks or discomforts: The risks of participating in this study are very minimal, no greater than playing a desktop video game. General risks such as motion sickness may occur at a very low level (i.e., eye strain, headaches, nausea, sweating, burping or dry mouth). If you experience any discomfort, you can immediately pause the scenario and rest, or stop continuing the scenario. You are always be in the view of the researcher throughout the study.

Benefits: The study would provide you a perceived view on pilot workload with the use of EFB. Your assistance in this project will help validate previous studies about the EFBs on pilot workload. The study could also help aviation safety regulators or researchers to provide further recommendations to minimize pilot workload in the future.

Confidentiality of records: Your individual information will be protected in all data resulting from this study. No personal information will be collected other than basic demographic descriptors. The online demographic questionnaire will not save your IP address. In order to protect the anonymity of your responses, I will keep your responses in a password protected file on a password protected computer. No one other than the researcher will have access to the computer and password. Any personal information that can identify you will be removed from the data collected. If you decide to opt out during the experiment, only the flight data collected to the point where you stopped will be kept for the use of future studies. Personal information about participants who have successfully completed the experiment and those who have "opt out" will be completely deleted at the end of spring 2019 semester. No video or audio recording will be done during the experiment.

Compensation: As an incentive for volunteering, participants who complete the study will be offered $10.00 Starbucks gift card. Participants who do not give their consent will not be able to participate in the study. Only participants who complete all four flight scenarios in the study will receive the incentive.

Contact: If you have any questions or would like additional information about this study, please contact Saravanan Suppiah, at suppiahs@my.erau.edu or the faculty member overseeing this project, Dr. Liu Dahai, at liu89b@erau.edu. For any concerns or questions as a participant in this research, contact the Institutional Review Board (IRB) at 386-226-7179 or via email teri.gabriel@erau.edu.

Voluntary Participation: Your participation in this study is completely voluntary. You may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Should you wish to discontinue the research at any time. Only the data collected up to the point where the participant discontinued will be kept for future studies. No personal information attached to the data will be used.

Participant Privacy: Any personal information that can identify you will be removed from the data collected and after removal of this information the data collected may be used for ***future research studies or distributed*** to another investigator for future research studies without additional informed consent from you or your legally authorized representative.

CONSENT. By signing below, I certify that I am a college student, a resident of the U.S. and I am 18 years of age or older. I further verify that I understand the information on this form, that the researcher has answered any and all questions I have about this study, and I voluntarily agree to participate in the study.

Signature of Participant ______________________________ Date: ___________________

Printed Name of Participant ___________________________

Appendix C

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix D

Workload Factors

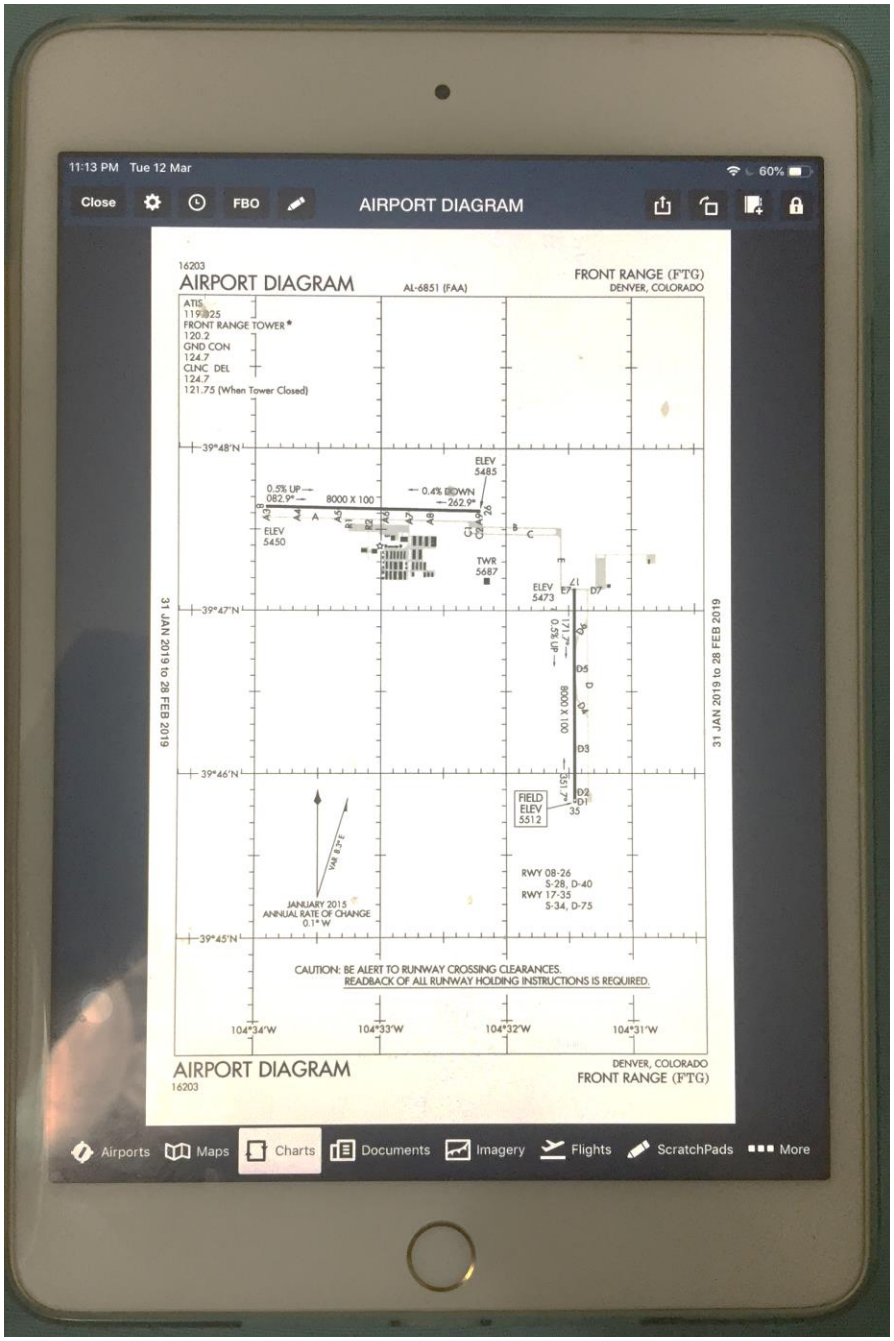
Title	Descriptions
MENTAL DEMAND	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Appendix E

Expected and Unexpected VFR Sectional chart on EFB

Appendix F

Expected and Unexpected Airport Map on EFB

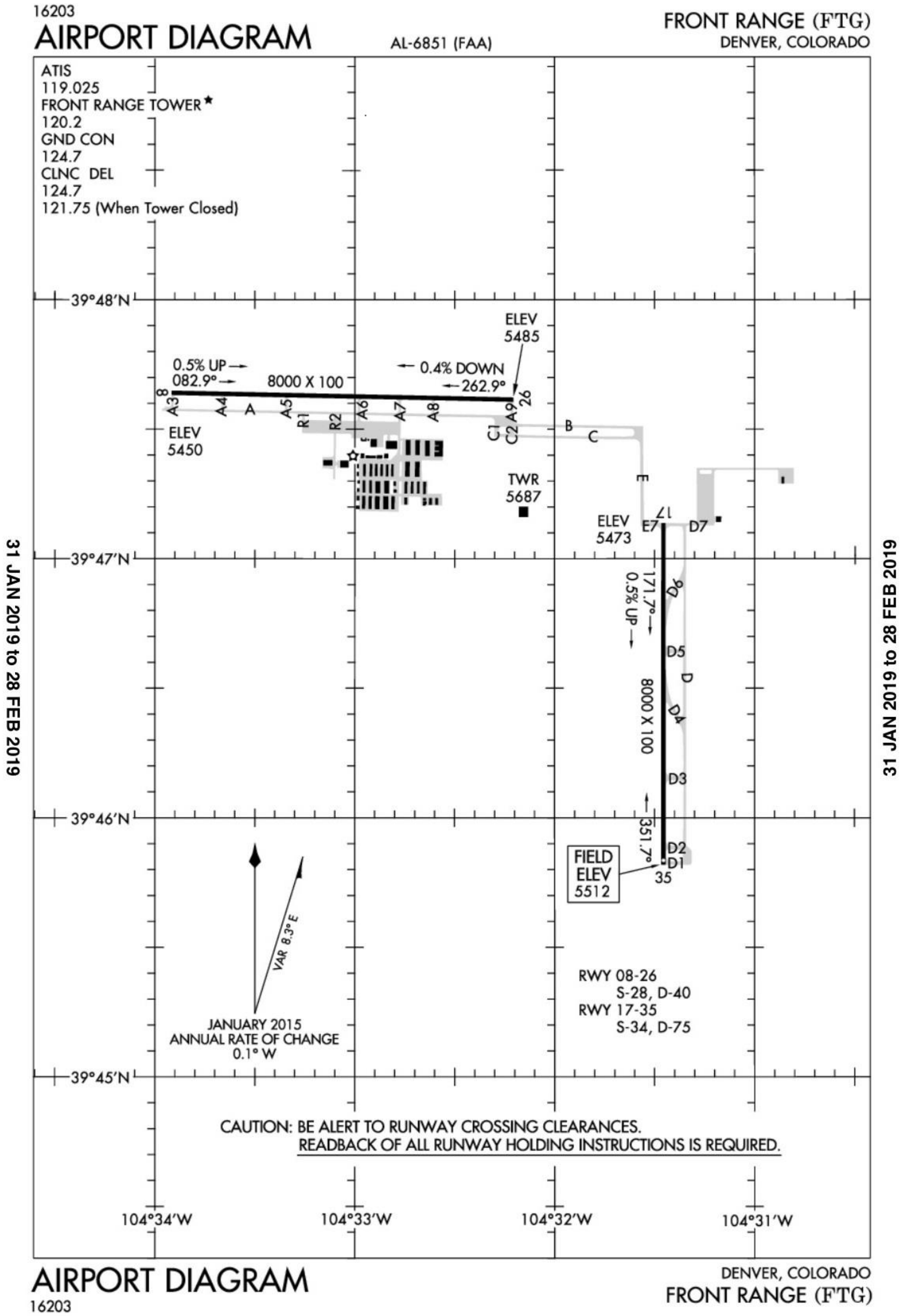


Appendix G

Expected and Unexpected VFR Sectional chart on Paper

Appendix H

Expected and Unexpected Airport Map on Paper



Appendix I

ATC and Pilot Communication

Expected Script

ATC: RIDDLE 141, MAINTAIN 6500 FEET ADVICE WHEN AIRPORT IN SIGHT.

PILOT: TOWER, RIDDLE 141, MAINTAIN 6500 FEET, AIRPORT IN SIGHT.

ATC: RIDDLE 141, YOU ARE CLEAR TO LAND RUNWAY EIGHT.

Unexpected Script

ATC: RIDDLE 141, MAINTAIN 6500 FEET.

MAKE STRAIGHT IN FOR RUNWAY 8.

ADVICE WHEN AIRPORT IN SIGHT.

PILOT: TOWER, RIDDLE 141, MAINTAIN 6500 FEET, AIRPORT IN SIGHT.

ATC: RIDDLE 141, CLEAR TO LAND RUNWAY 8.

* (At 5800 feet the following instructions are made)

ATC: RIDDLE 141, GO AROUND. TRAFFIC ON RUNWAY.

CLIMB AND MAINTAIN 6500 FEET.

ENTER RIGHT DOWNWIND FOR RUNWAY THREE FIVE.

CLEAR TO LAND RUNWAY THREE FIVE.

Appendix J

Pre-flight Instructions

Expected Pre-flight Instructions

- YOUR CALL SIGN IS RIDDLE 141.
- YOU ARE ON APPROACH 3 NM AWAY FROM FTG.
- YOU CAN ONLY ACCESS PAPER BASED AERONAUTICAL CHARTS.
- YOU MUST FLY THE AIRCRAFT SAFELY AND LAND ON RUNWAY.
- YOU ARE IN COMMUNICATION WITH NEARBY CONTROLLER.

Unexpected Pre-flight Institutions

- YOUR CALL SIGN IS RIDDLE 141.
- YOU ARE ON APPROACH 3 NM AWAY FROM FTG.
- YOU CAN ONLY ACCESS PAPER BASED AERONAUTICAL CHARTS.
- YOU MUST FLY THE AIRCRAFT SAFELY AND LAND ON RUNWAY.
- YOU ARE IN COMMUNICATION WITH NEARBY CONTROLLER.